# JunoCam at PJ39: What the pictures show

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Juno's Perijove-39 (PJ39) was on 2022 Jan.12, when Jupiter was nearing the end of its apparition for Earth-based observers. Perijove was over latitude 32.3°N (the NNTBs jet), and Juno crossed the equator at L1=102, L2=239, L3=101.5. The System 3 longitude (L3) is only 10° different from PJ38, and fortuitously, JunoCam got closeup views of the same important features that were imaged at PJ38, notably NN-LRS-1, the active region of the NEB(S), and STB spot 8 – showing similarities and changes over 44 days.

Whereas at PJ38 the spacecraft had been tilted to give a nadir view, at PJ39 it returned to the usual 'Gravity' (Earth-pointing) orientation, so the images at low latitudes have reverted to being somewhat oblique, although this is lessening with successive orbits. Another gradual change, as the orbit evolves, is that JunoCam is now seeing progressively more of the planet on the inbound leg (as it did in the early years of the mission), so our global maps (Figures 3 & 10) now show some of the NNTB on the side opposite to the perijove track.

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 (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.

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

## North Polar Region

*Circumpolar cyclones (CPCs)*:
Figure 1 is our map of the north polar octagon of cyclones. The central North Polar Cyclone (NPC) is now completely sunlit. It is still displaced from the N.Pole in the usual direction,, this time by 0.65° lat.
As the same longitude sector has now been covered for 4 consecutive perijoves, we have monitored the evolution of the octagon more closely than ever before. Despite its curious asymmetry, it has shown almost no change during these 5 months. Figure 2 shows our north polar maps for these 4 perijoves and an earlier composite.
CPC-7 is still displaced, this time being at 81.1°N, i.e. very far from the pole. Inside the octagon, there is still a sizeable AWO north of CPC-3, and a smaller anticyclonic vortex north of CPC-1 (red arrows).
At earlier perijoves we noted 2 or 3 extra cyclones that seemed to be semi-stably associated with the octagon, extending the 'vortex crystal', including one labelled 'IX' in Figure 2. At PJ36 this was distorted, and at subsequent perijoves its identification is uncertain; it could have become the elongated cyclone south of CPC-1 at PJ38 & PJ39, gradually drifting clockwise around the octagon, but this is speculative. On the other hand, at PJ39 there is another 'extra cyclone' next to CPC-7 (Figure 2); it was not there when last viewed at PJ35.

*Haze patterns & the Bland Zone*

Figures 3-5 show composite north polar projection maps, down to 30°N at the top edge. Figure 3 is from RGB images. Figure 4 is similar but gives priority to the near-terminator regions so as to show high-level hazes. White arrows indicate linear bands in and near the Bland Zone (BZ). A complex web of bright and dark haze bands was recorded in the inbound images, including a very bright <-shaped rainbow band on the terminator over the Bland Zone (see Fig.1); in image 2 it was projecting over the terminator, similar to one seen at PJ1.

Figure 5 shows maps from methane-band images. Methane-bright hazes are mainly prominent near the limb (esp. in the inbound images which had high phase angle), so the maps before and after north pole crossing (MEA) are composited separately; a combined map is in the centre. Note that the densest part of the North Polar Hood (NPH), whose outer edge typically coincides with linear bands in the Bland Zone, is methane-bright in the inbound images (as it was in the early years of the mission), but its centre becomes dark, i.e. transparent, in the later images taken from lower altitude (as seen for the past year or so). This supports our suspicion that the non-detection of the NPH at recent perijoves was due to the spacecraft trajectory, but the exact reason is still not clear.

The Bland Zone is largely clear of organised disturbances, apart from two short disturbed sectors: (i) around L3 ~ 340 ("2 o'clock" in the N. polar map, Fig.3) – this coincides with a conspicuous distortion of the NPH haze boundary on the methane maps, Fig.5; and
(ii) around L3 ~ 65 ("5 o'clock") – this is a beautiful 'bridge' of small vortices (Fig.6).
The RGB map (Fig.3) does not show any linear bands on most of the well-illuminated part, although they are visible as usual near the terminator (Fig.4). Southward from the Bland Zone, down to ~40°N, the terminator map and the methane maps show extensive loops and bands and patches of hazes, some of which partially coincide.

Where not masked by the diffuse high-level methane-bright hazes, the brightest features in the methane maps are the white bands in the FFRs, and the AWOs (except for the N5-AWOs). (See Figures 5 & 8, & section below on the N5 & N4 domains.) All this is the same as has been observed throughout the mission.

Figure 6 presents full-scale images of various interacting vortices in and around the Bland Zone. The most elaborate ones are marked in the upper image: the bracket indicates a complex 'figure-of 8' circulation! The box encloses a 'bridge' of connected vortices spanning the Bland Zone; this occupies the centre of the lower image. Popup clouds can now be resolved in many features in these latitudes. As Figure 7 shows, this is the same disturbed sector of the Bland Zone that was shown in our PJ38 report, although individual vortices cannot be matched up.

**High northern domains**

Figure 7 compares our cylindrical maps of the high northern domains (N4 to N6) at the last four perijoves. (These were part of Juno's "Great Blue Spot" sequence so all covered similar longitudes.) Features are marked as follows.

*In the Bland Zone (N6 domain),* boxes enclose disrupted sectors. These overlap at successive perijoves, but vary greatly in extent, so individual features can probably not be tracked. North and south of the Bland Zone, the extensive FFRs do not obviously match up between perijoves; much shorter intervals would be required to track them.

*In the N part of the N5 domain*, AWOs are labelled if they can be tentatively identified in the JUPOS chart [not shown; report in preparation]. At PJ36, N5-AWOs a & b had just converged and can be seen interacting; the JUPOS chart suggests they repelled each other. At subsequent perijoves, AWO-a can possibly be identified, but the fate of AWO-b is uncertain. At PJ39, three quite large AWOs are seen in the N5 domain near the N6 jet. One of them must be the large one that was tracked by JUPOS up to early Dec, with a very rapid prograde drift. It is probably the largest, most southerly one, at L3=94 (e), its rapid drift being influenced by the N6 jet. This may be the same one that was tracked in 2019-2020.

*In the N4 domain*, three AWOs that were tracked by JUPOS are marked A,B,D, along with a cyclonic lozenge (C) that was not tracked. The interactions of A,B,C are described below.

***N5 domain***

Figure 8 presents hi-res polar projections of RGB and CH4 images of features in the N5 and N4 domains, and NN-LRS-1. In N5, we note:

-- N5-AWO-a is only weakly methane-bright; rows of popup clouds in its outer collar are brighter.

-- In two FFRs (insets at top of Fig.8), the brilliant white spots are composed of popup clouds, very bright in both RGB and CH4 – probably vigorous convective plumes, i.e. thunderstorms.

--A little further south, several orange eddies at 50-52°N on the turbulent S fringe of these FFRs (near the N5 jet; marked with orange arrows in Figures 8 & 9) are only weakly methane-bright or not at all, which we have also seen on a few previous examples.

***N4 domain: an AWO crossing a jet!***

Whereas N5-AWOs tend to lie in the extreme north of the domain, N4-AWOs can be at any latitude within the domain, jostling with the large and numerous FFRs [ref.1]*. The JunoCam images always show spectacular scenes here, ever more so as the perijove latitude shifts north towards this domain, and some are shown in Figures 8 & 9.

Here we see an AWO (B), a reddish cyclone, a dark brown cyclonic lozenge (C), an unusual expanse of dense lanes of popup clouds, and a curious hourglass-shaped feature (A). Figure 7 shows them on the cylindrical map, at PJ38 & PJ39; Figure 8 shows PJ39 RGB & CH4 maps; and Figure 9 shows full-resolution images of them.

The hourglass-shaped feature is interesting as it straddles the latitude of the N4 prograde jet. Very likely, this is a N4-AWO that has moved south and is caught in the act of crossing this jet! This is the AWO labelled A in our ground-based tracking [see **Appendix A**]; it was tracked in N4 all through the 2021 apparition, but initially at higher latitude. (It can also be seen in earlier JunoCam maps: Figure 7) In Dec. it passed a smaller AWO (B) and moved south. I believe the AWO has split into two lobes to become the hourglass-shaped feature as it crosses the jet, as both lobes have anticyclonic morphology and are methane-bright. Most importantly, we have recorded exactly this behaviour -- i.e. an N4-AWO passing into the N3 domain -- on two previous occasions from amateur images, in 2011 Nov-Dec.[ref.1 & our 2011/12 final report] and in 2018 Feb-Mar. [ref. our 2017/18 report no.6] In the 2011 case, the AWO temporarily split into two connected lobes as it crossed the N4 jet, just as now. Other cases could have gone unrecorded, so the phenomenon may not be very rare. This is the *only* latitude in which there is any record of an anticyclonic oval directly crossing a prograde jet.

Another striking feature in this region is the convoluted region with many popup clouds forming dense lanes and larger rafts, p. the hourglass (A) and south of the cyclonic lozenge (C) (Fig.9). This region is actually the N4 jet downstream of A, and its unusual appearance further supports the idea that the hourglass is AWO-A disturbing the jet as it crosses it.

> **Ref.1:** Rogers J, Adamoli G, Jacquesson M, Vedovato M, & Mettig H-J (2017), 'Jupiter's high northern latitudes: patterns and dynamics of the N3 to N6 domains.' https://britastro.org/node/11328

***NN-LRS-1***

Figure 9 is one of our closest-ever views of NN-LRS-1, and its appearance is similar to previous views, with its reddish core, white collar, and tightly wound streaks around it. Surprisingly, the clouds in the oval all appear slightly blurred; there are no crisp edges or popup clouds, such as we have seen in other NNTZ AWOs before. It seems likely that the image is blurred due to the position of the oval near the horizon, as the spacecraft sped past it at perijove. [Bjorn Jonsson and Kevin Gill have also produced hi-res renditions of these images and confirm the blurred appearance. Unfortunately, the PJ38 full-res images were no better; they captured its edge more nearly vertically, but missed the interior.]

The image hints at popup clouds etc. inside it, such as were seen better at some earlier perijoves. NN-LRS-1 was earlier seen at PJ3, PJ7 & PJ14; NN-WS-4 at PJ1 & PJ12 (the best image of all) & PJ25; NN-WS-6 at PJ21 & PJ22; and short-lived NN-WS-7 at PJ28. The best images showed a scattering of popup clouds in the interiors of these anticyclonic ovals, but mostly the clouds in them appeared 'lumpy' as seen here.

## Global maps

Figure 10 is our JunoCam PJ39 global map. Figure 11 is a ground-based map. on Jan.9-10, just before PJ39 (lo-res as the planet was receding behind the Sun). (Also see the set of images, esp. Jan.10-13, in **Appendix A**.)

## N. Temperate & Tropical domains

The NTB and NEB are both very faint now, apart from a narrow S component of each belt. Most of these domains are almost white, and show cloud textures that we have noted at recent perijoves, including popup clouds and mesoscale waves in the NTZ, and amorphous sinuous patterns in the whitened northern NEB that show no sign of the usual zonal shear. However, map projections do show a subtle periodic brightness pattern with a wavelength of 1.0—1.1° longitude or ~1240 km along much of the faded NEB, at ~12-15°N (Figure 12A), similar to the wave pattern previously reported in Hubble images and seen at PJ34 and PJ38.

## The NEB(S) outbreak

> [*Note:* As usual, I refer to the southern component of a belt in the style 'NEB(S)', and the southern edge of a belt in the style 'NEBs'.]

Figure 12 shows hi-res maps of the NEB from the PJ39 images, with key features labelled.

The state of the NEB is the same as it was at PJ38 and throughout 2021. The belt is whitened and calm across most of its width, leaving only a very narrow, dark brown NEB(S) (Fig.11). The usual NEBs dark formations (NEDFs or 'hot spots') have disappeared, and all the features on the NEBs edge are drifting much more rapidly than usual, at DL1 ≈ -1.1 to -2.6 deg/day. However, throughout the apparition, small bright white spots representing convective outbreaks have appeared occasionally within the NEB(S) in a restricted longitude sector drifting at DL1 ≈ +0.4 to +1.7 deg/day. Typically, the bright spot has positive DL1, but then drifts south and breaks through into the EZ, adopting negative DL1. Their characteristic behaviour was described in our 2021 reports nos.6 & 7, and one was seen close up by JunoCam at PJ38 [PJ38 report Part II].

Since PJ38, these convective outbreaks have become more frequent and expansive, creating a long disturbed sector of the NEB(S), with quite prominent features developing on the NEBs edge. At PJ39, Juno again passed over the disturbed sector*, and again revealed the cloud patterns in this exceptional region, including an active plume (Fig.12).

*Note*: PJ39 was at similar L3 to PJ38 and also at similar L1, as the time for System 1 to circumnavigate the planet relative to System 3 (49 days) happens to be close to Juno's present orbital period (44 days). By a further coincidence, the difference between L3 and L1 was only 0.5 deg as Juno crossed the equator at PJ39, so the longitude scale on our maps applies to both systems.

These phenomena have been followed by ground-based observers despite the low altitude of the planet, as shown in our 2020 report no.7 (revised), copied in **Appendix B**. Using Shinji Mizumoto's numbering, the very bright plume is Plume 8, retrograding in L1; but adjacent to it is the remnant of Plume 7, which had already broken through into the EZ and was prograding rapidly. There are also several dark 'projections' from the NEBs into the EZ, here labelled a, b and c, with diverse drifts. As shown in the JunoCam images (Fig.12):

*Plume 8* had appeared around Jan.9 and is retrograding in L1. It appears as a compact mass of thick, elevated, bright white cloud, with suggestions of a cyclonic spiral pattern. Surrounding it are areas of diffuse, paler whitish haze.

There appears to be a wake or trail Nf. plume 8, i.e. downstream from it in the NEB, which includes trains of mesoscale waves (wavelength ≈60-90 km) – never previously seen in this latitude.
Also, f. plume 8 on the NEBs, there is a reddish-brown cyclonic spot.

*Plume 7* had appeared in Dec. then moved south to start prograding with DL1 ≈ -1.7 deg/day. It is now in northern EZ, much less bright than plume 8, pale ochre coloured, amorphous.

*Proj. a* (L1 ≥ 104): This is the p. end of a long dark bluish formation, formed on NEBs in a divergent part of the disturbed sector. JunoCam only viewed it near the limb, seeing nothing exceptional. Further f., the it includes an extremely methane-dark patch, but this is hardly visible to JunoCam.

*Proj. b* (L1 = 91): This well-defined mini-projection formed in early Jan. at the f. edge of plume 7, and is prograding at ~-1 deg/day (Jan.6-13). It has a curious structure in the JunoCam images, including a ⊃-shaped orange arc with associated pale whitish streaks, which interrupt and perhaps overlie the long linear grey streaks of a festoon in the EZ. How this odd structure relates to the very fast drift of this projection, or to the adjacent bright outbreaks, is difficult to assess from this snapshot alone.

*Proj. c* (L1 = 82): This marks the p. end of plume 7, prograding at the same rapid speed. Here too there are long linear streaks and an orange band, but it is all near the limb so not shown clearly.

**Equatorial Zone**

Although the orange Equatorial Band has not shown large-scale changes, it mostly looks very bland with only weak traces of mesoscale waves; they are much less evident than at most recent perijoves.. The bands of small, whiter clouds along its edges still show some periodic structure but less so than of late.

### South Tropical Domain

The SEB exhibits several features that we have noted at some previous perijoves (Figure 13):
--White patches in the northern SEB which show clear signs of anticyclonic rotation despite being in the cyclonic belt (marked "AWO" in Fig.13).
--Long red haze bands along the SEB(S), probably overlying some other cloud features.
--Mesoscale waves along the SEBs jet (brackets in Fig.13).
--An anticyclonic vortex retrograding on the SEBs jet ("SEBs ring" in Fig.13).

### South Temperate Domain: Transformation of STB spot 8

The same S. Temperate sector was imaged as at the last two perijoves. Again it showed STB spot 8, with a series of STBn jet spots streaming past it (Figures 13 & 14). The outbreak of these jet spots, from the region of Clyde's Spot, has become very active. Again, these spots are brown, rather diffuse, and with only slight signs of vorticity.

STB spot 8 is the cyclonic remnant of the Aug.21 convective outbreak, which was a disturbed little patch like a miniature FFR at PJ37 and PJ38. (Detailed background on the changes in the S. Temperate domain was given in our 2021 report no.5, up to PJ38.) Now (Figure 14), spot 8 has transformed into a quiescent dark oval! It is surrounded by a tightly wound spiral, but its dark brown interior is crossed by paler streaks with little evident vorticity, possibly clouds overlying the clearer, deeper vortex. It resembles the former STB DS6, and also some of the brown cyclonic ovals in the north, such as N4 spot C (see above).

Just to the south, in the S2 domain, the chain of anticyclonic vortices noted at PJ38 p. AWO-A1 has diminished, as the FFR from which they were emitted has moved closer to A1; but two very small, dark brown cyclonic ovals are still present alongside (like miniature versions of STB spot 8).

### South Polar Region

The comments on the SPR in our PJ38 report generally apply to the PJ39 images as well, and as the two perijoves differed by only 10° longitude, features can be directly compared.

Figure 15 is our south polar projection map of RGB images, cropped to 60°S. Below is part of our PJ38 map for comparison. The five circumpolar cyclones (CPCs) can again be tentatively identified. They appear to have collectively rotated by ~9° long. since PJ38, an unusually large amount. Still overlapping CPCs 3 & 4 is the dark Long Band, discussed further below. Just below CPC-5 in both maps is a small, well-defined, pear-shaped cyclone with a dark brown core, probably the same feature though it is further north at PJ39. Rapid cyclonic circulation along its edge can be seen by blinking individual PJ39 maps.

The big bright AWO at 70°S has retrograded by 34° long. since PJ38, consistent with the usual drift rate for this latitude, and a row of three FFRs p. it (cyan arrows on Fig.15) can probably be identified as having retrograded at the same rate. Two of these are roughly circular with brown interiors, resembling 'filled' CPCs; the third is more complex. Two smaller AWOs (small red arrows) have probably retrograded at similar rates. However, FFRs in the main belt slightly further north (~65-69°S), where the zonal shear is greater, cannot be confidently identified between the two maps.

Figures 16 & 17 present composite polar projection maps of the terminator regions, cropped to 45°S: Fig.16, at dawn; Fig.17, at dusk. Figure 18 shows maps of three individual images.

Images 53 & 98 are almost exactly one rotation apart, and show no perceptible differences in the patterns of dark and bright haze bands over the 10-hour interval. Figure 19 is a composite map in the methane band.

The general features of these maps are the same that we have often noted up to now, e.g:
--The main feature in the methane map is the bright South Polar Hood (SPH), with a wavy boundary at ~64°S (coinciding with the S6 jet). Inside it, most methane-bright patches are FFRs.
--The boundary of the methane-bright SPH does not usually correspond to any bright haze feature in the RGB terminator maps. Conversely, bands that catch the sunlight at the terminator are not reliably methane-bright. This mismatch between the methane-bright hazes and the high-level terminator hazes is still an unsolved issue.
--In the dawn and dusk terminator maps, the pattern at ~50-62°S (S4 & S5 domains) is the same as we described at PJ35 and PJ38.
--In the terminator maps, some bands show diurnal contrast reversal, most commonly meaning bright at dusk but dark at dawn. In many cases, given the difficulty of precisely registering lo-res maps of the terminator, it may be that a bright band shows up mainly at dusk but an adjacent dark band shows up mainly at dawn. There are several good examples in the PJ39 maps.

Major haze features at PJ39 are labelled consistently on Figures 17-19, as follows.
(1) The long-lived Long Band, overlapping the peripheries of CPCs-3 & 4. It is much the same as at PJ38, dark all across the sunlit side, spanning ~180° long. and fraying at the f. end. It is also mostly dark at both dawn and dusk terminators, except that the f. part becomes very bright at dusk. In the methane map, the whole Long Band (including the f. part) appears dark. So it is principally a clear lane in the SPH, but with a contrast-reversing haze band at the f. end.
(2) Another long band system further north at ~66-72°S, viz. two successive oblique bands covering >~45° long. each. They are bright at dusk (when parts appear as rainbow bands) but invisible at dawn. They occupy a similar position to the band with similar properties seen at PJ38, so it seems likely that this has persisted between perijoves. In the methane map, band 2a is methane-bright near the limb, forming a second edge to the SPH; but band 2b, viewed closer to the vertical, is barely visible within the SPH.
(3) This could be a remnant of one of two features that were seen at PJ38, which looked like well-defined elevated cloud patches over the S4 domain. The other no longer exists.
(4) Here again, haze bands appear to form a coherent elevated cloud feature, at 46-56°S (S3-S4 domains). The f. end shows diurnal contrast reversals. Features 3 & 4 are not visible in methane.
(5) The methane images near the terminator or limb show several weakly methane-bright bands outside the main SPH. These are not generally visible in the RGB terminator maps, except for 5a, shown bright at dusk when it was near the limb (Figure 18, image 50).

## Figures:

Figure 1:  Composite north polar projection map (down to 60°N at edges), showing the CPCs.

Figure 2:  Composite north polar projection maps from PJ39 & previous perijoves, showing the stability of the 'vortex crystal' of CPCs.

Figure 3:  Composite north polar projection map (down to 30°N at edges), from RGB images.

Figure 4:  Composite north polar projection map (down to 30°N at edges), from RGB images, favouring the near-terminator regions so as to show high-level hazes. White arrows indicate linear bands in and near the Bland Zone (BZ).

Figure 5:  Composite north polar projection maps (down to 30°N at edges), from CH4 images.

Figure 6:  Various interacting vortices in and around the Bland Zone. (See text for explanation.)

Figure 7.  Set of cylindrical maps, ~40-75°N:  PJ36-PJ39.

Figure 8.  Hi-res polar projection maps of images 20 (RGB) & 21 (CH4), showing features in the N5 and N4 domains, and NN-LRS-1.  *At top:* Details from unprojected images 22 & 21 showing how the very bright spots in FFRs are composed of popup clouds.

Figure 9.  Full-resolution images of features in the N5 and N4 domains, and NN-LRS-1.

Figure 10.  JunoCam PJ39 global cylindrical map.

Figure 11.  Ground-based cylindrical map. on Jan.9-10, just before PJ39.

Figure 12. Hi-res maps of the NEB from the PJ39 images, with key features labelled. (A) by Gerald Eichstädt & JHR;  (B) by Björn Jónsson.  Colours and intensities have been adjusted.

Figure 13.  Original image showing the SEB, as well as STB spot 8 & STBn jet spots.

Figure 14.  Original images showing STB spot 8 & STBn jet spots, PJ37-PJ39.

Figure 15.  Composite south polar projection map of RGB images, cropped to 60°S.  Below is part of our PJ38 map for comparison.

Figure 16.  Composite south polar projection map of the dawn terminator regions, cropped to 45°S.

Figure 17.  Same as Figure 16, for dusk.

Figure 18.  South polar projection maps of three individual images. Images 53 & 98 are almost exactly one rotation apart.

Figure 19.  Composite south polar projection map in the methane band, cropped to 45°S.