JunoCam at PJ33: What the pictures show

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The Juno mission was scheduled to end this July, but NASA have extended it for another four years. A table giving the provisional schedule of orbits up to the end of 2022 is posted on these web pages under "Results from Juno: 2021". Direct link: https://britastro.org/node/25896

PJ33 took place on 2021 April 15, and was originally planned so that orbital evolution would lead to the termination of the mission this July. In order to maintain the orbit for the extended mission, the perijove was delayed by exactly one jovian rotation, so equator crossing took place at 23:43 rather than 13:48 SCET, over the same longitudes as originally planned: L1=112, L2=161, L3=311. (SCET = UT at spacecraft.) Perijove was at 29°N over the NTZ.

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.) Note that colours are uncalibrated and enhanced, and colour descriptions herein are subjective perceptions.

Abbreviations and conventions are as in previous reports. P. = east, f. = 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 cluster of cyclones. The coverage overlaps that at PJ32 and confirms the rearrangements seen then: There is no longer a small AWO north of CPC-7, and CPC-7 (centred at 81.6°N) appears to have been excluded from the polygon as the flanking CPCs-6 & 8 are now adjacent. The central North Polar Cyclone is offset from the pole in approx. the same direction as at recent perijoves; the offset is ~0.6° at PJ33, and the NPC appears to be oval.

Figure 2 is a composite map of the north polar cluster from the last 4 perijoves. (The sector seen at PJ33 appears to have rotated by ~5°-9° since last observed.) The cluster now appears to be a heptagon, with 4 'filled' and 3 more diverse CPCs, but with CPC-7 and several smaller 'filled'-type cyclones as satellites around it (Figure 2); some of the latter could be the same as at PJ30 and PJ32, but we cannot be sure. (We may have a better opportunity to track features between perijoves during the extended mission, as the illumination and longitude coverage improve and the orbital period is reduced.)

The Bland Zone and haze bands

Figure 3 comprises north polar maps down to lower latitudes, in RGB and in CH4, plus one compiled from the terminator regions where haze bands are most visible. The Bland Zone is interrupted by a short chaotic sector. The N5 domain is not as full of FFRs as usual, but has a sector with sparser features, including three dark brown cyclonic formations: they are labelled 'N5TB' on the maps, indicating that they could be regarded as fragments of a 'N5

Temperate Belt' to use old terminology, although substantial dark belts are hardly ever seen in these high latitudes.

Over the Bland Zone and its southern flank, there is a typical high-contrast bundle of linear haze bands near the dawn terminator (at right in the maps), and fainter bands near the dusk terminator (at left). Further south there are extensive, elaborate haze bands down to the N3 domain. Many of these haze bands are also visible in the CH4 map, especially over regions that were imaged near the limb.

Figure 4 is our global cylindrical map.

Northern domains

N4 & N3 domains

The hi-res images show a pair of magnificent cyclonic circulations, in the N4 & N3 domains (Figure 5). Although one appears neutral in colour and the other orange (relative to their surroundings), both have an interior cloud deck that appears rather calm and flat, apart from scattered popup clouds.

In image 31 (taken at perijove over the NTZ), Gerald's unenhanced version reveals a high-altitude haze layer at the horizon over the N3 domain only, as has been seen at some earlier perijoves.

N2 domain: a FFR in the NNTB

JunoCam took a closeup view of a FFR in the NNTB, acccompanied by a CH4 image, which helps to understand the relative altitudes of different coloured clouds (Figure 6). The bright white strips in the FFR, topped by rafts of popup clouds, are the brightest in CH4 and thus the highest, whereas orange patches on cyclonic eddies are lower, having approx. the same brightness as their surroundings in CH4. (This is a preliminary description which could be improved by further 'cleaning' the methane image, making hi-res map projections, and accounting for any scattered white light in the instrument.)

Images at PJ26 produced similar results, but still only a few such features have been observed so further such images would be worthwhile.

North Temperate & Tropical domains

Both these domains are now calm after the upheavals in 2020. Along the NTBn edge, JunoCam got a good view of the conspicuous series of waves that has developed. On the NEBn edge, White Spot Z (WSZ) was captured on the horizon (Figure 7).

The cloud textures in the NTZ and NTropZ make an interesting contrast, and likewise those in the NTB and NEB (Figure 7). The NTZ has more contrast and small-scale irregularity in the cloud textures, whereas the NTropZ appears calmer and more uniform. Both have some bright popup clouds but they are more prominent in the NTZ; small ones are also present in the NTBs fringe and partly share its pale ochre colour.

The NTB and NEB both consist of wavy streaks with a scattering of reddish cyclonic vortices. The NTB has more contrast and some bright popup clouds, whereas the NEB has a more uniform light reddish-brown cast and, as usual, it all appears slightly diffuse. These images show the NEB just as it was beginning to grow exceptionally quiet and pale (apart from the dark brown NEB(S)), as shown by subsequent ground-based images; this may turn out to be the start of a cycle of fading then vigorous revival as seen in 2011-12.

Did JunoCam record a convective plume before it erupted in the NEB?

Three days after JunoCam's images, observer Niall MacNeill (Australia) discovered a new, very bright white, compact spot in that part of the NEB just f. WSZ (Fig.8A), very close to the position of the darkest cyclonic vortex imaged by JunoCam, labelled 'microbarge' in Fig.7. Such spots are convective plumes, not uncommon, and have repeatedly been observed to appear on the edge of a small barge (sometimes erupting from a preexisting rift as it streams past the barge); but they have never been proven to erupt within a barge, in contrast to those in the SEB. So there was immediate interest in whether JunoCam recorded any sign of this imminent outbreak.

In MacNeill's discovery image on April 19, 19:19 UT, the bright spot was at L3=298. It was also recorded by Clyde Foster on April 18, 03:26 UT (a very faint precursor), and on April 20, 03:24 UT, showing little if any motion in L3; but a drift of ~-1 deg/day would be possible given the uncertainties, and more typical of the latitude. Earlier images may show a tiny faint spot on April 16 at 19:58 UT (A. Wesley, near the limb) and 02:27 UT (Foster, just a few hours after JunoCam, L3 = 302.5), but it is very uncertain (Fig.8A).

In the JunoCam images, there is no bright spot near the 'microbarge' at L3 =297.3, but MacNeill pointed out a curious diffuse bright orange spot at L3 = 302.3 (arrowed in Fig.7), and wondered whether this was the incipient plume. There are haze streaks overlying it and a diffusely brighter area just south of it. It's intriguing to speculate that these brightenings could be a thick white plume rising below the brown and off-white clouds of the main cloud deck, which would emerge above those clouds 3 days later. However, diffuse variegations within the NEB are quite common and we may never know whether this was a precursor of the bright convective plume.

As this report was being finalised, another such bright spot appeared in the same position on May 12 (Fig.8B). The previous best image was on May 8 when no precursor was detected.

Equatorial Zone

The intense coloration in the EZ is undiminished, and the closeup cloudscapes are familiar from recent perijoves. The PJ33 images again show trains of mesoscale waves, and less regular cloud lanes with similar scales, and areas of very subtle mesoscale waves on the bland orange Equatorial Band at the limit of detectability.

PJ33 was just 17 days before Jupiter's equinox on May 2, so the EZ images have been scrutinised to see if the ring casts a shadow, but none is visible.

South Tropical domain

South Equatorial Belt (SEB)

Images at recent perijoves have repeatedly shown two novel types of features on the SEB(S): mesoscale waves, and narrow reddish haze bands. Both are visible in the PJ33 images (Figure 9). There is only a very faint train of mesoscale waves (above the row of black dots in Figure 9). There are multiple reddish haze bands aligned with the belt, and one or two draped around a southerly protrusion into the STropZ (red arrows mark the most obvious ones, and there are minor ones as well).

South Temperate domain

The highlight of the PJ33 images was the coverage of Oval BA and the S. Temperate domain preceding it. This is the sector in which a new STB structured sector* is expected, and last year two cyclonic spots appeared that seemed like possible precursors of it. One, called

DS6, was a compact, very dark brown oval, imaged closely at PJ26. The other began life as a small low-contrast cyclonic vortex, in which Clyde Foster discovered a methane-bright plume erupting on 2020 May 31; JunoCam imaged "Clyde's spot" closely two days later at PJ27; and over the next few weeks and months, ground-based images showed that it became a dark spot, called DS7, though it was always somewhat irregular. Amateur images in early 2020, after solar conjunction, showed DS7 persisting, but not DS6. PJ33 was our first opportunity to find out what is the present state of DS7 and what was the fate of DS6. The images immediately answered both questions (Figure 10).

Adjacent to oval BA is a conspicuous cyclonic oval, orange with a bluish-white collar. There had not been any such oval there previously during the JunoCam mission, and this can only be DS6, which has changed colour during solar conjunction. Such a colour change is not surprising as it is common for dark cyclonic ovals to become reddish and then pale or white. It can be seen in ground-based images as a bright white oval, since March 26. (JunoCam images typically show reddish colours more strongly than amateur images.)

DS7 (Clyde's spot) is revealed as a beautiful miniature FFR (Figs.9 & 10). This suggests that it has retained some convective and turbulent activity ever since its first eruption, growing to become a FFR – and it may well continue to expand until it becomes a dark turbulent STB segment (STB segment G, in my sequence)*.

*The history and characteristics of the STB structured sectors are documented in our long-term reports; most relevant is Ref.1. Segment A is the perennially renewed one f. BA. Segment B developed from a variable grey streak called DS2, from 1998 onwards, becoming a dark turbulent STB segment. Segment D repeated this process from 2008 onwards. It seems likely that Clyde's spot will expand similarly to become segment G. (Segments C, E & F were pale closed cyclonic circulations.)

Ground-based images showing Clyde's spot from PJ33 onwards are in Figure 8. In April it was not very well resolved, but higher-resolution images in May do resolve the spotty structure of the FFR on some dates, though not on others.

Ref.1: Rogers J, Adamoli G, Hahn G, Jacquesson M, Vedovato M, & Mettig H-J (2014). 'Jupiter's southern high-latitude domains: long-lived features and dynamics, 2001-2012.' http://www.britastro.org/jupiter/sstemp2014.htm

Also notable is the widespread darkening and disturbance in this sector of the S. Temperate domain, also evident in amateur images (Figure 8). This may include disturbance emanating from Clyde's spot and from the STB f. BA, as well as more general light-brown shading. Will this develop further?

Oval BA is again slightly reddish (though the colour is barely visible in ground-based images). The turbulent STB segment f. oval BA is ~45° long, the same length as at PJ32.

Figure 10 also beautifully shows the S2 AWOs, A1 to A4, which now form a regularly spaced chain separated by FFRs.

South polar region

Figure 11 is one of the images taken closest to the south pole. Juno's outbound trajectory over the south polar region is now higher and slower than earlier in the mission, which enables complete longitude coverage, albeit at low resolution. With images covering more than 8 hours, some longitudes were imaged in the evening then again in the morning.

S. Polar Hood & haze bands

Figure 12 is our composite map in the methane band, showing the S. Polar Hood (SPH) as usual. In recent perijoves we have increasingly noticed fainter methane-bright extensions outside the SPH near the terminator, and these can be better assessed now that we have images over most of a rotation. Figure 13 shows the locations of these in maps from some individual images: faint extensions visible near the terminator disappear under higher sun.

In RGB, also, maps of the near-terminator regions can now be compiled separately for dawn and dusk (Fig.14C&D), and compared with the map under high sun (Fig.14A). Haze bands are widespread. Most of these bands have bright and dark components, which show changes or even reversal of contrast between dawn and dusk (although further study will be needed to correlate them well, as there may be slight misalignments of the maps, or real motion over several hours). Extensive ripple-like patterns are again seen, especially near and outside the edge of the SPH. Inside the SPH, there are several notable bands also seen under high sun: (i) a long narrow band, nearly vertical on the right-hand side of the map, bright under high sun but mainly dark at dusk; (ii) a long bow-shaped band on the left-hand side of the map, tangential to CPCs 3 & 4, mainly dark under high sun; (iii) a **)**-shaped band below centre of the map, very bright at dusk but a 'rainbow band' plus prominent dark band at dawn. (ii) & (iii) together form a long band, very like the one that existed up until PJ12, although that one was tangential to CPCs 4 & 5 [now numbered as in Ref.2]. This long band is arrowed in Fig.14B and shown well in Fig.11.

Circumpolar cyclones (CPCs)

The CPCs can all be identified, albeit at low resolution, as shown in Fig.14B. The South Polar Cyclone (SPC) was poorly lit, but its centre can be taken as the centre of the overall circular pattern, because the near-central white patch rotated to the opposite side in 8.1 hours, as shown by blinking of maps 52 and 94.

Thus taking the centre of the SPC as a whole, we find that it has moved close to its position at PJ26 in accordance with the cyclic motion described in our PJ28 report (Figure 15). It is now further from the pole than ever before (3.1°). The gap between CPCs-1 & 2 is very wide (Fig.14B), which also corroborates a relationship that we reported tentatively up to PJ12 [Ref.2]*, and supports a geometric hypothesis of the south polar pentagon that we proposed in that paper. Thus, aspects of the variable motion and asymmetry of the pentagon are now found to have been surprisingly regular over the 4½ years of the mission. A report will be presented at the EPSC 2021 virtual conference.

*[Ref.2: F. Tabataba-Vakili, J.H. Rogers, G. Eichstädt, G.S. Orton, C.J. Hansen, T.W. Momary, J.A. Sinclair, R.S. Giles, M.A. Caplinger, M.A. Ravine, S.J. Bolton. 'Long-term tracking of circumpolar cyclones on Jupiter from polar observations with JunoCam.' Icarus 335 (2020), paper 113405 (online 2019).]

Figures

Figure 1. Composite north polar projection map down to 75°N at edges, showing the CPCs cluster.

Figure 2. Composite north polar projection map of the north polar cluster from the last four perijoves.

Figure 3. Composite north polar projection maps down to lower latitudes: (A) in RGB, (B) RGB compiled from the terminator regions, (C) in CH4.

Figure 4. Composite global cylindrical map.

Figure 5. Images of two quite large cyclonic circulations, in the N4 & N3 domains.

Figure 6. RGB and CH4 images of a FFR in the NNTB, looking east. *Black arrows* indicate selected extremities of the brightest strips in the FFR, allowing registration with the CH4 image. These are topped with bright white popup clouds and are methane-bright. The RGB image suggests that they may be extending above lower cloud layers. *Red arrows* indicate reddish patches, all of which have approx. the same brightness as the surroundings in the CH4 image: (1) a small reddish-brown cyclone; (2) an orange patch on a cyclonic eddy; (3) a yellowish-orange patch on a cyclonic eddy, which appears to be over-ridden by a bright white cloud strip. (All colour descriptions are relative. The CH4 image contained much noise, which has been partially removed in Photoshop.)

Figure 7. Images 31-34 showing the cloud textures in the quiescent NTZ, NTB, NTropZ, & NEB. The main panel is a stack of the versions posted by the JunoCam (MSSS) team, with only rough alignment. The side panels are full-resolution excerpts from the versions by Gerald Eichstädt. Intensities and colours have been arbitrarily adjusted.

Figure 8. Ground-based images showing two successive eruptions of a tiny bright spot (red arrow) in the NEB, in a dark brown formation just following White Spot Z: (A) just after PJ33 in April, (B) in May. Also shown is “Clyde’s spot” (cyan arrow).

Figure 9. Image of the SEB(S), showing reddish bands (between red arrows) and faint mesoscale waves (above row of black dots).

Figure 10. Cylindrical map of the S. Temperate and S.S. Temperate domains, from images 44 & 49.

Figure 11. View over the south polar region (image 62). This is a long exposure taken to record faint features at the terminator, hence the overexposed (deep blue) part of the crescent. Many haze bands are visible near the terminator, including some further south than the polar maps in Fig.14, in the S4 and (near bottom) S3 domains. There is also a long band visible on the sunlit disk, tangential to two CPCs.

Figure 12. Composite south polar projection map in the methane band.

Figure 13. South polar projection maps from some individual methane images, as numbered. White arrows indicate two locations where a faint extension of the S. Polar Hood is seen when near the terminator (see map 77), and a white box encloses a location with more complex such features. Some of these features are seen at both dawn and dusk, but not under higher sun. (The numerous curved streaks are caused by ‘hot pixels’ that produce streaks repeating on each strip of the image.)

Figure 14. Composite south polar projection maps. All are down to 60°S at the edges, shown at half scale, except for (B). (Full-scale versions are available if needed.)

Figure 15. Motion of the centre of the S. Polar Cyclone: (A) from PJ21 to PJ33, (B) throughout the Juno mission.