JunoCam at Perijove-30: What the pictures show

John Rogers (BAA) (2020 Nov.30)

Juno's perijove-30 (PJ3) was on 2020 Nov.8. The spacecraft crossed the equator at L1=292, L2=113, L3= 221. This was only 45 deg from the longitude at PJ29, so that many of the same features are seen in the imagery from both flybys. (To facilitate direct comparison, Figures 1-5 in this report are comparable to Figures 1-5 in our PJ29 report.)
Perijove was at 26.6°N, i.e. over the NTB, at an altitude of 3500 km.

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. Also, Kevin Gill has produced hi-res cylindrical maps for some latitude ranges, e.g. Fig.10.

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

Figure 1 is a unique, fortuitous view of Callisto – seen through a layer of haze above the horizon over the NNTZ. It was too far away to show effects of atmospheric absorption (unlike Io, similarly captured on the horizon at PJ16).

North Polar Region (Figure 2)

Circumpolar cyclones (CPCs) (Fig.2A):
The central North Polar Cyclone (NPC) is seen more clearly than ever before, partly because the sun is gradually rising on it (although equinox is not until next May), but also because it appears to be slightly displaced from the pole. For the first time, the images show slightly more than half of it, and an animation shows it rotating (though apparently not as fast as the filled CPCs). (Its rotation was already recorded by JIRAM imaging at 5 microns: Adriani et al., *Nature*, 2018.)
The images give an excellent view of three 'filled' cyclones, CPCs-3, 4 & 5. They were also seen at PJ29 and looked essentially the same, including the small AWO poleward of CPC-3. All three show counter-spiral structure near their centres; accordingly, an animation shows that CPC-5, at least, shows counter-rotation in the centre. These patterns are becoming clearer as the mission continues, as the spacecraft passes lower over the north polar region, and as the sun gradually rises there. CPC-6, one of the 'chaotic' cyclones, is poorly illuminated but seems to be more chaotic than ever with hardly any spiral structure.

Colour and methane maps of the north polar region are presented in Figs.2B & C. The Bland Zone is disrupted east of the N5-AWO, but distinct to its west. The usual linear haze bands are visible only far to the west (near the top in the maps: Figs.2B & C), towards the morning terminator and limb. On the RGB maps near the terminator, haze bands are also seen close to some of the CPCs (top part of Fig.2A), and over the N5 domain (Fig.2B). Further south, image 24 shows a high-altitude haze layer on the horizon (Fig.1), over the NNTZ and N3 jet, i.e. latitudes where we have seen a similar haze layer at some previous perijoves.

As at PJ29, we have a closeup view (Figure 3A,B) of the large AWO which belongs to the N5 domain, on the S edge of the Bland Zone; it has been tracked since 2019 March (see our 2020 report no.4). While the AWO looks the same as at PJ29, its surroundings have changed, with s similar-sized FFR adjacent to it. It is weakly methane-bright (Fig.2C), less so than smaller AWOs in the N4 and N3 domains. Fig.3A also shows several cyclone-anticyclone pairs in the Bland Zone (as pointed out by Gerald), one being just N of the N5-AWO. Also in the N5 domain, there are many cyclones with very dark cores (Fig.3A) (& cf. S2 and S3 domains, below). The N5 and N4 domains provide spectacular vistas, as always.

Northern domains

Figure 4 is a map of the planet over PJ30 from ground-based images, and Figure 5 is our map from the JunoCam images.

The N3 domain includes a large dark brown cyclone, then a beautiful pairing of an orange-cored cyclone with a small bright AWO (Figure 6), with many popup clouds visible.

NNTB: The images cover a pale orange sector of NNTB, probably the same one that was imaged at PJ29. Despite its paleness, it is methane-dark (Figure 2C), as is typical for cyclonic structures. Along the NNTBs jet, there are several dark spots, also tracked from Earth (Figure 4), suggesting that the NNTBs jet spot activity has (unusually) not been suppressed by the NTB upheaval. One NNTBs jet spot is connected by a conspicuous white streamer to the NTBn (Figure 7).

N. Temperate and Tropical domains

The NTB and adjacent zones have been transformed by the NTBs jet outbreak that began on August 18. Since the last of the three super-fast, super-bright plumes disappeared in the second week of October, the revived NTB has been maturing rapidly; ground-based images now show a dark NTB(S) component that is now turning reddish at some longitudes, and a more irregular NTB(N) component (Figure 4). Around the PJ30 track, the NTB was more disturbed than elsewhere and not yet reddish, although the adjacent NTropZ was ochre.

The JunoCam images (Figures 7 & 9) show an obviously disturbed NTB. The NTBn edge is sharp with a high-amplitude wave pattern, and the cloud textures suggest that the NTBn retrograde jet follows the course of the waves along this edge. The southern part of the revived belt is turbulent and not reddish, but the pale reddish colour to the south, covering the NTropZ, apparently overlaps the NTBs jet and thus the latitudes where we expect a reddish NTB(S) to develop.

The ground-based map (Figure 4) shows a reddish blob in the NTropZ, at 19-20°N, which I have tracked from amateur images at a drift rate of +1.4 deg/day in L1 (-6.0 deg/day in L3) (Oct.31-Nov.12). This is an unusual speed, and the speed and latitude show that it is on the S flank of the NTBs jet. Fortuitously, it was captured in the perijove images, and was revealed as a well-formed anticyclonic vortex (Figure 9). As with many large anticyclones, there are bands of popup clouds on and around it, but they are ochre, presumably because the ochre colour of the NTropZ is a haze overlying all other clouds.

PJ30 came 82 days after the start of the NTBs jet outbreak, approximately the same time lag as PJ3 after the inferred start of the 2016 outbreak. However, the JunoCam images look quite different: in the PJ3 image (Figure 8), the orange NTB(S) was already established and turbulence in the rest of the belt was on a smaller scale. This may be because the 2020 events are proceeding more rapidly, at least at the longitude covered.

The NEB, which is still very broad after the recent expansion event, shows beautiful smallscale turbulence with many orange cyclonic eddies. Near the S edge, one of the currently-common brilliant white points (small plumes) can be seen at the edges of a few images (& Figure 10); it was already present in a ground-based image by Clyde Foster one rotation earlier.
Figure 10 is a higher-resolution map of the equatorial region posted by Kevin Gill.

Equatorial Zone

The EZ still contains a broad reddish (ochre) Equatorial Band, and the EZ(N) is a complex mixture of streaks and patches ranging from ochre through white to blue-grey (Figures 10 & 11). The PJ30 images of it are dominated by a long NEBs dark formation (NEDF or 'hot spot'), which appears featureless; its dark, relatively bluish expanse (presumably a cloud-free void) is varied only by very diffuse faint redder areas (probably thin overlying haze). However, its p. (eastern) end (L3 = 209.5, L1 = 280) is abutted by a series of three bright cloud bands – two reddish, one white -- extending southwards from NEB 'rifts' (Figures 9 & 10). Dark bluish-grey wedges between them appear similar to the NEDF, so the map gives the impression that the rifts have expanded southwards across the NEDF. However, ground-based maps (Figure 11A&B) show that the p. end of the NEDF was fixed at L1 = 279 for a week before PJ30, when this set of bright streaks from the rifted region projected S immediately p. it, and the small dark patches developed between them. Rift projection events like this are common in ground-based records (and JunoCam also viewed some at PJ27). These JunoCam images provide a snapshot, which suggests that the usual EZ(N) clouds are cleared away between the protruding bright streaks, producing clear areas similar to the adjacent NEDF.

The rest of the EZ, as usual, shows dramatic vistas of muticoloured streaks and cloud formations. The images do not show extensive mesoscale waves this time, except for two feather-like cloud systems marked by boxes in Fig.10, where wave-like barbs project on either side of a central shaft of cloud. One is in the blue-streaked white EZ(S) at 4°S and is white; the other is in the north part of the ochre Equatorial Band at 1°N and appears pale ochre, probably because ochre haze overlies it.

S. Tropical domain

This is a quiet sector of the SEB. Two white ovals in its northern half (e.g. Figure 12) show structure suggesting that they are weakly anticyclonic, despite being located in the cyclonic belt; we have seen similar examples at several previous perijoves.

The SEBs is distinguished by two very different wave patterns. One is a long wave-train in the form of dark patches on SEBs at 17-18°S, with wavelength 3.5° (±0.7°, range, from 10 waves). This is probably an example of the latitudinal meandering of the SEBs jet that the JUPOS team has characterised in previous years, but with a shorter wavelength than was ever measured in ground-based images. (At PJ25, JunoCam imaged a set with wavelength 3.9°.) As this is the sector downstream of the GRS, these may be the waves in their early stages. The other type of waves (boxed in Figure 12) consists of parallel dark bands oriented roughly N-S, similar to mesoscale waves in the EZ, but in the SEBs at 16-17°S, transverse to streaks marking the N flank of the SEBs jet peak. There are two sets with a mean wavelength of 0.32° (380 km). Similar waves were seen in this latitude at PJ28.

Also on the SEBs, sinuous red haze bands are again visible, faintly. This time they wander widely in latitude, with meridional segments possibly related to the mesoscale wave-trains.

Southern domains (Figure 13)

S. Temperate domain: The STB latitudes are almost entirely white in this sector, which is all within the extent of the former STB Spectre. Two wavy or turbulent fawn-coloured bands probably represent the two components of the STBn prograde jet. On the S side, at L3 < 225, the STZ is completely dark – a not uncommon reversal of the canonical belt/zone albedo pattern. This dark STZ is a band that has extended W (f.) from the dark STB segment f. oval BA. Its well-defined f. end may be a site of anticyclonic hemi-circulation.

Further W, at L3=279, is the cyclonic hemi-circulation which was the f. end of the STB Spectre. Since PJ28 it has lost all the dark material that had accumulated there, although the anticyclonic vortex on its S side is still just discernible, now white (Figure 13); it is clearly bright in the methane band (Figure 14). Conversely a small, low-contrast cyclone in the whitened STB (Figure 13) is dark in methane (Figure 14).

S2 and S3 domains: There is a good view of S2-AWO A7, and a long FFR p. it. There are also large FFRs in the S3 and S4 domains. Also notable are cyclones with very small, very dark brown cores (Figure 13).

South Polar Region (Figure 15)

Figure 15 presents our usual composite south polar projection maps, showing the familiar features of the SPR in RGB and in low-sun RGB and in the methane band.

Haze bands:
Figure 15C is a map favouring the near-terminator regions where haze bands are more visible. At PJ29, there was a widespread pattern of faint narrow striations running at shallow angles to lines of latitude, and a more prominent ⊃–shaped bright band at L3 ~ 130-180. At PJ30, the pattern is similar, although the striations are not seen so widely. The ⊃–shaped feature is still present (on the right of the map), now fainter but multiple. It is similar to bands seen at other perijoves.

In the methane map (Figure 15D), the visibility of the bright S. Polar Hood (SPH) varies with longitude. This is an effect of the viewing angle, as can be seen by comparing the original images in Figure 14. In early images, much of the SPH is in the central region of the disk and so has low optical depth: it is not very bright and FFRs are easily seen through it. In late images, taken from over the dark side, most of the SPH is closer to the limb, where it appears optically thicker and masks the FFRs below. Wisps of methane-bright haze are also visible outside the SPH near the terminator.

Circumpolar cyclones (CPCs) (Figure 15A&B):
All but one of the cyclones are visible (CPC-5 being out of view) and form a fairly symmetrical pentagon, with a small gap between CPC-2 & 3, as at PJ29 although the pentagon has rotated by ~2-3° since then. Most notably, the central South Polar Cyclone has drifted closer to the pole than it has been since PJ11, now being only 1.4° from the pole. Thus it continues its cyclic motion in longitude and latitude, this year making a larger loop than previously (Figure 16).

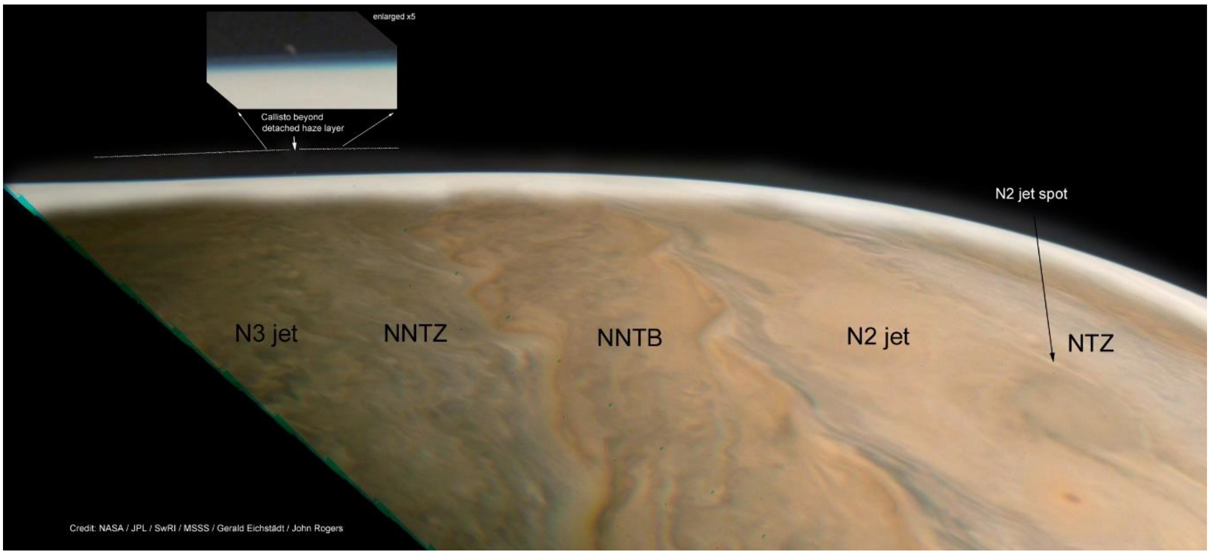

Figure 1. Callisto, seen through a layer of haze above the horizon (identified by Gerald Eichstädt). This is part of Gerald's draft version of image 24, with the limb region brightened relative to the rest of the planet and the dark sky above (so the diffuse light strip around the horizon is artificial). Callisto is seen at almost half phase and only about 4 pixels across. The detached haze layer is over the NNTB and the N3 jet.

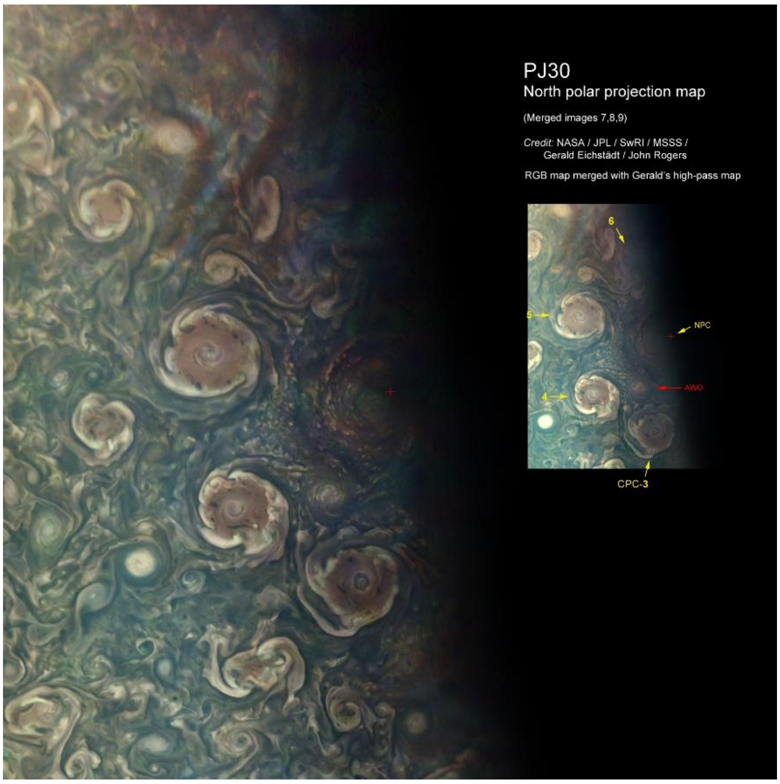

Figure 2. North polar projection maps, composited as usual.
(A) RGB, down to 75°N at edges, showing the circumpolar cyclones (CPCs, numbered in the inset). To enhance contrast, the RGB map has been merged with a high-pass-filtered version by Gerald.

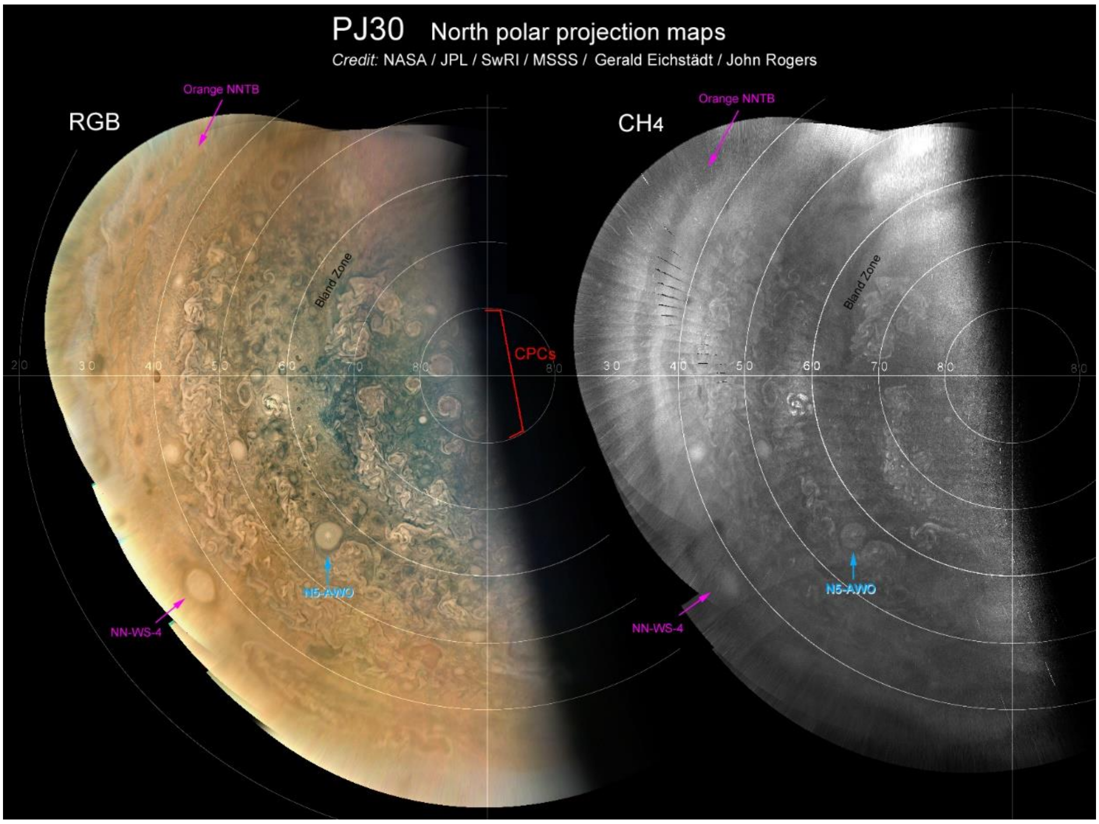

Figure 2. (B) RGB, down to the NTZ. (C) CH4, at same scale as (B).

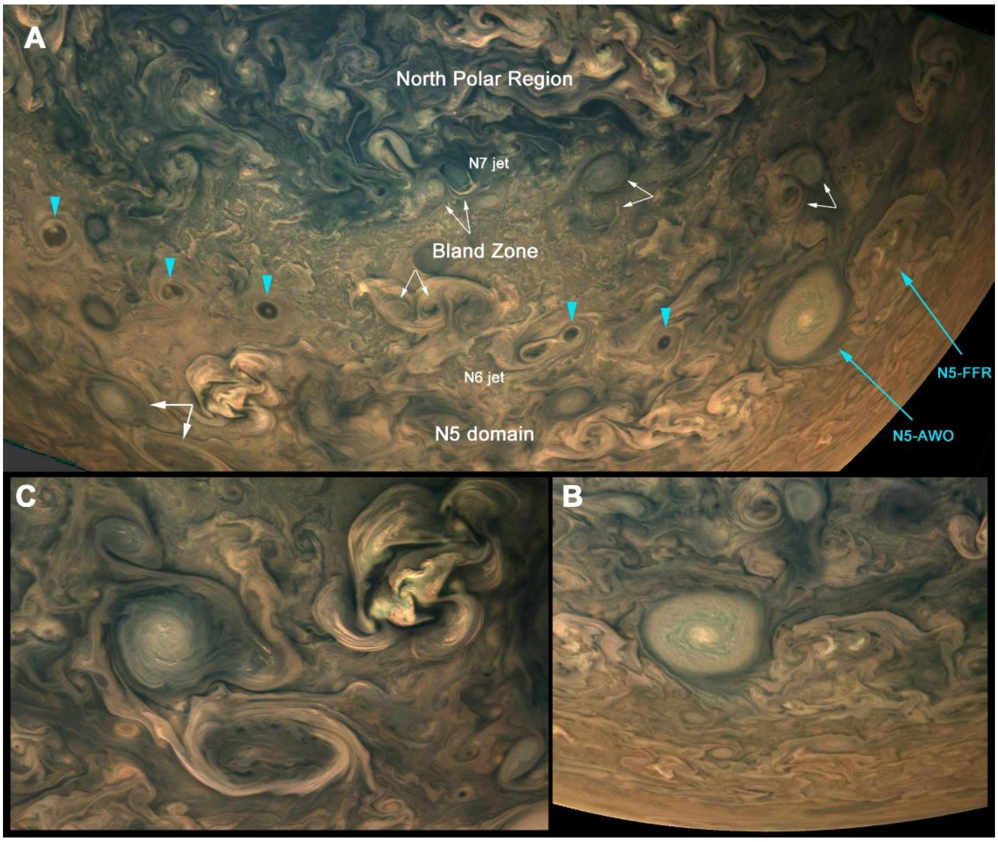

Figure 3. Parts of images showing the Bland Zone and N5 domain (Gerald Eichstädt). North is up.
(continued on next page)

Figure 3 (cont.): (A) Image 14. Features marked are: the large AWO and adjacent FFR on the N edge of the N5 domain; cyclone-anticyclone pairs (paired white arrows); cyclones with compact, very dark cores (large blue arrowheads); approximate latitudes of the N6 and N7 prograde jets. (B) Image 13 (enlarged 30%). The large N5-AWO and adjacent FFR. (C) Image 17. A comparatively large cyclone-anticyclone pair in the N5 domain, with a few popup clouds inside the anticyclone; and a very bright FFR, with thick banks of popup clouds.

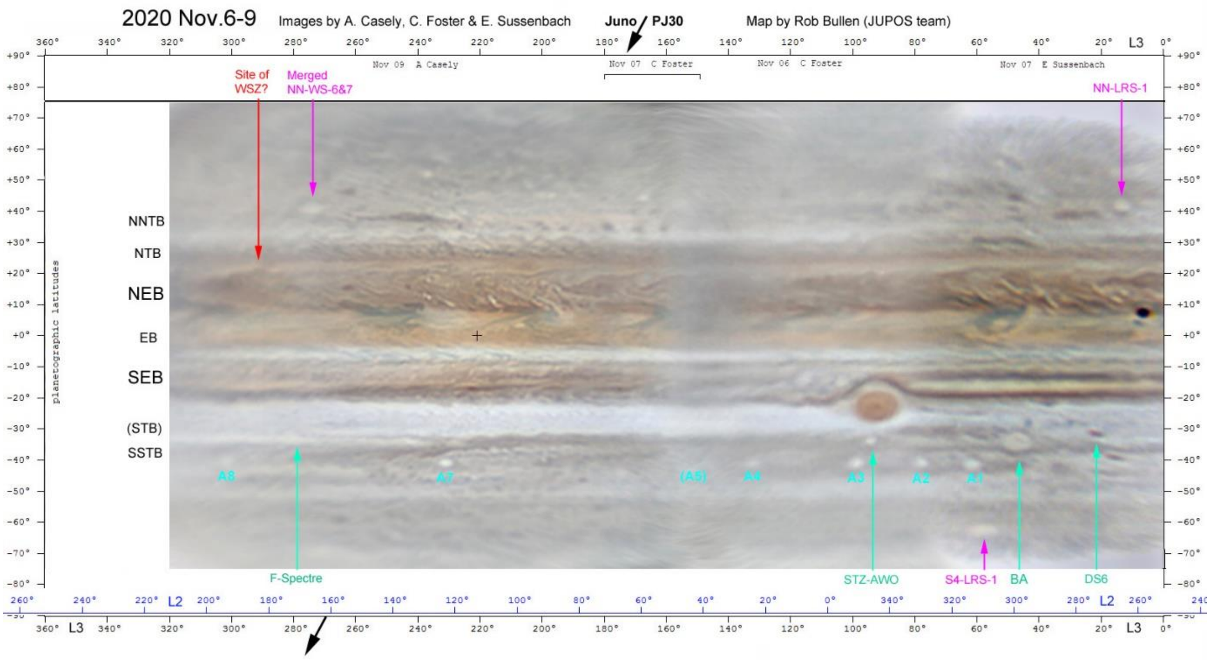

Figure 4. Map of the planet from ground-based images close in time to PJ30. A cross marks the point where the track crossed the equator (not adjusted for drift).
Figure 11A is a part of this map enlarged to match the JunoCam map (Figure 5).

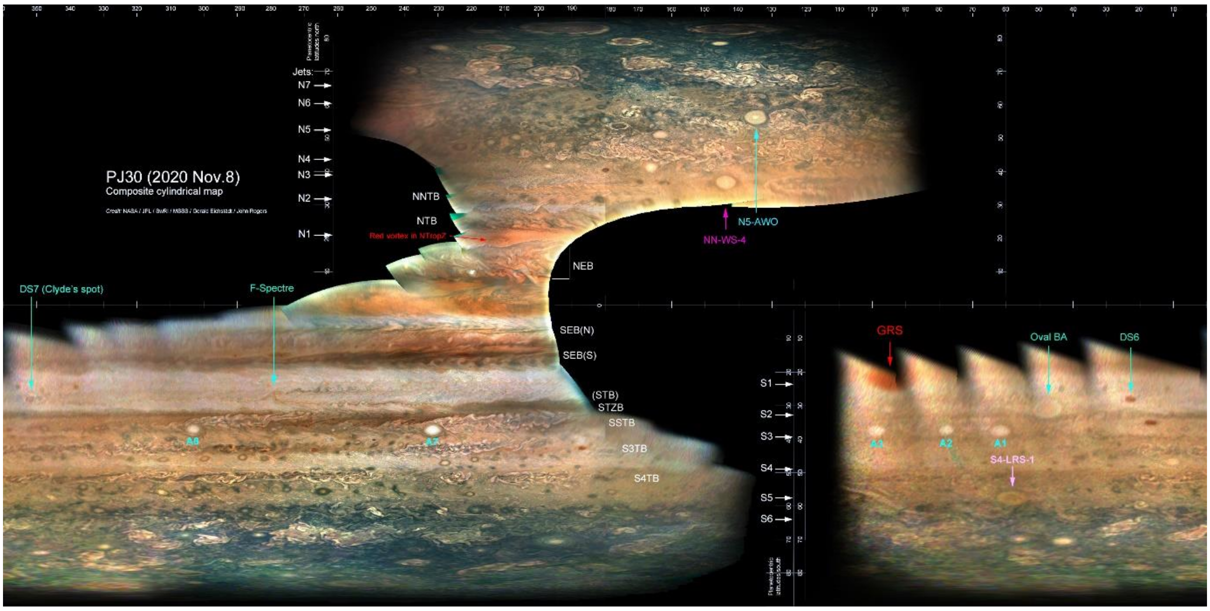

Figure 5. Map of the planet from JunoCam images at PJ30.

Figure 6 *(below R).* Cyclone-anticyclone pair in the N3 domain. Image 22, processed by Björn Jónsson and enhanced by JHR. (Gerald Eichstädt and Kevin Gill also posted enhanced versions of this field.) South is up, to maintain the perspective.

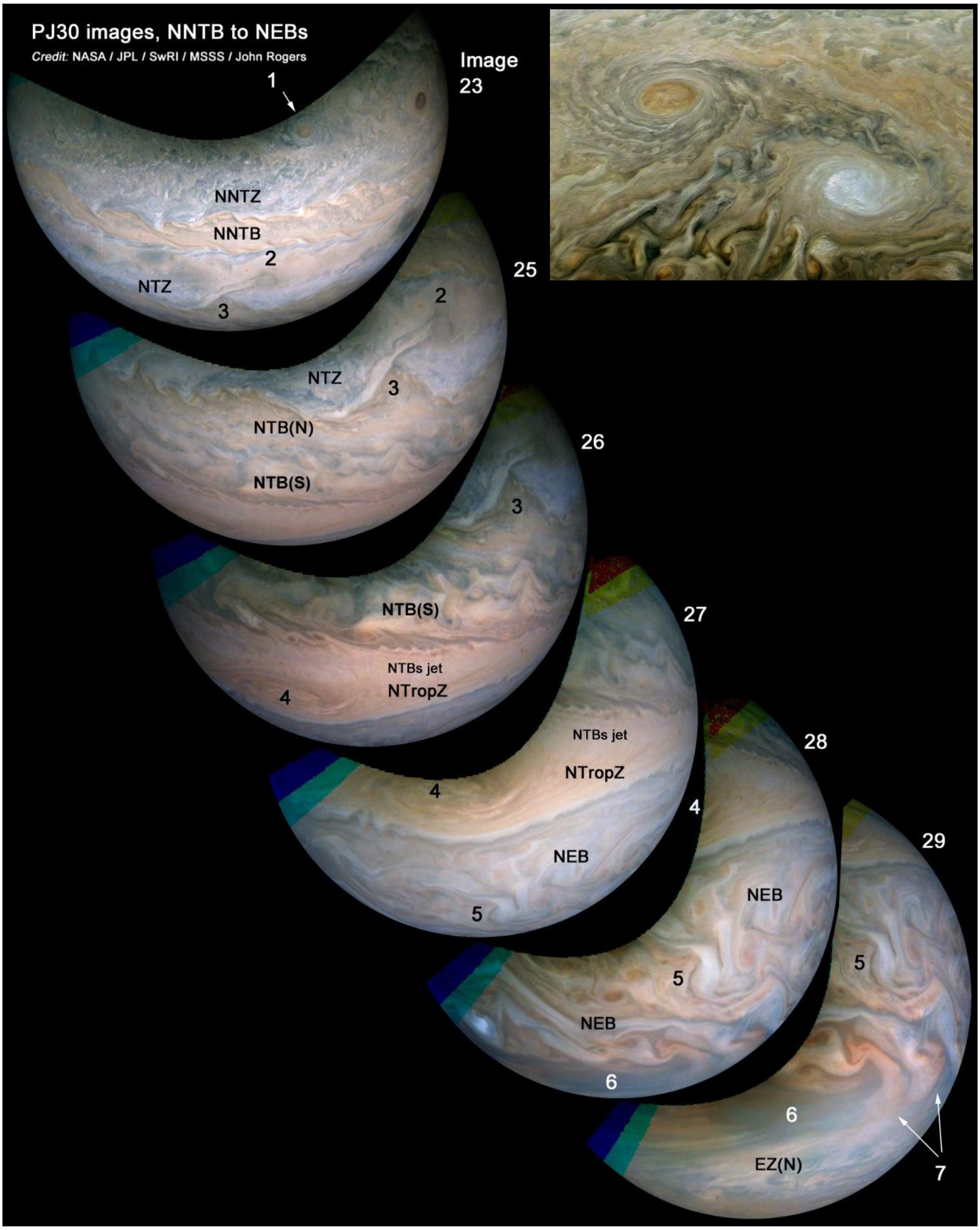

Figure 7. Set of images from the NNTB to the NEBs (initial colour version posted by the JunoCam team, contrast-enhanced, at half size). Some key features are marked and serve as reference points between images: (1) The orange cyclone in N3 domain, shown in Fig.6. (2) One of several NNTBs jet spots; (3) Projection northward from NTB(N); a bright white streamer links (2) & (3). (4) Reddish blob prograding in NTropZ, shown here to be an anticyclone. (5) One of several small white rift features in NEB. (6) NEBs dark formation. (7) Two reddish rifts protruding from NEB across (6).

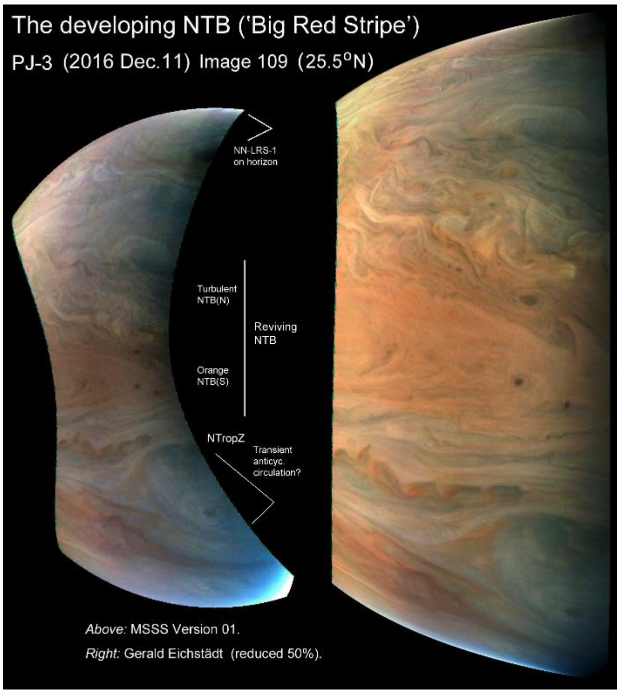

Figure 8. Image of the NTB at PJ3, image 109 (2016 Dec.11). (L) first version from the JunoCam team, contrast-enhanced, for comparison with PJ30 image 27 in Figure 7. (R) Full-quality version from Gerald, produced subsequent to our posted report. (Whereas the view at PJ3 was almost downwards towards the sub-spacecraft track, the views at PJ30 are very oblique.)

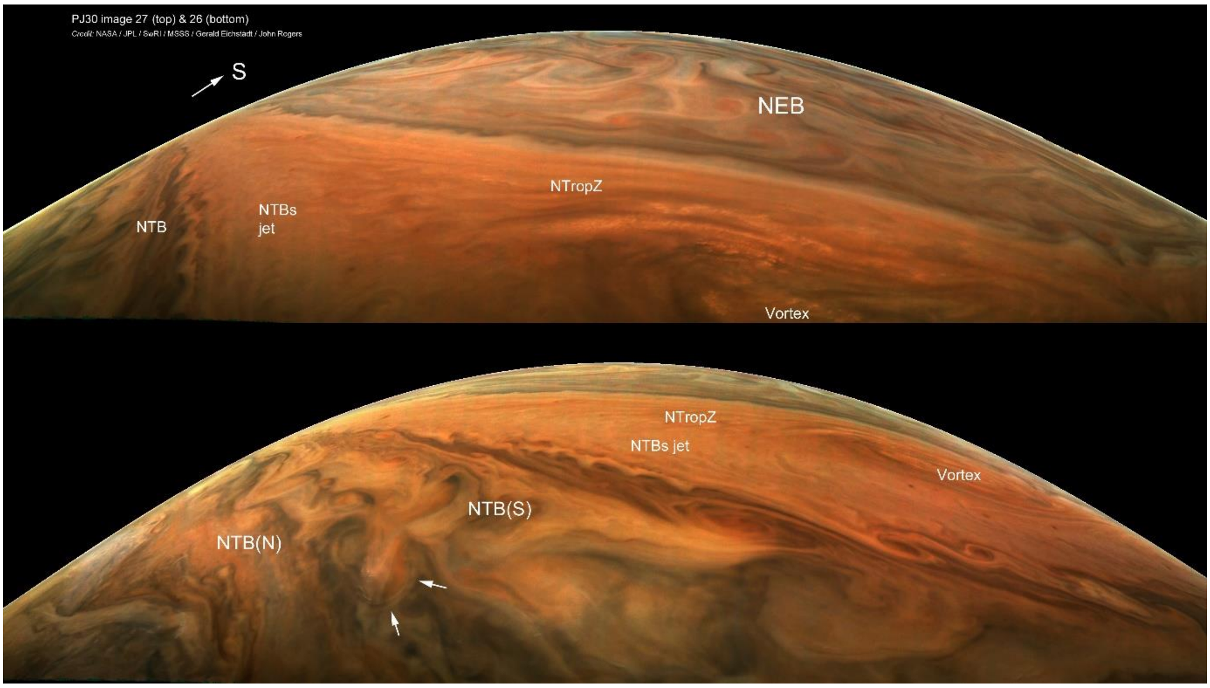

Figure 9. Part of PJ30 images 26 (bottom) & 27 (top), looking SE across the NTB & NTropZ & NEB. The reviving NTB shows a complicated mixture of cloud and haze streaks, some of them cross-cutting, as we commonly see in turbulent regions of other belts. Like the NEB, the NTB is almost devoid of popup clouds, but one cluster of several (possibly a very weak plume?) is half-surrounded by a pair of concentric arcs which could be a wave structure (white arrows), as we also observed at PJ28 in the NNTB and possibly the NEB. The images also show the fast-prograding reddish anticyclone in the NTropZ, labelled 'vortex', in the foreground of image 27; there are many popup clouds on and around it.

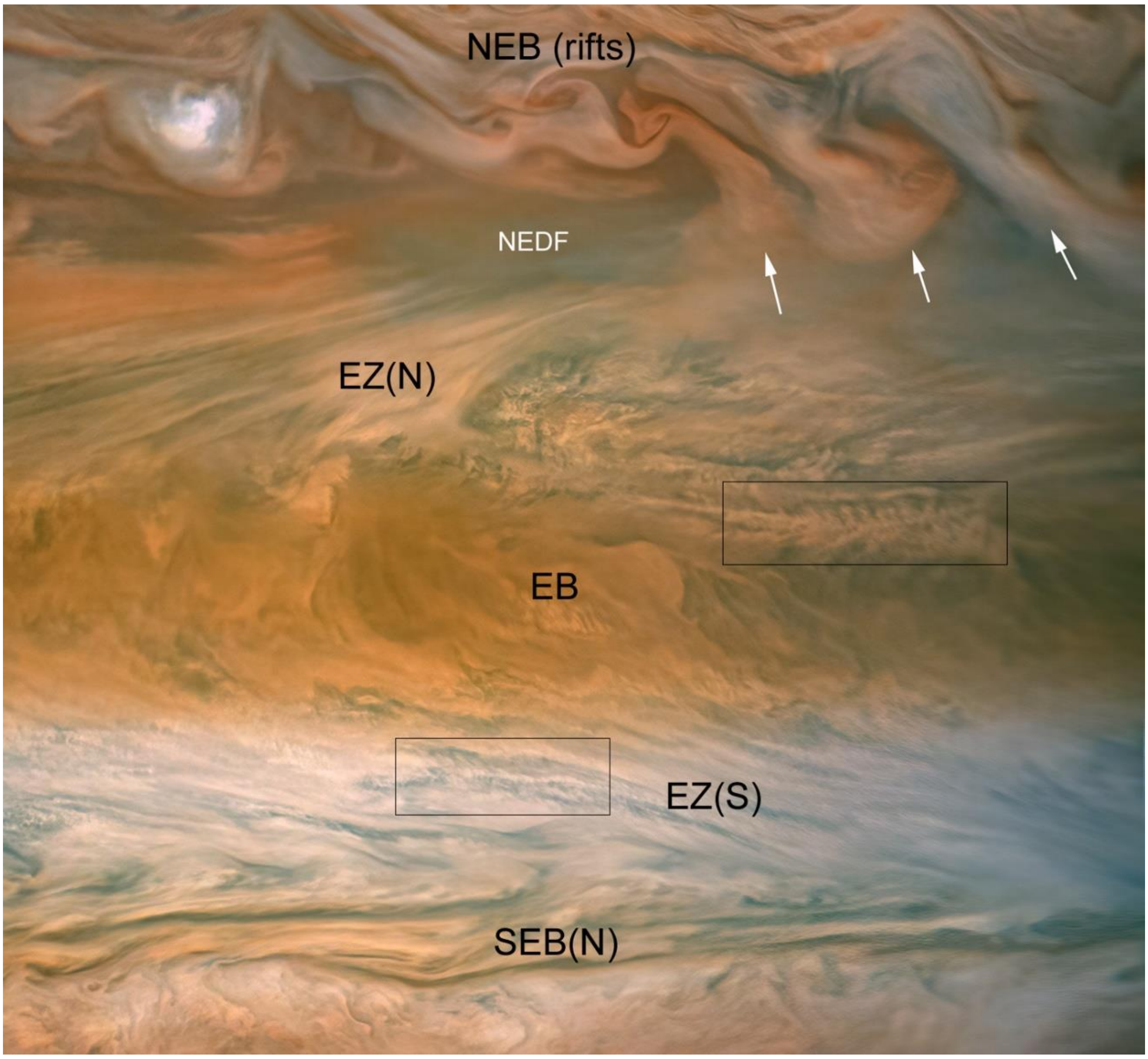

Figure 10. Hi-res cylindrical map of the equatorial region, produced by Kevin Gill (posted on the JunoCam web site). This copy is at half scale, and is contrast-adjusted and labelled. White arrows indicate the three rifts protruding from the NEB into the EZ(N). Boxes enclose feather-like patterns with mesoscale waves.

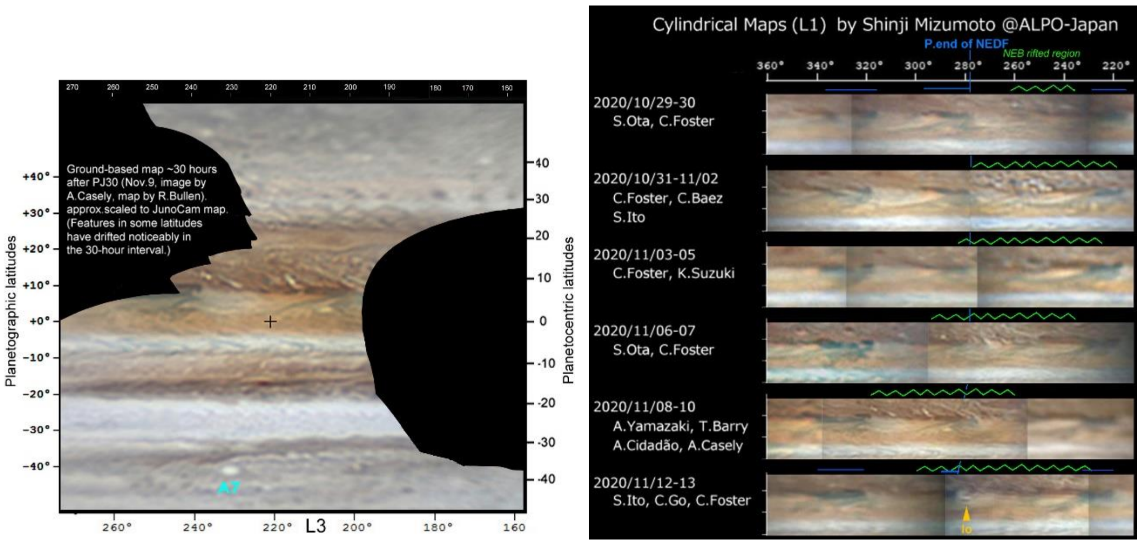

Figure 11. Ground-based maps. (A) The part of Figure 4 corresponding to the JunoCam perijove map (Figure 5) is enlarged to the same scale to facilitate identification of features in the NTB and

NEB (though it has not been adjusted for zonal drifts in the ~30 hours since the flyby). Original image on Nov.9 by Andy Casely, map by Rob Bullen.
(B) Ground-based maps of the EZ, by Shinji Mizumoto (ALPO-Japan), in L1, centred on the NEBs dark formation (NEDF) viewed by JunoCam. A rifted region was developing in the NEB (green zigzag over each map, drifting west relative to L1) and began to pass the relevant NEDF in early November. The closest images to PJ30 were on Nov.7 (C. Foster) and 9 (A. Casely); both show this set of bright streaks from the rifted region projecting S over the NEBs, at the p. end of the NEDF.

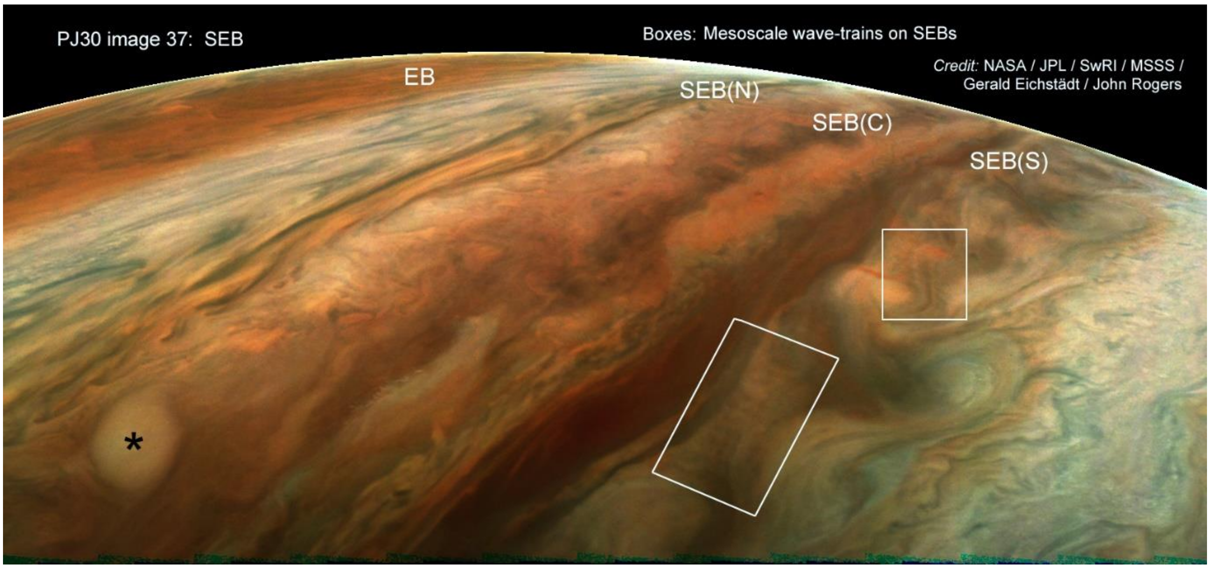

Figure 12. One of several views of the SEB, showing a white oval in northern SEB with hints of anticyclonic structure (asterisk), and the mesoscale waves in the SEBs (boxed).

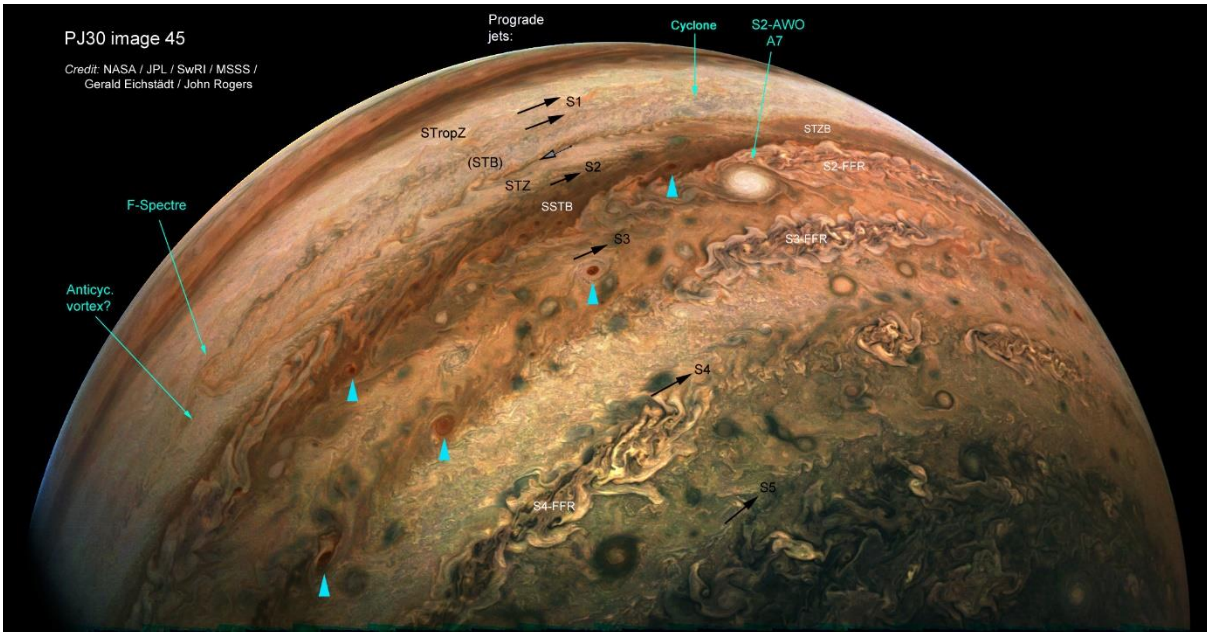

Figure 13. Key features in the southern temperate domains (image 45). Positions of the prograde jets are estimated from the visible textures. Light blue arrowheads indicate compact dark cores of cyclones (also see Figure 3). Most of these features are also visible at higher resolution in image 44.

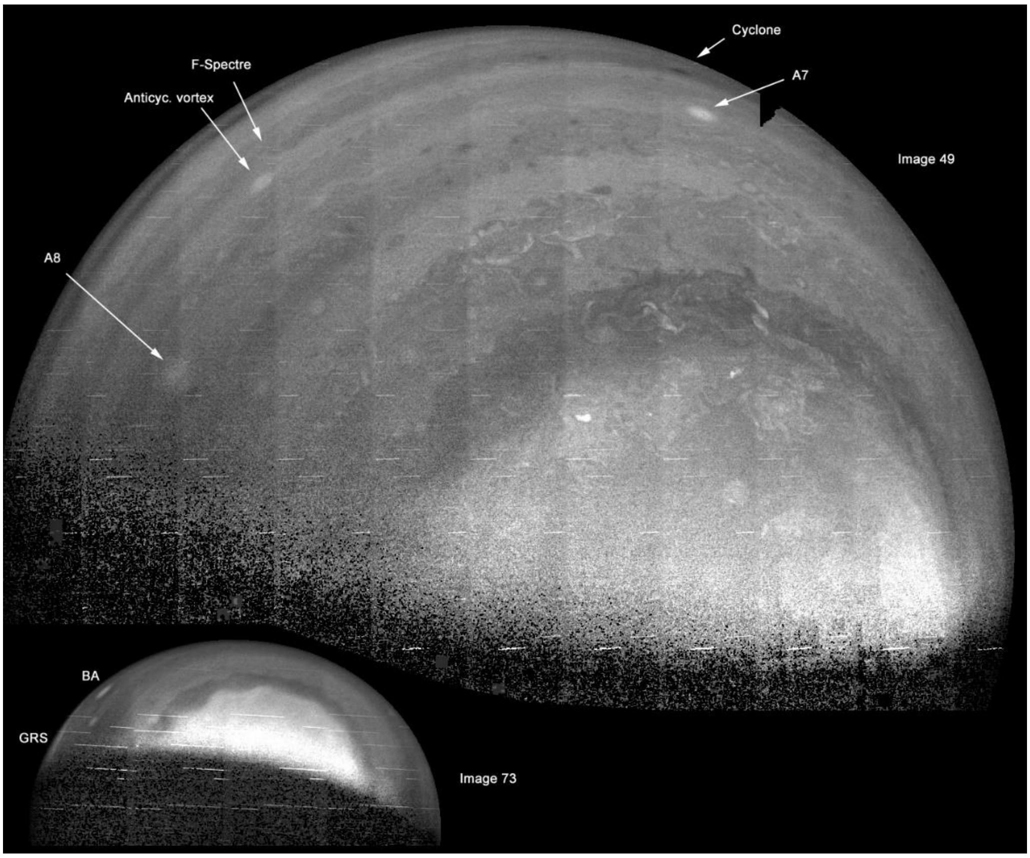

Figure 14. Methane images from the start and end of the outbound sequence, processed by Gerald, shown to scale. The brightening near the terminator is an artefact of the image processing. The rows of bright dashes are due to 'hot pixels' that are streaked due to the long time-delayed integration times of the methane images.

Figure 15. Four south polar projection maps: captions on the figure. *[On next page]*

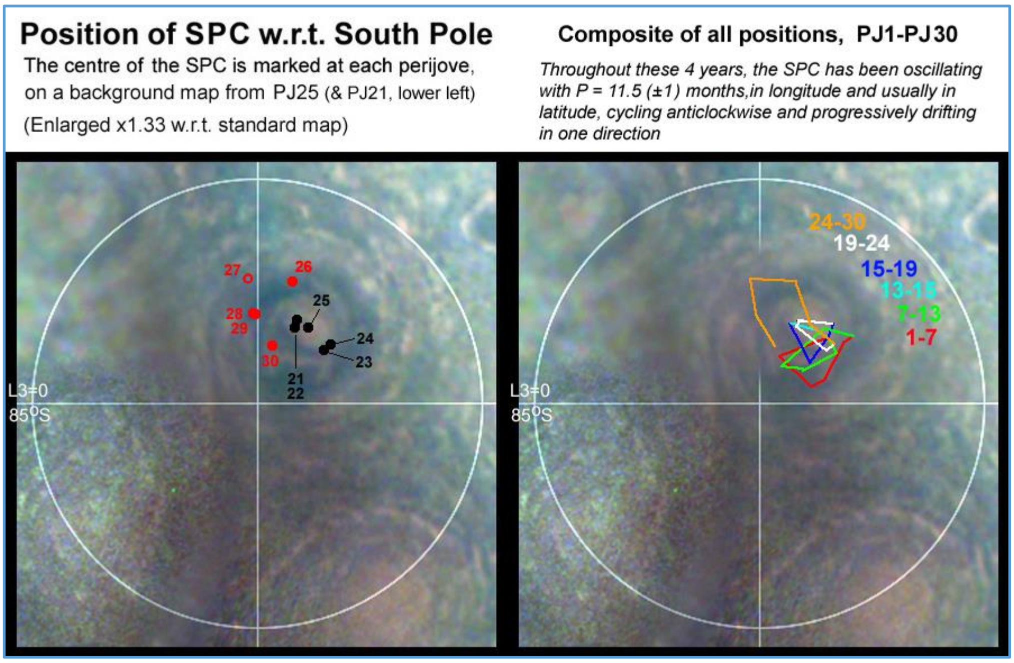

Figure 16. Plot of the position of the centre of the South Polar Cyclone relative to the south pole (continued from our PJ28 report).

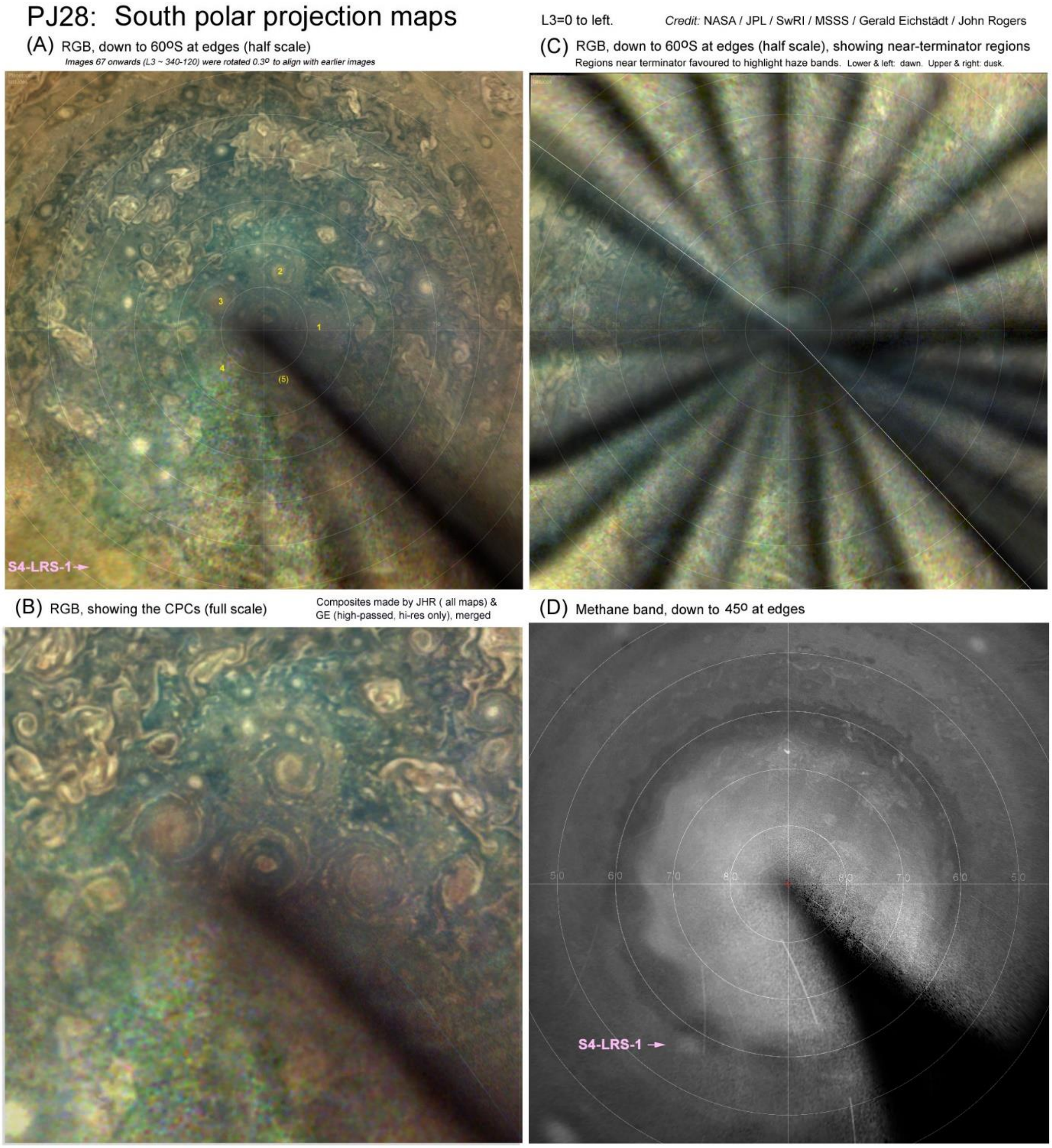

Figure 15. Four south polar projection maps: captions on the figure.