JunoCam at Perijove-12 (2018 April 1): What the images show

John Rogers *(2018 April 27)*

Introduction and Summary

PJ-12 was the last perijove currently planned at which the spacecraft would be turned so that the MWR, as well as JunoCam, could view the track below. With continuing evolution of the orbit [see our report on PJ-10], such pointing is now costly in terms of fuel and solar energy input. So this may have been the last best chance to get widespread coverage of the planet inbound and outbound, and hi-res images of the low latitudes below the spacecraft near perijove.

And JunoCam got the jackpot. Highlights of the images include:
--The approach images, at high phase angle, revealed the complete pattern of northern hemisphere haze bands in swirling, eddying detail for the first time.
--An anticyclonic white oval (AWO) in the NNTZ, called NN-WS-4, was viewed close up and revealed spiral ridges of clouds and rapid rotation.
--In the NEB, a miniature 'barge' was viewed close up.
--High-quality images of the Equatorial Zone revealed 'mesoscale waves' to be very widespread.
--The spacecraft flew 10° p. the p. end of the GRS, and right over the region where the STropD was spilling turbulence into the STropZ. Thus JunoCam obtained unique closeups of this phenomenon, as well as complete views of the GRS as the spacecraft moved south, which will enable an animation of the complex dynamics.
--The view of the south polar pentagon of cyclones was perhaps the best yet, due to the displacement of the pentagon maximally into sunlight, and top-quality image return. These views confirm the cyclic behaviour of the pentagon, and give several new clues to its dynamics. It is still accompanied by a long haze band, which was brilliantly lit at the terminator.

This report depends on the work of the NASA JunoCam team: Drs Candy Hansen (Principal Investigator), Glenn Orton, Tom Momary, and Mike Caplinger (Malin Space Science Systems); and Gerald Eichstädt, who produces the high-quality processed images and the map projections. Gerald has posted a PJ-12 flyby movie:

https://www.missionjuno.swri.edu/junocam/processing?id=4548

As usual, this report draws on two sets of the JunoCam images [see our report on PJ-6]. One is the set quickly released by the JunoCam team, usefully projected as if from a point above Juno's track, but at reduced resolution. The other set was produced by Gerald, at full quality and resolution. In addition to the unenhanced versions, Gerald also produced outstanding versions with the illumination compensated and the contrast enhanced, and these (with further empirical contrast adjustments) are used herein. All have been further contrast-enhanced for display.

Since our paper was published (Adriani et al., 'Nature', March 8), we are now able to post more details of the on the circumpolar cyclones (CPCs) and polar hazes – topics on which the JunoCam team is preparing further publications. Hence, this report is in two parts: (I) The polar regions; (II) Middle and lower latitudes. For conventions and background, please see our previous reports.

Part I: The polar regions

Northern hemisphere

Figure N1 shows two inbound images and the image (no.77) closest to the north pole, all in Gerald's high-contrast versions. Figure N2 shows image 77 and the companion methane-band image, in the JunoCam team versions. (We do not yet have map projections of these images with full sensitivity.)

Northern circumpolar cyclones:
Three of the 8 CPCs are shown: CPCs-1, 2, & 3, all 'filled'. (My usual numbering is used, not that in the 'Nature' paper.) CPC-2 is the small 'filled' cyclone in the 'chaotic' set. CPC-1, the largest, is only just emerging from the terminator and I cannot see counter-spiral structure within it, so it is unlikely that its central rotation will be detectable from these images. Inside the ditetragon, there is a long arc of white shadow-casting cloud centred close to the pole (Fig.N2), which could be the outer edge of the retrograde current that was reported from JIRAM images in the 'Nature' paper. The original images also faintly show a shorter arc inside it.

Approach images and high-latitude haze bands:
Inbound, Juno viewed the planet as a crescent (i.e. at high phase angle), and the images – esp. in Gerald's high-contrast enhancements – show mainly the high-altitude hazes (e.g. Figure N1). At previous perijoves we have mainly seen these near the terminator, but now we see them completely. The composite polar projection map in Figure N3 at last shows the true pattern of the northern hemisphere hazes, and it is wonderful! (Figure N4, for comparison, is a map largely showing areas in full sunlight.)

The map shows the pale bluish-white North Polar Hood (NPH) extending down to the Bland Zone (~60-64ºN), where the usual long linear slightly oblique bands can be seen. From these bands, similarly bluish-white bands and arcs extends to the south in huge waves and dramatic swirls. They give a 3D impression, as if the bright bands or areas are elevated cloud decks casting shadows (dark bands) – although some also have a dark band on the sunward edge. They do not appear to be affected by the underlying circulations, as they run unperturbed across FFRs and the N5-AWO (see below).

The waves and swirls may be divisible into three zones: one of high contrast from ~63 to 51ºN (i.e. from the N6 to the N5 jet, overlapping both); one of lower contrast down to ~45-39ºN (the N4 and N3 jets); & one of very low contrast and finer texture, down to ~31ºN (the N2 jet).

Figure N5 is a methane-band map of the northern hemisphere. It shows multiple edges to the methane-bright NPH, which correspond very well to the waves and swirls seen in the high-phase-angle colour map.

Discussion: South of the N6 jet, these hazes do not obviously trace out the known zonal wind profile, but they may be influenced by it, as their latitudinal limits suggest. By comparison with Figure N4, we can see that the patterns could largely be reproduced if the white hazes were arising in the N4 and N5 domains, and spreading northwards and southwards until entrained by the next or next-but-one prograde jet. It may be significant that the N4 and N5 domains are largely filled with large FFRs (folded filamentary regions) which generate the most frequent lightning strikes on the planet, so these thunderstorms could be generating the high-altitude white hazes. Indeed at higher latitudes, JunoCam images have shown that bright streaks in FFRs are methane-bright [see our reports on previous perijoves, & Figure S6 below].

Previous maps for comparison:
From JunoCam, this map can be compared with the north polar maps we produced at **PJ-9** (Fig.14 of our report) and **PJ-11** (Fig.3 of our report). The tracing of the haze bands was much more limited in those maps, but was consistent with what we see now. PJ-11 Fig.3 showed extensive haze bands over the N3/N4/N5 domains down to 38ºN, near the terminator. It also included our only north polar projection of a methane image so far (albeit of a

narrow sector): this showed waves and swirls of the edge of the NPH around 45-55ºN, just as we see in the PJ-12 colour map.

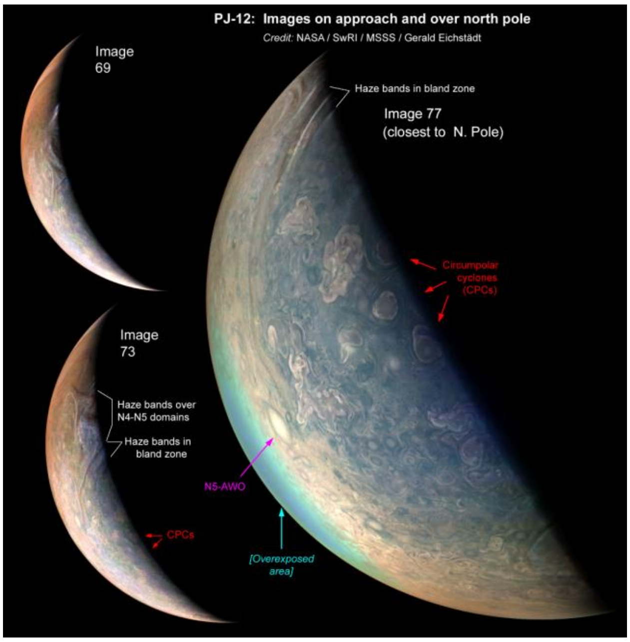
The PJ-9 and PJ-11 maps also showed a disrupted sector of the Bland Zone, and a large N5-AWO adjacent to it; these may be the same features seen at PJ-12 but this remains to be determined.

From other perijoves, we have not yet made composite north polar projection maps down to the mid-latitudes, but they will not reproduce the PJ-12 map as they were not made at such high phase angles.

There is previous literature on the high-latitude haze patterns from Hubble and Cassini, in UV and methane band, as follows, although their maps had lower resolution:
S-L et al.(1998) GRL 25, 4043; Vincent et al.(2000) Icarus 143, 205; B-I et al.(2008) Icarus 194, 173.
There is also information from ground-based infrared images, still to be analysed.

The main outlines of these haze features can now be detected in the best amateur methane-band images. Figure N6 compares the JunoCam maps with polar projection maps from images taken by Chris Go on April 1, the day of Juno's PJ12. The multiple edges of the N. Polar Hood revealed by JunoCam are also recorded in Go's image, along with some of the methane-bright waves and patches. Also, Go's IR image confirms that an IR-dark streak at 50-53ºN corresponds to a visibly dark lane between FFRs.

The Bland Zone mostly has its usual appearance in the over-the-pole images (Figure N2) and the following, closer images (Part II, Figure C4). As is often seen, the long dark brown linear bands can be traced around much of the disk; and one of them clearly appears to be a thinning of otherwise widespread white haze, as a small bright cyclonic vortex has much higher contrast within the brown band than features outside it. This brown band is also methane-dark. However, the linear bands do not extend into the 'lower half' of the over-the-pole image (Fig.N2), p. a large N5-AWO. In this sector the Bland Zone is disrupted by chaotic turbulence. (A similar disrupted sector was also imaged at PJ-9 and PJ-11 at overlapping longitudes and may be the same sector.) This sector was deficient in visible haze bands (Fig.N3). This was unfortunate, as it was the sector beneath the fly-over track, and was the target of the only methane image yet taken at these latitudes (Fig.C4, image 83), which consequently shows no haze features, just the FFRs in the N4 and N5 domain and, more faintly, a N5-AWO.



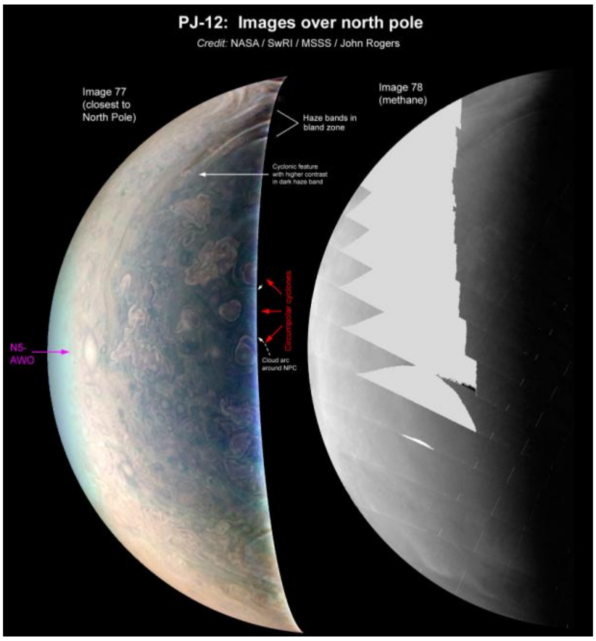


Figure N1 (L). Two examples of inbound images, and the image (no.77) closest to the north pole ('minimum emission angle'), all in Gerald's high-contrast versions.

Figure N2 (R). The over-the-pole image (77) and the companion methane-band image, in the JunoCam team versions. Given the decreasing inclination of the orbit, these images were taken at only 84.3ºN. A fine triplet of images was taken over the north pole with long exposures ('high TDI') and high quality, to give maximum sensitivity on the terminator. The brightest part of these images is washed out in bright cyan because it was overexposed deliberately to enhance the terminator.

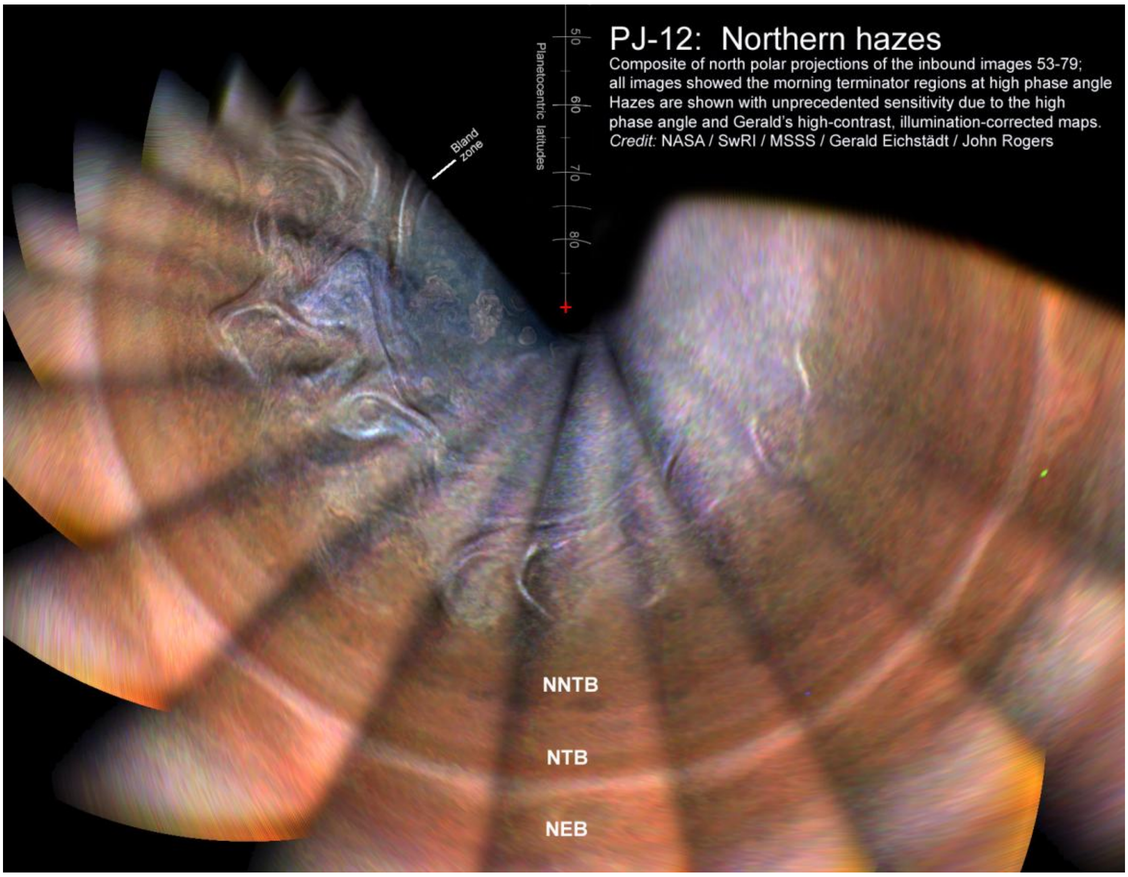


Figure N3. Northern hazes. This is a composite of Gerald's polar projection maps of the PJ12 inbound images (high phase angle and high-contrast processing). (The belt/zone contrasts are quite odd at this high phase angle.) The white features are high-altitude hazes. In Figs.N3 to N5, L3=0 is to the right.

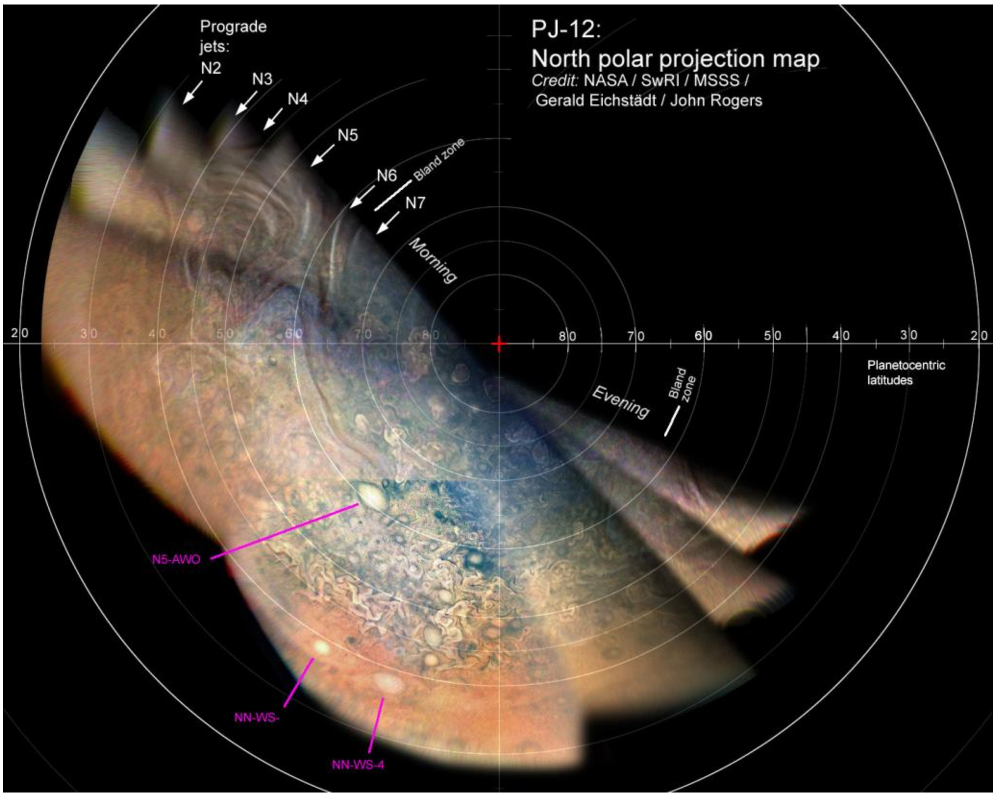


Figure N4....

Figure N4. Northern hemisphere cloud patterns. This is a composite of Gerald's polar projection maps of the PJ12 images 74-80, as it passed over the north polar region and down towards NN-WS-4, largely showing areas in full sunlight.

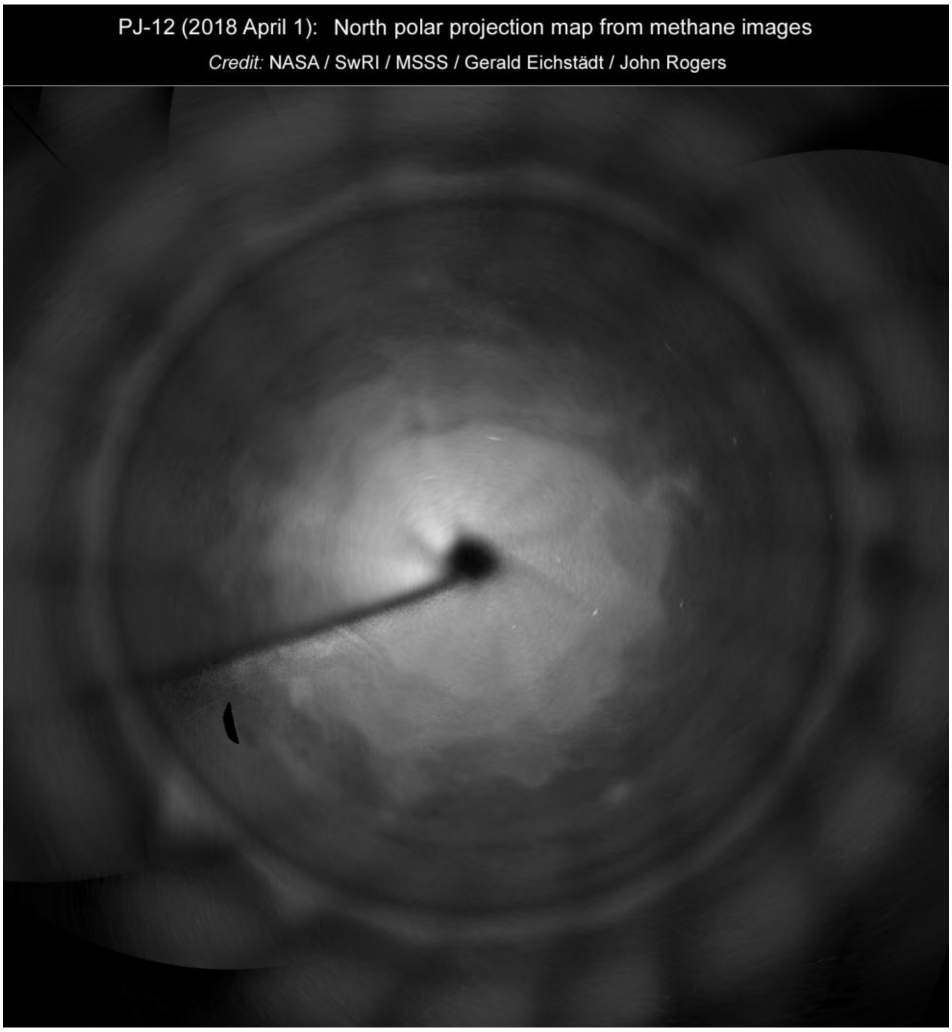


Figure N5. Northern hemisphere methane-band map, compiled from Gerald’s map projections of the inbound methane images.

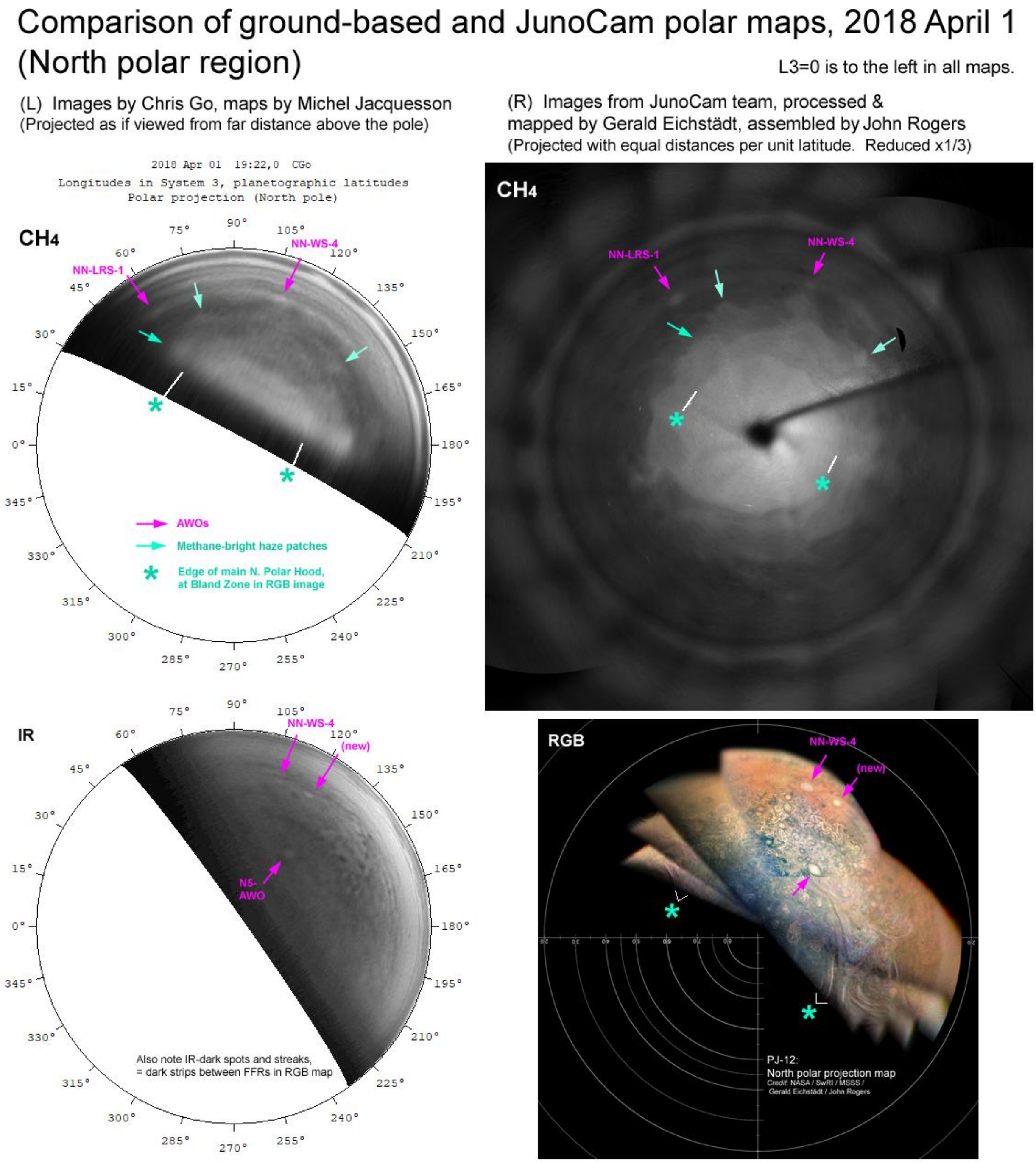


Figure N6. Comparison of polar maps: Chris Go vs JunoCam. The JunoCam maps (at 1/3 scale) are compared with maps from images in methane band and in near-IR continuum taken by Chris Go on April 1, the day of PJ12. Michel Jacquesson projected the images into polar maps, here enhanced and labelled. (Note that Gerald and Michel used different projections so the latitudinal scales are very different.) L3=0 is to the left (opposite of Figs.N3 to N5).

Southern hemisphere

Figure S6 shows the over-the-pole image (105) and companion methane image (106). They show the now-familiar features of the south polar region, which are mapped in Figure S1.

Southern circumpolar cyclones:

The PJ-12 images are among the best and most complete yet obtained of the pentagon and ancillary features (Figure S1). This is partly because the team obtained images with long exposure ('high TDI') and high quality, over the pole and occasionally later. [Image 115 is obviously better than other outbound images, and shows as much of the haze bands as several adjacent images together.] Also, the pentagon is optimally illuminated, as it is now at summer solstice (the pole tilted by 3.5º), and is displaced almost maximally away from the pole (by 2.1º), so the centre was illuminated with a solar elevation of 5.6º.

All 6 CPCs are seen well except for CPC-5, which is only seen partially and at low resolution. Gerald has posted an animation:
http://junocam.pictures/gerald/uploads/20180410a/jnc_pj12_polS_75_to_90_deg_reg_enh_denoise_12frames.gif
--which may be the best yet, clearly showing the cyclonic rotation of 4 CPCs and several FFRs and 3 small AWOs. It also shows a much slower, irregular cyclonic circulation within the gap (see below).

The central cyclone, CPC-6, is now at latitude 87.9ºS (±0.2º); thus it has moved to low latitude again, closely following the same loop as recorded previously (Figure S2). So it has now completed nearly two cycles around this loop since PJ-1 in 2016 August.

The CPCs largely retain their individual characteristics but with some changes. CPC-2 now has a prominent filled core, as it did from PJ-1 to PJ-9 but not at PJ-11. CPC-6 (the South Polar Cyclone) no longer has the central white oval which was a feature at early perijoves, though it always contains a dark annulus.

Notably, each of CPC-2 & 3 has an outer spiral arm continuous with an adjacent FFR. Could these be a 'smoking gun' for the energy supply into the CPCs? Gerald's animation shows rapid divergence along each of these white streaks, such as commonly occurs on similar interconnections between adjacent CPCs (arrows on Figure S1). There is no evident flow from the FFR into the CPC; rather, clouds flow into both circulations from a point between them, which could be due to upwelling at that point.

The gap (between CPC-2 & 3 as always) is less wide than it was. It contains a small bright spot which Gerald's animation shows to be a cyclonic eddy within a very slow irregular cyclonic circulation. This is the first time we have detected flow there.

At PJ-11 there was a small white spot in the gap, which could be this cyclonic eddy, or it could be the small AWO that is now lodged at the outer edge of CPC-3. Another AWO is between CPC-1 & 2.

Haze bands:

Figure S3 shows composite maps of south polar haze bands compiled from Gerald's map projections, selecting the regions near the terminator where haze bands are seen.

The persistent Long Band of haze is fully present and spectacular, brightly caught in sunlight along the terminator; it shows 'rainbow' colours all along its length (blue towards the sun, red on the shadowed side). In the outbound images, where it is on the morning terminator then on the sunlit side, it is not bright but dark. The earlier bright band and later dark band appear to be coincident along most of the length, but adjacent at the NW end.

Apart from the long band, there are only a few minor (dark) streaks in the haze at >67ºS. But again there are many haze bands further north, lying obliquely across the S5 domain, although they are quite faint and narrow.

Figure S4 is a methane-band map of the south polar region. It nicely shows the wave systems around the edge of the methane-bright SPH (= S6 jet) and around the edge of the methane-dark S. Polar Belt (= S5 jet). More unusually, it shows that the Long Band (and specifically its centre line between the blue and red sides) is a distinct boundary between brighter SPH at lower latitude and less bright SPH at higher latitude, i.e. over the CPCs.

The methane image (106) taken over the pole (Figure S6, image 106; not included in Figure S4) was obtained with exceptionally high quality. Methane-bright features within it include many bright strips in FFRs (as usual), the ‘filled’ CPC (but other CPCs are barely visible), and the W end of the Long Band where it extends onto the sunlit side. Surprisingly, the largest AWO, at 71ºS, is not methane-bright.

As in the north (Figure N6), some of the features revealed by JunoCam are also visible in Chris Go’s ground-based methane and IR images on the same date (Figure S5). The sharp, wavy edge of the methane-bright S. Polar Hood is reproduced in the map of Go’s image. Most remarkably, the Long Band – a persistent band of bright and dark haze associated with the polar pentagon of cyclones – corresponds to a brightness boundary within the SPH in both methane maps. Go’s IR image resolves the chain of large FFRs at ~70ºS.

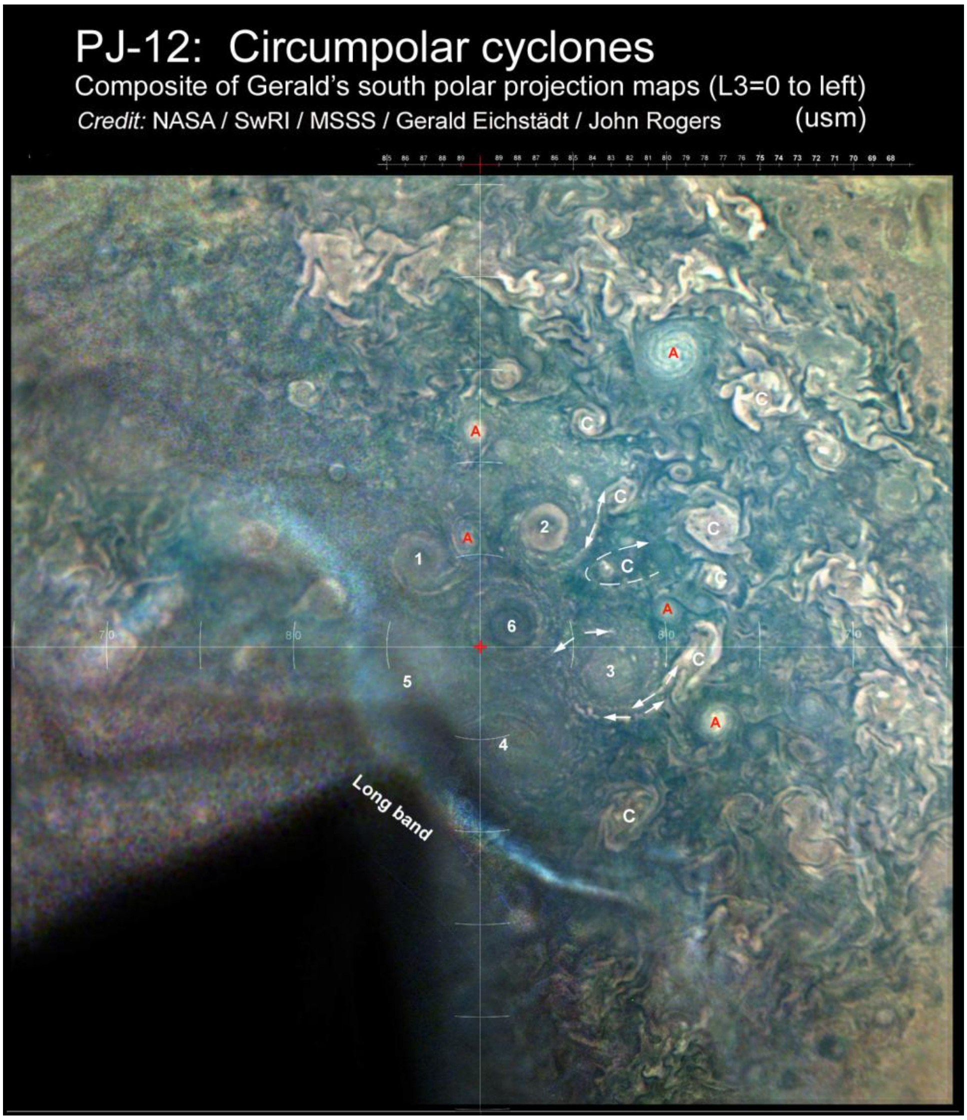


Figure S1: Composite map of the south polar region (unsharp-masked). CPCs are labelled with my usual numbering. C = other cyclonic features, A = AWOs, as shown in Gerald’s animation.
See Figure S3 for unlabelled version. In all maps (Figs.S1-S5), L3=0 is to the left.

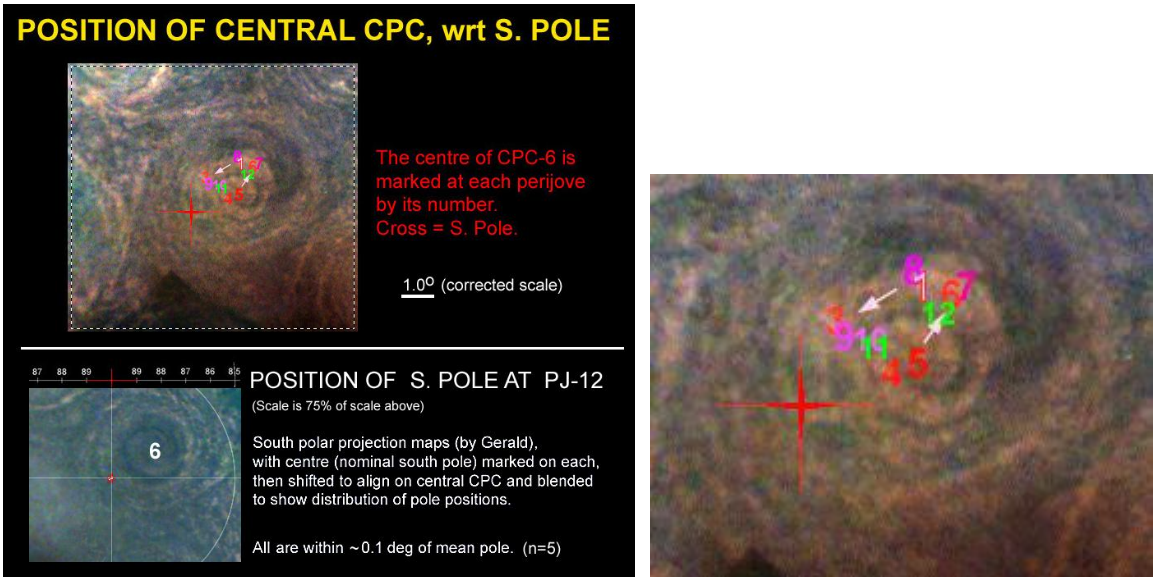


Figure S2: *Top & R:* Position of the central cyclone at each perijove , relative to the south pole (red cross), overlaid on a representative image. *Bottom:* Accuracy of determination of the south pole position in Gerald's maps.

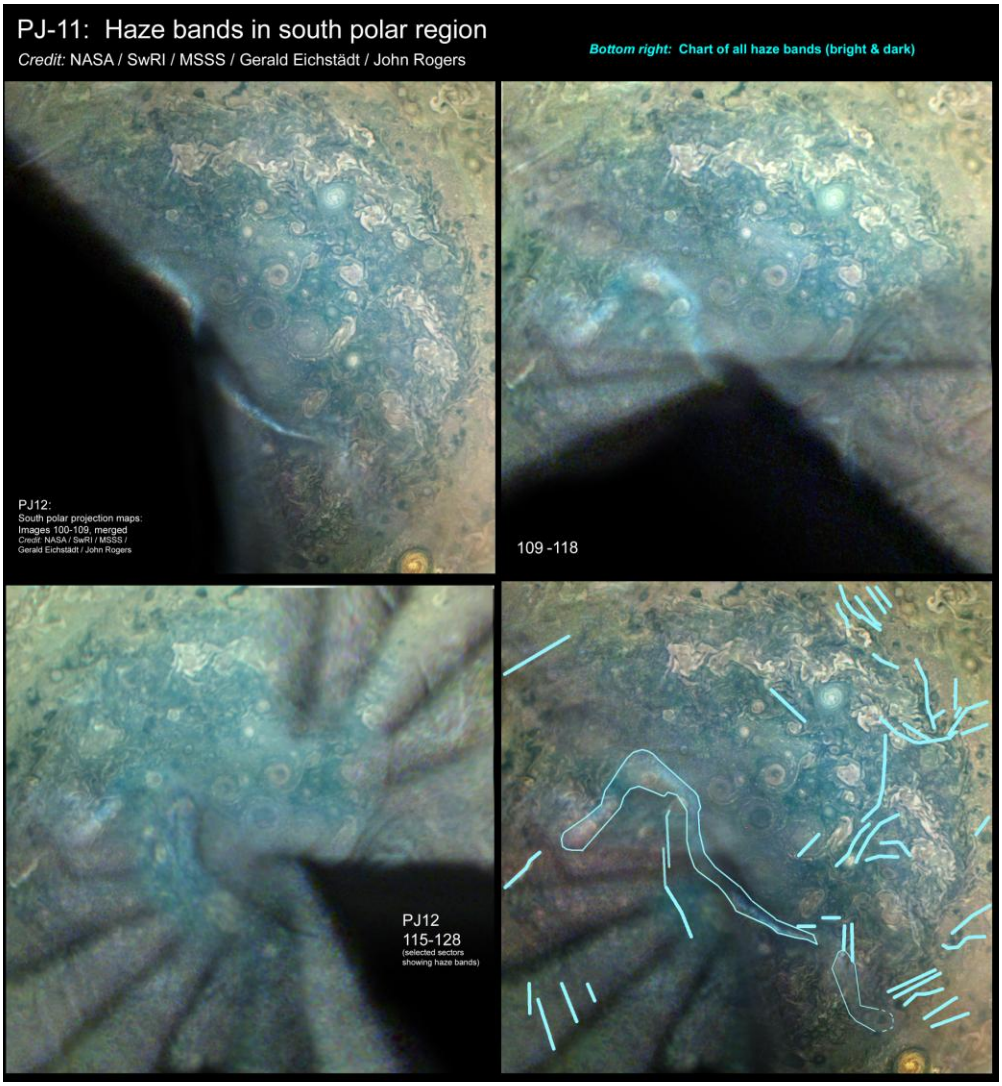


Figure S3...

Figure S3: Maps of south polar haze bands. Three panels are composite polar projections of over-the-pole and outbound images, selecting the regions near the terminator where haze bands (bright or dark) are seen. The fourth panel indicates the locations of all the haze bands on a composite map. The Long Band snakes across the field of view near the centre.

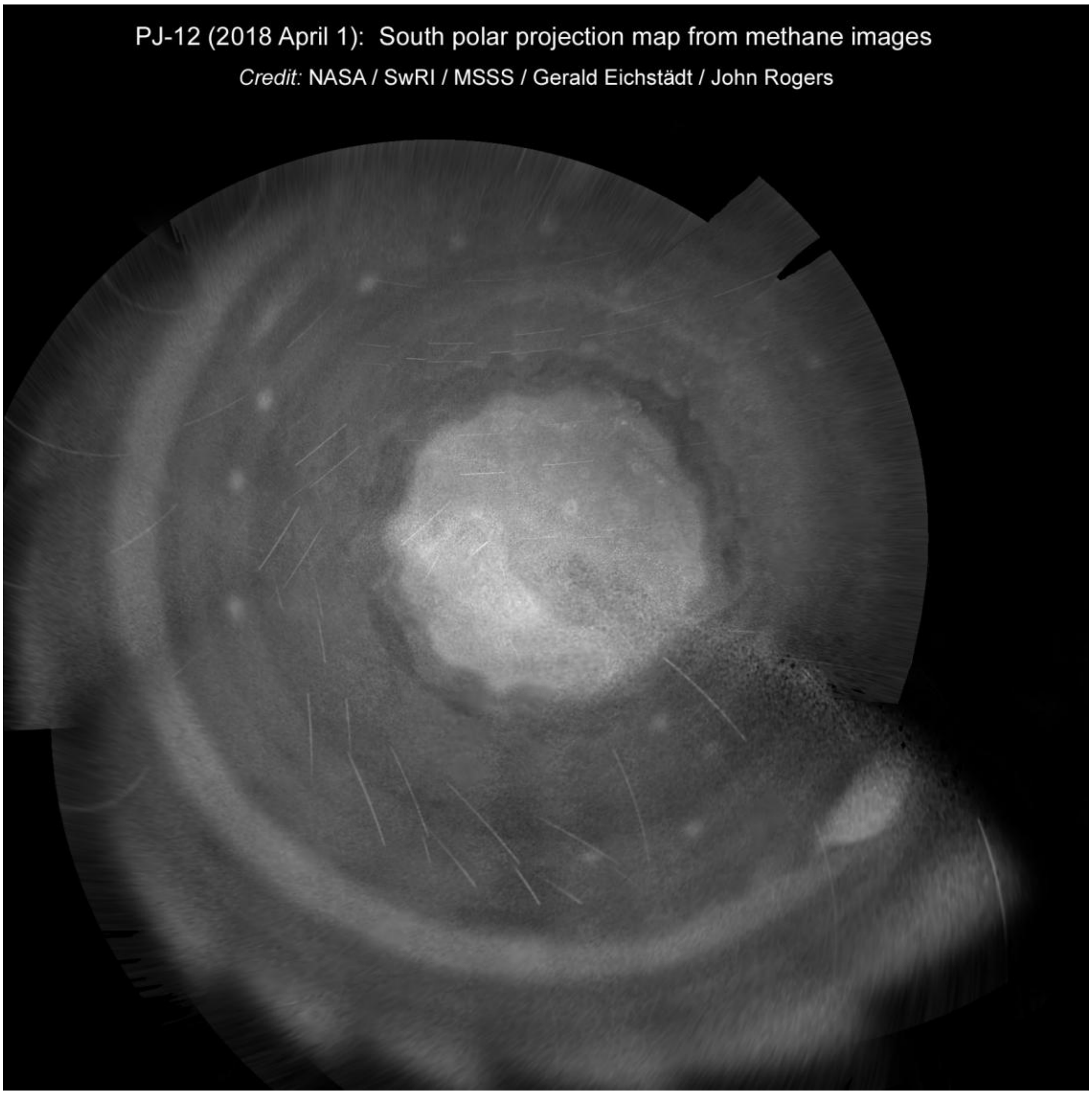


Figure S4: Methane-band map of the south polar region, compiled from Gerald's map projections of the outbound methane images.

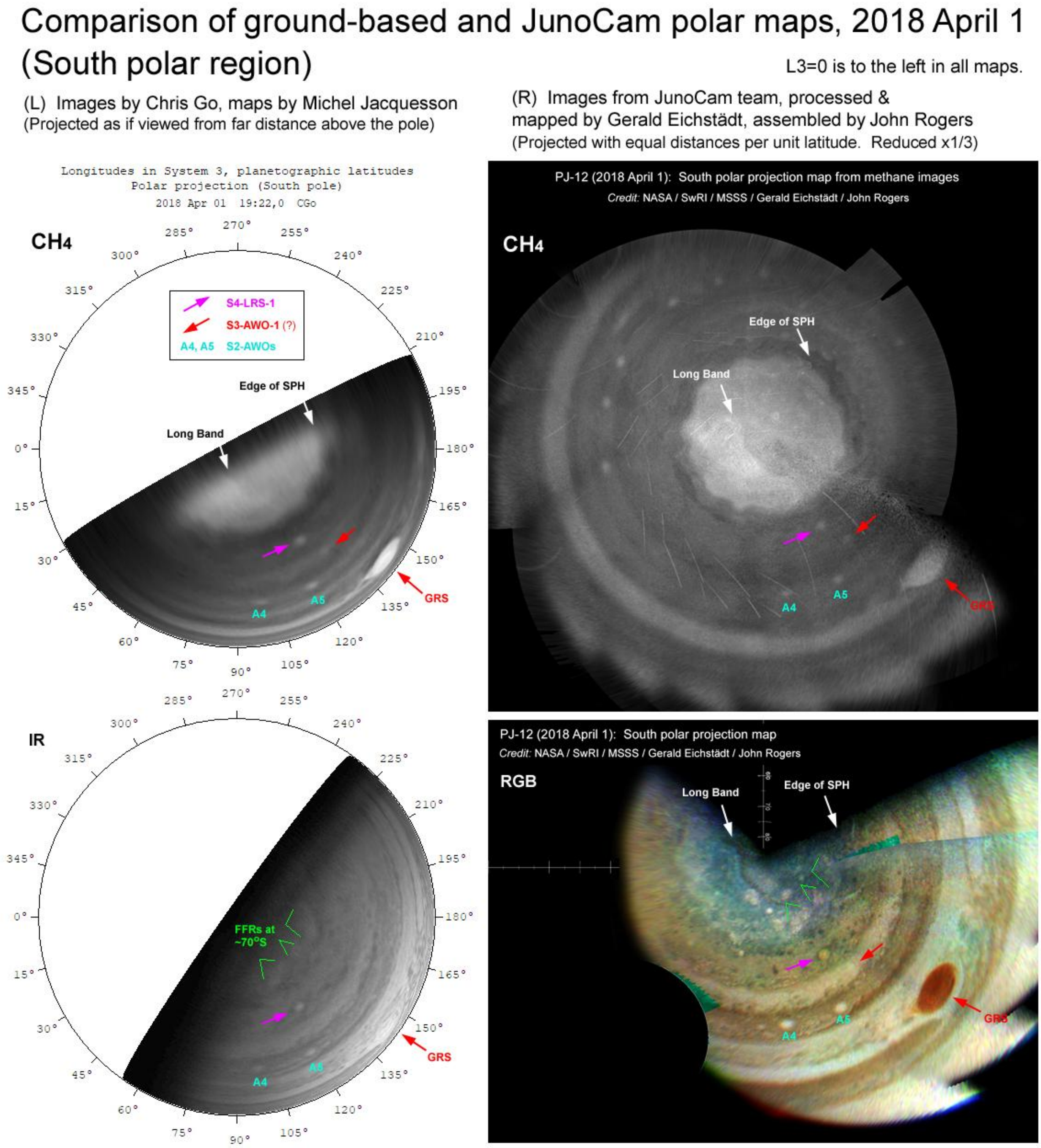


Figure S5. Comparison of IR polar maps: Chris Go vs JunoCam. Like Fig. N6, this compares the JunoCam maps with polar projection maps from images taken by Chris Go on April 1, as projected byMichel Jacquesson.

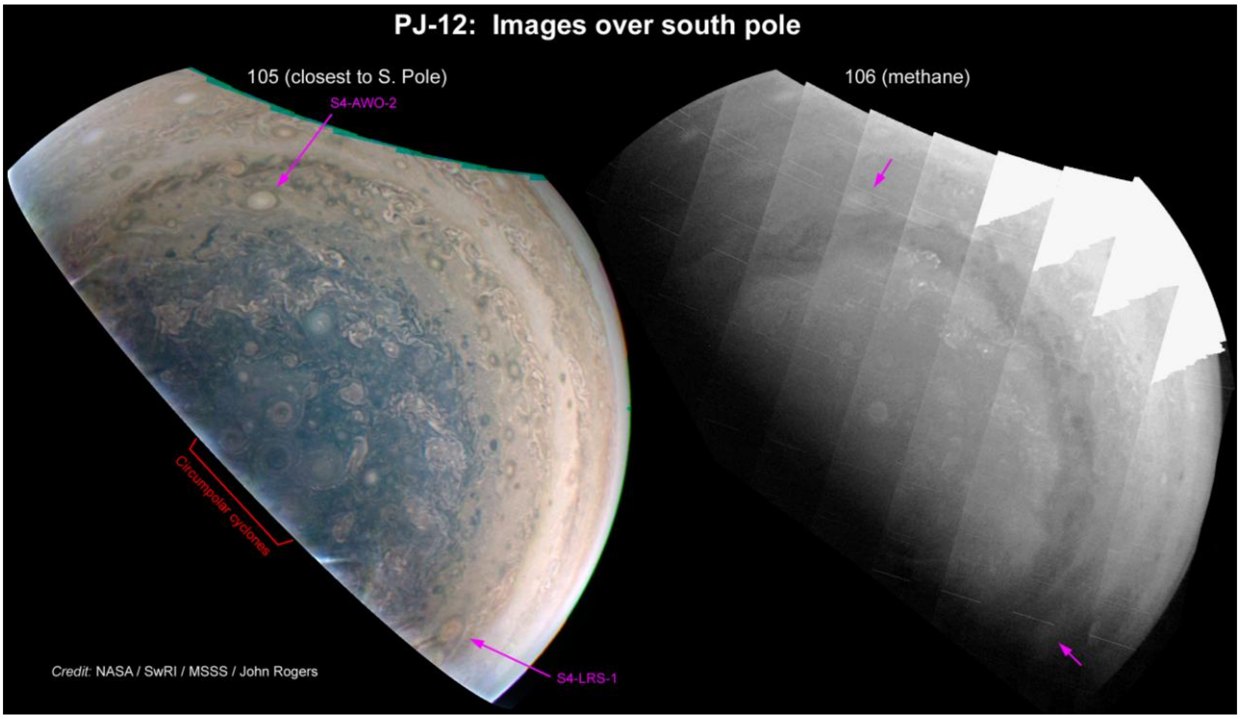


Figure S6 The image taken closest to the south pole ('minimum emission angle') (105) and companion methane image (106).