Jupiter in 2021/22, Report no.7: Equatorial Region Update

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[Original post, 2022 Jan.24; Part II revised, 2022 Feb.22]

Part I. Slow-moving methane-bright patches on EZ

In 2020, from amateur methane-band (889 um) images, we discovered an unprecedented pattern of waves on the EZ that were almost stationary in System 3 longitude (L3), and thus disconnected from the fast equatorial current [see our 2020 reports no.4 (Part III) & no.5, and Ref.1]. This wavetrain, with wavelength ~20° longitude, was present around L3 ~ 150-250 in 2020 May and July, although not distinctly during most of June. In 2021, similar features have again been observed, but instead of extended wave-trains, they are large isolated methane-bright patches that extend across the whole EZ. As in 2020, they move only slowly in L3, and are principally visible in methane-band images, although they are associated with the orange, UV-dark Equatorial Band (EB). In fact, this year we also detect them in UV images, as the methane-bright patches are centred on UV-dark bulges in the EB. They are usually not evident in RGB images because of interference from streaks of other colours. In methane images they tend to be most obvious when near the limb.

The recorded instances are summarised below, and illustrated in compilations of methane-band images (Figures 1-7), either as cylindrical maps produced by Shinji Mizumoto (ALPO-Japan), or as images. A few UV images are also included. Figures 1-8 are all large compilations of maps or images, provided in a ZIP file.

1. May-June: This methane-bright patch was reported briefly in our 2021 report no.2 & in an EPSC talk (Ref.1)]. It was present at least from May 11 to mid-June (Figs.1&2). It was reported by Chris Go on May 22 and attracted much attention from observers, including professionals, while Shinji Mizumoto made a very useful series of strip-maps by which to track it. It was initially at L3 ~ 245 (overlapping the longitude range of last year's wavetrains). Its south edge was initially a trough in a short wave-train like those in 2020, extending as far as 6-7°S (SEBn), but soon the flanking waves disappeared. Its north edge was an arc projecting to 8-9°N (NEBs); the f. end of this arc remained near L3 ~ 248 since May 22, whereas the p. end accelerated to lower longitudes, suggesting that this methane-bright streak was increasingly affected by the rapid equatorial current (see chart in Fig.2). Many of the subsequent methane-bright patches showed a similar semi-detached northerly streak.

[Figure 1 (maps by Shinji Mizumoto) includes RGB maps which do not show the methane-bright patch, but do show two small, apparently unrelated, white outbreaks in the NEB, both indicated by green arrows:
(i) A rift in the NEB(S) that had begun as a bright point on May 8, and progrades and expands and breaks thru into the EZ(N).
(ii) A small bright white point that appeared following White Spot Z in the northern NEB (at top left): we can see that it only lasted a few days.
(Note that these rifts are not expanding across the width of the NEB, which is extremely quiet, as in 2011.)]

2. In mid-August a similar feature developed near L3 ~ 70, and by Aug.31 there were two similar features at L3 ~ 40 (subsequently nearer 30; this was the least distinct of the three) and L3 ~ 0 (Fig.3). The three of them persisted until Sep.23 (Figs.4&5). By early Oct., they

were dissipating, but the initial one still existed at L3 ~ 73 with a very bright northern streak, and a new one was developing at L3 ~ 312 (Fig.6).
The Hubble OPAL maps on Sep.4 (not shown here) include this trio of methane-bright patches, and a blink animation of the methane-band maps shows the complexity of rapidly moving and varying streaks relative to the three larger, quasi-stationary bright areas. They are also clearly visible in UV maps.

3. From Oct.20 to Nov.11, there was an isolated methane bright patch near L3 ~ 310 (probably the same one observed from Oct.6-8 as there were few methane images here in the interim). It was also especially distinct in UV as a dark swelling of the EB. By Nov.20, methane images showed it only as a bay in EZs, and it was not detected thereafter.

4. From Dec.21 to 2022 Jan.5 there was a methane-bright patch at L3 ~ 240-250 (just Nf. the GRS) – mainly shown in images by Joaquin Camarena, Manos Kardasis & Isao Miyazaki (Fig.7). It was only slowly prograding in L3. Like similar patches earlier in 2021, it spanned the EZ with northern and southern arcs; and was quite distinct when near the limb. The last images showing a trace of it were on Jan.12-14.

These were the most prominent and persistent such features during 2021. They appeared at various well-separated longitudes (but not near any of Juno's equator-crossing longitudes). Although this survey may have missed some lesser ones, and there were some gaps in methane-band coverage, such features were definitely absent over large sectors, for instance near the GRS longitudes in Aug. & Sep. The EZ often appeared complex in methane images, and there may well have been a confusing mixture of streaks drifting and evolving at very different speeds, which would require more intensive observation and analysis to dissect (e.g. with the Hubble OPAL maps on Sep.4).

The leading hypothesis for these slow-moving features is that they are at very high altitude. The fast equatorial jets are expected to weaken with increasing altitude until they reach almost zero speed. High-level wind speeds on the equator cannot be readily calculated from available data, and may be variable, but the zero-speed level could perhaps be around 100-200 mbar (interpolating across the equator in Fig.D3 of Ref.2), or around 10-20 mbar (Ref.3). It is plausible that the methane-bright orange haze over the EZ could extend that high. It may be possible to test this hypothesis using IR images in the 2-3 micron range, which Dr Glenn Orton and colleagues have obtained with the NASA IRTF on several dates.

References:

1. Rogers J & Go C. 'Stationary waves in Jupiter's Equatorial Zone in 2020.' Europlanet Science Congress (online, 13–24 Sep 2021), EPSC2021-95, https://doi.org/10.5194/epsc2021-95 or at: https://britastro.org/node/26504

2. L.N. Fletcher, G.S. Orton, T.K. Greathouse, J.H. Rogers, Z. Zhang, F.A. Oyafuso, G. Eichstädt, H. Melin, C. Li, S.M. Levin, S. Bolton, M. Janssen, H-J. Mettig, D. Grassi, A.Mura, & A.Adriani. 'Jupiter's Equatorial Plumes and Hot Spots: Spectral Mapping from Gemini/TEXES and Juno/MWR.' JGR-Planets, 125 (no.8), e2020JE006399 [Appendix D]. https://doi.org/10.1029/2020JE006399 (2020) (& https://arxiv.org/abs/2004.00072)

3. Benmahi, B., Cavalié, T., Greathouse, T. K., Hue, V., Giles, R., Guerlet, S., Spiga, A., & Cosentino, R. 'The equatorial wind structure in Jupiter's stratosphere from direct wind and temperature measurements with ALMA and IRTF/TEXES.' Europlanet Science Congress (online, 13–24 Sep 2021), EPSC2021-223, https://doi.org/10.5194/epsc2021-223.

Part II. Bright plume outbreaks in the narrow NEB(S) *[REVISED, 2022 Feb.22]*

In our 2021 Report no.6 (https://britastro.org/node/26451), we described the state of the NEB and these outbreaks up to 2021 Dec.4, including one directly observed by JunoCam at PJ38 on Nov.29. Since then, there have been important developments. Three more outbreaks have occurred (numbers 7-9), so the activity is increasing in frequency and extent. And the JunoCam PJ38 and PJ39 image sets have been processed and mapped; by great good luck, both sets captured an active plume and other features in the heart of the outbreaks. (Details of these observations are given in our PJ38 and PJ39 reports, posted herewith.) So we have revisited the ground-based images around both perijoves to give as much information as possible about the features shown in them. This revised report follows on from Report no.6, and they together form our account of these phenomena in 2021/22.

These events have all been thoroughly documented by co-author Shinji Mizumoto, whose sets of maps are posted on the ALPO-Japan web site (http://alpo-j.sakura.ne.jp/Latest/j_Cylindrical_Maps/j_Cylindrical_Maps.htm). Many of the recent maps covering the outbreak longitudes are reproduced here with further annotation.

The typical course of each outbreak is as follows. It begins with a small brilliant white spot in the NEB(S) at ~10°N, which is also transiently methane-bright. After about a week it extends tenuous white streaks to Sp. and Nf., and the dark brown NEB(S) may become broadened Nf. the plume, giving the impression of a wake that disrupts the whitish cloud cover of the mid-NEB. Also after about a week, an extremely methane-dark spot (or more) appears adjacent to it. Initially the plume is retrograding (DL1 ≈ +1 to +2 deg/day), but then it moves south to the NEBs edge and reverses its drift to prograding (DL1 ≈ –1 to -2 deg/day), joining the superfast features that have replaced the usual NEBs dark formations (NEDFs) on the otherwise quiet NEBs.

Figure 8 shows charts of (A) all the outbreaks during the apparition, & (B) the more recent ones with drift measurements. Note that all the outbreaks have occurred within a restricted longitude sector with DL1 ~ +0.4 to +1.7 deg/day.

The outbreaks in 2021 Nov-Dec. (up to PJ38):

PJ38 was on 2021 Nov.29.

Figure 9 presents the ground-based maps from Nov.5 to Dec.5, annotated to identify the outbreaks and the features seen by JunoCam at PJ38, including superfast projection(s) (black lines) and a methane-dark patch (black arrows). Original images around the time of PJ38 are in Supplementary Figure S1.

Figure 10 presents maps of the PJ38 JunoCam images (from our PJ38 report). The most striking feature is the very bright white convective outbreak, Plume 6. This had appeared 8 days earlier, and like all these outbreaks, it was initially retrograding in L1, then (the day before PJ38) moved south to the NEBs edge and reversed its drift. It was short-lived but its drift rates were apparently similar to others. JunoCam caught it while it was still a bright plume. Whitish streaks (a1 & a2) may be traces of the original outbreaks of plumes 5 & 6 respectively. Other labelled features are described in our PJ38 report. The ones that we have tracked are:

(c) This vague blue-grey patch coincides with the strongly methane-dark patch that was still retrograding from plume 5.

(g) This small blue-grey projection with festoon is a typical super-fast feature, tracked by the JUPOS and ALPO-Japan teams from mid-Nov. to Dec.5, with DL1 = -2.5 deg/day, possibly decelerating to -2.0 deg/day.

Some other features (d, f) may be super-fast festoons that were not tracked. Small projections and festoons with super-fast speeds of DL1 ~ –1 to -2.5 deg/day were a feature of the quiescent NEBs at this time, and in ground-based images, poorly resolved ones could account for some variations in the NEBs edge and in the blue-grey formations corresponding to the methane-dark patches.

The outbreaks in 2022 Jan. (up to PJ39):

Figure 11 presents the maps from Dec.12-31, and Figure 12 from Jan.1-20. The latter are labelled around PJ39 to identify the features seen by JunoCam, including superfast projection(s) and a methane-dark patch. Suppl. Figure S2 shows the original images around the time of PJ39.

Outbreak no.7 began as a tiny white spot on Dec.18, and was brighter on Dec.21. It behaved just like its predecessors. It initially had positive DL1, and after about a week, a dark bluish, very methane-dark spot formed adjacent to it. The growing white spot then moved south to break thru into the EZ and changed to negative DL1 (~-1.7 deg/day), i.e. in the same super-fast range exhibited by other features on NEBs at this time. Meanwhile the extremely methane-dark spot persisted for over a month, at 9°N, and retained its positive DL1 (+1.7 deg/day), which would be normal for a latitude of 10°N.

Outbreak no.8 appeared close to plume no.7 on Jan.6, becoming bright on Jan.9. It again had positive DL1 (+2.0 deg/day), so it passed north of plume 7 on Jan.11, then continued along the increasingly disturbed sector between plume no.7 and its retrograding methane-dark spot. Around Jan.19-23, as usual, plume 8 moved south and reversed its drift, meanwhile generating a very methane-dark spot which continued to retrograde at +2.0 deg/day.

PJ39 was on Jan.12, passing over longitudes close to the PJ38 track, both in L1 and in L3. (Coincidentally, L1=L3 on the date of PJ39.) Although the planet was sinking into the evening twilight, ground-based observers managed to get good enough images to track the features that appeared in Juno's images (Figure 12 & Suppl. Figure S2).

Figure 13 shows the JunoCam map at PJ39 (from our PJ39 report). The plumes and projections marked were tracked in amateur images as follows:

Plume 8 had appeared around Jan.9 [yellow arrowhead in our maps, Figure 12] and is still a very bright compact white spot in the NEB(S). It is retrograding with DL1 ≈ +2.1 deg/day.

Plume 7 had appeared in Dec. and moved south to span the NEBs and change its speed to prograding, around Jan.1 [red arrowhead in our maps]. At PJ39 it is a whitish area in EZ(N), prograding with DL1 ≈ -1.7 deg/day.

Proj. a (L1 ≥ 104): This is the p. end of a long dark bluish NEDF which was elongating. The p. end was not methane-dark, and was virtually stationary in L1 up to Jan.11, but then began prograding at ~-1 deg/day. Further f., the NEDF includes the extremely methane-dark patch created in association with plume 7 in Dec., still retrograding (see above); but being at L1 = 120 on Jan.12, this patch 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. It is prograding at ~-1 deg/day (Jan.6-13). It is not notably methane-dark [A. Cidadão, Jan.11], though a methane-dark patch would develop nearby on Jan.18.

Proj. c (L1 = 82): This is the p. end of plume 7, though it was not a distinct mini-projection until Jan.10. It is prograding at ~-1.7 deg/day (Jan.11-18), like plume 7.

Outbreak no.9 appeared on Jan.15, adjacent to the methane-dark spot from outbreak no.7. It shared the retrograding drift of that spot and remained just f. it for 3 weeks, although it did break thru into the EZ.

This brings us to the end of the apparition. Most of the last useful images are mapped in Figure 14 (Jan.31—Feb.15), showing that the outbreaks are still extensive and perhaps still growing. They appear particularly dramatic in the IR850 filter used by Antonio Cidadão (i.e., IR continuum from ~850-1000 nm; e.g. Suppl. Figure S3), even up to Feb.21. It will be important to get observations as soon as possible after solar conjunction, to find out whether all this activity is leading to a full-scale NEB Revival.

Discussion:

The visible appearance suggests that each outbreak begins with the eruption of a convective plume, and vigorous updraft in the plume leads to adjacent downdrafts (creating a clear deep hole that is very methane-dark) and a disturbed wake (white streaks and reddish-brown belt). The initial retrograding speed for the plume and for the methane-dark spot is fairly close to that expected for the latitude of ~10°N from the usual zonal wind profile.

The JunoCam images at PJ38 and PJ39 fortunately captured all the types of feature in these outbreaks:

Bright active outbreaks were captured at maximal resolution at PJ38 (plume 6) & PJ39 (plume 8). Each was a thick mass of bright white clouds, with a hint of cyclonic structure, surrounded by thinner whitish veils, consistent with these being the top of powerful convective storms with hazes expanding from them. Plume 6 was partly overlaid by orange hazes. In both cases, wakes of whitish haze were seen, containing mesoscale waves at PJ39.

NEBs festoons with super-fast speed, possible or definite, were recorded at both perijoves, showing long blue-grey and whitish streaks, and orange haze bands sometimes cutting obliquely across them, consistent with super-fast features being deep-seated, overlaid with hazes. However, whether these aspects are significantly different from normal times needs further study.

Methane-dark patches were ill-defined blue-grey patches (PJ38): they were only imaged at lo-res near the limb, but were probably partly overlaid with whitish or orange haze bands, consistent with these too being deep features.

The methane-dark patches' intensity, longevity, and steady drift with a speed that is actually rather slow for their long-term latitude of 9°N, all suggest that they are not just local disturbances advected by the zonal winds. Such methane-dark features are presumed to be very clear deep holes in the upper clouds, and this is confirmed by 5-micron images on Nov.27 (Figure 9) which show that several such methane-dark patches are very bright (i.e. hot) in thermal infrared, implying a lack of deeper clouds as well. Thus, these patches are somewhat similar to the usual (but now mostly absent) NEDFs at 6-8°N, which are thought to be Rossby waves moving more slowly than the NEBs jet in which they are embedded.

We do not know why the plume always drifts south to break thru the NEBs. As noted in 2021 report no.6, the plumes are similar to tiny brilliant spots that have often been noticed in the NEB(S) in normal times (e.g., see our report on PJ20), and these often move southwards likewise; sometimes they contribute to a bright 'plume core' in northern EZ at the base of a festoon (e.g. in the Voyager images).

In normal times, tiny brilliant spots in the NEB(S) generally do not develop into larger rifts or disturbances across the NEB. However, the NEB Revival in 2012 did begin with bright spots in this latitude. So spots like this could eventually initiate the next NEB Revival, and we wait to see whether this will happen during solar conjunction.

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Figures for Part II:

Figure 8. Charts of the NEB(S) outbreaks. (A) All the outbreaks during the apparition; (B) The more recent ones with drift measurements.

Figure 9. Maps (Nov.5—Dec.5), with JunoCam at PJ38, including superfast projections (vertical black lines) and a methane-dark patch (black arrows). The thermal-IR image at 5.1 microns on Nov.27 is from Dr Gordon Bjoraker using the iSHELL imager on the NASA-IRTF, Hawaii. It closely matches the CH_4 image on Nov.29 from Paul Maxson.

Figure 10. Maps of the PJ38 JunoCam images [from our PJ38 report]. The full-res image of the plume was posted in 2021 Report no.6.

Figure 11. Maps (Dec.12-31) [from Fig.8 of original Report no.7].

Figure 12. Maps (Jan.1-20) , with JunoCam at PJ39, including superfast projection (vertical black lines) and a methane-dark patch (black arrows).

Figure 13. JunoCam map at PJ39 [from our PJ39 report].

Figure 14. Maps (Jan.31—Feb.15) at the end of apparition, showing the outbreaks still extensive.

Supplementary Figures:

Figure S1. Original images around the time of PJ38, including methane images. (A cropped alignment was shown in 2021 Report no.6.)

Figure S2. Original images around the time of PJ39.

Figure S3. Images near the end of the apparition, by Antonio Cidadao on Feb.7 in IR850 filter. (This filter shows maximal contrast of features on NEBs).