# Jupiter in 2015-16: Interim report no.3

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**Summary**

This report covers 2015 Nov. to 2016 Feb. The planet's appearance is largely normal, but with a large dark North Temperate Disturbance, and ongoing broadening of the NEB to the north. This NEB expansion event is proceeding slowly, as in 2000, but already covers >140 deg. longitude. Methane-band images reveal a pattern of waves overlying the expanded sector and for some distance on either side, with wavelength 18 deg. The NEB has substantial rifts; the NEBs dark formations are large and have unusually slow drift rate. The GRS is still exceptionally small and red, but still interacts with retrograding vortices from the SEBs jet as it did in the Voyager years. There is no dark STB, but three structured sectors are still discernible: Oval BA, which has now decelerated as the spot f. it has become quiescent; the STB Ghost; and spot DS5, which is now red and fading, and looks likely to persist as a duplicate of the STB Ghost. We also document the long-lived ovals and interesting smaller features in many latitudes from the N2 to the S4 domain.

## Introduction

As Jupiter comes up to opposition on March 8, this report describes the features of the planet so far this apparition. In view of the forthcoming Juno mission, we provide plenty of detail and illustrations, although the planet's appearance is largely normal. **Fig.1** is a map of the planet with major features labelled. **Fig.2** shows aligned images in visible, IR, UV, and methane band, by Tomio Akutsu. **Figs.3 & 4** show some of the best images, with important spots labelled.

This report mainly covers the period up to Feb.10 when the latest JUPOS charts were completed, but includes some more recent information as observers keep producing exciting images. Many thanks to all the observers, and to the JUPOS team (Gianluigi Adamoli, Michel Jacquesson, Marco Vedovato, Hans-Jörg Mettig) for providing the positional measurements and charts. Labelled versions of some charts are in the attached ZIP file.

This year I am producing image compilations and maps with north up (unless otherwise stated), to accord with NASA practice during the Juno mission, so longitude increases to the left. In contrast, the JUPOS charts are compatible with maps with south up, so longitude increases to the right. Vedovato's regular maps are produced in both orientations, and some maps with south up are attached herewith as supplementary figures.

The **Table** below gives positions and drift rates for major features. As usual, drift rates are quoted in Systems I or II per 30 days (DL1 or DL2, deg/mth). For the convenience of people who use L3, longitudes are quoted for 2016 Jan.15, as L2 = L3 on that date. DL3 = DL2 + 8.0 deg/mth.

## N3 to N5 domains

The JUPOS charts (not shown) track 1 or 2 white ovals in each of these domains, as follows (latitudes inferred from similar features in the previous apparition):
N5 domain (~60ºN): DL2 = +10 deg/mth.
N4 domain (54ºN): DL2 = -25, and (51ºN) DL2 = +5.
N3 domain (45ºN): DL2 = -14 and -28.

| *Domain/ current* | *Spot* | *L2 = L3* (Jan.15) | *DL2* (deg/mth) | *Notes* |
|---|---|---|---|---|
| *N.N.Temp.:* | LRS-1 | 17 | -1.5 | (since Nov.; variable) |
| | WS-4 | 60 | -10 | (since Nov.; variable) |
| | WS-6 | 270 | -1 | (since Nov.; variable) |
| *N.Temp.:* | Dark streak | 86 | +17 | (shortly p. the NTD) |
| | F.end NTD | 257 | (+22) | (variable) |
| *N.Trop.:* | NEBn bulge | 45 | -1.4 | (f. end of expanded sector; now a barge) |
| | NRS-1 | 106 | (-10) | (oscillating, P = 2 months) |
| | Grey ADS | 249 | (+3.5) | (oscillating, P = 24 days) |
| | WSZ | 280 | -6.0 | (unusually slow) |
| | Barge (new) | 312 | -1.8 | |
| *S.Trop.:* | SEB: barge | 69 | +9.0 | |
| | GRS | 239 | +1.5 | (oscillating, P = 90 days) |
| *S.Temp.:* | Oval BA | 9 | -12.2 | |
| | STB Ghost (p.end): | 148 | -16.3 | |
| | DS5 | 313 | -16.0 | (slightly oscillating) |
| *S.Polar:* | S3-AWO-1 | 354 | (-18) | (oscillating, P ~ 1 month) |
| | S4-AWO-1 | 275 | (-17) | (oscillating) |
| | S4-AWO-2 | 20 | (-14) | (oscillating) |

**N.N. Temperate (N2) domain** *[see JUPOS chart N2]*

Three long-lived AWOs are still present in the NNTZ: LRS-1 (since 1993 or earlier), WS-4 (since 2003), and WS-6 (since 2010). In mid-Jan.[**Fig.6**], methane images showed LRS-1 is very methane-bright as usual, WS-4 moderately so, and WS-6 only faintly detectable. LRS-1 has the same dull fawn colour as its surroundings, so is only resolvable in v-hi-res images [**Fig.3**]. WS-4 is still bright white, small and rimless. WS-6 looked like WS-4 up to the end of Dec., but v-hi-res images show changes since then [**Fig.4**]. It was apparently disturbed by turbulence at the f. end of a 'folded filamentary region' (FFR) in the NNTB, first on Jan.2-5, then again on Jan.19-22 [**Fig.4**]. It remained intact and emerged with a dark rim and a slight reddish tint (Jan.29, Olivetti), though the colour rapidly faded to off-white. But it is still not strongly methane-bright (Feb.8, Akutsu and Miles).

The NNTB is present at all longitudes, though with variable width.

**N. Temperate (N1) domain** *[see JUPOS chart N1, & maps*: **Fig.5**]

This domain is much as it was in the last apparition. The main feature is the persistent N. Temperate Disturbance (NTD), which is now ~120º long and very dark. The attached JUPOS chart includes the whole chart from our 2014/15 apparition report [ref.1].

*NNTBs (N2) jet*: This jet is still active, carying white spots at most longitudes – including many within the NTD in Nov., and one which originated near the f. end of the NTD and travelled right through it in Dec-Jan.

*NTD:* The p. end of the NTD is always at a region of small-scale rifting in the NTB; this was around L2 ~ 90-120 in Nov. During Jan., the rifting became more extensive and perhaps more intense, spanning L2 ~ 100-150. The f. part of the NTD is especially dark grey, filling the NTZ; it has a sharp f. end with DL2 = +22 deg/mth.

There have been several short dark streaks of NTB(N) p. the NTD; one of them turned red then faded away in Nov-Dec. F. the NTD, the NTB is faint.

The NTB(S) is still faint and fawn-coloured at all longitudes, and I still expect a NTBs jet outbreak soon, probably in the first half of 2017 [ref.2].

**N. Tropical domain** *[see JUPOS chart N0, & maps*: **Fig.5**]

The NEB expansion event continues. The expanded sector was ~95º long in Nov. and is ~143º long now (from L2 = 45 down to L2 ~ 262, in Jan-Feb.). This indicates a mean rate of growth of 12 deg/mth, though it may be slower at present. The f. end has remained almost fixed at L2 = 50 (Nov.) --> 45 (Jan-Feb.), at a prominent northward bulge of NEBn **[Fig.3]**, which is probably the same as the largest bulge in spring, 2015 [ref.3 = Report no.1]. The p. edge has advanced almost imperceptibly past white spot Z (WSZ, which is prograding at DL2 = - 6 deg/mth) **[Fig.4]**, and is presently an oblique boundary apparently anchored to another bulge fixed 15º p. the centre of WSZ.

Outside the expanded sector, the NEBn still has irregularities, including just two stable bulges, which may have persisted since the last apparition [see JUPOS chart]. There are also two anticyclonic dark spots (ADSs) in this sector. One is called the NEBn red spot (NRS-1), as it was strongly reddish when first seen last Oct., but is now just a small grey-brown ring, oscillating in longitude with a period of 2 months. The other ADS arose around Nov.22, apparently emitted Np. from an adjacent bulge [see images in ref.4 =Report no.2]; it became a small, very dark grey spot, oscillating with a period of 24 days.

New circulations are already forming within the expanded sector. The f. end has rounded up into a new red-brown anticyclonic oval, here named NRS-2 **[Fig.3].** The long-lived bulge just f. it now contains a distinct brown barge, since late Dec. A barge has also formed 29º f. WSZ, at least as early as Nov; and now in Feb., another barge seems to be forming just 12º f. WSZ. So the formation of barges has already begun, and will no doubt continue as the expansion becomes complete.

All these features are typical of NEB expansion events – including bulges which may contain cyclonic vestiges or precursors of barges, and ADSs which may be oscillating and grey or red-brown. They were documented in our reports for 2000/01 [refs.5&6]. They probably appear due to undulations of the NEBn retrograde jet, which generate cyclonic and anticyclonic circulations on each side: ADSs early in the expansion event, and AWOs and barges later.

*Methane-dark waves:*

Methane-band images show a notable, widespread pattern of methane-dark waves on the NEB, which was seen first and most clearly in professional images at 2.16 microns taken by Dr Glenn Orton & colleagues, but is also visible in amateur images at 0.89 microns [ref.4]. **Figs.6-8** show it in 2016 Jan. & Feb. Such a pattern was conspicuous during the NEB expansion event in 2000 [refs.5&6], but since then has only been observed once, in a restricted sector in 2009.

However, it may have been under-observed in recent years, because of the prevalent use of rather broad (18 nm width) filters at 0.89 microns [ref.7]. In 2000, the pattern was mainly recorded by T. Akutsu with a 6-nm filter, and this year, it is best recorded by P. Miles using a 8-nm filter (by Baader; on a new 20-inch telescope, which overcomes the difficulty of low light levels in this deep absorption band) **(Figs.7 & 8)**. The pattern is only partially visible in images using 18-nm filters, though this may vary with the precise specifications of the manufacturer: the 18-nm filter by Chroma, used by Chris Go, seems to record the NEB waves better than others **(Fig.6)**.

Preliminary measurements on methane-band images in Feb. show 14 methane-dark patches, all in the sector from L2 = 218 up to 127, with a fairly regular spacing of 18º (±3º), except for two intervals of 35º. However the pattern does not look quite so regular, as some patches are stronger than others, and some have not been consistently present. The expanded sector is from L2 ~ 262 up to 45, so the waves cover it and extend p. and f. beyond it. Near the f. end of the expanded sector, they map to the p. edges of NEBn bulges, as in 2000; but elsewhere there is no consistent relationship to the visible cloud structures in the NEBn. We will wait to see whether such a relationship becomes apparent with maturation of the expansion event, and/or with longer-term tracking, both of the methane-dark patches, and of the visible NEBn bulges etc. (Both are evidently varying on a timescale of several weeks, but the coverage so far has not been sufficient to track them.)

*NEB rifts:*

Throughout Nov. to Jan. there have been several large rifted regions in the NEB, collectively affecting about half the circumference. The main rifted regions drift at ~-2.6 and -2.9 deg/day in System II, i.e. still within the 'slow rifts' range that we have found to be associated with NEB expansion events [ref.2].

**Equatorial region: NEBs** *[see JUPOS chart_NEBs, & maps:* **Fig.9**]

There are still many large NEBs dark formations, as usual. They are quite variable in appearance, often being disturbed by mid-NEB rifts. On the attached JUPOS chart, the tracks are indistinct because of the irregular and variable shapes, but inspection of aligned maps [**Fig.9**] confirms the persistence of major features whose tracks are estimated on that chart. About six of the dark formations are long and slow-moving, with DL1 ranging from ~ +9 deg/mth (the most distinct one) to +18 deg/mth. This is similar to the range in 2014/15 (+7 to +20 deg/mth) [ref.1]. The sector from L1 ~ 290-100, which had only slim, fast-moving formations from 2015 April onwards, was largely the same until 2015 Nov-Dec., when slow-moving formations developed in its p. half, while in its f. half (from L1 45-105) a series of minor formations developed spaced 18º apart, with an intermediate drift, DL1 ~ -6 deg/mth. This arrangement suggests that two overlapping wave patterns with different spacings and speeds are controlling the NEBs dark formations, as has been observed in some previous apparitions, especially 2007 [ref.8].

**S. Tropical domain**

The GRS is at L2 = 239, with DL2 = +1.5 deg/mth (since 2015 March), and the 90-day oscillations are still obvious. It is still notably small and strongly red. As measured by M. Jacquesson on 11 of the best images from Nov. to Feb, the mean length has been 13.7º (±0.5º, SD). It was 14.2º long in Nov., unchanged since early 2015, but it shrank to only 13.0º in Jan., for unknown reason – and has recovered to ~14º in Feb. The width was 9.7º (±0.23)º throughout.

Anthony Wesley and Phil Miles have just produced animations of the GRS rotation, from near-infrared frames taken over 1h 46m on Feb. 22 and map-projected. The internal circulation of the GRS is clearly visible, as is relative motion of the major jet streams. Links:

http://www.acquerra.com.au/astro/gallery/jupiter/20160222-160900/anim.gif [AW]
http://imgur.com/eHShgO9 [PM].

On the SEBs, five white spots or rings (vortices) have been tracked with DL2 = +129 (±6) deg/mth, i.e. full jet speed, until they entered the Red Spot Hollow (RSH). One entered the RSH on Jan.1 [**Fig.4**] and was last seen, torn apart on the N edge of the GRS, on Jan.4. Two more arrived near the end of Jan. Another entered at the RSH on Feb.8 [**Fig.10**]. It seems to have formed a complicated fold at the f. end on Feb.11; part of this rolled up as a dark grey spot which lingered from Feb.12-17; then on Feb.18-20, it was dragged around the S side of the GRS to the p. end (as noticed by M. Valimberti). (Similar ambivalent behaviour of spots reaching f. end of the GRS was seen in 2015 Feb.

[ref.1] and in the Voyager 1 movie.) After this one, the JUPOS chart does not show any other spots with such high speed coming along behind.

The rifted region in the SEB f. the GRS is now of normal extent and activity. The short-lived bright spots within it are often methane-bright **[Figs.6-8]**.

Elsewhere in the SEB, two small barges – which were the last two remaining, from several recorded last apparition – merged at L2 = 54 on Nov.28-29, as shown in [**Fig.11**]. The merger proceeded exactly as we have observed for several such mergers in the NEB [refs.9,10]. The two barges slid together at slightly different latitudes in accord with the speed gradient across the belt, merged smoothly, but then appeared to overshoot, almost pulling apart again (Dec.7), before pulling back and undergoing at least one cycle of oscillation in length. Eventually the merged, larger barge did stabilise and it is still conspicuous, with increasing L2.

**S. Temperate (S1) domain** *[see JUPOS chart S1]*

This domain is blank except for the 3 structured segments, which are showing interesting changes, as follows.

*Segment D:* The dark streak on the f. edge of Oval BA has now shrunk to become a very small spot [**Fig.3**], and accordingly [ref.11], Oval BA shows every sign that the turbulent activity f. it has finally declined. It has no dark rim, the STB(N) p. it is quite faint, and there are only a few dark spots Sf. it; and, most distinctively, it has decelerated. I had expected all this to happen last spring or summer [ref.2], but as the dark streak's turbulent activity persisted, the quiescence was delayed, and oval BA showed only partial and variable deceleration to a mean of DL2 = -12.7 deg/month since 2015 June. But now it is fairly slow, DL2 = -12.2 deg/month since 2015 Nov. However the dark spot is still disturbed so these changes may not be quite final yet.

*Segment E (the STB Ghost):* This is still a pale blue loop, but methane-dark - just like the former Segment C (STB Remnant) [ref.11]. It still intercepts S2 jet spots: one came up to it in Jan., without change until it had just come alongside the Ghost, then it halted and faded away.

*Segment F (dark spot DS5):* This has been a small, extremely dark spot within an oblique cyclonic blue loop. As previously suggested, it is developing exactly like the STB Remnant in 2004 and STB Ghost in 2012 [ref.11]. It was still a very dark spot up to mid-Dec., 2015, but then became less intense and red-brown, which of course indicated that it was about to fade away. Indeed it is now fading rapidly in early Feb. **[Fig.12]**. The blue loop around it still exists, and is methane-dark (though not yet as dark as the STB Ghost: compare Figs.6-8 & Fig.12); so this loop appears likely to persist as a duplicate of the STB Ghost. If it does, what shall we call it? – how about 'STB Spectre'?

Interesting motions have developed f. DS5, between the two locations where we have previously observed rapidly-moving spots to arise or recirculate anticyclonically in the STZ [ref.11]: (i) from prograde SSTBn jet to retrograde STBs, at DS5 as at the STB Ghost; (ii) from retrograde STBs jet to prograde SSTBn, tens of degrees p. oval BA. As shown in **Fig.12**, in Jan., two small dark spots arose Sf. DS5 and retrograded (DL2 = +24, lat.33.2ºS); around Jan.23 they halted, 20-30º p. BA, then began prograding in STZ (one reaching DL2 = -24.5, lat.34.3ºS). Meanwhile a third spot emerged Sf. DS5 and retrograded like the first. They all paralleled the ZWP [Fig.12-inset] though 0.5º south of the Cassini profile – perhaps suggesting an altered ZWP in this region. The origin of the spots was unclear but they could have been induced by a new large turbulent sector (FFR) in the SSTB which developed alongside this sector in Jan., with disturbance moving north from there alongside DS5 to the STBn jet.

(Similar recirculation was observed here in spring, 2015 [ref.11]. However the HST maps of 2015 Jan.19 showed the SSTBn jet flowing continuously past these locations and the STB Ghost, suggesting that only distinct spots are intercepted, not the general flow of the jet – as with the S. Tropical Disturbance observed by Voyager.)

These patterns of movement may remain sparse as the relevant locations gradually separate; or they could, conceivably, develop into a proper anticyclonic circulation.

**S.S. Temperate (S2) domain** *[see JUPOS chart S2]*

There are now 9 long-lived AWOs here, which continue to follow the general rules described in our long-term report [ref.12]: "There have always been between 6 and 9 long-lived AWOs in this domain from 1986 to 2013,..... In contrast, transient AWOs also appear (...the recent frequency has been about one every two years), but do not last more than 1-2 years." Of the 11 AWOs that were present in 2014/15 [ref.1], A7a and A7b were new and small and have now disappeared again. However, another tiny one has appeared in the long gap. The 9 long-lived ones (numbered A0 to A8 for historical reasons) have continued to converge and now occupy only 210º of longitude. But their minimum separations are 15º so they are likely to remain stable. Last apparition, a cyclonic white oblong appeared between AWOs A4 and A5, and this has lengthened as usual, now being an impressive 33º long.

**S3 and S4 domains** *[see JUPOS chart S3&S4]*

There is one very long-lived AWO in the S3 domain, and one (which is actually reddish) in the S4 domain, as well as another AWO in the S4 domain that arose more recently. All three ovals are presently prograding with mean DL2 between -14 and -18 deg/mth, but with high-amplitude oscillations so DL2 ranges from ~0 to -30 (or -40 for the S3-AWO). The oscillations are semi-regular with periods between 1 and 2 months. Curiously, S3-AWO-1 is still quite close to S4-AWO-2, as it was last apparition; and in some previous years we have noticed AWOs in these two domains remaining close to each other, even though they does not appear to be any direction connection.

## References to our reports:


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    'Jupiter's southern high-latitude domains: long-lived features and dynamics, 2001-2012.'
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## Figures

**Fig.1**. Map of the planet on 2016 Jan.29-31, in L3, with major features labelled.
(See Fig.S-1 for version in L2 with south up.)

**Fig.2** shows aligned images in visible, IR, UV, and methane band, by Tomio Akutsu. *South is up in this set.* In the southern hemisphere, note oval BA (top & bottom panels) and the GRS (middle panel) which are dark in UV, bright in methane and IR, and red in visible light. The NEB is broadened alongside oval BA but not alongside the GRS; this applies in the methane images as well as the colour images. In the methane images, the EZ extends further north than in the other wavebands, and there is a very dark NTB(S).

**Fig.3. S**ome of the best images showing NN-LRS-1 and WS-4; the barge in the SEB; Oval BA; and the f. end of the NEB expansion event including the new NEBn Red Spot 2 and the new barge.

**Fig.4**. Some of the best images of the GRS side, with important spots labelled: NN-WS-6, which twice becomes entangled with streamers from an adjacent folded filamentary region (FFR) in the NNTB; WSZ, near the p. end of the NEBn expansion; STB-DS5; and S2 AWOs A2 to A5, with segments of the SSTB that are either turbulent (FFR) or whitened. A retrograding spot from the SEBs jet (red arrow) enters the Red Spot Hollow on Jan.1, and seems to be torn apart north of the GRS by Jan.4.

**Fig.5.** Maps of the northern hemisphere, in L3, with important features labelled.
(See Fig.S-5 for version in L2 with south up.)

**Fig.6**. Methane images by Chris Go in 2016 Jan. Some anticyclonic ovals are marked including those in the N2 domain.

**Fig.7**. Methane images by Phil Miles on New Year's Eve and in 2016 Jan. Methane-dark waves on the NEB are marked by cyan dots above.

**Fig.8**. Methane images by Phil Miles and by Chris Go in 2016 Feb. Methane-dark waves on the NEB are marked by cyan dots above.

**Fig.9.** Maps of the equatorial region, 2015 Nov. to 2016 Jan, aligned in L1.
(See Fig.S-9 for version with more frequent maps, with south up.)

**Fig.10.** A retrograding spot on the SEBs jet (red arrow) enters the Red Spot Hollow on Feb.8, and reaches the f. end, where it seems to generate a dark spot that, after 6 days hesitation, streams around the N side of the GRS (purple arrow).

**Fig.11.** Two small barges merge in the SEB.

**Fig.12.** STB spot DS5: its reddening and fading, and partial recirculation of small spots Sf. it.