Jupiter in 2014/15: Final numerical report

John Rogers (British Astronomical Association) & Gianluigi Adamoli (JUPOS team),
with data from the JUPOS team (GA, Michel Jacquesson, Marco Vedovato, Hans-Joerg Mettig, & Grischa Hahn)

(2015 Jan.26)

Summary

Jupiter was generally normal in 2014/15, with no major upheavals in any of the domains, and no exceptional colouring of any zones.
Separate reports are posted for the S. Temperate domain (which included oval BA and dark spots associated with it, the STB Ghost, and a continuing outbreak of STBn jet spots), and for the SEBs (which exhibited a distinctive wave pattern).
The GRS was still exceptionally small and red, with an internal circulation period of 3.7 (±0.1) days. Sometimes the circulation could be detected in only one hour. The post-GRS rifted region contracted to almost nothing in 2015 Feb., but then gradually recovered.
The SEBn had no major disturbances, and its speed was the normal maximum (DL1 = -109 deg/month).
The NEBs carried 7-9 typical large dark formations, with irregular spacing, drifting at DL1 ~ +9 deg/month. Some smaller features had DL1 ~ -16 deg/month.
Two substantial NEB rifts developed in 2014 Sep-Oct., near white spot Z; they had slower drift rate than most NEB rifts. They expanded over subsequent months. There were no persistent features on NEBn except white spot Z.
The N. Temperate domain included some dark streaks and a large, variable N. Temperate Disturbance (NTD). This domain continued to evolve following the upheaval in 2012, showing the elaborate types of behaviour that we documented in the previous cycle. The N2 jet was very active, and some of its spots were intercepted by an oval at the f. end of the NTD.
Anticyclonic ovals (white or reddish) were tracked in all domains from S4 to S0 and from N0 to N5. As usual, those in high-latitude domains (S4, S3, N2, N4) (all of which included long-lived ovals) were subject to oscillations and sudden changes in drift rates. Retrograding dark spots were also detected in these four domains.
Zonal drift profiles (ZDPs) were well defined, although curiously, the ZDP from the NTropZ to the N3 domain appeared to be 0.4 to 0.8° further south than usual. Prograde jet speeds were defined for the S2, S1, N2, and equatorial jets. The speed tables will be useful for predicting drifts of features during the Juno mission in 2016-2017.

Introduction

Opposition was on 2015 Feb.6, at declination 16ºN, on the Cancer/Leo border.

As usual, very many high-quality images were received from observers around the world, almost all taken using webcam selective stacking technology [Refs.23&24]. Two innovations led to even better images than in previous years. First, the derotation app in WinJUPOS enabled images to be constructed from longer video sequences than previously. Second, the ASI120MM and related cameras produced by ZWO (Suzhou, China), giving high sensitivity and resolution, were acquired by many observers.

The list of observers is posted herewith as Report no.11: http://www.britastro.org/jupiter/2014_15report11.htm.

The first images were taken in late August, 2014, by Isao Miyazaki, and there was widespread good coverage from late September, 2014, until mid-June, 2015. Miyazaki and Michel Jacquesson continued imaging until mid-July, and Anthony Wesley continued taking hi-res infrared images before sunset up to the end of July.

There was exceptionally good coverage from 2015 Feb.25 to March 11, when Damian Peach made a special trip to Barbados to take images under the best conditions, and Christopher Go, Tiziano Olivetti, Kevin Quin and others did some of their best work so as to provide near-continuous v-hi-res coverage – which was only limited by bad weather across much of Europe and the USA.

Phenomena of the galilean moons were of great interest, especially mutual eclipses and occultations which were recorded at high resolution by some observers. These have been covered separately [Reports nos.1,4,6].

The JUPOS team measured the images using WinJUPOS as usual, making 64059 measurements during the apparition. From these, they produced standard charts of longitude vs. time for spots in all latitude ranges. An annotated set of JUPOS charts is included with this report. Unless otherwise indicated, black points are dark spots, green points are bright spots, and red points are red spots.

Throughout this report, drift rates are given in degrees per 30 days in longitude system 1 (DL1) or 2 (DL2) (deg/mth). P. = preceding = planetary east (left in images); F. = following = west (right). South is up in all images.

An interim report was posted [Ref.1, hereafter referred to as Report no.3], covering the first half of the apparition, and the material will not be repeated here. It included a hi-res map made on 2015 Jan.19-20. Serendipitously, the Hubble Space Telescope also made a pair of maps on two successive rotations on Jan.19, which can be 'blinked' to reveal fantastic detail in the planet's atmospheric currents [Ref.3]. We have now posted a set of hi-res amateur maps from 2015 Feb.27 to Mar.7, which can likewise be 'blinked' to show these wind motions [Ref.2 = Report no.9]. Zonal wind profiles (ZWPs) were also published with both the HST maps and the amateur maps.

Dr Leigh Fletcher has posted a nice general account of the 2014/15 apparition at:
http://planetaryweather.blogspot.co.uk/2015/09/jupiter-weather-report-201415-apparition.html

General appearance

The overall appearance of the planet remained normal, as described in Report no.3. **Fig.1** is a v-hi-res map of the planet in 2015 March, with major features labelled. **Figs.2-4** show sets of methane-band images, highlighting the major anticyclonic ovals (all methane-bright except for white spot Z) and the STB Ghost (methane-dark).

Southern hemisphere

South Polar and Temperate Regions

South Polar region:

An unusual amount of detail was recorded at high southern latitudes in v-hi-res images from Jan. to March (e.g. **Fig.5**).

This was partly due to the improved images in recent years, and partly due to the tilt of the planet, which now has the S pole tilted towards us for the first time since 2008. We wondered whether there had been a real clearing of the usual South Polar Hood (SPH), a bluish-white haze which usually overlies the SPR down to latitude ~67ºS, on the poleward side of a diffuse dark belt. In the best maps in early 2015, this haze is barely visible and there sometimes appear to be concentric belts even closer to the pole. However, I suspect there has been no real change. Sharp near-polar belts are not visible on maps from all v-hi-res observers' images, nor are they reproducibly at the same latitudes; they could be artefacts produced during image and map processing. HST images and map in 2015 Jan [Ref.3] show no obvious difference in the SPH from HST images in 2008, 2009 or 2014, or from the Cassini map in 2000.

Nevertheless, this year's images have recorded real features in this region. The 'South Polar Belt' at ~63-67ºS is evident in many v-hi-res maps, with the edge of the whitish SPH at ~67ºS, then irregular whitish areas up to ~72-74ºS. On the maps in early March (Fig.5), a circular white spot was confirmed at ~72ºS.

S4 & S3 domains [JUPOS chart S3&S4]:

There were AWOs in each domain as usual, as described in Report no.3. In the S4 domain at ~60ºS, AWO-1 was almost certainly the long-lived one, as it was clearly reddish and methane-bright (Figs.3 & 5), whereas AWO-2 was white. A third, smaller AWO with rapid drift (DL2 = -28 deg/mth) approached AWO-2 in March, but was last imaged on March 24 when not yet in contact, and was not visible a week later.

The single prominent AWO in the S3 domain at ~50ºS (labelled S3-AWO-1) continued to show striking oscillations though with variable period. From Feb. to April it was crossing the sector of retrograding dark streaks at 49ºS (see below), and this may have caused the short-period oscillations (P = 1.0 to 1.7 months) in those months.

The retrograding dark streaks at ~49ºS mostly had DL2 ~ +11 deg/mth, and occurred from L2 ~ 50 to 260. Maps (Jan. to March) showed them as strings of short dark streaks in a whitish zone, possibly retrograding from dark grey belt segments slightly further north near L2 ~ 40-55 and 175-195, with micro-turbulence visible on their N sides in the highest-resolution maps. These were prograding segments of S^3TB at 46.4ºS, tracked with DL2 ~ -16 deg/mth [see JUPOS chart S3&S4: brown shading]. This arrangement supports our previous hypothesis that such retrograding dark streaks emerge from turbulent cyclonic sectors in the S3 domain as they do in the S1 (S. Temperate) domain [Ref.4]. Indeed the HST maps of Jan.19 [Ref.3] demonstrate this origin clearly. (And, whereas most of these dark streaks were at 49ºS, the JUPOS chart showed a few short parallel tracks up to 57ºS, implying associated dark spots in the S4 domain.)

The fast-moving dark spot mentioned in Report no.3 showed almost continuous acceleration, from DL2 = -26 (Sep-Oct, at 46ºS) to -42 in Dec-Jan. Having turned red in Dec-Jan., it disappeared in Jan. as expected.

S2 domain [JUPOS chart S2]:

There were 11 AWOs in the S.S. Temperate domain, including two new ones named A7a and A7b. They had been gathering closer in longitude, now forming a single array spanning 230º long. Their mean DL2 ranged from -25 (A6 at the p. end of the array) to -30 (A4 and A5, at the f. end). However, in 2015 March, A5 decelerated to DL2 = -26.6, due to expansion of the cyclonic white oblong p. it (see below).

Also, the cyclonic white ovals (derived from red ovals in the last apparition) persisted between AWOs A7a and A8, and between A0 and A1. The cyclonic ovals sometimes bounced to and fro between the flanking AWOs.

Another cyclonic white oblong present in 2013/14, between A3 and A4, had broken up in late May, 2014, just before solar conjunction. Then a new cyclonic white oblong developed between A4 and A5 during solar conjunction, between 2014 May and Aug.; it was very bright in late Aug. when the apparition began. In 2015 March it started to expand, as such oblongs normally do.

S2 jet:

Only a few spots were tracked, for only a few weeks each. Some disappeared at the STB Ghost, and others in the tail of the STB dark segment.

S1 domain and S1 jet [JUPOS chart S1]:

This report has already been posted as Appendix 2 of our long-term synthesis, 'Jupiter's South Temperate Domain, 2012-2015' [Ref.5].

South Tropical domain

STropZ and SEBs jet:

Following the GRS the SEBs was chaotic with large dark patches, gradually resolving into spots towards higher longitudes. In the remaining sector, comprising ~180° p. the GRS, distinct spots, rings, and waves were observed. Hi-res images revealed a wealth of small-scale detail, and JUPOS measurements revealed a wide range of speeds. Most features had speeds close to the ZWP, although their appearance varied between different sectors. They included rings (vortices) with full jet speed, up to DL2 = +121 deg/month, i.e. typical jetstream spots. However there were also wave-like features at the same latitude as the jet peak with much slower retrograding speed, similar to what we observed in 2011, but more extensive. (These are described in our separate report [Ref.6, *posted herewith*], and in a professional paper [Ref.7].)

GRS:

The GRS was at L2 = 223 on Feb.6, and had DL2 = +1.2 deg/mth throughout the apparition, with the usual 90-day oscillation superimposed. It was still a well-defined, strongly orange oval, although involved with dark streaks around it: the S. Tropical Band (see above) which detached from its p. end in Jan-Feb., and a connection to the SEBs at its f. end.

Its length, width, and internal circulation have all diminished over the last few years [Refs.8,9a,9b; & our 2014/15 reports no.2, 3 & 7], and Michel Jacquesson continues to make precise measurements of them. The length had recovered slightly to a mean of 13.9° (±0.8°) in 2014/15, with no significant change from 2014 Sep. to 2015 May. The width was only 8.5° (±0.15°; n=5) in 2014 Nov-Dec., narrowed from both the N and S edges, but it then recovered and remained at 9.3° (±0.3°; n=46) in 2015 Jan-May.

The internal circulation period is measured by tracking the position angle of small grey streaks within the GRS, from one jovian rotation to the next, and sometimes over several days. Jacquesson's recent measurements give the following results (continued from Report no.3). The mean is exactly the same as over the previous 13 months.

GRS rotation period, 2014-15

2015	P (days)	+/-	Notes
Feb.4-6	3,57	0,07	(1 spot over 3 days)
Feb.11-21	3,83	0,29	(1 spot over 11 days)
Feb.6-Mar.5	3,67	0,06	Mean of 10-hour measures on 6 dates
Feb.28-Apr.13	3,75	0.08	Mean of 10-hour measures on 5 dates
Mean:	3,71	0,11	

The first two entries are for long-term tracking of single spots. The last two are averages of measurements from pairs of images ~10 hours apart on 5 or 6 different dates.

He also found faster rotation for two separate spots over 10-hour intervals, equivalent to P ~ 3.06 days, which requires confirmation, but is consistent with the faster speeds shown for small-scale features by HST [Ref.10].

Some recent images show even more internal detail, and if such images are taken as the GRS crosses the disk, it is now possible to detect its circulation over just one hour (although the angular displacement of ~5° is too small to allow useful measurement). This has been achieved using images on Nov.1 (by Miyazaki; see Report no.2), Feb.26 (by Peach; see Report no.7), March 5 (by Go & Olivetti; Fig.6), and March 29 (by Go; Fig.6).

The v-hi-res images sometimes show a consistent pattern (Fig.6), just as in the HST images of 2014 April 21 [Ref.10] and 2015 Jan.19 [Ref.3]. In these, the N half contains a series of small, equally-spaced dark spots; sometimes a white rift intrudes into the N half from the p. end; and the S half may contain a larger streak, along the outer edge. We suggest that the dark spots in the N half are continuously created at the p. end of the GRS; in the HST images of 2014 April 21 they appeared as chevrons 'budded off' at the p. end every 5 hours. (This process may have been caught in Miyazaki's images on Nov.1: see Report no.2.) We suspect they may not last for more than one rotation, whereas the larger dark streak(s), at slightly larger radius, are the ones that we track with over longer intervals, perhaps more distinctly visible when in the S half.

Several retrograding rings (vortices) on SEBs were tracked until they entered the Red Spot Hollow (RSH). [see figures in Ref.6]. Fig.6 shows one swept around the RSH to the f. end, where it formed a methane-bright streak; it seems likely that this was the vortex being pulled apart (as in the Voyager movies), with one part being swept into the GRS, and the other part escaping to retrograde on SEBs.

SEB [JUPOS chart SEB]:

In 2014/15, the SEB was generally normal. In 2015 Jan., the GRS was at L2 = 223, with the usual rifting f. it up to L2 ~ 270. This rifted region contracted to almost nothing during Feb.; so on any given date in late Feb. and early March there was only one tiny bright spot immediately f. the GRS, or none at all (Fig.6). During March the number and scale of these white spots gradually expanded again, and by May the rifted region had returned to its usual complexity with several white spots at once.

There was a small but very dark red mini-barge (L2 ~ 30 --> 55), at 16.9°N, with a tiny light spot on its N edge at 14.9°N. An even smaller mini-barge f. it faded away in Dec-Jan., but a tiny, more northerly light spot persisted on the same track thereafter. These examples confirm our conclusion from previous apparitions that these cyclonic circulations commonly have a light spot in their N edge which may persist even after the dark mini-barge has disappeared. Another light spot in the SEB (L2 ~ 80 --> 120; 16.3°N) may have been on the track of a mini-barge in the previous apparition.

Equatorial Region

SEBn:

The JUPOS chart shows an overall drift rate of DL1 = -109.5 (±2) deg/mth [u_3 = 158 (±1) m/s]. This is clearly indicated both by two long-lived bands of points (representing short disturbed sectors of SEBn adjacent to spot-free sectors), and by several lines of up to 4 points (which may be tracks of single spots with this speed, but do not have the minimum 5 points which we require for confidence). There are no other features. The speed corresponds to the normal maximum for the SEBn jet [Refs.11,12a,12b]. Surprisingly, it is faster than indicated by ZWPs this apparition, whether from amateur images (146 m/s; M. Vedovato) or HST images (152 m/s; Ref.3). The discrepancy could be because the ZWPs were affected by ephemeral slower spots [as previously noted; Refs.12a,12b], though no such tracks are seen in the JUPOS chart.

NEBs [JUPOS chart NEBs]:

There were 7-9 persistent large dark formations at irregular intervals around the planet, with typical but variable appearances ranging from white-cored plumes to long plateaux. On JUPOS charts, these formations do not always show up clearly because of their irregular and variable extent, but 6-8 of them can be identified on [JUPOS chart NEBs] and on maps **(Fig.7)**, with typical DL1 = +9 deg/mth overall, though ranging from ~0 to +21 over shorter intervals. An additional major formation, at L1 ~ 270 --> 330, can be tracked on maps **(Fig.7)** but not on the chart, because it was particularly long and variable. This was the only major formation in a sector ~130º long, within which there were some short prograding tracks for both white and dark spots, with DL1 ranging from -8 to -27 deg/mth, mean = -16.3 deg/mth (N = 12) (u_3 = +113 m/s). (Note that the ZWP from HST maps [Ref.3] shows a peak u_3 ~ +116 m/s for the NEBs jet, suggesting that these prograding motions applied over a wider range, as indeed can be seen by blinking the HST maps.)

In March-April, a large expanding rift passed round the NEB, disrupting some of the large dark formations, and the sector with fast-prograding spots shifted to higher longitudes. Some well-tracked dark projections with DL1 ~ 0 developed near the boundaries between the two sectors.

Northern hemisphere

N. Tropical domain

NEB rifts [JUPOS chart NEB-rifts]:

Two substantial NEB rifts developed early in the apparition and expanded. On the JUPOS chart, they are evident as bands of points representing white spots or streaks which appeared within the rifts, often moving faster. The initial drift of each rift was unusually slow, but over several months, each rift expanded and accelerated up to normal speeds, thus:

	DL2 (deg/day, ±0.1)
Rift A	-2.1 (Oct-Nov), -3.7 (Nov-Dec)
Rift B	-1.8 (Oct-Dec), -2.2 (Jan-Mar), ~-3.5 (Apr-May).

Rift A was already present on the first map made in 2014 Sep., just p. white spot Z (WSZ). Rift B developed in Oct., also just p. WSZ, apparently emerging from a turbulent region adjacent to the oval **(Fig.8A)**. The maps **(Figs.7 & 8B)** nicely show the intricate turbulence of the rifts as they expanded over subsequent months.

The initial slow speeds of these rifts are typical of the start of a NEB expansion event [Ref.13], and thus led to a prediction that they would initiate such an event [Ref.14].

NEBn [JUPOS chart N0]:

In this apparition there were none of the classical barges and AWOs, except for WSZ. The NEBn edge, at ~17ºN, was irregular with many bays and projections which lasted for only weeks or, at most, up to 3 months. The white bays all had DL2 = +5 to +16 deg/mth, except for two more strongly retrograding in the NEBn jet [JUPOS chart N0]. The more consistently retrograding bays or projections, with DL2 = +6 to +9 deg/mth, sometimes occurred in pairs or triplets with a separation of 10-19º; others with near-zero drift were not regularly spaced but tended to have larger separations. However, we did not find any evidence that these features were organised as wave-trains with regular characteristics.

The white bays were measured at 16.1—17.4ºN. The dark projections, further north, showed a continuous range of drifts from DL2 = -9 (the same as WSZ) to +34 (peak of NEBn jet), and lay on a rough anticyclonic gradient (Fig.11), which was ~1º south of the Cassini ZWP.

The ZDP for the whole northern hemisphere is shown in Fig.11. Strangely, almost the whole pattern from the the NTropZ to the N3 domain appears to be shifted ~0.4º to 0.8º south of the Cassini ZWP! In the NTropZ, this discrepancy could be because the measured latitudes of bays and projections did not represent the dynamical centres of the features; and in the retrograding mid-regions of each domain, it could be partly because of the usual blunting of the profile. However, in this apparition the discrepancy appears to be more general, including the N2 jet. This apparent shift is unexplained. It seems implausible that the jet pattern could really change on such a large scale, but we have not found such a discrepancy in previous years.

We were aware that a NEB expansion event could begin in 2015, and during the first half of the year, there were signs of increased emission of dark material northwards from the NEB, which Christopher Go and Christophe Pellier both suggested might be the early stages of the expansion event, but it did not develop decisively.

--One example occurred at the New Year, just after Rift B had passed, when a projection extended northwards and extruded dark material around a bay, which formed a small, very dark grey-brown spot at 19ºN, i.e. an anticyclonic dark spot (labelled ADS on the JUPOS chart) [L2 = 280 --> 290; see maps in Report no.3 (Fig.11), & in Fig.8]. However this did not survive past April.

--Another example (pointed out by Go) is in Fig.9: in 2015 March, just after Rift B had passed, a shallow bay at L2 = 115 deepened and a prominent projection developed on its f. side, extruding dark material around the bay – but with no lasting effect.

--Most notably, the sector f. WSZ showed some transient broadening in 2014 Oct-Nov. (when Rift B developed p. WSZ), and it remained disturbed thereafter, sometimes with undulations, especially after Rift B (then much larger) passed it in late March (Fig.8). (This sector would then broaden fully during solar conjunction.)

For WSZ, the latitude and drift were still near their usual values. Its drift appeared rather smooth overall, but with small irregular oscillations with an amplitude of several degrees. Throughout the apparition the spot itself was a white oval, but surrounded by pale fawn-coloured shading.

N1 domain (North Temperate region) including North Temperate Disturbance (NTD)
[JUPOS chart N1&N2-jet]

The N. Temperate domain, and especially the NTD, has continued the elaborate types of behaviour that it showed in 2014 and in the previous cycle from 2009-2012, which we have described fully [Ref.15]. The typical processes described in that report are confirmed in the present apparition. A detailed description up to 2015 Jan., with maps, was given in Report no.3, from which this report follows on.

General appearance (Figs.12 & 13):

(1) The NTB(S) has been a very pale, fawn, featureless band throughout the apparition, continuing to fade, thus extremely faint in 2015.

(2) There have been long dark grey or brown streaks representing segments of NTB(N), at 29-30ºN, spanning a sector of ~170º longitude, which coincided with the NTD in 2014 Sep. and partially so later. All were dark grey in autumn 2014, but all faded or disappeared in early 2015. Of these, the darkest but shortest (designated d0) and a long pair of streaks (d7-d8) turned reddish-brown in Jan-Feb. then faded away in March (d7) and April (d8, d0) –

typical examples of cyclonic dark streaks turning red just before they disappear. The remaining dark grey streak (d9) was suddenly disrupted in late March and April by the expansion of turbulent rifting there (see below). A pair of dark spots at 28ºN originated at the same time and place, prograding with DL2 = -54 deg/mth within the NTB.

(3) The other ~180º longitude had almost no visible NTB, but a prominent southerly 'NNTB' was formed from dark spots on the NNTBs jet (N2 jet; see below).

Drifts:

There were a few dark spots in the NTB with rapid prograding drifts typical of the *North Temperate Current B (NTC-B)*, p. the mini-rifted region, the best-observed pair being mentioned above (DL2 = -54).

Otherwise, all features moved with the usual *North Temperate Current A (NTC-A)* (except d1 which began with slightly prograding drift at 28.6ºN, then moved north and emerged into the NTC-A at 29.6ºN).

The North Temperate Disturbance (NTD):

In Report no.3 we described how the NTD (dark grey NTZ) was ~150º long in 2014 Sep., extending f. to a maximum length of ~240º in Nov; then the p. and f. sectors partially cleared, as there was no longer a mini-rifted region near the previous p. end. A mini-rifted region 80-100º f. the previous one marked the position of the new p. end of the NTD in Jan. This mini-rifted region lay between streaks d9 and d7, at L2 = 300-325 at the end of Feb., and the NTD spanned L2 325-57 (92º long).

This mini-rifted region was apparently re-invigorated and expanded in late March [Fig.12], becoming larger and destroying streak d9. It continued to define the NTD p. end up to June. The NTD f. end was established in Jan. just f. spot w3 (at that time a Little Red Spot: LRS), as a distinct dark 'step' curving around the LRS; then in Feb.-April it was up to 26º f. w3, for a total length of ~67º.

These observations amply confirmed our first condition for a NTD [Ref.15]: a region of mini-rifts in the NTB, which gives rise to disturbance f. it. Our second proposed condition – recirculation of spots from the retrograding NTBn into the NTZ – was not evident as such in 2015, but smaller-scale eddying was not precluded, and three distinct vortices had appeared within the NTD.

These were three slow-moving anticyclonic rings, two being very small (Fig.13), but the third – close to the f. end – being w3 (LRS in Jan.). This LRS had formed by intercepting prograding N2 jet spots [Report no.3], and it continued to do so as described below (Fig.14). The weak reddish colour that developed in Jan. faded again in Feb. and was not evident from March onwards; w3 was then a white oval with dark rim. It was still methane-bright in March (Figs.3 & 4). Further f., w2 was a similar anticyclonic ring which was also methane-bright but more weakly (Figs.3 & 4).

N2 jet (NNTBs jetstream):

Activity on the N2 jet was at a high level. Up to late Jan. [Report no.3], the JUPOS chart showed only sparse activity on the N2 jet, mainly white spots. However the maps showed an arrangement much the same as in subsequent months, including typical rings on the NNTBs (N2 jet) (Figs.1 & 12-14), so the lack of tracks on the JUPOS chart before Jan. was probably attributable to the crowding of spots and the paucity of hi-res images. Many tracks of N2 jet spots appeared in late Jan. and Feb., arising near L2 ~140 and ~200.

It seems likely that the spots arose from disturbance which was prograding on the N2 jet from the giant FFR in the NNTB (see below), whose p. end was at L2 ~ 270-280, although spots did not become distinct enough to be tracked until they were at much lower longitudes. From L2 ~ 110-240, a long, very dark, southerly 'NNTB' consisted almost entirely of N2 jet spots; many of them were rings (so presumably anticyclonic vortices, as is typical), others were tiny white ovals embedded in a more extensive dark band [see maps (Figs.1 & 12), & animations [Ref.2]]. In Jan-Feb., this band thinned out p. L2 ~140 so that N2 jet spots were more easily seen on it as distinct dark rings, which is presumably why some tracks started at that longitude.

According to the JUPOS chart, almost all the N2 jet spots disappeared near the f. end of the NTD or oval w3 (which had turned into the LRS on absorbing some of these spots in Dec: Report no.3). Actually, of the volley of N2 jet spots numbered 1-7 on Fig.13, no.1 was indeed destroyed as it interacted with w3 (Fig.14), but nos. 2 and 3 survived passing w3 into the NTD, though possibly less distinct. These spots had lower contrast once they were within the NTD, and were finally destroyed upon reaching the NNTB's giant FFR.

The dark spots on the N2 jet (except for three outliers described below) had a mean speed of DL2 = -80.9 (±5.1) deg/mth, which is typical, at 34.6 (±0.4) °N latitude. The white spots on the jet were mostly slightly slower and further south, which may be because they tended to be larger (and thus had visible white cores). They lay on an anticyclonic gradient, consistent with being anticyclonic vortices, as usual.

Three anomalous dark spots, in a limited sector in April-May, had fast speeds (-88 to -95 deg/mth) and lay far north at 36.1°N. We found a few similar spots in 2005 and 2006 [Ref. 16], and many in 2011/12 [Ref.17]. Taken together, these results suggest that the true peak of the N2 jet, at least in some sectors and epochs, is around DL2 ~ -104 (±5) deg/mth at latitude 35.6 (±0.2) °N. Peak locations from spacecraft other than Cassini are spread around this position [Ref. 18].

N2 domain *[JUPOS chart N2-merged]*

NNTB:

Visually there appeared to be a dark NNTB at most longitudes, except where it was subsumed into the NTD, but hi-res maps showed that this was not a complete belt. A sector ~90° long, overlapping the p. half of the NTD, was pale, and v-hi-res maps revealed it as an unusually long and broad turbulent sector of NNTB (folded filamentary region, FFR: Figs.12, 13, 15). From Dec. to May, its p. end was fixed at L2 ~ 270-280, and its f. end at L2 ~ 0-20.

P. and f. the giant FFR were segments of true dark NNTB. On the f. side, near the f. end of the NTD, there were two very dark grey-brown streaks of NNTB(N). P. the giant FFR, the NNTB thinned out towards lower longitudes, until from L2 ~ 110-220, it was a very dark, southerly band consisting almost entirely of N2 jet spots.

NNTZ:

There were four major and two minor AWOs in this domain (Fig.15), including the very long-lived LRS-1. The nature and history of these ovals have been described [Refs.19 & 20]. LRS-1 was colourless and very pale this apparition, eventually becoming white within its fawn-coloured surroundings (Figs.13-15). LRS-1 was still prominent in methane images (Figs.3 & 4).

Of the other (white) ovals, only one was consistently methane-bright, both in 2013/14 and in 2014/15 (though not as methane-bright as LRS-1); so we identify this as the long-lived WS-4, which has existed since 2003. WS-4 maintained fairly steady prograde drift throughout both apparitions.

Two other AWOs persisted throughout the 2014/15 apparition: one was WS-6 (tracked since 2010), and the other was a new one, denoted WS-a. Both of them were generally invisible in methane images, or only faintly or occasionally visible in a few images. Both of them showed marked oscillations in drift rate with a period of ~1.5 months. For WS-a, at least one of its decelerations was apparently induced by the impact of a retrograding dark spot; a similar event was observed for WS-4 in 2013/14 [see JUPOS chart], and three such events were observed in 2004-2006 [Ref.16]. This phenomenon is thus confirmed as typical for this domain.

Finally two shorter-lived small AWOs had retrograding speeds, DL2 = +13 deg/mth. Both disappeared in December, WS-b as it approached WS-4, and WS-c as it entered the sector in which the giant FFR was subsequently recognised (see above).

We previously found that these NNTZ ovals fell on different ZDP lines according to their colour and methane-brightness, which were functions of their size [Refs.19&20]. This correlation has held up in most subsequent apparitions, but in 2014/15, ovals in all four classes (LRS-1, WS-4, WS-6 and WS-a) all followed the same ZDP line, previously typical of LRS-1; i.e. the white ovals were at lower latitude than usual for their speed (Fig.11). (In Fig.15, LRS-1 is centred further south than the others, but this was probably because it was travelling more slowly at the time.) Fig.15 shows that the ovals still differed in size in the usual order: LRS-1 > (WS-4, WS-6) > WS-a. In the absence of any other explanation, we wonder whether the ZWP may be altered in some sectors. We also note that the ZDP (Fig.11) for most spots from the NEBn to the N3 domain, not just these NNTZ AWOs, is more southerly than usual by ~0.4 to 0.8 deg.

North Polar Region (N3, N4, N5 domains)

North of the NNTZ, the NPR showed no conspicuous features except for a very dark brown bar at L2 ~60 in the N4 domain (d1), but there were many white ovals (all likely to be anticyclonic [AWOs]), and innumerable small dark spots and mottlings. This region has no well-defined belts, and is packed with chaotic structures. All this is typical, and is shown in several v-hi-res image sets (Figs.15-17) and polar projection maps (Fig.18).
Similar polar projection maps were published in our final reports for 2007, 2010, and 2011/12 (Fig.35 therein). The Cassini polar map movie [Ref.21] dramatically showed the chaotic motions in this domain, within which the standard jets and currents emerge as average motions. [Because the NPR is no longer tilted towards us, the maps do not consistently show the v-hi-lat patches that were recorded in 2011/12. Hints of belt structure at >70ºN are probably artefacts of processing, as discussed for the SPR.]

The drifts were also typical, being segregated by latitude into the canonical N^{3}TC [mean DL2 = -18.1 (±4.4) deg/mth, at 45ºN] and N^{4}TC [mean DL2 = +5.4 (±3.6) deg/mth, at 50-51ºN], with faster-moving AWOs further north at ~54ºN and ~62.5ºN.

N3 domain:

There were many small rings (AWOs) moving with the N^{3}TC. They are visible in various figures, including Figs.17 & 18.

N4 domain [JUPOS chart N4]:

This domain was well populated, though not so crowded as in other apparitions. There have been obvious differences in spot population between apparitions. In 2011/12, white and dark spots were uniformly distributed along the domain. In 2006, features were mostly white spots, in the cyclonic domain. In 2014-15, dark spots were in the cyclonic domain, white ones in the anticyclonic latitudes.

As in the past, spots adhered closely to the Cassini ZWP; the ZDP (Fig.11) showed much less southward shift than for the NNTC and N^{3}TC. Many short-lived features had slow drifts typical of the N^{4}TC. The most conspicuous feature was a very dark bar at L2 = 60, 51ºN (Jan.-March). The only long-lived spot in the N^{4}TC was w7 at 51ºN (see below).

There were also three long-lived AWOs further north at 53-54ºN, with much faster, more variable drifts. They were bright white with dark rims. The first two were tracked throughout the apparition, and possibly since 2013. The changes in drifts were sometimes gradual but sometimes abrupt, taking place within no more than a few days.

a) N4-AWO-a: The most conspicuous AWO at 54ºN. It oscillated irregularly between fast and slow speeds, from -4 to -39 deg/mth, as is typical for these hi-lat AWOs. It passed w7 in early February. In spite of their difference in latitude, they interacted anyway, as w7 showed a notable northward migration from 51.0 (±0.3) to 52.5 (±0.6) ºN, starting around the time of their conjunction, though without change of speed; it survived only one month thereafter. The conjunction is shown in **Fig.16**. (**Spot w7** was a tiny white oval throughout, even when in contact with AWO-a; only its latitude changed. After the conjunction, w7 was well shown in Fig.13; it looked like AWO-a and –b, though smaller, up to March 6. These latitudes imply that w7 was wafted by the passing AWO from the retrograde jet into the anticyclonic domain; the images suggest that it became a well-formed AWO, so it is not clear why it did not survive.)

b) N4-AWO-b: Tracked from Oct. to April. It is well shown in Fig.13. Like AWO-a, it oscillated continuously between fast and slower drift rates; after a fast run in Nov-Dec., it underwent 3 cycles with period 25-30 days from Jan. to March, before disappearing.

c) N4-AWO-c: Tracked during a 3-week slow-moving phase (-2.7 deg/mth, 53.3ºN), though it had much faster, variable drifts before and after. **Fig.17** shows how a tiny w.s. began as a filament of a FFR on the S edge of AWO-c, and then persisted as a tiny w.s. for a month.

We have not identified specific causes for the sudden changes in speed of these AWOs, but interactions with the seldom-resolved turbulent features of the region are possible. For instance, the sudden drift changes of AWO-c in Feb.&Mar. occurred while a large FFR lay on its southern edge **(Fig.17)**.

N5 domain:

Two AWOs were observed with rapid prograding drifts, at 62.5(±0.1)ºN. One of them was well documented, for about two months, accelerating slightly. They lay perfectly on the Cassini ZWP.

References:

1. Rogers JH (2015) 'Jupiter in 2014/15: Interim report'. [Report no.3]. http://www.britastro.org/jupiter/2014_15report03.htm

2. Rogers JH (2015) 'Jupiter in 2014/15: Animated maps from ground based images'. [Report no.9]. http://www.britastro.org/jupiter/2014_15report09.htm

3. Simon AA, Wong MH & Orton GS (2015). 'First results from the Hubble OPAL program: Jupiter in 2015.' Astrophys.J. [in press]. *& maps posted at:* http://hubblesite.org/newscenter/archive/releases/2015/37.

4. 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

5. Rogers JH (2015) 'Jupiter's South Temperate Domain, 2012-2015'. http://www.britastro.org/jupiter/2014_15report08.htm

6. Rogers J, Adamoli G (2015) Jupiter in 2014/15, report no.10 *[to be posted with this report]:* 'The SEBs in 2014/15'. http://www.britastro.org/jupiter/2014_15report10.htm

7. Rogers J, Fletcher LN, Adamoli G, Jacquesson M, Vedovato M & Orton GS (2015). Submitted to Icarus. 'A Rossby wave pattern on Jupiter's fastest retrograde jet at 20ºS.'

8. Rogers JH and Jacquesson M. (2015) *Abstract for EPSC 2015 in Nantes:* 'Circulation of Jupiter's Great Red Spot measured from amateur and Hubble images.'

9a. Rogers J (2014). Jupiter in 2013/14: Report no.7: 'The Great Red Spot in 2013/14: Faster shrinkage and evidence for faster wind speed.' http://www.britastro.org/jupiter/2013_14reports.htm [go to no.7], or: http://alpo-j.asahikawa-med.ac.jp/kk14/j140406s.htm

9b. Rogers J, Adamoli G & Jacquesson M (2015) Jupiter in 2013/14: Report no.9: 'The GRS and adjacent jets: Further analysis of amateur images, 2013/14' http://www.britastro.org/jupiter/2013_14report09.htm

10. Simon AA, Wong MH, Rogers JH, Orton GS, de Pater I, Asay-Davis X, Carlson RW & Marcus PS (2014) 'Dramatic Change In Jupiter's Great Red Spot From Spacecraft Observations' *Astrophysical Journal Letters*, 797:L31-L34 [doi:10.1088/2041-8205/797/2/L31].

11. Rogers JH & Mettig H-J. (2008), 'Influence of Jupiter's South Equatorial Disturbance on jet-stream speed'. JBAA 118 (no.6), 326-334.

12a. Simon-Miller AA, Rogers JH, Gierasch PJ, Choi D, Allison MD, Adamoli G, Mettig H-J (2012). 'Longitudinal variation and waves in Jupiter's south equatorial wind jet.' Icarus 218, 817–830. [doi:10.1016/j.icarus.2012.01.022]

12b. Adamoli G & Rogers J (2012), Jupiter in 2010/11, Report no.26: 'The SEBn in 2010: The dual motion of the chevrons in the rapid jetstream.' http://www.britastro.org/jupiter/2010report26.htm

13. Rogers J (2015 Dec.) 'Relationship of NEB rifts to NEB expansion events.' http://www.britastro.org/jupiter/relationnebrifts.htm

14. Rogers J (2015) 'A 3-year weather forecast for Jupiter: Prospects for Jupiter in 2015-2017.' http://www.britastro.org/jupiter/2014_15reports.htm [go to Report no.5].

15. Rogers J & Adamoli G (2015) 'Life cycle of the North Temperate Domain and Disturbance, 2009-2012.' http://www.britastro.org/jupiter/2011_12/NTD2009-12report.zip

16. Rogers JH & Adamoli G (2015), 'Jupiter in 2005 and 2006: Final report.' http://www.britastro.org/jupiter/2006report13.htm

17. Rogers J & Adamoli G (2015), 'Jupiter in 2011/12: Final report up to 2012 Feb.' http://www.britastro.org/jupiter/2011report09.htm

18. Rogers JH (2013), 'Reference list of Jupiter's Jets'. http://www.britastro.org/jupiter/reference/jup_jets/ref_jets.htm

19. Rogers JH, Adamoli G & Mettig H-J (2011) JBAA 121 (no.1), 19-29. 'Jupiter's high-latitude storms: A Little Red Spot tracked through a jovian year.'

20. Adamoli G & Rogers J (2013 Jan.) 'NNTZ: Anticyclonic ovals, 2008-2012', in: 'Jupiter in 2012/13: Interim report no.9' Appendix 1: http://www.britastro.org/jupiter/2012_13report09.htm

21. NASA/JPL/SWRI/CICLOPS (2001), 'Jupiter Polar Winds' [Cassini north polar projection movie in near-infrared]. http://www.ciclops.org/view.php?id=81

22. Porco CC et 23 al. (2003) Science 299, 1541-1547. 'Cassini Imaging of Jupiter's Atmosphere, Satellites, and Rings.'

23. Mousis O et 31 al., 'Instrumental Methods for Professional and Amateur Collaborations in Planetary Astronomy' *Exp.Astron.*, **38**, 91-191 (2014). DOI 10.1007/s10686-014-9379-0

24. Kardasis E, Rogers JH, Orton G, Delcroix M, Christou A, Foulkes M, Yanamandra-Fisher P, Jacquesson M, & Maravelias G. 'The need for Professional-Amateur collaborations in studies of Jupiter and Saturn.' JBAA (2015, in press).

Figures

Fig.1: Hi-res map of the planet on 2015 March 5-6, made by Marco Vedovato from images by C. Go & T. Olivetti. Major features are labelled. (Polar projections of the same map are in Figs.5 and 18.)

Fig.2: Set of images in 2015 March. Top row: UV (first image) and visible colour. Bottom row: methane band. (For more methane images of the GRS, see Fig.6.)

Fig.3: Three pairs of images in 2015 Feb.. Top, visible (RGB); bottom, methane band (889 nm). (Earlier methane images, up to Jan.28, were in Report no.3.) They include the major long-lived ovals in N. Tropical domain (White Spot Z) and the S4 and N2 domains, as well as the STB Ghost.

Fig.4: Another set of methane images, 2015 March, all by C. Go (filter width 18 nm). Methane-bright AWOs are indicated in the S4, S2, S1, N1 and N2 domains. They include NTZ spots w3 (LRS in Jan.) and w2 (more weakly), and NN-LRS-1 and NN-WS-4.

Fig.5: Polar projection map of the southern hemisphere on 2015 March 5-6, from images by Go & Olivetti, as in Fig.1.

Fig.6: V-hi-res images of the GRS in 2015 Feb-Mar., including 3 methane-band images. Red arrow indicates vortex R9 retrograding on the SEBs jet and being swept around the RSH to the f. end, where it forms a methane-bright streak. It seems likely that this was the vortex being pulled apart (as in the Voyager movies), with one part being swept into the GRS, and the other part escaping to retrograde on SEBs. Vortex R18 enters the RSH on March 8, but is not obvious therafter; it may be the white streak tracked on March 10 (red arrowhead). Contrast in the methane images has been enhanced to show that the centre of the GRS is more methane-bright than the periphery. Also note only small-scale activity in the SEB f. the GRS, although one small bright spot is weakly methane-bright (cyan arrow).

Fig.7: Maps of the equatorial region aligned in System I, from 2015 Jan.-April. The major NEBs dark formations are tracked by blue lines. NEB rifts are underlined in green.

Fig.8: Maps of the NEB: (A) 2014 Sep-Nov; (B) 2015 Jan-April. Green line(s) below each maps mark the approximate extent of the rift(s). SZ is white spot Z. All maps made by Marco Vedovato unless otherwise stated.

Fig.9: Images showing oval BA and the sector p. it in 2015 Feb-March. A bay in NEBn (red arrowhead) becomes temporarily enclosed by dark brown projections after a large rifted region passes it.

Fig.10: ZDP for the southern hemisphere, with Cassini ZWP [from Ref.22] for comparison.

Fig.11: ZDP for the northern hemisphere, with Cassini ZWP [from Ref.22] for comparison.

Fig.12: Maps from 15-70ºN, 2015 Feb. to June, with major features labelled. *Figs.12 to 14 show the N. Temperate region at progressively greater temporal and spatial resolution.*

Fig.13: V-hi-res maps in Feb.-March covering the NTD, with N2 jet spots prograding up to it.

Fig.14: V-hi-res images showing N2 jet spot no.1 interacting with the NTZ white oval w3. Note that w3 appeares double on March 2 during the interaction.

Fig.15: V-hi-res images of the major features of the N2 domain: four AWOs, and the giant FFR.

Fig.16: A retrograding tiny white spot [w7] passing AWO-a in the N4 domain, 2015 Feb.

Fig.17: A tiny white spot [w5] appearing at AWO-c in the N4 domain, 2015 March. It begins as a filament of a FFR on the south edge of AWO-c.

Fig.18: Polar projection maps of the northern hemisphere, made by M. Vedovato from images by T. Olivetti and C. Go, as in Fig.1.