[Final version, 2015 March 16]

JUPITER IN 2005 AND 2006

John Rogers & Gianluigi Adamoli,
using results from the JUPOS team (Hans-Joerg Mettig, Gianluigi Adamoli, Michel Jacquesson, Marco Vedovato, Grischa Hahn)

III. EQUATORIAL REGION

Southern Equatorial Region: SEBn/EZ(S), with the South Equatorial Disturbance (SED) *[Chart J8]*

The SED in 2005 and 2006 was described in our paper [Ref.9] -- including detailed charts and images for 2005 [Fig.8 therein] -- and our on-line long-term report [Ref.10].

In 2005, the SEBn jet was well characterised. The tiny spots (chevrons) on the SEBn edge had speeds of DL1 = -47 to -63 deg/mth, but these short-lived features lay within 3 or 4 disturbed sectors which were tracked with DL1 ~ -104 deg/mth, the full SEBn jetstream speed. These sectors crossed the SED track without evident interaction. For our charts and image compilations for 2005, see [Ref.9, esp. Fig.8] and [Ref.10, Fig.3].

In 2005, the SED ('main complex' in some earlier reports) was quiescent and very inconspicuous, but it could still be recognised by a very bright streak in EZ(S) with a blue-grey streak on its N edge, which was tracked with DL1 = +26 deg/mth. It passed the GRS in mid-Feb. (Fig.24) and early April (Fig.25), but still did not become conspicuous (Figs.24-26).

In 2006, in contrast, the SEBn jet was not detectable, and the SED did not have its familiar form. This was at least partly because few SEBn features could be tracked, as the EZ(S) gradually developed brown shadings. The EZ(S) gradually changed from brilliant white to yellowish by 2006 July, and with a broad diffuse grey EB developing, the usual blue-grey streak of the SED was not visible. In late June, three dusky grey-brown 'veils' alongside whiter patches were noted; one of these turned out to be the long-lived SED (see below). Another had the appearance of a secondary SED ('SED-m3' on Chart J8: a brown veil at 6ºS, followed by a bright spot and notch (Fig.30) although it only lasted a few months. The only other trackable features were four bright spots at various longitudes (6-7ºS, DL1 ~ +6 deg/mth), which became evident as the EZ(S) darkened. The long-lived SED passed the GRS on April 11, June 2, July 18, and Sep.3 (Fig.23); but its track was discontinuous.

> The SED was difficult to identify in early 2006. There was a similar feature at L1 ~ 270 in March ('SED-m2' on Chart J8), but it disappeared as it passed the GRS. The long-lived SED seems to have been opening up as it passed the GRS on April 11, but then a second such feature appeared on passing the GRS on April 16, 37º higher in longitude (Figs.23 & 28). The SED track from 2005 could have matched up with either of these, and also with the single track of the SED in May-June. However it was still not conspicuous, and was not recognised until late May when Hans-Joerg Mettig and Christophe Pellier identified one of the brown veils, f. the GRS at L1 = 12, as the SED (Fig.23). It passed the GRS on June 2, with DL1 ~ +16 deg/mth. In late June it developed the typical SEBn rift and white spot, on the p. edge of the brown veil; the same feature was at L1 = 30 on July 1. (See colour and methane images on June 27 in Fig.8.)
>
> The track of the SED then underwent repeated shifts to the east (p.) (Chart J8). As the SED again approached the GRS for its next passage in July, it had shifted ~35-40º p. After this passage, it had the classic SED appearance (rift, white spot, methane-dark step-up), and there was no such

feature f. it. (Fig.P17, & Ref. 5 no.9). It was tracked to Aug.19 then became obscure. On Sep.3-11, it was identified again as it passed the GRS, but had again shifted p. by ~25-30º (Fig.23).

These inconsistencies were perplexing, and such discontinuous shifts to the east (p.) had not previously occurred, but their limited and reproducible range, and the classic form of the SED observed after them, suggests that they were shifts of the existing SED, not new features. One possible interpretation is that there was an indistinct wave pattern with wavelength ~30-40º p. the original SED track throughout 2006, with small SED-like features coming and going at the crests of the waves, represented on Chart J8 respectively by SED-1b; SED-1a/-1c; SED-m2/-2; and SED-m3/-3. Although this idea is speculative, it is consistent with what we recorded in the next year, 2007. Then, a similar 30º wave pattern p. the SED was suggested, and a similar 30º eastward shift of the SED was observed in detail [Refs.1 & 24]. It could also relate to the ~20º wave pattern p. the SED that was observed in Cassini movies [Ref.26].

Equatorial Zone: General description

In 2005, the EZ was bright, largely white (especially the southern part); blue-grey festoons and other streaks were present in the central and northern parts as usual, but mostly rather chaotic and faint. Many good images showed a faint yellow-orange tint within the central part, a remnant of the previous year's coloration, but never strong enough to constitute a distinct EB.

In 2006, it was notable that dark features accumulated all across the EZ, intensifying gradually from January to July. Most obviously, the bluish-grey festoons in EZ(N) became much bigger and darker, a brown EB developed, and in summer 2006, diffuse stretches of yellowish-brown shading spread over EZ(S) as well, while the EB became even darker with brown and blue-grey streaks mixing into a neutral grey.

Northern Equatorial Region: EZ(N)/NEBs *[Chart J9]*

In this report we use the neutral term 'formations' for the major dark features on the NEBs edge, encompassing various visual appearances described metaphorically as 'plateaux', 'projections', etc. These are not true projections from the NEBs edge, but separate weather systems distinguished by their dark blue-grey colour (and their high temperature in professional images at 5 microns). Physically there is evidence that they are cloud-free regions representing a circum-global wave pattern [Refs.27-29]. 'Festoons' are thin blue-grey streaks curving from the dark formations into the EZ.

EZ(N)/NEBs in 2005

In 2005, as in the previous apparition, the region was dominated by slow-moving (retrograding in L1) irregular dark formations. Their tracks were variable and uneven, but showed consistent averages overall. From 2004 Dec. to 2005 Feb., there were only six persistent formations (here numbered A1 to A6), mostly long dark plateaux with DL1 ~ +22 deg/mth. From 2005 March to July, there were more dark formations (here numbered 1 to 11) and they had mean DL1 ~ +13 (although the transition was not abrupt, and a few features still had the more extreme retrograding speeds). A detailed account is in the **Appendix** (below). Here we just summarise and discuss the main conclusions.

Arrays of large dark formations could be seen to persist with fairly consistent tracks throughout many months in 2004/05, despite great variability in their appearance and motions. The p. and f. ends of these formations often adopt short-term drifts that may cover a wide range of speeds. In some cases these can be attributed to interference by smaller adjacent features, e.g. the small prograding spots that are quite commonly present, or dark retrograding spots that are slightly further north in the NEB, or an additional overlapping wave-train (see note to Table 6C in Appendix). But most of the variations or shifts appear to be random, while the dark formation as a whole maintains a consistent long-term drift.

These motions probably represent a complex mixture of real winds and wave phenomena. The large dark formations are believed to be waves, with phase speed related to wavelength [Refs.1,27,28]. To see whether the analysis in 2005 and 2006 supports this model, the data have been tabulated (Table 6C in Appendix) and plotted (**Fig.27**). The results are mixed: while the 2004-05 and 2006 points fit the overall correlation well, the points from 2005 April-May are only in modest agreement. Perhaps this was still a time of transition?

Many of the changes in the dark formations appear to have been caused by the passage of rifts (bright turbulent regions in the NEB). There were multiple examples of the various interactions previously reported [Refs.17 & 30], in which NEB rifts either disrupt a NEBs formation, or cause it to enlarge and darken. The disruptions of the five large formations in Jan-Feb. were apparently initiated by passing rifts, although the fact that they were all completely disrupted, and did not re-form on the same tracks, suggests that the rifts may have just initiated a change in pattern that was liable to happen for some other reason.

The great range of speeds recorded at 7-8ºN does not represent a latitudinal gradient, as this only operates at >8ºN. Rather, all these speeds are within the peak of the NEBs jet, where they may represent either wave motions as just discussed, or true wind speeds, which vary with altitude (faster below the cloud-tops, slower above the cloud-tops), so some might be due to phenomena at different levels. The same ambiguity arises in 2006 (see below).

EZ(N)/NEBs in 2006

The aspect and motions were very different in 2006, when the region was dominated by a very regular array of 12-13 conspicuous dark NEBs formations (‘projections’) with faster rotation period (DL1=0). I.e. they returned to a normal drift rate after the exceptionally slow drift rates (positive DL1) of the previous few years. All this represented a reversion to the state last seen in 1999.

In 2006, the main features in Chart J9 were the big dark projections (~7–9ºN), and the white spots or areas f. each of them (6-8ºN). The big projections had DL1 ~ 0 to +5 overall, while shorter, better-defined features within their overall tracks had DL1 from -10 to +9. (Various smaller features also moved in the same speed range, regardless of latitude, indicating that they were associated with the big plumes, either directly or as part of a wave pattern.)

Also, between some of the large formations were smaller, very dark spots or projections with DL1 ~ +10 to +30 deg/mth (e.g. Fig.28). These were on the visible NEBs edge, at 8.4ºN (±0.3º) which was almost the same latitude as the other NEBs features, so they may represent the extreme of variability on the NEBs jet; on the other hand, they match the Cassini ZWP so they could represent the start of the great speed gradient across the NEB. The same ambiguity applied to retrograding dark features in 2005 (above).

Tracking of short-lived white spots revealed two interesting types of behaviour which may be more common than has been appreciated hitherto.

(I) Retrograding white spots in NEBs breaking through into EZ.
A small but brilliant white spot erupts in southern NEB, with positive DL1 due to its latitude, then breaks through into EZ(N), either at the p. or f. side of a NEBs dark formation. In 2006 we documented many examples, viz:
Following proj. **a**, 3 to 8 examples from March to June (**Fig.28)**; f. proj. **c**, one in Feb.; f. proj. **d**, one in May [Ref.5 no.8]; p. proj. **e,** two examples in June (**Fig.31)**; and p. proj. **k**, a pair in July **(Fig.17**).

Such events have been seen on other dates, including one in the Cassini movie in 2000, and one during the Voyager 1 encounter [Ref.17, Figs.8.2 & 9.2; same on cover of Ref.30].

So these brilliant white spots in southern NEB sometimes break through on the p. edge of a NEBs projection (forming a bright notch), sometimes on the f. edge (where the spot may become the core of a plume). These bright spots are presumably convective storms, possibly thunderstorms, and they seem to interact with the large dark formations which are believed to be largely cloud-free wave features. It would be interesting to understand how these large waves promote the growth and southward drift of adjacent convective storms. The interaction resembles the way the SEB rifts couple to the SED (also seen in Fig.P17).

(II) Prograding bright spots within plumes
Following dark projections **i** and **k**, the JUPOS analysis showed a succession of short-lived white spots with remarkable prograding drifts, at ~8ºN.
(1) F. proj. **k**, two in May were well defined (nos.5 & 6 in **Fig.29**: DL1 = -17, at 8.1ºN); but there may have been two others in June and July (**Fig.29)**. Each of these was a new small brilliant spot in EZn just f. the base of the festoon, which formed a transient bright plume core, pushing Np. against it.
(2) F. proj. **i**, Chart J9 shows 3 successive white spots in June-July which comprised a rapidly prograding plume core of proj. **i**. Two of them are shown in **Fig.30**, though only one of them was measured (DL1 = -28, 8.2ºN).
(See the figure legends for details.)

These prograding plume cores have not been commonly recorded, and it is not clear whether they represent (i) true wind speeds converging on the base of the dark projection, as observed in Galileo and Cassini images [Ref.29]; or (ii) propagation of convective clouds without physical drift; or (iii) convection from the faster current below the main cloud-tops, as was possibly observed by the Cassini flyby [Refs.29 & 31].

REFERENCES follow Part V in separate file.

FIGURE LEGENDS are at end of this file.

Appendix:
EZ(N)/NEBs in 2005: Detailed account ***[see Chart J9 & Figs. 3 & 24-26]***

In 2005, as in the previous apparition, the region was dominated by slow-moving (retrograding in L1) irregular dark formations. Their tracks were variable and uneven, but showed consistent averages overall. From 2004 Dec. to 2005 Feb., there were only six persistent formations (here numbered A1 to A6), mostly long dark plateaux with DL1 ~ +22 deg/mth. From 2005 March to July, there were more dark formations (here numbered 1 to 11) and they had mean DL1 ~ +13.

The tracks of these features are not always obvious on the raw JUPOS charts, because they are too large and irregular to be measured as single features, and their p. and f. ends often drift to and fro irregularly. However, coherent tracks can be identified (shaded bands in **Chart J9**), and they coincide exactly with the major dark blue-grey formations shown on images and maps **(Figs. 3 & 24-26)**. Here we give a summary of their evolution based on the chart and one one or two circum-global sets of images per month, as well as a few examples of short-term behaviour – more of which could be found by further study of the images.

Throughout 2004 Dec. (**Fig.3**) and 2005 Jan., there were just six large dark formations, which are here numbered A1 to A6. Most were long plateaux with only weak festoons or none. There were also long, very dark grey sectors of NEB(S) between some of them (A6-A1-A2). The mean spacing was ~60º, and four of them had overall DL1 ~ +21 to +23 deg/mth, while two had DL1 ~ +14, for an overall mean drift of +19; however these averages cover considerable irregularity in their spacing and motions.

The overall pattern changed massively in 2005 Feb. Only one of the six large formations clearly persisted (A3, which became no.5). The other tracks on the JUPOS chart all terminated around the end of Jan., and were replaced by short-lived features: some quasi-stationary plateaux, other small projections and dark and white spots.
The images in Feb.(**Fig.24**) suggest that these disruptions were due to the passage of large NEB rift systems, as seen alongside the chaotic remnants of A1 and A4-A5. A6 had broken up earlier, as a rift passed on Jan.28. Among the short-lived small features in Feb-March were several prograding bright white spots adjacent to a small dark projection or p. end of dark plateau (e.g. DL1 = -25 to -31.5). These were similar to small prograding features seen in many recent apparitions.
Then in March-April a new set of dark formations developed. There were 7 in March, increasing to 11 in April, which we have numbered 1 to 11. These had less positive drift than the earlier set, mean DL1 ~ +13 (**Figs.24-26;** See captions for details).

Throughout April to June, there were usually 11 major dark formations. For 7 of them, the overall tracks had DL1 ~ +10 to +16 (mean, +13), but for one of them, DL1 was still +23. (The other three tracks were very irregular or discontinuous.) But as in Dec-Jan., most of the formations did not drift smoothly at these rates, but had alternating faster and slower speeds at one or both ends.

Short-term drift rates were analysed for 76 track segments which were reasonably well defined and steady, mostly with durations of 7 to 40 days. These covered a wide range of speeds with no apparent pattern. They included p. and f. ends of plateaux (mean DL1 = +11; range +41 to -25); dark spots or projections (mean DL1 = +4; range +14 to -11); and white spots or plumes (mean DL1 = +3; range +13 to -13). They were between 6.7 and 8.2ºN, with no latitudinal speed gradient.

Tracks were also measured for six dark spots slightly further north in the NEBn, at 8-9ºN (mean 8.5ºN ±0.25º). These had larger retrograding drifts (mean DL1 = +39 ±12), in accordance with the usual gradient. Unexpectedly, four of these tracks, running across the N edge of major NEBs plateaux, carried onwards as tracks for the rapidly-retrograding f. end of the plateau for ~2 weeks each, indicating that these spots could partially 'capture' the larger formations.

Table 6C: Spacing and speed of NEBs dark formations

Dates	n	mean spacing (deg.)	mean DL1 (deg/mth; *approx.*)
2004 Dec-2005 Jan.	6	60	+19
2005 April-May	11	32.7	+13
2005 May (stat. features)*	(6/111˚)	22.2	+3
2006 March-July	13	27.6	+1

(n, number around the planet)

*The chart shows a series of quasi-stationary features from L1 ~ 50-220 in 2005 May, interrupting the overall retrograding drift of the large formations; they were mainly p. ends of the large plateaux, or smaller projections. These features were fairly evenly spaced, allowing for one or two gaps, so they could represent an additional superimposed wave pattern. However this entry (open red circle in **Fig.27**) does not fit very well with the overall correlation.

FIGURE LEGENDS (continued)

Fig.23. Images showing the S. Equatorial Disturbance (SED) in its various manifestations throughout 2006. The SED is mainly identified as a rift in SEB(N), which reappears each time the locus passes the GRS, but sometimes is ~30-40º preceding its previous track.
(a) April, passing the GRS and duplicating. One SEB(N) rift (L1 = 338) passes the GRS on April 11. A second rift (L1 = 16 --> 26) then forms across the SEB(N) just after passing the GRS. Either of these could be on the SED track as extrapolated from 2005.
(b) May-June, passing the GRS. The SED was identified by H-J. Mettig as the prominent feature at L1 ~ 10 on May 21-28, with rift and brown veil in EZ(S), approaching the GRS. However it became less conspicuous after passing the GRS on June 2.
(c) Late June. The same feature remained visible (L1 ~30), with the typical SED rift, plus the brown veil. A smaller duplicate of it can be seen ~40º p., which presumably developed into the main SED in mid-July. *Bottom:* 'Secondary SED' at lower longitude.
(d) July, passing the GRS on July 18. The SED was prominent, but at L1 ~ 0, 35-40º p. its previous track. [Also see v-hi-res infrared images from Hawaii on July 13 (Gemini Obs.) and 20 (Keck Obs.).]
(e) August. The same SED feature, with a white spot at the mouth of the rift increasingly prominent as the EZ(S) darkens around it. *Top:* Methane image, showing the typical SED pattern of a dark patch coinciding with the SED with darkened EZs p. it *[Refs,9 & 25]*. By reference to the structure of the SED as shown in previous spacecraft images, the methane-dark patch probably coincides with the anticyclonic gyre, with the visible rift at its p. end and brown veil over its f. end.
(f) September, passing the GRS on Sep.3. The SED was again distinct but 25-30º p. its previous track.

Fig.24: Images in 2005 Feb. & March, roughly aligned in L1. The major dark NEBs formations are labelled in green below the images. Detailed notes:

In 2005 Feb., only one of the six large formations clearly persisted (A3, which became no.5). The other tracks on the JUPOS chart had all terminated around the end of Jan., and these images in Feb. suggest that these disruptions were due to the passage of large NEB rift systems, as seen alongside the chaotic remnants of A1 and A4-A5.

The March image set shows five of the new set of dark formations soon after they appeared; they were well-defined, very dark plateaux. A sixth (no.1) formed between March 13-16 as a small dark projection, as a bright white spot in the NEB passed. Two long sectors still lacked major formations, but contained mini-plumes; at least one of these was prograding (DL1 = -8.5). These two sectors were alongside long rifts, and only as the rifts moved on did new large formations appear in them, in April (nos.6,7,9,10).

Fig.25: Images in 2005, early April. The major dark NEBs formations are labelled in green below. New dark formations 2,6,7,9,10 are mostly distinct and dark although still quite small. Nos.2,7,10 are still involved with rifts.

Fig.26: Hi-res images & maps from 2005 April 20 to May 1, by Peach, aligned in L1 to show short-term changes within the overall pattern. The 11 major dark NEBs formations are labelled in green below the images. Several phenomena can be seen:
--At this time, seven of the dark formations had temporary quasi-stationary p. ends (see Table); but there was nothing morphologically distinctive about them.
--Two projections (nos.4 and 11) expanded hugely due to interactions with NEB rifts.
--One projection (no.7) was split by a white cloud and its p. end then became a prograding small projection.

Fig.27: Chart of drift rate vs spacing (or speed vs wavenumber) for the dark NEBs formations. Data for the 2005 and 2006 apparitions have been added to the chart already published in our 2007 report *[Ref.1]*.

Fig.28. Image set showing NEBs phenomena in 2006: Retrograding white spots in NEBs break through into EZ. *Left:* Enlargement of JUPOS chart, with parallel chart of latitude vs time, showing white spots on NEBs, individually colour-coded. *Right:* Image set.

Following proj. **a** (L1 = 5), the JUPOS analysis showed a succession of short-lived white spots with retrograding drifts: three were adequately tracked but there were probably 8 of them from March to June. Their speeds were DL1 = +18 to +23 deg/mth, and the latitude of each spot rapidly decreased from 9-10.5ºN (when first detected) to ≤7ºN. I.e., these were bright white plume-heads which erupted within the southern NEB, accordingly having positive DL1, but moved south and broke through the NEBs edge into the EZ(N). These images also show several retrograding small dark projections f. projs. **a** and **b**, on the visible NEBs at 8.3 (+/-0.2) ºN. (More such examples are in Figs.17 & 31.)

Fig.29. Image set showing NEBs phenomena in 2006: Prograding white plume cores. *Left:* Enlargement of JUPOS chart, with parallel chart of latitude vs time, showing white spots on NEBs, individually colour-coded. *Right:* Image set.

Following proj.**k** (L1 = 310), the JUPOS analysis showed a succession of short-lived white spots with remarkable prograding drifts, at ~8ºN. Two in May were well defined [nos.5 & 6]: DL1 = -17, at 8.1ºN; but there may have been two others in June and July. The images show that each of these was a new small brilliant spot in EZn just f. the base of the festoon, which formed a transient bright plume core f. it, pushing Np. against it. The second then split to produce a new brilliant spot on its f. side which remained in the southern NEB.

Fig.30. Image set showing NEBs phenomena in 2006: More prograding white spots.

Between projs. **i** and **j**, several rapidly prograding white spots were recorded within NEBs; two were tracked, DL1 = -26 to -28, at 8.2ºN. WS15 was a prograding notch, starting at the p. edge of large dark formation **j**; it was at lat.+8.1º (+/-0.35); it was not a plume core and may resemble prograding features in other years. There were also 3 successive white spots in June-July which comprised a rapidly prograding plume core of proj.**i.** This image set shows two of them; one prograded from L1 = 268 to 264, June 4-10. The second appeared in southern NEB on June 24 (possibly developing from the first), broke thru into EZn and became a brilliant prograding plume core, lat. +8.2 (+/-0.3) ºN, merging with the previous plume core.

However, not all bright plume cores were prograding. One [pink arrow] erupted as a bright w.s. within the base of proj.**k** (June 13, L1 = 314), and elongated f., becoming a new brilliant plume core (June 29, L1 = 319) [nos.8&9 respectively as plotted in Fig.29.]

Fig.31. Image set showing NEBs phenomena in 2006: Retrograding white spots in NEBs break through into EZ.

This set shows two examples of brilliant white spots which appear within southern NEB and break thru into EZ(N) just p. NEBs proj.**e** (L1= 135), on June 5 and 13. Also note the appearance of an adjacent white spot in NEB on June 12, which destroys a pre-existing barge beside it (L2~135). This figure continues the series shown in *[Ref.5 no.8]* which showed a similar brilliant spot in southern NEB in late May which merged with the EZ(N) just f. proj.**d** (at L1 = 110).