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JUPITER IN 2005 AND 2006

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

This report is dedicated to the memory of two expert observers:
Erwin van der Velden, resident in Australia, who died aged 39 in 2005;
and Dr Donald C. Parker, resident in Florida, who died aged 76 in 2015.
An astronomical tribute page to Erwin van der Velden has been posted by his sister:
http://www.erwinvandervelden.nl/

EXTENDED SUMMARY – *is provided in a separate file.*

I. INTRODUCTION

The apparitions of 2005 and 2006 are considered together in this report, as the aspect and activity of the jovian atmosphere was much the same in both years. These were the last years of 'normal' behaviour before the onset of the global upheaval of 2007. Indeed the main changes in 2006 – altered motions in the STropZ, and brown shading in the EZ – turned out to be fore-runners of this global upheaval.
In addition to the usual report on all the major features, we have analysed the JUPOS database to provide drifts and latitudes for many smaller features so as to give a zonal drift profile (ZDP) in these last years of normal activity, which is particularly comprehensive for 2006. This can be compared with the global ZDP which we have already published for 2007 [Ref.1], and with the zonal wind profile (ZWP) revealed by spacecraft imaging.

Opposition in 2005 was on April 3, in Virgo, at 4ºS.
Opposition in 2006 was on May 4, in Libra, at 15ºS.

Image coverage:
For 2004/05, Isao Miyazaki took images throughout 2004 Oct. but the first to show features was on Oct.20. Useful images were taken almost every day by various observers in 2004 Nov. and Dec., with increasing resolution (**Fig. 3**). Numerous good images were taken from 2005 Jan. to July **(Figs.4 & 5)**. The closing months were again covered mainly by Miyazaki, with decreasing resolution in Aug. and little resolvable in Sep.
For 2005/06, the first images were posted by the ALPO-Japan in 2005 Dec., notably by T. Olivetti and H. Einaga. Many excellent images were taken from 2006 Feb. to early Sep. Frequency and resolution of images decreased during Sep., but Miyazaki obtained some lo-res images up to mid-Oct., 2006.

Observers:
Table 1 gives the full list of observers. By 2005, webcam imaging had been widely adopted so numerous observers were producing remarkably good images, and 2006 can perhaps be regarded as the year when this technology reached its full potential. Given the southerly declination of the planet, Australian observers made especially valuable contributions, particularly in 2006, as did Fabio Carvalho in Brazil.

Notably, Damian Peach took his telescope to Barbados [Ref.2], and produced a series of images of unprecedented quality from 2005 April 19 to May 9. He returned to Barbados from 2006 April 7-25 with a larger telescope, this time with Dave Tyler and Bruce Kingsley, and obtained an even more outstanding set of images. **Figs.5 & 6** are hi-res maps of the planet prepared by Peach from his own images in 2005 April and 2006 April, on which we have labelled the major features.

Conventions:
In this report we use our new simplified nomenclature for belts and jets [Refs.6 & 15], in parallel with the more traditional names. As always, longitudes are measured in System II and drift rates (DL2) are in degrees per 30 days unless otherwise stated. Latitudes are zenographic. South is up in all images.

Table 2 lists the latitudes of belts in 2006.
JUPOS charts, which show longitude vs time for all spots, are presented in **Charts J1-J15.** Unless otherwise stated, black points are dark spots, red points are bright spots. **Tables 3-8** list drift rates and latitudes for all the currents, jets, and important individual spots.

We have already posted plenty of material from these apparitions, including compilations of images and some JUPOS results, in two interim reports in the Journal [Refs.3 & 4], in various interim reports on our web site [2005, no longer posted but available on request; 2006, Ref.5], and in our long-term reports on the high southern domains [Ref.6], the S.Temperate domain [Ref.7], the GRS [Ref.8], the SEBn jet and SED [Refs.9 & 10], NEB barges merging [Ref.11], white spot Z [Ref.12], the NTBs jet [Ref.13], and the NNTZ ovals [Ref.14].

Methane-band images

Good images were taken by several observers in the near-infrared methane absorption band at 889 nm; at this wavelength, features are brighter if they have more high-altitude haze. examples are in **Figs.7-9.**

An exceptional set was produced by Antonio Cidadao in 2005 (examples in **Fig.7**). He took numerous images with an 889 nm (width 18 nm) filter, using adaptive optics, then 'flat-fielded' them by dividing by a longitudinally-averaged image. (He had shown in the previous apparition that there was no albedo contribution to the resulting ratio images.) He also compiled them into rotation movies. The examples in **Fig.7** are stills from these movies, along with contrast-enhanced copies. Inspection of the movies shows that essentially all the features, however diffuse and irregular, are real (except perhaps for some artefacts at the edges of the planet or of the belts, due to variations in alignment or resolution relative to the axisymmetric mask). This valuable data set has not yet been analysed; it could form the basis for a professional student project.

The brightest features in the methane images are always the polar hoods, the EZ, and the anticyclonic red ovals. Other features of interest in many of these images (e.g. Paolo Lazzarotti's on 2006 April 10 in **Fig.8**), include:
--An AWO on the SSTB is just detectable (they are usually too small to be recorded).
--A white spot in the mid-SEB disturbance is methane-bright, indicating that its clouds extend unusually high for 'rift' spots.
--The visually faint NTB is still very dark in methane; however the visually faint STB is faint in methane, except for the STB Remnant which stands out as distinctly dark.
--NN-LRS-1 is methane-bright.

Also see the superb adaptive-optics near-infrared images from Hawaii (Gemini on 2006 July 13/14 and Keck on July 20/21), at:

http://www.gemini.edu/jupiter06

http://www.keckobservatory.org/recent/type/news [go to 2006 July 29]

II. SOUTHERN HEMISPHERE

South Polar Region, S4 and S3 domains (Chart J1)

The appearance was typical with the usual sharp boundary at 53 S, and long segments of narrow 'S3TB'. The major features were long-lived anticyclonic white ovals (AWOs) in the S4 and S3 domains, and a persistent sector of retrograding dark streaks in the S3 domain, which are all described in our long-term report [Ref.6].

S4 domain:

There were two persistent AWOs at ~60ºS, with varying speeds, still showing strict correlation of latitude with speed (**Fig.10**). The largest and longest-lived (A) had the exceptionally fast speed of DL2 = -45 deg/month until 2005 April, when it seems to have merged with a smaller white spot p. it. This event is shown in **Fig.11**, though no details of the merger were visible. The AWO then decelerated to DL2 = -17. In 2006, AWO-A was again well tracked, and it performed 1.5 cycles of a smooth sinusoidal oscillation with P = 4.3 months, DL2 varying from -40 to +5 deg/mth! The other persistent AWO (B) was only sparsely recorded in 2005, but better tracked in 2006, when it also showed sinusoidal variations: 2.5 cycles of P = 1.7 months, with similar range of DL2.

S3 domain:

At ~50ºS, there were two long-lived AWOs in 2005, only one of which survived in 2006. In 2005 it had slight, irregular oscillations, then in 2006 it displayed exceptionally regular oscillations: almost 5 cycles with P = 1.0 month. Like the S4-AWOs, these S3-AWOs change their latitude along with their drift rate (**Fig.10**, and Ref.6 Figs.13 & 15).

Remarkably, these S3-AWOs repeatedly became loosely associated with the S4-AWOs, in both apparitions (e.g. Figs.11 & 14, & Chart J1). The chart suggests that they have a tendency to remain together, although they can also drift apart again. (We have noticed similar behaviour in 2013-2015.)

Also in both apparitions, remote from the S3-AWO, numerous dark spots or streaks were arising and retrograding with DL2 ~ +8 to +15 deg/mth, at 49ºS, straddling or south of the retrograding jet, like the sets in the SSTZ and STZ. They constituted a narrow oblique spotty or streaky sector of 'S3TB', ~40º long. This sector of retrograding spots was first recorded in 2005 March (though it could have been present in earlier months). It would persist until 2010, drifting at DL2 ~ -7 to -9 deg/mth (i.e. fixed in L3, and typical of the S.S.S. Temperate Current [S^3TC]) [see Ref.6, Section 6.2 & Fig.13].

S3 jet (Chart J2)

This jet is unique in having both white and dark spots prograding along it, moving with the same speed (mean DL2 = -97 deg/mth in both years) [Ref.6]. In 2005, the JUPOS chart showed white spots around two-thirds of the circumference and dark spots around the remainder. (Three white spots each lasted 75 days and covered 190-220º in L2.) In 2006, there were still plenty of spots but only in a sector ~120º long, with both bright and dark spots. [In Ref.6, prograding spots are marked on the 2005 map, and the ZDP is shown in Fig.11B.]

S2 (S.S.Temperate) domain *(Chart J3)*

SSTZ:
There was just one distinct white SSTZ sector in 2005, f. oval A5, and none in 2006.

AWOs and SSTB:
We already posted a report covering three years, 2004-2006 [Ref.5 no.4], and a full long-term report [Ref.6, esp. Fig.7].

Throughout both years, the seven major long-lived AWOs were A1 to A5, forming a closely-spaced array, and A8 and A0, a separate pair [**Figs.4-6, & 12-15,** & Ref.6 Fig.7C].

Ovals A1-A5 were embedded in solidly dark SSTB except for two white oblongs (‘lozenges’) between A2-A3 and A4-A5, which were gradually expanding as usual [Ref. 5 no.4 & Ref.6]. The lozenge between A4-A5 was longer-lived but not so bright, rather pale blue-grey. The lozenge between A2-A3 existed from early 2005 to mid-2006. In 2006 June it developed blue-grey shading **[Fig.15]** which darkened to obliterate the lozenge during July [see 2006 report no.11, Fig.16]; at the same time, the sector between A1-A2 brightened to form a new white lozenge (which would persist and expand in 2007). Also, as the A2-A3 white lozenge broke up, oval A3 immediately rebounded from oval A4, to which it had been uncomfortably close. This was probably due to release of pressure from the former white lozenge, which had been expanding as usual, and probably thus pushing A2 and A3 apart [Ref.5 no.11].

Oval A8 had existed for years, but A0 first appeared in 2005 Jan., forming a triplet with a cyclonic white oval (‘C1’, persisting from 2004) and a smaller AWO (‘A0b’; not present before or after 2005). F. this triplet was a cyclonic red bar, first recorded in 2005 Feb (**Fig.12;** see below). A0 and A0b and the red bar were all first seen alongside oval BA (**Fig.12)**, possibly formed there because of perturbation of the S.S. Temperate currents by the great oval.

One of these cyclonic features may have been a renewal of a notable feature seen transiently in 2004 Jan-Feb. This was a dark barge in 2003 Dec./2004 Jan., which turned red, then white in 2004 Feb-Mar. This cyclonic white oval may well have survived solar conjunction to early 2005, either as the central oval of the triplet, or as the red bar f. it. After 2005, the red bar disappeared as A0 converged on A1.

Finally, a new AWO called A6 was first seen at the start of the 2006 apparition, just p. BA, so it also may have formed alongside that great oval. It had a cyclonic white oval on its f. side, and the pair persisted through 2007 [Ref.6 Fig.7C&D].

Slow-moving dark spots in the S2 domain (~40ºS)
Sometimes, the JUPOS chart reveals a sector containing dark spots at 40.6ºS [Ref. 6 section 4.4]. They are slow relative to the AWOs which dominate this domain, but never retrograding. From their latitude, they are on the anticyclonic side of the retrograde jet (in the nominal SSTZ), so they may be comparable to the slow-moving dark spots seen in the STZ f. dark STB sectors. In 2005 and 2006, they were present for ~40º p. AWO A8, with DL2 = -21, on an apparently undisturbed sector of SSTB. No source regions were resolvable.

S2 jet (SSTBn jetstream) [Chart J4]

The SSTBn boundary with the white STZ was sharply defined all around the planet, except f. oval BA where the SSTB was sometimes not fully separated from the dark sector of STB.

The S2 jet activity was also similar in 2005 and 2006, and remarkable. Small, sparse dark jetstream spots were appearing at quite well-defined longitudes but the nature of the sources is puzzling. As described in [Ref.6], in 2005 most of them were arising 60-70º p. the STB Remnant (see below) in an undisturbed sector of STZ, but a few arose elsewhere. In 2006, most were arising ~70-80º p. oval BA.

Their speeds ranged from the jet peak (well displayed in 2005) to lower speeds and latitudes along a well-defined anticyclonic ZDP [Ref.6 Fig.5B]. In 2005 they started with DL2 ~ -80 to -100; four spots seemed to define the jet peak with DL2 = -94.8 (±4.9) deg/mth at latitude 35.1ºS (±0.1º), although there was one even faster outlier, with DL2 = -107 at 36.5ºS. But most of them showed rapid deceleration at the end of their track to DL2 ~ -45 to -30, as they drifted N into the STZ; four within the Sf. tail of the STB dark segment A (Nf. S2-AWO A5); two alongside that STB segment; and one or two at the f. end of the STB Remnant (recirculating to retrograde in the STZ) (marked on Charts J4 & J5).

In 2006, their speeds were slower and more diverse than in 2005, and two of them recirculated into the STZ: one at the STB Remnant, another elsewhere.

S1 (S. Temperate) domain *[Chart J5]*

Throughout these years there were just two structured sectors of the domain. One comprised the single large anticyclonic circulation, called **Oval BA**, and a long dark STB segment f. it (see below). The other, far less conspicuous, was a long-lived faint blue-grey oblique streak, which we named the **STB Remnant** [Figs.7 & 18 (2005) and 8 & 15 (2006)]. We believe it was a cyclonic circulation. Its history was described in [Ref.7], with illustrations from 2005 [Fig.7B therein].

Oval BA underwent a notable change during these years. In 2005, as previously, oval BA was a white oval (though never very bright) **(Figs.12 & 13).** In 2006 Feb., Christopher Go noticed that it had turned orange. The change was covered in our interim reports online [Ref.5 nos.3 & 7] and in JBAA [Ref.4]:

> "...But from the start of this apparition it has appeared orange (Fig. 3 & cover). This was first evident in an image by Tiziano Olivetti on 2005 Dec. 9, and was reported by Christopher Go on 2006 Feb.24. The colour is confined to an oval ring within BA, and if anything it has intensified during the apparition. Two teams of scientists obtained time on the Hubble Space Telescope to image it (*see cover*). Then in 2006 July, its drift carried oval BA past the GRS, producing a striking sight of these two orange ovals in contact."

The colour seems to have gradually intensified from 2005 Dec. to 2006 April, and remained strong thereafter **(Figs. 16 & 17;** also note how UV-dark it is in **Fig.8)**. All the best images show the orange colour was mainly in an annulus within the larger oval, which probably coincided with the fastest circulating winds [Ref.16]. The development of colour in oval BA may resemble the way in which the GRS first became red, starting with a dusky annulus in the 19th century [Ref. 5 no.7 & Ref.17]. (For further summary and discussion of the redness of BA in 2006 and thereafter, see Ref.7 and professional references therein.)

As it started to pass the GRS in late June, a short sector of the whitened STB immediately p. oval BA dramatically turned very dark, blue-black (June 21—July 7); but this dark patch shrank quite quickly (July 8-27) **(Figs. 16 & 17)**. Albedo changes like this are quite common as these great S. Temperate ovals pass the GRS, apparently because the compression of jets between them destabilises the cloud layers. However, as expected, the GRS passage did not affect oval BA itself: the orange ring was still a notable feature in August **(Fig.17)**.

There was just one **dark segment of STB**, f. oval BA, which had formed when a separate dark segment collided with oval BA in 2003-04 [Ref.7]. The dark segment was gradually shrinking, from 75º long in early 2005 to 60º long in late 2006. There was a small AWO on its S edge, wandering slightly in longitude (but surprisingly, not in latitude). As usual, this dark segment had a spotty or streaky dark 'tail' extending to Sf., made up of slower-moving spots and streaks in the nominal STZ latitudes (see below). Elsewhere the STZ and STB latitudes were white.

The 'Sf. tail' of the dark STB segment was only ~40º long in early 2005, but as it passed the GRS, it lengthened such that the f. end remained alongside the GRS throughout 2005 April-May, so it extended to ~70º long. During 2006 it was ~60º long. Drifts within it were very interesting [Ref.7, inc. Fig.8B]: Rapidly retrograding speeds developed for dark spots in the 'tail' in 2005, DL2 up to +30 deg/mth, as discovered at the time by K. Horikawa analysing observations for the ALPO-Japan. This is the full speed of the retrograding STBs jet, which had not otherwise been detected in ground-based images. These speeds were maintained here in 2006 (4 with DL2 = +31 to +37, one with +43!) (and in 2007). We suspect that this outbreak of dark spots in the STBs jet, from 2005 to 2007, was a consequence of the collision of STB segments in 2003/04. There were also many dark spots or streaks with DL2 = 0 to +8 deg/mth (2005, 2006), on a well-defined gradient just south of the retrograding jet.

The STZ Sf. the STB Remnant also showed variation in the ZDP [Ref.7, inc. Fig.8B]: the ZDP here was displaced southwards or slower than normal, from 2004 to 2007 – including the tracks of spots which recirculated from the SSTBn prograding jet to become slow-moving in the STZ or retrograding in the STBs jet. This recirculation mainly happened at the Sf. end of the STB Remnant (7 spots, 2004-2008, including some very small ones not included in the general analysis). No SSTBn jet spots passed the STB Remnant unimpeded. These observations suggest that the STB Remnant altered the ZWP f. it.

S1 jet (STBn jetstream) [Chart J5]

In 2005 there were numerous small dark brown spots prograding in the STBn jet. They were arising just p. oval BA, continuing the dense outbreak which began in 2004 Feb. (when the STB dark segment assembled f. oval BA) [Ref.7]. In 2006 they were much smaller and sparser. Their speeds were typical of the jet, mostly DL2 ~ -75 to -95. (In 2006, some of them were decelerating.) But there was no overall correlation with latitude, as they were all within the broad jet peak [Ref. 7].

In 2005, many of the jet spots disappeared on reaching the STB Remnant. Two which did survive the passage (e.g. Fig.18) accelerated as they approached it and decelerated as they passed it, also shifting north to 27.4ºS, suggesting that the STB Remnant altered the ZDP Np. it as well as Sf. it. The first of these spots arrived at the GRS in 2005 May, and disappeared on the S edge of the GRS (Fig.19).

S. Tropical domain

STropZ and SEBs in 2005 [Chart J6]

In 2005, the STropZ and SEB and GRS were very similar to their state during the Voyager 1 encounter. The STropZ was largely clear and white up to 2005 March, although narrowed f. the GRS.

A bright AWO was slow-moving at L2 = 60 --> 75, p. the GRS (Figs.11,14,19); we call this oval Q, as proposed in [Ref.5 no.5 & Ref.18]. As noted in that report, it is common for an anticyclonic oval like this to exist tens of degrees p. the GRS. In previous apparitions we have recorded them forming or intensifying by mergers with retrograding SEBs jetstream spots, then they drifted slowly towards the GRS, and eventually merged with the GRS [Ref. 19]. Ideally we would name them Q1, Q2, etc. in sequential order, starting with the long-lived one which merged with the Red Spot Hollow in 1997 [Refs.20-22]. But as we have not yet produced a definitive list of them, we just call any such white spot 'oval Q'. A similar oval Q existed in 2006, but because of its variable drift, it is not clear whether this was the same one tracked in 2005.

There were also some dark spots at 21-23ºS with modest retrograding speeds correlated with the latitude. In 2005, six of these were persistent; two of them drifted south and recirculated in the STropZ.

SEBs jet, 2005:

From the GRS (at L2 ~101) up to L2 ~ 335 (Fig.5), the SEBs was fringed by a streaky grey band at ~22ºS, which we call 'SEB(SS)'. An adjacent streaky dark band at 19.6ºS marked the peak of the SEBs jet; dark spots were tracked along it through much of this sector, moving with the full speed of the SEBs jet, DL2 = +113 to +126 (mean +118), thus coinciding with the peak of the Cassini ZWP (except for one outlier tracked for 4 weeks with DL2 = +136.5) (see ZDP in **Fig.20A**). Several white spots were also tracked (e.g. Fig.18).

From L2 ~ 335 up to the GRS, SEBs jet spots were well-defined rings. The best images showed them distinctly as white ovals with dark rims – evidently anticyclonic vortices as at the time of Voyager 1, spaced ~20-30º apart on average (Fig.5). In 2005 Feb., they were conspicuous and several entered the Red Spot Hollow. But later, most of them were very small, and only four were conspicuous enough to track, from 2005 Feb. to May, as they passed Oval Q and approached the GRS, with DL2 = +102 to +120.

Curiously, the ZDP chart (**Fig.20A**) shows that these ovals at 21ºS lay ~0.6º S of the spacecraft ZWP, whereas all other bright and dark spots lay close to it. However, this seems to be normal: the same has been true of coherent vortices on the SEBs jet in the past, whether in BAA/JUPOS data or in Cassini data (**Fig.20D)**.

Examples of these SEBs jet spots squeezing past oval Q were imaged on 2005 April 3-5 (Fig.4), April 20, May 2(Fig.14), and May 21 (Fig.19). Their entry into the Red Spot Hollow was recorded in Dec.(2004) and in Feb., but later ones which entered the RSH became very small (April 28) or invisible (one after May 9; one after May 26, Fig.19).

From the end of 2005 March, as several SEBs jet spots had reached the GRS, a dark S. Tropical Band (STropB) at 24ºS emerged from the p. end of the dark GRS collar, and prograded with DL2 = -44, enveloping Oval Q in early April. This typically happens when a SEBs jet spot outbreak is declining [ref.17].

STropZ and SEBs in 2006 [Chart J6]

In 2006 the full-speed SEBs jet activity was no longer detectable. There were only modestly retrograding speeds, DL2 = +23 to +58 deg/mth, mostly from L2 = 350 to the GRS; these features were dark streaks or spots in the dark grey SEB(SS), which was now present at all longitudes, at 21-22 S. Their ZDP (**Fig.20B**) was close to that of 2005 and to the spacecraft ZWP.

Of the more persistent dark spots or streaks with mostly positive DL2 at 22-23ºS, four drifted south in June, reversed their drift and recirculated in the STropZ, where they disappeared by fading or shrinking. These four (*a—c;* DL2 = +32 to +14; and G; DL2 ~ 0) halted and shifted to 23ºS, then prograded briefly (≥-22 deg/mth) at 24ºS, before disappearing (**Chart J6** & **Fig.15**). Spot *a* dwindled to a tiny dark spot, possibly orbiting within a white bay; spot *b* just faded away.

There was again a STropB at 24ºS p. the GRS, with a tenuous p. end, which emerged gradually in 2006 March, and was prominent from April to June (Fig.16). From March to June, 5 successive p. ends or darker sectors were tracked prograding from the GRS, with DL2 ranging from -25 to -67. The STropB detached from the p. end of the GRS around July 1, and prograded in the STropZ as a strikingly oblique, very dark spotty band (Fig.17, & Ref.5 no.9). (Indeed it resembled the f. end of a S. Tropical Disturbance, p. oval Q, although there was no evidence of large-scale recirculation at that time.)

What happened p. GRS after oval BA passed it in 2006?

In 2006 July, as oval BA reached the p. edge of the GRS, there was considerable disturbance in the STropZ p. it, with the STropB detaching from GRS, oval Q appearing bright white, and various connecting streaks (Fig.17). However everything then calmed down. The main STropB prograded and faded away, and an extra wisp of STropB detached from the p. end of the GRS in Sep. (Fig.23(f)).

The retrograding spot activity on SEBs had also ended in June-July. The last substantial stragglers, with DL2 ~ +30 [*e & f* on **Chart J6**], disappeared in July. By Aug-Sep., although the spotty SEB(SS) (DL2 ~ +30?) and various faint grey wisps in STropZ (DL2 ~ -22?) still existed, there were no coherent jetstream spots or other spots (Fig.23(f)), and no coherent spots were reaching the GRS. The GRS had already begun emerging as an oval separate from its surroundings from June onwards, and especially in August (see below).

These changes are interesting because at the start of the next apparition, in 2007 Jan.[Ref.1], the STropZ contained two S. Tropical Disturbances (dark barriers interrupting the SEBs jet). We cannot detect the origin of these STropD's in the 2006 images. They did not arise at the time of the passage of oval BA p. the GRS: this sector was very quiet when last seen in 2006 Sep. But the end of retrograding activity, and the strong tendency for eddying in the STropZ, both in 2006 June, seem in retrospect to have marked a relevant transition. The recirculation of four slowly-retrograding dark spots in 2006 June was not unique (there were two similar events in 2005, and in some previous apparitions); but it did seem to indicate an increased tendency for this eddying. Perhaps this continued thereafter, culminating during solar conjunction in the organised circulation that characterises STropD's.

Great Red Spot (GRS)

The GRS was at L2 = 101 in 2005 April, and 111 in 2006 May, with mean DL2 = +0.7 deg/mth throughout. The 90-day oscillation was clearly recorded throughout [Ref.8]. The mean length was ~16.5º (±1.0º, SEM) in 2005 March-May, and 16.6º (±0.1º, SEM) in 2006 March-June, except for 2006 May when it was ~17.4º long although not so well defined. The width in latitude was 10.0º, with edges at 17.1ºS (±0.3º, SD) and 27.1ºS (±0.3º, SD) [data from M.Jacquesson].

In 2004 Dec. (Fig.3), the GRS was an isolated oval, light orange with darker rim and core, well separated from the Red Spot Hollow (RSH) by a bright white strip.

In 2005 Feb., as substantial SEBs jet spots arrived at its p. end, images showed dark streaks moving on the S edge, so that in 2005 April-June there was a complete dark grey southern rim or arch, connecting to a STropB p. the GRS, while the northern edge of the GRS had faded: a typical 'Voyager aspect' (Figs.4,5,14). In May, a dark grey streak was also observed within the GRS, and we suspected a remarkably short rotation period. As we then established such a short rotation period in 2006 [Ref.8], we have now compiled the images from 2005 May and used the same technique to measure the circulation of the leading and trailing ends of this dark grey streak (**Fig.19**). The results show a steady rotation period of 4.71 (±0.06) days, over 3 full rotations – consistent with the gradual shortening of the period that we have documented in 2006 and subsequently.

In 2006 Jan.-May, the GRS still had the typical 'Voyager aspect', with SEBs jet spots impinging on the N side (Fig. 16). A dark grey streak was often imaged circulating inside the GRS, displaying a rotation period of 4.4 to 4.5 days, through three consecutive rotations in April and three in July. These results in 2005 and 2006 were the first precise ground-based measurements of the internal circulation since the 1960s, and the period was considerably shorter than in the Voyager images. [Ref.8 & Fig.17].

The N rim faded progressively from 2006 May to July, and a light strip separated the GRS proper from the RSH. In 2006 August, the S rim also faded, leaving the GRS as an isolated oval [Figs.17 & 23(f)].

SEB [Chart J7]

In 2005, the SEB was exactly as it was during the Voyager 1 flyby and in many other years. Images showed a dark grey SEB(N) and dark brown SEB(S) from L2 ~ 260 to the GRS, and the perennial rifted region f. the GRS, which sometimes contained very bright white spots.

Mini-barges (cyclonic circulations) and associated white spots:
A red-brown bar ('barge') in southern SEB was imaged in 2004 Dec. (**Fig.21)**. It shrank to a tiny red wisp during 2005 Feb-May, as a white spot developed on its N edge [SEB nos.1a & 1b in Chart J7 and the Table; **Fig.21]**. White spot no.2 was also on the N edge of a tiny red streak in the barge latitude; white spot no.3 looked similar but with no red streak. The evidence indicates that all three white spots, at ~15.5ºS, were northerly appendages to persistent 'mini-barges' at ~16.5ºS even though these were not always visible. First, nos.1 and 2 were visibly associated with minibarges. Second, the ZDP shows that these white spots at ~15.5ºS were slightly north of the mean spacecraft ZWP, whereas all other features from 12-17ºS were slightly south of it. Third, all three tracks (Chart J7) appeared to be continuous with tracks of red-brown minibarges in 2006. So these minibarges were probably persistent circulations of variable size with variable white spots on their N edges.

Rifted regions in mid-SEB:
In 2004/05, large-scale convective activity was restricted to the perennial post-GRS disturbance, where numerous white spots were prograding at lats.~13-14ºS. Their measured tracks had speeds around DL2 ~ -55, but they tended to decelerate to DL2 ~ -15 as they approached the GRS.

During solar conjunction some time before mid-Oct., 2004, there had evidently been an extension of this activity up to L2 ~ 150, and new white spots were appearing up to L2= 169 up to early Dec., 2004 (e.g. Dec.9, **Fig.3**); but in mid-Dec. the activity was declining and prograding with smaller-scale turbulence. It was again renewed on 2005 April 21, when observers pointed out a brilliant new white spot erupting at L2 ~ 155 [Ref.3 & **Fig.22**]. New white spots appeared at this source, at L2 ~ 157, on April 21, 27, 30, and May 5 and 17, as shown in **Fig.22**. Don Parker's methane image on 2005 June 15 (Fig.7) showed that another such spot was methane-bright.

In late 2005, two **mid-SEB outbreaks** began. These are large-scale outbreaks of convective white clouds, similar to those in the perennial disturbance f. the GRS, but remote from it; the last one had been in autumn 2003. These outbreaks were covered in [Ref.5 nos.1&2].

The first outbreak started during solar conjunction and had its f. end near L2 = 180 (2005 Dec.9, T. Olivetti), soon extending to L2 = 195 (Dec.24 and Jan.8, H. Einaga of ALPO-Japan). It could alternatively be regarded as yet another extension of the perennial post-GRS disturbance, depending on one's definition, though it was further f. than the extensions in 2004 and 2005 April.

The second outbreak began at the start of the apparition, on 2005 Dec 10, at L2 = 350 (Olivetti's image). It was first reported by Einaga, who recorded it on 2005 Dec.18, and was tracked by him. It continued to show vigorous activity, producing more white spots, spreading to lower longitude, as is typical. The f. end and source prograded from L2 ~ 350 in Dec. to 330 on Feb.5, 320 on Feb.24, and 310 in mid-April, 2006. Throughout this time, new white spots continued to appear at this source (e.g. April 10, Fig.8; *also see figures in Ref.5 nos.2 & 4*). Indeed it was still producing bright white spots up to L2 ~230 as of 2006 July 1 (Miyazaki & Akutsu, e.g. Fig.9).

So by 2006 Feb, most of the SEB was in turmoil! These two mid-SEB outbreaks led to disturbance almost all round the SEB (Fig.6), including more spots in northern SEB spreading p. the RSH. Just f. the GRS, white spots were tracked between 13-15ºS. At L2 ~ 160-280 (within the mid-SEBOs), many were tracked between 11-13.5ºS. At higher longitudes (outside the rifted regions), many less conspicuous white spots were tracked at ~11ºS. The white spots lay on a consistent cyclonic gradient, independent of longitude, which was essentially the same as in 2005 (see ZDPs in Fig.20). This was slightly south of the Cassini ZWP over most of the SEB, but this may not be significant as spacecraft ZWPs show considerable scatter. Thus the ZDP seems to represent the ZWP, which did not change detectably during the mid-SEB outbreaks. However, short-lived white spots (lifetimes <20 d) showed more scatter in the ZDP than long-lived spots (Fig.20B), suggesting that spots can be born with a variety of speeds, but only those which match the local ZWP, or adjust towards it, survive for a long time.

Dark spots were mainly recorded at ~11-13ºS, rapidly prograding, and some of them survived for some time (in 2005, one covered ~200º in L2).

REFERENCES follow Part V.

FIGURE LEGENDS: next page.

FIGURE LEGENDS

South is up in all figures unless otherwise stated (Fig.2).

Fig. 1: Occultation of Jupiter by the Moon (South polar region), 2004 Dec.7: image sequence by Don Parker, taken with 254-mm Mewlon telescope. South is up. Brightness was adjusted separately for Jupiter and the Moon.

Fig. 2: Occultation of Jupiter by the Moon (North polar region), 2005 Feb.27: image sequence by Maurice Valimberti. North is up (unlike other figures). Brightness was adjusted separately for Jupiter and the Moon.

Fig. 3: Images all around the planet in 2004 Nov-Dec., at the start of the 2004/05 apparition. Some major features are indicated, including dark formations A1-A6 on NEBs.

Fig.4: Images around the planet on 2005 April 3-5. (Compare with Peach's map a few weeks later in Fig.5.) Major features are labelled on some images, including the AWOs in the S2 domain, oval Q in the S. Tropical domain, and barges and AWOs in the N.Tropical domain. As opposition was on April 3, these images include two transits of Io in front of its shadow, and one transit of Ganymede adjacent to its shadow.

Fig.5: Map of the planet prepared by Damian Peach from his own images in 2005 April, with labels added for the major features.

Fig.6: Map of the planet prepared by Damian Peach from his own images in 2006 April, with labels added for the major features.

Fig.7: Images of Jupiter in the 889-nm methane band, 2005. (See figure for caption.)

Fig.8: Multispectral image sets in 2006 by several observers, including ultraviolet, methane band, and near-infrared continuum, with visible colour (RGB) images for comparison.

Fig.9: Multispectral image sets in 2006 by Tomio Akutsu, including ultraviolet, methane band, and near-infrared continuum, with visible colour (RGB) images for comparison.

Fig.10. Charts of long-lived AWOs in south polar region, 2006. (A) S4-AWO-A, showing regular, synchronous oscillations in longitude and latitude vs time. (B,C) ZDPs for both S4 AWOs and for S3-AWO-1, showing both fast and slow phases of their oscillations. These ZDPs are for 2006 only; in our long-term report [Ref.6] we showed ZDPs for all years.

Fig.11. Images showing the approach and merger of two white spots in the S4 domain. After an alert by H-J. Mettig, the two were tracked up to April 10, and were apparently merging in the near-simultaneuous images by Tyler and Lazzarotti on April 13, but no details of the merger were visible. Also note the S.Trop.Band emerging p. the GRS, with Oval Q due N of the merging S4 spots.

Fig.12. Images including Oval BA and surroundings, 2004/05.

Fig.13. Images including Oval BA and surroundings, 2005 April, at high resolution by Peach.

Fig.14. Images of longitudes from Oval BA to the GRS, 2005 April-May, at high resolution by Peach. Oval Q and white spot Z are also well shown.

Fig.15. Images of the S. hemisphere in 2006 June, showing the ovals in the S2 domain, and dark spots *a-f* in the STropZ, some of which recirculate. The STB Remnant is alongside spots *a* and *b*.

Fig.16. Images including the GRS and oval BA in 2006 April-June. See image for caption. *[Some images were shown in Ref.4]*.

Fig.17. Images including the GRS with oval BA passing it in 2006 July-August. *[Previously posted in Ref.5 no.9.]* This shows: Internal circulation of GRS [Ref.8]; SED passing GRS; & bright spot(s) in the southern NEB (red arrows) breaking through into the EZ(N) at the p. edge of dark projection **k** on July 10. See caption on image for further details.

Fig.18. Images in 2005 April-May showing the STB Remnant and spots moving in the S3 jet, SSTB, S1 jet (STBn jetstream), and STropZ.

Fig.19. The GRS in 2005 May, with spots moving rapidly around and inside it.
Inset: Chart of position angle vs time for the dark grey streak in the GRS (red arrowhead on the images), measured by JHR on images stretched to circularise the GRS, as in [Ref.8]. The trailing end had a period of 4.7 days; the leading end was less well defined but was consistent with the same period.

Fig.20. **(A,B)** ZDPs for STropZ and SEB: (A) 2005, (B) 2006.
(C,D) ZDPs for STropZ and SEBs jet in other years for comparison: (C) 2007, (D) averages for apparitions 1999-2002 and for historic BAA data, plus the typical position of SEBs jet vortices in Cassini data. *[Charts (C,D) were previously posted in Ref.23. The line is the ZWP from Cassini [Ref.33], for comparison.]*

Fig.21. Images in 2004/05 showing how a dark red-brown barge in SEB shrinks as a white spot develops on its N edge. Three white spots at this latitude were probably appendages to inconspicuous cyclonic circulations at the 'barge' latitude (as also a much larger one in 2011-2014).

Fig.22. Images in 2005 April-May, showing a new extension of the post-GRS disturbance in the SEB, which started on April 21.