Jupiter in 1998/99

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A report of the Jupiter Section (Director: John H. Rogers)

The most important event was the merger of the famous long-lived white ovals BC and DE in the South Temperate region. This occurred in early 1998 during solar conjunction. The merged oval 'BE' was slightly larger, of low contrast, but distinct in good images. The remaining oval, FA, was gradually converging on oval BE.

In the South Equatorial Belt, a major new 'mid-SEB outbreak' of turbulent white spots began during solar conjunction and spread most of the way around the planet. The EZ/NEBs edge was unusually disturbed, with especially large and variable projections and plumes. The NEB had reverted to its usual width after the expansion event of 1996. The array of 'barges' that formed as part of the expansion event persisted along its north edge, though they were shrinking during the apparition. One rapidly-moving white spot destroyed barges in its path and created small new ones in its wake.

Introduction

Opposition was on 1998 September 16, at declination 4°S, between Aquarius and Pisces. This report follows on from our previous one for 1997.[1]

The *Galileo* spacecraft continued in orbit during 1998, but was now into the *Galileo* Europa Mission, chiefly targeting Europa at each perijove. Therefore only occasional observations of Jupiter's weather systems were targeted, chiefly of the new white oval BE (see below), and some NEBs features.

Interim reports were published by the BAA[2,3] and ALPO.[4]

PC-JUPOS

PC-JUPOS is a set of software specially written for the observer of Jupiter by Grischa Hahn and H–JM.[6] Its roots go back to the end of the 1980s when H–JM created a *Turbo Pascal* program for collecting CM transit timings of the former East German planetary group. From 1992 onwards Grischa Hahn of Dresden, another Jupiter observer, has been improving the software; he also wrote the CCD measurements module. PC-JUPOS uses the DOS operating system and does not require special hardware or software. The 'JUPOS headquarters' at H–JM's home simply consists of a nine-year-old PC 286.

The CCD measurement software requires images in PCX format, though other customary formats like JPEG or GIF can be accepted and converted to PCX. Date and time of the exposure must be input; JUPOS can then calculate the CM longitude.

A typical content of a PC-JUPOS measurement screen is shown as Figure 1. First the image is zoomed to an appropriate size, its brightness increased to such a degree that Jupiter's limb becomes clearly visible, and the elliptical outline frame placed upon it. If the disk proportions are distorted due to effects of previous image processing, the 'aspect ratio' must be modified appropriately. Then brightness, contrast and gamma coefficient are set so that atmospheric features are best visible. Now, if the small cross-wires are moved to any feature, its longitude and zenographic (jovigraphic) latitude co-ordinates will instantly appear on the screen.

To obtain precise positions, it is essential to position the outline frame as precisely as possible, but this is often difficult. Images with high contrast do not show the genuine limb as the outer portions of the planet shade into the dark background. On the other hand, images taken under bad seeing sometimes show the limb more extended than normal. A moon or shadow visible near or on the disk can be helpful: a comparison of its measured co-ordinates with those computed by the PC-JUPOS ephemerides module may reveal a possible displacement of the outline frame. Another source of imprecision arises far from opposition, when Jupiter's terminator is in view and darkens the p. or f. limb considerably; then it becomes difficult to fix the aspect ratio of high-contrast images. However, if a given observer uses the same imaging system throughout the apparition, the aspect ratio can be determined near opposition and applied also at other times.

Finally the results (date, time, feature, jovigraphic positions, and other information) can be saved to a special database. Further functions of PC-JUPOS enable the user to select features of particular regions and plot their movement in drift charts, such as Figure 12.

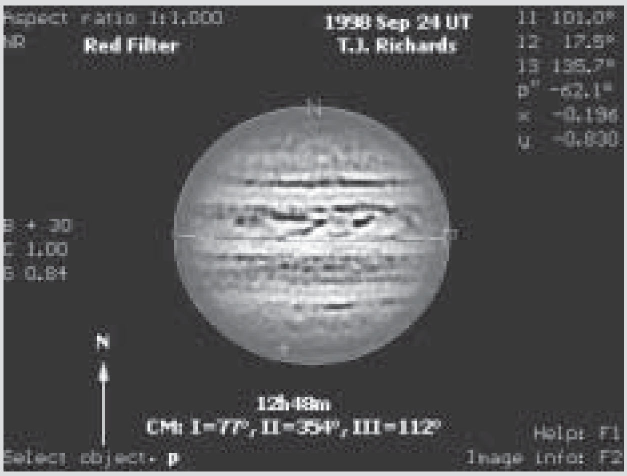

Figure 1. PC-JUPOS measurement of an image taken by T. J. Richards. Cross-wires used for identifying the feature are placed near the southern (bottom) pole for better visibility.

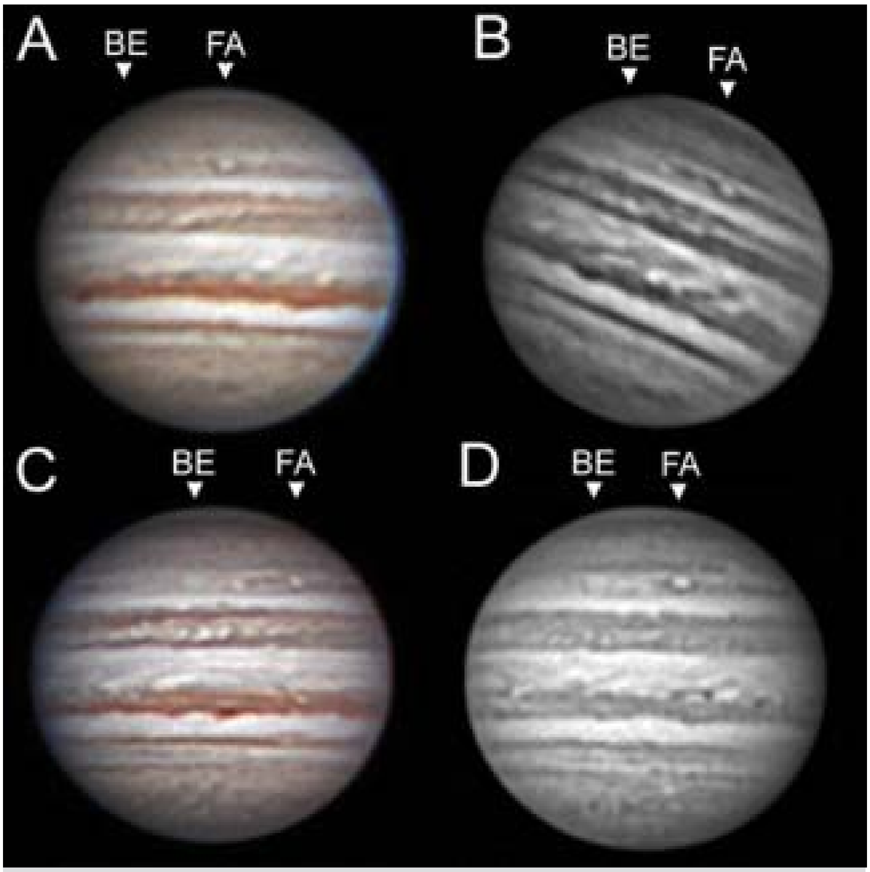

Figure 2. Hi-res images showing ovals BE and FA with the mid-SEB outbreak, whose source/ f. end is always alongside oval FA.
(A) June 28, 09.16 UT, CM1 83.5, CM2 312.5 (Parker). (Oval BE near p. limb, FA on CM.)
(B) Aug.12, 00.31 UT, CM1 33 CM2 281 (Dijon).
(C) Aug.25, 05.30 UT, CM1 109, CM2 256 (Parker). (Oval BE just p. CM, FA on f. side, with small cyclonic white oval between them.)
(D) Nov.6, 10.10 UT, CM1 293, CM2 242 (Bratislav Curcic & Stefan Buda, Australia, with 250mm Dall–Kirkham). (Oval BE on p. side, FA on f. side.)

PC-JUPOS: computer-based analysis of Jupiter observations

In previous apparitions, all measurements on images have been made by JHR, manually on printed images using a transparent overlay [see Appendix 1 of ref.5]. In the 1998/99 apparition, CCD images were also measured by H–JM using an interactive computer system on screen, called PC-JUPOS.[6] (see box). André Nikolai also used PC-JUPOS to measure his own images.

The hi-res images by Isao Miyazaki and Don Parker were measured both by H–JM using PC-JUPOS, and by JHR manually in the usual way. Comparing the results, there does not seem to be any systematic difference in longitudes or drifts. A slight difference emerges from the measurements of the Great Red Spot: nominal drift rates were +0.7 (±0.3)°/mth from JHR and +0.4 (±0.2)°/mth from H–JM. This is consistent with a slight phase effect in JHR's measurements on paper prints (+0.3°/mth), which is the same as indicated by GRS longitudes over the last two apparitions, and half the usual phase effect in visual transit data; it implies zero phase effect in the PC-JUPOS on-screen measurements.

The JUPOS system allowed even smaller features to be tracked than those which JHR measured. Thus on the NEBn, although all the spots listed in the table were tracked by both methods (and most also by visual observers), PC-JUPOS analysis revealed additional small, slightly retrograding dark spots (Figure 12). PC-JUPOS showed ten of them, where JHR only followed four. On the other hand, manual analysis allows features to be annotated so that some obscure but distinctive features, such as the rapidly-moving little red spot on NNTBs, were tracked by JHR but not by PC-JUPOS. In principle, however, PC-JUPOS allows all such features to be tracked, and it provides digital data in a format that can easily be plotted and processed further.

Observations

Observers are listed in Table 1.

Isao Miyazaki sent approximately 600 CCD images; equally

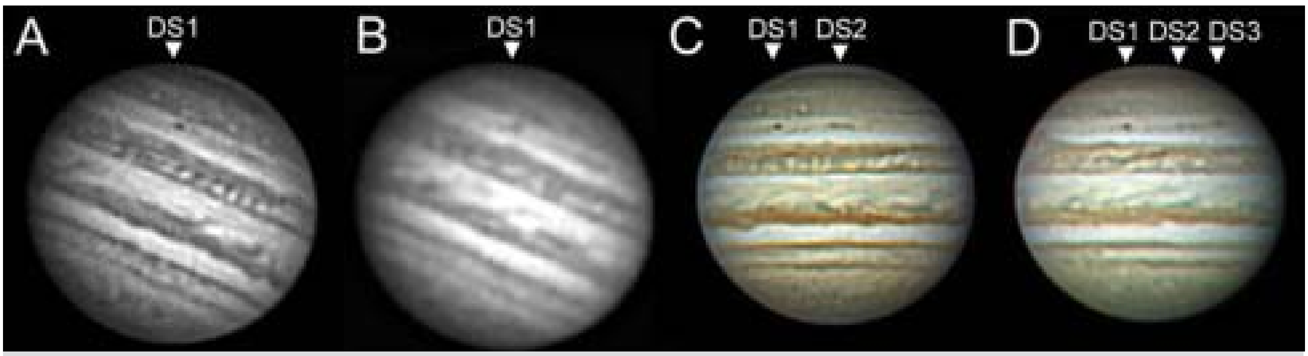

Figure 3. Images showing the STB dark spots, as well as the leading part of the mid-SEB outbreak, which slides north of a dark red-brown streak in SEB at L2 ~ 200.
(A) July 23, 01.48 UT, CM1 159.5, CM2 200 (Dijon). (DS1 is the very small, very dark spot just p. CM; DS2 is the grey streak on f. side.)
(B) Aug.6, 03.05 UT, CM1 259, CM2 192 (Peach). (DS1 is just p. CM.)
(C) Oct.12, 12.42 UT, CM1 38, CM2 177 (Miyazaki) (DS1 on p. side, DS2 on CM.)
(D) Dec.4, 10.19 UT, CM1 36, CM2 131.5 (Miyazaki). (DS1 p. CM, DS2 faint f. CM, followed by the new dark DS3.)

Table 1. Observers of Jupiter, 1998/99

M. Adachi	Otsu, Japan	310mm refl.
A. Cidadao	Oeiras, Portugal	250mm Sch–Cass. (CCD)
E. Colombo	Milano, Italy	254mm refl.
B. Colville	Cambray, Ontario, Canada	250mm Sch–Cass.(CCD); 300mm Sch–Cass.(CCD)
E. Crandall	Winston–Salem, NC, USA	254mm refl.
P. Devadas	Madras, India	360mm refl.
J. Dijon	Champagnier, France	520mm refl. (CCD)
C. Ebdon	London	250mm refl.
M. Foulkes	Hatfield, Herts.	203mm Sch–Cass; 254mm refl.
M. Frassati	Crescentino, Italy	200mm Sch–Cass.
D. Graham	Brompton-on-Swale, N. Yorks.	150mm Mak–Cass;
	Coshocton, Ohio, USA	356mm Sch–Cass.
D. Gray	Kirk Merrington, Co. Durham	415mm Dall–Kirkham
H. Gross	Hagen, Germany	210mm off-axis Cass.
A. Heath	Long Eaton, Notts.	200mm Sch–Cass.
C. Hernandez	Miami, Florida, USA	200mm Sch–Cass.
K. Horikawa	Yokohama, Japan	160mm refl.
M. J. Houston	Glengormley, N. Ireland	200mm refl.
D. Lehman	Fresno, CA, USA	250mm refl.
J. P. Manteca	Barcelona, Spain	250mm Sch–Cass. (CCD)
R.J. McKim	Oundle, Northants.	216mm refl.
F. J. Melillo	Holtsville, New York, USA	200mm Sch–Cass. (CCD)
H–J. Mettig	Dresden, Germany	150mm OG
I. Miyazaki	Okinawa, Japan	400mm refl. (CCD)
A. Nikolai	Berlin, Germany	150mm OG (CCD); 100mm OG
D. Niechoy	Göttingen, Germany	200mm refl.
D. C. Parker	Coral Gables, Florida, USA	410mm Sch–Cass. (CCD)
D. Peach	King's Lynn, Norfolk	300mm Sch–Cass. (CCD)
T. Platt	Binfield, Berks.	318mm Quad–Schiefspiegler (CCD)
Z. Pujic	St. Lucia, Queensland, Australia	320mm refl.
T. J. Richards	Eltham, Vic., Australia	180mm OG (CCD)
A. Sanchez Caso	Gualba, Spain	300mm Sch–Cass. (CCD)
R. W. Schmude	Barnesville, GA, USA	250mm refl.
R. M. Steele	Leeds, W. Yorks.	300mm refl.
J. Stellas	Athens, Greece	
R. Tatum	Richmond, VA, USA	250mm refl.
P. Tanga	Torino, Italy	420mm OG (CCD)
S. R. Whitby	Hopewell, VA, USA	152mm refl; 178mm OG

The following kindly e-mailed collections of their national data:
J. McAnally (Assoc. of Lunar & Planetary Observers, USA)
T. J. Richards (Astronomical Society of Victoria, Australia).

fine images were submitted by Don Parker. We also received an increasing number of good CCD images by e-mail from other observers worldwide. Some also made them available on their own web sites; see links from our Jupiter Section web site.[7] Among visual observers, the greatest contributor was Makato Adachi, who sent 157 drawings. Other substantial sets of good drawings and transits included those from Colin Ebdon, David Graham and David Gray in England, and from H–JM. Kuniaki Horikawa also made many drawings and transits, which he analysed himself and published on his web site;[8] these data were plotted by JUPOS along with H–JM's own transits, and supported the analysis from images. Tracks of spots were established from the full set of JUPOS data, although only the image measurements are counted in the numbers in the tables.

This report has principally been compiled from images. However, the more fortunate visual observers were able to see most of the features reported. Thus Adachi, Frassati, Horikawa, Mettig, and Graham (as guest of Tom Dobbins in Ohio) could occasionally see small spots such as the SSTB white ovals, the STB dark spots, and the N.N. Temperate bright ovals, as well as the low-contrast oval BE. (Oval FA, though smaller, was easier to see.) Other visual observers, including those in the UK who still had to contend with the planet's southerly declination, could not clearly resolve such small features. However all observers could see the many dark barges on NEBn, and the prominent and active projections and white spots on NEBs.

Visual colour and intensity estimates are given in Table 2. Zenographic belt latitudes, measured by JHR from images, are in Table 3. Subsequent tables give latitudes, longitudes, and drift rates of spots. As usual, longitudes (L1, L2) are given in Systems I and II, and drifts (DL1, DL2) are per 30 days.

South Polar region and S.S.S. Temperate region

The CCD images appear to show a white South Polar Hood with a dark collar, as in previous years, but these features are exaggerated by the digital image sharpening.[1]

A small, bright, pinkish or warm-tinted spot was recorded on the north edge of the south polar collar, at 62°S (no.1 in Table 4), looking very much like one recorded in 1996 and 1997 at 60°S. This may have been a single long-lived spot. However in 1998, either the motion was very irregular, or there were three such spots in succession. Either way, the drifts varied from ~0 to –27°/mth. A small white spot in S^3TZ, lat. 50°S, had similar rapid drift. It is unusual that these spots paralleled the SSTC drift further north, but there was no visible connection and this may have been merely coincidence.

From the south polar collar to the STZ, the region was mostly dusky and contained multiple narrow belt segments. From L_2 ~110–190 (July), ~90–170 (Sep.), there was a white S^3TZ (49–54°S). Its ends were diffuse, but just p. it was the distinct f. end of a dark S^3TB segment, with slow albeit variable drift typical of the S^3TC (DL2 = –7). Although similar white sectors were present in 1996 and 1997, they were not at consistent longitudes.

S.S. Temperate region

The principal features were the seven small long-lived anticyclonic white ovals (AWOs) at 41°S, moving with SSTC as usual. Most could be tracked from 1997; one had disappeared and a new one had appeared. One of the seven shrank to invisibility in autumn 1998. As usual, the latitude of the AWOs was fixed regardless of the surrounding belt patterns.

In the sector alongside the aforementioned S^3TZ, there was a broad double belt including both S^3TB and SSTB, with the AWOs lying between its components (Figure 4). Further f., south of ovals BE and FA, there was a rather narrow dark SSTB, but no other significant belts nor ovals in the S.S. Temperate region. From late September this SSTB segment had a distinct f. end at an AWO (no.4 in Table 4), which

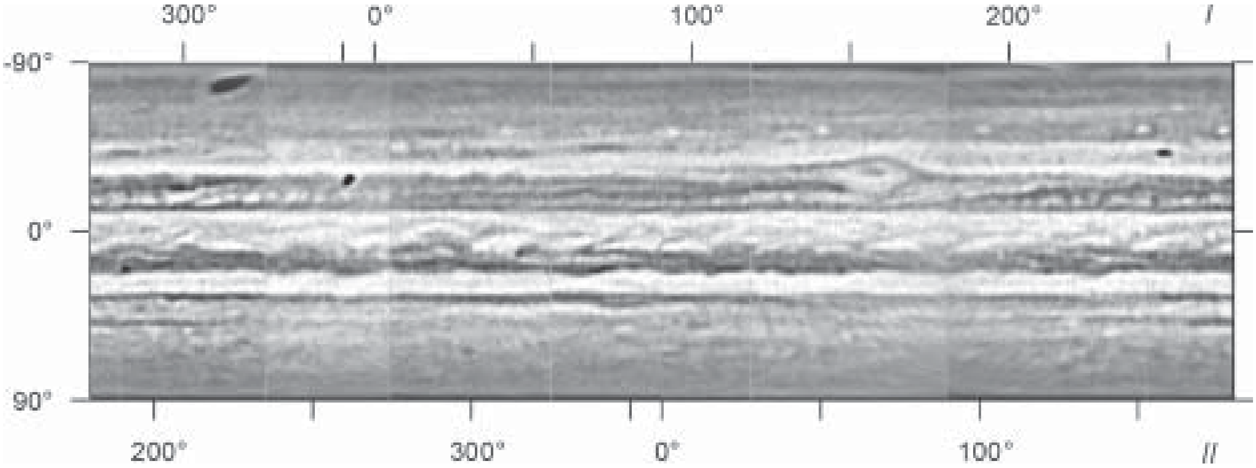

Figure 4. Map of the planet, 1998 Sep. 24–26, from 8 white-light images by Isao Miyazaki, mapped as a photomosaic by Hans-Joerg Mettig, using a program specially written by Grischa Hahn. South is up, as in all subsequent figures. Longitude scales are for System I above and System II below. Dark spots at L2 ~ 225 (SPR) and 260 (SEBs) are the shadows of Callisto and Europa; one at L2 ~ 160 is STB Dark Spot 1. For original images see refs. 2 & 7.

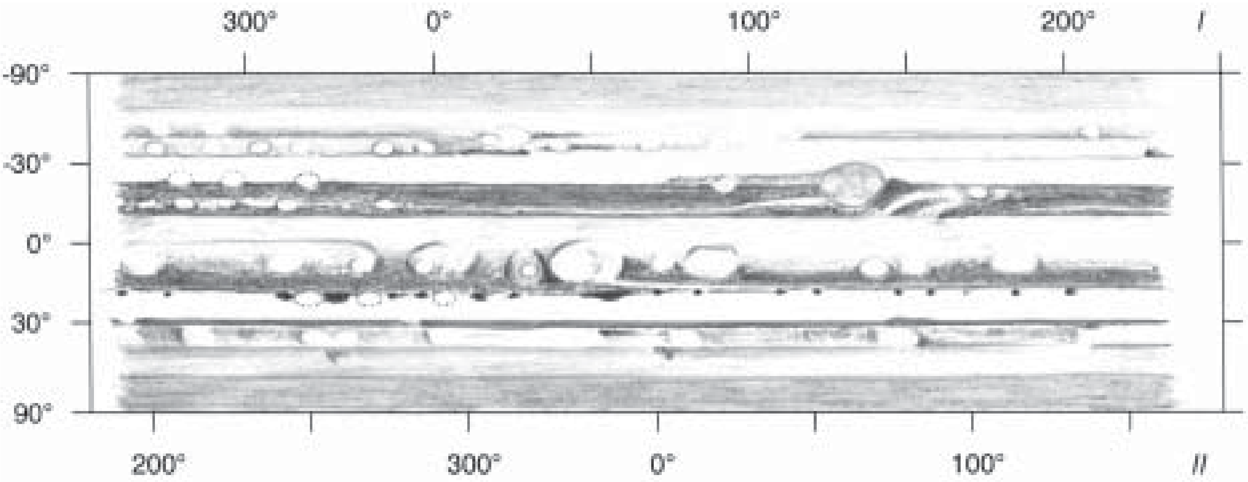

Figure 5. Visual map of the planet, 1998 Sep. 20–24, drawn by Hans-Joerg Mettig from 12 of his original drawings, taken with the 150mm coudé refractor of the Radebeul Observatory, near Dresden, Germany. Compare with Figure 4.

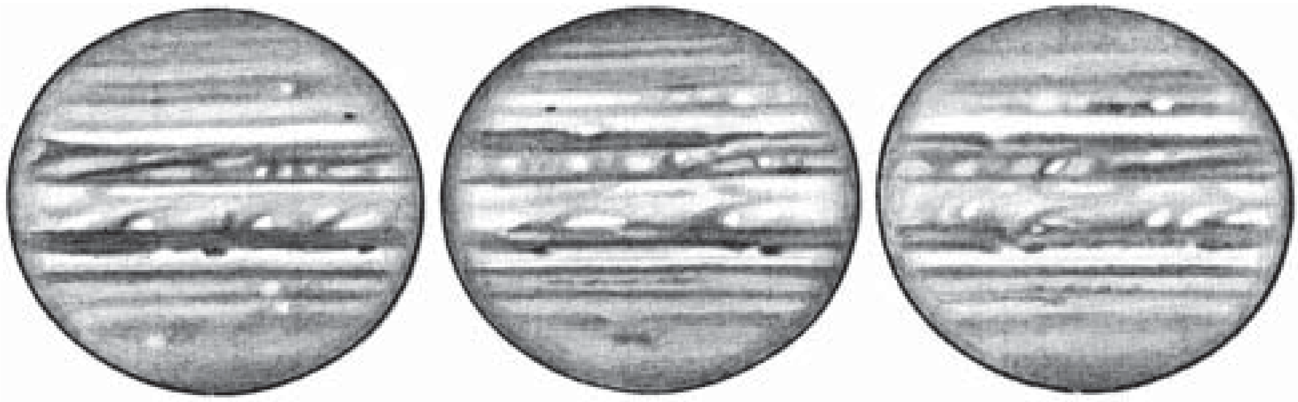

Figure 6. Three drawings by Makoto Adachi, covering half the planet in August, including the S. Temperate spots and SEB rifts.
(A) *(left)* Aug.5/6, 15.38 UT, CM1 200, CM2 137 (GRS on p. limb).
(B) *(centre)* Aug.15/16, 16.26 UT, CM1 9, CM2 230 (STB DS1 on p. side, DS2 on f. side).
(C) *(right)* Aug.11, 14.22 UT, CM1 22, CM2 273 (oval BE just p. CM, cyclonic white oval on CM, oval FA in f. side; source/f. end of mid-SEB outbreak on CM).

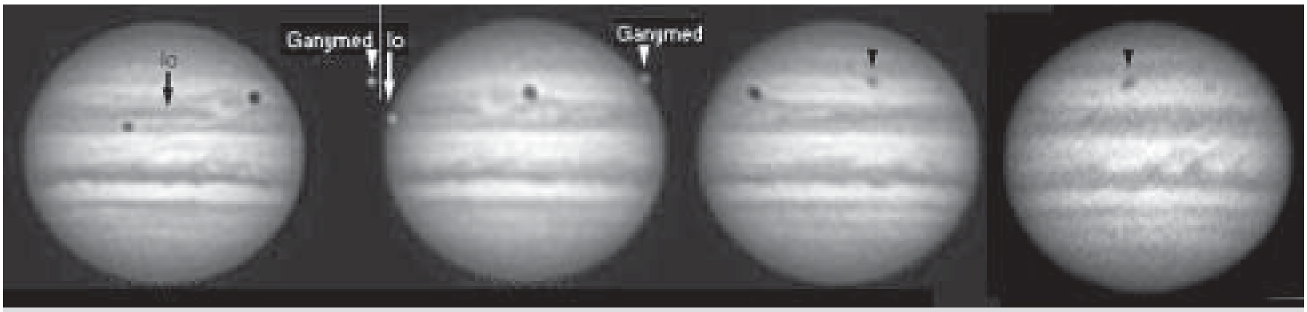

Figure 7. Double transit of Io (I) (arrow) and Ganymede (III) (arrowhead) and their shadows, on 1998 Aug.31/Sep.1, imaged from Germany by André Nikolai (A–C) and from Ontario by Brian Colville (D).
(A) *(left)* 00.10 UT, CM1 301, CM2 37;
(B) *(centre left)* 01.18 UT, CM1 342, CM2 78;
(C) *(centre right)* 02.26 UT, CM1 23, CM2 119;
(D) *(right)* 03.06 UT, CM1 45, CM2 143.
Black spots transited in the following order: ShI, ShIII (on f. end of the GRS), III, then STB DS1.
In (B), Io (at end of transit) and Ganymede (at start of transit) are on the p. and f. limbs.

hitherto had no dark surround as it was passing through dusky or complex regions.

South Temperate region

The major event in this region was the merger of long-lived ovals BC and DE, which happened during solar conjunction, some time between 1998 January 17 and March 27. This event was very important because mergers of large anticyclonic circulations such as these had been predicted by atmospheric models, but never observed until recently. Indeed, these large ovals instead seemed to repel each other. Ovals BC, DE, and FA had been familiar features of Jupiter's South Temperate region since the 1940s,[5] and they had sometimes converged but never collided. Around 1990, ovals BC and DE had come to lie 18–20° apart, and they remained so until late 1997. Therefore, when the first observations of the 1998 apparition showed only one oval in place of BC and DE, NASA scientists made every effort to get observations of it from astronomers worldwide including the BAA, and to image it with the Hubble Space Telescope and the *Galileo* Orbiter, in order to study its structure and dynamics.

In retrospect, ovals BC and DE were beginning to converge in late 1997.[1] They had maintained almost steady drift of –12°/mth in 1997 while passing the GRS, their centres 18° apart. However in late October, just after passing the GRS, BC decelerated and DE accelerated, bringing them only 11° apart in 1997 December. In 1998 January both ovals were smoothly accelerating but continuing to converge (10° apart on Jan.17).[9] Six weeks later, after solar conjunction, there was only one oval, which was named 'BE'. It lay approximately on the previous track of oval BC, but we believe that oval DE had merged with BC, rather than just disappeared: firstly because of their rapid convergence observed just before solar conjunction, and secondly because of the distinctive properties of oval BE thereafter. The merger happened by 1998 March 27, as there was a single oval then in images from the NASA Infrared Telescope Facility (IRTF) (Dr Glenn Orton, pers. comm.), and a single bright spot on a lo-res image on March 31 (Miyazaki). However the merger was first reported in early May by Dr J. Lecacheux and colleagues at the Pic du Midi Observatory,[9] and quickly confirmed by Miyazaki. The anticyclonic white ovals are always bright in methane-band images, and BE was as methane-bright as its predecessors;[2,3,10] these images confirmed that there was now only one oval, not two.

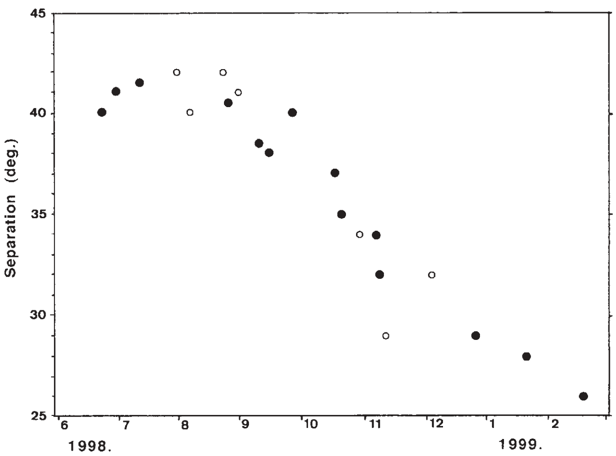

Figure 8. Convergence of ovals BE and FA, as measured by JHR from CCD images (mostly by Miyazaki). The centre-to-centre distance is plotted in degrees longitude. Open symbols are imprecise measurements. Measurements in infrared methane-band images from the NASA Infrared Telescope Facility (Dr Glenn Orton, pers. comm.) showed the same trend but averaged about 2° closer.

Images of oval BE are in Figure 2. At visual wavelengths, oval BE was of low contrast, but it was distinct in good images, and slightly larger than its precursors.[2,3] It remained less bright, and had no dark rim; indeed in July and August it was almost as grey as its lightly shaded surroundings. At first oval BE was moving unusually fast (DL2 = –16° per month) but after June it had a more typical drift of –12°/month. Latitude measurements showed no significant difference from oval FA (33°S), either before or after the deceleration.

The other major spots in the region were as follows, numbered as in Table 4; see Figures 2–8.

(No.14) Anticyclonic oval BE.

(No.15) A small cyclonic white oval, first seen distinctly on June 30 immediately Nf. oval BE, although bright or reddish patches were there earlier. Since then it drifted to lie close to oval FA, before disappearing in November as BE and FA converged.

(No.16) Anticyclonic oval FA, 40° f. BE, still very distinct. Ovals BE and FA converged at ~2°/mth from July onwards, starting from 41° in 1998 July (centre to centre) (Figure 8). Convergence was especially fast in November (about 8°), then they remained 30° apart during December. They converged slightly again in January and separation decreased to 26° on 1999 Feb. 17, the last Miyazaki image. However, data from Dr Glenn Orton (pers.com.)

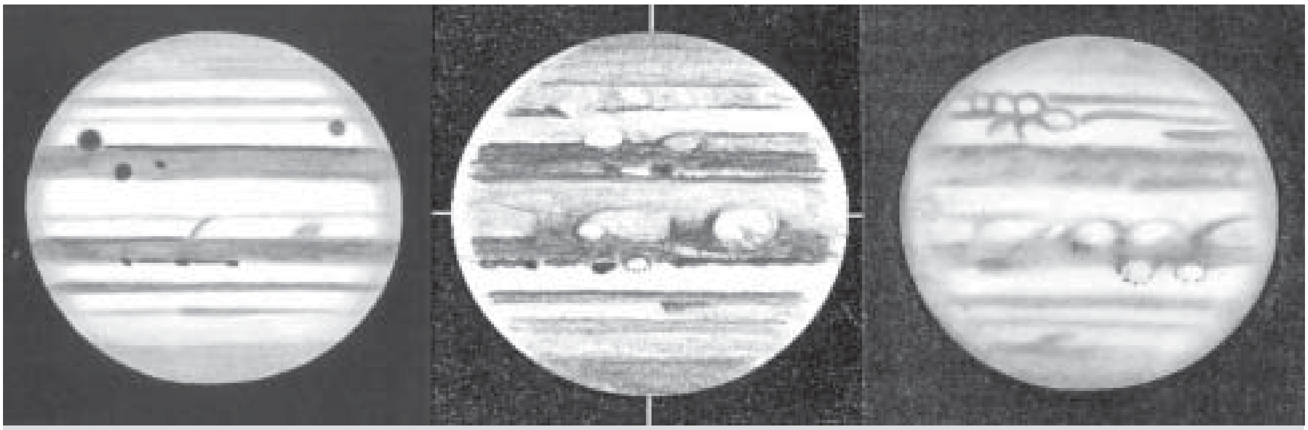

Figure 9. Drawings of the sector p. the GRS.
(A) *(left)* Aug.24, 22.30 UT, CM1 213, CM2 3 (Foulkes). One week before Figure 7, there was another double transit of Io (invisible near CM) and Ganymede (dark on f. side) and their shadows (on p. side).
(B) *(centre)* Oct.18, 22.14 UT, CM1 254, CM2 345 (Mettig). On the CM are p. end of S. Tropical Band, and white spot Z on NEBn, interacting with dark barge p. it.
(C) *(right)* Oct.20, 03.15 UT, CM1 235, CM2 317 (Graham, with Tom Dobbins in Ohio). Shows the same features as (B), on f. side.

Table 2. Intensities and colours, 1998 (visual estimates)

	Foulkes (Aug–Feb)	*Frassati (June–Dec)*		*Gray (June)*	*McKim (Sep–Oct)*	*Heath (Sep–Nov)*		
N=		*9*		*3*	*4*	*12*	*(R–B)*	
SPR	Grey	4.3	grey-brown	Grey	3.0	3.0	1.5, 2.1	Sl. warm grey
SSTZ	Light grey or yel.	3.6	yel.-brown	–	–	–		
SSTB	Greyish	–		Grey	3.8	–		
STZ	Cream or w.	3.2	yel.-brown	Greyish-w.	1.8	–		
STB	Greyish	4.2	brown	Grey-fawn	4.2	4.1	1.2, 1.4	Grey
STropZ	Cream or w.	1.9	light yel.-w.	Light yelh-grey	0.6	0.8	1.2, 2.1	Warm off-w.
GRS	Faint grey	3.9	pink	–	2.8	3.3	3.0, 3.2	Hint of pink
SEB(S) & (N)	Brown	4.8	brown	Brown	4.9	5.0	1.3, 2.6	Brownish
EZ(S)	White or yelh-w.	1.2	yelh-w.	Off-w.	0.6	0.7	0.6, 1.3	Off-w.
EZ(N)	or light grey			Pale yelh.	0.7			
NEB(S) & (N)	Brown	5.6	brown	Brown	5.1	5.0	1.5, 2.9	Brownish
NTropZ	White or yelh.-w.	2.2	light yel.	Yel.	1.2	0.6	0.4, 1.5	Off-w.
NTB	Brown	5.3	brown	Brownish-grey*	4.4	4.9	0.9, 1.3	Grey
NTZ	Light grey or yel.	2.9	yel.	Brownish	2.1	2.2	1.8, 2.4	–
NNTB	Grey	4.5	brown	Deep brown-ochre	4.0	–		
NNTZ	–	3.5	yel.-grey	–	2.8	–		
NPR	Grey	4.3	grey	Blue-grey	3.0	3.4	1.6, 2.1	Sl. warm grey

Notes
w., white; yel., yellow; yelh.; yellowish. N= number of observations (number for GRS was smaller).
Heath's 'R–B' column is the difference between his estimates in red (CM25) and blue (W44a, W47) filters.
*To Gray, NTB or its southern half was 'blue-grey/slate' on June 29 and 30 and 'distinctly blue' on July 22.

Table 3. Latitudes of belts, 1998

	(a)	*(b)*
SPHn/SPBs	−70.6	−70.7
SPBn	−64.3	−63.3
STropBand	−24.2	–
SEBs	−22.0	−21.7
Brown SEB(C)	−16.7	–
Blue SEB(C)	−14.2	–
SEB(N)s	−10.4	–
SEB(N)n	−07.5	−06.6
EBs	−04.7	−03.6
NEBn	+17.1(±)	+16.7
NTropBand (blue)	+21.8	+21.8
NTBs (orange)	+25.8	+25.3
NTBn	+28.7	+28.7
NNTBs	+34.3	+36.0
NNTBn	–	+38.7

Zenographic latitudes were measured from Miyazaki's images in Aug.–Sep. by JHR; (a) 3 images, CM2~0; (b) 3 images, CM2~180.

with the NASA/IRTF operators showed separation only 22° (±1°) at the start of March, just before solar conjunction, suggesting rapid convergence had resumed. This set the stage for another merger predicted some time in 1999.[10]

(No.11, DS1) A small, extremely dark spot on STBs, which attracted much attention as it looked almost black. It first appeared in 1997 October.[1] In 1998 it was first imaged on May 20, and appeared much darker on June 25 and 27. It was a sharply defined oval, probably a 'barge', i.e. a cyclonic dark spot in STB latitude (Figures 3, 6, 7). It was reddish-black or brown in some of Miyazaki's images in Nov. and Dec. It persisted, with no change in appearance or drift, until 1999 Jan–Feb., when it was approaching the GRS.

(No.12, DS2) A second dark feature ~30° f. DS1. This was a variably dark grey streak. Sometimes it was ill-defined; sometimes it was involved with one or more tiny white spots. It was most distinct in May and June and September.

(No.13, DS3) A third dark spot, first imaged on Oct. 20. It was a dark grey patch in STZ (not STB) latitudes, further south than the others, embedded in shading. In December it was rather more

Table 4. Longitudes and drifts, 1998: southern hemisphere

1998: *No.*	*Description*	*L2(O)*	*DL2*	*Lat.β″*	*Dates*	*N*	*1997:* *No.*	*L2(O)*	*DL2*	*O–O* *DL2*
SPC										
1	Pinkish light spot SPBn	316	−27	−62.2	June–Oct.	12	?1	344	~0	# −26
S^3TC										
2	F. end dark S^3TB	83	−7	–	July–Oct.	13	–			
3	W.s.. S^3TZ	170	−24	−50.0	June–Oct.	16	–			
SSTC										
4	AWO (tiny, between var. narrow belts)	10	−24.8		June–Jan.	34				
5	AWO (bright)	58	−27.0		May–Dec.	44	$ 2	42	−26.7	−25.6
							$ 3	66	−28.0	−27.4
6	AWO (tiny)	84	−27.3		May–Oct.	19	4	(86)	−26.1	−27.0
7	AWO	113	−32.8		May–Oct.	29	5	146	−28.0	−29.3
			–> −24.8		Oct.–Jan.	14				
8	AWO (recoiled from no.9, Aug.–Oct.)	162	−23.5		May–Aug.	35	6	163	−26.4	−26.9
			–> −33.2		Aug.–Oct.					
			–> −26.0		Oct.–Jan.					
9	AWO	185	−30.0		June–Dec.	36	7	183	−26.2	−26.7
10	AWO (variable surroundings)	321	−27.4		June–Jan.	31	1	338	−25.3	−28.1
Average			−27.4	−41.7	(±3.3)	11				
STC										
11	DS1 Small, very dark spot STBs	164	−15.7	−30.8	June–Feb.	57		–		
12	DS2 Dusky streak STBs	192	−17.0	−30.8	May–Feb.	41		–		
13	DS3 Dark spot STZ	(213)	−17.0	−32.9	Oct.–Jan.	16		–		
14	BE Large grey oval BE (M)	243	−16.4		Mar.–July	9	$ BC	59	−12.1 #	−15.5
			–> −11.6	−32.9	July–Jan.	21	$ DE	76	−11.0 #	−17.7
15	– Cyclonic white oval in STB	260	−9.0	−31.1	June–Nov.	27		–		
16	FA White oval FA (M)	281	−13.7	−33.4	May–Jan.	50	FA	100	−11.9	−13.3
17	– ‘Step-up’ of STB to S	330	−14.4		June–Dec.	29	?9	240	(−11)	−20.1
Average			−14.4		(±2.8)	8				
STBn jetstream										
18	Tiny dark spot in faint STB	(86)	−73	−28.5	Aug.–Sep.	6	–			
STropC										
19	Great Red Spot (M)	67	+0.4	−21.2	June–Feb.	63	GRS	64	+0.7	+0.3
20	Red-brown streak in SEB	(151)	+7	(−16.5)	Sep.–Nov.	10				
21	Red-brown streak in SEB	200	+5	−16.5	May–Oct.	14				
22	Dark spot SEBs/STropZ	(267)	+7	−23.0	July–Sep.	16				
23	Red-brown streak in SEB (& w.s. to N, tracked until Dec.)	340	−12	−16.7	Aug.–Oct.	11				
24*	Dark spot SEBs/STropZ	(20)	+9 –> 0	−22.5	May–Sep.	19				
25*	P. end of STropB	~12	(see text)	−23.7	Aug.–Oct.	16				
26*	W.s. in STropZ(N)	(14)	+5.3	−22.0	Oct.–Jan.	9				
Average	(nos. 20, 21, 22, 24, 26)		+5.6		(±3.0)	6				
Mid-SEB disturbances										
27	2 spots at f. edge of post-GRS outbreak	–	~−50		Sep., Oct.	6/2				
28	4 spots at f. edge of mid-SEB outbreak	–	~−75		July, Oct.	14/4				
29	3 spots late in mid-SEB outbreak	–	−57		Oct., Nov.	14/3				
30	F. edge/source of mid-SEB outbreak	~276	−15.5		Mar.–Sep.	19				

Notes

The columns are as follows: Number; Description; L2(O), System II longitude at opposition on 1998 Sep. 16; DL2, System II drift in degrees per 30 days (for DL3, add +8.0°/month); β″, Zenographic latitude; Dates of observation or drift measurement; N, Number of rotations on which longitude was measured from images. The last four columns give data from the 1997 apparition, followed by DL2 (O–O), the average drift rate between oppositions in 1997 and 1998.

$ May be identified with either or both of two spots in 1997, which were converging and may have merged during solar conjunction.

Drift rate is for a shorter interval over solar conjunction: No.1, 1997 Oct.–1998 June; No.14 (BC, DE), 1998 Jan.–June.

AWO = anticyclonic white oval. (M) These spots were bright in methane band, and all anticyclonic.

* Nos. 24, 25, 26: these three features fall on a common track. No.25 was also influenced by STBn jetstream; see text.

dark and compact but still southerly (Figure 3D).

The STB was a substantial dark belt only f. oval FA. About 50° f. FA, it shifted southwards and broke up into small dark spots or streaks, before disappearing near the longitude of the GRS. F. the GRS, the STB reappeared but was rather diffuse and faint, eventually merging with shading around oval BE. This fainter sector gradually darkened, as well as accumulating the dark spots DS1 to DS3. One tiny jetstream spot was tracked within it for 19 days (no.18 in Table 4).

It will be worth looking out for further changes in the South Temperate domain. It is possible that a new generation of ovals could appear in the same way that the present generation did, as observed around 1940 by the BAA and by E. J. Reese.[5] The situation before 1940 was similar to the present situation, with the STB rather narrow, and an earlier generation of long-lived ovals reaching its end. Three dark sectors of STZ (‘inter-ovals’, analogous to South Tropical Disturbances) appeared, expanded, and decelerated, to enclose the three ovals. We should look out for new ‘inter-ovals’ from now on.

Table 5. Longitudes and drifts, 1998: equatorial region

No.	*Description*	*L1(O)*	*DL1*	*Dates*	*N*
N. Equatorial Current					
	Dark projections (f. edges):				
1	Var. dark feature	40	–10.0	June–Oct.	26
			–> (–8.6)	Oct.–Dec.	9
2	Var. dark feature	62	–11.2	June–Oct.	27
			–> +3.6	Oct.–Feb.	15
3	Plume –> Dark plateau	80	–10.7	May–Sep.	22
			–> +5.0	Sep.–Jan.	19
4a	Dark feature	(102)	–10.7	May–Aug.	8
4b	Conspic. dark plateau	104	(+5.6)	Sep.–Dec.	21
5a	Dark proj.	143	(+7.5)	Sep.–Nov.	13
5b	Dark plateau		+10.0	Dec.–Feb.	9
6	Dark plateau	182	+8.8	July–Oct.	26
			–> (–5.7)	Oct.–Nov.	12
7	Large dark plateau,	213	+5.8	May–Sep.	13
	later inc. plume		–> (–6.4)	Sep.–Nov.	11
			–> +7.1	Nov.–Feb.	14
8a	Dark block,	233	+1 (var.)	May–Oct.	31
8b	later inc. plume	(240)	(+0.4)	Dec.–Feb.	14
9	Plateau,	265	+4.1	June–Feb.	51
	with plume (till Oct.)				
Average	positive drifts (exc. 8 & 9):		+6.8	(±2.2)	8
Average	negative drifts:		–9.1	(±2.4)	6
N. Intermediate Current					
10	F. end of rift in NEB	50	+119	Aug.–Nov.	15

Features 4a–4b, 5a–5b, and 8a–8b, may have been the same objects, but the connections were not clear. Possibly 5a and 6 merged to form 5b.

South Tropical region

Great Red Spot

The GRS was nearly stationary at L2 = 67. Its form was typical, as in the *Voyager* era. In June and July it had a large orange area in the southern half, and a variable grey south rim. From Aug. 1 onwards, the internal reddish area had become smaller, and the south rim became a dark grey arch extending p. into a new S. Tropical Band.

STropZ/SEBs

The S. Tropical Band emerged from the p. end of the GRS dark rim (Figures 9, 10, 13). It was 15° long on Aug. 1 and grew until it encountered a small dark slow-moving spot in northern STropZ, which then provided a fixed p. end for the Band at L2 ~ 12 (Table 4). Thereafter, the p. end of the South Tropical Band varied in position and definition. It was usually near L2 ~12 or 35; but over short periods of a few days, there was evidence of rapid prograding motion ranging from DL2 ~–43 to –88. This indicates that the STBn jetstream was affecting the dark material of the Band locally, although the overall p. end was approximately fixed in the STropC.

A new bright white spot appeared on SEBs p. the GRS in late October, and drifted slowly towards the GRS (no.26 in Table 4). This spot was not unusual, but was interesting because it was bright, and because it was on the former track of the same STropZ dark spot that temporarily formed the p. end of the S. Tropical Band.

These spots, and one or two other dark spots on SEBs, were presumably anticyclonic, while several dark red-brown streaks within the SEBs at 17°S were presumably cyclonic; but both types moved with the typical STropC speed of DL2~+5 to +9°/mth, providing strong confirmation that the STropC is a genuine current with a mean rotation period slightly slower than the GRS [pp.164–7 of ref.5].

Conversely there were a few small dark condensations on SEBs that were probably moving with the retrograding jetstream, but none was tracked through more than three observations.

South Equatorial Belt

The SEB was internally disturbed, mainly due to a major new 'Mid-SEB Outbreak'. Such an outbreak consists of turbulent cyclonic white spots prograding rapidly from a slow-moving source in the belt.[5] It resembles the perennial region of SEBZ disturbance f. the GRS (the 'post-GRS disturbance'; Figure 11).

From the mid-SEB outbreak source to the GRS, the SEB was triple. The N. and S. components were dark grey-brown. The SEB(C) component was blue-grey at most longitudes, but in two sectors it was interrupted by a white strip alongside a dark red-brown streak of SEB(C) lying slightly further south, at 17°S (Figure 11). One of these sectors was very short, with just a white spot on its north edge; the other sector extended to the GRS. There were similar dark red-brown streaks at other

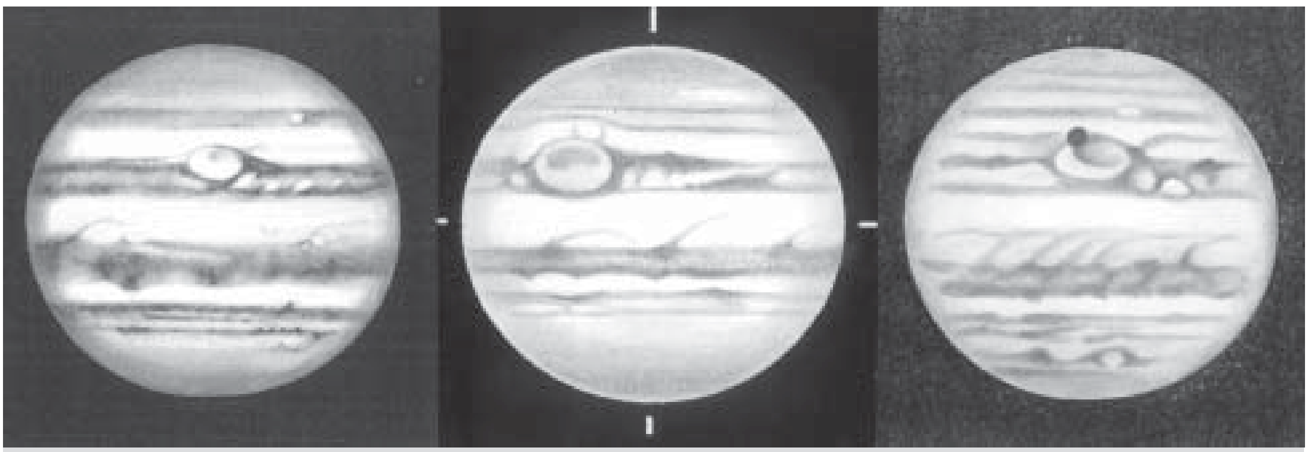

Figure 10. Drawings of the sector f. the GRS.
(A) *(left)* Aug.8, 01.24 UT, CM1 147, CM2 65 (Bullen).
(B) *(centre)* Oct.10, 23.25 UT, CM1 193, CM2 90 (Frassati)
(C) *(right)* Oct.21, 02.10 UT, CM1 354, CM2 68 (Graham, with Dobbins in Ohio). GRS on CM, with Ganymede on its S edge in transit as a dark disk.

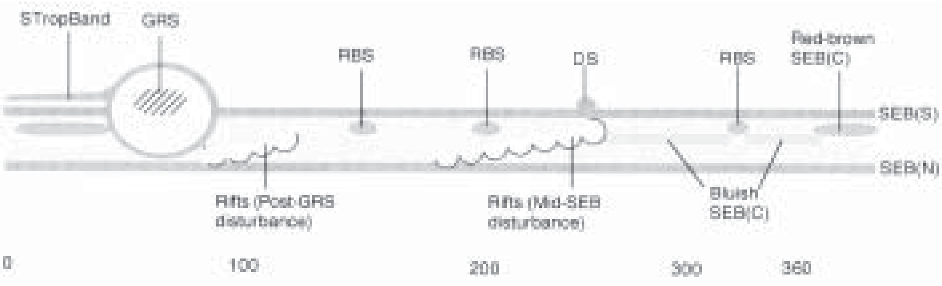

Figure 11. Diagram of the features of the SEB. DS, dark spot on SEBs; RBS, red-brown spot in SEB. An approximate (compressed) System II longitude scale is given beneath.

longitudes, moving with the STropC; these streaks are the SEB's equivalent of 'barges'. In November these streaks were often lost in the turbulence coming from the mid-SEB outbreak, but they still reappeared at times.

The post-GRS disturbance was restricted to a small region beside the GRS in June and July. But a white spot appeared f. this (at L2 = 96) on Aug.6, and several more lined up in a row by Aug. 14–17, so the source and f. end of the disturbance was at L2 = 110 in September. At least three new white spots appeared near L2 = 108 in Sep. and Oct., moving with DL2 ~ –45 or –54°/month over a few days.

The new mid-SEB outbreak (the first for over ten years) began during solar conjunction. It was visible in the first (lo-res) image on March 31, with a f. end/source near L2 ~4. By chance, this slowly prograding f. end/source kept position roughly alongside oval FA throughout the apparition (no.30 in Table 4; Figures 2, 4, 6). New spots still seemed to be appearing there up to September, and one as late as October; several examples had DL2 ~ –75 in July and October. Otherwise we have not tried to track single spots in this long bright chain, which prograded through the north half of the SEB and was intruding north of the post-GRS disturbance by August. After then, activity from the original source declined.

Although the source of the mid-SEB outbreak had virtually ceased after September, a volley of white spots derived from it, comprising a bright turbulent 'rift' or SEBZ segment, was still prograding in the northern SEB in Oct. and Nov. This rift had a f. end and secondary source which prograded from L2 = 220 (Sep. 30) to 166 (Dec. 26), producing several bright white spots prograding at DL2 = –57°/mth (no.29 in Table 4). By Dec. 1, this rift system was under-riding the post-GRS disturbance, and by the end of December, the two were continuous up to L2 ~ 160.

Equatorial region

As in recent apparitions, the EZ(S) was a bright white strip with sharp borders, but the rest of EZ appeared rather dull and subtly coloured. Colour CCD images showed this was due to a maze of faint streaks and spots.

The EZn/NEBs interface was exceptionally disturbed. The NEBs projections were distinctly bluish, and were especially prominent in some sectors, often as distinct bluish 'plateaux'. There were also some bright white spots or plumes; classic white plumes were quite common. These features frequently changed their appearance, sometimes (but not always) because of interactions with the long-lived NEB rift system that passed them at DL1 ~ +119°/mth.

A detailed analysis of all these changes is beyond the scope of this report. We have done a JUPOS analysis of longitudes of

Table 6. Longitudes and drifts, 1998: North Tropical region

1998: No.	*Description*	*L2(O)*	*DL2*	*Lat. β″*	*Dates*	*N*	*1997:* No.	*L2(O)*	*DL2*	*O–O* DL2
NTropC										
	Dark bulges NEBn (d.s.; 'barges') & white bays NEBn/NTropZ:									
1	Big, dark bulge ($)	135	–0.9	+17.6	May–Dec.	59	8	157	–1.5	–1.6
2	White bay	(148)	–3.0		Nov.–Jan.	19	9	189	–4.4	–3.0
3	D.s. ($$)	190	–2.7		May–Aug.	12	11	226	–0.6	–2.7
			–> –0.1	+16.3	Aug.–Jan.					
4*	D.s. ($$)	(244)	–0.7		May–Sep.	15	12	270	–2.4	–1.9
4b	D.s.	(224)	–0.8		Dec.–Feb.	6				
5	White bay	252	–1.0	(+18)	May–Sep.	18	13	280	–2.1	–2.1
6	V.d.s.	260	–4.2		May–July	11	14	290	–1.2	–2.2
			–> –0.9	+17.0	July-Dec.					
7	White bay	298	–2.3	(+18)	June–Nov.	20	–			
8	Large v.dark streak, often projecting, var. form ($$) (= largest barge in 1997)	337	–2.3	+17.7	May–Nov.	36	4	38	–5.6	–4.5
9	Small d.s. ($$)	352	–6.5	+16.0	Aug.–Sep.	23	–			
10	White bay (see text)	356	–10.0	+17.0	May–Oct.	22	5	86	–1.7	–6.7
	#[Lat. for associated w.s. in NTropB]		–> –5.7	#20.2	Oct.–Feb.	16	7	130	–10.5	–10.0
	Small dark spots f. white spot Z:									
11	D.s. ($$)	88	+7.0	+16.6	May–Oct.	13				
12	D.s. ($$)	54	+4.2	+16.6	June–Oct.	29				
13*	D.s.	40	+2.4	+16.6	July–Dec.	33				
14	Small d.s. –> new large barge	(4)	+5.2	+16.3	Sep. –Jan.	23				
Average			–1.2		(±4.1)	18				

Columns are as in Table 4. Most of the dark 'barges' were getting smaller ($) or disappearing ($$).
*No.4 virtually disappeared, but a trace prograded to the site where no.4b then appeared.
No.13 persisted with faster drift into January.

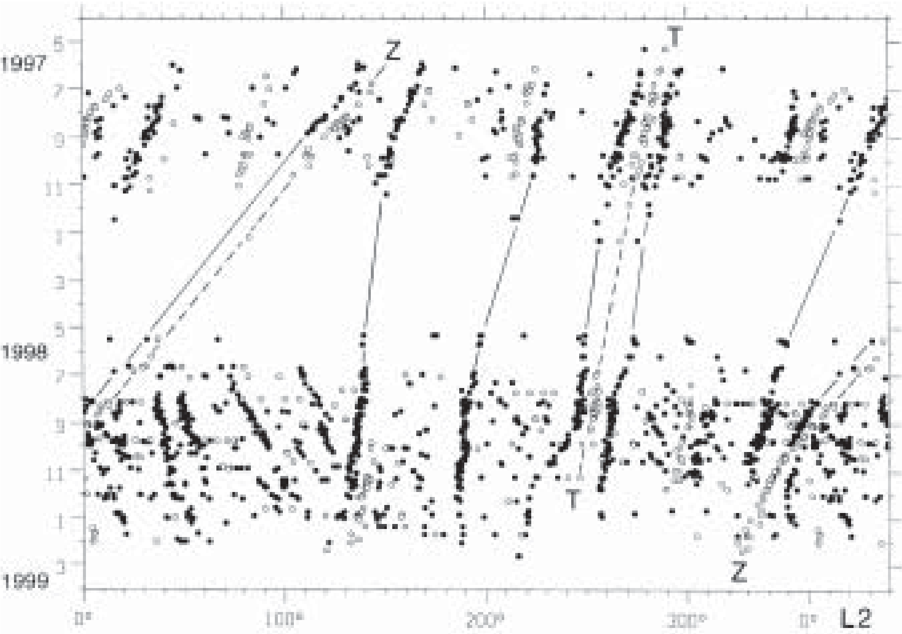

Figure 12. JUPOS charts of the NEBn, 1997 and 1998/99. The ordinate is labelled in months. Black circles are dark spots ('barges'); open circles are bright spots ('portholes' in 1997, 'bays' in 1998/99). Dashed lines connect up two persistent white spots: fast-moving white spot no.10 (Z), and slow-moving white spot no.5 between two barges forming the triplet (T). Solid lines show how the major barges persisted. The 1997 data are from visual transits by several observers, with personal equations corrected. The 1998 data are from visual transits and (mostly) measurements from images.

the f. ends of dark features ('plateaux' or 'projections'), which are usually the locations from which festoons or plumes arise. At least nine features of this type were tracked through the apparition (see Table 5), and we have examined their appearance on images at six epochs from August to November.

At the start of the apparition in 1998 May–June, there were 3 distinct sectors: (i) a sector where features were either subdued or chaotic, L1 ~300–30; (ii) a sector with DL1 ~ –11°/mth (projections 1–4); (iii) a sector with positive DL1 up to +9°/mth (projections 6–9). In Sep–Oct., most of the projections reversed their drifts. Projections 2–4 simply switched to positive drifts (DL1 ~ +5), while projections 6–9 alternated between positive and negative drifts. In fact the near-zero mean motions of nos. 8 and 9 conceal oscillations. Thus no.9 was alternating between DL1 ~ –5 and +10 with a period of ~46 days, and no.7 ended up on the former track of no.6 – showing how difficult it can be to keep track of these projections over long periods. Some of the tabulated drift changes took place with the projection temporarily indistinguishable or unobserved, but others were well observed and took place within a few days without major change of shape of the projection. By early 1999, the projections in all sectors had more coherent drifts ranging from 0 to +10°/mth.

The shapes of these features did not show consistent changes after drift reversals nor after passages of the NEB rift, even though the rift usually caused disturbance or enlargement or disruption of the projection as it passed. Almost every one of these features was sometimes the f. end of a dark plateau, sometimes a plume, or both at once. These appearances did not correlate with drift rate. Thus when nos. 2 and 3 changed from negative to positive drift, no.2 changed from a dark spot to a plume, but no.3 changed from a plume to a dark plateau. Sometimes (e.g. L1 ~ 120–200 in late August), the EZn/NEBs

Table 7. Longitudes and drifts, 1998: North Temperate region

No.	*Description*	*L1*	*DL1*	*Dates*	*N*
NTC-C					
	Tiny dark projs. NTBs (7)	−62.6	−291.6 (±1.7)	May/June–Dec./Jan.	(7 spots)
NTC-B					
	Oblique rifts in NTB (2)	+87	−142 (±3)	July/Aug.–Oct./Nov.	(2 rifts)

1998: No.	*Description*	*L2(O)*	*DL2*	*Lat.β″*	*Dates*	*N*	*1997: No.*	*L2(O)*	*DL2*	*O–O DL2*
NTC-A										
1	P. end dark bar in NTZ	347	+11.6	+29.9	July–Jan	37				
2	F. end dark bar in NTZ	353	+11.1	+29.9	Aug.–Jan.	28				
3	F. end second dark bar	(10)	+10.9		Nov.–Jan.	7				
	(For other dusky streaks, see text)		+12 to +30							
Average			+19.6							
NNTC etc.										
4	Tiny red spot on NNTBs (M)	235	−41	(+36)	June–Sep.	10	7	348	−26	#−36
5	Dark red-brown spot in NNTB	9	+2.0	+38.8	Aug.–Oct.	14				
6	Small w. oval interrupting NNTB	134	−22–> −14	+36.4	Aug.–Dec.	27				
7	W. oval in NNTZ (var. drift) (M)	142	−9.8	+42.0	May–Dec.	27	10	309	−13	−12.4
8	W. oval in NNTZ (M)	347	−2.7	+41.0	June–Oct.	17	9	67	−10	−6.0
	(decelerated again after Nov.)		–> (−12)		Oct.–Nov.	10				
Average	(Nos. 5–8)		−7.9		(±7.5)	5				

Notes
Columns are as in Table 4. The last four columns give data from the 1997 apparition, followed by DL2 (O–O), the average drift rate between oppositions in 1997 and 1998.
For no. 4, drift rate is from 1997 Oct.–1998 June. (M) These spots were bright in methane band, and all anticyclonic.

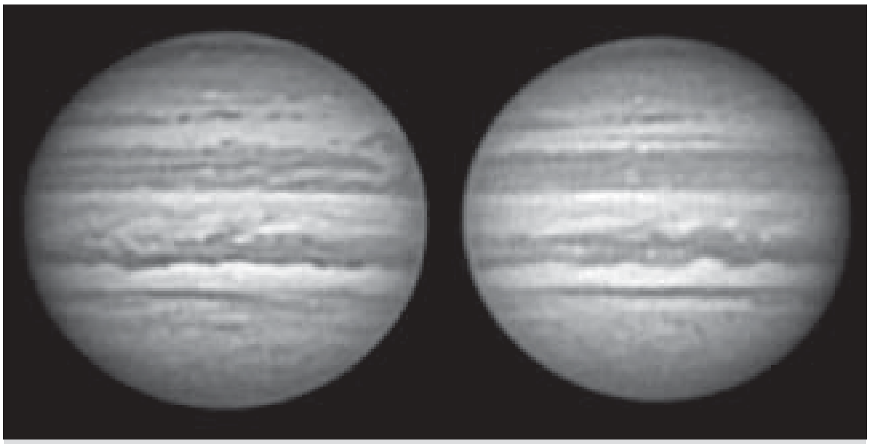

Figure 13. Images showing white spot Z on NEBn, by Isao Miyazaki. (Also see Figure 9.)
(A) Aug.3, 20.20 UT, CM1 56, CM2 7. Big barge no.8 on p. side; spot Z on CM, visible as a shallow bay in NEBn with a tiny white oval in N. Tropical Band. Also note NTB rift on f. side. Also, GRS is near f. limb with first signs of S. Tropical Band emerging p. it.
(B) Nov.16, 10.48 UT, CM1 94, CM2 327. Spot Z is now a big bright bay, just f. CM. Big barge no.8 (on CM) has almost disappeared; instead, dark material is accumulating in a new big barge f. spot Z.

features were less conspicuous with lower contrast, although images revealed that they were still large and variable.

The disturbed sector (L1 ~300–30) always contained some major dark blocks and/or plateaux like those elsewhere, though they were even more variable. As an example, we examined the rapid largescale changes in this sector in early September. These changes were largely due to passage of a bright turbulent 'rift' in the NEB, seen at L1 ~308–342 on Aug. 31. As the rift drifted to higher L1 (varying in appearance), white spots continued to develop on the N. edge of a blue 'plateau' at L1 = 325–342 on Sep. 5 & 7, and the rift was bright again and interacting with dark bluish NEBs projections at L1 = 13–39 on Sep. 14. (However projections 1 and 2, immediately following, were already disturbed and temporarily merged into a single dark plateau on Aug. 25, before the rift arrived.)

Within the NEB, there were two persistent rifted regions ~180° apart. The more conspicuous moved with DL1 = +119 (DL2 = –110; typical N. Intermediate Current). It was ~40° long but sometimes extended further p. (as rifts remained hung up on NEBs plateaux). The other rifted region was just a sector where a few small white spots or longer NEBZ segments were occasionally seen, and had similar NIC drift.

N. Tropical region

The NEB was narrower than last year; it had reverted to its usual width after the expansion event of 1996. As well as the dark bluish sectors of NEB(S), there were sectors of very dark brown NEB(N), mainly seen alongside or following the passage of the rift. (These may have been enhanced by image processing.)

Along the NEBn edge, there were many dark red-brown spots and streaks. These were the array of 'barges' that formed in early 1997 as part of the expansion event, now left exposed on the edge of the narrowed belt. They are tracked in Table 6 and Figure 12. They all diminished in size and/or intensity as 1998 progressed, consistent with the typical lifetime of 1–2 years. They were not as well-defined as barges in some apparitions, being either small very dark spots, or streaks or bulges with ill-defined ends.

The sector from L2 ~270–60 was variable; there were often minor features not listed in the table, whereas the listed dark spots were occasionally lost in longer NEB(N) streaks when a NEB rift had passed. This sector was also disturbed by the remarkable white spot which we call 'Z' (Figures 9 & 13).

White spot Z, one of the 'bays' in NEBn, was persistent although not always conspicuous, as it was moving through a region of variable dark streaks on NEBn. It had an exceptionally fast drift (DL2 = –10; no.10 in Table 6; see Figure 12). It could be identified with a 1997 white spot with similar rapid drift, and/or a slower-moving white spot p. it; the former probably overrode or merged with the latter during solar conjunction, maintaining average DL2 = –10 throughout. Although the main white bay, like others, had a latitude of ~17°N, it was accompanied by a tiny white spot due north at 20°N, within the bluish N.Trop.Band (Figure 13A). This latitude is more typical for anticyclonic spots in NTropZ and suggests that spot Z was more substantial than the other 'white bays'. As it moved along the NEBn edge, white spot Z seems to have greatly influenced the dark 'barges'. It came up to and destroyed a tiny dark spot p. it (no.9), and then in October it impacted on the largest dark barge which had persisted since 1997 (no.8). This had been a variable dark streak, and in early October was not distinguishable as a NEB rift had passed, but on Oct. 18 the interaction with white spot Z had induced a northward dark projection from the p. part of dark streak no.8. In November, as the white bay Z pressed against the f. end of the barge, the bay deepened and slowed to DL2 = –5°/mth, while the barge was deformed and then faded. Meanwhile a new dark barge formed f. the white bay Z, stationary at L2 =352. Images from Nov. 16 to Dec. 5 even suggest that very dark material may have flowed from the old barge to the new barge around the south edge of the bay (Figure 13B). The white bay Z was still very deep in January, at L2 =336; and the big new barge or bulge f. it also persisted. Indeed, these were only the leading members of a series of prominent bays and bulges which then developed in the sector L2 350–50 in Nov–Dec. (Most of them are not listed in Table 6 as drifts were not well determined, but they include no.14 which became prominent from November onwards.)

New dark spots ('mini-barges') were being created following white spot Z throughout the apparition (nos.11–14 in Table 6). These had not existed in 1997 before white spot Z passed by, and they had positive DL2 in contrast to other NEBn barges. They were probably newly created in the wake of white spot Z where it destabilised the retrograding NEBn jetstream, and the spots were probably retrograding because they were interacting with this jetstream [cf. *Voyager* data, chapter 8.4 of ref. 5]. The JUPOS chart (Figure 12) tracked additional spots of this type f. spot Z (ten of them, DL2 = +2 to +16), and also a few at other longitudes (DL2 = +7 to +12).

Of the prominent bays and bulges which developed f. spot Z in Nov–Dec., some also had slightly positive drifts; so the creation of new retrograding features was continuing.

There was also a flurry of activity at other longitudes in December. Whereas several of the pre-existing barges had faded or disappeared, new stable dark barges developed at L2 =147 (with white bay p. it) and 222, and persisted at least until February. The NTropZ was bright white, with a tenuous blue N. Tropical Band in the middle.

North Temperate region

NTBs jetstream spots

This outbreak of small dark spots on the NTBs edge continued, with almost unchanged speed of DL1 = –62.6 (±1.7). JHR, measuring the more distinct spots, recorded five of them. They were all recorded as disappearing in Aug–Sep., in interesting circumstances: three of them became brown or even reddish, and sometimes diffuse, in their final weeks, and they were last recorded in this state as they passed the NTB rifts. However H–JM, measuring even smaller features in contrast-enhanced images, found that there were seven of these spots or projections, and tracked them all to December or January. They had slightly different but invariant speeds, and some may have persisted since 1997 with essentially the same speeds.

NTB rifts

Two long oblique rifts were present from Aug. 1 onwards, trending Sp–Nf, ~20° long though with ill-defined ends (e.g. Figure 13A). They moved at a constant speed DL1 = +87 (DL2 = –142).

While the jetstream spots represented the N. Temperate Current C (NTC-C), these rifts represented the NTC-B, and were a classic example of NTC-B appearing at the end of a NTC-C jetstream outbreak (though one such NTC-B rift was also seen in 1997). The NTC-B was recorded from the 1920s to the 1940s, but not again until the 1990s. (Neither NTC-B nor NTC-C represents the full speed of the NTBs jetstream, which is called NTC-D [chapter 7.4 of ref. 5]; this was revealed in a different type of jetstream outbreak from the 1960s to 1990, but since 1990, the activity has reverted to the older pattern with NTC-C then NTC-B.) Modern resolution shows that the NTC-B features are cyclonic rifts (occasionally containing a small white spot), similar to those of the NEB which also move at a speed intermediate between Systems I and II.

North Temperate Belt and Zone

Apart from these rifts, the NTB was a solid dark belt. A few detached dark features were seen in NTZ, most notably a very dark streak from August onwards (nos.1–2 in Table 7).

Otherwise, NTZ consisted of long white sectors alternating with at least two long grey sectors, the latter usually being resolvable as dusky grey NTZB streaks in the middle of the zone. Two p. ends and three f. ends of these sectors were tracked, all retrograding with the usual N. Temperate Current (NTC-A), but with interesting variations. Each of these ends displayed ‘serial behaviour’ which is typical of these latitudes, temporarily either halting or being replaced by a similar feature at about the same longitude, such that the apparent overall drift (DL2 = +14 to +19, av. +16°/mth) was less than the actual short-term drift (DL2 = +12 to +30, av. +26°/mth). This suggests the influence of the retrograding NTBn jetstream, which is not directly observable from Earth. These dusky sectors extended to cover more than half the NTZ by late October.

N. N. Temperate region

There was a distinct NNTB, but no distinct belts further north.

One remarkable spot was a tiny red oval (no.4 in Table 7) on the NNTBs edge with DL2 = –41. It was only just resolved in colour images, but was bright in methane. It was just like a spot in 1997 with DL2 = –26, and the observations can be connected up through solar conjunction (Table 7). So this was almost certainly a single long-lived spot of a type never before recorded, gradually accelerating towards the NNTBs jetstream speed. It was bright pink in images on 1998 Sep. 8 and 25, but was last imaged on Sep. 30 when it was barely discernible. One more typical dark jetstream spot was imaged on the NNTBs, with DL2 ~ –73, but only in three images over nine days.

Also in the NNTB was a notable white oval (no.6 in Table 7), which appeared on Aug. 27 on NNTBn, but soon interrupted the belt. It too had unusually rapid drift. Another NNTB spot (no.5) was dark red-brown, with more typical NNTC drift, DL2 = +2. Being cyclonic by latitude, neither spot was bright in methane images; this accords with previous observations.[1]

There were two more typical and long-lived white ovals in NNTBn or NNTZ, both anticyclonic by latitude, both bright in methane, with NNTC drifts of DL2 = –10 (no.7) and –3 (no.8). These were the same two methane-bright ovals tracked in 1997, and no.8 had been a Little Red Spot in 1996.[1] Spots 6, 7, and 8 demonstrate the gradient of speed with latitude that is sometimes observed within the NNTC [p.91 of ref. 5].

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