Jupiter in 1999/2000. I: Visible wavelengths

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

During this very favourable apparition, there was increased activity in several regions on Jupiter, with interesting events on both large and small scales. The most notable event was the merger of the last two great white ovals in the South Temperate region, in 2000 March, leaving a single oval which is called 'BA'. There was also a remarkable 'South Equatorial Disturbance', developing progressively during the apparition. It had a main complex manifested as a bright rift and dark bluish patch, which grew larger and larger, and a stormy sector spreading on the prograding jetstream which covered more and more of the circumference as the apparition progressed. The appearance of this disturbance was unprecedented, but dynamically it resembled great white spots seen in 1979 and 1879.

The Equatorial Band and the festoons in the northern Equatorial Zone were much darker and more stable than in recent years. Dark material also appeared to be flowing off the NEBn into the North Tropical Zone. The NEB itself also appeared disturbed, both with persistent barges and bays on the north edge, and with frequent internal bright rifts.

Introduction

The 1999/2000 apparition was favourable for northern hemisphere observers, with the planet at perihelion and quite far north. Opposition was on 1999 Oct.23 at declination 10°N, on the border of Pisces and Aries.

This report follows on from that for 1998/99.[1] An interim report including full details of the South Temperate ovals merger was published in this *Journal* in 2000 August.[2]

Observations began with Miyazaki's first images on 1999 April 24, although little could be resolved until June. As usual, Miyazaki sent images in colour, in white light, and in the methane band, a total of approximately 600 altogether. The first image in the year 2000 was taken by Ikemura on 2000 January 1 at 11.42 UT. The last image was Miyazaki's on 2000 April 17.

Several other observers worldwide are now producing excellent CCD images. These are measured using the PC-JUPOS computer system,[1] producing a database of unprecedented detail and accuracy. As a result, the account of local features and drifts for this apparition, which comprises the largest part of this report, is derived from CCD images alone. Observers and recorders worldwide now comprise an informal collaborative network linked by the Internet, with the best imagers distributing their images to us and to each other via e-mail or Web sites. Measurement of images, and preparation of photomosaic maps and longitude charts, are done using PC-JUPOS by Mettig and Peach (plus Nikolai's measurements of his own images). Charts of longitudes were generated in the same way for both 1998/99 and 1999/00, and many spots could be tracked between the two apparitions, as noted in the tables of this report. The results showed clearly that there is no phase effect in the measurements.

Visual observations are complementary to the CCD imagery. The Jupiter Section continues to encourage observers at all levels to observe Jupiter visually. For this report, visual observations have been analysed by Foulkes, to record what visual observers were able to see of the jovian phenomena, to report colour and intensity impressions, and to provide a range of illustrative drawings. The following 'General Description' section records the appearance of each belt and zone from both visual reports and images. As all CCD images are enhanced for sharpness and contrast before analysis, colours and intensities seen in them should not be accepted uncritically, and visual reports remain worthwhile for comparison. Additionally, advanced visual observers are still welcome to contribute detailed sets of observations that fit into the feature-tracking programme; a set by Horikawa has been included in this report.[6] Section members have conducted a discussion of the future role of visual observations[3,4] and a new Section programme has been adopted which reflects their complementary role (reference 4, and Jupiter Section Web site).

The visual observers are listed in Table 1A. Mario Frassati provided some beautiful colour drawings (e.g. Figure 3B). Makoto Adachi provided a fine set of 136 drawings which were extraordinarily detailed, accurate, and artistic (e.g. Figures 6, 9, 19A). He saw many small streaks and spots that eluded most other visual observers, including the S^{3}TB, all of the S.S. Temperate white ovals, the smaller S. Temperate ovals, an STBn jetstream spot, the South Equatorial Disturbance as early as October, the incomplete North Tropical Band, North Temperate dark streaks, and Io in transit appearing orange (October 9).

This report uses the usual nomenclature of belts and zones.[5] Longitudes are measured in Systems I or II, and are abbreviated as L1, L2; central meridian longitudes, CM1, CM2; drift rates, DL1, DL2 (degrees per 30 days). To maintain the link between our reports and the direct experience and history of visual observers, we continue to use longitude System II, and we will continue to publish images and drawings with south up. (Conversion to System III is easily made using the information in the table footnotes.)

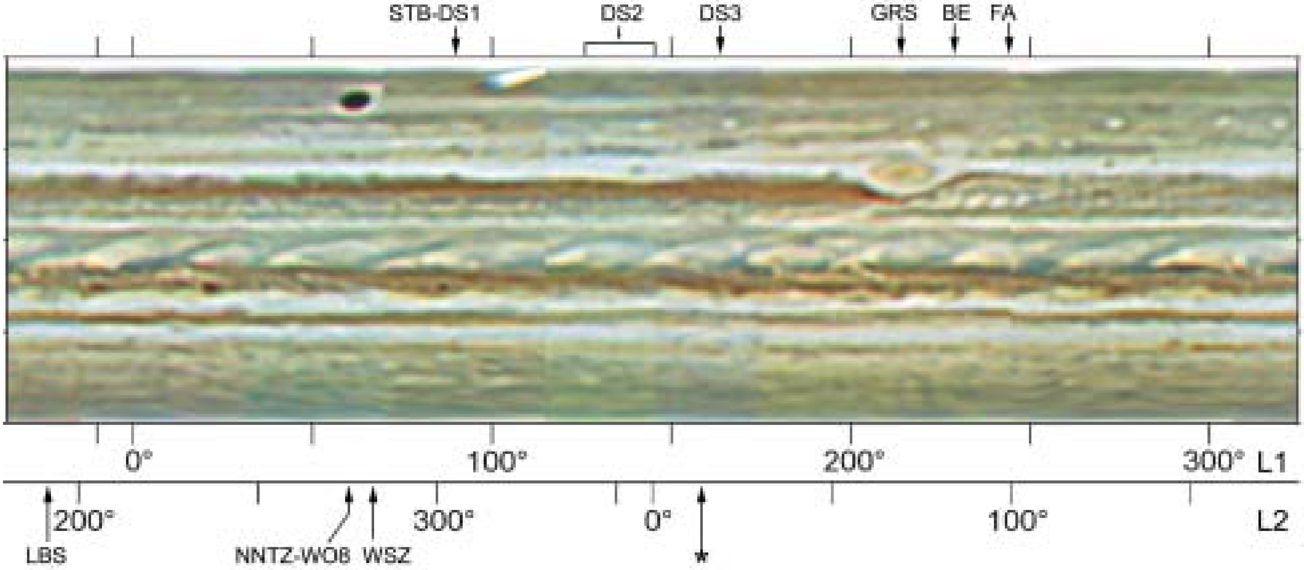

Figure 1. Map of the planet, 1999 Oct. 14–15. Images by Miyazaki were projected into this map by Mettig using PC-JUPOS. South is up, as in all figures. The white streak and black spot in the south polar region are a satellite and its shadow. Important spots are indicated. Asterisk marks where the Little Red Spot on NNTBs is interacting with a NNTBs jetstream spot. The main complex of the South Equatorial Disturbance is passing the Great Red Spot.

Figure 2. Two of the highest-resolution images ever taken with an amateur telescope, by Di Sciullo (copyright Excelsior Optics, Florida). Both show the GRS.
Left: 1999 Sep. 30d 06h 50m (approx.), CM1≈79, CM2≈46: Includes STZ spot DS3, close to the shadow of Ganymede, and at right Ganymede itself with surface markings visible (enlarged 2×).
Right: 1999 Nov. 16d 01h 47m, CM1=121, CM2=91: Includes ovals BE and FA alongside the GRS, with internal structure in oval BE.

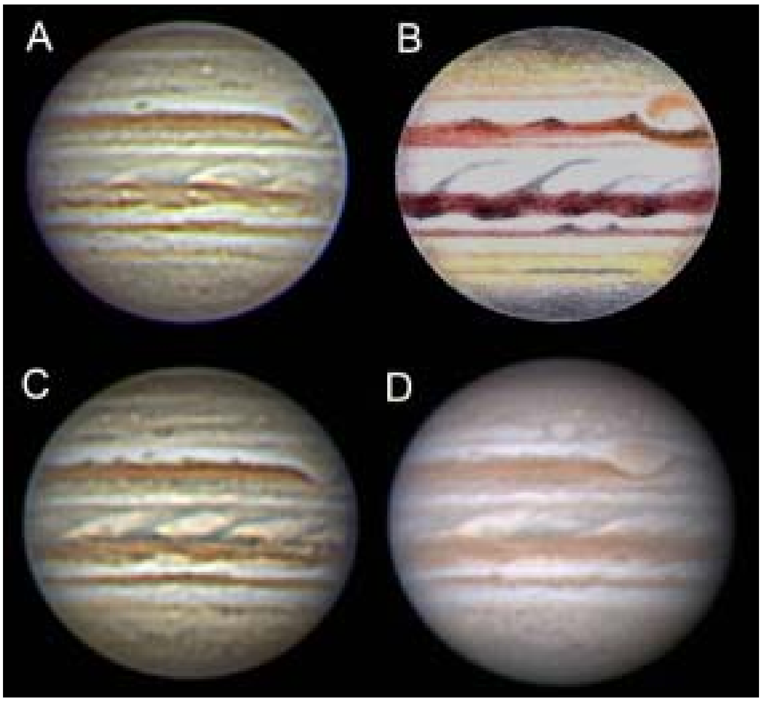

Figure 3. Colour images of the sector p. the GRS, showing the major S. Temperate spots, the new dark oval in STropZ (on p. side), and the changes in the SEB.
A. Sep.5d 20h 23m UT, CM1=225, CM2=19 (Miyazaki). On the STBs are DS2 (streak p. CM) and DS3 (streak f. CM). SEB is dark orange-brown in its S half, and full of tiny spots in its N half.
B. Sep.26d 23h 10m, CM1=47, CM2=37 (Frassati drawing). Jetstream spots are now notable on the SEBs and NTBs.
C. Nov.13d 12h 09m, CM1=27, CM2=17 (Miyazaki). S. Temperate DS3 is now a ring, just p. the CM. There are prominent jetstream spots on SEBs but internally the SEB is unchanged.
D. Jan.10d 01h00m, CM1=134, CM2=46 (Di Sciullo). White oval BE is on CM, and FA is dull reddish f. it as it passes the GRS. Northern SEB is now quieter and a dark blue streak is appearing within it. (See Part II for further change in the SEB in March.)

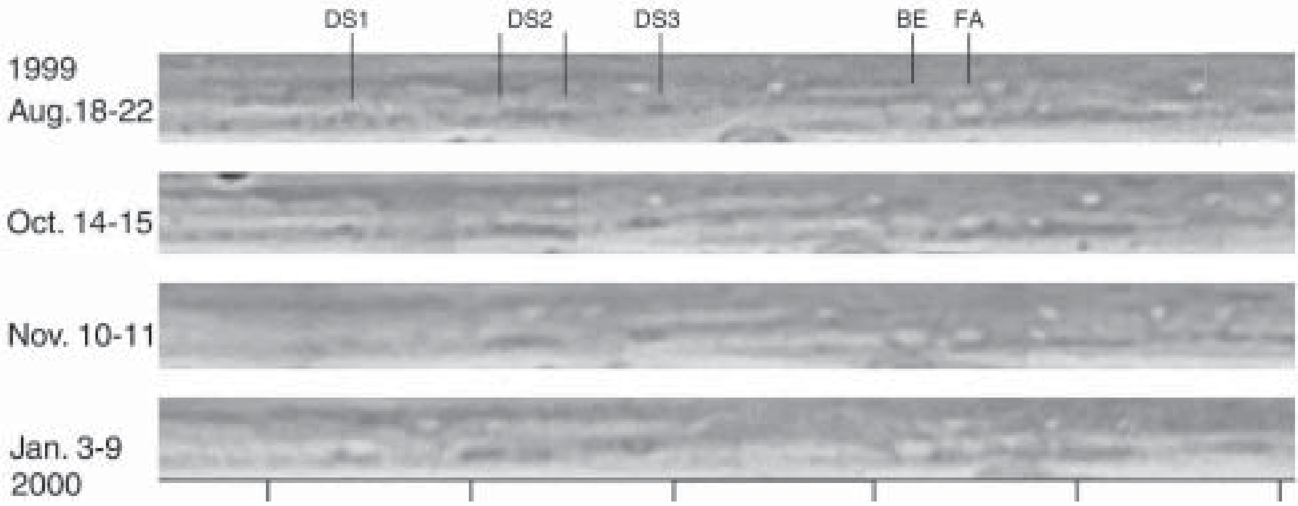

Figure 4A. Strip-maps of the S. and S.S. Temperate regions during the apparition, aligned on oval BE. Ovals BE and FA were still separate in the last map but oval FA was obscure while passing the GRS. Images by Miyazaki were projected into these maps by Mettig. Marks are at intervals of 50° longitude.

General description

Here we list the appearance of belts and zones both visually and in processed CCD images. (The 'visual' descriptions do not include the extra detail shown in Adachi's drawings, which were comparable to good CCD images.) For the appearance in methane-band images, see Part II of this report, as well as notes below on individual features in the North Tropical and Temperate Regions.

Table 2A gives the visual colour estimates of the major features. Colours of belts and zones were generally normal. A number of observers made visual white light intensity observations, as shown in Table 2B. In addition, Alan Heath

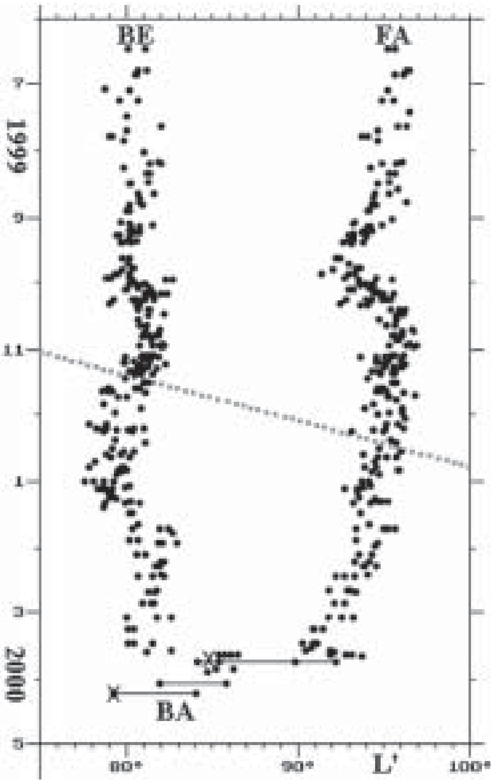

Figure 4B. Drift and merger of ovals BE and FA during the apparition. This is a PC-JUPOS chart by Mettig from amateur images, plus Pic du Midi in the last row (April 7). In the last weeks, horizontal lines connect paired nuclei in the single merging complex that became oval BA, and X marks the centre of the methane-bright oval BA on Pic du Midi images; it coincided with the more preceding of the paired nuclei, initially between the tracks of BE and FA, but then moving back onto the extrapolated track of oval BE. The diagonal track represents the centre of the GRS. The vertical scale shows the start of each month. The horizontal scale is System II longitude minus 12°.9/month.

Table 1A. Visual observers, 1999/2000

Observer	*Location*	*Telescope*
M. Adachi	Ohtsu City, Japan	310mm & 600mm refl.
G. Adamoli et al.*	Italy	108mm OG
L. Aerts	Belgium	250mm SCT
A. G. Bowyer	Epsom	300mm refl.
R. Bullen	Bognor Regis	210mm refl.
E. Colombo	Brugherio, Italy	254mm refl.
E. Crandall	Winston-Salem, USA	254mm refl.
P. Devadas	Madras, India	360mm refl.
C. Ebdon	Highams Park, London	254mm refl.
D. Fisher	Sittingbourne, Kent	215mm refl.
M. Foulkes	Hatfield, Herts	203mm SCT, 203mm OG & 254mm refl.
M. Frassati	Crescentino, Italy	200mm SCT
D. Gray	Kirk Merrington, Durham	415mm Dall–Kirkham
P. Grego	Birmingham	250mm refl.
H. Gross	Hagen, Germany	210mm & 250mm refl.
C. Harder	Germany	250mm refl.
A. Heath	Long Eaton, Nottingham	203mm SCT
C. E. Hernandez	Florida, USA	203mm SCT
K. Horikawa	Yokohama, Japan	160mm refl.
J. Knott	Liverpool	216mm refl.
R. J. McKim	Upper Benefield, Northants	102mm OG, 216mm refl., 409mm Dall–Kirkham
P. Moore & C. Lintott	Selsey, Sussex	127mm OG, 318mm refl., 381mm refl.
J. Mosch	Meissen, Germany	130mm OG
P. Parish	Rainham, Kent	102mm OG
J. Rogers	Linton, Cambs.	250mm refl.
S. Naylor	Blackpool	203mm SCT
I. Stellas	Athens, Greece	102mm OG
R. Tatum	Richmond, USA	254mm refl., 180mm OG
F. Wächter	Radebeul, Germany	80mm OG
S. R. Whitby	Hopewell, VA, USA	152mm refl.

*Data from the following visual observers were communicated by Gianluigi Adamoli, Jupiter Recorder of the Planets Section of the Unione Astrofili Italiani: G. Adamoli, M. Cicognani, I. Dal Prete, G. Farroni, M. Frassati.

OG, object glass (refractor); SCT, Schmidt–Cassegrain telescope; refl., reflecting telescope.

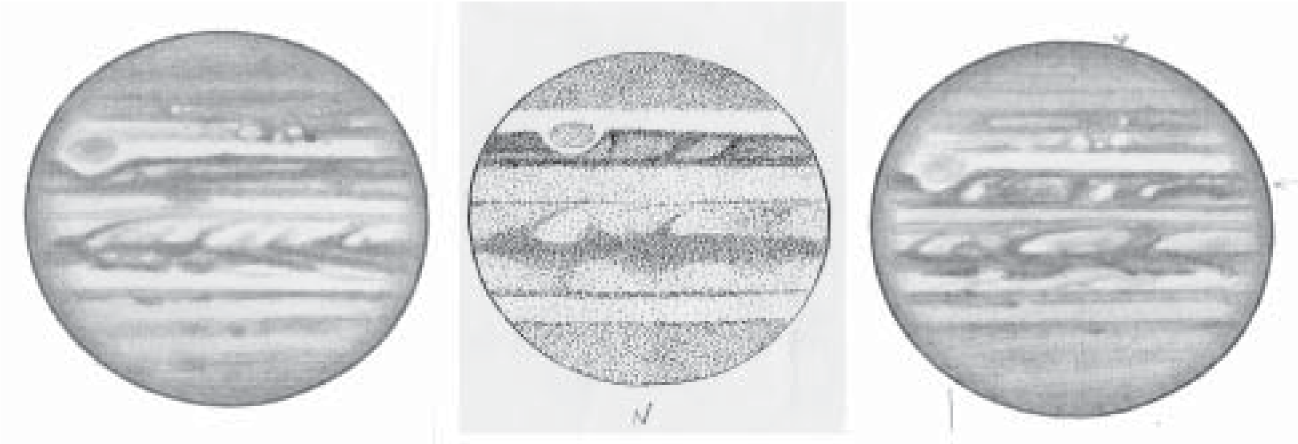

Figure 5. Three early drawings showing the GRS and turbulent region f. it, with ovals BE and FA approaching it and a small cyclonic white spot between them.
A. *(left)* Aug. 8d 19h 45m, CM1=99, CM2=106 (Adachi).
B. *(centre)* Sep. 7d 23h 56m, CM1=310, CM2=88 (Ebdon).
C. *(right)* Sep. 4d 16h 57m, CM =301, CM2=104 (Adachi). This shows the new mid-SEB rift, one rotation after the last image in Figure 9.

continued his series of intensity estimates using both red and blue filters.

Latitudes of belts and zones are listed in Table 3.

South Polar to S.S. Temperate region

Visually, the SPR usually appeared featureless. However, one or two belts were occasionally seen at high southern latitudes and a bright S^3TZ was detected at some longitudes. A dark 'SSTB' was usually seen.

Table 1B. CCD observers, 1999/2000

Observer	*Location*	*Telescope; CCD camera*
Tomio Akutsu	Tochigi, Japan	320mm refl.; Teleris 2
M. Brown	Huntington, Yorks., UK	370mm refl.
Alberto Sanchez Caso	Barcelona, Spain	310mm SCT; SX 12 bits.
Antonio Cidadao	Oeiras, Portugal	254mm refl.; SBIG ST-5c
Brian Colville	Ontario, Canada	305mm refl.; Pixel ST-237
Jean Dijon	France	500mm refl.; Kodak KAF400
Maurizio Di Sciullo	Coconut Creek, FL, USA	256mm refl.; SX HX 516
Gino Farroni	St.Avertin, France*	
Todd Gross	USA	230mm refl., etc; MX-5c
Derek Hatch	UK	150mm OG; MX-5c
Yuichi Iga et al.*	Japan	280mm SCT
Toshihiko Ikemura	Nagoya City, Japan	305mm Refl.; NEC Picona
Steve Massey	Siding Spring, NSW, Australia	
Frank J. Mellilo	NY, USA	203mm refl.; SX MX-5
Isao Miyazaki	Gushikawa, Okinawa, Japan	404mm refl., Lynxx PC
M. Mobberley	Cockfield, UK	360mm refl.; SX SXL8
David M. Moore	Phoenix, AZ, USA	362mm refl.; Astrovid 2000, SX HX-5
Andre Nikolai	Berlin, Germany	150mm Apo OG; OES LcCCD14SC
Donald C. Parker	Coral Gables, FL, USA	406mm refl., Lynnx PC
Tim J. Parker	Pasadena, CA, USA	318mm refl., SX HX516
Damian Peach	Kings Lynn, UK	305mm refl., SBIG ST-5c
Tom Richards et al.	Australia	180mm EDT Apo OG; SBIG ST-7e
Robert Schulz	Vienna, Austria	203mm refl., SBIG ST-7
Luigi Testa	Parma, Italy*	
Tan Wei Leong	Singapore	280mm refl., SBIG ST-7

*Data from Farroni and Testa were communicated by Gianluigi Adamoli, Jupiter Recorder of the Planets Section of the Unione Astrofili Italiani. Yuichi Iga (ALPO-Japan; ref. 7) communicated images by: T. Ikemura, Y. Oshihoi, K. Maeda, Y. Iga.
We also measured a few images from Dr. J. Lecacheux and colleagues (Observatoire du Pic du Midi; ref. 8), late in the apparition. SX, Starlite Xpress.

The global photomaps derived from CCD images (Figure 1) showed a conspicuous bright S^3TZ, with indistinct ends, around about half the planet (very roughly, L2 ~ 250–30). Alongside it was a massive dark S^3TB, and between the S^3TB and a tenuous true SSTB, S.S. Temperate latitudes were increasingly light, with a bright SSTZ consisting of a series of diffuse white ovals.

Around the other half of the circumference, belts and zones were not conspicuous, though there was a dark (S)SSTB.

South Temperate region

Visually the STZ appeared to be light. Under good seeing, the STB appeared to be divided into two overlapping sectors each with fainter ends. The white ovals BE and FA were difficult to see visually, even under good seeing. Probably the last visual observation of them was on 2000 Jan. 27 by Bullen (Figure 2D of ref.2).

The global photomaps (Figure 4A) show the STB divided into two sectors, each of which began tenuously at lat. 27–28°S, swelled into a typical dark STB at higher longitudes, and then veered southwards, ending alongside the tenuous p. portion of the other sector. One of the two STB sectors had dark spots (DS1–DS3) on its S. edge, and f. DS3 it joined a SSTB. The other STB sector ran alongside the white ovals BE and FA, and f. its deflection southwards, it dissipated in a bright STZ.

South Tropical region

South Tropical Zone
Visually the STropZ appeared white and featureless. Some small dark jetstream spots on SEBs were seen visually, sometimes separated by light spots.

Images revealed that both edges of the STropZ were disturbed by new outbreaks of activity on the STBn and the SEBs jetstreams, consisting of small dark spots typical of such outbreaks, over a wide range of longitudes. SEBs jetstream activity was possibly less conspicuous after January, though this may have been merely an effect of decreasing resolution.

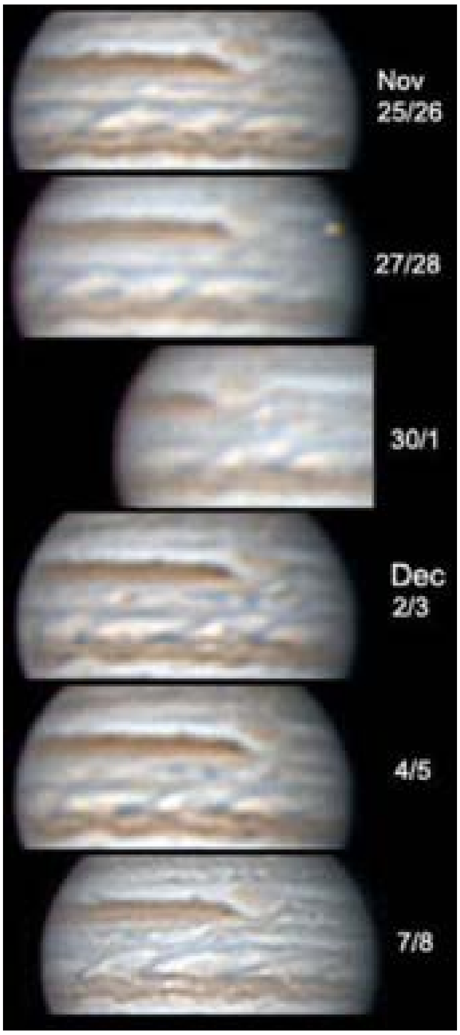

Figure 6 *(left).* A set of colour images (all by Cidadao), showing the spectacular appearance of the South Equatorial Disturbance passing the GRS in 1999 Nov–Dec. After various dark and bright spots in the stormy sector have passed by, the main bright rift passes the centre of the GRS on Dec.4/5, and in contrast to its appearance a few days earlier, it becomes a complete rift through SEB(N) as it moves p. the GRS on Dec.7. (Also see the image on Dec.7 by Don Parker in Ref.2.) Also of note are dark SEBs jetstream spots approaching the GRS: one enters the Red Spot Hollow on Nov.28, and another is approaching it at the end of the series. Ovals BE and FA are passing the GRS but are of low contrast.

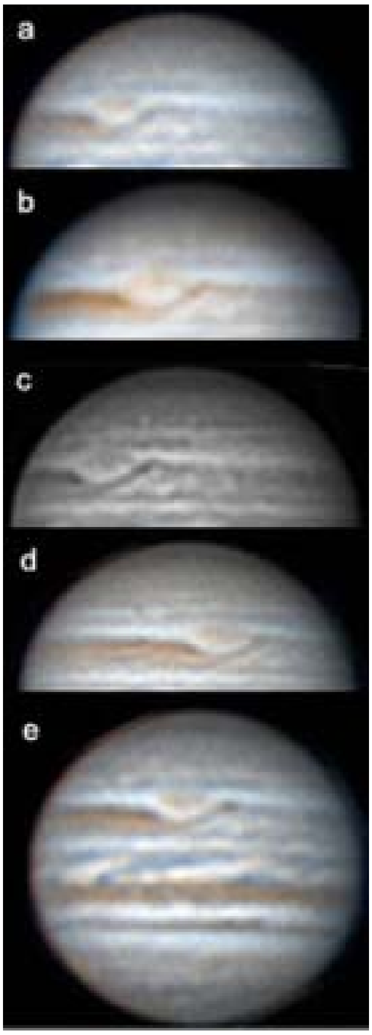

Figure 7 *(right).* A set of colour images showing the circulation of the GRS at the new year; these are some of the last images of 1999 and the first of 2000. In **(a)** there is a bright white spot in northern part of the GRS, which has circulated to the f. part as seen in **(b)** and **(c)**, and then disappears. Oval BE can be seen Sp. the GRS; oval FA is obscure as it passes the GRS.
(a) 1999 Dec.30d 18h 11m UT, CM2=97 (Cidadao).
(b) Dec.31d 03h 49m, CM2=83 (D. Moore).
(c) Dec.31d 14h 12m, CM2=103 (Tan Wei Leong).
(d) Dec.31d 23h 03m, CM2=64 (Cidadao).
(e) 2000 Jan.1d 19h 23m, CM2=81 (Cidadao).
(The appearances of the GRS in the first and last images were confirmed visually by Rogers.)

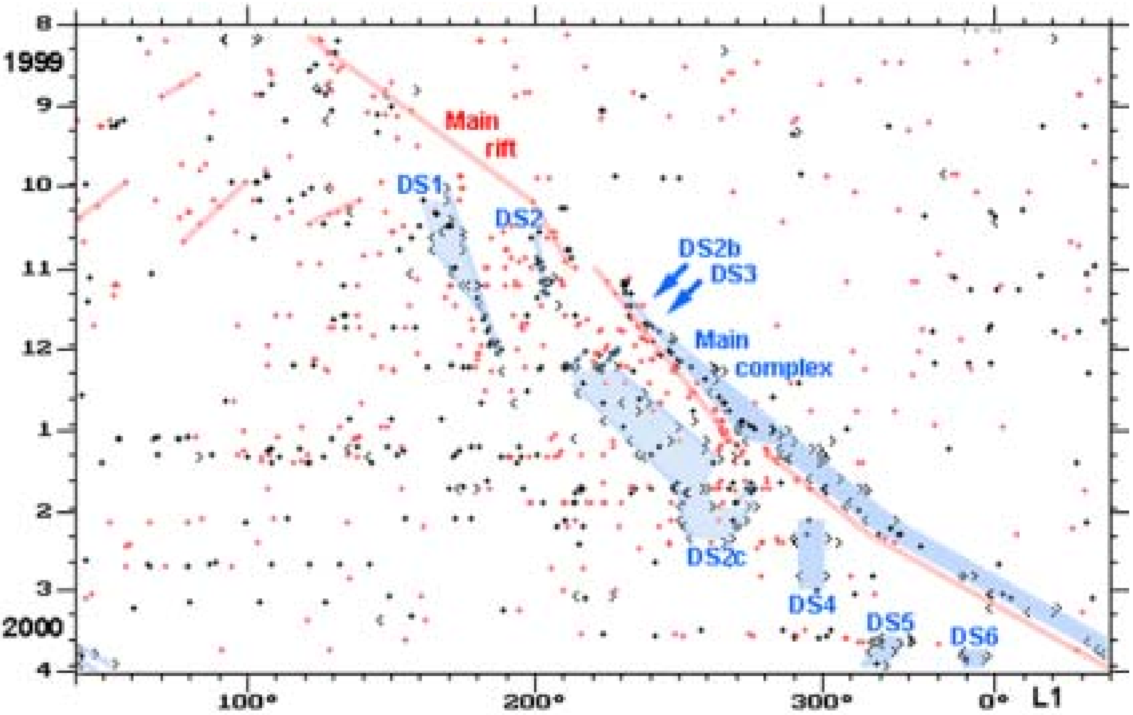

Figure 8. Chart of the spots in the South Equatorial Disturbance, produced using PC-JUPOS by Mettig. Red points indicate bright spots, black points indicate dark spots, and black < > (and blue shading) indicate dark streaks, all between 4–9°S. Longitude scale is System I. The main rift is not consistently plotted because of its variable appearance, but its location is marked by a red line. Note that its location can be defined simply by the density of small spots p. it and absence of spots f. it.

Table 2A. Visual colour estimates

	Adachi (July 23–Jan 8)	*Colombo (Nov 25–Dec 2)*	*Devadas (Oct 20–Jan 1)*	*Foulkes (Aug 6–April 5)*	*Frassati (Aug 11–Oct 31)*	*Heath (Sept 7–Feb 13)*	*Rogers (Dec)*
SPR		Grey	Grey	Grey	Grey	Warm tone. Yellowish	
SSTZ		Grey or yellow		Light grey or dull white	Grey		
SSTB		Grey		Warm grey or brown			
STZ		Yellowish grey	White or dull white	Dull white or light grey	Yellowish		
STB		Grey		Warm grey	Brown	Grey	Warm grey
GRS	Light reddish		Light pink	Warm grey or reddish		Grey or pink	Pale reddish
STropZ		Yellow	White or dull white	White or yellowish white	White or yellow	Yellowish	White
SEB(S)	Dark brown or orangey	Reddish	Light red	Brown. Darker p. GRS	Brown	Brown	Brown
SEBZ				Dull white in places			
SEB(N)	Grey or bluish	Reddish	Light red	Grey (Fainter p. GRS)	Brown	Brown	Brown
EZ(S)		Yellow	Light bluish	White or dull white	White	White	Slight bluish grey
EB	Light blue		Bluish grey or bluish	Strong grey	Grey		Cold grey
EZ(N)		Yellow	Light bluish	Light grey, shaded	White	White	Slight bluish grey
NEB	Dark brown or orangey	Reddish	Reddish	Brown	Brown	Brown or orange	Brown
NTropZ	Southern half yellowish. White	Yellowish	White, dull white or yellow	White or yellowish white	Yellow	White	White
NTB	Dark brown	Reddish	Red	Dark brown or warm grey	Brown	Grey	Grey
NTZ		Light grey		Light grey or dull yellow	Yellow	Off white	Whitish
NNTB		Grey		Dark grey	Brown		
NPR		Grey	Grey	Grey	Grey	Grey	

Table 2B. Average visual intensity observations

	Colombo (Nov 25 –Dec 16)	*Crandall (July 10 –Oct 28)*	*Frassati (Aug 11 –Oct 31)*	*Heath (Oct 11–Feb 19)*				*McKim (Nov 17 –Jan 6)*	*Rogers (July 21 –Jan 1)*	*Schmude (Feb 25 –Mar 2)*
	No filter	*No filter*	*No filter*	*No filter*	*Red (W25)*	*Blue (W44a)*	*Blue (W47)*	*No filter*	*No filter*	*No filter*
SPR	3.2 (3)	4.4 (12)	4.3 (4)	3.0 (27)	2.5 (19)	3.5 (19)	4.0 (19)	3.5 (2)	2.9 (6)	3.0 (2)
SSTZ	2.8 (3)	3.0 (1)	3.6 (4)	–	–	–	–	–	1.4 (2)	–
SSTB	3.3 (3)	5.0 (5)	–	–	–	–	–	4.0 (2)	3.6 (5)	5.0 (1)
STZ	3.0 (3)	3.0 (1)	3.2 (4)	–	–	–	–	–	1.5 (2)	–
STB	3.5 (3)	4.6 (8)	3.6 (4)	3.7 (26)	3.3 (18)	4.0 (18)	4.1 (17)	5.0 (2)	3.2 (6)	3.5 (1)
STropZ	2.2 (3)	2.5 (12)	2.1 (4)	0.8 (27)	0.9 (19)	1.4 (19)	2.1 (19)	0.5 (2)	0.1 (5)	2.0 (2)
GRS	–	6.3 (3)	4.0 (10	2.8 (3)	1.0 (2)	3.7 (3)	4.0 (1)	2.8 (2)	1.5 (1)	–
SEB (p.GRS)	5.3 (3)	6.8 (12)	5.1 (4)	5.0 (26)	4.4 (18)	5.4 (18)	7.0 (18)	6.7 (3)	6.8 (6)	5.0 (2)
SEB	5.2 (3)			2.9 (8)	3.2 (6)	4.0 (6)	5.0 (6)	4.0 (3)		
EZ(S)	–	4.7 (9)	–	–	–	–	–	0.8 (2)	0.8 (6)	2.5 (2)
EB	2.7 (3)	5.0 (12)	2.7(4)	4.8 (25)	4.1 (17)	3.5 (16)	3.4 (11)	3.3 (2)	3.3 (6)	3.8 (2)
EZ (N) (or total EZ)	2.2 (3)	4.7 (9)	1.2 (4)	1.4 (27)	1.1 (19)	2.0 (19)	2.4 (19)	0.8 *(2)	0.8 (6)	2.5 (2)
NEB(S)	5.5 (3)	7.4 (12)	5.8 (4)	5.0 (27)	4.5 (19)	5.5 (19)	7.0 (19)	5.8 (2)	6.2 (6)	6.5 (2)
NEB(N	5.3 (3)		5.8 (4)					5.2 (2)		
NTropZ	2.2 (3)	2.9 (12)	2.2 (4)	0.9 (27)	0.6 (23)	1.2 (23)	1.8 (23)	0.9 (2)	0.3 (6)	2.0 (2)
NTB	4.8 (3)	6.8 (11)	5.7 (4)	5.0 (27)	4.2 (19)	4.9 (19)	4.1 (19)	5.0 (2)	5.7 (6)	5.0 (2)
NTZ	2.3 (3)	3.3 (11)	2.7 (4)	1.6 (27)	1.4 (19)	2.1 (19)	2.3 (18)	0.9 (2)	0.5 (6)	2.0 (2)
NNTB	3.2 (3)	5.8 (5)	4.4 (4)	–	–	–	–	4.0 (2)	3.4 (6)	3.8 (2)
NNTZ	2.8 (3)	–	3.5 (4)	–	–	–	–	–	–	3.0 (1)
NPR	3.0 (3)	4.0 (12)	4.3 (4)	3.0 (27)	2.5 (19)	3.5 (19)	4.0 (19))	3.5 (2)	2.9 (6)	3.5 (2)

Intensities are made on the scale 0: bright white. 10: black.
The number of observations is shown in ().
Note: Heath made no colour filter observations after December 19.

Great Red Spot

Visually, the GRS generally appeared as a pale uniform reddish oval separated from the SEB by bright material. Its f. end was often seen attached to the f. shoulder of the well-defined Red Spot Hollow. Under good seeing, some internal structure was detected. Bullen and Frassati frequently recorded the Np side or northern half to be pale. The GRS appeared faint to Devadas with the northern half ill-defined. McKim observed a darker southern rim with an ill-defined northern edge. Grego recorded a dark rim. Adachi and Devadas frequently recorded a darker centre.

Images confirmed that the GRS was typical in appearance, with only a little reddish colour. (More details are given below and in our interim report).[2]

South Equatorial Belt

Visually the SEB appeared as one of the darkest belts, comparable to the NEB. At most longitudes it appeared double with a darker broader southern component, especially p. the GRS. The southern component was fainter f. the GRS. Most visual observers noted a strong colour contrast between the two components, with the SEB(S) appearing brown or reddish compared to the grey SEB(N). On Nov. 28, Dobbins noted the SEB(N) was exceptionally faint f. the GRS; his announcement enabled the Director using Miyazaki's images to identify the South Equatorial Disturbance for the first time.

The region of mid-SEB turbulence f. the GRS was still present (Figures 5, 7, 9), comprising light spots and dusky streaks in the SEBZ, up to a diagonal dark streak spanning the SEBZ. A few of the spots appeared very bright. After December, fewer spots were observed.

Images confirmed that the dark, central/southern SEB component was strongly reddish; it was especially dark p. the GRS. In contrast, the SEB(N) was neutral in colour, quite narrow, and increasingly disturbed in the longitudes of the South Equatorial Disturbance. As also noted visually, the SEB(N) was sometimes fainter than the new dark streaks in EZ(S) and the massive EB.

The mid-SEB outbreak of 1998 had finished by the start of the apparition, although tiny spots still remained for some months in a narrow northerly SEBZ. The region of mid-SEB turbulence f. the GRS persisted as usual, but became less active after November, with typically only one white spot present. By January the SEB was a solidly dark belt at most longitudes (Figure 3). In March, the SEB seemed generally quieter, with a light yellow SEBZ and bluish northern streak developing Np. the RSH, and the GRS appeared slightly redder (see Part II).

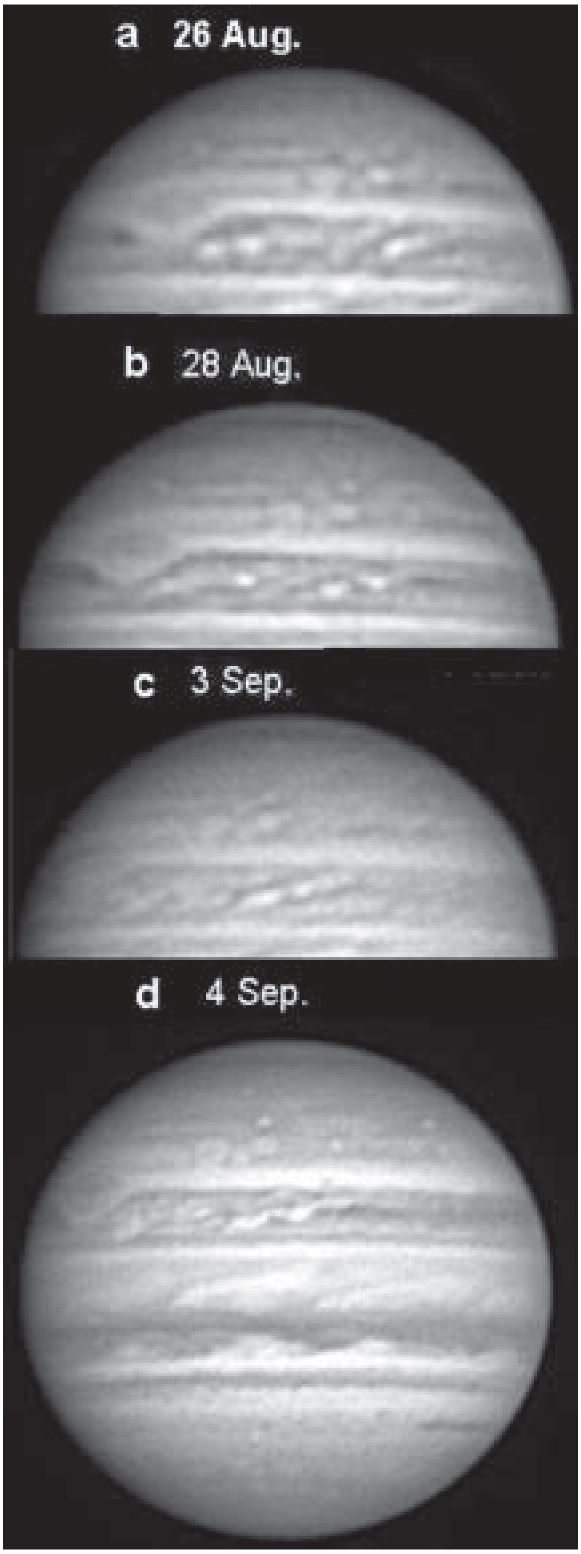

Figure 9. Four images showing development of a new mid-SEB rift just f. the previous rifted region. It appeared some time between Aug.22 and Aug.25.
(a) Aug.26d 04h 32m (Cidadao). **(b)** Aug.28d 16h 14m (Miyazaki). **(c)** Sep.3d 02h 07m (Peach). **(d)** Sep.4d 07h 22m (di Sciullo). One rotation later, see Adachi's drawing in Figure 5C. Ovals BE and FA are also visible, approaching the GRS, with internal structure in oval BE.

Equatorial region

Visual and CCD observations both showed the major changes that took place in this region.

EZ(S) was initially a bright white strip with no major features, as in previous years. But the South Equatorial Disturbance became more and more prominent, generating a 'stormy sector' of extensive dark streaks and shadings that appeared dramatic in hi-res images. Visually the Disturbance was less prominent but some of its features were recorded in good seeing from December onwards (Figure 11).

The Equatorial Band was exceptionally dark (described as striking by Bullen), and blue-grey in colour.

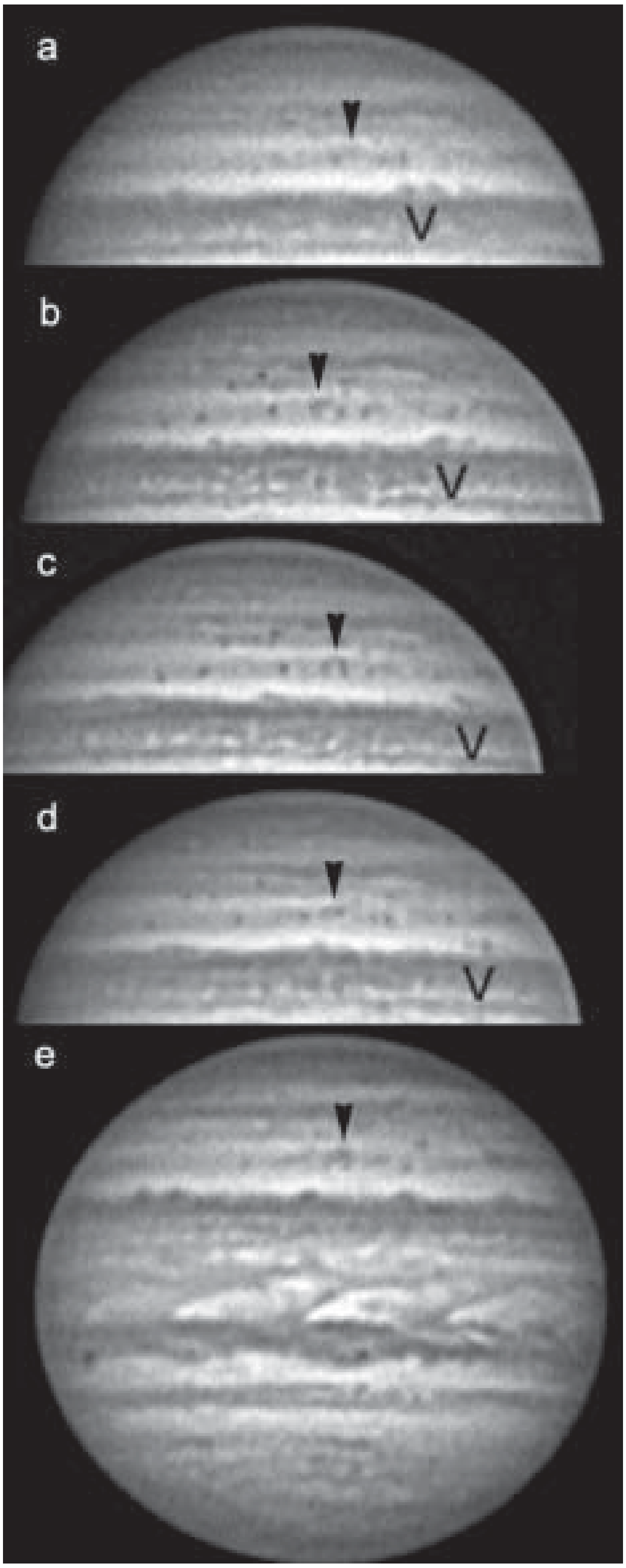

Figure 10. Five images (all by Miyazaki) showing development of jetstream spots on STBs and SEBs, and associated slower-moving spots, as described in the text. A cluster of tiny dark spots in STB, only just forming on Aug.14, proliferate and exhibit a range of speeds up to the STBn prograding jetstream speed of ~ –3°/day. The most southerly spot in this cluster is DS1 (marked by arrowhead) but it does not become distinct until the last image. DS2 is a dark streak on STBs near the f. limb. The two earliest SEBs jetstream spots are also visible on the f. side on Aug.14 and 19 (indicated by V), then they circulate and merge, to form the dark oval in STropZ that is shown in Figure 3. **(a)** Aug.14d 20h 44m, CM2=324. **(b)** Aug.19d 19h 58m, CM2=328. **(c)** Aug.21d 21h 06m, CM2=310. **(d)** Aug.26d 20h 28m, CM2=318. **(e)** Oct.31d 14h07m, CM2=294; now there is a long line of SEBs jetstream spots.

Table 3. Latitudes of belts

Range (a):		
	SPB	−64.5
	SPRn	−54.7
	(S)SSTB	−42.0
	SSTB(N)	−36.0
Range (b):		
	SPRn/S^3TZs	−53.2
	S^3TBs/ S^3TZn	−48.0
	S^3TB	−45.3
	SSTB(N)	−37.0
	STB(N)	−27.4 –> −29.3
	STBn	−27.4
	SEBs	−21.4
	SEBn	−8.0
	EBs	−4.1
	EBn	+1.0
	NEBs	+8.8
	NEBn	+16.9
	NTBs	+25.0
	NTBn	+28.1
	NNTBs	+36.9
	NNTBn	+40.0
	N^3TB	+46.0
	N^4TB	+55.1

Zenographic latitudes were measured from 6 images by Isao Miyazaki and 6 by Don Parker, spread through many months and longitudes. The high southern latitudes are divided by longitude range: (a) L2~ 70–200 (with white ovals at 41°S, but no conspicuous belts or zones); (b) L2~250–30 (with few white ovals, but conspicuous S^3TZ and S^3TB).

EZ(N) had a very conspicuous array of 12 dark projections from NEBs, leading into well-formed festoons, which were also darker than usual and swept Sf. to merge with the massive EB. These were visible even in small apertures. Many observers commented on the grey, bluish grey or blue colour of the projections and NEBs plateaux, coupled with the brightness of the associated white plumes. Some of their changes in appearance were followed visually. This darkening represented a major change from the previous apparition. Visually, EZ(N) appeared the most disturbed region on the planet.

North Tropical region

North Equatorial Belt

Visually, the NEB was generally considered to be the darkest belt, usually with a brown or reddish colour. Visual and CCD observations both recorded the unusual activity of the NEB, which had frequent bright rifts within it, and an exceptional amount of dark material around it. Dark material was conspicuous both on the south side in EZ (see above) and on the north side in NTropZ (see below). Also the NEBn appeared thrown into notable waves at some longitudes. Within the northward bulges on NEBn, there were several dark brown barges; visually these were very conspicuous, dark brown or chocolate-coloured, and easily visible even with apertures as small as 80mm.

North Tropical Zone

Visually, the NTropZ appeared bright or dull white, although occasionally a light yellow colour was recorded. A number of white spots and large bays were observed which encroached into the NEBn.

In images, the NTropZ appeared generally white, but had many small dusky spots and streaks (some of them being

Table 4A. Longitudes & drifts, 1999/2000: southern hemisphere

1999/00: No.	*Description*	*L2(O)*	*DL2*	*Lat.*	*Dates*	*1998/99:* L2(O)	*DL2*	*(O-O)* DL2
SPC								
1	Pinkish light spot in S^{4}TZ	101	–28	–60.0	July–Sep.	316	–27	–16.0
			–> –2	–58.7	Sep.-Oct.			
			–> –19	–59.5	Nov.-Jan.			
S^{3}TC								
1	Tiny w. oval	(216)	–35	–50.1	Aug.–Oct.	170	–24	–23.4
2	Dark streak	135	–20	–46.4	Sep.-Oct.	–		
3	Dark streak	(167)	–18	–46.4	Nov.-Dec.	–		
4	Bright spot	250	–29.5	–46.1	Aug.-Jan.	–		
SSTC								
	Anticyclonic white ovals (AWOs):			–40.6				
1	AWO	351	–23.0		June-Nov.	321	–27.4	–24.6
			–> –26.5		Dec.-Mar.			
2	AWO	12	–29.7		June-Nov.	10	–24.8	–26.7
			–> –24.8		Nov.-Apr.			
3	AWO [Slower in June-Aug.]	69	–28.3		Aug.-Mar.	58	–27.0	–26.0
4	AWO	121	–25.0		June-Nov.	113	–24.8	–26.2
			–> –28.8		Nov.-Apr.			
5	AWO	152	–27.8		July-Mar.	162	(var.)	–26.1
6	AWO [Faster, June-Aug.; slower, Mar.-Apr.]	166	–26.8		Aug.-Feb.	185	–24.6	–28.2
7	P. end patchy dark SSTB	190						
8	Tiny red-brown spot in SSTZn	248	–29.6	–37.9	Aug.-Sep.	–		
			–> –25.4		Oct.-Nov.			
9	Bright spot SSTZ	280	*–12.1	–38.9	Sep.-Oct.	–		
10	Bright patch SSTZ	302	–20.5	(–39)	Sep.-Oct.	–		
STC								
1	AWO-BE [Slower, Jan.-Mar.]	80	–13.1	–32.3	June-Jan.	243	–11.6	–12.2
2	Cyclonic white oval	87	–13.2	–30.3	June-Dec.	260	–9.0	–12.9
3	AWO-FA [Slightly faster, Feb.-Mar., then merged with oval BE]	95	–13.3	–33.0	June-Feb.	281	–13.7	–13.9
4	Small AWO on STBs	112	–13.5	–33.1	June-Mar.	–		
5	F. end dark STB	135	–14.5	–	July-Jan.	330	–14.4	–14.6
6	Dark spot detached from Sf. end of STB	194	*–1.6	–32.4	Sep.-Oct.	–		
7	Dark spot DS1a on STBs [Faster, Jan.-Mar.]	301	–13.8	–30.6	June-Jan.	164	–15.7	–16.6
8	Dark spot DS1b in STB	309	–14.2	–30.2	July-Mar.	–		
9	Dark streak DS2: p. end	336	–15.0	–31.3	June-Mar. }	192	–17.0	–15.4
10	Dark streak DS2: f. end	355	–14.5	–31.3	June-Mar. }			
11	Dark spot DS3 on STZB	15	–13.7	–33.1	June-Feb.	(213)	–17.0	–14.8
STropC								
1	GRS [17 deg. long]	71	+0.8	–22.6	June-Mar.	67	+0.4	+0.3
2	Dark spot in STropZ [formed by merger of 2 SEBs jet spots; see text]	356	–6.0	–23.5	Sep.-Oct.	–		
			–> +9.0		Oct.-Dec.			
3	Dark red-brown streak ('barge') in SEB: p. end	(112)	–10	–16.4	June-Sep. }	?(151)	+7	–2.2
4	ditto: f. end	(131)	–7	–16.4	June-Sep. }			

Notes to Table 4A:
Columns are as follows. Number; Description; L2(O), System II longitude at opposition on 1999 Oct.23 (for System III, subtract 137.0 degrees); DL2, System II drift in degrees per 30 days (for DL3, add +8.0 deg/month); Zenographic latitude; Dates of observation or drift measurement. All drifts were derived from a large number of images.
AWO, anticyclonic white oval. *Spots with anomalous drifts not included in mean in Table 4B.
The last 3 columns give data from 1998/99 apparition, followed by DL2(O-O), the average drift rate between oppositions.

wisps of a N. Tropical band at ~20°N). It appeared as though dusky material was flowing off the NEBn and getting caught in small local circulations. A 'Little Brown Spot' was the most conspicuous example (see below), but there were similar dusky patches Np. other barges. After the new year, the dusky material largely faded away, though the NEBn barges and Little Brown Spot remained.

However this activity was to resume in the next apparition and was found to comprise a long-drawn-out NEB expansion event. Such events had occurred in 1993 and 1996, and the 1999/2000 event fitted into a three-year cycle that had also prevailed in earlier historical eras.[5] However, the NEB broadening events in 1993 and 1996 had proceeded briskly starting from a single focus. In contrast the 1999/2000 NEB broadening event developed very slowly and irregularly from summer 1999 to late 2000, with no evident

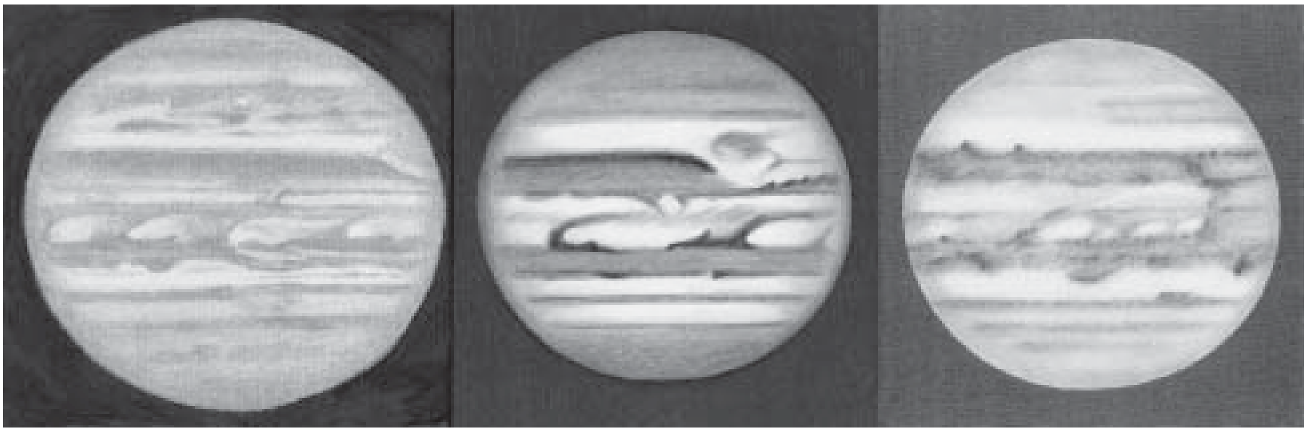

Figure 11. Three drawings showing the region p. the GRS, and features of the South Equatorial Disturbance.
A. *(left).* 1999 Oct. 20d 12h 21m, CM1=201.7, CM2=14.8. (Adachi). Shows the disturbed SEBn/EZ(S) approaching the CM.
B. *(centre).* 2000 January 6d 17h 45m, CM1=116.4, CM2=53.0. (McKim). Shows the GRS with a pale northern half and the dark SEB(S) p. Note the white spot in the EZ(S) on the CM.
C. *(right).* 2000 March 4d 19h 40m, CM1=332.4, CM2=185.7. (Bullen). Shows the disturbed SEBn/EZ(S) near the f. limb, and the Little Brown Spot in NTropZ near CM.

pattern. Thus the common cycle of NEB activity can be implemented via different dynamical pathways.

North Temperate region to North Polar region

Visually, the NTB appeared almost as dark as the NEB. Some dark NTBs jetstream spots and some darker segments of NTB were occasionally recorded. The NTZ appeared quite broad and light and featureless. In October, McKim noted that this and the NTropZ appeared almost as bright as the EZ. The NNTB appeared dark visually, and under good seeing some darker sections were seen.

In images, the NTB was a massive very dark belt. The NTZ was clear and white. There were only tenuous fragments of NNTB, and general shading further north.

The NPR generally appeared grey and featureless to visual observers. However in good seeing, one or two vague belts, lighter zones and vague light and dark spots were recorded both visually and in images.

Table 4B. Average drifts of currents, 1999/2000, southern hemisphere

Current	*Type of spots*	*N*	*DL2: Mean (Range)*	*Latitudes*
SPC	Pinkish light spot in S^4TZ	1	–17.7	59-60°S
S^3TC	Misc. spots	4	–25.4 (–18 to –35)	46-50°S
SSTC	AWOs and other spots	9	–26.4 (–20.5 to –30)	38-41°S
SSTBn jet	Tiny dark spot	1	–85	(36°S)
STC	AWOs and other spots	10	–13.9 (–13 to –14.5)	30-33°S
STBn jet	Tiny dark spots	11	–77 (–60 to –113)	27°S
SEBs jet	Small dark spots	27	+95 (+79 to +106)	21°S
	(plus others in range between SEBs jet and STropC; see text)			
STropC	Misc. spots	3	–2.0 (–10 to +9)	16-24°S
(Mid-SEB)	White spots in SEB f. GRS	>6	–54 (–43 to –74)	10-16°S
(Mid-SEB)	Tiny light spots elsewhere	21	–80 (–68 to –90)	10-16°S

Notes to Table 4B:
This table gives the mean speed and range of each current, some of which are not itemised individually in Table 4A. N, number of spots included (some with multiple drifts).
Latitude ranges (zenographic) are from Table 4A, plus the following:
STBn jetstream spots 1 and 2, 27.0 (±0.8) deg.S;
SEBs jetstream spots, 20.7 (±0.5) deg.S.

Local features and drifts

South Polar region

For the fourth consecutive apparition, a slightly reddish light oval was tracked along the edge of the South Polar Belt at ~60°S, with its speed (DL2) varying between –28 and –2°/mth (Table 4A, SPC no.1). The latitude (measured with standard deviation of 0°.3 to 0°.6) varied along with the speed, possibly a significant correlation. This may well be the same spot that has shown this behaviour since 1996. It is probably similar to the 'Grand Spiral' imaged at 60°S by *Voyager* [p.82 of ref.5].

An even smaller light oval at 50°S, with an even more remarkable rapid drift, has probably been tracked since 1998 (Table 4A, S^3TC no.1).

South South Temperate region

In the S.S. Temperate domain, there were still six anticyclonic white ovals at 41°S, all tracked since 1998 and most since several years earlier (Table 4A, SSTC nos.1–6). They have a tendency to repel each other when they approach (as the homologous S. Temperate ovals did in earlier decades), and the associated changes in drift can be quite sudden. They have gradually converged so that they now occupy only 175° of longitude. Mostly they lay on the north side of a dark (S)SSTB, but belts and zones were not conspicuous in this sector.

On the other side of the S.S. Temperate region, a brightening SSTZ consisted of a series of diffuse white ovals (e.g. SSTC no.9 and 10; probably cyclonic). These white ovals were inconstant, and had slower drifts than normal SSTC.

South Temperate region

The white ovals on STB

The most memorable event of the apparition was the merger of the two remaining

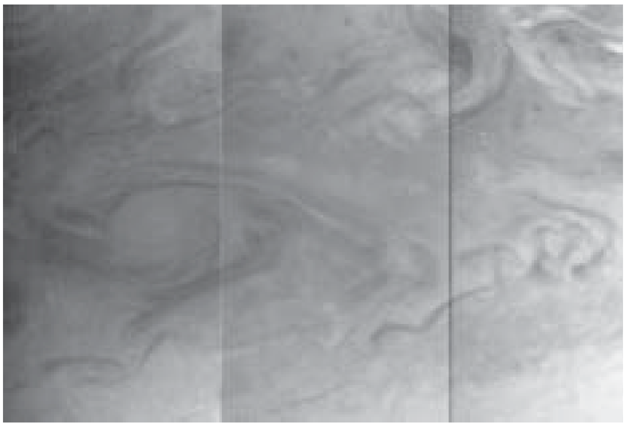

Figure 12. Close-up view of STZ Dark Spot 3 from *Galileo* at the C22 encounter, 1999 Aug. 13. South is up, as in all Figures. The spot (left) appears as an irregular oval with anticyclonic circulation, and a turbulent wake on its f. side (right).

white ovals. Three such ovals had been familiar features of the planet since around 1940, and were the longest-lived features apart from the GRS, but they had been gradually shrinking over the years. Ovals BC and DE apparently merged during solar conjunction in 1998.[1,9,10] The resulting oval 'BE' had been converging on the remaining oval FA and their merger was eagerly awaited, but their separation fluctuated during 1999, and it was feared that they would not interact before solar conjunction.

Through most of the apparition, BE and FA were 15° apart, separated by a small bright cyclonic white oval (Figures 2–5, 9, 12). Oval BE had a complex internal structure, which began with a white gap in its northern rim on July 1, and white and grey material seem to have been drawn into the oval from this point, as pointed out by Miyazaki in his images on July 3 and 8. Thereafter, oval BE often appeared to consist of three light spots (N, Sp., and Sf.), although ground-based images were not sufficient to resolve the structure clearly. In August the Sf. spot was brightest and was the only part bright in methane images (Aug.6), but later the methane-bright spot coincided with the centre of the visible oval.

The measured latitudes for ovals BE and FA shifted northwards between summer and autumn, without evident cause. The measured latitude of oval BE was 32.6 (±0.4)°S in July–Aug., 32.0 (±0.4)°S in Oct.–Nov. For oval FA it was 33.3 (±0.4)°S in July–Aug., 32.6 (±0.5)°S in Oct.–Nov.

From December onwards, the ovals were passing the GRS. At this time, BE and FA were still 15°.5 apart, and neither changed speed when passing the GRS (Figure 4B). They did change in appearance: ovals BE and FA, and a third smaller anticyclonic white oval f. them (STC no.4 in Table 4A), were each transiently obscured in turn as they passed the p. end of the GRS (Figures 3D, 4, 6, 7). Oval BE was very inconspicuous on Dec.5, but then in mid-December it brightened and changed shape, and the cyclonic oval between BE and FA (STC no.2) apparently moved south or disappeared. Oval BE remained still large and internally complex. Then at the new year, oval FA became small and faint and reddish. On 2000 Jan.1–8, it was quite inconspicuous, especially in blue light, but it recovered thereafter. Finally the small, third white oval became obscure during Jan.22–30 in turn, but it too recovered thereafter.

We had anticipated that the passage of ovals BE and FA past the GRS might destabilise them sufficiently to trigger their long-awaited merger, and the likelihood of this seemed to rise with the disappearance of the cyclonic white oval between them. Indeed this marked the beginning of their final rapid convergence which led to their eventual merger (Figure 4B). Oval BE decelerated in early Jan., and oval FA accelerated in Feb., so they converged until they interacted in late March.

The ovals finally collided and merged during just one week, 2000 March 18–24.[2,11] CCD images showed them in contact but still undisturbed on March 15, but oval BE was missing or disrupted on March 19 and 20, and by March 24 there was just a single irregular white complex. At the same time the interaction was monitored in infrared wavebands by professional observers. Developments differed in the visible, near-infrared, and methane-absorption wavebands, probably representing different currents at different altitudes as the two ovals were caught in a mutual vortex; however, it seems likely that they merged. In any case, the single oval that emerged (at all wavelengths) was closer to the track of BE than FA. On March 29 it was at L2 = 17, and the mean motion was ~ –13°/month. The details of the merger, from professional as well as amateur images, have already been published.[2,11]

The three dark spots on STBs

The other interesting sector of the S. Temperate region contained a remarkable collection of small dark spots in various latitudes (Figures 1, 4, 10). Three (DS1, DS2, DS3; STC nos.7–11 in Table 4A) had existed in 1998 and were still present, although this did not become clear for several months because of a proliferation of other tiny spots. They had passed the GRS during solar conjunction.

DS1 in 1998 had been a small, intensely dark, cyclonic spot on STBs,[1,12] and in 1999 spot DS1a was obviously the same spot, although not quite so dark. However it had shifted 10–15° p. its previous track during solar conjunction, and its drift oscillated during 1999/2000. DS1b was a tiny dark grey spot which appeared on the previous track of DS1, but it was further north, within the STB, at the p. edge of a small gap. Alongside DS1a and DS1b to the north, tiny dark spots were appearing both in the STB (motion uncertain, perhaps transient) and on the STBn (moving with the prograding jetstream; see below) (Figures 4, 10). There was no visible source for them.

DS2 was still a spotty dark streak on STBs, as in 1998 (Figures 4, 10).

DS3 was still a more southerly dark spot, in the anticyclonic latitudes of the STZ. After passing the GRS at the start of the apparition in July, without change in speed, DS3 was very dark, and from September onwards was either double or bright-cored (Figures 2A, 3, 4A). It was observed by *Galileo* at the C22 encounter (Figure 12).

The three dark spots were still distinct and characteristic in Miyazaki's images in Dec. (Figure 4A). A particularly good image on 2000 Jan.9 showed DS1 reddish, DS2 grey, and DS3 a ring. Images on Feb. 5 still showed DS1, but DS2 had broken up and faded considerably.

South Tropical region

There were new outbreaks of activity on both the STBn and the SEBs jetstreams, consisting as usual of small dark spots, over a wide range of longitudes. There were also two slow-moving dark spots in mid-STropZ (L2 ~ 130 and 360 in Sep.), which were originally retrograding.

STBn jetstream outbreak

The STBn jetstream outbreak was the first since 1994. The tiny prograding dark spots were all arising near DS1/DS2 (see above & Figure 10). They were not yet present on July 14. The first pair of spots appeared about Aug.8, very small and inconspicuous. Miyazaki's images on Aug.14–26 (Figure 10) showed tiny dark spots prograding on SSTBn (one, DL2 = –85°/mth), STBn (the first two in the outbreak, DL2 = –110 and –88), and mid-STB f. them (at least three, DL2 = –60 to –64). Although the first two on STBn were separating, they then converged again and probably merged. The resulting larger reddish spot decelerated progressively to DL2 ~ –62 as it approached the GRS. Meanwhile a third spot apparently moved N to STBn and accelerated from –60 to –113, before gradually decelerating again. This one caught up its merged predecessors just as they reached the f. end of the GRS, where they all merged into a complex with SEBs jetstream spots as well in early November [see below; & Figure 3 in Ref.2]. These were the only spots to travel a long way along the STBn. Later ones, also arising near DS1, travelled less than 90° in longitude before disappearing. They had speeds between –65 and –78, and were still seen as late as January. Thus the STBn jetstream spots' speeds ranged from –60 to –113°/month, with a nominal mean of –77 (Table 4B).

STropZ, with SEBs jetstream outbreak

The SEBs jetstream outbreak had begun earlier. Dark spots looking like jetstream spots on SEBs/STropZ were visible in the first images of the apparition, from 1999 June 12 onwards, and were tracked from July onwards.

(In the following account, in contrast to other latitudes, we refer to the magnitude of retrograding speeds, i.e. 'faster' speeds correspond to slower rotation periods.)

The first spot tracked had a drift (DL2) of only +55°/mth, but the second had DL2 = +85, which was typical of the subsequent spots. These two conspicuous spots converged and in August they merged with each other and with a smaller spot just f. (Figure 10). As they did so, they drifted south into the STropZ and decelerated, while approaching the GRS. The merging spot reached its highest longitude, L2 = 3, on Aug.27–Sep.3, and its highest latitude, 23.6°S, around Sep.5. On Sep.5 it was a conspicuous dark oval in mid-STropZ (STropC no.2 in Table 4A; Figure 3A). Thereafter it was almost stationary in longitude (drifting back to L2 = 357 by Oct., then up to L2 = 8 by Jan) and in latitude (23.6°S). It changed little, gradually fading, until early Jan. (Figures 3C, D). After that, it was not clearly tracked, but it may have persisted faintly and played a supporting role in the interaction of ovals BE and FA in March.[2]

Around 2000 March 20 a dark column appeared across the STropZ at L2 = 22 alongside the interacting ovals, apparently derived from another retrograding SEBs jetstream spot which halted at this point; it may have been caught up in the anticyclonic circulation of the earlier spot. SEBs jetstream spots were behaving in exactly the same way p. the GRS during the *Voyager* mission (pp.211–212 of Ref.5).

A second near-stationary dark spot in STropZ also arose as an SEBs jetstream spot which decelerated in 1999 August. Unusually it was just f. the GRS, with speed declining from DL2 = +42 to ~0 at L2 = 132, but then it disappeared in early September.

Subsequent jetstream spots behaved more typically. At least 21 more spots were tracked, with speeds varying from +73 to +106. Some spots' speeds varied, but a fairly consistent average of +95 was maintained (Table 4B).

However most spots decelerated gradually around L2 ~ 0 (where they passed the slow-moving dark spot no.2 in STropZ, described above), and especially as they neared the RSH. Moreover, at least four pairs merged as they neared the RSH. In contrast some spots proceeded steadily up to the RSH, and some were followed into and around the RSH (including two illustrated in Figure 3 of Ref.2).

The SEBs jetstream spots were present all around the SEBs, typically becoming recognisable at L2 ~ 130–160 (f. the post-GRS turbulent region). They became more numerous and conspicuous from late August onwards. This coincided with the increase in mid-SEB activity f. the GRS (see below). Some bright white spots nestled in the bays between the dark jetstream spots, probably moving with them. Late in the apparition, fewer spots were tracked, but many small crowded ones were recorded in hi-res images, so the activity was continuing at least until late March.

Great Red Spot

The GRS was typical in appearance, with only a little reddish colour. In July, red material was confined to a rather small patch in the centre, and there were unusual bluish streak(s) in the outer part, as in 1997 after the white oval merger. In August, the GRS was completely detached from the SEB, presenting an undisturbed oval, with a rim that was increasingly dark grey. But thereafter it became frequently distorted as SEBs jetstream spots impinged on it (see above) and circulated around it or within it, as in the *Voyager* movies. An example was observed over the new year (Figure 7).

Images on Feb. 6 and 10 showed a new South Tropical band beginning to emerge from the p. end of the GRS; but it disappeared soon after.

The longitude of the GRS was increasing at DL2 = +1°/mth, unusually so in the absence of any visible perturbation. Its length was 17°.

Mid-SEB rifts

The region of mid-SEB turbulence f. the GRS persisted as usual. The *Galileo Orbiter* obtained detailed images of this turbulent region on 1999 May 4, including two of the bright white spots which were shown to be thunderstorms with lightning.[2,13]

An extension of activity occurred when a bright new white rift appeared between Aug.22 and 25 (Figures 5, 9). (It was at L2 = 120 on Aug.26, prograding). It was just f. the

Table 5. Drifts in the South Equatorial Disturbance (South Equatorial Current)

		A. Individual drifts			B. Mean drifts		
Group	*Type of spots*	*L1(O)*	*DL1*	*(Dates)*	*DL1: Mean or range*		*Lat.*
I	Main complex and f. edge:@						
	Overall f. edge of disturbance:	213	+33 to +50	(Aug.-Mar.)	(Overall)	+33	(5-8°S)
	Main rift (gap in SEBn):	210	+22 to +50	(Aug.-Mar.)	(Short intervals)	+15 to +22	
	Dark bluish patch at f. edge (with break in EB)	–	+28 to +50	(Nov.-Apr.)	(Feb.-Mar.)	+50	
II	Dark blue streak complexes:					+12 to +20	6.4°S
	DS1 (secondary disturbance & transient rift)	170	+12	(Oct.-Dec.)			
	DS2c: P. end	–	+20	(Dec.-Feb.)			
	DS2c: F. end	–	+19	(Dec.-Feb.)			
III	Dark blue streaks or patches in EZ(S) developing p. main complex:					–4 to +5	6.1°S
	DS2a (with break in EB)	200	+5	(Oct.-Nov.)			
	DS4	–	+2	(Feb.)			
	DS5	–	–4	(Mar.)			
IV	Dark spots (DS2b, DS3), and bright spots emerging Np. mouth of main rift					0 to –30	6.6°S†
V	Tiny dark and bright spots on SEBn (p. stormy sector)					–35 to –53	7.1°S†
VI	*Max. speed of jetstream (from Voyager)*					*–45 to –114*	7°S

Notes to Table 5:

@Drifts in main complex and f. edge were as follows:
Overall f. edge of disturbance: L1(O) = 213; DL1 = +33 (Aug.-Feb.), +50 (Feb.-Mar.)
Main rift (gap in SEBn): L1(O) = 210 (f. edge, 213); DL1 = +33 (Aug.-Oct.) to +22 (Nov.-Jan.) to +50 (Feb.-Mar.).
Dark bluish patch at f. edge (with break in EB): DL1 = +28 (Nov.-Dec.) to +50 (Feb.-Mar.) to +39 (Apr.).
Because many of these spots were short-lived or rapidly varying, most of the speeds are imprecise. They are quoted in degrees per month here, but in degrees per day in the text. †Latitudes are for dark spots/streaks only.

post-GRS disturbed region, so was merely an extension of it, not a separate mid-SEB outbreak. It appeared very near the p. end of one of the dark reddish-brown streaks (STropC nos.3–4 in Table 4A; Figure 1). These are 'mini-barges' at ~17°S, and *Voyager 2* observed a mid-SEB outbreak beginning precisely in the centre of one such streak [pp.186–7 of Ref.5]. A second white spot appeared in the same place on Aug.28 (Figure 9).

The region of mid-SEB turbulence f. the GRS showed only low-level activity after November, with typically only one white spot there at any time (e.g. Figure 7).

The PC-JUPOS chart of the SEB latitudes in 1999 shows the typical drift of –54 to –80°/month in System II, not only f. the GRS but all around the belt, thanks to tracking of very small and faint spots. These may have been residual turbulence from the 1998 mid-SEB outbreak. The mid-SEB seemed much quieter after the start of 2000.

Equatorial region (south): The South Equatorial Disturbance

One of the most remarkable developments in the apparition was a disturbance in EZ(S)/SEBn, which began from a minor notch in SEBn, and gradually grew to become a spectacular bright-and-dark complex extending from SEBn across the equator with a 'stormy' EZ(S) extending a long way p. it. We call it the South Equatorial Disturbance (SED). The source was a feature at the f. end, which we call the SED main complex, that included an oblique rift in SEBn. This was similar to the long-lived white spot or rift that existed from 1976–1989, and another from 1879–1885 (see Discussion below). However it differed from these well-known features in moving more slowly at its inception, and in generating ever-increasing dark disturbance around and p. it. Because it was so impressive, well-observed, and potentially important for understanding jovian dynamics, we give a full account of it here, including Figures 8, 13, 14 and Figure 6 and Table 5. It continued as a major feature in the next apparition (2000/01), when it was also spectacular at near-infrared wavelengths, and was imaged by the *Cassini* spacecraft.[14] The second half of this account will therefore appear in the next apparition report.

The disturbance was discovered on 1999 Nov.28 when Tom Dobbins reported that the SEB for ~40° f. the GRS was abnormally light visually. On inspecting images, it became evident that this 'fading' was due to disturbance approaching the GRS along the SEBn/EZs, including two rifts in SEBn which could be tracked back at least to Nov.18. The f. one of these, the main complex, could be tracked back further with DL1 ~ +0.7°/day, and it persisted as the major feature of the disturbance.

In the text of this report, longitudes and speeds are relative to System I; 'faster' and 'slower' refer to rotation periods. Speeds are quoted in degrees per day because most features were short-lived or variable, so monthly speeds (as given in Table 5) are inevitably imprecise.

We define the longitude of the main complex as the L1 of the f. end of the bright indentation/rift in SEBn, or the p. end of the dark patch/streak at that point.

This feature was first recorded on 1999 July 23, as a pair of tiny rifts in SEBn, with no major disturbance evident. It progressively grew throughout the apparition. The disturbance was not visibly induced by any other features, although at least some of its features would later be induced or intensi-

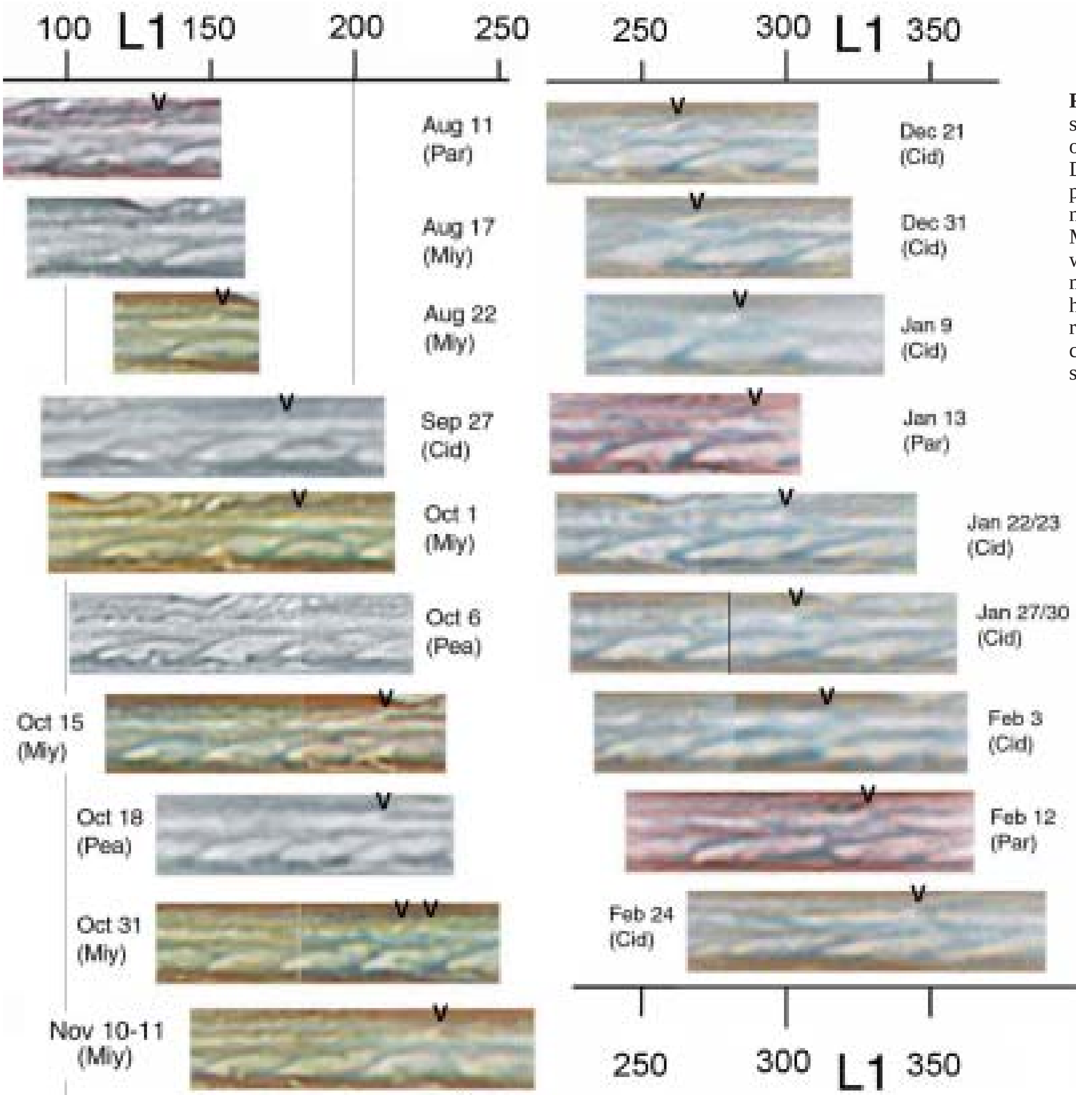
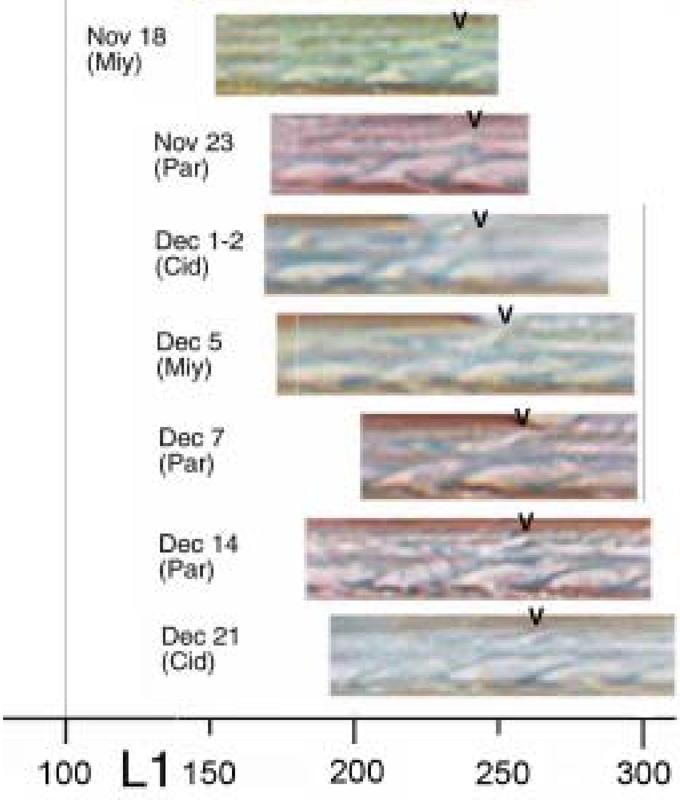

Figure 13. Strip-maps showing the development of the South Equatorial Disturbance during the apparition. Images by the named observers (Cidadao, Miyazaki, Parker, Peach) were projected into strip-maps by Mettig. Arrowheads indicate the main rift. (For more views of conjunctions with the GRS, see Figures 1, 6, 14.)

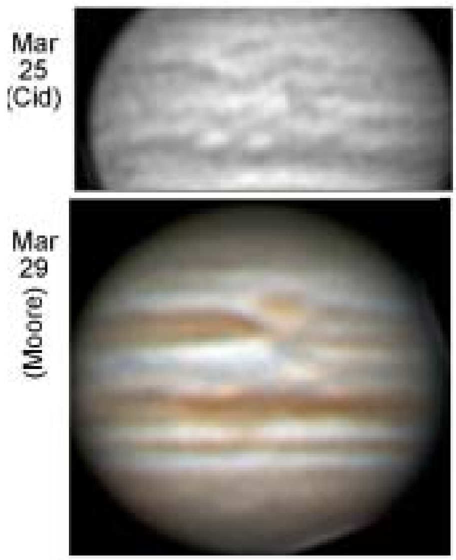

Figure 14. Two images showing the SED main complex passing the GRS again in 2000 March, when it was at its most spectacular. **(a)** March 25d 19h 24m, CM1=33, CM2=86 (Cidadao; red light). **(b)** March 29d 02h 14m, CM1=36, CM2=64 (D. Moore). Note the very bright spot marking the main rift (on CM), and the very dark (blue) patch f. it, with EB deflected around it.

fied when it passed the GRS region. Initially the main complex was inconspicuous and variable, but its presence was evident from the increasing amount of small-scale disturbance in the EZ(S) p. it (Figures 8, 13). The chart shows that this source of disturbance moved with DL1 = +1.1°/day from Aug. to Feb. Meanwhile the disturbance spreading p. from it had created an extensive 'stormy sector' of EZ(S)/SEBn.

The main bright rift acquired a dark bluish feature on its Nf. side in October, which appeared to displace or obscure the dark EB around it. The bright rift and the dark streak or patch were both minor at that time, but became progressively bigger and more intense, right up to the last observations in 2000 April, when the rift was very bright and the dark patch was very dark and large.

The drift of the main complex was not always continuous. On at least four occasions the main rift showed less retrograding motion, then a new main rift suddenly appeared about 10° f. it. Another phenomenon seen several times was white material streaming Np. in EZ(S) from the mouth of the rift or nearby.

Every 7–8 weeks, the main complex passed the GRS, and then it became most conspicuous. The main complex passed the GRS on 1999 Aug.18, Oct.15, Dec.5, and 2000 Jan.28 and March 28. The passages in 1999 Dec. and 2000 March in particular produced a brilliant white streak preceded by intensified dark blue patches (Figures 6, 13, 14).

A wide range of drift rates (Table 5) revealed that the SED was a great solitary wave retrograding in the SEBn jetstream, giving rise to complex disturbances propagating towards the maximum jetstream speed. In order of increasing speed, these were as follows:

I. The main complex of rift and dark patch, marking the source and f. end of the disturbance, moved at DL1 ≈ +0.5 to +1°.6/day, and occasionally it would 'jump' 10° f.

II,III. Dark blue patches were created p. the main complex on passing the GRS, with DL1 ≈ +0.7 to –1°.0/day

IV. Bright material emerged from or near the mouth of the rift into EZ(S) with DL1 ≈ ~0 to –1°/day, as if accelerating towards the speed of the jetstream.

V. Tiny spots p. the stormy sector p. it moved at DL1 ≈ –1.2 to –1°.8/day, i.e. approaching the material speed of the jetstream:

VI. The SEBn jetstream as measured by spacecraft: DL1 = –3.1 to –3°.8/day.

A detailed chronicle of the South Equatorial Disturbance

The main complex at the f. end of the disturbance

The first record of the main complex was on Miyazaki's image on 1999 July 23, as a pair of tiny rifts in SEBn. On Aug.6 there was a single rift with bright spot and dark patch at its mouth in EZ(S) – already the classic structure of the main complex, although small. In Aug. and Sep. it remained minor, sometimes showing the classic rift structure, but sometimes being almost imperceptible. On Aug.18 it passed the GRS, inconspicuously. Just afterwards, on Aug.22, a new white spot appeared to re-form the main rift, 10° f. the track of the previous one; and over the next few days, white material poured Np. from its mouth at DL1 ~ –1°/day.

The main complex was also very inconspicuous on Sep.29. However on Oct.1 it had restored the SEBn rift and the EZ(S) white area at its mouth, and also acquired two other features that would persist: a bluish streak or patch in EZ(S), and deflection of the EB around it. On Oct. 1 all these features were very minor (indeed, the rift was absent again on Oct.6–8). But as the main complex approached and passed the GRS, various features were induced in succession (see below): dark spot DS1 (Oct.6, L1 ~ 165); 'cold' white spot (Oct.13, L1 ~ 190), DS2 (Oct.20, L1 ~ 200), and opening and brightening of the main rift as it passed the GRS (Oct.15, L1 = 204). The spots p. the main complex had faster motion, and together with smaller-scale disturbances spreading even further p. (see below), all these features generated a growing 'stormy sector' of EZ(S), which was impressive in hi-res images from Oct.27 onwards.

Meanwhile the main rift continued to develop after this passage. In late Oct. and early Nov., the main rift showed less retrograding motion (about +0.5°/day), but on Oct.31, the locus of the main rift again jumped f. as a new bright spot on SEBn suddenly appeared 10° f. the previous one. Also, these bright spots apparently were accompanied by more extensive bluish shading than before, replacing part of the adjacent EB. The f. end of the main complex was formed by a very dark streak on SEBn, but during Nov. this migrated north, and from Nov.14–23 the main rift (bright spot) slid f. alongside it, thus displacing the main complex ~10° f. for a third time. The true motion of the bright rift was DL1 ~ +0°.5/day.

In late Nov., a spectacular picture developed as the stormy sector again passed the GRS region, and this was when it was first noticed visually (see above). We find that this passage induced or re-induced all the major features p. the main complex (described below), including two very dark spots with a white spot between them which moved at DL1 ~ –1°/day (Dec.1–7); they were followed by one or two bright spots actually emerging p. from the mouth of the main rift as it passed the GRS (Dec.5 onwards). However the main rift itself was already conspicuous before this passage, and did not change much.

Indeed there were no further sudden changes during December, but the dark blue patch at the f. end continued to grow bigger and obviously displaced the EB around it. There were no more 'jumps' in Dec., and the differential motion of the SEBn rift (DL1 = +0°.7/day) relative to the f. end of the main complex (DL1 ~ +1.1°/day) was apparently due to continuous growth of the dark bluish patch at the f. end.

On 2000 Jan. 9, the rift again jumped f., as a second white spot appeared 9° f. the previous one, and then re-formed the main complex with the same appearance as before. The previous white spot then probably prograded rapidly in the EZ(S) (see below).

In Feb., the main complex was further f. and it had slowed down considerably. The main feature was the very dark bluish patch in EZ(S), DL1 = +1.6°/day. The SEBn rift was usually represented by a bright white spot on its p. side. The pair passed the GRS around Jan.28 and March 28. At the latter passage they were both very intense (Figure 14), and on the north side of the very dark patch was a bright white area straddling the equator, the most extreme disruption of the EB to date. They were still very intense in the Pic du Midi images of April 7 (Figure 6C of Ref.2), and still present in the final images of the apparition, by Miyazaki on April 17.

Near-infrared images

The few methane-band images that covered the SED showed surprisingly little in it; the main rift never appeared methane-bright. Indeed the main complex sometimes showed up on methane images as a dark patch in EZ(S), which covered the mouth of the visible rift as well as the dark blue patch Nf. it (Oct.25, Akutsu; Oct.27, Dec.5, Miyazaki; see Part II of this report). We did not receive any methane images of it after the new year. However the final methane image taken by the Observatoire du Pic du Midi on 2000 April 7 showed a much more dramatic picture [Refs.2,8, and Part II of this report]. Continuum near-infrared images from the Pic du Midi at that time were also informative: the visibly bluish patches at the main complex and further p. (DS5, DS6), were the darkest features on the planet in these 'I-band' images. These aspects were to be prominent in amateur as well as professional images in the next apparition, so an account will be given in the next report.

Bright spots emerging Np. the main complex

We repeatedly found evidence for bright material emerging from or near the mouth of the main rift, into EZ(S), and moving faster, i.e. with DL1 from ~0 to –1°/day, while the main rift was retrograding at ~+0.5 to +1°/day. Some such bright spots appear definite, while others are only probable because they were ill-defined and short-lived. However it is likely that this was a recurrent phenomenon, especially when the main rift was passing the GRS. Such white spots or streaks were noted on Aug.22–28 (–1°/day, beginning as it passed the GRS p. edge); Oct.13–31 (DL1 ~ 0, as it passed the GRS); Dec.4 onwards (–1°/day, as it passed the GRS); Dec.14–24 (–1°/day); and probably Jan.9 onwards, though there were multiple white spots then. Some of these EZ(S) white spots appeared 'cold' white in images in contrast to the 'warm, creamy' tint of the bright spot forming the main SEBn rift further S and f.

Faster-moving features: dark streaks

These were among the most conspicuous features of the 'stormy sector' of EZ(S). They were dark patches or streaks (elongated E–W) in EZ(S). They emerged p. the main complex, and were generally induced, and in some cases re-induced, when these longitudes were passing the GRS. There were six major ones, called DS1–DS6 (Table 5).

The first two were induced by GRS passage in October. DS1 differed from subsequent dark features in several ways, suggesting that it perhaps comprised a secondary disturbance complex rather than a passive consequence of the main complex. It was slow-moving (DL1 ~ +0°.4/day); it was dark grey-brown rather than bluish; and on Nov.18 a minor SEBn rift developed at its p. end. On Nov.28, while passing the GRS, both DS1 and the rift p. it were spectacularly re-intensified; this was the 'secondary rift' which attracted attention then, however it did not persist after December.

DS2a (L1 ~ 200) developed on the p. edge of the main complex on Oct.20, just Np. the GRS. It was still quite faint on Oct.24 but very dark blue on Oct.29 and thereafter; it was weaker on Nov.10. Along with DS1, it was rejuvenated while passing Np.the GRS on Dec.1, as a long dark blue streak (DS2b).

DS3 was a new very dark blue spot which also appeared alongside the GRS on Dec.1 (L1 ~ 225). From Dec.1–7, DS2b and DS3 and a bright spot between them moved at DL1 ~ –1°/day. Then they merged into a long, retrograding dark blue streak, called DS2c. This was tracked from Dec. to Feb, with DL1 = +0°.7/day. However it was complex, and may not have been a coherent feature. Rather it may have represented a locus of variable dark streaks 25–50° p. the main rift, i.e. a wave moving in the wake of the main complex. In fact there were several indications of motions of ~ –1°/day at its f. end, including white spots as described above.

When the stormy region next passed the GRS in late January, the SEBn broke up into waves Np. the GRS, i.e. numerous small dark spots spaced 6° apart. There were 6 on Jan.22 and 11 on Jan.27. These overlapped the longitude of DS2c, and often had white spots between them. DS2c was not so identifiable after early Feb., but a succession of very distinct, stationary dark spots arose at a similar distance p. the main complex: DS4 to DS6.

DS4 (L1 ~ 295) was a new dark blue patch in EZ(S) which appeared faintly on Feb.3, p. the main rift, just after it passed the GRS. It was very dark blue from Feb.8 onwards, lengthening, and still prominent on Feb.24.

DS5 (L1 = 323), another similar patch, appeared on March 2, not near the GRS. It was conspicuous in images of March 18 (Pic du Midi, passing GRS, very dark in I-band) and March 20–29 (amateur images).

DS6 (L1 ~ 350) was another blue dusky patch, seen March 25–29, again immediately after passing the GRS.

In conclusion, these dark blue patches were created p. the main complex on passing the GRS, and had a range of speeds from +0°.7/day (closer to the main complex, presumably waves that were similar or related to it) to –1°/day (approaching the SEBn jetstream speed). However most were almost fixed in System I, presumably representing a wave type with an intermediate speed.

Even faster-moving features: tiny spots on SEBn

Even faster speeds were shown by tiny spots on SEBn further p. in the stormy region. They were small and ephemeral so the very fast motions are not obvious on the PC-JUPOS chart. However, careful examination of Miyazaki's best image pairs taken 2 days apart, from Oct. to Dec., allowed motions to be measured in long chains of tiny dark and bright spots along SEBn/EZs, p. the main stormy sector. The mean displacement of 12 such spots was DL1 ~ –1°.8/day. This confirms that the tiny short-lived spots generated on SEBn in the stormy sector were moving at speeds close to that of the SEBn jetstream (see below).

Discussion of the South Equatorial Disturbance

The detailed structure and circulation of the SED main complex were to be revealed in the next apparition, when the *Cassini* spacecraft showed that it had circulation just like that of the 1979 Great White Spot. For now, we simply point out the parallels between the visible-light observations of the SED in 1999/2000 and the Great White Spots in 1976–1983 and in 1879–1885. In spite of the different visible appearances, it seems that all three disturbances were fundamentally similar, being centred on an oblique rift in SEBn which led into anticyclonic circulation in the EZ(S), and all retrograding as a great wave relative to the SEBn jet.

The full speed of the SEBn jet has been a matter of discussion. Early *Voyager* measurements showed a speed of –1°.5/day, but this may have been dominated by disturbances such as the smallest ones that we tracked in the stormy sector, which may yet be waves that do not represent the true wind speed. More painstaking measurements on *Voyager* images have given a speed of –3.1 to –3°.8/day, and the same speed range has been maintained from 1995 to 2000 in Hubble Space Telescope and *Galileo* images [p.153 of Ref.5; Refs.15–17]. The consensus of all these values is DL1 = –3°.5/day (+155 m/s in System III).

The discrepancy between the motion of the SED main complex and the full speed of the jet, which we have documented in 1999/2000, was of course clearly revealed by *Voyager* in 1979[18] – although that Great White Spot did not produce obvious disturbance on its p. side, until many years later. However the same differential motion was, remarkably, detected by visual observers in 1881/82: W. F. Denning and A. S. Williams believed then that dark material was repeatedly erupting from a source ~35° f. the Great White Spot, and streaming towards and across it at –1°.9/day [p.154 of Ref.5].

The drift of the main complex was not always continuous; several times the main rift 'jumped' 10° f. This phenomenon also was repeatedly displayed by the Great White Spot of 1879–1885 [p.154 of Ref.5].

Passages of the SED past the GRS sometimes intensified both dark and bright features, including the main bright rift. In this the SED resembled the Great White Spot in 1979–1983. Then it was hypothesised that the cyclonic turbulence f. the GRS fed energy through the rift into the SED.

Finally, there could obviously be an analogy with the well-known disturbances which are almost always present along the NEBs: the dark projections and associated bright spots or plumes, often at ~30-degree intervals. The *Galileo* and *Cassini* spacecraft have revealed that here too exists a jet much faster than System I below the cloud-tops, so the NEBs blue projections and white spots resemble the SED main complex in being waves that propagate through this jet.[19] It remains to be seen whether the same meteorological patterns can account for the periodic waves of the NEBs and the solitary wave of the SEBn.

Equatorial region (north)

EZ(N) had a very conspicuous array of 11 dark projections/festoons, most of them followed by a white plume. The festoons, and the EB into which they merged, were much darker and more regular than usual. These projections were very stable this year, in contrast to the chaos of the last 2 years

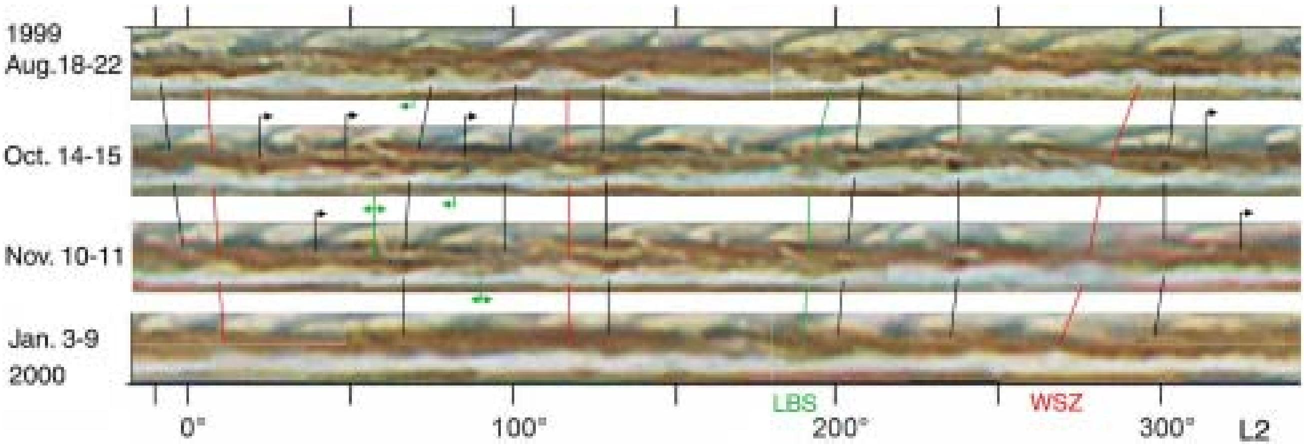

Figure 15. Strip-maps of the NEB, showing smallscale drifts and circulations. Images by Miyazaki were projected into these maps by Mettig. Important features on NEBn are tracked as follows:
Black lines: stable barges (cyclonic dark oblongs); Black arrows: small dark spots retrograding on NEBn; Green arrows: dusky streaks and spots in NTropZ, prograding or oscillating; Green line: Little Brown Spot; Red lines: major white ovals including White Spot Z.

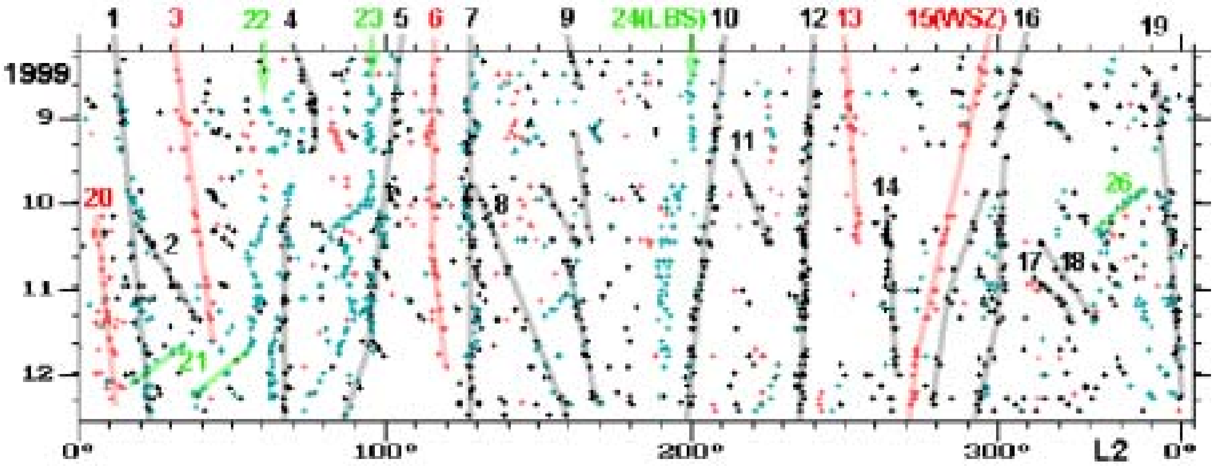

Figure 16. Drift chart of spots in NEBn and NTropZ during the apparition, produced using PC-JUPOS by Mettig. Black crosses: dark spots on NEBn at 15–18°N. They include the prominent, nearly-stationary 'barges', and smaller dark condensations on NEBn which were retrograding. Red crosses: bright spots or 'bays' between the barges at 15–18°N, including white spot Z (no.15, WSZ). Blue-green crosses: dark spots at 18–22°N. These were the dusky streaks in NTropZ, with prograding or oscillating motion, and the Little Brown Spot (no.24, LBS).

Figure 17. Three early colour images (all by Miyazaki) showing the origin of the Little Brown Spot (LBS) in NTropZ. A small arrow indicates barge no.10; an arrowhead indicates the LBS.

A. 1999 June 24d 20h 10m, CM1=210, CM2=201: before the LBS appeared; NEB is disturbed by a large rift.
B. July 13d 20h 17m, CM1=333, CM2=179: the new LBS.
C. August 6d 20h 09m, CM1=157, CM2=180.5.

Table 6. Longitudes and drifts: equatorial region (North Equatorial Current)

No.	*L1(O)*	*DL1*	*(oscillations?)*	*Dates*
Dark projections from NEBs (mostly followed by white plume):				
1	8	+5.5	–	Aug.-Feb.
2	32	+9 –> 0	(P ~ 60 d)	Jun.-Mar.
3	61	+3.8	–	Jun.-Feb.
4	113	+6.4	(P ~ 20 d)	Jun.-Jan.
5	146	+8 –> –3.5	(irregular)	Jun.-Feb.
6	171	+1.0	(slight)	July-Mar.
7	199	+2.2	–	June-Mar.
8	230	+3 –> 0	(slight)	June-Mar.
9	257	+4 –> +2	–	June-Apr.
10	290	+3 –> +8	–	June-Mar.
11	324	0 –> +7	–	June-Mar.

Notes to Table 6:
Columns are as follows. Number; L1(O), System I longitude at opposition on 1999 Oct.23; DL1, System I drift in degrees per 30 days; Dates of observation or drift measurement. All drifts are derived from a large number of images, and are mostly averaged over minor variations. Several projections oscillated with period ~ 20 days.

(Table 6; Figure 13). As there was a twelfth, more variable feature between nos. 3 and 4, the mean spacing was 30°.

This stability allowed slight oscillations in longitude to be detected for several of the projections, mostly with periods of ~20 days, and amplitudes up to a few degrees.

North Tropical region

Mid-NEB rifts

Bright ‘rifts’ in mid-NEB were quite often observed, and had typical North Intermediate Current drifts (Table 7B). The level of rift activity was not unusual. One rather northerly and slow-moving rift attracted attention when Tom Dobbins of the ALPO noticed it visually on Nov.12, at L2 = 233, alongside a dark NEBn ‘barge’; it was notably bright and compact. Images showed that a tiny spot on this track had arisen ~2 weeks earlier, but the very bright spot appeared on Nov.7, then after Nov.12 it showed the usual elongation in the Sp. direction.

Features on NEBn

There were conspicuous dark bulges and bright bays along NEBn at many longitudes. This array of features has existed since 1997 with some modification. The dark bulges in 1999/2000 were in fact centred on the persistent dark barges, and the bright spots included the peculiar white spot Z. The PC-JUPOS chart revealed that the complex and interesting pattern of drifts was basically the same as in 1998,[1] but even more fine detail was seen (Figures 15, 16). These drifts will be described in order of rotation period (see Table 7A).

(i) The fastest-moving spot on NEBn was white spot Z (NTropC no.15 in Table 7A; DL2 = –6°/month). It had maintained a surprisingly fast drift since 1997, and was still destroying projections ahead of it (e.g. no.14).

(ii) Major dark ‘barges’: Three major barges persisted from 1997, and still had slowly prograding drifts (Nos. 5 and/or 7, 10, and 12; DL2 = –1 to –6). Although classical dark barge shapes were not always distinct within the dark bulges, in Nov. and Dec., some of the dark spots actually looked more classically barge-like than before. Barges nos.10 and 12, 3 years old, had been a close pair in 1998 but had drifted apart. No.12 (L2 = 237) was especially dark and compact.

(iii) In contrast, the sector f. white spot Z in 1998 exhibited many small, newly created, slowly retrograding, dark spots, and this activity was still evident in 1999/2000 (DL2 = +2 to +5). Dark barges nos.1 and 4a, and other shorter-lived spots nearby, may have been the same dark spots that were newly created in 1998, and no.19 appeared during solar conjunction.

(iv) There were also small dark spots on NEBn which moved even slower, lasting for 2–5 weeks each. They were seen all around the NEBn, though the most distinct retrograding spots arose f. the white bay no.20. The best-tracked were nos.2, 8, 11, 17, 18, mostly with DL2 = +11 to +20, but no.17 had DL2 = +32 for 2 weeks – clearly under the influence of the NEBn retrograding jetstream.

All these NEBn spots had measured latitudes of 16–18°N (Table 7A). This is unusual: the expected latitudes are [pp.115 & 399 of Ref.5]: 16°N for cyclonic dark barges; 17–18°N for small spots partly entrained by the retrograding jetstream; and 19°N for anticyclonic white ovals. In this apparition, the overlap in latitudes was probably because the dark barges were attended by dark material extending north into the NTropZ, while the white spots were mainly visible as bays between barges, not as complete ovals.

North Tropical Zone

In NTropZ, there were many dusky spots and streaks, especially just Np. the NEBn barges/projections. Some were evidently trapped at these locations, though oscillating (NTropC nos.22, 23, 24 in Table 7A). The most prominent was the Little Brown Spot (no.24, LBS; see below). Others broke free and prograded rapidly on a tenuous N. Tropical Band at 20°.5N, with DL2 = –31 to –39 (nos.21, 22a, 23(parts), 25, 26).

The LBS was at the canonical latitude for anticyclonic ovals, as were the oscillating streaks in NTropZ (19°N). The little streaks which ran faster, sometimes along partial NTropB, were at 19–20°N. A similar streak with DL2 = –38 at 19°N was observed in 1993 during the NEBn expansion event.[20]

The Little Brown Spot

This notable spot in NTropZ formed within a few days in July, at L2 = 205, just p. a dark grey projection of NEBn. The dark grey projection, containing a small barge (NTropC no.10), had become conspicuous at L2 = 210 on July 4 and 6. On July 9 a light orange patch appeared on its p. side, and on July 11 and 13 this had rounded up into a prominent yellowish-brown or orange-brown oval at L2 = 205. This was the Little Brown Spot (LBS), presumably anticyclonic, and remained stable for the rest of the apparition (Figures 17–19).

Its initial orange tint suggested that it might become a true Little Red Spot, but it never did. After a few weeks it became merely brown like the NEB, and it was no more conspicuous than other, minor features.

Moreover, in methane images it was dark, not bright – unlike all anticyclonic reddish ovals ever observed. It was recorded in many of Miyazaki’s methane images, in which the LBS with surrounding region was notable as a large dark area – in fact, the main methane feature in the NTropZ (July 13 to Sep.24) (see Part II of this report). Later this methane-dark patch was offset slightly, extending from the centre of the LBS to the NEBn barge f. it (Oct.14 to Dec.11). There were other methane-dark bulges from NEBn into NTropZ as well, aligned with visible dark bulges, but the LBS feature was always the most conspicuous.

Table 7A. Longitudes & drifts, 1999/2000: northern hemisphere

1999/00: No.	*Description*	*L2(O)*	*DL2*	*Lat.*	*Dates*	*1998/99:* L2(O)	*DL2*	*(0-0)* DL2
NTropC								
	Features on NEBn:							
1	Bulge / small dark barge	19	+2.3	+18.0	June-Mar.	(late-appearing)		
2	Small dark spot	28	*+17.4	+16.6	Oct.-Nov.	–		
3	White spot or bay	40	+4.8		July-Nov.	(late-appearing)		
4a	Small v. dark spot or barge	(80)	(+3.0)	(+17)	July-Sep.	40	+2.4	+3.0
4b	ditto	67	–0.2	+17.3	Oct.-Jan.	–		
5	Dark projection	97	–2.7	+18.0	June-Oct.	135	–0.9	–2.8
			–> –6.3		Nov.-Feb.			
6	Large creamy-white complex oval	116	+0.3	+16.8	July-Nov.	(148)	–3.0	–2.4
7	Big proj. inc. small v. dark barge	128	+0.5	(+17)	June-Feb.	?135	–0.9	–0.5
8	Dark spot	139	*+11.2	+17.4	Oct.-Dec.	–		
9a }	Small dark proj.	{ (169)	+3.2	(+17)	June-Aug.	(late-appearing)		
9b }	(possibly up to 5 successive spots)	{ 160	+5.0		Oct.-Dec.	–		
10	Dark proj. / small dark barge	203	–3.5	+16.5	June-Feb.	(224)	–0.8	–1.6
11	Small v. dark spot	(229)	*+12.0	(+17)	Sep.-Oct.	–		
12	Proj. / v. dark barge	237	–1.1	+16.5	June-Nov.	260	–0.9	–1.7
13	White bay	(256)	+2.3		Aug.-Oct.	–		
14	Dark projection	263	+2.2	+16.6	Oct.-Dec.	–		
15	Bright white bay (spot Z)	281	–5.6	+17.3	July-Mar.	356	–5.7	–5.6
16a }	Extended dark bulge / barge	{ 288	–7.8	(+17)	July-Nov.	–		
16b }	(splitting off other dark spots on f. side; stationary after Nov.)	{ 300	–1.8	+16.9	Sep.-Feb.	–		
17	Small dark spot (f. 16b)	(309)	*+32	+16.5	Oct.-Nov.	–		
18	Small dark spot (f. 17)	319	*+20	+16.5	Oct.-Nov.	–		
19	Dark bulge	357	+1.8	+17.6	Aug.-Dec.	–		
20	Large creamy-white complex oval	7	+3.0	+17.2	Oct.-Dec.	–		
NTropC (cont.) & faster								
	Features in NTropZ:					*L2(date)*		
21	Dusky spot or streak (slight, on NTropB)	(see R)	–38	+20.2	Nov.-Dec.	35 (1999 Nov.20)		
22	ditto (p. barge/proj. no.4b) (Oscillating, DL2 ~ –11 to +8)	59	(see L)	+19.0	Oct.-Nov.			
22a	(emerged from no.22)	–	(–35)	+19.5	Nov.-Dec.			
22b	(emerged from no.22)	(66)	(–2)	+18.5	Nov.-Dec.			
23	Dusky spot or streak p. proj. no.5)	(96)	0.0	+19.0	Aug.-Sep.			
	(From Oct., oscillating, DL2 ~ –36 to +4, & emitting small streaks, DL2 ~ –36 to –15)		(–> see L)		Oct.-Dec.			
24	Little Brown Spot (p. barge/proj. no.10)	192	–3.4	+19.0	July-Nov.			
25	Tiny dusky streak (p. barge no.12)	(see R)	–39	(+19)	Jan.	229 (2000 Jan.1)		
26	Tiny dusky streak (p. barge no.19)	(see R)	–31	+18.9	Sep.-Oct.	348 (1999 Sep.26)		
NTC								
1a	Dark streak NTZs (faded in Sep.)	(4)	+13.0	+30.2	June-Sep.			
2a	Dark streak NTZs (faded in Sep.)	(24)	+12.2	+30.2	June-Sep.			
2b	Bright oval NTZs	26	+12.9	+29.1	Sep.-Feb.			
3	Dark spot NTZs (gradually fading)	231	+11.6	+30.0	June-Dec.			
4	Bright oval NTZs	263	+14.4	+29.4	July-Jan.			
NNTC								
1	Little Red Spot on NNTBs (Methane-bright)	0	*–36	(+34)	Aug.-Oct.	235	–41	–44.4
2	P. end dark NNTB	31	–4	(+37)	Aug.-Nov.	–		
3	P. end dark NNTB	(145)	(–8)	+37.3	July-Oct.	–		
4	F. end dark NNTB	(186)	(–13)	+37.3	July-Oct.	–		
5	P. end dark NNTB	(198)	(–11)	+37.3	Nov.-Jan.	–		
6	F. end dark NNTB	270	–15 –> 0	(+37)	Oct.-Jan.	–		
7	White oval NNTZ	19	**	+40.5	June–Apr.	142	(–10)	–8.6
8	White oval NNTZ (Methane-bright)	270	**	+40.6	July-Mar.	?347	(var.)	–1.7
9	White spot NNTZ (small & bright)	(96)	–13	+41.2	July-Oct.	–		
N^3TC								
1	White spot	72	–21.5	+43.6	Sep.-Jan.			
2a	Dark spot (tracked for 3 weeks; –> no.2b?)	(89)	*–36	(+45)	Sep.-Oct.			
2b	Dark spot (initially faster, = no.2a?)	(74)	–17	+45.2	Nov.-Jan.			
3	Dark spot	135	(–13)	(+45)	Sep.-Nov.			
4	White spot	174	–20	(+45)	Oct.-Feb.			
5	Dark spot	181	–20	(+45)	Oct.-Jan.			

(see notes opposite)

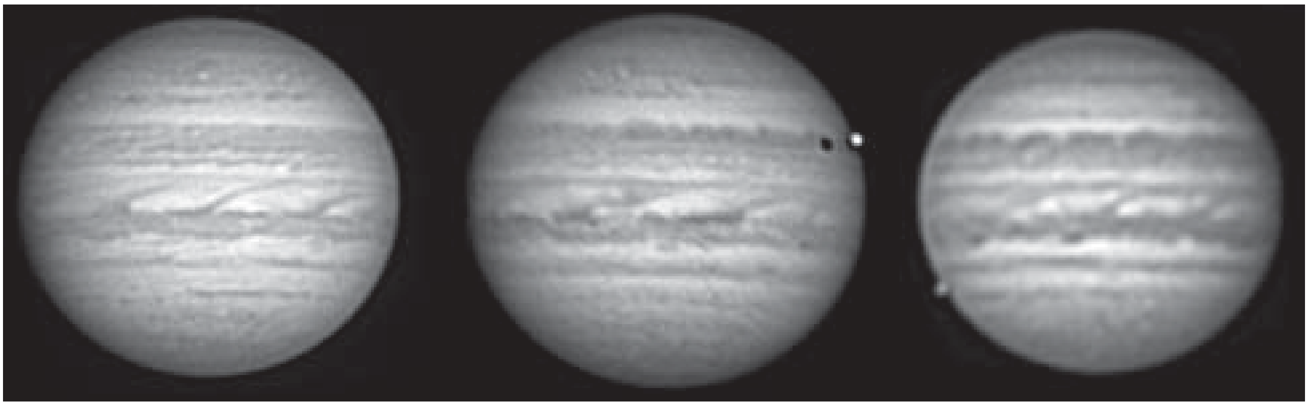

Figure 18. Three images showing the LBS and dark barges on NEBn; compare drawings in Figure 19.
A. Sep.8d 01h 07m UT, CM1=353, CM2=130 (D. Peach). The LBS is on f. side.
B. Oct.16d 13h 54m, CM1=345.5, CM2=189 (S. Buda & B. Curcic, Australia; 250mm Dall–Kirkham; image forwarded by T. Richards). The LBS is on the CM. Io and its shadow are beginning a transit.
C. Nov.28d 15h 48m, CM1=9, CM2=244 (Tan Wei Leong). On the NEBn are two very dark barges on the p. side, and brilliant round white spot Z on the f. side. Europa is entering occultation.

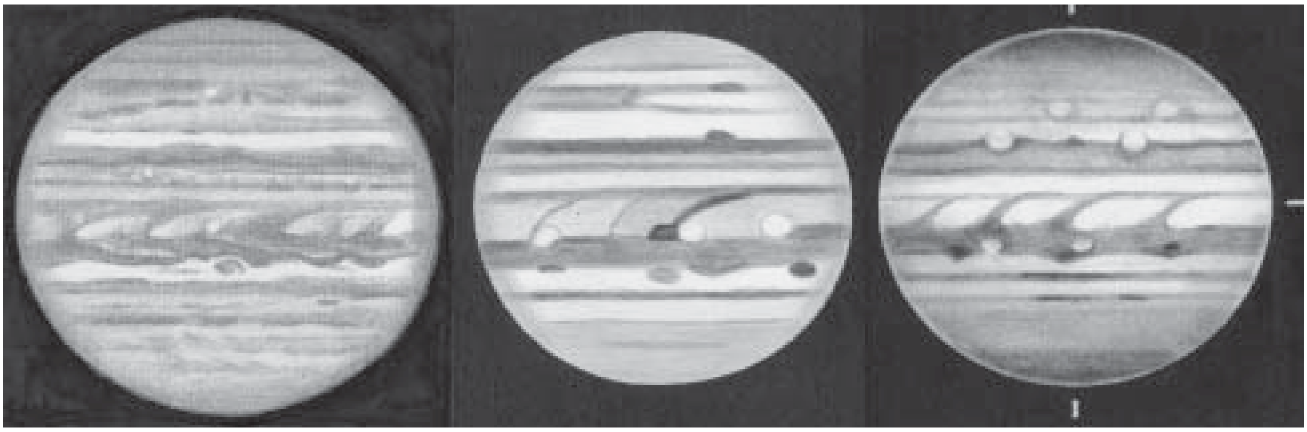

Figure 19. Three drawings showing the LBS and dark barges on NEBn; compare images in Figure 18.
A *(left)*. Sep. 29d 15h 00m, CM1=220, CM2=192 (Adachi). Shows the LBS on the CM. Note the triple SEB, the waviness of the NEBn and the fragmentary NTropZB and NTZB. Dark NTBn spot near the f. limb.
B *(centre)*. Oct. 12d 20h 40m, CM1=321.5, CM2=193 (Foulkes). Shows the LBS on the CM and a very dark NEBn barge near the f. limb.
C *(right)*. Oct.31d 21h 40m, CM1=121, CM2=207 (Frassati). Shows three dark barges on NEBn; also several dark jetstream spots on SEBs with white spots between them.

Similar little brown spots have been reported before in the NTropZ, including one that formed during the *Voyager* missions [pp.118–123 of Ref.5], and another that marked the start of the NEB expansion event in 1993.[20] These appear to be anticyclonic ovals, but dominated by belt-like brown clouds rather than GRS-like high red haze.

Discussion of the currents on the NEB north edge

The remarkable motions that we have recorded, both in 1998/99 and 1999/2000, show strong parallels with those recorded in *Voyager* images in 1979 [pp.118–123 of Ref.5; this analysis previously presented in Ref.21].

Voyager images first revealed the retrograding NEBn jetstream at 17°.6N (DL2 = +45°/mth), which takes a sinuous course with cyclonic dark ovals ('barges') on its S side and anticyclonic white ovals ('portholes' or 'bays') on its N side. The full speed of this jetstream has never been detected from Earth, but some of the tiny retrograding spots that we have listed were clearly under its influence.

Voyager imagery also revealed:

– Dark patches like waves on the retrograding NEBn jetstream (DL2 = +34°/mth) were arising from a large 'rifted region' in NEB.
– Some of these dark patches circulated into the NTropZ near the p. edges of barges.
– At one such site, the circulation developed into an anticyclonic Little Brown Spot at 20°N which persisted for months.

The phenomena we have described were obviously very similar.

Notes to Table 7A:
Columns are as follows. Number; Description; L2(O), System II longitude at opposition on 1999 Oct.23 (for L3(O), subtract 137.0 degrees); DL2, System II drift in degrees per 30 days (for DL3, add +8.0 deg/month); Zenographic latitude; Dates of observation or drift measurement. All drifts were derived from a large number of images unless otherwise stated. Drifts in brackets are imprecise. ['See L' and 'See R' refer to more detailed figures given in columns to left or right.] *Spots with anomalous drifts not included in mean in Table 7B. The last 3 columns give data from 1998/99 apparition, followed by DL2(O-O), the average drift rate between oppositions.
**Two white ovals in NNTZ oscillated with periods 3-4 months. No.7: DL2 range –14 to –1, observed for 2.5 cycles.
No.8 (methane-bright): DL2 range –18 to –5, observed for 2 cycles.

In 1979, this activity was occurring f. a long-lived cyclonic ‘rifted region’ in the NEB, which disturbed the NEBn retrograding jetstream and probably thus created the barges and other circulations downstream [pp.118–123 of Ref.5]. In 1999, there was no such rifted region, but the most well-defined retrograding spots arose following stable white spots which formed especially pronounced ‘bays’ in the NEBn: nos.6, 15 (white spot Z), and 20. These bays probably deflected the NEBn retrograding jetstream, perhaps setting up waves downstream like the rifted region in the *Voyager* era.

Are these phenomena always present, or are they connected to the NEB expansion event that was progressing slowly during 1999/2000? To some extent they may be always present, as the zonal currents are permanent, and some local circulations such as rifts, barges or ovals may be present at any time. Certainly the recent advances in CCD imaging and PC-JUPOS analysis have allowed us to track tiny features that would otherwise have been overlooked. However the number and prominence of the NEBn circulations certainly increases during or after a NEB expansion event, so there is probably more largescale eddying then; also the dark cloud streaks that comprise the expansion event provide tracers for motions that would otherwise not be revealed. Thus these motions were particularly detectable in this apparition, and also in 1993 during an earlier NEB expansion event.[20] During the *Voyager* era in 1979, there was no expansion event, but the long-lived rifted region of NEB may have played a similar role as a source of energy and turbulence that generated waves and circulations in the adjacent sector of NEB [p.123 of Ref.5].

North Temperate region to North Polar region

NTBs jetstream spots

There were still 7 small dark features on NTBs moving at –10°/day in System II – the North Temperate Current C. Often they appeared bluish. Amazingly, the PC-JUPOS chart shows that these 7 jetstream spots have all persisted through 3 apparitions from 1997 to 2000 (and indeed to 2001). They had accelerated very slightly since 1998 but their mean speed during solar conjunction was almost identical to their mean speed in 1999/2000. Their individual drifts were not identical but they appear to repel each other, never coming too close, just like the white ovals in the SSTC.

The longevity of these 7 spots has also been recognised by Garcia–Melendo et al.,[22] who traced them all back at least to 1995, and possibly to 1991. Data were insufficient to track them in the early 1990s, but their drift has clearly been steadier from 1996 onwards.

Usually, such NTBs jetstream spots are small dark spots, presumed to have anticyclonic circulation by analogy with similar spots seen by spacecraft on other jetstreams.[5] However in this apparition, their appearance was variable and often inconspicuous: sometimes a small dark hump, sometimes a diffuse projection, but often a ‘step-down’ of the NTBs edge. This transformation is explained by Hubble Space Telescope images:[22] the spots are indeed formed by anticyclonic ovals, but these have fairly low contrast, whereas a ‘hump’ of NTB material piled up on the p. side of the oval constitutes the feature visible in ground-based images.

North Temperate Belt and Zone

There were no major features. Of the few NTC spots recorded in Table 7A, nos. 1a and 2a were dark streaks in southern NTZ touching projections from NTBn; they were dark in July and August, but rapidly became faint and reddish in early September. In October, only faint shadings remained, and in November, cream-coloured bright spots appeared on the same tracks, nos.1b (not listed, short-lived) and 2b. Another bright spot, no.4, may have persisted from 1998. Latitudes indicate that all these features were cyclonic.

NNTBs jetstream spots

There was a volley of several small dark spots on the NNTBs jetstream. These spots were tracked from October for

Table 7B. Average drift of currents, 1999/2000, northern hemisphere

Current	*Type of spots*	*N*	*DL2: Mean (Range)*	*Lat. range*
NIC	White spots in NEB rifts (Aug.-Dec.)	6	–102.7 (–83 to –118)	10-15°N
	White rift (Dec.-Jan.)	1	–38	
NTropC	(i, ii) Long-lived barges and white spot Z [nos.5,10,12,15,16]	5	–3.9 (–1 to –8)	16-18°N
	(iii) Other dark spots, barges, and bays	12	+2.3 (0 to +5)	16-18°N
	(iv) Small dark spots on NEBn [nos.2,8,11,18]	4	+15.1 (+11 to +20)	16-18°N
	(v) Fast-moving dusky spots in NTropZ [nos.21,22a,23(parts),25,26]	5	–35.8 (–31 to –39)	19-20°N
NTBs jet	Small humps on NTBs	7	–293 (–291 to –296)	24.3°N
		[DL1 =	–64.4 (–62.3 to –67.3)]	
NTC	Misc. spots	5	+12.8 (+11.6 to +14.4)	29-30°N
NNTBs jet	Small dark spots on NNTBs	6	–78.3 (–73.6 to –80.7)	34.8°N
	LRS on NNTBs (methane-bright)	1	–36	(34°N)
NNTC	NNTB segments & NNTZ white ovals	8	–9.3 (0 to –18)	37-41°N
N^3TC	Misc. spots	5	–18.3 (–13 to –21.5)	43-45°N
N^4TC	White spots	8	+4.7 (0 to +9)	49-53°N§

Notes to Table 7B:
This table gives the mean speed and range of each current, some of which are not itemised individually above.
N, number of spots included (some with multiple drifts).
§ N^4TC white spots: Two of these were initially at 52.8 (±0.6) deg.N, but then shifted to 51.4 and 50.9 deg.N. Others were at 50.4 and 49.4 deg.N; average 50.7 deg.N. This corresponds to the cyclonic 'N^4TB' domain, which is unexpected, as white spots are more commonly seen at 52-55 deg.N in the anticyclonic 'N^4TZ' domain. (All these spots had very similar drift rates throughout.)

2–3 months, with some variation in speed (summarised in Table 7B). The outbreak apparently started earlier as spots close to these tracks were also imaged in July and/or August. From July to January, this set of spots (albeit varying) did a complete circuit round the planet.

Methane-bright spots

Miyazaki's methane images (see Part II of this report) revealed only two bright spots in the north. One was rapidly prograding on NNTBs at DL2 = –36°/mth (NNTC no.1 in Table 7A). In colour images it was a tiny Little Red Spot (LRS) on the NNTBs edge, like the one recorded in 1997 and 1998, and it was probably the same spot. When first recorded on 1999 Aug.22 it was a tiny orange lozenge with bright centre. In October it became confused by a very dark grey NNTBs jetstream spot overtaking it; this obscured it in visible and methane light on Oct.10, but the LRS was reappearing on Oct.15 (Figure 1).

The other methane-bright spot was in NNTZ at 41°N (NNTC no.8 in Table 7A), and appeared in colour images as a small, light or creamy-white spot in dusky NNTZ. It is possible that this was the same methane-bright spot tracked from 1996 (when it was an LRS) to 1998; but if so its drift during solar conjunction would have been very slow, although not unprecedented. In 1999/2000 its drift oscillated between –18 and –5°/month.

There had been two methane-bright ovals in this anticyclonic latitude in 1997 and 1998, and the second one did persist in 1999/2000 as a white oval (NNTC no.7), but it no longer appeared methane-bright.

Both of these ovals showed regular oscillations in drift with a period of 3–4 months (see Table 7A footnote). The speed changes were sometimes quite abrupt. These ovals had shown similar fluctuations in previous years. Drifts in NNTZ have previously shown a range from typical NNTC (mean DL2 = 0) to typical N^3TC (mean DL2 = –15);[5] these two methane-bright ovals have oscillated regularly between these two speed ranges.

Other features in far northern currents

In the NNTC, the main features were dark sectors of NNTB (Table 7A), with variable drifts in the range from NNTC to N^3TC. These sectors were ~25–50° long, and were quite conspicuous but lasted only a few months, as is typical.

In the N^3TC, there were several bright and dark spots (including shorter-lived ones with similar drifts to those listed in Table 7A). The white spots had more stable tracks than the dark spots.

In the N^4TC, there was a more regular and stable array of white spots: eight of them were each tracked for 3–7 months, with only small fluctuations in drifts (Table 7B).

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