Jupiter in 2000/2001
Part I: Visible wavelengths – Jupiter during the *Cassini* encounter

John H. Rogers, Hans–Joerg Mettig, Damian Peach & Michael Foulkes

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

The main changes on Jupiter in 2000 were the disappearance of the dark band and festoons in the Equatorial Zone, and the broadening of the North Equatorial Belt (NEB) into the North Tropical Zone. While dark projections on the southern NEB diminished in number, irregular projections from the northern NEB eventually constituted a classical expansion event which was complete by the start of 2001, and the expanded belt was pockmarked with dark 'barges' and white ovals.

Most of the major spots had persisted from the previous apparition, especially anticyclonic ovals, and their drifts, circulations, and appearances were largely unchanged. These included not only the Great Red Spot and a brown ring in the S. Tropical domain, but also anticyclonic white ovals in almost every other domain. Some of these, in latitudes ranging from the South Polar region to the N.N.Temperate region, apparently persisted between apparitions in spite of showing large and sudden changes in their drift rates.

Outbreaks of dark spots were continuing in the SEBs, NTBs, and NNTBs jetstreams. In addition, we detected several spots moving in the SSTBn jetstream, which has rarely been detected from Earth, and one each in the NTBn, NNTBn, and N^5TBs jetstreams, which have never previously been detected from Earth.

The highlight of the apparition was the *Cassini* spacecraft flyby. *Cassini* images revealed details of all the spots and circulations that we recorded; examples are presented in an Appendix. Observations at non-visible wavelengths, from amateur and professional observers and from *Cassini*, will be presented in Parts II and III of this report.

Introduction

Opposition was on 2000 November 28, at declination 20°N in Taurus. Jupiter was thus high in the sky for northern hemisphere observers, forming a magnificent group with Saturn and the Hyades and the Pleiades. It was very well covered by observers around the world.

This report follows on from that for 1999/2000.[1,2] An interim report on 2000/2001 has been published.[3]

The highlight of the apparition was the *Cassini* spacecraft flyby. *Cassini* imaged the planet almost continuously from 2000 Oct 1 to Dec 18. Its closest approach to Jupiter was on Dec 30, and it acquired more targeted close-up images of some regions on that date and for several weeks thereafter. The imagery in Oct and Nov generated movies of the clouds like those produced by the *Voyager* spacecraft in 1979. The *Cassini* movies were of similar resolution but higher quality, and they were accompanied by similar coverage in ultraviolet and infrared wavebands which *Voyager* did not image. We have already given brief summaries of the flyby,[3,4,5] and in an Appendix to this paper, we present examples of *Cassini*'s global imagery in visible colour, to correlate these images with our own report. (Otherwise, this report is entirely derived from amateur observations as described herein, apart from specific references to spacecraft imagery where it elucidates the physical nature of the spots that we have tracked.) Indeed, as this paper was being prepared, there had only been limited releases of *Cassini* data: a small number of publicly released images, and movies derived from global maps which we did not study in detail. A synopsis of the imaging science from the flyby has now been published.[6] The full *Cassini* data set will be a valuable resource, which could answer many questions about the detailed dynamics and three-dimensional structure of the cloud formations we observe.

The *Cassini* flyby was also the occasion for additional imagery by the aging (but still intermittently functional) *Galileo* Orbiter, and for extensive infrared imagery by both professional and amateur observers on Earth. These infrared data sets will be described in Paper II of this series. Finally, in Paper III, we will synthesise all the data sets as they apply to one major disturbance of 2000/01, the South Equatorial Disturbance.

The major part of this report is derived from amateur CCD images, analysed using the PC-JUPOS software, as described for previous apparitions.[1,7,8] The observers are listed in Table 1A. As before, images were contributed from all round the world, via e-mail or via websites. The first images were on 2000 June 14 by Isao Miyazaki. Miyazaki was unfortunately unable to continue imaging after 2000 August, but several other observers produced images of excellent quality which amply covered the apparition. There were good images almost every night from August to November, often from several observers spaced around the world so that all jovian longitudes were covered frequently. There was still intensive coverage in December and January, though more uneven in frequency

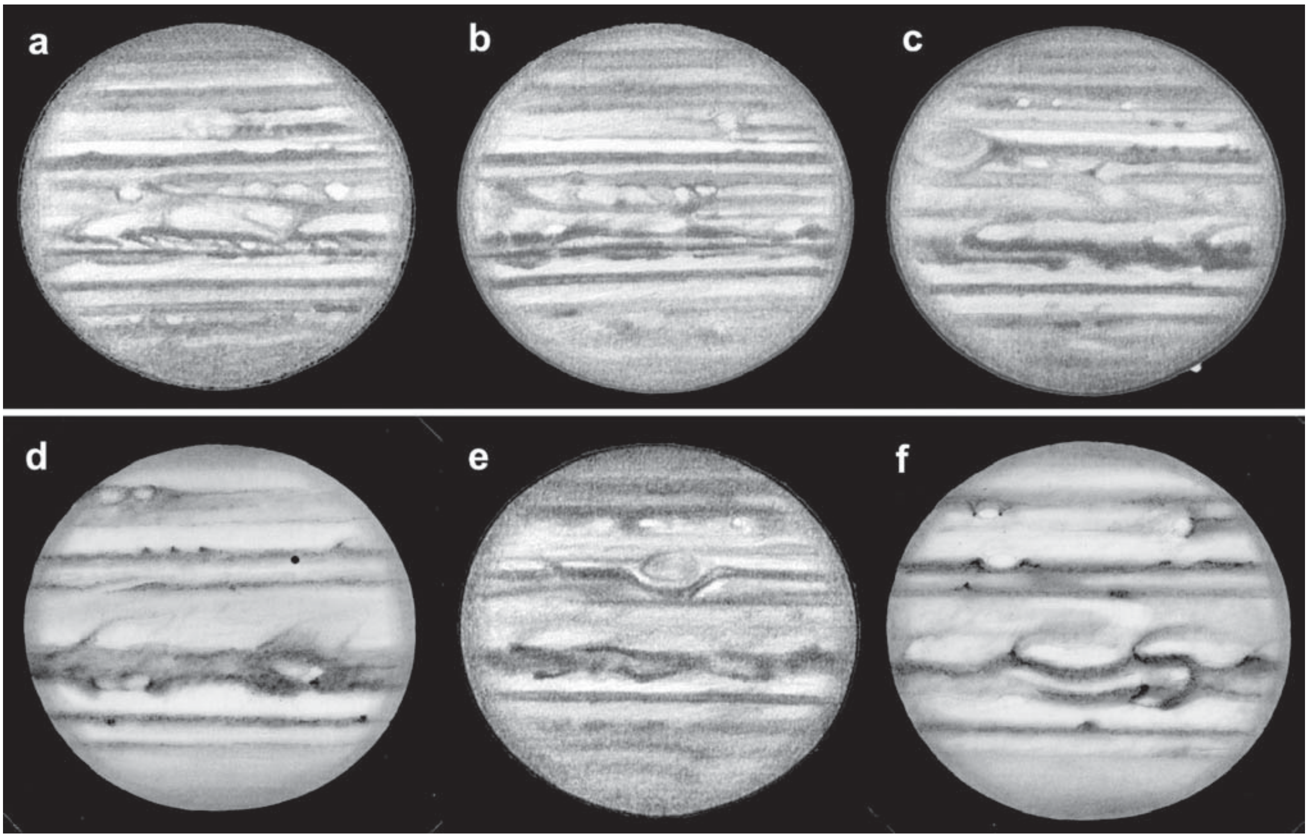


Figure 1. (a, b, c). Three drawings by Adachi in 2000 August, all showing the stormy sector of EZ(S).
(a) Aug 3d 19h 46m, CM1= 185.8, CM2= 319.1 (Adachi). Shows oval BA on CM.
(b) Aug 15d 19h 02m, CM1= 252.9, CM2= 294.9 (Adachi). Shows oval BA f. the CM, and the main complex of the S. Equatorial Disturbance near the CM.
(c) Aug 28d 19h 58m, CM1= 178.0, CM2= 120.6 (Adachi). Shows a series of white SSTZ ovals, and the GRS with the disturbed SEBZ f. it. Ganymede is half out of occultation on the Nf.limb.
(d) Oct 2d 00h 30m, CM1= 155.9, CM2= 205.3 (Bullen). (This rift in the SEBn was not close to the SED.)
(e) Oct 11d 14h 53m, CM1= 102.4, CM2= 70.8 (Adachi). Shows a number of white SSTZ ovals and the dusky brown STropZ oval (no. 4) p. the GRS.
(f) Nov 4d 00h 03m, CM1= 111.9, CM2= 262.0 (Bullen). Shows oval BA near f. limb and a white SSTZ oval near p. limb.

and resolution because of winter weather. The most prolific imager was Antonio Cidadão, who produced over a hundred images per month, obtaining exceptional resolution with only a 25cm aperture,[9,10] and also beginning to use infrared wavebands (see Paper II). The last good images were on 2001 April 25 by Cidadão, although Frank Melillo managed to obtain an image as late as May 10.

Japanese observers also produced many images, with careful colour balance, and compiled them digitally into whole-planet maps,[11] the first on 2000 July 16–22 and the last on 2001 April 4–7.

The PC-JUPOS database for the apparition comprised 17,676 separate measurements of features on CCD images. These are the basis for all the positional data reported in the tables and in the section on 'Local features and drifts', unless otherwise stated.

Visual observers also contributed valuable observations, although the number was regrettably fewer than in previous years. This may have been in part due to some observers switching from visual to CCD observations. Visual observers are listed in Table 1B. Visual observations comprised transit timings, drawings, and colour and intensity estimates.

The PC-JUPOS database included 461 visual transits by Horikawa, and 256 transits by German observers. Transits by British and American observers were analysed manually.

The most notable drawings were again those of Makoto Adachi, who provided a series of over 60 finely executed drawings from 2000 July 18 until 2001 April 27, a few of which are reproduced in Figure 1 (also see Figure 9 and ref. 3). These drawings were extraordinarily detailed and accurate, recording detail that generally eluded other visual observers. In particular he recorded a number of high southerly latitude belts including the S^3TB, all of the white SSTZ ovals, a STBn jetstream spot, the South Equatorial Disturbance, the incomplete NTropZ band, NNTB dark streaks and fine structure in the major belts.

Some colour drawings were provided by Mario Frassati[3] and by Christophe Pellier. The planet showed only subdued colours this apparition.

Alan Heath continued his programme of visual intensity observations, which has now been made over many apparitions. His observations were made in both integrated light and with colour filters. In addition to using Wratten filters, Heath experimented with liquid filters of the type used in the 19th century. These plus other visual colour and intensity estimates for the belts and zones are given in Table 2.

In the following 'General description' section, we describe the appearance of the planet from both visual ob-

Table 1A. CCD observers, 2000/01

Observer	Location	Telescope	Camera
Akutsu, Tomio	Horishima, Japan	320mm refl.	Teleris 2
Bernasconi, Andre	Milano, Italy	130mm OG	SBIG ST-5C
Camaiti, Plinio	Cerrina Tololo Obs., Italy	280mm SCT	LynxxII PC or ST-7E
Chevalley, Patrick	Geneve, Switzerland	150mm refl.	QuickCam
Cidadão, Antonio	Oeiras, Portugal	254mm SCT + AO-2 and 280mm SCT + AO-2	SBIG ST-5c ST-237
Colville, Brian	Cambray, Ontario, Canada	305mm SCT	Pixcel ST-237
Daniels, Douglas	London, UK	420mm refl.(Cass.)	[?]
Daversin, Bruno	Lidiver, France	600mm refl.(Cass.)	Philips VestaPro
Dijon, Jean	France	500mm refl.	Kodak KAF400
Di Sciullo, Maurizio	Coconut Creek, Florida, USA	258mm refl.	SX HX516
Dittie, Georg	Bonn, Germany	150mm OG (Schiefspiegler)	Canon XL-1
Grafton, Ed	Texas, USA	356mm SCT	ST6
Gross, Todd	USA	230mm refl., etc.	SX MX-5c
Jacquesson, Michel	Sevigny–Waleppe, France	203mm SCT	QuickCam VC
Ikemura, Toshihiko	Nagoya City, Japan	310mm refl.	NEC Picona
Melillo, Frank J.	Holtsville, NY, USA	203mm SCT	SX MX-5
Miyazaki, Isao	Akamichi, Okinawa, Japan	404mm refl.	Lynxx PC
Mobberley, Martin	Cockfield, Suffolk, UK	360mm refl.(Cass.)	SX MX-5c
Moore, David M.	Phoenix, Arizona, USA	362mm refl. or 250mm refl.	SX HX516
Munsterman, Henk	Meppel, Netherlands	356mm refl.	ST-7E
Parker, Donald C.	Coral Gables, Florida USA	406mm refl.	Lynxx PC
Parker, Timothy J.	Los Angeles, CA, USA	318mm Cass. & 152mm OG	SX HX516 Nikon Coolpix
Peach, Damian	King's Lynn, UK	305mm SCT	SBIG ST-5c
Sanchez–Luque, Jesus R.	Cordoba, Spain	280mm SCT	Audine CCD or home-made CCD
Sørensen, Jesper	Copenhagen, Denmark	305mm SCT	SX MX-5c
Strange, David	Worth Matravers, Dorset, UK	500mm refl.	SXF
Zanotti, Ferruccio	Ferrara, Italy	235mm SCT or 450mm refl.	Sony Digital 8 video

Notes
Yuichi Iga (ALPO-Japan[9]) communicated images by ALPO-Japan observers including H. Einaga, N. Ito, and himself.
OG, object glass (refractor); refl., reflector; SCT, Schmidt–Cassegrain (usually by Celestron or Meade); SX, Starlight Xpress.

servations and CCD images. Latitudes of the belts (zenographic) are given in Table 3. Individual spots and their motions as derived mainly from images will then be considered in the section on 'Local features and drifts'. Latitudes and drift rates of spots will be given in Tables 4–6. (Spots in most of the jetstreams are not listed individually; the data for all currents are summarised in Tables 4B and 6B.) In general the belt structure and the wind speeds were normal for their latitudes.[12] However, the high quality of the images and computer-based analysis enable us to report on the history and motions of atmospheric features in exceptional detail, which may be useful for comparison with the *Cassini* observations. Many of the spots are labelled on the maps in Figures 2 and 6.

This report uses the usual nomenclature of belts and zones.[12] 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). (Conversion to System III is easily done using the information in the table footnotes.) All images and drawings are printed with south up.

Table 1B. Visual observers, 2000/01

Observer	Location	Telescope
Adachi, Makoto	Ohtsu City, Japan	310mm refl.
Alzner, Andreas	Hemhofen, Germany	325mm refl.(Cass.)
Bowyer, A. G.	Epsom Downs, Surrey, UK	300mm refl.
Buggenthien, Ruediger	Luebeck, Germany	180mm OG
Bullen, Robert	Bognor Regis, UK	216mm refl.
Colombo, Emilio	Cambio, Italy	150mm refl.
Crandall, Ed	Winston–Salem, USA	254mm refl.
Foulkes, Michael	Hatfield, Herts., UK	254mm refl., 203mm SCT
Frassati, Mario	Crescentino, Italy	200mm SCT
Graham, David	Ripon, Yorks., UK	150mm Maksutov
Harder, Christian	Germany	250mm refl.
Heath, Alan	Long Eaton, Notts., UK	250mm refl.
Hernandez, Carlos	Florida, USA	203mm SCT
Horikawa, Kuniaki	Yokohama, Japan	160mm refl.
Knott, John	Liverpool, UK	216mm refl.
McKim, Richard	Upper Benefield, Northants., UK	216mm refl., 410mm Dall–Kirkham Cass.
Mosch, Joerg	Meissen, Germany	130mm OG
Parish, Peter	Rainham, Kent, UK	102mm OG.
Peach, Damian	King's Lynn, UK	305mm SCT
Pellier, Christophe	Bruz, France	178mm refl.
Rogers, John	Linton, Cambs, UK	250mm refl.
del Valle, Daniel	Aguadilla, Puerto Rico	203mm refl.
Wohler, Cai–Uso	Germany	100mm OG, 120mm OG, 200mm refl.

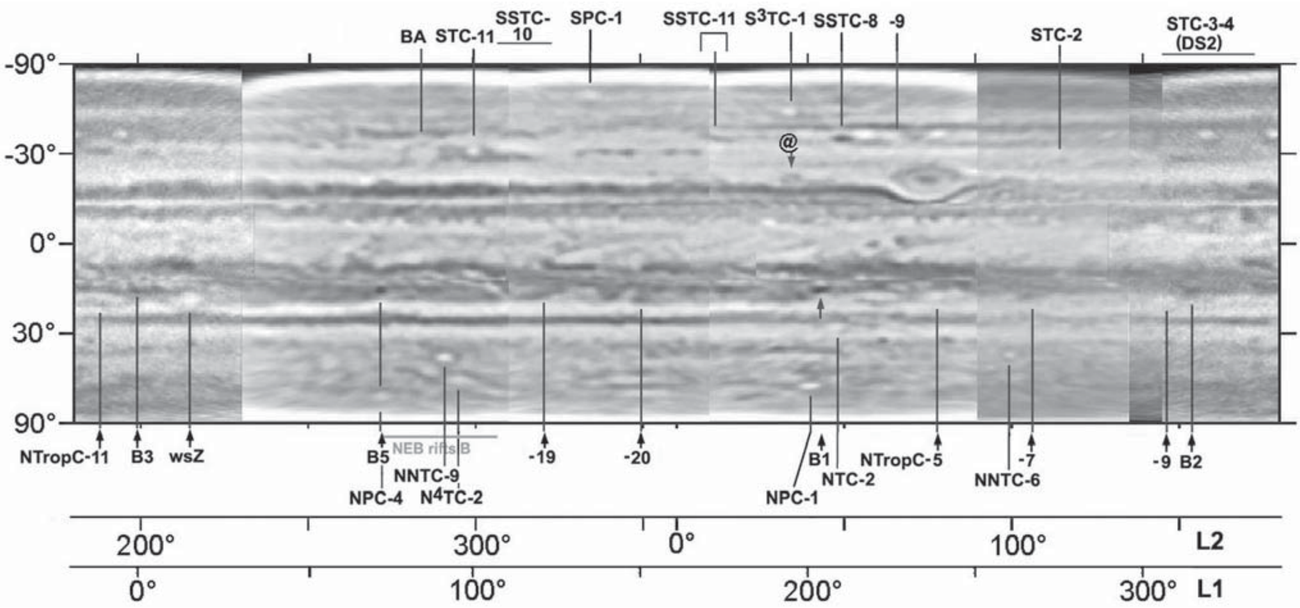


Figure 2. Map of Jupiter, 2000 October 27–30. Images by Don Parker, Cidadão, and Dijon, compiled by Mettig. The equatorial region (–12 to +14°) is aligned to October 28.7. (Because of the realignment, rifts in the NEB are not well shown.) Features are labelled as in Tables 4A and 6A, and STropC no.4 indicated by @. (Compare with the *Cassini* map in Figure A1.)

General description

South Polar and Temperate regions

S. Polar Region to S. S. Temperate Belt

A bright S^{3}TZ was present all apparition at L2> 100 (Sep), L2~ 100–250 (Oct), L2~ 60–230 (Dec/Jan). This was seen by several visual observers (Adachi, Foulkes and McKim) as was an S^{4}TB.

Images revealed complex structure in the SSTB latitudes. In one sector of SSTB there were many small white ovals, sandwiched between a southerly SSTB (44°S) and a narrow true SSTB (37°S; Table 3). In the sector f. that, there were dark streaks of southerly SSTB. In a third sector, the SSTB latitudes were light. This faded sector of SSTB had persisted since 1999 July; it was passing the GRS in 2000 July, but became more broken up by the new year.

Visually, the SSTB and SSSTB appeared as a single dark belt, requiring good resolution to separate them. The small white ovals were usually seen by Adachi and occasionally by Bullen, Frassati, McKim, Peach and Pellier.

S. Temperate Belt

As in the previous apparition, there were only two short dark sectors of STB, one f. oval BA, and one derived from the previous Dark Streak 2. Each of them comprised a broad dark grey STB segment in the usual latitude, followed by dark streaks at higher latitude (which had a much lower drift rate in L2 than other features in the domain).

Generally the STB appeared faint visually with the dark segments detected only in good conditions. Adachi frequently recorded a double structure and some dark spots. Adachi and Bullen detected some faint STZ spots.

Oval BA was not detected by many visual observers. However, oval BA was easily visible to Adachi and Peach during July and August (Figures 1a,b), although it appeared faint to Adachi in later months.

South Tropical region

S. Tropical Zone

The STropZ was, as usual, clear and white except near the GRS. It generally appeared bright and white to visual observers.

Images showed that a dark S. Tropical Band emerged p. the GRS, from a dark S. rim of the GRS, in mid-July. It persisted, in tapered and fragmentary form, until September, and faded away in October. Many visual observers were able to detect this feature. There was also a dusky oval tens of degrees p. the GRS, prominent in images and seen by Adachi. (The Band and the oval will be described more fully in a later section).

Great Red Spot

Throughout the apparition, the GRS had its typical form, as during the *Voyager* encounters. Hi-res images showed it as an orange oval (the orange colour being mainly in a dark central condensation), with a grey-brown oval rim, mostly detached from the SEB; and a darker grey outer rim, sometimes connected to the S.Tropical Band p. the GRS. Low-resolution visual observations only showed the GRS as a distinct uniform oval. However higher resolution visual observations showed it to be a pale orange or pinkish oval with a darker southern rim separated from the SEB. Adachi often observed the dark central bar, which was also occasionally recorded by Pellier. Its f. end was often seen attached to the SEB, although McKim observed it to be separated on January 7.

Table 2A. Visual intensity observations, 2000/01

Observer (dates)	Colombo (Jan 3 to Mar 15)	Del Valle (Oct 24 to Jan 23)[a]	Frassati (Sep 2 to Feb 26)	McKim (Nov 3 to Apr 23)	Heath (Nov 20 to Jan 20)[b]			
	No filter	No filter	No filter	No filter	No filter	Red (W25)	Blue (W44a)	Blue (W47)
SPR	3.1 (4)	4.7 (43)	4.7 (3)	3.4 (5)	3.0 (10)	2.4 (10)	3.4 (10)	4.0 (10)
SSTZ	3.0 (4)	2.9 (23)	3.7 (3)	–	–	–	–	–
SSTB	3.3 (4)	4.7 (31)	–	4.1 (5)	–	–	–	–
STZ	2.3 (4)	–	3.3 (3)	1.4 (4)	2.3 (5)	2.0 (1)	–	–
STB	2.5 (4)	–	3.7 (1)	3.6 (4)	3.8 (10)	3.2 (9)	4.1 (6)	4.6 (6)
STropZ	2.0(4)	2.3 (42)	2.1 (3)	1.1 (5)	1.5 (10)	1.4 (10)	2.1 (10)	2.7 (9)
GRS	2.5 (2)	5.9 (14)	3.8 (2)	3.6(5)	4.0 (1)	2.0 (1)	5.0 (1)	5.5 (1)
SEB(S)	5.0 (6)	5.9 (43)	5.5 (3)	5.1 (5)	5.4 (10)	4.7 (10)	5.8 (10)	6.8 (10)
SEBZ	–	2.8 (37)	3.3 (3)	1.5 (5)	–	–	–	–
SEB(N)	4.9 (6)	5.8 (43)	4.5 (3)	4.9 (5)	4.6 (10)	4.2 (10)	5.2 (10)	6.4 (10)
EZ(N&S)	1.8(6)	3.7 (43)	1.2 (3)	1.2 (5)	1.5 (10)	1.1 (10)	1.5 (10)	2.0 (10)
EB	1.4 (6)	–	2.8 (3)	2.3 (4)	3.4 (4)	4.0 (2)	4.2 (2)	–
NEBs Proj.	–	5.9 (21)	–	–	–	–	–	–
NEB	5.6 (6)	6.7 (43)	5.3 (3)	5.3 (5)	5.0 (10)	4.5 (10)	5.5 (10)	7.0 (10)
NEBn barges	–	8.3 (4)	–	–	–	–	–	–
NTropZ	2.4 (6)	2.0 (43)	2.1 (3)	1.3 (5)	1.2 (10)	1.0 (10)	1.4 (10)	2.2 (10)
NTB	4.1 (6)	5.6 (43)	5.6 (3)	4.9 (5)	5.2 (10)	4.4 (10)	5.5 (10)	5.4 (10)
NTZ	2.3 (6)	2.1 (43)	2.6 (3)	1.4 (5)	1.4 (10)	1.2 (10)	1.4 (10)	2.4 (10)
NNTB	3.4 (4)	5.3 (16)	4.6 (3)	4.1 (5)	4.3 (6)	3.8 (5)	5.1 (5)	5.3 (5)
NNTZ	3.0 (4)	3.1 (7)	3.6 (3)	2.8 (2)	2.5 (1)	–	3.0 (1)	–
NPR	3.1 (4)	4.9 (43)	4.7 (3)	3.4 (5)	3.0 (10)	2.5 (10)	3.5 (10)	4.0 (10)

Notes Intensities are made on the scale from 0 (bright white) to 10 (black). The number of observations is shown in brackets. (a) Del Valle made estimates using the ALPO scale and these have been subtracted from 10 in order to be aligned with the BAA scale, although one cannot expect the absolute numbers to be equivalent. (b) Heath made no colour filter observations after Dec 19.

Table 2B. Visual colour estimates

Observer (Dates)	Colombo (Jan 3 to Mar 15)	Foulkes (Nov 3 to Feb 24)	Frassati (Sep 2 to Jan 26)	Heath (Nov 19 to Feb 15)
SPR	Grey	Grey	Grey	
SSTZ	Yellowish grey	Light grey	Grey or yellow	
SSTB	Grey	Grey		
STZ	Yellow	Light grey	Yellow	
STB	Pale grey	Faint grey	Brown	
GRS		Pink	Orange	
STropZ	Yellow or white	White	White yellow	White
SEB(S)	Red-brown	Brown	Brown	Reddish brown
SEBZ		Dull white or shaded.	White	
SEB(N)	Red-brown	Brown	Brown	Reddish brown, orange or dull orange
EZ(S)	Yellow or white	Dull white	White	
EZ(N)	Yellow or white	Light grey or white.	White	
EB	Pale grey	Faint grey	Grey	
NEB	Red or brown	Dark brown.	Brown	Reddish brown or orange
NTropZ	Yellow	Yellowish white	White or yellow	White
NTB	Grey or brown.	Greyish brown or warm brown	Brown	Colder than NEB
NTZ	Yellow	Dull white or white	White or yellow	
NNTB	Grey	Grey or greyish brown.	Brown	
NNTZ		Light grey	Grey or yellow	
NPR	Grey	Grey	Grey	

Notes Adachi, Bullen, Knott and McKim made colour observations on only a couple of nights. Adachi recorded the GRS as orange. McKim noted that all major belts appeared brown when viewed through the 410mm Dall–Kirkham.

S. Equatorial Belt

The SEB structure was much the same throughout the apparition. It was as broad and dark as usual, but in contrast to recent years, it was clearly double with an obvious SEBZ, which was easily visible visually even with small apertures.

SEB(S) was broad and very dark, dull brown in colour. It appeared fairly quiet at low resolution, but hi-res images revealed considerable turbulence on its S edge – the ongoing SEBs jetstream outbreak, which also included distinct dark retrograding humps. Visually the SEB(S) appeared darker than the SEB(N), and a few dark spots were seen by Adachi, Bullen and Pellier.

The light yellow SEBZ had first been noted in Miyazaki's image on 2000 March 3, p. the GRS, but by July it existed all round the SEB. (A similar SEBZ had last been present in 1995.) After the summer it was largely white, or fawn-coloured p. the GRS, in images. Some SEBZ disturbance persisted f. the GRS although it was inconspicuous and quieter than usual. This latter light region was easily detected by visual observers, even with apertures as low as 100mm (Parish). The SEBZ p. the GRS appeared more shaded to visual observers.

SEB(N) was variable on account of the ongoing S. Equatorial Disturbance. In the summer, images showed a long bluish

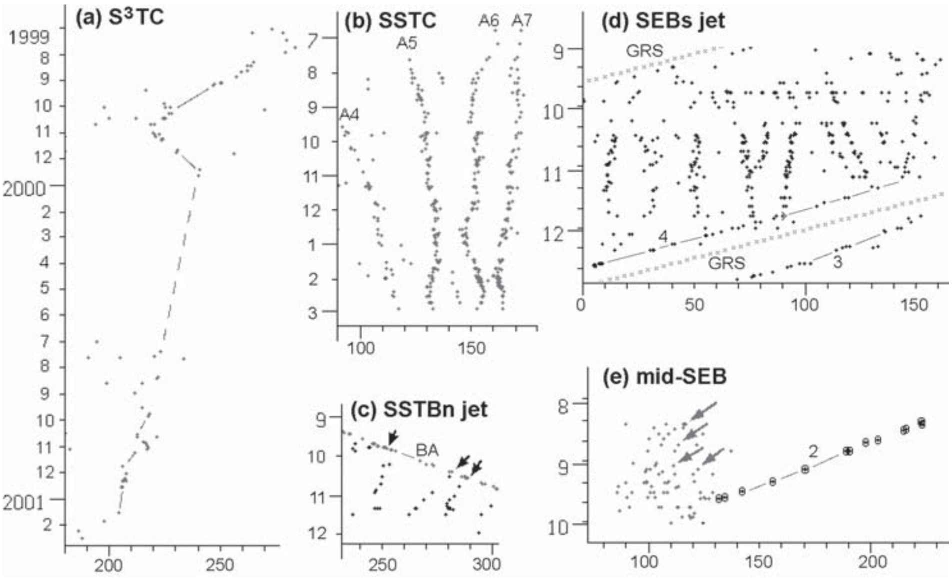


Figure 3. Excerpts from JUPOS charts, showing interesting drifts of spots in longitude. Each chart covers a specified latitude range; on the horizontal axis are longitudes in a system with a specified drift rate per day relative to System II; on the vertical axis are months of 2000/01, marked on first day of the month. Points forming near-vertical lines represent spots moving close to the specified drift rate.
(a) S^3TC: 55 to 47°S, L2 –0.5°/day; the long-lived white oval no.1, with variable speed.
(b) SSTC: 43 to 36°S, L2 –0.9°/day; AWOs nos. A4 to A7, converging and rebounding.
(c) SSTBn jetstream: 36 to 29°S, L2 –2.0°/day; tiny dark spots (black points,drifts arrowed) p. white oval BA (grey points forming diagonal line).
(d) SEBs jetstream: 25 to 18°S, L2 +3.5°/day; dark spots or humps on SEBs. Also included are STropC dark spots nos.3 and 4. (The GRS is shown by grey crosses forming diagonal lines.)
(e) Mid-SEB: 18 to 10°S, L2; white spots in the turbulent SEBZ (grey points, drifts arrowed), and the faster-moving reddish-brown spot no.2 (black symbols).

northerly SEB(C) sector p. the RSH, and elsewhere a grey-brown SEB(N) which was weak and disturbed. After October the SEB(N) recovered as a dark belt at most longitudes.

Southern Equatorial region

South Equatorial Disturbance (SED)

This major disturbance had developed during the last apparition; full details will be given in Paper III. Images showed the SEB(N) and EZ(S) to be substantially disturbed for more than half the circumference of the planet in 2000 June and July. There were bright spots and blue shadings and streaks in EZ(S), especially in the ‘stormy sector’ p. the main complex. The stormy sector was most striking when passing the GRS in mid-July, and the main complex at its f. end was still very impressive in June and July. F. the main complex, EZ(S) was still bright white although small spots and projections were detectable in hi-res images.

By October, the South Equatorial Disturbance was subsiding; the stormy sector and main complex were unremarkable at visible wavelengths. All around the planet, the disturbance then consisted merely of small blue projections with tiny white spots between them – not much more disturbed than normal. However in the near-infrared, it was still conspicuous, as we will describe in Paper III.

Adachi recorded the South Equatorial Disturbance from July until October and his drawings show much fine detail (Figures 1a–c). However other visual observers generally did not record the disturbance.

Northern Equatorial region

In the previous apparition, the EB and the EZ(N) festoons had been exceptionally dark. In 2000 June and July, images showed that they still were: the EB was broad and dark, and both the EB and the festoons were even broader than last apparition, diffuse and grey. EZ(N) was dull, with its lighter areas having a creamy or even faint orange colouration. The NEBs projections were still large and dark. But this appearance did not last. In August–September, the EB was irregular and broken up, the blue-grey streaks being diffusely intermingled with the pale ochre shading of the EZ(N); this appeared feebly yellowish-brown (fawn) in most images. (It was only slightly shaded in Cidadão’s blue images.) By early October, the EB had largely disappeared. Meanwhile some of the NEBs projections also disappeared, leaving only 7 instead of the previous 11–12 projections, and their festoons were much reduced in prominence. By December most images showed virtually no EB nor festoons.

These changes were also evident to visual observers. Adachi observed a dark EB early in the apparition, but later in the apparition, he and most other visual observers recorded the EB as faint. The EZ as a whole appeared dull to many visual observers. The dark NEBs projections appeared bluish or grey (McKim and Pellier) and the bright plumes appeared bright white (Pellier). Later in the apparition, fewer projections were detected visually.

North Tropical region

N. Equatorial Belt

The NEB was a broad dark belt, with some light rifts. Rifts were especially numerous early in the apparition. Many visual observers detected the rifts. (Adachi recorded much fine structure, including a triple belt structure during early August.)

It became evident that the irregular activity noted along the NEBn edge in 1999/2000 was developing into a classical but slow NEB expansion event, which became complete around the end of 2000. As recorded in images, the broadening proceeded at different rates in two sectors of the NEB, separated by the dark ‘barges’ numbered B1 and B5, as follows:

a) from B5 to B1 [L2~ 260–20]; fully broadened early in the apparition. The NEB was already fully broadened in June–July from L2~ 240–330. From there a narrow N. Tropical Band (NTropB) at ~19.5°N led up to barge B1 at L2~ 60, and this

Table 3. Latitudes of belts, 2000/01

	Lat.	*(S.d., N)*
SPRn or S^4TBn*	–52.4	(±1.11, 8)
(S)SSTB*	–43.8	(±0.87, 4)
SSTB(N) or SSTBn*	–37.2	(±0.93, 8)
STB(N)	–28.1	(±0.51, 12)
STBn	–26.9	(±0.38, 8)
SEBs	–20.6	(±0.36, 14)
SEBn (Jul–Sep)	–9.2	(±0.80, 5)
SEBn (Oct–Feb)	–8.0	(±0.51, 8)
NEBs	+8.5	(±0.32, 14)
NEBn@	+20.5	(±0.30, 15)
NTBs	+25.0	(±0.47, 15)
NTBn	+28.2	(±0.39, 14)
NNTBs/NPRs	+35.1	(±1.00, 14)

Notes The table lists average zenographic latitude (± standard deviation; number of observations).
*Far southern belts are listed only for the sector L2~ 50–220 in Oct–Dec. This sector displayed a distinct S^3TZ, (S)SSTB, AWOs, and narrow SSTB(N). (At other longitudes, 'SSTB' was irregular and features further south were indistinct.)
@Latitude of NEBn is given only for sectors which had completed expansion.

sector darkened quickly after July, especially with the appearance of a large brown patch on the NTropB just Np. barge B1, around L2~ 40, in September. For some months this patch was reddish-brown and marked a distinct f. end to the broadened sector.

b) from B1 to B5 [L2 ~ 50–260]; irregular NEBn edge in 2000; broadening completed around the end of 2000. In this sector the strip from 17 to 19.5°N was initially light yellowish, punctuated by white spots and dark projections, with some dusky streaks in the NTropZ. (In June these apparently included the former Little Brown Spot at L2~ 160, but in July it was barely visible.) There were also streaks of narrow NTropB at 19.5°N which became the NEB(N) as the sector gradually darkened. Darkening of the yellowish sector around white spot Z is well shown in Figure 5 (column 3).

By the new year, the NEB was fully broadened essentially all round the planet, though there were still some light streaks and white ovals in the northern part near the GRS longitudes. There were also dark barges in the usual latitude but now embedded within the belt, several of them conspicuously dark and long-lived. Around much of the circumference, the new N edge was a narrow 'NEB(N)' at 19.5°N. There may also have been some concomitant reddening of the NEB, as it was a rich brown colour, making it the reddest belt.

Visually, the dark barges were easily visible, even with modest apertures. Many visual observers recorded the NEBn having a 'wavy' structure.

N.Tropical Zone

The NTropZ was essentially a normal white zone, which became narrow as the NEB expansion proceeded.

North Temperate to Polar regions

NTBs jetstream spots were still tracked in images but were inconspicuous. A few minor NTBs spots were seen by Adachi and Bullen.

The NTB was still a very dark massive belt. Most visual observers saw a light NTZ, although a faint NTZ band was detected by Adachi. Images revealed small dark jetstream spots in the latitude of NNTBs.

The NNTB was mostly absent, apart from a distinct dark segment 12–50° long around L2~ 0. Even this was mostly absent during October. Visually, however, a NNTB sometimes appeared darker than the NTB at some longitudes; Adachi and McKim sometimes detected some darker NNTB segments that were occasionally seen by other visual observers.

However, the canonical latitude of the NNTBs edge was a sharp boundary between the bright NTZ and the dusky high latitudes, within which there was little sign of belt-zone structure in images. Some visual drawings at some longitudes showed a diffuse NNTZ and some patchy higher latitude belts (Adachi, Foulkes,and McKim).

Local features and drifts

S. Polar region

In each of the last apparitions since 1996, a single small bright spot has been tracked around the edge of the dark south polar region at ~60°S. Its speed has varied considerably, but it is probably the same spot; its speed DL2= –17°/month during 2000/01, and its implied DL2= –7.1°/mth during solar conjunction, are both within the range that it showed during the last apparition. This spot has also been described from Hubble Space Telescope (HST) and Pic du Midi images.[13]

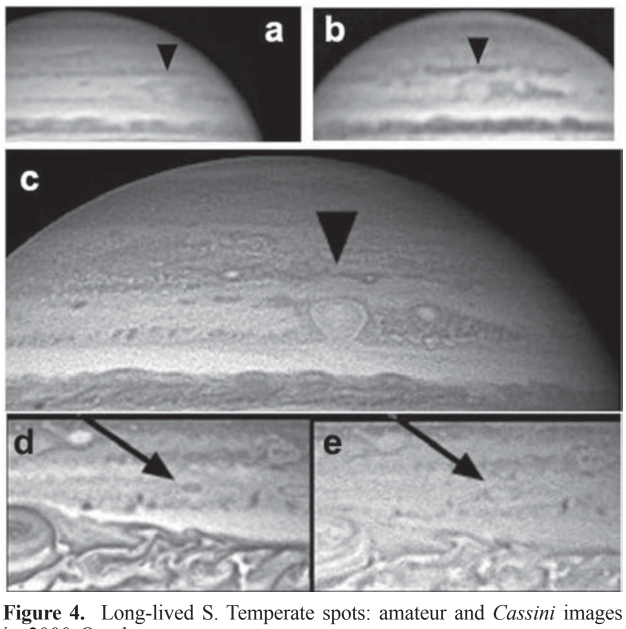


Figure 4. Long-lived S. Temperate spots: amateur and *Cassini* images in 2000 October.
(a–c) Oval BA, indicated by arrowhead; **(a)** Oct 13, CM2=255, by Damian Peach; **(b)** Oct 29, CM2=282, by Don Parker; **(c)** Oct 23, *Cassini* ISS, blue image, sharpened. Note the regular oval internal structure in oval BA.
(d,e) Dark spot 1a (STC no.1): Oct 23, *Cassini* ISS, blue image (d) and red image (e), sharpened. The spot is a dark oval in the blue image, bright in the red, showing that it is red, like the GRS which is at the left edge.

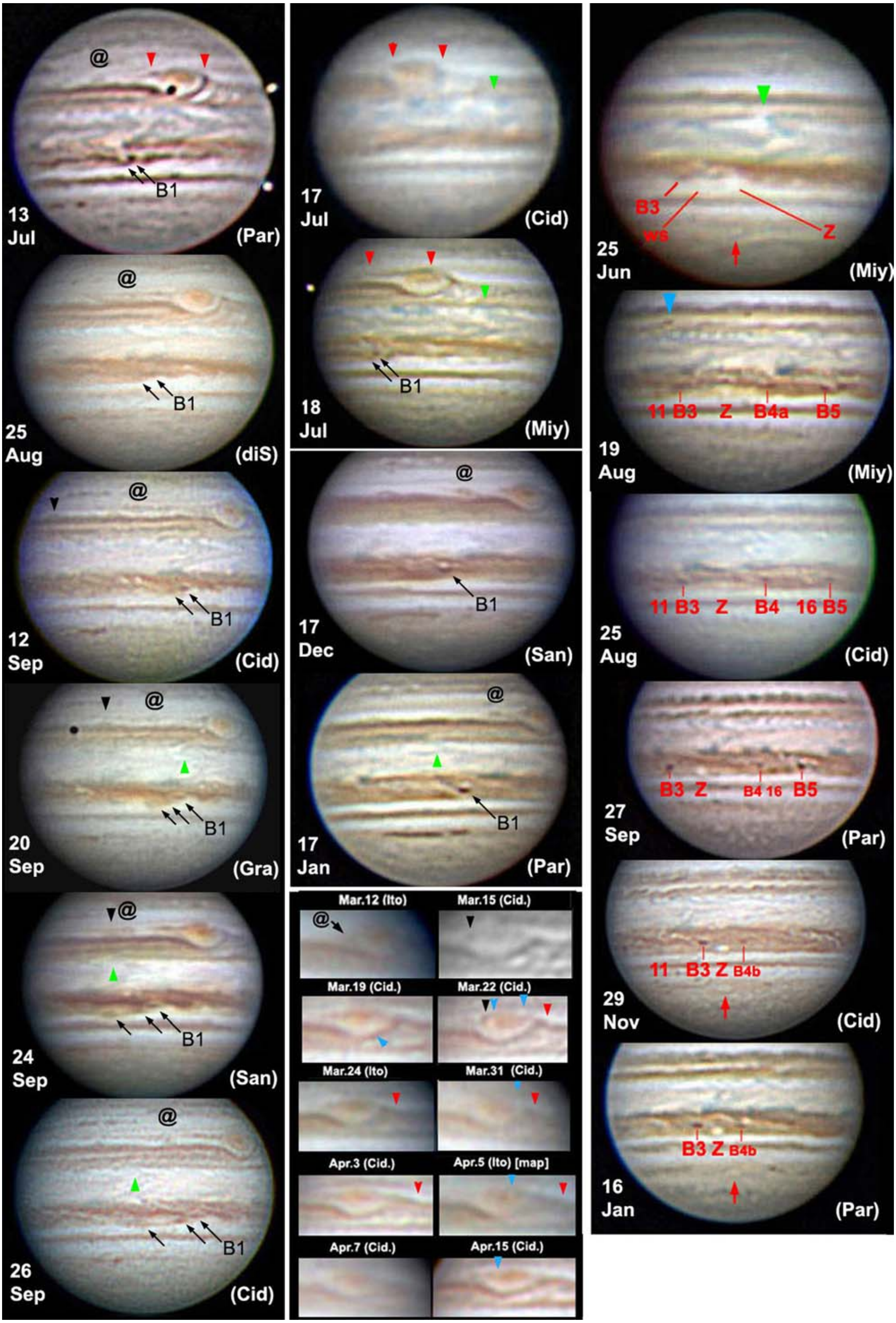

@
B1
13 Jul
(Par)
@
B1
25 Aug
(diS)
@
B1
12 Sep
(Cid)
@
B1
20 Sep
(Gra)
@
B1
24 Sep
(San)
@
B1
26 Sep
(Cid)
17 Jul
(Cid)
B1
18 Jul
(Miy)
@
B1
17 Dec
(San)
@
B1
17 Jan
(Par)
Mar.12 (Ito)
@
Mar.15 (Cid.)
Mar.19 (Cid.)
Mar.22 (Cid.)
Mar.24 (Ito)
Mar.31 (Cid.)
Apr.3 (Cid.)
Apr.5 (Ito) [map]
Apr.7 (Cid.)
Apr.15 (Cid.)
B3
WS
Z
25 Jun
(Miy)
11 B3 Z B4a B5
19 Aug
(Miy)
11 B3 Z B4 16 B5
25 Aug
(Cid)
B3 Z B4 16 B5
27 Sep
(Par)
11 B3 Z B4b
29 Nov
(Cid)
B3 Z B4b
16 Jan
(Par)

Figure 5. *(opposite)* Colour images showing developments during 2000/2001.

Columns 1 & 2: Images showing the longitudes p. the GRS, including NEB barge B1, throughout the apparition. (Also see Figure 8 for monochrome images in months that are not shown here.)

In the S. Tropical Region, @ indicates the brown oval in STropZ (STropC no.4). The origin of a S. Tropical Band is shown on July 13, 17, and 18; red arrowheads indicate the p. and f. ends of dark material which may have flowed around the S rim of the GRS. In Aug–Sep this dark S. Tropical Band lies along the S. border of the STropZ brown oval, which can only be discerned as a tiny bright-cored ring. Images on Sep 12–24 show a dark SEBs jetstream spot (black arrowhead) retrograding towards the oval; they are in contact on Sep 26 and the jetstream spot was not seen thereafter. In Dec and Jan, after the Band dissipated, the oval no.4 was again conspicuous as it approached the GRS. It reached the p. edge of the GRS around March 12, and could not be clearly recognised thereafter. The last panel shows 10 images of the GRS during and after its encounter with the brown oval. Events cannot be followed clearly but note an anomalous dark spot (black arrowhead), bright spots (blue arrowheads; these are not satellites in transit), and a dark hump retrograding on SEBs (red arrowhead).

Green arrowheads indicate the main complex of the South Equatorial Disturbance, approaching the GRS in July, and just past (p.) the GRS in Sep and Jan. In July it was generating massive disturbance, but in Sep it was much reduced, and in Jan it was only a minor feature.

In NEBn, two arrows indicate barge B1 and the dark projection just Np. it (NTropC no.1b). The images on Sep.20, 24, and 26 show a yellowish-brown ring (no.1a, marked by the third arrow) which appeared just p. the projection and prograded rapidly on the narrow N. Tropical Band for a few days. Later a diffuse dark orange-brown area developed in this region (e.g. Dec 17). Note that the NEB was initially narrow across most of this region but was fully expanded by January. Most images also show the dark segment of NNTB and a few NNTBs jetstream spots.

Observers are indicated on the images: Cid, Cidadão; diS, di Sciullo; Gra, Grafton; Ito, Ito; Miy, Miyazaki; Par, Don Parker; San, Sanchez. CM1 and CM2 longitudes are as follows: 2000 July 13 (10h11m UT), 121, 58; July 17 (04h23m UT), 180, 88; July 18 (19h56m UT), 187, 82; Aug 25, 80, 48; Sep 12, 196, 29; Sep 20 (time not stated); Sep 24, 301, 42; Sep 26, 298, 23; Dec 17, 218, 32; 2001 Jan 17, 75, 20.

Column 3: This set of images shows the longitude of NEB white spot Z throughout the apparition. Note the progressive darkening of the NTropZ p. w.s.Z, becoming part of the expanded NEB. Spots in the NEB are indicated with red labels, as in Table 4A (w.s.Z and barges B3 to B5 are named, and NTropC spots nos.11 and 16 are numbered). The first image shows another white spot (ws) p. w.s.Z, that merged with it or disappeared in August. A red arrow in some images indicates NNTC spot no.8, the light oval in NNTZ.

A green arrowhead on June 25 indicates the main complex of the South Equatorial Disturbance. A blue arrowhead on Aug 19 indicates reddish-brown spot no.2 in the SEBZ.

CM1 and CM2 longitudes are as follows: 2000 June 25, 269, 240; Aug 19, 225, 236; Aug 25, 264, 234; Sep 27, 168, 246; Nov 29/30, 258, 210; 2001 Jan 16, 253, 205.

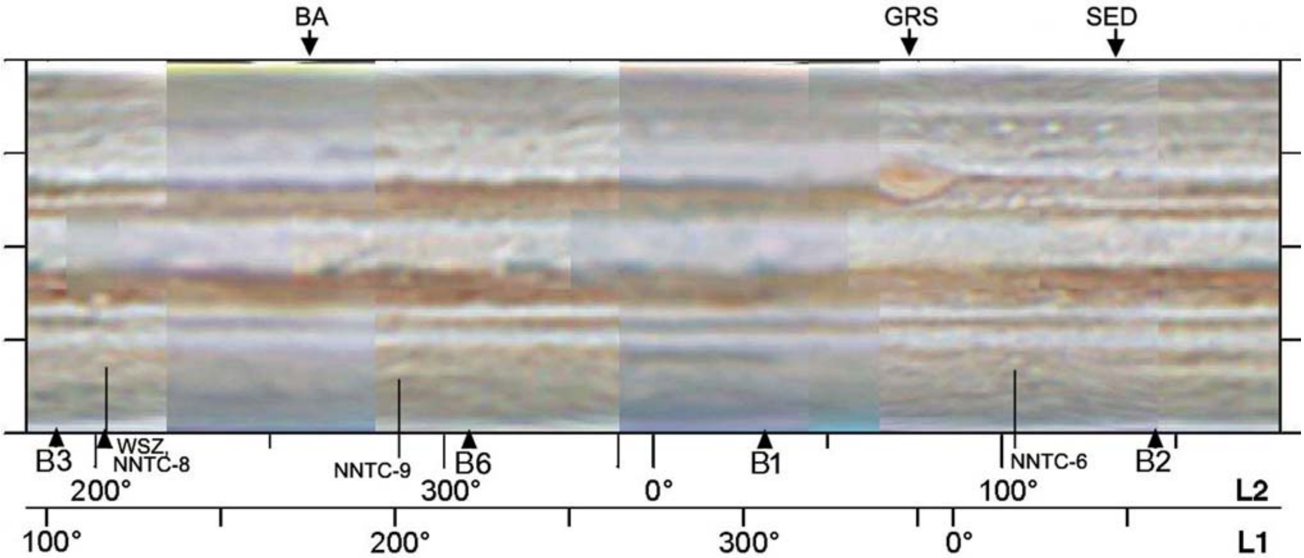


Figure 6. The Millennium Map of Jupiter. Images from 2000 Dec 26 to 2001 Jan 2, by Cidadão and Akutsu, compiled by Mettig. The equatorial region (–12 to +14°) is aligned to December 29.5. Major features are marked including STC oval BA, the S. Eq. Disturbance main complex, NEB barges B1, B2, B3, B6, and NNTC white ovals 6, 8, and 9.

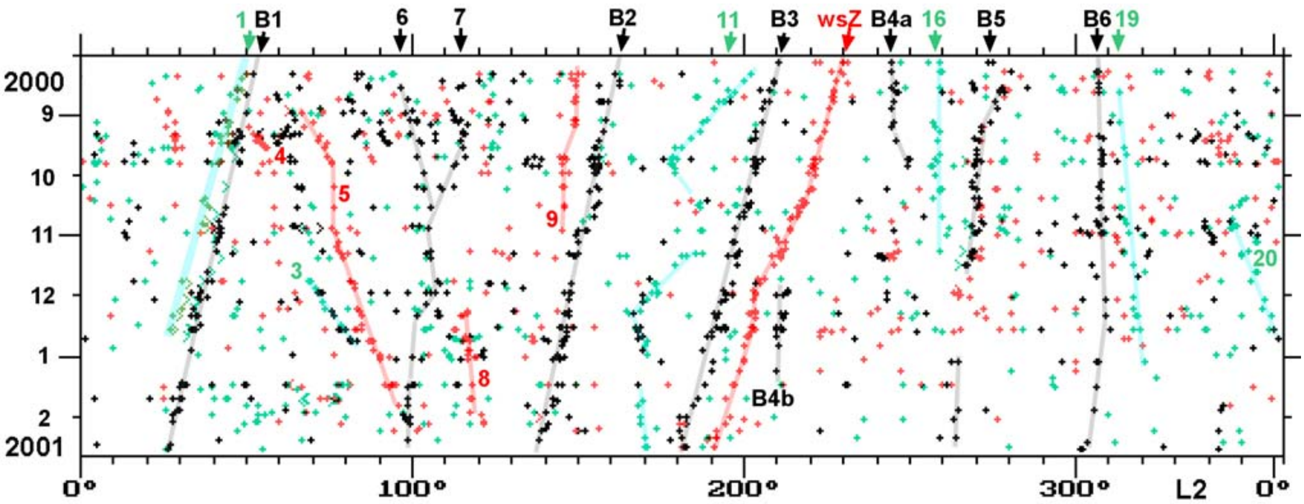


Figure 7. JUPOS chart of spots in northern NEB. Black, lats.14–18°N, dark spots; green, lats.18–23°N, dark spots; red, lats 14–23°N, bright spots. Spot tracks are numbered as in Table 6A for NTropC.

Table 4A. Positions and drifts of spots, 2000/01: Southern hemisphere

No.	Description	Lat.	L2(O)	DL2	Dates	DL2(C)	L2(1999)
SPC							
1	W.s.	−59.4	312	−17	Sep–Dec	?−7.1	101
S³TC							
1	W.s.	−50.1	6	(−18, var.)	Sep–Jan (Aug–Feb)	−17.5	250
SSTC							
A1	AWO	−40.2	15	−24.5	Aug–Feb	−24.7	351
A2	AWO	−40.2	31	−24.5	(Jun)Jul–Feb	−25.5	12
A3	AWO	−40.2	50	−28.5*	Jun–Dec (−Feb)	−28	69
A4	AWO	−40.2	104	−22	Jul–Feb		–
A5	AWO	−40.2	132	−25.5*	Jun–Jan (−Apr)	−25.5	121
A6	AWO	−40.2	150	−27 (var.)	(Jun–Apr)	−22.5	152
A7	AWO	−40.2	166	−27.5	Jun–Apr	−26.5	166
8	D.s.	−38.6	24	−25	Jul–Jan		
9	Cyclonic WO	−39	(38)	−25.5	Jun–Nov		
10	Dk strk*	−40.7	285	−28	Oct–Jan		
11	Dk strk	(−39)	(343)	−20.5	Sep–Nov		
STC							
1	Small d.s.STBs (DS1a)	−31.2	(85)	−15.5	Jun–Oct	−19?	301
2	Small d.s.STB (DS1b)	nd	96	−17	Jul–Apr	−17	309
3	P. dk.strk. STB (DS2)	−31.0	131	−15.5	Jun–Apr	−15.5	336
4	F. dk.strk. STB (DS2)	−31.0	156	−15.5	Jun–Mar	−15.5	355
5	P. dk.strk. STB(S)	−32.5	166	−15	Nov–Feb		
6	F. dk.strk. STB(S)	−32.5	179	−18 ! −6	Nov–Feb		
7	D.s.(=DS3 or fragment)	−32.7	(191)	−10.5	Aug–Nov	? −14.5	15
8	Small AWO (DS3 core?)	−34.1	193	−12.2	Jul–Feb	? −12.5	15
9	W. oval BA	−32.2	270	−12	Jun–Apr	−12.5	(80,95)
10	P. dark STB	−30.9	276	−12	Jun–Apr		
11	Small AWO	−34.1	287	−15 ! −11	Jun–Jan	−14.5	112
12	F. dark STB	−30.9	300	−14	Jun–Apr		
13–18	Fragments of STB(S):	−33.0	*				
13	D.s.			−6	Aug–Sep		
14	D.s.			−3	Aug–Nov		
15	D.s.			−2	Aug–Nov		
16	D.s.			−3(var.)	Oct–Dec		
17	D.s.			−2	Nov–Jan (−Feb.)		
18	D.s.			−13	Dec–Mar		
STropC							
1	GRS	−22.7	75	0.0	Jun–Apr	0.0	71
2	Dk.proj.SEBs	−22.5	(90)	+0.5	Jul–Sep		
		−22.8	104	+7*	Sep–Dec		
3	D.s.STropZ	−22.8	128	+4.5	Nov–Jan		
4	D.s.STropZ	−23.3	39	+2.9	Jun–Oct	0.0	356
				+5.6	Oct–Feb		
(Mid-SEB)							
1–4	Spots on SEB(N)s:						
1	dark reddish–brown spot	−13.4[332 on Aug 20]		−54	Aug		
2	dark reddish–brown spot	−13.1[196 on Aug 20]		−73	Aug–Sep		
3	p. broader belt segment	−13.1[242 on Nov 1]		−40	Oct–Nov		
4	white spot SEB(N)s	−12.5[148 on Dec 19]		−107	Dec		
Also:	(8 white spots or streaks f. GRS; see Table 4B.)						

Notes

Columns are as follows: *Current and feature number. Description* (AWO, anticyclonic white oval; d., dark; w., white; s., spot; proj., projection). *Latitude* (zenographic; average of numerous JUPOS measurements on hi-res images) *L2(O)*, System II longitude at opposition on 2000 Nov.28 (in brackets if it is an extrapolated value). (For System III, subtract 30.0°.) *DL2*, drift in System II longitude in degrees per 30 days (all from at least 6 PC-JUPOS measurements, usually many more; var., variable). (For DL3, drift in System III longitude, add 8.0°/month.) *Dates:* months for which the drift was determined; in brackets, additional months during which the feature was probably recorded. *DL2(C),* DL2 during the period of invisibility surrounding solar conjunction in 2000. *L2(1999)*, L2 at the previous opposition on 1999 Oct 23 (as cited in our previous report[1]).

**Notes on individual spots:*

SSTC no.A3: slowed in December when it came within 18° of AWO no.A2 p. it.
SSTC nos.A5, A6, A7: see text and chart.
SSTC no.10: this was a dark segment of 'Southerly SSTB', f. a longer segment in the same latitude.
STC nos.13–18: these were fragments of STB(S) 10–50° f. no.11.
STropC no.2: had an even larger positive drift in Dec.

A similar small white spot was also tracked in the S.S.S. Temperate anticyclonic domain, at 50°S, and it too was apparently tracked since the previous apparition, and showed a similar range of drift speeds with sudden changes both last apparition and this (Figure 3a).

S. S. Temperate region

There were seven small anticyclonic white ovals (AWOs) at 40-41°S, six persisting from the previous apparition plus one new (or revived) one (Table 4A). We have given them permanent names A1–A7. They were all confined within 150° longitude by 2001 January; thus the convergence of this set of AWOs had continued. It was again evident that the tendency for the ovals to converge was balanced by a tendency for them to repel when they came within 18° of each other – comparable to the repellent tendency established in the 1960s[14] for the larger AWOs in the S. Temperate region. On four separate occasions this apparition, two of the ovals recoiled from each other. One such interaction was between ovals A2 and A3, which recoiled after approaching within 18° in Dec–Jan. The other three interactions involved approaches of oval A6 to within 8–13° of another oval; it rebounded from A7 in July, from A5 in Dec–Jan., and from A7 again in Feb. (Figure 3b). (This latter convergence started in late December when A6 suddenly decelerated; alerted by Peach and Cidadão, observers hoped to witness their merger, but after rapidly converging to about 7.8° apart on Feb 4–8, they rebounded to 8.3° on Feb 9–11, and continued to separate thereafter.)

From Oct to Jan, a few small dark spots were visible on the 'STZB' for up to 60° p. oval BA.

Six of them were tracked for several weeks each, rapidly prograding (Table 4B, Figure 3c). The speed and latitude show that these spots were on the *SSTBn jetstream*, which has only been observed from Earth a few times since its discovery by *Voyager*.

Table 4B. Average speeds of currents: Southern hemisphere

Current	*Type of spots*	*Sense*	*N*	*DL2: Mean (Range)*	*Latitudes*
SPC	White spot	A?	1	–17	–59.4
S^3TC	White spot	A	1	–18	–50.1
SSTC	White spots (AWOs)	A	7	–25.6 (–22 to –28.5)	–40.2 (av.)
SSTC	Other spots	C	4	–24.7 (–20.5 to –28)	–38 to –41
SSTBn jet	Small dark spots	J	6	–65.7 (–50 to –77.5)	–34.8 (av.)
STC:					
[1–4, 9–12]	Principal spots & belt segments	C/A	8	–14.2 (–11 to –17)	–31 to –34
[5–8,13–18]	Dark spots/streaks Sf.others	A	10	–8.2 (–2 to –18)	–32.5 to –34
SEBs jet	Dark projs. (omitting all DL2 < +90)	J	21	+107.7 (+92 to +127)	–20.8 (av.)
STropC	Misc. spots SEBs/STropZ	A	4	+3.4 (0.0 to +7.0)	–22 to –23
(Mid-SEB)	White spots/streaks f. GRS	C	8	–26.1(–10 to –38)	–14
(Mid-SEB)	Other spots on SEB(N)s	C	4	–68.5 (–40 to –107)	–13

This table gives the mean speed and range for each current, some of which are not itemised individually in Table 4A. *Sense:* whether the spots were anticyclonic (A), cyclonic (C), or on a jetstream (J). *N:* number of spots included.

S.Temperate region

Oval BA

Oval BA, which formed by merger of two pre-existing great white ovals in 2000 March, was still visible, at the p. end of a very dark broad sector of STB. Early measurements of its longitude were quite scattered, and up to September there was still some irregularity to its motion. This could have represented oscillations resulting from its dramatic formation, but we could not establish any pattern with the limited observations available. Later, the drift was steady.

It was a large whitish oval, but not conspicuous as it was not very bright and had only a tenuous, sometimes incomplete dark rim around it (Figures 4a,b). In some images, it did not have a distinct outline, as the dark rim was either absent or unresolved; sometimes it looked more triangular than oval. However, the *Cassini* images showed that there was indeed a truly oval core, with a less regular pale border that included a small gap in the STB (Figure 4c).

The group of dark spots on STBs

Since 1998 there has been a group of interesting dark spots on STBs, and they still existed.

DS1a (formerly DS1) was a small dark spot on STBs. In this apparition it was very small but still recognisable by its distinctive latitude. It was faint in October and it disappeared in November as it approached the GRS. In *Cassini* images, it was a little red cyclonic oval, and it could still be seen clearly in Dec. alongside the GRS (Figures 4d, e and Figure A2).

DS1b was a small dark spot within the STB. *Cassini* images showed it to be the p. edge of a cyclonic light oval.

DS2 was a long dark streak. In this apparition it had developed into a substantial segment of dark STB, though sometimes irregular. It began passing the GRS in Feb. *Cassini* images showed it dark and turbulent.

DS3 had been a more southerly dark spot in anticyclonic latitudes of STZ,with a white core. In this apparition it was broken up into less regular spots: first a dark spot with slower drift (STC no.7 in Table 4A), then a longer dark streak or streaks replacing it, also with decelerating drift (STC nos.5–6), plus a white spot at the f. end of the group (no.8). These dark streaks were very similar to those Sf. the other dark segment of STB, f. oval BA (nos.9–16). The white spot (no.8) – shown as a well-formed anticyclonic oval by *Cassini* – could represent the actual core of the circulation of former spot DS3.

The STBn jetstream

This jetstream had been active in the previous apparition. Some dark spots were observed in this latitude early in this apparition, and *Cassini* images showed some very small spots moving along it. However these were too small for us to track, so the jetstream did not show visible activity this apparition.

South Tropical region

Spots in STropZ

The most notable spot was a dusky brown oval in the STropZ (STropC no.4 in Table 4A), p. the GRS. This was apparently the same little brown oval that was observed to form in 1999, which had revived in 2000 March, and then remained stationary at L2= 18 during solar conjunction. In 2000/2001 it was drifting slowly towards the GRS. Initially it was difficult to make out, as it was involved with the S. Tropical Band from July to September (Figure 5), except in hi-res images which revealed it as a small bright-cored ring embedded in the N edge of the Band. From October onwards, as the Band disappeared, it was a fairly conspicuous dusky brown oval (Figures 1e, 5, 8). *Cassini* images clearly showed its anticyclonic circulation (Figure A2), and hi-res infrared images showed it to be methane-bright (see Paper II).

It arrived at the p. end of the Red Spot Hollow in 2001 March. The images then (taken only by Cidadão and Ito) had reduced resolution as the end of the apparition approached, and the interaction with the GRS cannot be followed clearly. However the images did show rapid changes in the GRS, which could indicate clouds from the oval being rapidly whirled around in the GRS (Figure 5), from March 14 up to the last good image on April 15. During the same period, dark material re-accumulated at the p. end of the GRS, and a dark hump grew on SEBs at the f. end of the GRS and retrograded – possibly another remnant of the oval. Thus the interaction of the oval with the GRS may have been irregular and prolonged, as was also the case during an earlier merger of a slow-moving STropZ oval with the GRS, in 1997.[15,16,17]

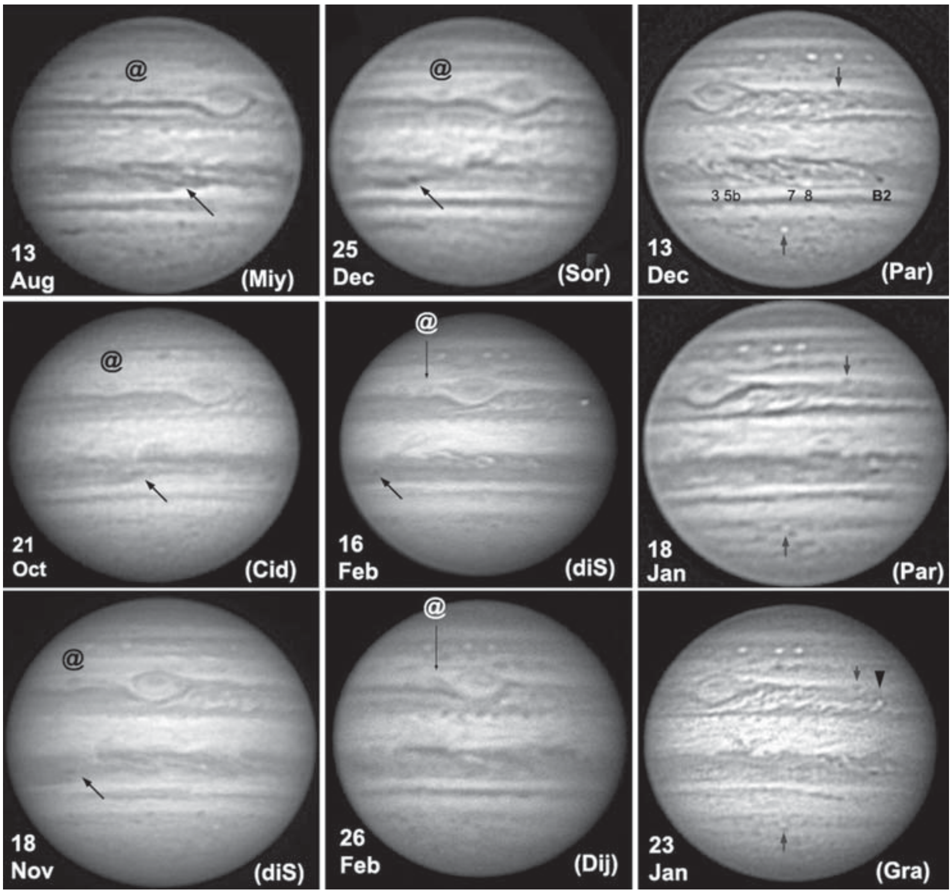


Figure 8. Images showing developments during 2000/2001.
Columns 1 & 2: Images of the GRS and longitudes p. it, including the STropZ brown oval (STropC no.4)(@) and NEB barge B1 (arrow). See legend for Figure 5 for details.
Column 3: Longitudes f. the GRS. Features in northern NEB are labelled in the Dec 13 image; note this sector was darker in Jan as the NEB expansion was completed. Arrows indicate STropC dark spot no.3 (slowly retrograding on SEBs) and NNTC white oval no.6. Also note the SSTZ AWOs. In the last image on Jan 23, a new bright spot is erupting in mid-SEB (arrowhead).
Observers are indicated on the images: Cid, Cidadão; Dij, Dijon; diS, di Sciullo; Gra, Grafton; Miy, Miyazaki; Par, Don Parker; Sor, Sørensen. CM1 and CM2 longitudes are as follows: 2000 Aug 13, 348, 45; Oct 21, 153, 49; Nov 18, not stated; Dec 13, 257, 109; Dec 25, 301, 56; 2001 Jan 18, 175.5, 112.5; Jan 23, 210, 110; Feb 16, 3, 79; Feb 26, 76, 71.

STropC no.2 (Table 4A) was an earlier hump at the f. edge of the RSH, which detached and slowly drifted in increasing longitude. No.3 was a small dark spot in STropZ. All had slightly retrograding drifts which are typical of the STropC. The chart hints at the existence of several other small projections, and also white bays which were recorded by visual observers rather than CCD images (as these diffuse bright areas tend to be indistinct in images); if real, their speeds ranged from DL2~ +5 to +35°/mth.

The SEBs jetstream

The retrograding SEBs jetstream continued to show intense activity, in the form of small humps or condensations on SEBs. They appeared rather small and chaotic, less distinct than the regular array of dark projections in the previous apparition. Thus on the chart the tracks appear unusually crowded and variable in speed, partly because PC-JUPOS has allowed us to measure smaller features than would have been possible before (Figure 3d). Most of these spots remote from the GRS moved with speeds between DL2= +100 and +125°/mth, average +108, which is typical. However, there was a huge range of speeds in the sector p. the GRS – or, more pertinently, p. the slow-moving STropZ oval no.4, as few if any jetstream spots persisted past that oval, so none entered the Red Spot Hollow. Some SEBs spots proceeded up to that oval with retrograding speeds undiminished and then disappeared; others reduced their retrograding speeds, smoothly or suddenly, to achieve DL2 in the range +75 to +33.

After November, few distinct spots could be tracked on the SEBs. This may have been partly because of poorer seeing, but more generally because activity was at a smaller scale than before. Some hi-res images, and the JUPOS chart, show that there really were fewer distinct jetstream spots, and activity was probably more chaotic.

Great Red Spot

The GRS was 18° long. There was a strikingly dark patch at its f. edge on July 4 and 6, and this may have been the source of a dark S. Tropical Band which started emerging from the p. end of the GRS on July 13. The dark material that formed the Band can be tracked flowing around the S edge of the GRS on July 17–18 (Figure 5, column 2), and it may have derived from the dark patch at the f. edge. The Band persisted until September then faded away.

The GRS was virtually stationary at L2= 75 throughout the apparition. However the chart does show a wobble with amplitude 1–2° and period about 82 days (Figure 10) – the 3-month oscillation that was tracked during the 1960s and 1970s.[18] In recent decades when the GRS has had a somewhat irregular visible outline, this oscillation has never been so conspicuous, although JUPOS analysis of amateur data has revealed that it was still present in the early 1980s with amplitude 0.9°, and possibly present with reduced amplitude thereafter.[19] The oscillation in the present apparition was exceptionally distinct.

Mid-SEB f. GRS

The turbulent region of SEBZ f. the GRS was fairly subdued this apparition. However, enough white spots or streaks were tracked to show that they had typical drifts of DL2= –10 to –38, running from L2~ 110 down to the GRS (Figure 3e and Table 4B).

Several spots were observed with faster drifts on the S edge of the SEB(N). Two of them were notably reddish brown spots, conspicuous against the bright SEBZ, observed over 2 weeks and 4 weeks in Aug–Sep. (Mid-SEB nos.1 & 2 in

Table 4A; see Figure 3e and Figure 5 [Aug 19]). It is remarkable that these spots had shape and colour typical of mini-barges, but latitude and motion typical of turbulent rifts. Another fast-moving spot was a small bright white spot (Mid-SEB no.4 in Table 4A) observed over Dec 18–24. As it first appeared at L2= 149, it may have been a precursor of the outbreak described below.

A new extension of the post-GRS disturbance began in January. Another precursor of it was a prograding light spot imaged at L2= 137 on 2001 Jan 14. However the outbreak was first clearly recorded on Jan 23 when a much brighter white spot was imaged at L2= 146, lat. 16°S, by Ed Grafton (Figure 8). On Jan 25/26 (Cidadão) the spot was larger, dimmer, and more northerly (14°S); it was also bright in a simultaneous methane image, indicating that it was projecting to unusually high altitude (see Paper II). While that spot enlarged northwards and prograded as a fading streak as usual, a pale light spot was again recorded at L2= 146 on Jan 28, and was much brighter (L2= 147, lat.15°S) on Jan 31. A fourth bright spot appeared at L2= 155 on Feb 4. All four spots in succession prograded at DL2~ –28 to –30°/mth.

South Equatorial region

This was dominated by the continuing South Equatorial Disturbance (SED), which will be described fully in Paper III. Here we summarise the drift rates observed from visible-light images (Table 5A). The main complex was the only persistent part, initially a brilliant rift and dark blue patch (see Figure 5: June 25 & July 13–18), then subsiding until it was just a discontinuity in SEB(N) (arrowed in Figures 5 and A1). During July and August the bright rift in the main complex moved steadily with DL1 = +37°/mth, and this same drift was the overall rate for the main complex throughout the apparition, even though at later times it was too variable or indistinct to be tracked continuously. Other features on SEBn/EZs were short-lived and so only approximate drift rates were obtained. In Table 5 we summarise the best-documented spots (at least six observations each). Because most of them could only be tracked for a few weeks, the drift rates are imprecise, but they appear to be representative of larger numbers of similar features. These included dark blue-grey streaks within ~40° p. the main complex, up to 2000 Dec, with DL1~ +8 to +38°/mth; and much smaller dark streaks or projections and bright spots further p., with DL1~-41 to –74°/mth. At least one pair of spots, a long way p. the main disturbance, had DL1= –85°/mth, which is the fastest speed yet observed from Earth in this latitude, and approaches the full speed of the jetstream as recorded by spacecraft.

An unrelated and transient rift appeared in SEB(N) around Dec 11, at the p. end of a white SEBZ, at L1~260, L2~130. (It is visible in Figure 8, Dec 13.) This could have been due to the prograding p. end of the white SEBZ being deflected northwards by the turbulent SEBZ f. the GRS.

North Equatorial region

A major planetary change in this apparition was the near-disappearance of the EB, the EZ(N) festoons, and many of the associated dark projections on NEBs. From October onwards, only seven conspicuous dark NEBs features remained. They were dark bluish plateaux or projections, of differing size and intensity. They had a strong retrograding drift (DL1~ +9°/mth) (Table 5B), in contrast to the previous apparition.

This seems to be a repeat of the changes in 1988/89, when a NEBn expansion event was also followed by general fading and deceleration of the NEBs features. There was also a deceleration in 1996 along with the NEBn expansion event. It is interesting that this deceleration has occurred not only after a NEBn expansion event, but also just after perihelion, in view of the previous history of such correlations [p.144 of ref. 12].

North Tropical region

NEB rifts

There were two persistent rifted regions of the NEB, with drifts in the North Intermediate Current (Table 6B). Rifted region A, from July to Oct., had overall DL2~ –65°/mth. It was last seen as a pair of small bright spots 5° apart moving at DL2= –105°/mth (L2 233–> 206, Oct 15–23).

Table 5A. Drifts in South Equatorial region (SEC)

Description	*No.of spots*	*Distance p. main complex*	*DL1 (mean)*	*(range)*	*Dates*
SED: Main complex	1	0°	+37		Jun–Mar
F.ends dark streaks	4	25°	+23	(+8 to +38)	Jun–Nov
Small w.s. & d.s.	5	40–110°	–52	(–41 to –58)	Sep
Small w.s. & d.s.	2	130°	–74		Oct
Dark spots	2	110–260°	–85		Oct–Nov
Dark spots	3	30–160°	–41		Dec–Jan

Table 5B. Drifts in North Equatorial region (NEC)

No.	*Description*	*L1(O)*	*DL1*	*Dates*
	Dark projections on NEBs:			
1	Plateau or streak	12–27	+13	Sep–Apr
2a	Plateau	(95)	+12	Jun–Aug
2b	Plateau/proj. with plume	70–81	+12	Sep–Mar
3	Proj. with plume*	125	(var.)	Aug–Feb
4a	Plateau/Proj.	(163)*	+5	Aug–Oct
4b	Proj.	(177)*	+7	Dec–Mar
5	Large plateau/proj.	227–237	+8 var.	Aug–Apr
6	Small plateau/proj.	258	+7 var.	Jun–Jan
7	Large proj.	296	+9 var.	Jul–Apr
8	Plateau	(346)	+12 var.	Aug–Nov
average			+8.6	

Notes
L1(0), System I longitude at opposition on Nov 28. *DL1* is in degrees per month.
**Notes on individual spots:* SED main complex, at opposition, L1= 7.
NEBs projection 3, with white plume, followed by dark NEBs and dark EB segments.
NEBs projection 4a, probably the same as 4b, actual L1(O)=170.

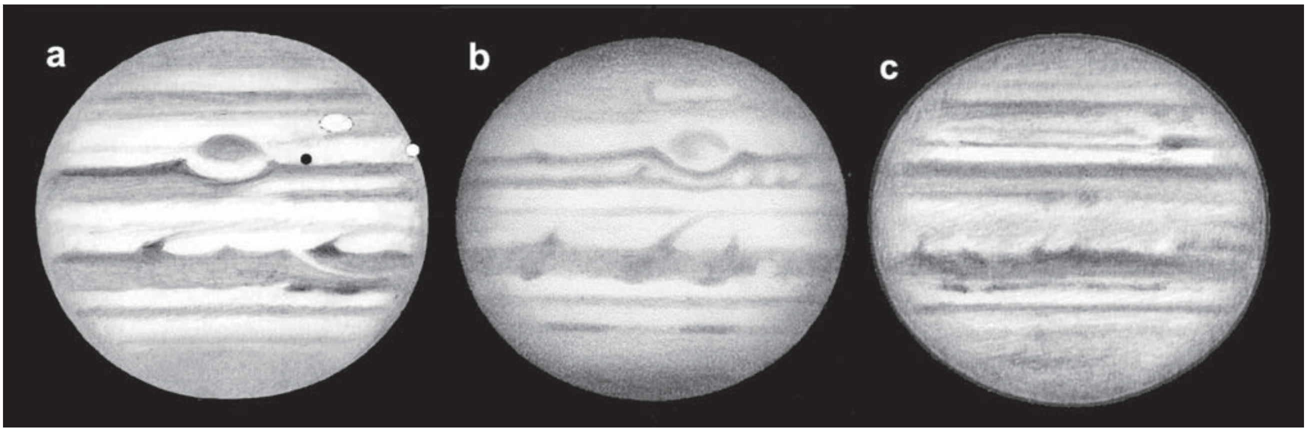


Figure 9. Drawings. **(a)** 2000 Nov 12d 21h 13m, CM1= 350.7, CM2= 72.9 (McKim). Shows Europa on f. limb and its shadow f. GRS. (A week later, using his 410mm Dall–Kirkham Cassegrain on Nov 19, McKim was able to resolve the disks and colours of the satellites. Io appeared yellowish as did Ganymede; Europa appeared white or slightly bluish; and Callisto appeared yellowish-white.) **(b)** 2001 Jan 26d 17h 40m, CM1= 187.8, CM2= 59.0 (Frassati). Shows the GRS, the disturbed SEBZ f. it, and white ovals in the SSTZ. **(c)** 2001 Feb 5d 10h 26m, CM1= 60.9, CM2= 218.1 (Adachi). Shows oval BA near the f. limb.

Rifted region B persisted throughout the apparition. It was at L2~ 0–50 in Sep, L2~ 300–340 in mid-Oct, and L2~ 200–230 around Jan 1. From July to Sep its overall DL2 was –80°/mth. From Sep to Nov, many individual bright spots were seen moving with similar speeds (DL2= –90, –71, –68), but each one arose f. the previous one, so the overall locus of activity moved with DL2~ –40°/mth. From Jan to Feb, there again was a coherent rift moving with DL2~ –80. (These NEB rifts are not clearly shown on the whole-planet maps because System I and II have been realigned along this latitude.)

A detailed analysis of the NEB rifts was independently performed by Yuichi Iga.[20] He identified several locations, each lasting 3–5 months, drifting with DL2~ –63°/mth, within which individual rifts would appear. An individual rift would start as a white spot and then extend in the p. and f. directions over 15–30 days, reaching up to 110° long before disappearing.

NEBn/NTropZ

The chart (Figure 7) and table (Table 6A) show a great diversity of spots and drifts in these latitudes, but they were all behaving in the same regular ways as we have reported in 1998/99[7] and 1999/2000[1] and in the *Voyager* movies (pp.118–123 of ref.12). Again the spots fell into several groups according to their drift rates and latitudes, as follows:

(i) The fastest-moving spot was still the northerly, long-lived, and evidently powerful white spot Z, at 19°N, still rapidly prograding (DL2= –6°/mth) (Figure 5, third column). This white oval has existed since 1997 and has always had a faster drift than the other NEBn features. It eliminates other spots preceding it, and new spots are created following it. In early August 2000, it was gradually approaching another white oval in the same latitude, which either disappeared or merged with w.s.Z around Aug 10. Over subsequent months, the strip of NTropZ flanking w.s.Z gradually became dull yellow-brown, until w.s.Z appeared as a brilliant 'porthole' within the expanded NEB.

In November, w.s.Z came up to the f. side of barge B3, temporarily causing w.s.Z to decelerate and B3 to accelerate; thereafter, both moved on together, 9° apart, with the original speed of w.s.Z. The area of NEB around the pair became lighter again. This interaction was beautifully imaged by *Cassini* in Dec (Figure A3) and in Jan (crescent image in ref.3). The latter image suggested that the brightening of the adjacent NEB was due to the opposite circulations of the white spot and barge drawing light NTropZ material through the narrow gap between them.

(ii) Three small but intensely dark 'barges' created in 1997 (now called B1, B2, B3) still persisted, at 16.1–16.4°N, and still had prograding drifts (DL2= –4°/mth), as they have done throughout.

(iii) Several other dark spots or small barges were appearing in the same latitude but with slower drifts. If they persisted, they accelerated up to the same speed as the older barges. Some appeared shortly f. w.s.Z: barges B6 and B5 (born late in the previous apparition), B4a (born in 2000 July, short-lived), and B4b (born in 2000 Nov), were all at 16.1–16.4°S with initial DL2~ 0, and accelerated to DL2~ –3°/mth within time ranging from a few months (B4b, B5) to a year (B6).

Another new small barge, B8, formed in a rather chaotic sector f. barge B1, when two of the small dark patches at ~17°N (NTropC nos.6 & 7a in Table 6A) merged to form spot no.7b with DL2= –3. (We name this B8 because another barge, B7, also formed just p. it during the next solar conjunction.)

In general these new small barges were less intensely dark than the three long-lived barges (see the *Cassini* map). However the *Cassini* images confirm that they had the same cyclonic circulation as the older barges [e.g. B4b in Figure A3.].

(iv) Other small dark spots and bright ovals lay slightly further north at 17–18°N, in the strip between the original NEBn and N.Trop.Band, which eventually was subsumed in the expanded NEB. These had slower drifts. The chart (Figure 7) shows several such dark spots or projections with positive DL2 over a month or so. The best tracked were a group in that same chaotic region f. barge B1, and included NTropC no.3, as well as white spots nos.4,5,8 (Table 6A; DL2= +4 to +16). These slow motions were presumably due to the proximity to the NEBn retrograding jetstream, although there were no spots with the full jetstream speed. Conversely another such white oval (no.9) was initially retrograding but then halted near the p. edge of prograding barge B2.

(v) There were also small dark spots on the N. Tropical Band which became the expanded NEBn, at 19.5°N (green symbols in Figure 7), with a variety of drifts. Those p. B5 and f. B6 (NTropC nos.16,19,20) had DL2 ranging from 0 to +7. However a spot or spots between B2 and B3 (no.11) appeared to be oscillating to and fro, like some such spots in the previous apparition, with DL2 ranging between +7 and –17°/mth; in each case the rapid prograding drift stopped suddenly within no more than a week, and there was no significant change in the latitude of 19.4°N. This was a little grey spot, shown in the *Cassini* closeups to be an anticyclonic ring (Figure A3). Its oscillation could represent intermittent pressure from surges of material recirculating anticyclonically at the p. edge of barge B3.

The forms around the barges also indicated complex circulations. While hi-res images (and the *Cassini* images) confirmed that the barges were small coherent cyclonic circulations in a well-defined latitude, lower-resolution images often showed large, less regular, dark patches at these locations, because the barges were often associated with dark northward projections on their p. sides. These are now well-recognised as sites of anticyclonic circulation from NEBn onto the N.Trop.Band (e.g. formation of Little Brown Spot in ref. 1, and pp.118–123 of ref.12). This phenomenon was clearly illustrated in the *Cassini* images (Figure A3).

Of particular note was the region Np. barge B1, where there was not only a dark projection, but also a large orange-brown cloud that developed just p. it (L2~40 –> 20) (Figure 5). In 2000 August, the NEB was not yet expanded here, and the main feature was an oblique dark bulge into NTropZ, leading into the grey N.Trop.Band or new NEB(N) on its p. side. In Sep, improving images resolved this bulge into the dark barge B1 at 16.2°N, and a projection or dark spot just Np. it at 17.8°N (NTropC no.1b in Table 6A) leading p. into the new NEB(N). In late Sep, a yellowish-brown ring appeared just p. this projection, at 19.0°N, and rapidly prograded along the N.Trop.Band (NTropC no.1a; Figure 5: Sep 20–26). In Oct, the region just p. the projection had an orange-brown tint, and this darkened during Nov–Dec, developing into a large diffuse dark orange-brown cloud (Figure 5: Dec 17, & Figure A2). For all this time, it marked the f. end of the fully-expanded NEBn, and it also encroached on the NTropZ. This complex remained conspicuous up to late Dec, but then merged into the rest of the NEB; the expanded NEB was now continuous visually.

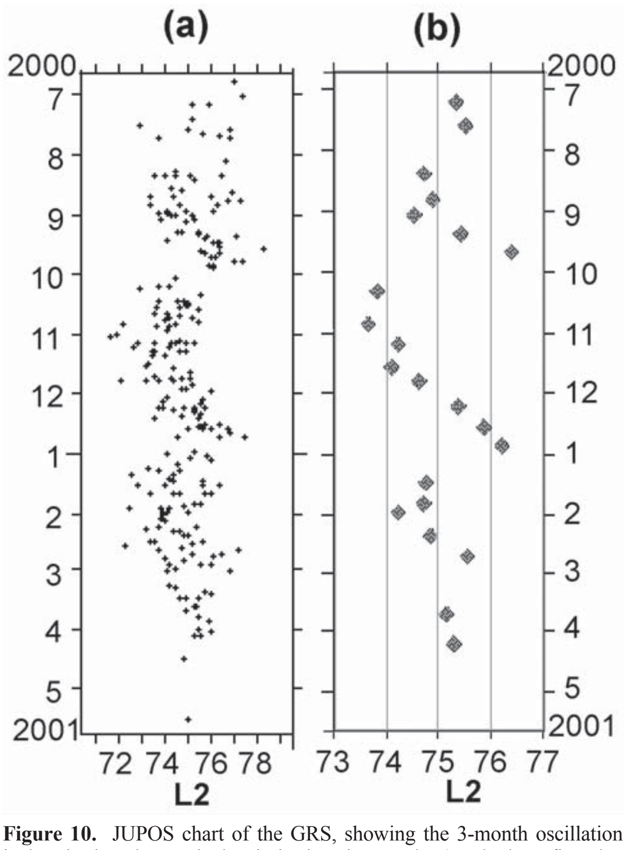


Figure 10. JUPOS chart of the GRS, showing the 3-month oscillation in longitude. The vertical axis is time in months (marked on first day of month). **(a)** All data including transits; **(b)** 5-point means of measurements from images (or 3- or 4-point means from December onwards in order that all averages covered less than 14 days).

North Temperate to Polar regions

The PC-JUPOS database enabled the tracking of many small spots in many different currents (e.g. Figure 11), all consistent with the patterns previously established by ground-based and *Voyager* observations. There are three interesting themes to the currents in these high northern latitudes,[12] all of which were illustrated in unusually precise detail by our tracking in this apparition. First, the alternating pattern of jetstreams; second, 'serial behaviour'; third, the gradient of speed with latitude across the N.N. Temperate domain.

NTBs jetstream spots

There were still seven indistinct humps on the NTBs edge, moving with the N. Temperate Current C (Table 6B). These were the same seven jetstream spots that have been tracked since 1997[1] or even earlier.[21] They maintained essentially the same speed. As in 1999/2000, the visible features were indistinct humps, not the usual anticyclonic rings. However the *Cassini* images, like previous HST images,[21] showed that there is indeed a well-formed anticyclonic vortex at the f. edge of each hump, but without much contrast, so what we see is dark NTB material piled up against the ring (Figure A3).

NTBn current and jetstream

Features in NTC-A in Table 6A were within a cluster of minor grey projections on NTBn and small white ovals flanking them. Individual features could only be traced for a few months but the cluster had persisted from the previous apparition. As usual, all were in cyclonic latitudes around 29°N.

One small dark spot on NTBn (31.3°N) was tracked at DL2= +49°/mth from Nov 7 to Dec 12 (Figure 11a). This is the first ground-based detection of the retrograding *NTBn jetstream*.

NNTBs jetstream spots

On the sharp southern boundary of the dusky north temperate and polar regions – the canonical latitude of the NNTBs edge, at 34.6°N – there were many tiny dark spots moving with the NNTBs jetstream. Thus a substantial jetstream outbreak was occurring. Speeds were fairly uniform, from –72 to –84°/mth, which is typical (Table 6B). One other spot (no.2), at 34.0°N, showed DL2= –38°/mth instead (Figure 11b).

N. N. Temperate Belt

The only conspicuous feature in the 'NNTB' latitudes was a dark brown bar or NNTB segment which had appeared in

Table 6A. Positions and drifts of spots, 2000/01: Northern hemisphere

No.	Description	Lat.	L2(O)	DL2	Dates	DL2(C)	L2(1999)
NTropC							
1a	d.s.	19.0	[32 on Sep.21]	(–36)	Sep.		
1b	proj.	17.8	(31)	–5	Jul–Sep		
2	dark barge B1	16.2	37	–4.2	Jul–Apr	–3	97
3	proj. or d.s.	17.4	71	+13	Nov–Dec		
4	w.s.	17.5	[55 on Sep 15]	+16	Sep		
5a	w.s.	17.0	[73 on Sep 15]	+8	Sep		
5b	w.s. (porthole)	17.9	82	+7	Oct–Jan		
6	dark proj.	16.5	(106)	+2	Aug–Oct		
7a	dark proj.	17.2	(106)	(–3)	Sep–Oct		
7b	small dark barge B8	16.8	106	–3	Nov–Feb		
8	w.s.(porthole)	(18)	112	+4	Dec–Jan		
9	w.s.	17.5	(145)	–1	Jul–Oct		
10	v.d.barge B2	16.4	148	–4	Jun–Apr	–4	203
11a	small grey d.s.on NEB(N)	19.4	–	–17	Aug–Sep		
11b	"	19.2	172	–14	Nov–Dec		
11c	"	19.6	–	+1	Dec–Feb		
12	v.d.barge B3	16.2	195	–4→–6	Jun–Apr	–3	237
13	w.s.Z	19.1	205	–6 (var.)	Jun–Apr	–4.5	281
14	d.s. =barge B4b*	nd	211	–0.5	Nov–Jan		
15	d.s. = barge B4a	16.4	(259)	+3	Jul–Sep		
16	dark streak on NEB(N)	19.2	(260)	0	Aug–Nov		
17	small dark barge B5*	16.1	267	–3	Sep–Mar	–2.5	300
18	small dark barge B6	16.3	307	0→–2.5	Aug–Apr	–0.5	late
19	dark streak on NEB(N)	19.5	318	+2	Aug–Dec		
20	dark streak on NEB(N)	19.8	354	+7	Oct–Dec		
NTC–A							
1	w.s.	29.4	(47)	+14	Dec–Mar		
2	w.s.	29.0	56	+12	Jul–Nov		
3	dark proj. NTBn	28.5	70	+14	Nov–Jan		
4	w.s.	29.2	74	+13	Nov–Dec		
5	dark proj. NTBn	28.5	79	+12.5	Jul–Nov		
New jets							
1	Small d.s. NTBn	31.3	175	+49	Nov–Dec.		
2	Small d.s. NNTBs	34.0	[40 on Sep 18]	–38	Aug–Sep		
3	Small d.s. NNTBn	38.6	[331 on Sep21]	+55	Sep.		
NNTC							
1–2:	Dark segment of NNTB:						
1a	p.end	38.2	(357)	+1	Jul–Sep	–0.5	late
2a	f.end	37.9	(3)	–1	Jul–Sep	–3	late
1b	p.end	38.2	346	+6→–14	Nov–Mar		
2b	f.end	37.9	36	var.*(serial)	Nov–Mar		
3	d.s.	38.2	223	0	Nov–Feb		
4–5:	Dark segment of NNTB:						
4	p.end	38.4	287	+5.5(serial)	Oct–Jan		
5	f.end	39.3	300	(0)	Oct–Jan		
6–9:	AWOs:						
6	Small w. oval	41.5		–7	Aug–Oct		
		40.3		+9	Oct–Nov		
		40.6	104	–1	Nov–Jan		
7	Small w. oval	40.7	(145)	–9	(Aug) Sep–Nov		
8	Light oval	40.3	203	0*	Sep–Feb	–4.6	270
9	Bright w. oval	41.3	(280)	–10	Jul–Nov(Dec)	–6.5	19
N^3TC							
1	d.s.	45.3	–	–16	Jul–Aug(Sep)		
2	d.s.	45.8	*	–18	Jul–Sep		
3	d.s.	45.8	*	–20	Aug–Oct		
4	d.s.	45.3	*	–18	Nov–Feb		
5	d.s.	45.3	*	–23	Jan–Mar		
N^4TC							
1	small w.oval	51.2	230	2	Aug–Dec	1?	223
2	small w.oval	51.4	(298)	4	Jul–Oct	5	250
3	small w.oval	50.0	(346)	3	Aug–Nov	1.5	320
NPC							
1	w. oval	54.1 (±0.7)	–	–12	Aug–Sep		
		54.4 (±0.3)	(358)	–47	Oct–Nov		
		53.5 (±0.6)	360	–2	Dec		
		nd	–	–23	Jan		
2	w.oval	59.0	148	+9	Jul–Jan		
3	w.oval	60.8	(205)	+10	Jul–Aug	+13	41
4	w.oval	60.1*	282	+12	(Aug)Oct–Jan		

Notes to Table 6A

Columns are as follows: *Current and feature number* (numbers with suffixes a,b,c, probably refer to the same object). *Description* (AWO, anticyclonic white oval; d., dark; w., white; s., spot; proj., projection). *Latitude* (zenographic; average of numerous JUPOS measurements on hi–res images; nd, not determined). *L2(O)*, System II longitude at opposition on 2000 Nov 28 (in brackets if it is an extrapolated value). (For System III, subtract 30.0°.) *DL2*, drift in System II longitude in degrees per 30 days (all from at least 6 PC–JUPOS measurements, usually many more). (For DL3, drift in System III longitude, add 8.0°/month.) *Dates:* months for which the drift was determined; in brackets, additional months during which the feature was probably recorded. *DL2(C)*, DL2 during the period of invisibility surrounding solar conjunction in 2000. *L2(1999)*, L2 at the previous opposition on 1999 Oct 23 (as cited in our previous report[1]) ('late' indicates that the feature appeared late in the apparition, typically in 2000 Jan, so was not listed in ref.1).

**Notes on individual spots:*

NTropC no.14: Small new barge B4b followed mostly by visual observations.

NTropC no.17: Barge B5 was sometimes inconspicuous; its track was irregular in August, and again in early December, when it was apparently masked by a passing rift.

NNTC no.2b: Average DL2~ 0, but apparent rapid alternation between +10 and –14, each lasting only a few weeks ('serial behaviour'; see chart).

NNTC no.8: Average DL2= –4.6 deg/mth during solar conjunction from 2000 Feb. to Sep., then halted at L2= 206 until late Nov; then shifted suddenly to L2= 200, only to drift back again at +2°/mth until March.

N^3TC: All longitudes in the range L2 40–110.

NPC no.4: Latitude was +62.3°N in Aug when stationary.

2000 January (NNTC nos.1 & 2 in Table 6A; 38°N). From June to Sep, it was 12–20° long, with p. and f. ends at L2= 355 and 7. After being indistinct during October, it revived in late November with a length of 50°, and its p. and f. ends showed the 'serial behaviour' that is often observed in these latitudes. That is, over short intervals they move rapidly p.

Table 6B. Average speeds of currents: Northern hemisphere

Current	*Type of spots*	*Sense*	*N*	*DL2: Mean (Range)*	*Latitudes (deg.N)*	*Voyager DL2*	*Voyager Lat.*	*HST DL2*	*HST Lat.*
NIC	Mid-NEB rifts	C	8	–79.9 (–65 to –105)	12 to 13				
NTropC	Dark & bright spots	C/A	19	+0.5 (–6 to +16)	16 to 19	+45	17.6	+25	16.6
(NEBn)	Dark spots/streaks NEB(N)	A	6	–3.5 (–17 to +7)	19 to 20				
NTBs jet	Slight dark projs. NTBs	J	7	–291.8 (–289 to –293.5)	24.9 (av.)	–375	23.8	–322	23.5
NTC-A	Grey projs. & w.ss. NTBn	C	5	+13.1 (+12 to +14)	29				
NTBn jet	Small dark spot NTBn	J	1	+49	31.3	+69	31.6	+27	30.7
NNTBs jet	Tiny dark spots NNTBs	J	19	–76.4 (–72 to –84)	34.6 (av.)	–94	34.5	–106	34.7
NNTBn jet	Small dark spot	J	1	+55	38.6	+31	39.5	+34	38.8
NNTC	Dark segments of NNTB	C	7	~+1 (–14 to +6)	38 to 39				
NNTC	White ovals in NNTZ	A	4	–3.0 (–10 to +9)	40 to 41.5				
N^3TC	Dark spots	C	5	–19.0 (–16 to –23)	45 to 46				
N^4TC	Small white ovals	C!	3	+3.0 (+2 to +4)	50 to 51				
N^5TBs jet	White oval	A/J	1	–47	54.4	–59	56.6	–91	55.1
NPC	White ovals	A/J	3	+10.3 (+9 to +12)	59 to 61				

Notes
This table gives the mean speed and range for each current, some of which are not itemised individually in Table 6A.
Sense: whether the spots were anticyclonic (A), cyclonic (C), or on a jetstream (J). *N:* number of spots included.
DL2: Drift in System II longitude per 30 days. To convert DL2 to DL1, add 228.9°/mth. To convert DL2 to DL3, add 8.0°/mth.
For comparison with our jetstream data, the last four columns give the latitudes and speeds of jets derived from images by *Voyager*[22] and the HST.[24] (The NEBn jet is included for reference although our observations did not detect it this apparition.) The jet speeds have shown real variations, but the latitudes have probably not changed significantly. The HST study derived latitudes that were typically ~1° lower than in the *Voyager* study for these high-latitude jets, and this seems likely to be mainly due to systematic measurement errors. Our latitudes tend to agree better with the HST values.

or f. (in this case, with speeds of either –8 to –14, or +6 to +10°/mth); but over a longer interval remain at approximately the same L2 (in this case, L2~ 344–354 and 29–37). (Figure 11c). Several less conspicuous bars in the same latitudes showed similar behaviour.

On NNTBn from Sep 21–26, around L2~ 330, a small dark spot displayed an unprecedented speed: DL2~ +55°/mth (latitude 38.6°N) (Figure 11c). This must be the first ground-based observation of the retrograding *NNTBn jetstream*.

N. N. Temperate white ovals

There was no visible NNTZ, but at least four anticyclonic white ovals were tracked in the NNTZ domain at 40–41°N (NNTC nos.6–9 in Table 6A). These displayed systematically faster drifts when at slightly higher latitudes; oval no.6 itself displayed this relationship as it drifted to and fro during the apparition. This behaviour confirms the gradient of speed with latitude across the N. N. Temperate domain that has been observed in previous apparitions (pp.48, 91, 264, 269–270 of ref.12). In particular the long-lived white or reddish ovals in the NNTZ, such as nos.6–9 in this apparition, often move faster than other features in the NNTC. This behaviour may be regarded also as an example of the N^3TC invading the adjacent NNTC domain, and also as an example of long-lived anticyclonic circulations drifting faster than other features in the same domain (as seen, for example, with the Great Red Spot and with NTropC white spot Z).

NNTC ovals nos.8 and 9 were particularly long-lived and interesting. Both persisted from the previous apparition, when they had shown regular oscillations in drift rate with a period of 3–4 months. In 2000/01, both still showed fluctuating drifts, which were consistent with the previous oscillations with a period of 3.6 months in each case (Figure 11d).

No.8 was a large well-defined oval, but pale; it had a pale fawn tint resembling the surrounding zones, so it could only be identified on the best hi-res images (Figure 5, third column, & Figure A3). It was however still bright in methane images – the only such spot in the northern latitudes this apparition (see Paper II). It was measured using PC-JUPOS from visible-light images (Figure 11d), and by hand from methane images (see Paper II), and these measurements agreed on its irregular motion (Table 6A).

No.9 was a conspicuously bright oval on hi-res images. It had persisted since 1997, when it had been a methane-bright Little Red Spot, though it was not methane-bright nor reddish after 1998.

Higher latitudes

In the *N. N. N. Temp. domain,* the main features were small dark spots at 45–46°N, between L2~ 20–110, prograding with the usual N^3TC (Figure 11e). There were two or three at any one time, lasting up to three months; the more coherent ones are listed in Table 6A.

In the *N. N. N. N. Temp. domain*, the most persistent features were bright spots at 50–51°N, slow-moving, i.e. in the usual N^4TC. Of the best-tracked three (Table 6A), at least two had persisted from the previous apparition. The latitude suggests that these were cyclonic.

One of the most remarkable spots of the apparition was a bright white oval at 54°N with an unprecedented motion (NPC no.1 in Table 6A & 6B; Figure 11f). At first it had DL2~ –12°/mth (variable), then it suddenly accelerated to –47°/mth (Oct–Nov), a speed never before recorded in this latitude. This must be the first ground-based detection of the *N^5TBs jetstream*. The spot's rapid movement is also clearly visible in the *Cassini* movie.[25] Then it suddenly halted (DL2~ –2 throughout Dec); then it accelerated again (DL2~ –23 in Jan). There appears to be a correlation of speed with latitude, in that it travelled fastest when furthest N (54.4°N; Table 6A). So this was an AWO in the N^4TZ domain which wandered in latitude, temporarily entering the N^5TBs prograding jetstream.

Finally, even further north, there were at least three light ovals with speeds of DL2= +11°/mth, at 59–61°N, one of which had persisted from the previous apparition. Bright ovals with similar drift and latitude were also recorded by *Voyager* [pp.83 & 92 of ref.12]. They may represent a retrograding N^{5}TBn jetstream. The persistence of these ovals is remarkable, and may have been underestimated in the past because we did not plot this latitude range as a whole for previous apparitions.

Discussion: Long-lived anticyclonic ovals

This apparition we have recorded an exceptional number of long-lived spots, mainly anticyclonic ovals, which have persisted through one or more solar conjunctions. These included not only the Great Red Spot and a brown ring in the S. Tropical domain, but also anticyclonic white ovals in almost every other domain: one in the N. Tropical (the fast-moving white spot Z), two in the N. N. Temperate (one being methane-bright), three in the N. N. N. N. Temperate (though the latitude indicates these may be cyclonic), one in the North Polar region, three in the S. Temperate (including the newly merged oval BA), seven in the S. S. Temperate, one in the S. S. S. Temperate, and one in the South Polar region. The latter two high-latitude spots, and the N. N. Temperate ones, apparently persisted between apparitions in spite of showing large and sudden changes in their drift rates.

After our analysis was complete, a survey of long-lived AWOs was published using HST and Pic du Midi images.[13] This survey confirms our tracking of long-lived AWOs at 60°S (their Figures 6 and 10) and 60°N (their Figure 13), and shows details of the dynamics of these polar vortices.

Discussion: Rare detections of jetstreams

The jets (jetstreams) are the most important structural features of Jupiter's atmosphere, and determine the boundaries of each belt and zone. They are only intermittently visible from Earth, when there are outbreaks of small dark spots on them, and these 'jetstream outbreaks' have historically been a well-defined category of disturbance on Jupiter, sometimes associated with other types of disturbance.[12] Only a few of the jetstreams had been detected from Earth before the *Voyager* encounters. The *Voyagers* revealed that the pattern of jetstreams is regular and stable, even when there are no visible spots on them,[22] and this has been confirmed more recently by the HST[23,24] and by *Cassini*.[25]

In 2000/01, there were substantial outbreaks continuing on the SEBs and NNTBs jetstreams. In addition, the seven spots on the NTBs jetstream, although visually inconspicuous, must be a sign of continuing activity on that jetstream. Presumably all these jetstream spots were small anticyclonic ovals, as revealed by the *Voyager* and *Cassini* images.

In addition, the JUPOS measurements allowed us to track smaller, shorter-lived spots than has normally been done before. This led to the detection of a further four jetstreams; they had been detected by *Voyager* and the HST but never by visual observers and, in three cases, never before from Earth (Table 6B). These were the jetstreams on SSTBn (six dark spots; recorded a few times previously by hi-res amateur images), NTBn (one spot), NNTBn (one spot), and N^{5}TBs (a bright white oval). Apart from the last, all the features recorded were tiny dark spots. These results show that even amateur images can resolve some of the fundamental motions in these complex regions of the planet, and could perhaps monitor their stability for many years to come.

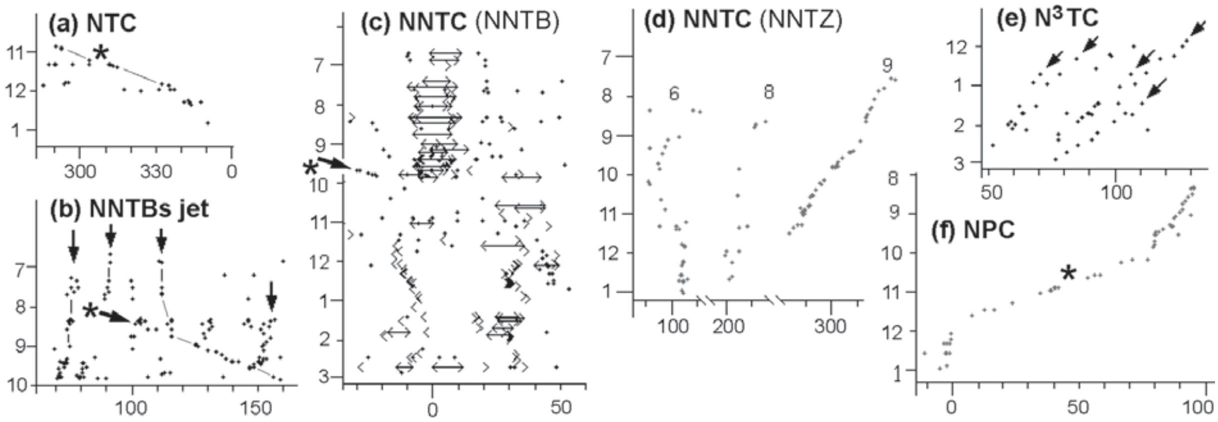


Figure 11. Excerpts from JUPOS charts, showing interesting drifts of spots in longitude, including the previously unobserved jetstreams on NTBn, NNTBn, and N^{5}TBs. Each chart covers a specified latitude range; on the horizontal axis are longitudes in a system with a specified drift rate per day (a,b) or in System II (c–f); on the vertical axis are months of 2000/01.
(a) NTC: 27 to 33°N, L2 +0.5°/day; one small dark spot is moving in the NTBn jetstream (*) ('New jets no.1' in Table 6A).
(b) NNTBs jetstream: 33 to 36°N, L2 –2.5°/day; several dark jetstream spots (vertical arrows), and one slower-moving spot (*) ('New jets no.2' in Table 6A).
(c) NNTC: 36 to 39°N, L2; p. ends (<) and f.ends (>) of dark segment of NNTB, which show 'serial behaviour' in that they drift up or down in L2 only to be replaced by a similar feature at the same L2. Points represent small dark spots, one of which moves with the NNTBn jetstream (*) ('New jets no.3' in Table 6A).
(d) NNTC: 39 to 42°N, L2 in three sectors to show NNTC spots nos.6, 8, and 9, which are AWOs in NNTZ.
(e) N^{3}TC: 42 to 47°N, L2; small dark spots.
(f) 'NPC': 52 to 60°N, L2; white oval NPC no.1, temporarily moving with the previously unobserved N^{5}TBs jetstream (*).

Appendix: A *Cassini* atlas of Jupiter

In this Appendix we show examples of the *Cassini* imagery to give detailed views of the atmospheric features that we have tracked, as we did for *Voyager* imagery in our 1978/79 report.[26] The patterns revealed in the *Cassini* imagery are very similar to those revealed by *Voyager*, except for the different condition of the STB, EZ(S), and NTB in the two epochs. Jetstreams are present in the same latitudes, and those on SEBs and NNTBs (as well as NTBs) again carry oval spots. The same types of spots and disturbances are visible, in the same latitudes. Thus the internal structure of the GRS and AWOs, and of cyclonic ovals, filamentary regions, and rifts, is just as seen in the *Voyager* imagery. All this confirms that the patterns seen are fundamental characteristics of the atmosphere of Jupiter.

All the Cassini images are from the Imaging Science Subsystem, team leader Dr Carolyn Porco (CICLOPS/Southwest Research Institute, Boulder, Colorado).[6] Images are credited to NASA, the Jet Propulsion Laboratory, and the University of Arizona. The images are from the ISS and JPL web sites.[25]

The images are shown with south up, and labelled with the feature names or numbers from Tables 4A and 6A.

Map of the planet

Figure A1 (pages 212–213) is a complete map of the planet on 2000 October 31. An approximate longitude scale in System II has been added. This was the first of a series of hi-res colour maps that comprised a movie, showing the planet's winds in spectacular detail. All the features we tracked at this time can be identified on the map, and virtually all the major 'spots' on the map were tracked in our data. It can be compared with the amateur map of Oct 27–30 (Figure 2). Arrows at left indicate the estimated latitudes and directions of the jetstreams referred to in the preceding text. STropC spot no.4 is labelled @, and the main complex of the S. Equatorial Disturbance is labelled SED.

Southern hemisphere

Figure A2 is a full-colour image of the southern hemisphere taken on 2000 December 12, at CM2~ 50, showing the Great Red Spot, and Io and its shadow on the SEB.

In the SSTZ, one can see AWOs A1 to A4, and between them cyclonic spots nos.8 (dark 'mini-barge') and 9 (white oval). On the faint STB immediately S of the GRS, one can see DS1a (arrowed), now a faint but strongly orange cyclonic oval. The long-lived brown oval in the STropZ is revealed as an anticyclonic ring (arrowed @). In the SEB, there is intense disturbance in the rifted region f. the GRS. Bright spots in this turbulent cyclonic region are clouds rising from dense thunderstorms.[6,27] The SEBn edge and EZ(S) is patterned with numerous small projections derived from the waning South Equatorial Disturbance.

Northern hemisphere

In Figure A2, the EZ(N) and NEBs edge show an intricate mixture of clouds of different tints, apparently overlapping at different altitudes, especially around the dark bluish 'NEBs projections' at left and right sides of the frame. *Cassini* and *Galileo* data are now leading to a model of these projections as deep waves almost devoid of clouds.[5] Conversely the numerous bright 'rifts' visible in the NEB are probably dense clouds rising from thunderstorms like those in the SEB.[6,27]

At bottom left of Figure A2 in the NEB is barge B1, with obvious orange-brown colour and cyclonic (anticlockwise) circulation. Below left from it, also arrowed, is the brown 'projection' (NTropC no.1) marking the f. edge of the expanded NEBn, which appears to be confined by a sharp front. Further left again, also arrowed, is the orange-brown cloud that was a notable feature during the expansion of the NEB, probably trapped in a partial anticyclonic (clockwise) circulation Np. the barge.

Figure A3 is a two-colour image of the northern hemisphere taken on 2000 December 13, at CM2~ 190.

In the EZ(N)/NEBs, there is an intricate mixture of overlapping clouds (as in Figure A2). Again a turbulent white NEB 'rift' opens into the EZ, and there is a distinct impression of NEB clouds spreading over the normal boundaries of the belt. In the EZ, white clouds may be progressively masking the usual dark features. There is only one bluish NEBs 'projection', and that is partly overlapped by brown NEB material.

The NEB has completed its northward expansion in this sector, and the texture is interesting. The image includes five spots that we tracked in the NEB (N. Tropical Current), all revealed as well-defined circulations. Three are reddish-brown barges, B2 and B3 and the newly forming small barge B4b. They show cyclonic (anticlockwise) circulation; but in each case there is also anticyclonic (clockwise) circulation at the p. edge. Amateur images and JUPOS charts have given the impression of brown belt material being drawn Np. from around the barges and cusps, to prograde in the former NTropZ, and this is reinforced by this image showing streaks in that direction. There are also two spots revealed as anticyclonic: NTropC no.11 (a small grey ring) and white spot Z (a very striking white oval).

Two NTBs jetstream spots are shown; note how the anticyclonic circulation of the NTBs jetstream rings appears to be entraining streamers from the NTB, confirming the origin of the dark humps that we have tracked.

In the N. N. Temperate Current, one can see fragments of NNTB including dark spot no.3 (a cyclonic oval), but also less stable cyclonic circulations termed 'folded filamentary regions' (FFRs), which are too low-contrast to be tracked in amateur images. Two AWOs are also visible: no.7 (a small white oval) and no.8 (a light oval with a reddish core). No.8 was the only methane-bright oval in these latitudes, and its reddish tint is typical of methane-bright spots. Further north, one sees numerous FFRs and small rings, most of which were too indistinct to be tracked in amateur images.

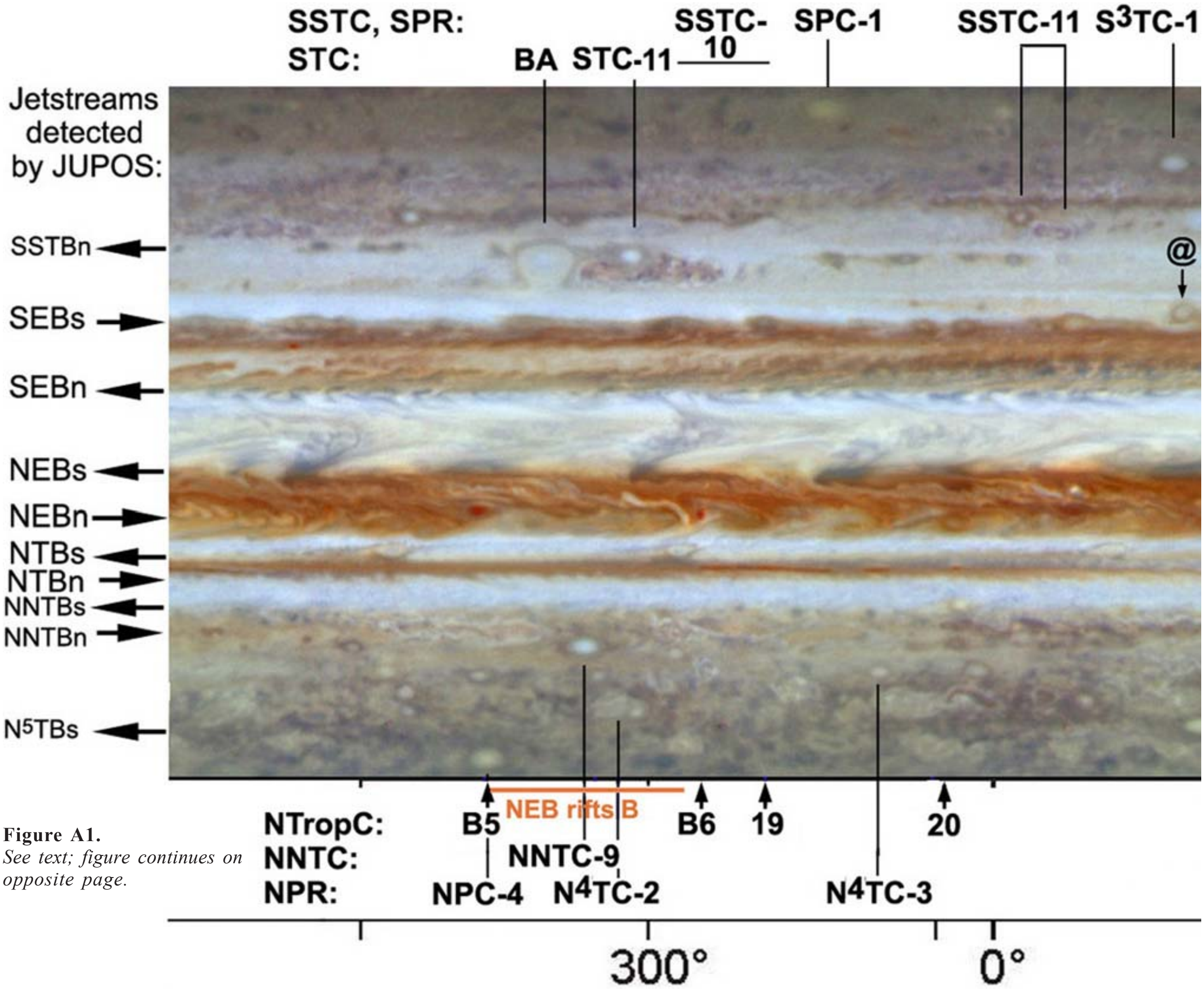


Figure A1.
See text; figure continues on opposite page.

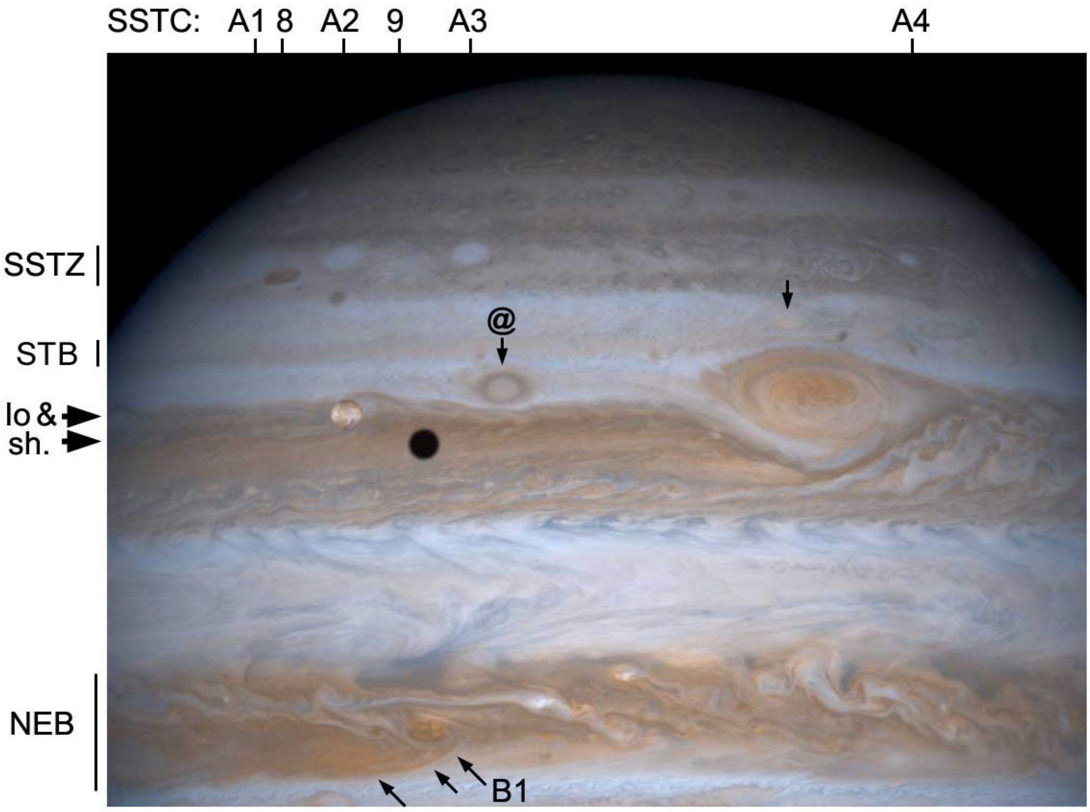
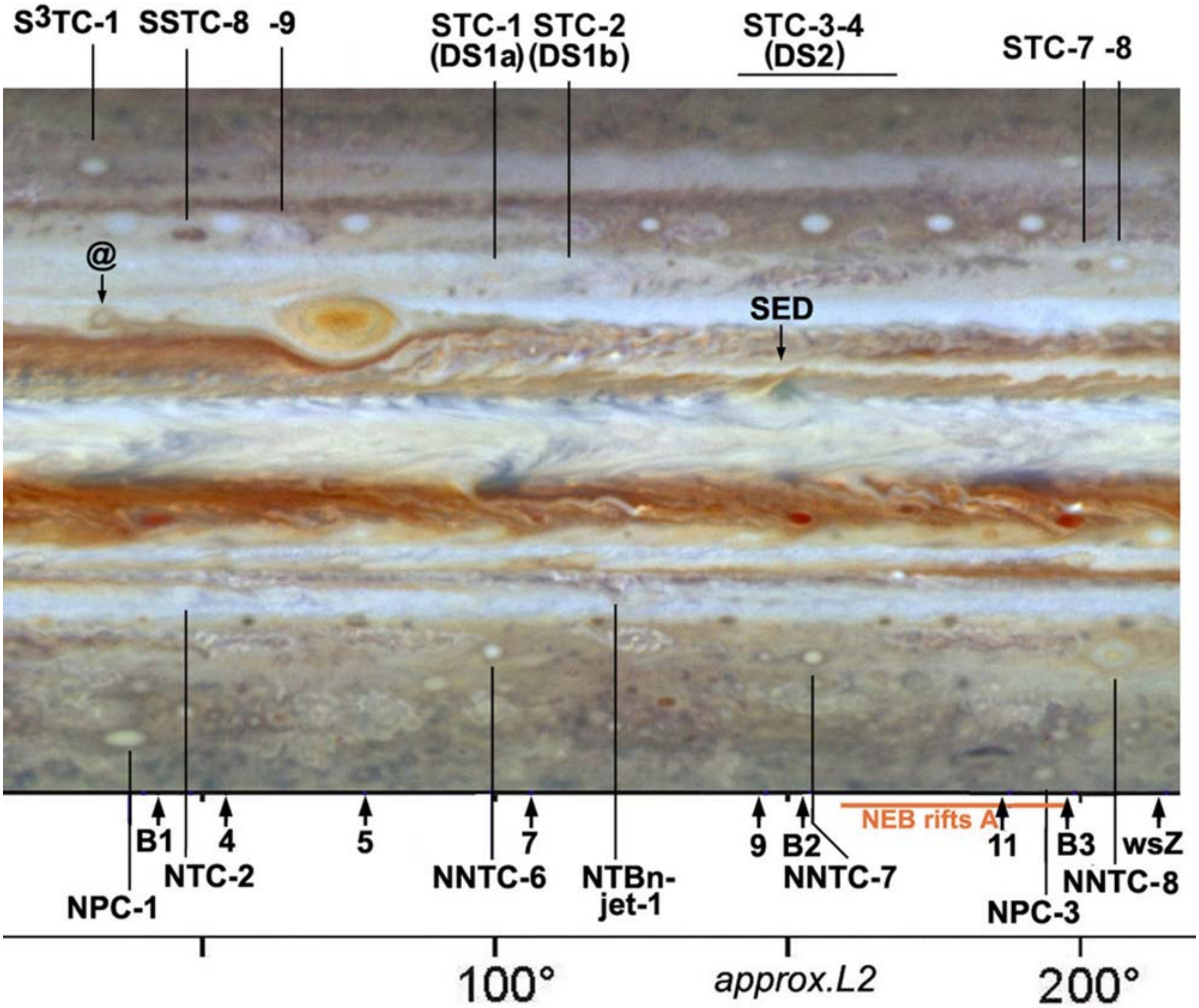


Figure A2.
See text.



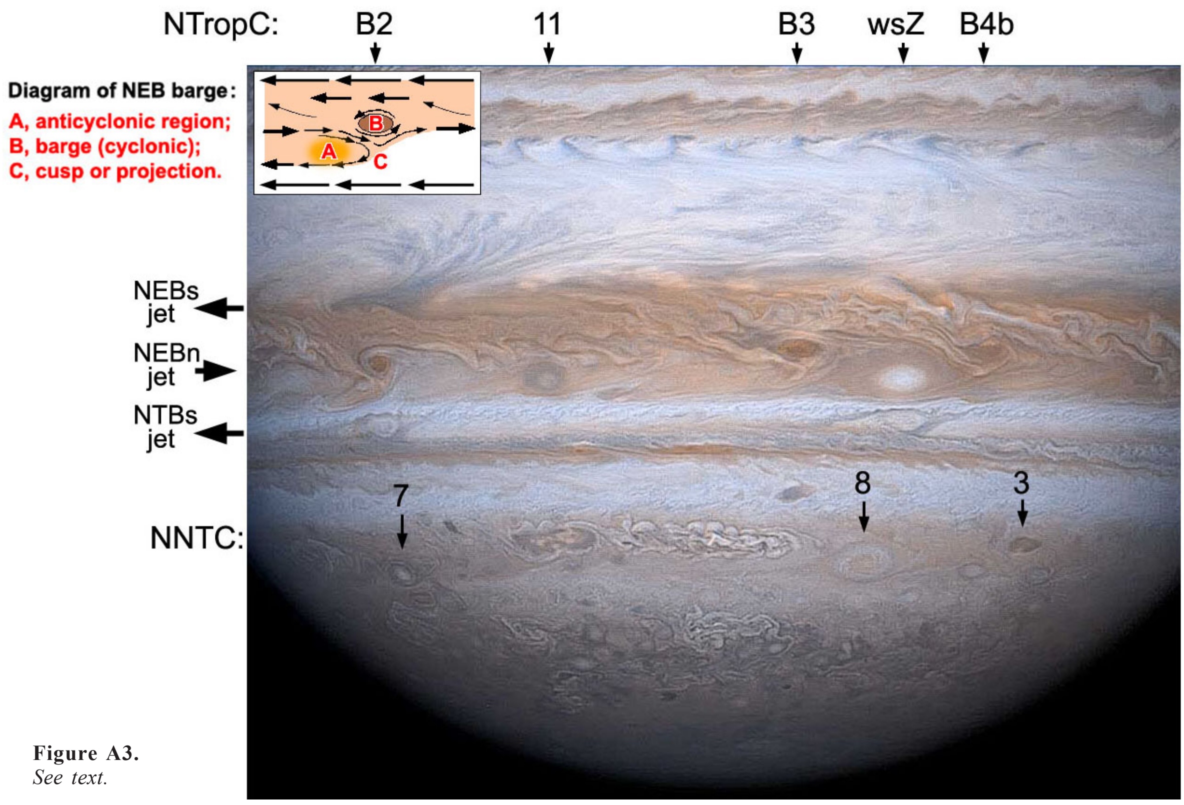


Figure A3.
See text.

In Paper II we will present a review of infrared images from *Cassini* and from ground-based observers, which will include further information on the spots in these far northern latitudes.

Address: John H. Rogers, 10 The Woodlands, Linton, Cambs. CB1 6UF. [jhr11@cam.ac.uk]

References

1 Rogers J., Mettig H.–J., Peach D. & Foulkes M., 'Jupiter in 1999/2000, Part I: Visible wavelengths', *J. Brit. Astron. Assoc.,* **113**(1), 10–31 (2003)
2 Rogers J., 'Jupiter in 1999/2000, Part II: Infrared wavelengths', *J. Brit. Astron. Assoc.,* **113**(3), 136–140 (2003)
3 Rogers J. H., 'Jupiter in 2000/2001' (Interim report), *J. Brit. Astron. Assoc.,* **112**(1), 2, 8, 9 (2002)
4 Rogers J. H., '*Cassini* and *Galileo* view Jupiter in stereo', *J. Brit. Astron. Assoc.,* **111**(2), 59–60 & cover (2001)
5 Rogers J. H., '*Cassini* and *Galileo* reveal secrets of Jupiter's dark patches', *J. Brit. Astron. Assoc.,* **111**(5), 245 (2001)
6 Porco C. C. *et 23 al.* '*Cassini* imaging of Jupiter's atmosphere, satellites, and rings', *Science* **299**, 1541–1547 (2003 March 7)
7 Rogers J. H. & Mettig H.–J., 'Jupiter in 1998/99', *J. Brit. Astron. Assoc.,* **111**(6), 321–332 (2001)
8 JUPOS web site: http://home.t-online.de/home/h.j.mettig/ or http://jupos.org
9 ALPO-Japan web site: http://www5.ocn.ne.jp/~planets/Jupiter2000 Apparition.htm
10 Antonio Cidadão web site: http://www.astrosurf.com/cidadao/
11 Cidadão A., 'Thoughts on super-resolution planetary imaging', *Sky & Tel.* **102**(6), 127–134 (2001)
12 Rogers J. H., *The Giant Planet Jupiter,* Cambridge University Press (1995)
13 Morales–Juberias R., *et al.*, 'A comparative study of jovian cyclonic features from a six-year (1994–2000) survey', *Icarus* **157**, 76–90 (2002)
14 Sato T., 'Statistical establishment of the repulsive force between the long-enduring white ovals in the STZ of Jupiter', *The Heavens* (Japan) **50**(530), 187 (1969), reprinted in *J. Brit. Astron. Assoc.,* **84**, 439–442 (1974)
15 Rogers J. H., 'Jupiter in 1997' (Interim report), *J. Brit. Astron. Assoc.,* **107**(6), 333–335 (1997)
16 Rogers J. H., 'Jupiter in 1997', *J. Brit. Astron. Assoc.,* **111**(4), 186–198 (2001)
17 Sanchez-Lavega *et 7 al.*, 'Dynamics and interaction between a large-scale vortex and the Great Red Spot on Jupiter', *Icarus* **136**, 14–26 (1998)
18 Solberg H. G., 'A 3-month oscillation in the longitude of Jupiter's Great Red Spot', *Planet. & Sp. Sci.* **17**, 1573–1580 (1969)
19 Hahn G., 'The 90-day oscillation of the jovian Great Red Spot', *J. Brit. Astron. Assoc.,* **106**(1), 40–43 (1996)
20 Iga Y., 'Formation of NEB rift in 2000–2001', ALPO-Japan 25th Jupiter Conference (2001)
21 Garcia–Melendo E. *et 6 al.*, 'Long-lived vortices and profile changes in the 23.7°N high-speed jovian jet', *Icarus* **146**, 514–524 (2000)
22 Limaye S. S., 'Jupiter: new estimates of the mean zonal flow at the cloud level', *Icarus* **65**, 335–352 (1996)
23 Beebe R. F. *et al.*, 'Comparison of *Galileo* Probe and Earth-based translation rates of Jupiter's equatorial clouds', *Science* **272**, 841 (1996)
24 Garcia–Melendo E. & Sanchez–Lavega A., 'A study of the stability of jovian zonal winds from HST images: 1995–2000', *Icarus* **152**, 316–330 (2001)
25 *Cassini* imaging science team web site: http://ciclops.lpl.arizona.edu/, and *Cassini* mission web site: http://saturn.jpl.nasa.gov/
26 Rogers J. H. *(ed.)*, 'Jupiter, 1977–1981: The Voyager Years', *Mem. Brit. Astron. Assoc.* **43**, Part 3 (1992)
27 Gierasch P. J. *et al.,* 'Observation of moist convection in Jupiter's atmosphere', *Nature* **403**, 628–630 (2000)

Received 2003 August 09; accepted 2003 November 29