Jupiter in 2000/2001

Part III: The South Equatorial Disturbance – a large-scale wave in a prograde jet

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

The South Equatorial Disturbance (SED) was a unique disturbance that lasted from 1999 to 2002, comprising a solitary wave in the South Equatorial jet. In this second report on it, we describe its changing appearance and dynamics, combining data in many wavebands from amateur observers, from the NASA Infrared Telescope Facility, and from the *Cassini* spacecraft.

The focus of the SED appeared in visible light as a bright rift in SEBn with a dark bluish patch in EZ(S); it was most prominent in the first half of 2000. It generated major disturbance in the EZ(S) for a long way preceding it. The main complex drifted more slowly than System I, but features preceding it moved faster, eventually reaching the full speed of the South Equatorial jet (hereby detected from the ground for the first time).

Images in the near-infrared revealed major reorganisation of the cloud layers throughout the disturbance, at least from early 2000 onwards. At ~0.8 and 1.6 μm, the visibly bluish patches were extremely dark, suggesting that mid-level cloud layers were disrupted. At 4.8 μm, some areas were transparent but others were not. In the methane absorption bands (0.89 and 2.3 μm), the usual bright haze of the EZ(S) was absent over and preceding the SED.

The SED was well placed for *Cassini* imaging, which revealed an anticyclonic circulation in the main complex. This reinforces its similarity with the great white spots of 1979 and 1879. Analysis of its dynamics may give insight into the more numerous wave disturbances that are familiar in the North Equatorial jet.

Introduction

The South Equatorial Disturbance (SED) was a unique disturbance that lasted from 1999 to 2002, affecting the southern Equatorial Zone (EZ(S)) and South Equatorial Belt north edge (SEBn). Here we describe its development in 2000/2001, with a synthesis of visible and infrared (IR) data sets as described in the first two parts of our 2000/2001 report[1,2]; hereafter Papers I and II. This is the second instalment of our report on the SED. The first instalment was included in our report on the 1999/2000 apparition, where we described the development of this feature from a tiny rift to a spectacular disturbance.[3] It has also been illustrated in several interim reports.[4–6]

In the first observations of the 2000/2001 apparition, in 2000 June, the SED was still spectacular in visible light. It had also developed a striking appearance in the near-infrared, both in continuum and in methane absorption bands. As the apparition progressed, it subsided at visible wavelengths but remained conspicuous in methane bands. Imaging by the NASA Infrared Telescope Facility (IRTF) began in August but the SED main complex was first captured near the central meridian in mid-November. Then, from Nov until Jan, it was observed at high resolution by the *Cassini* spacecraft and in infrared images by *Galileo* and the IRTF. The final observations by both amateurs and IRTF were in late April, 2001. Table 1 gives a chronological guide to illustrations of it in 2000/2001, published in this paper and our previous reports.

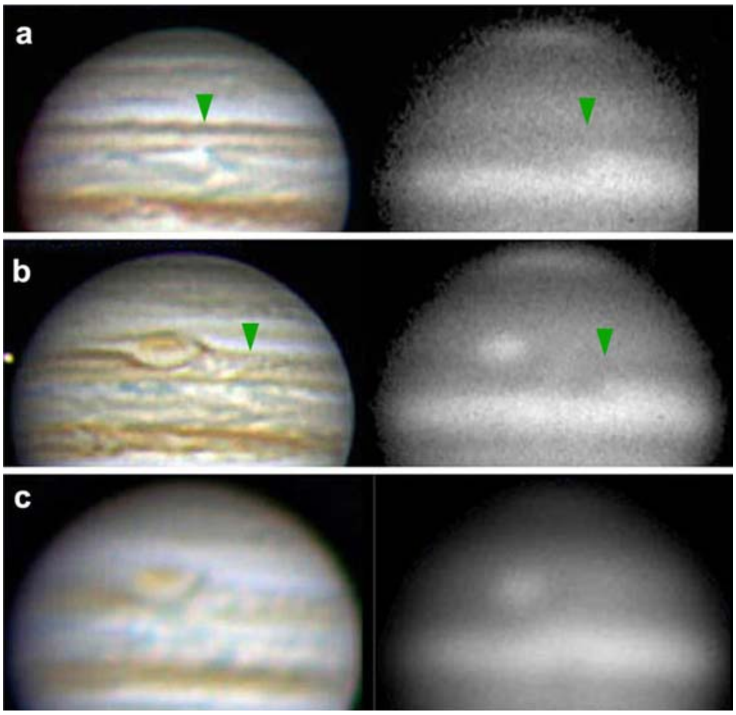
The focus of the SED was a discontinuity in the SEBn which we call the main complex.[3] This appeared in summer 1999,

Table 1. Illustrations of the SED main complex

Dates	*Amateur images*	*Dates*	*IRTF images*
2000		*2000*	
July 13–24	Figure 1; Paper I Figure 5	July	–
Sep 14–26	Paper I Figure 5; Paper II Figure 2	Sep 29	Paper II Figure 9
Oct 17–23	Figure 6	Oct	–
Nov 4–7*	Figures 2, 3, 5A	Nov 11–15	Figures 3 & 11A
Dec 14	Figure 5B	Dec 29*	Figure 11B; ref.5
2001		*2001*	
Jan 1	Cover of *Journal*, 2001 April[5]		
Jan 15–17	Figures 7 & 8	Jan 8–12	Figure 7
Mar 19	Figure 13A	Mar 6	Paper II Figure 18
Apr	–	Apr 26	Figure 13B

This table lists illustrations of the SED main complex in 2000/2001, in this paper and our previous reports.
Amateur images: Visible light, ±infrared.
IRTF images: This list includes almost all that were obtained of the main complex.
*Also: 2000 Nov 23, false colour version of Akutsu images;[6]
Dec 31, false colour version of *Galileo* NIMS images: Paper II Figure 6.

Note: South is up in all images in this paper. In the SED, arrowheads mark the main complex in continuum wavebands and its f. end in methane wavebands. The NEB is shown in all images for comparison with the SEB, and in many cases it shows the pattern of methane-dark waves reported in Paper II. In many figures the images are cut off north of the NEB. See tables in Papers I and II for details of observers and equipment.



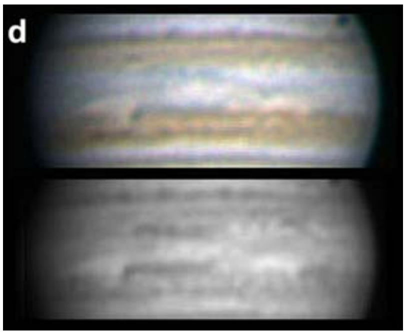


Figure 1. (a–c) The main complex in its most elaborate phase in 2000 June and July, imaged in visible colour (RGB, *left*) and methane (0.89µm, *right*). Also see Figure 5 of Paper I (2000 July 13, 17, 18 in colour).

(a) June 25 (Miyazaki): RGB, 20h14m UT, CM1=169, CM2=240; methane, 4 min later. Green arrowhead marks the main complex.

(b) July 18 (Miyazaki): RGB, 19h56m UT, CM1=187, CM2=82; methane, 15 min later.

(c) July 23 (Akutsu): RGB, 19h06m UT, CM1=225, CM2=83; methane, 6 min later. The main complex is passing the GRS.

(d) August 1 (Akutsu), 18h43m UT, CM1=192, CM2=341: Colour (top) and I-band (bottom) showing the stormy sector p. the main complex.

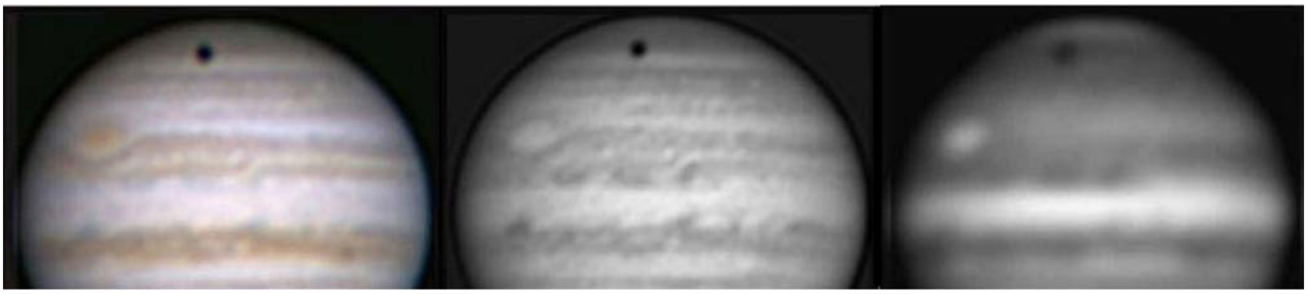


Figure 2. The main complex in 2000 November. An example of the triptychs taken by Akutsu: visible RGB *(left)*, I-band *(middle)*, methane 0.89µm *(right)*. Nov 4, RGB 15h46m UT, CM1=327, CM2=112; I-band 15h50m UT; methane 15h52m UT. The main complex is on the central meridian (CM), approaching the GRS on the p. side.

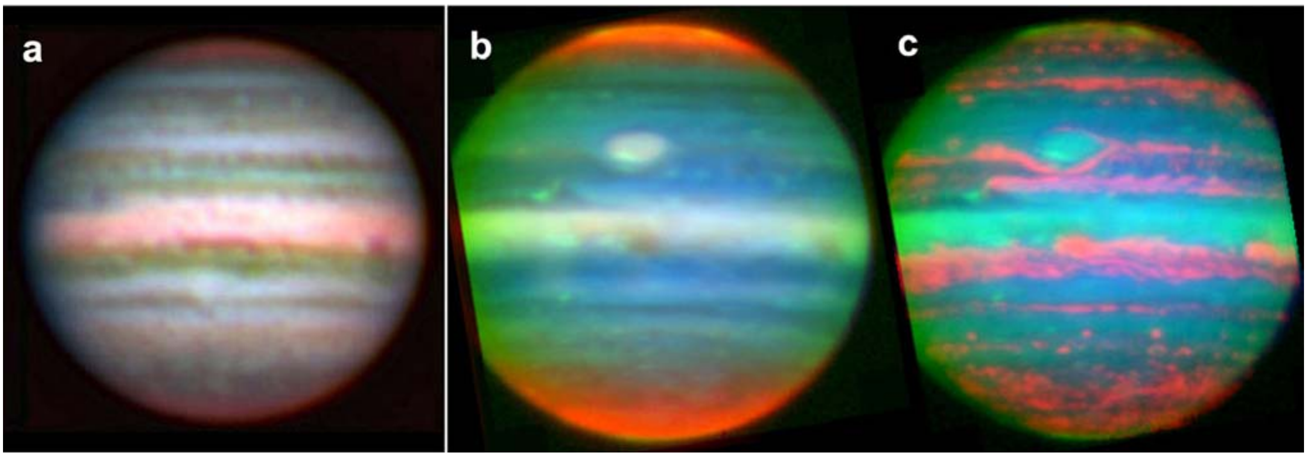


Figure 3. False-colour versions of IR images in November (composited by JHR). The main complex is on the p. side. In (**a, b**), bright pink over the EZ represents high-altitude haze, which is absent from the SED, but extends slightly north over the NEBs (see Paper II). Also, red over each polar region is the Polar Hood. In (**b, c**), the bright yellow or green strip over each pole is the aurora emitting at 3.8µm.

(a) Nov 7, approx.14h05m UT, CM1=20, CM2=142 (Akutsu). Blue channel= white light, green channel= I-band, red channel= methane (0.89µm). (Also see similar image on Nov 23 in ref.6.)

(b) Nov 15, approx. 09h04m UT, CM3=50 (IRTF). Blue= 1.6µm, green= 3.8µm, red= 2.3µm. The main complex has just passed the GRS. (Also see Figure 11.)

(c) As (**b**) but red= 4.8µm, showing internal heat that emerges mainly in belts that are dark at shorter wavelengths. (The 4.8µm image was taken 8 min before the 3.8µm image, so there is mismatch near the limb.)

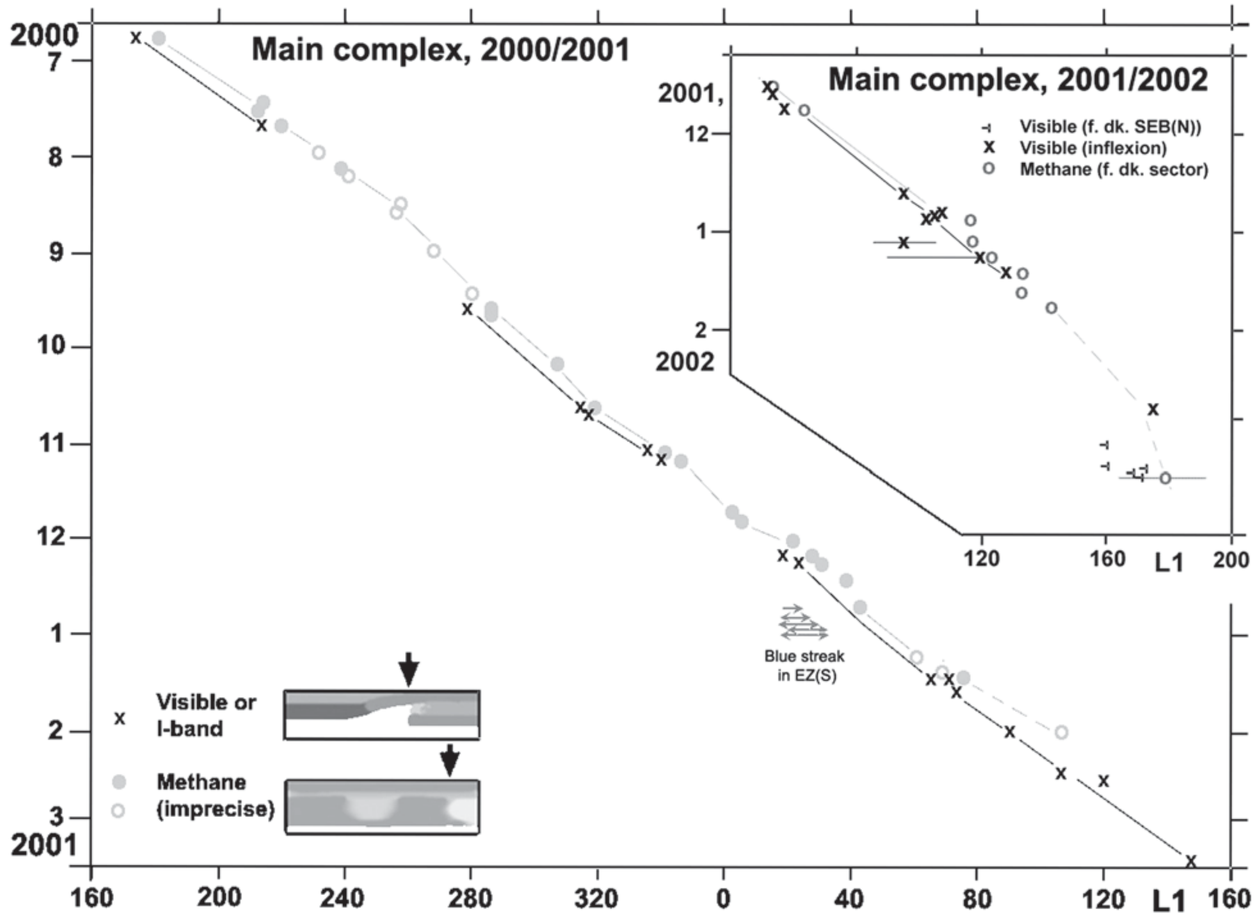


Figure 4. Chart of the motion of the main complex in System I longitude (L1), 2000/2001 and 2001/2002. Circles are measurements of the 'step-up' at the f. end, on amateur methane-band images, mostly by Akutsu. (Two in 2001 Jan were from IRTF images.) Crosses are measurements of the main complex in visible or I-band, defined as the f. edge of the bright rift, or p. end of the dark SEBn or dark blue patch. This is typically 7° p. the 'step-up' in methane. From 2000 June 25 to 2001 Jan 17, the mean drift (DL1) was +1.23°/day, +36.8°/mth. After 2001 Jan, the main complex was tapered and very ill-defined in methane images, though a discontinuity in SEBn could still be seen in I-band images.

and was often an obvious feature by the start of 2000. In visible light, the main complex manifested as a bright rift in SEBn and a dark bluish patch in EZ(S); it was especially prominent after passing the Great Red Spot. During its most prominent phase, it generated a 'stormy sector' in the EZ(S) for a long way preceding the main complex, consisting of dark blue patches, with smaller dark and bright spots further ahead. In 1999/2000, the main complex moved slowly (DL1~ +0.5 to +1.6°/day), but disturbances in the stormy sector moved at a range of faster speeds, ranging up to DL1~ –1.8°/day at the p. extremity of the disturbance.[3] In 2000/2001, it was not so thoroughly tracked in visible images as, for most of the time, it was either too complex (including when passing the GRS in 2000 July and Sep) or too ill-defined (at most other times). However, the main complex was well tracked in the methane band from 2000 June to 2001 January (Figure 4). Its f. end was at L1= 55 on 2001 Jan 1, and the mean drift in System I was +1.23°/day (+36.8°/mth). This f. end was about 7° f. the centre of the main complex as defined visibly, i.e. the bright rift and the p. end of the SEB(N), which had the same drift rate. The main complex as defined visibly passed the GRS centre on 2000 July 23 (Figure 1), Sep 16 (Paper II), Nov 11 (Figures 3 & 11), 2001 Jan 7 (Figure 7) and March 5 (Paper II).

Visible appearance in 2000/2001: a large-scale wave in the prograding jetstream

In 2000 June and July, the SED main complex was initially much as it had been before solar conjunction. It was first imaged on 2000 June 25 (Figure 1), showing the classic bright rift with dark blue patch and interruption of the EB alongside it, as in March–April. The main rift disappeared as it approached the GRS but erupted again spectacularly as it passed the GRS on July 23 (Figure 1). By early August the main complex was barely perceptible in visible light (although the stormy sector p. it was still impressive, and even more so in I-band – see below). The main complex reappeared as a bright rift on Sept 19 just after passing the GRS, and was nicely imaged from Sept 19 to 24 (Paper I), but quickly closed up again. After Sept 24, it was never a major visible feature again,and the rift was barely detectable if at all. The rift did revive temporarily between Oct 17 and 23 (Figure 6), and again just after passing the GRS in mid-Nov. Then the main complex was minor or invisible in late Nov and in Dec. (Figure 5B and Ref.5). (However, it was still well-defined and striking in I-band and methane images – see

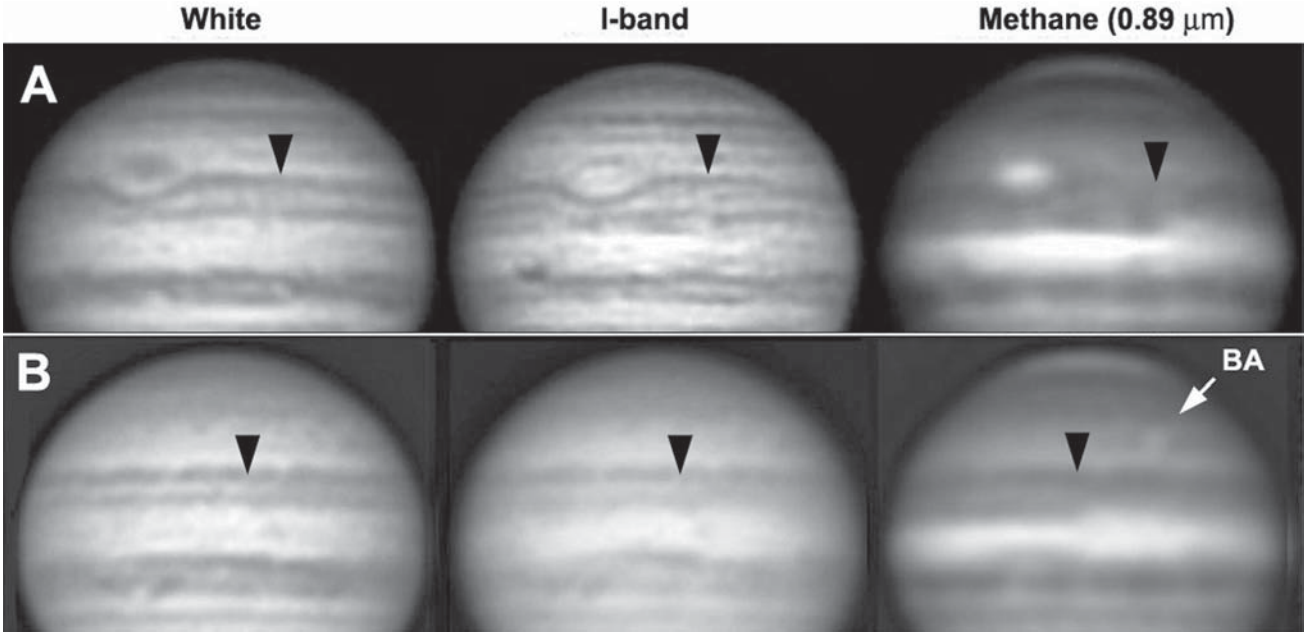


Figure 5. The main complex in 2000 Nov and Dec, showing the rapid fading of the dark patches in I-band. These two triplets were taken in white light *(left)*, I-band *(centre)*, and methane (0.89μm, *right*).
(A) Nov 7 (Colville): White light, 02h54m UT, CM1=330, CM2=97; I-band, 02h40m UT; methane, 02h46m UT. (Also see Figures 2 and 3.)
(B) Dec 14 (Akutsu): White light, 11h51m UT, CM1=25, CM2=226; I-band, 11h57m UT; methane, 12h16m UT.

below.) After its next GRS passage, in 2001 January, the main complex was mainly visible as a discontinuity in the SEB(N) (Figure 8). It had the same appearance two months later after its last observed GRS passage.

In summary, the main complex typically became most prominent after passing the Great Red Spot; but it became less prominent in late 2000 at visible wavelengths.

The stormy sector consisted of major disturbance in the EZ(S) spreading a long way p. the main complex, including both dark and bright spots. The stormy sector was long and impressive in 2000 July and August (Figure 1). It became less impressive as the apparition proceeded, but there was still considerable disturbance on a small scale, around more than half the planet's circumference. This was very well shown by *Cassini* images (Figure 6, and Appendix to Paper I). Some substantial blue-grey streaks were still observed shortly p. the main complex, but one in 2000 Dec (marked on Figure 4) was the last such feature. As a result we could only establish a few definite speeds on SEBn in 2000/2001; however, enough features were tracked to show that the drifts were similar to those of the previous apparition, with some being even faster

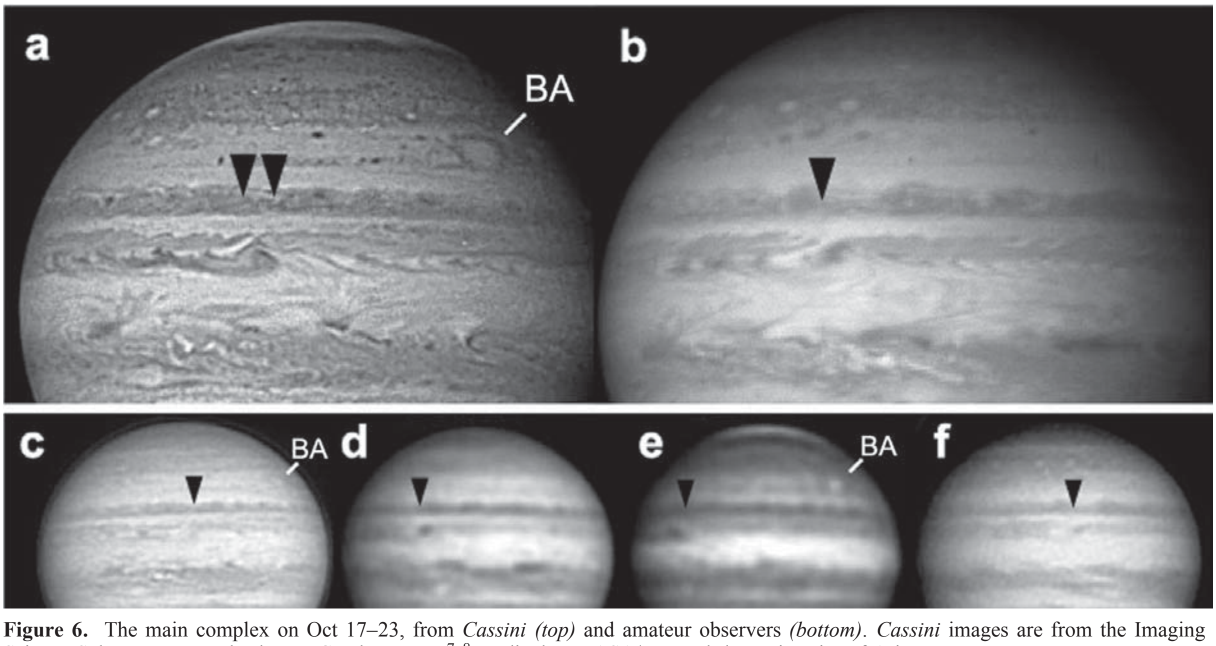


Figure 6. The main complex on Oct 17–23, from *Cassini (top)* and amateur observers *(bottom)*. *Cassini* images are from the Imaging Science Subsystem, team leader Dr Carolyn Porco,[7–8] credited to NASA/JPL and the University of Arizona.
(a) Oct 17 (*Cassini*), 727nm weak methane band. **(b)** Oct 23 (*Cassini*), red light. **(c)** Oct 17, 04h33m, CM1=312, CM2=238 (Cidadão), red light. **(d)** Oct 22, 03h25m UT, CM1=341, CM2=229 (Colville), I-band. **(e)** Oct 22, 03h58m UT, CM1=1, CM2=249 (Colville), methane (0.89μm, broad filter). **(f)** Oct 23, 08h10m UT, CM1=313, CM2=192 (Gross), red light.

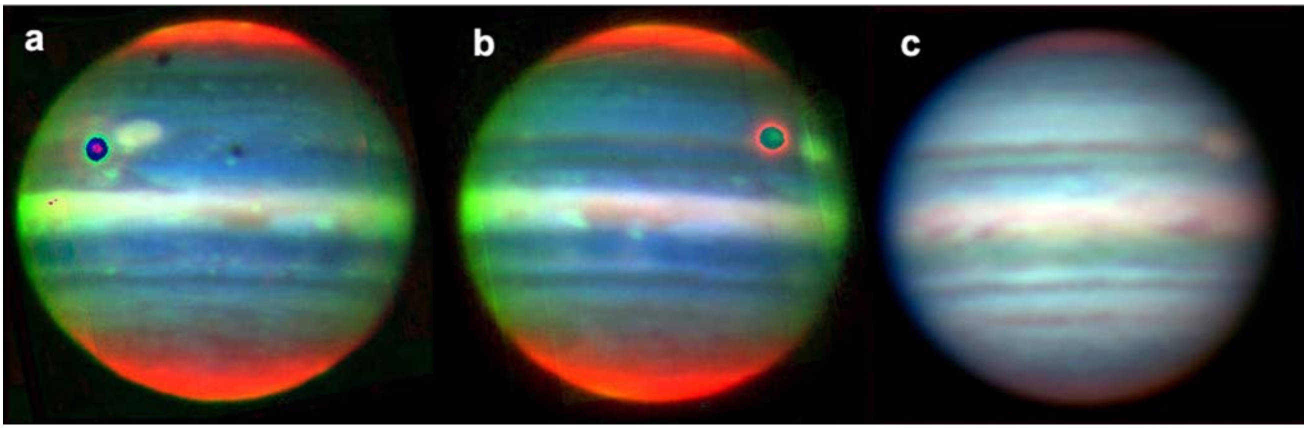


Figure 7. False-colour IR images showing the main complex in 2001 January as it passed the GRS. (Composites made by JHR.)
(a) Jan 8, approx.04h08m UT, CM3=85 (IRTF). The main complex, GRS, and Io, are in conjunction on the p. side. Blue= 1.6µm, green= 3.8µm, red= 2.3µm (as in Figure 2b).
(b) Jan 12, approx.05h02m UT, CM3=0 (IRTF). The main complex, GRS, and Europa, are on the f. side. Colours as in (**a**). (The different coloured rings around the satellites are due to different degrees of saturation of the image.)
(c) Jan 15, images as in Figure 8 (Akutsu). The main complex is on the CM; GRS on f. limb. Blue= white light, green= I-band, red= methane (0.89µm) (as in Figure 2a).

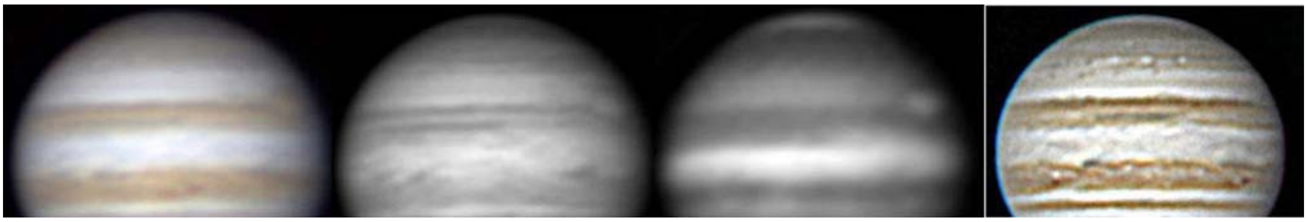


Figure 8. The main complex on 2001 Jan 15–20. The main complex is on the CM; GRS on f. limb.
Triplet by Akutsu, Jan 15: *(left)* Visible RGB 12h32m UT, CM1=63, CM2=20; *(middle)* I-band 12h36m UT; *(mid-right)* methane 12h39m UT. *(Far right)*: Jan 20 (D. Parker): Visible RGB 00h42m UT, CM1=61, CM2=343.

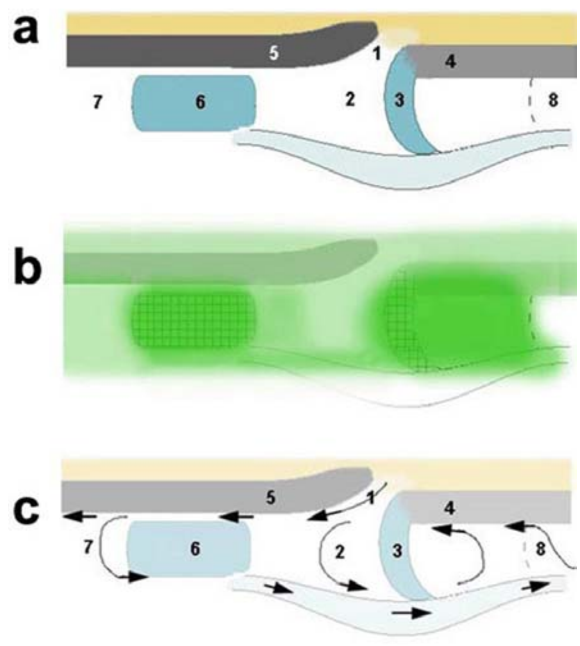


Figure 9. Diagram summarising the typical appearance of the main complex, (a) in visible light; (b) in methane bands; (c) with flow patterns, inferred from *Cassini* images and from analogy with the 1979 white spot in *Voyager* images. Numbers 1–8 identify sectors referred to in the text: 1, main rift; 2, mouth of rift; 3, blue patch; 4, 5, SEB(N); 6, blue patch(es) in stormy sector; 7, bright patches in stormy sector; 8, normal EZ(S).

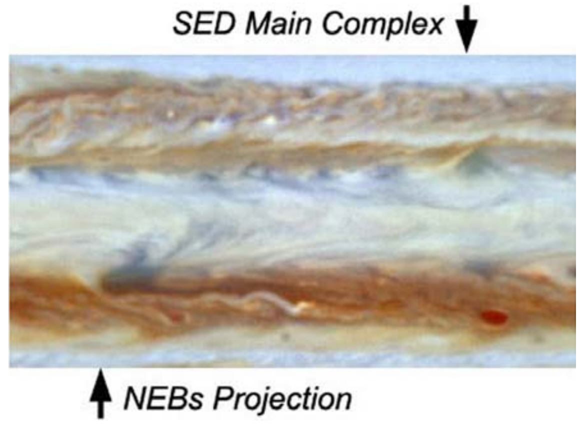


Figure 10. Detail from the *Cassini* visible-colour map on Oct 31, showing the similarity between the SED main complex and the p.end of a typical NEBs projection.[1,7]

(Table 5A of Paper I). These included several dark blue-grey streaks within ~40° p. the main complex, up to 2000 Dec, with DL1~ +8 to +38°/mth (+0.3 to +1.3°/day); and much smaller dark streaks or projections and bright spots further p., with DL1~–41 to –74°/mth (–1.4 to –2.5°/day). At least one pair of spots, a long way p. the main disturbance, had DL1= –85°/mth (–2.8°/day), which is the fastest speed yet observed from Earth in this latitude, and approaches the full speed of the jetstream as recorded by spacecraft (–3.1 to –3.8°/day).

In summary, the range of speeds observed in 1999/2000[3] had shown that the SED main complex was a powerful solitary wave in the SEBn jet. While the wave moved rather

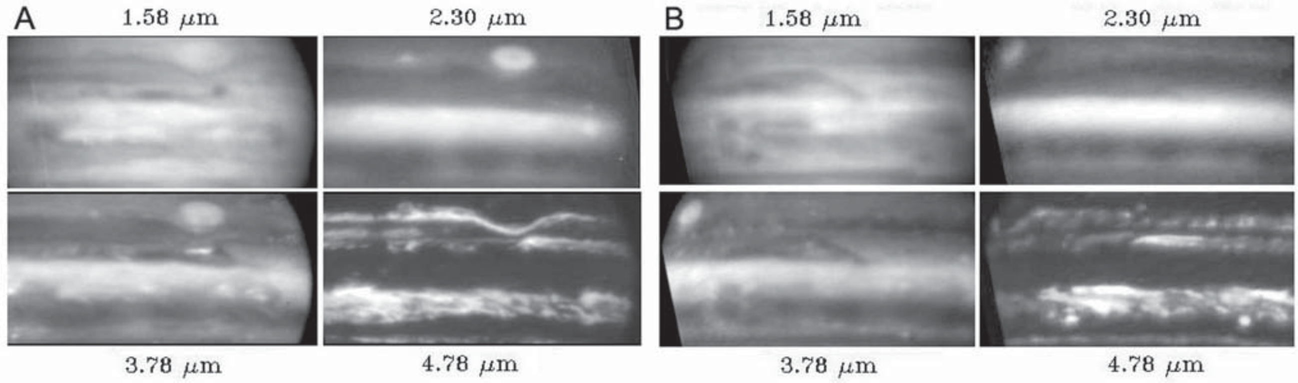


Figure 11. The main complex in 2000 Nov and Dec; examples of the sets taken at the NASA-IRTF. There is no fading at these wavelengths, unlike shorter wavelengths in Figure 5.
(A) Nov 11, approx.14h52m UT, CM3=17. The main complex is passing the GRS.
(B) Dec 29, approx.06h51m UT, CM3=118. The f.end of the main complex is in the centre of the frame, approaching the GRS which is at the p. limb. (False-colour versions of these IRTF images on Dec 29 were on the *Journal* cover in 2001 April,[5] together with visible-colour images by Cidadão and *Cassini*.)

slowly, it generated disturbances which prograded with a range of faster speeds, towards the peak speed of the jet. The pattern in 2000/2001 was similar. (Even faster speeds were to be observed in 2001/2002, right up to the peak speed of the jetstream; see below.)

Although the SED faded in visible light, plenty of very dark streaks were still recorded in 1.6μm images (see below). The fading of the SED at visible wavelengths may have been due to a general spread of white cloud all across the EZ, rather than a dynamical change in the SED itself, as most of the visible NEBs projections and festoons faded away over the same time period, whereas the south and north halves of the EZ both continued to show very dark features at 1.6μm (Paper II).

High-resolution appearance from *Cassini*: a unique dynamical pattern

Although only the highlights from the *Cassini* image sets have been released so far, they have been very revealing, and the full data set will enable comprehensive analysis of the SED phenomenon.[7,8] One distant image, showing the spectacular structure in a weak methane band (sensitive to both altitude and albedo), is in Figure 6, along with a red-light image. The highest-resolution images from *Cassini*, targeting the turbulent SEB f. the GRS, fortuitously captured the SED as it passed by around 2001 Jan 1, and showed both the detailed form and the unusual cloud structure of the main complex.[5]

A time-lapse movie compiled in I-band during *Cassini*'s approach[9] spectacularly revealed the wind patterns. Along the SEBn, the high-speed jet was obvious; the SED main complex was prominent as a wave retrograding within it; the main rift had clouds spilling out of it into the EZ, and the mouth of the rift opened into a striking anticlockwise (anticyclonic) circulation. This was the same circulation as observed by the *Voyager* spacecraft in 1979 in a great white spot at the same latitude (see below).

Infrared appearance in 2000/2001: a unique pattern of cloud layers

Images in the near-infrared, sensitive to different cloud layers, were very impressive and informative. The remarkable aspects were first shown in a set of images from the Pic du Midi on 2000 April 7.[10] These aspects would be repeated throughout the 2000/2001 apparition in many images from both amateurs and professionals (data sets described in Paper II, mainly produced by TA and GSO). The wavebands of interest were as follows; see Paper II for detailed background and latitude measurements.

1) *Thermal infrared* (4.8μm from IRTF). In these images, there were bright spots and streaks forming a band along the EZs edge, largely coinciding with the small blue spots in the stormy sector. Thus the usual correlation between the 4.8μm and visible wavebands was observed, confirming that the main cloud layer was deficient in these patches. The 4.8μm emission did not extend below 7.0°S, i.e. it observed the usual SEBn boundary, which was also the visible SEBn boundary as the EZ whitened during 2000. Visibly blue features extending further N into EZ(S) were surprisingly dark at 4.8μm, most notably the large bluish patch at the main complex. This suggests that the EZ's normal 5μm-absorbing cloud layer was only disrupted along the SEBn edge. Even the SEB(N) just p. the main complex was only weakly glowing at 4.8μm. In contrast, the SEB(N) f. the main complex was especially bright, indicating absence of deep cloud, as in the NEBs hotspots/projections.

2) *Near-infrared continuum* (0.7–0.9μm = 'I-band'; 1.6μm from IRTF). These images showed all the visibly bluish patches as extremely dark, exaggerating the visible-light appearance. This suggested that the main cloud layers (~0.8 to 2 bars) were cleared in these patches, including in the main complex. In August this appearance extended up to ~250° p. the main complex, so the stormy sector was still striking in I-band (Figure 1). These dark patches were forming a streaky band in EZ(S); as if to compensate, the SEB(N) was faint or fragmentary where the stormy sector was conspicuous, although it later became very dark just p. the main complex. During autumn 2000, the EZ(S) dark streaks and patches faded away in I-band as in visible light (Figures 2 & 5), but they did not fade at 1.6μm (nor 3.8μm) (Figure 11). This paradoxical development was also shown by the EZ(N) dark projections and festoons, and could be explained by the fact that 1.6μm (like 3.8μm) is weakly methane-sensitive, so it can probe a cloud layer more selectively than visible and 4.8μm wavebands (Paper II). Possibly the new visibly white cloud layer was rather

deep, or possibly it was absorbing at 1.6 and 3.8µm (Paper II); however, a detailed analysis has yet to be made.

3) Methane absorption bands (0.89µm; 2.3 and 3.8µm from IRTF). The whole of the SED was diffusely dark in all these wavebands, in latitude down to ~4°S in the EZ (5.6°S at 0.89µm), and in longitude up to the f. end of the main complex which was defined by a sharp 'step-up' or 'wedge'. Even the rift in the main complex was only a little lighter. Indeed this anomalous darkening covered not only the visible 'stormy sector', but also the EZ(S) further p. over EZ(S) where there was little visible disturbance. So the usual bright, high-altitude haze cover of the EZ was absent over and p. the SED, even where the visible cloud layers were still largely intact.

This methane-band appearance developed late in the history of the SED. In 1999/2000, the few methane images available (at 0.89µm from Isao Miyazaki) had shown nothing anomalous apart from a minor dark feature sometimes detectable over the main complex.[3] However, in spring 2000, this developed into the much more striking structure revealed in the Pic du Midi image (2000 April 7).[10] This remarkable aspect persisted throughout the 2000/2001 apparition, showing little change – not when the main complex passed the GRS, nor when the SED became inconspicuous at visible wavelengths. However the shape of the 'step-up' at the main complex in methane did change very gradually. In IRTF images, there was essentially no change in its wedge-shaped appearance from 2000 Sep to 2001 March. In amateur images, with lower resolution, it initially appeared as a fairly rectangular step, but after 2001 Jan it appeared more tapered and quite ill-defined (Figure 13A). Through the apparition, methane and I-band images increasingly suggested that the disturbance was focusing into a dark band in EZ(S) at ~4–7°S; and as the f. end of the main complex tapered into this band it became less distinct. The last images from IRTF on 2001 April 19 and 26 show the f. end breaking up into rather tattered remnants (Figure 13B).

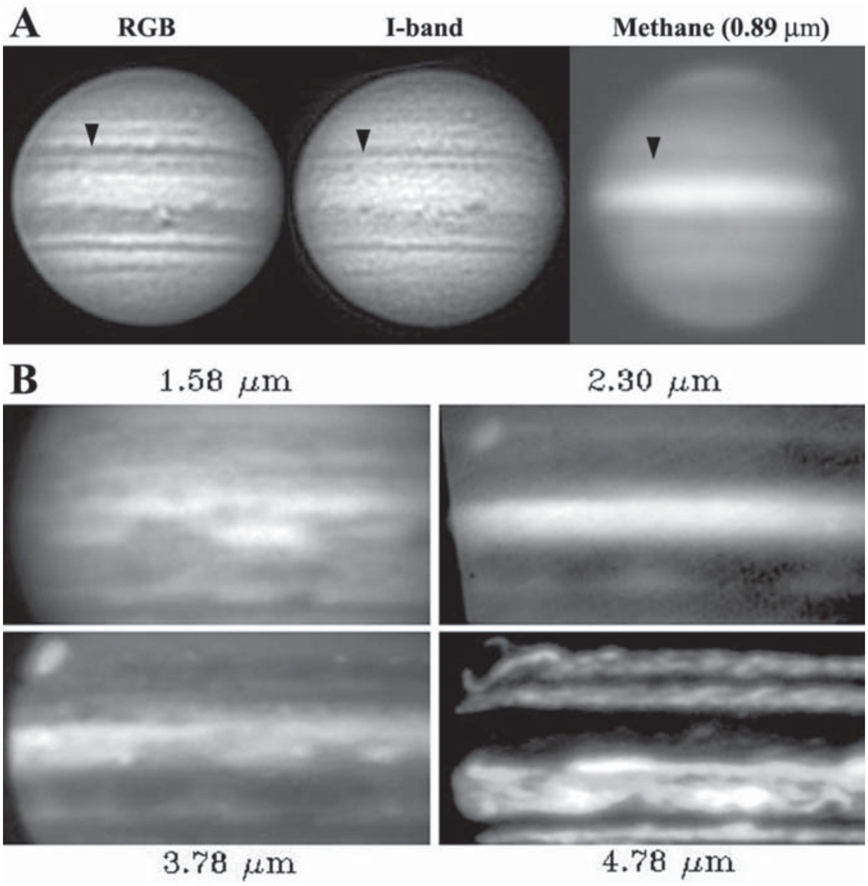


Figure 13. Decline of the main complex in 2001 March–April. **(A)** March 19 (Cidadão): *(left)* RGB, 19h31m UT, CM1=177, CM2=11; *(middle)* I-band, 19h37m UT; *(right)* methane (0.89µm), 19h46m UT. The main complex is on the p. side, now faint in all wavebands.

(B) April 26 (IRTF): set taken around 04h51m UT, CM3=150. The main complex occupies the left half of each frame, and still shows prominent dark streaks in IR wavebands, but its extent is no longer well defined. The GRS is on the p. limb.

Discussion: Cloud structure

These multispectral maps of the SED are summarised in Figure 9. They can be interpreted in terms of the general model of jovian cloud layers (Paper II). Normally, the SEB has a brown high-tropospheric haze, and thin or absent clouds at the visible and 1–2 bar levels; while the EZ has methane-reflective stratospheric and white high-tropospheric hazes, and thick clouds at the visible and 1–2 bar levels. Evidently the usual cloud layers of the SEB and EZ were greatly disrupted within the SED.

It can be seen that the main complex consisted of several sectors radiating away from the focal point where the rift broke through the SEB(N), as numbered in Figure 9. These sectors had very different and anomalous ar-

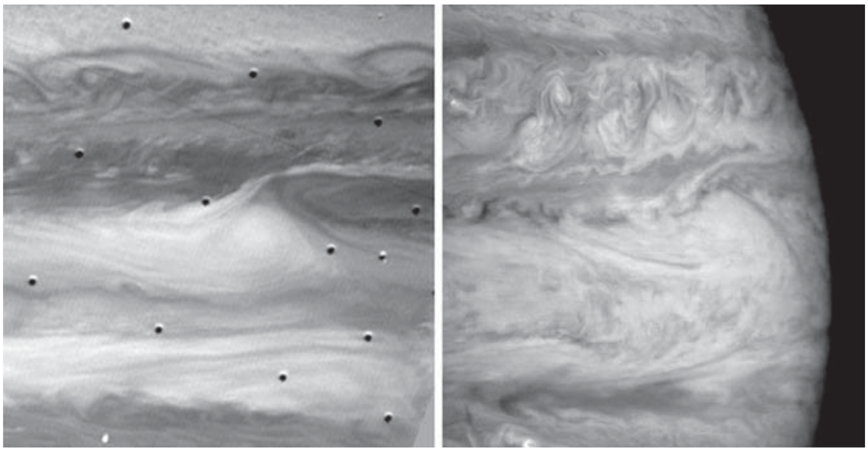


Figure 12. Comparison of the great white spot imaged by *Voyager* with the SED main complex imaged by *Cassini*, showing very similar flow lines. The images span from STropZ at top to NEB at bottom.

(Left): Voyager 1, 1979 Feb 18, green image (image 15925.46, from the NASA PDS web site; credit NASA/JPL and *Voyager* imaging team led by Dr Bradford Smith).

(Right): Cassini, 2000 Dec 31, near f. limb, red image (from the false-colour image;[5] credit NASA/JPL, University of Arizona, and *Cassini* imaging team led by Dr Carolyn Porco).[7]

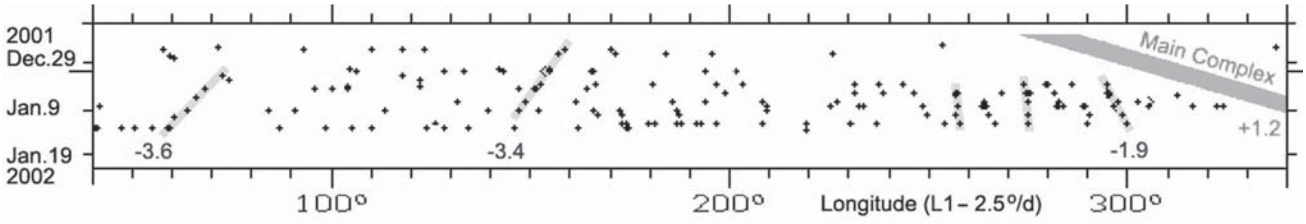


Figure 14. JUPOS chart of SEBn in 2002 Jan, showing drifts of small dark spots which range up to the peak speed of the jet. Longitude is given in System I minus 2.5°/day. Drifts for the better-defined spots are given in °/day in System I, ranging from +1.2°/day for the main complex (shown schematically; see Figure 4; equivalent to +90 m/s in System III) to –3.8°/day for the furthest p. spot (equivalent to +164 m/s in System III).

rangements of cloud layers. Let us describe them in the order that they would be encountered by a parcel of air following the circulatory path implied by the *Cassini* images. Air flows from the SEB through the narrow rift (1), emerging at its mouth (2) with bright visible clouds but little methane-reflecting upper haze. As the air circulates anticyclonically in the EZ(S), residual upper haze is stripped away (in contrast to anticyclonic circulations at higher latitudes which have enhanced upper haze). In this circulation, visible clouds come and go, while deeper (5μm-absorbing) clouds are thick, being the main cloud layer in the blue patch (3). Thus the blue patch has a very anomalous cloud structure (almost the opposite of the NEBs hotspots). The adjacent SEB(N) (4) has only a thin layer of haze or visible cloud, and no detectable deeper clouds (thus resembling the NEBs hotspots).

Preceding the main complex, in the stormy sector, there are belt-like patches (6), including small-scale bluish streaks which have their cloud layers disrupted at all levels, and larger bluish patches which retain a deep cloud layer like the one in the main complex. These alternate with zone-like regions (7), but these too are anomalously clear of high-altitude haze.

Comparison of the different cloud levels may help to answer the important question of where the driving force of the SED comes from. The most extensive disruption was in the high-altitude haze layers; however this developed late, changed only slowly (on a timescale of many months), and was very diffuse; so it was probably a consequence of the disruption at deeper levels. It may have been caused by ascending waves similar to those seen over the NEB (Paper II). The next level down includes the main visible cloud-tops (and probably the clouds sensed in I-band and at 1.6 and 3.8μm), and this showed extensive disruption – more so than the deeper clouds where 4.8μm radiation is absorbed. As the I-band level was also where coherent circulation could be seen,[9] this would be consistent with the driving force operating mainly at the visible and I-band level, rather than deeper down. There is evidence pointing in the same direction for other major disturbances, viz. the South Tropical Disturbance (pp.212–213 and 261–262 of ref.11) and the North Equatorial Belt broadening event (Paper II). While much more analysis will be needed to give a conclusive answer, there is a clear possibility that what we see – the cloud layers which absorb sunlight and which undergo most of the jovian weather – is in fact the most important level for large-scale disturbances.

Relation to other disturbances on SEBn and NEBs

In summary, the SED was a long-lived focal disturbance affecting a range of levels in the atmosphere, comprising a great solitary wave in the South Equatorial jet. It moved much more slowly than the jet, but it generated disturbances which accelerated towards the speed of the jet.

Major disturbances in this latitude are not common, and the SED appeared historically unique in the extensive dark (bluish) disturbance associated with it at its maximum development, both in the main complex and p. it in the EZ(S).

However the SED main complex showed clear similarities with 'great white spots' seen in the same latitude around 1879 and 1979 (pp.154–157 of ref.11). The former, tracked from 1879 to 1885, did have some dark material just p. and f. the great white spot. Moreover, W. F. Denning and A. S. Williams thought that dark patches were repeatedly erupting from a source ~35° f. the white spot, streaming towards it with DL1~ –1.9°/day, and tending to obscure it as they crossed it (pp.154–157 of ref.11; see Figure 9.21 therein).

The 1979 disturbance was tracked by amateur observers from 1976 to 1989 and was viewed in detail by *Voyager* (Figure 12).[11,12] It consisted principally of a white spot in EZ(S), of varying intensity, with a rift structure very similar to that of the present SED. *Voyager* images revealed anticyclonic circulation in it,[13] just like the circulation revealed by *Cassini* images in the present Disturbance. It also resembled the present Disturbance in that the bright spot at its mouth sometimes became much more conspicuous as it passed the GRS. By analogy with those *Voyager* observations, it is possible that the cyclonic turbulence f. the GRS fed energy through the rift into the SED.

The 1979 disturbance also had very anomalous structure in the infrared, but apparently different from that in 2000; the white spot was warm at 5 microns [refs.12,14, & references therein]. It would be worth revisiting the 1979 data to define more precisely the similarities and differences relative to the 2000 SED.

The SED also has similarities to the familiar dark bluish 'projections' on the NEBs edge (Figure 10). They are of course much more common and numerous, typically being ~30° apart on the NEBs. Was the SED a solitary example of the same type of wave? If so, can it help us understand the NEBs projections (5-micron hotspots)?

The SED and NEBs projections do seem to be analogous in major respects: the visible pattern; the wave structure drifting near System I speed in a much faster jet; and the anticyclonic circulation.[15] The rift and blue patch of the SED may be homologous with the p. end and festoon of a NEBs projection (Figure 10), which are all dark at 4.8µm. For homology to the NEBs dark projections, which are always very bright at 4.8µm (5-micron hotspots), we would nominate the SEB(N) f. the main rift of the SED; the main difference is that this component does not protrude into the EZ, unlike the NEBs projections/hotspots.

An elegant model is now being developed for the dynamics of the NEBs projections/hotspots.[16,17] It will be interesting to see whether the same model can account for the solitary wave of the SED. Analysis of the dynamics of the South Equatorial Disturbance, in its splendid isolation, may give insight into the much more numerous wave disturbances that are familiar in the North Equatorial jet.

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Postscript: Appearance in 2001/2002

The main complex of the SED remained intermittently detectable in both visible and methane bands at least up to 2002 April, although it was inconspicuous. It continued to move at DL1~ +1.3°/day. In visible light, it was simply a discontinuity between sectors of SEB(N); in methane bands, it still showed a dark EZ(S) on the p. side, but this was now a band separate from the methane-dark SEB and had a tapered f. end, so it was less distinct than before. Elsewhere the EZ(S) was devoid of major features. However in early 2002, some very small projections from SEBn were tracked and they showed a range of speeds, faster with increasing distance p. the SED, and the furthest p. of them actually moved at DL1= –3.8°/day (Figure 14), representing the first ground-based detection of the full speed of the South Equatorial jetstream.

References

1 Rogers J. H., Mettig H.–J., Peach D. & Foulkes M., 'Jupiter in 2000/2001, Part I: Visible wavelengths', *J. Brit. Astron. Assoc.*, **114**(4), 193–214 (2004)
2 Rogers J. H., Akutsu T. & Orton G. S., 'Jupiter in 2000/2001, Part II: Infrared and ultraviolet wavelengths', *ibid.*, **114**(6), 313–330 (2004)
3 Rogers J. H., Mettig H.–J., Peach D. & Foulkes M., 'Jupiter in 1999/2000, Part I: Visible wavelengths', *ibid.,* **113**(1), 10–31 (2003)
4 Rogers J. H., Foulkes M., Mettig H.–J. & Peach D., 'Jupiter in 1999/2000: Activity old and new', (Interim report), *ibid.,* **110**(4), 174–177 (2000)
5 Rogers J. H., '*Cassini* and *Galileo* view Jupiter in stereo', *ibid.*, **111**(2), 59–60 & cover pictures (2001)
6 Rogers J. H., 'Jupiter in 2000/2001' (Interim report), *ibid,* **112**(1), 2, 8, 9 (2002)
7 *Cassini* mission website: http://saturn.jpl.nasa.gov/ and *Cassini* imaging science team web site: http://ciclops.lpl.arizona.edu/
8 Porco C. C. *et 23 al.*, '*Cassini* imaging of Jupiter's atmosphere, satellites and rings', *Science* **299**, 1541–1547 & online supplement (2003)
9 *Cassini* movies compiled by Dr A. Vasavada, NASA-JPL, shown at Jupiter conference, Boulder, 2001
10 Rogers J. H., 'Jupiter in 1999/2000, Part II: Infrared wavelengths', *J. Brit. Astron. Assoc.,* **113**(3), 136–140 (2003)
11 Rogers J. H., *The Giant Planet Jupiter*, Cambridge University Press, 1995
12 Sanchez–Lavega A. & Rodrigo R., 'Ground-based observations of synoptic cloud systems in southern equatorial to temperate latitudes of Jupiter from 1975 to 1983', *Astronomy & Astrophysics* **148**, 67–78 (1985)
13 Beebe R. F., Orton G. S. & West R. A., 'Time-variable nature of the jovian cloud properties and thermal structure: an observational perspective', in *Time-Variable Phenomena in the Jovian System,* NASA SP-494 (Belton M. J. S., West R. A. & Rahe J., *eds.*), 245–288. (NASA, Washington DC, 1989)
14 Bézard B., Baluteau J. P. & Marten A., 'Study of the deep cloud structure in the equatorial region of Jupiter from *Voyager* infrared and visible data', *Icarus* **54**, 434–455 (1983)
15 Vasavada A. *et al.*, '*Galileo* imaging of Jupiter's atmosphere', *Icarus* **135**, 265–275 (1998)
16 Showman A. P. & Dowling T. E., 'Nonlinear simulations of Jupiter's 5-micron hot spots', *Science* **289**, 1737–1740 (2000)
17 Rogers J. H., News note: '*Cassini* and *Galileo* reveal secrets of Jupiter's dark patches', *J. Brit. Astron. Assoc.,* **111**(5), 245 (2001)

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