Jupiter's South Temperate domain: Evolution 1991-1999 and dynamics of cyclonic structured sectors as seen in Hubble maps

--**John H. Rogers** (BAA)

Summary

We have recently published detailed reports on the long-term behaviour of the South Temperate domain from 2000 onwards, based on amateur images. Here we supplement these reports by study of Hubble and other professional images, from 1991-1999 and in recent years, to gain more insight into the cyclonic features which have not been fully resolved from the ground.

I. In 1993, after several years when the South Temperate Belt (STB) was absent, its dramatic revival was largely due to the appearance of a new long dark turbulent sector, whose appearance fulfilled the usual requirement for several structured sectors spaced around the domain. In this year, exceptionally, darkening and turbulence spread all around the domain. The form of the new sector was consistent with the structure of dark STB segments established more recently.

II. In 1994, Hubble maps showed that the revived dark STB consisted of a series of contiguous cyclonic disturbances, collectively much longer than a typical structured segment. The following element of the series was the new structured sector of 1992-93, and it had a near-constant rapid drift such that the whole dark STB contracted steadily over the next 5 years, converging on the slower-moving group of great anticyclonic white ovals. By 1998, there was just one sector of cyclonic disturbance left, and the leading pair of great ovals merged, and new cyclonic features developed tens of degrees preceding the merged oval to generate the next structured sector. So this whole process appeared to be driven by the new dark sector of 1992-93, which behaved just like structured sectors post-1998.

Zonal wind profiles from these years confirm the same pattern that we have found in later years, that the jet peaks at 29.5ºS and 32.5ºS are strong alongside dark and turbulent STB segments, and weak or absent in quiescent sectors.

III. In more recent years, Hubble images of the pale cyclonic sectors ('STB Remnant', 'Ghost', and 'Spectre') confirm that they have cyclonic circulation, and in 2016, also confirm anticyclonic circulation south of the newest one.

Introduction

The South Temperate domain always comprises from two to four structured sectors, i.e. large-scale structures such as cyclonic belt segments and anticyclonic white ovals (AWOs), usually separated by more quiescent sectors [refs.1,2]. But its overall pattern has changed radically over many decades, largely in connection with the evolution of the great AWOs. The history from the 1940s up to 1990, when there were three great AWOs gradually shrinking, has been described [ref.1]. The history from 2000 to 2015, since the three great AWOs merged into a single one, has also been described in detail; during these years, the remaining AWO has defined one structured sector, and successive cyclonic sectors have developed elsewhere and prograded until they collide with it [refs.2-4]. However, the history in the 1990s has not been fully examined until now.

This omission is mainly due to the limitations of ground-based resolution in the 1990s. Our data up to 1998 still consisted largely of visual transits and photographic prints. From 1998

onwards, the data quality improved as the planet moved to northerly declination, and more CCD images were obtained, and the JUPOS project began measuring images.
We completed reports on each of these apparitions, published in the Journal of the BAA [refs.5 & 8-12] except for those of 1993 and 1994, which are complete but still not finalised for publication [refs.6 & 7]. (Our maps from1995-2000 were published in [ref.2, Fig.1].) These reports tracked the 3 great AWOs over the whole decade until they merged, as well as several minor AWOs and cyclonic ovals for 1-3 years each. But in addition, there were long STB segments whose boundaries and latitude shifts were often indistinct. From more recent years, we know that cyclonic segments are important structural features of the domain, but may be of low contrast visually – unresolvable in the conditions of the 1990s. We also know that a dark STB segment generates dark, slow-moving spots and streaks at its south-following end ('Sf. tail'); but in the 1990s, the latitude difference may have been difficult to resolve. So it has not been clear whether there was a systematic pattern of 2-4 structured sectors in the 1990s comparable to those before and after.

The known history of the decade can be summarised as follows. In the years up to 1989, most of the visible dark STB had disappeared, so that from 1989-1992 the STB was nothing more than a very tenuous STB(N), except for short dark ovals or streaks f. the AWOs. Meanwhile, the three AWOs, shrinking, had drifted closer together: by 1990, two of them (BC and DE) were a stable pair 18º apart, with the third (FA) ~110º f. them. In 1993, there was a dramatic revival of the dark STB at almost all longitudes. Over the next few years, all these features progressively rearranged. Oval FA converged on ovals BC and DE, and a smaller AWO appeared between them, until they formed a tightly-spaced chain alternating with several cyclonic ovals. Meanwhile the long dark STB segments evolved into a single STB segment f. the chain of ovals, shortening. Then in early 1998, ovals BC and DE merged, and in early 2000, the resulting oval merged with FA in turn, producing oval BA as the only remaining large AWO, with a short dark STB segment f. it. Meanwhile, starting ~80º p. BA, three very dark spots appeared in 1997-1998, which were the precursors of the next dark STB segment.

We can now revisit these years with the insights gained from more recent studies, to see whether these events can be understood better. First I describe the 'STB Revival' in 1993, from our unpublished report and from published professional images. Then I investigate the evolution from 1994 to 1999, combining our published BAA data with v-hi-res maps from the Hubble Space Telescope (HST). Finally I show how more recent HST images confirm the cyclonic circulation that we had inferred in low-contrast structured segments in 2009, 2015 and 2016.

I. The 'STB Revival' in 1993

In 1991-92 [ref.5], up to 1992 July, the STB was almost invisible, except for a dark segment (21º long) f. oval FA. The three great ovals still existed: oval FA fairly conspicuous with a dark rim; but BC and DE (only 16º apart) were small and rimless and hard to make out. A dark spot appeared between them quite suddenly in 1992 June.

Miyazaki's photographs did show two small faint oblique streaks across the STZ (at L2 ~355 and 65 on Feb.27), and in retrospect, the second of these may have been the nucleus which expanded so dramatically in the following apparition.

The dramatic revival of the STB in 1993 is described here from our report [refs.6 & 13]; sketch-maps from the best photographs are in **Fig.1**. Further details are added from some published hi-res images taken from the Pic du Midi or elsewhere in 1993 April-June [ref.14].

When the apparition began in 1992 Dec. there were already three conspicuous dark segments: (1) the pre-existing short one f. BA; (2) a new one remote from the others, already very dark and tapered to the Sf. end, ~30º long; and (3) another one f. BC and DE.

No.(2) was 33º long in Feb., then it lengthened rapidly as sectors p. and f. it turned dark, until it covered ~90º altogether in April-May, and merged with the dark segment (1) f. FA. However much of this length consisted of extensions f. in the STZ (a Sf. tail, as new dark spots appeared in the STZ and became embedded in more continuous dark material), and p. forming a STB(N) (suggesting STBn jet activity). A hi-res IR image on April 8 [ref.14] showed that both the STB segment and the STB(N) p. it were conspicuously spotty, suggesting that the segment was turbulent and the STBn jet was active; the spotty STB(N) was longer on June 4 & 15.

No.(3) was alongside the GRS in March-May, and changeable; f. the GRS it formed a Sf. tail, trending southwards to a variable f. end, which merged with dark SSTB flanking oval FA. Thus the whole sector between DE and FA filled up with dark streaks and spots, and in June, dark spots were tracked along it in the STBn jet [refs.6 & 14], probably recirculated from the SEB Revival around the GRS and the STrD p. end ('C1'); while the STB(N) was diffusely darkening p. BC.

Although the 3 sectors showed short-term variations in extent and intensity, overall they lengthened rapidly until by June they almost encircled the planet. Only a short sector p. oval BC remained white, and even this began to turn dusky in July. (Also in late July, a new white oval appeared immediately f. DE; was this cyclonic, or the first appearance of AWO-XY?)

Several interesting conclusions can be drawn from this account.

(i) The revival of the STB seemed to occur by sectors turning dark, not by any violent disturbance nor large-scale circulation patterns.

(ii) It was centred on 3 long sectors with roughly equal spacing; but the main structural change was the appearance of one new long dark segment. As we show below, this was probably derived from a small faint streak recorded by Miyazaki in 1992, ~140º f. FA and ~100º p. BC. So this fits perfectly into the general pattern that a new structured sector develops to fill a gap, always maintaining 2-4 structured sectors around the circumference.

(iii) The new segment seems to have behaved like more recent dark segments, turbulent and generating spots in the STZ Sf. it and on the STBn jet p. it. It was revealed in 1994 by HST to be a turbulent cyclonic sector (see below).

(iv) All this activity had begun by 1992 Dec., when the SEB was faded. In early 1993 there was a S.Tropical Disturbance – ~75º long, though faint – which must have altered the zonal winds across the STropZ [refs.6 & 14]; and there may have been some activity on the STBn jet by early April. There have been other occasions when S. Trop. Disturbances or STBn jet activity arose during SEB Fades [ref.1 & paper in preparation], and I suspect the SEB Fade entails an increased tendency for recirculation in the STropZ. If so, these phenomena may have contributed to triggering the rapid, widespread darkening of the STB. However, I suspect that the complete absence of visible STB up to 1992 was itself an unstable state. All this was before the SEB Revival began on 1993 April 6 [ref.13], although during the SEB Revival, darkening of one STB sector was reinforced by the circulating current.

II. Evolution of the S. Temperate domain from 1994-1998

After the 'STB Revival' in 1993, there was extensive dark STB, and a STBn jet outbreak observed in 1994. During 1995, oval FA converged on ovals BC and DE until by 1995 Oct. there was a regular array of AWOs (BC – DE – XY – FA, where XY was a smaller one of more recent origin), alternating with cyclonic ovals of various colours. (One of these, tracked over several years, was called the 'morphing spot' because of its remarkable changes in colour [ref.8

& Appendix to ref.2]; it is now recognised as an example of a very dark cyclonic oval which turned red before turning white.) This array of ovals was stable in 1996 but convergence continued as XY disappeared in 1997, then, dramatically, BC and DE merged in early 1998, and the resulting oval in turn merged with FA in early 2000 March. The convergence and mergers of these ovals have been extensively described from ground-based, Hubble, and Galileo data [refs. 11, 12, 15-22], and will not be covered in this report.

But what happened at other longitudes of the S. Temperate domain during these years? This can be investigated by integrating our BAA reports with maps from HST, which were made during the Comet Crash in 1994 [ref.23], then once or twice per year in 1995-1997, and for a short sector in 1998 [refs.24, & 25]. Dr Amy Simon has kindly provided full-size versions of these maps for 1994-1996 [ref.24], and I also examine those published [ref.25] for 1997 and 1998. The maps for the S. Temperate domain are shown in **Fig.2**, and a summary chart in **Fig.3**.

These maps and charts clearly reveal how the domain evolved during these years. The behaviour was strikingly simple, and dynamically consistent with that in more recent years, despite differences in visible appearance.

Just one new structured sector had appeared in 1993 (probably originating in 1992), completing a trio of structured sectors, as described above. In 1994 the new dark sector was revealed by HST as a turbulent cyclonic sector ('folded filamentary region', FFR), and additional FFRs had developed to fill the space between this and oval FA p. it. There was also a dark 'Sf. tail' in the STZ, as usual f. turbulent STB sectors. Thus the HST maps show that in 1994, a year after the STB Revival, the long dark STB spanning ~180º actually consisted of three successive FFRs, separated by oblique bands with small AWOs adjacent, plus the dark 'Sf. tail' in the STZ. (There was also a fourth FFR p. oval BC, to be discussed below.)

Although the FFRs could not be resolved in ground-based data, the small AWOs could, and BAA tracking confirms that two of them persisted from 1994 to late 1995, probably the same two recorded by HST in late 1996, only one of which remained in 1997. These small AWOs continued to separate the three FFRs. These FFRs were drifting faster than the great AWOs and gradually caught up with them and merged, until by 1998 Sep. there was just a single dark STB segment 40º long f. FA.

The f. end of the STB proper was recognised and tracked by the BAA in only some of these years, but was consistent with the f. end of the last FFR in the HST maps: it turns out to have been a single f. end with almost constant drift from 1993 to 2000. Indeed, the first of the f. ends in 1993 may have been derived from the faint streak recorded in 1992 with approximately the same speed, DL2 = -15 deg/mth. In 1993 the new dark sector developed multiple f. ends, and either the first or second of them (on tracks 20º apart) could connect with the subsequent track. The data are consistent with a constant drift of DL2 = -15.5 (±0.5) deg/mth from 1994-1996, and probably 1993-1996. This same f. end moved slightly slower in 1996 (-13.4 deg/mth: ref.9), then had a constant drift of -14.5 (±0.1) deg/mth from 1996 to 2000.

F. this definitive f. end, the Sf. tail was always present, though spotty and variable. The HST maps show that in 1994 its f. end elongated so as to remain fixed alongside the GRS in 1994 (as we have noted in more recent years: ref.2). Occasional slow-moving features tracked by the BAA can now be identified as features of this Sf. tail: in 1993, a dark spot in the STZ, DL2 = -7.5; in 1995, three dark spots with DL2 = -7; in 1997, a STB f. end with DL2 ~ -11; and a southerly dark spot in late 1999, DL2 = -1.6.

This behaviour fits in well with the behaviour of dark STB segments since 2000: always drifting faster than the great AWO and being blocked from passing it; and always emitting a Sf. tail of slow-moving spots. The distinctive aspect in 1994-1997 was that, instead of 2-4 widely separated structured sectors, all the activity was located in one very long sector. Moreover, our evidence since 2000 has suggested that a dark turbulent STB segment f. the great AWO exerts an eastward force on it [ref.2]. Likewise in 1993-1999, the same model would suggest that it was the turbulent STB sectors that pushed oval FA eastwards to form a stable array with ovals BC and DE, and ultimately pushed these great ovals into merging with each other.

Meanwhile ovals BC and DE had a mean drift of DL2 = -12.8 (±0.05) deg/mth from early 1991 to mid 1995. (The BAA records indicate slower drifts during apparitions than between them, up to the end of 1994; this may be due to the effect of phase on visual and photographic measurements, which are subject to an extra +0.6 deg/mth on average during an apparition [ref.1]; but there may have been a real shift to lower longitude between 1993 and 1994, although it must have happened after 1993 July and thus many months after the onset of the STB and SEB Revivals.) After the ovals all assembled into a chain in 1995, oval BC decelerated; its mean drift was -11.7 (±0.1) deg/mth from early 1996 to late 1997.

There was also a fourth FFR, p. oval BC, in a location where no such disturbance has been seen since 2000. In 1994 it appeared to be generating a substantial outbreak of STBn jet spots p. it. These jet spots appeared to originate from a region of cyclonic disturbance ~20º p, oval BC and prograded at DL2 ~-75 to -105 deg/mth [ref.7]. Indeed, Don Parker's images on 1994 March 20 showed the FFR here. The FFR persisted (still emitting jet spots) until 1997, but after the mergers of AWOs it was no longer seen on their p. side. It may have drifted away in the p. direction as DS2 (STB segment B). Signs of eddying in the STZ tens of degrees p. oval BC were already visible as early as 1995, and eventually gave rise to DS1 (p. DS2). (Since 2000, in this sector there has been no FFR, but cyclonic spots have repeatedly arisen there, and since 2011 there is evidence for a more permanent site of eddying tens of degrees p. oval BA [refs.3 & 4, & see below].)

Zonal wind profile (ZWP):

In our previous long-term reports, for 2000-2015, we showed that one of the twin peaks of the STBn prograde jet, at 29.5ºS, is faster alongside STB structured sectors than in undisturbed sectors [ref.2 & 3]. (The other peak of the STBn jet, at 26-27ºS, is less variable.) In some data sets the STBs retrograde jet is also faster alongside structured sectors [ref.2].

We can enquire whether a similar pattern obtained in the 1990s by reference to maps and ZWPs from HST published in [ref.25]. One example was presented in [ref.25: their Fig.2 panel 4], and clearly showed the same phenomenon that we described since 2000. The STBn sub-peak at 29.5ºS and the STBs jet peak at 32.5ºS were much faster alongside a dark turbulent sector of STB (two FFRs) on 1997 June 25 than alongside a pale undisturbed sector on 1995 Oct.5.

For a more comprehensive view, **Fig.4** shows all 4 ZWPs which they obtained for the southern hemisphere on 4 different dates, and maps of the approximate sectors from which they were generated (from longitude information kindly given by Enrique Garcia-Melendo). It turns out that the ZWP of 1997 June 25 was the only one to show strong jet peaks at 29.5ºS and 32.5ºS, and the only one to cover a long disturbed cyclonic sector. The other 3 ZWPs all had a single STBn peak at 26-27ºS, and a very weak STBs peak (~-5 to -10 m/s) at 32.5ºS: these were either in long undisturbed sectors (1995 Oct.5, 1996 Oct.21), or in a complex region containing two great AWOs and various smaller circulations, which likely interrupted the pattern of jets (1998 July 16).

These data are fully consistent with our post-2000 conclusions, that the jet peaks at 29.5ºS and 32.5ºS are strong alongside dark and turbulent STB segments, and weak or absent in quiescent sectors.

II. Circulation in and around the STB Remnant/Ghost/Spectre: HST pairs in 2009 Sep. 2015 Jan., 2016 Feb.

Since 2003, some STB structured segments are not dark and turbulent, but are pale oblique loops which appear to be cyclonic circulations: segments C (the STB Remnant), E (STB Ghost), and F (DS5, --> STB Spectre?). But ground-based images are not sufficient to demonstrate their circulation. Here we show these 3 features in pairs of HST images or maps taken ~10 hours apart on 2009 Sep.18-19, 2015 Jan.19, and 2016 Feb.9-10 **(Fig.5a&b).** By 'blinking' the images, one can see evidence for the expected cyclonic circulation, clockwise around the pale blue loop, in each case.

In addition, we have repeatedly observed anticyclonic hemi-circulation of small spots due south of these structures, from the SSTBn jet to the STBs jet. However, this is not evident in the general flow of the jets in the first two image pairs; this may indicate that the structure is a barrier to discrete spots but not to the background wind flow. However, in the second image pair there is an oblique streak marking an albedo boundary which appears to mark the path of recirculation, and in the third pair, anticyclonic motion can be seen at this point. These images are therefore consistent with previous inferences from ground-based observations.

References

1. Rogers JH (1995). *The Giant Planet Jupiter*. Cambridge Univ. Press.
2. Rogers J, Adamoli G, Hahn G, Jacquesson M, Vedovato M, & Mettig H-J (2013). 'Jupiter's South Temperate domain: Behaviour of long-lived features and jets, 2001-2012.' http://www.britastro.org/jupiter/stemp2013.htm
3. Rogers JH (2015) 'Jupiter's South Temperate Domain, 2012-2015'. http://www.britastro.org/jupiter/2014_15report08.htm
4. Rogers J (2016), Jupiter in 2015-16: Interim report no.3. https://britastro.org/node/7181

Our final reports, 1992-1999:

5. Rogers JH & Foulkes M (1994), JBAA 104 (no.4), 167-178. Jupiter in 1991/92.
6. Rogers JH & Foulkes M (in preparation). Jupiter in 1992/93.
7. Foulkes M & Rogers JH (in preparation). Jupiter in 1994.
8. Foulkes M & Rogers JH (2000 Oct.) JBAA 110 (no.5), 237-252. Jupiter in 1995.
9. Rogers JH & Foulkes M (2001 April), JBAA 111 (no.2), 67-77. Jupiter in 1996.
10. Rogers JH (2001 Aug.), JBAA 111 (no.4), 186-198. Jupiter in 1997.
11. Rogers JH & Mettig H-J (2001 Dec.), JBAA 111 (no.6), 321-332. Jupiter in 1998/99.
12. Rogers J, Mettig H-J, Peach D & Foulkes M (2003), JBAA 113 (no.1), 10-31. 'Jupiter in 1999/2000, Part I: Visible wavelengths.'

13. Rogers J (1993) JBAA 103, 157-159. 'Exciting events on Jupiter.' (Interim report, 1993)
14. Sanchez-Lavega A, Gomez JM, Lecacheux J, Colas F, Miyazaki I, Parker D & Guarro J (1996b) Icarus 121, 18-29. 'The South Equatorial Belt of Jupiter, II: The onset and development of the 1993 disturbance.'

Mergers of ovals BC-DE-FA:

15. Rogers J.H. (1999) JBAA 109 (4) 172. Notes and News: 'The last days of Jupiter's white ovals?'
16. Rogers J, Foulkes M, Mettig H-J & Peach D (2000 Aug.), JBAA 110 (4), 174-177. 'Jupiter in 1999/2000: Activity old and new.' (Interim report)
17. Simon AA, Beebe RF, Gierasch PJ, Vasavada AR, Belton MJS & The Galileo Imaging Team (1998) Icarus 135, 220-229. 'Global context of the Galileo-E6 observations of Jupiter's white ovals.'
18. Sanchez-Lavega A et 7 al. 'Interaction of jovian white ovals BC and DE in 1998 from Earth-based observations in the visual range.' Icarus 142, 116-124 (1999)
19. Sanchez-Lavega A et 12 al. 'The merger of two giant anticyclones in the atmosphere of Jupiter.' Icarus 149, 491-495 (2001)
20. Morales-Juberias R, Sanchez-Lavega A, & Dowling TE (2003) Icarus 166, 63-74. 'EPIC simulations of the merger of Jupiter's white ovals BE and FA: altitude-dependent behaviour.'
21. Youssef A & Marcus PS (2003) Icarus 162, 74-94. 'The dynamics of jovian white ovals from formation to merger.'
22. Rogers JH, Mettig H-J, Cidadão A, Sherrod PC, and Peach D (2006). 'Merging circulations on Jupiter: observed differences between cyclonic and anticyclonic mergers.' Icarus 185, 244-257. http://dx.doi.org/10.1016/j.icarus.2006.05.022

HST maps:

23. Hammel HB et 16 al. (1995) Science 267, 1288-1296. 'HST imaging of atmospheric phenomena created by the impact of comet SL9'.
24. Simon-Miller AA, Banfield D & Gierasch PJ (2001) Icarus 149, 94-106. 'An HST study of jovian chromophores.'
25. Garcia-Melendo E & Sanchez-Lavega A (2001) Icarus 152, 316-330. 'A study of the stability of jovian zonal winds from HST images: 1995-2000.'
26. Simon AA, Wong MH & Orton GS (2015). 'First results from the Hubble OPAL program: Jupiter in 2015.' Ap.J.L.

Figures

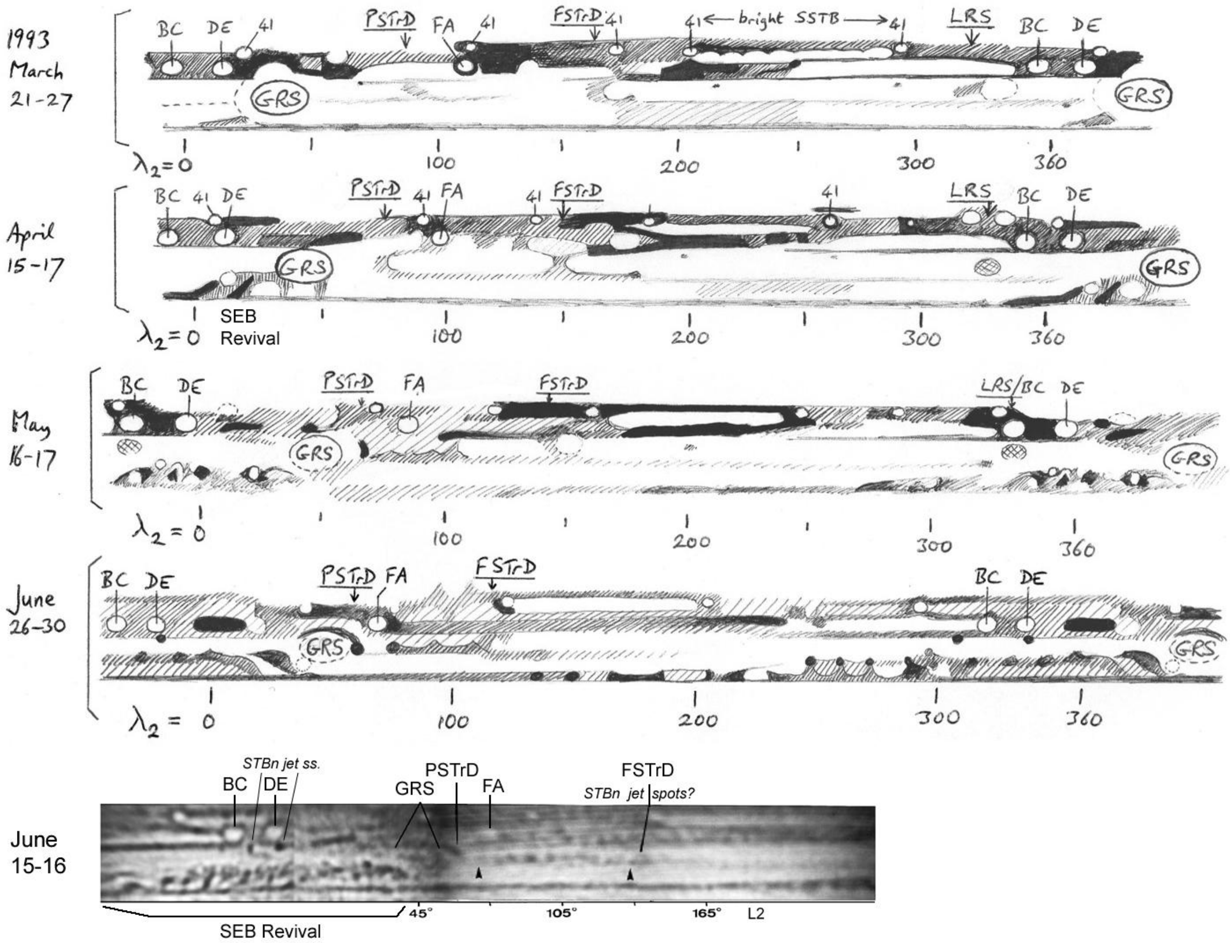

Figure 1. **(A) Maps of the S. Temperate and Tropical domains in 1993**, drawn by JHR from photographs and CCD images by Isao Miyazaki and Don Parker. AWOs BC, DE, and FA are marked, as well as the p. and f. ends of the S. Tropical Disturbance (PSTrD, FSTrD), and a Little Red Spot (LRS) in the STropZ. Small AWOs in the S2 domain at 41°S are marked (41).
(B) Map on June 15-16, adapted from maps published in [ref.14], taken with red&green (left) or red (right) filters. South is up in all maps.

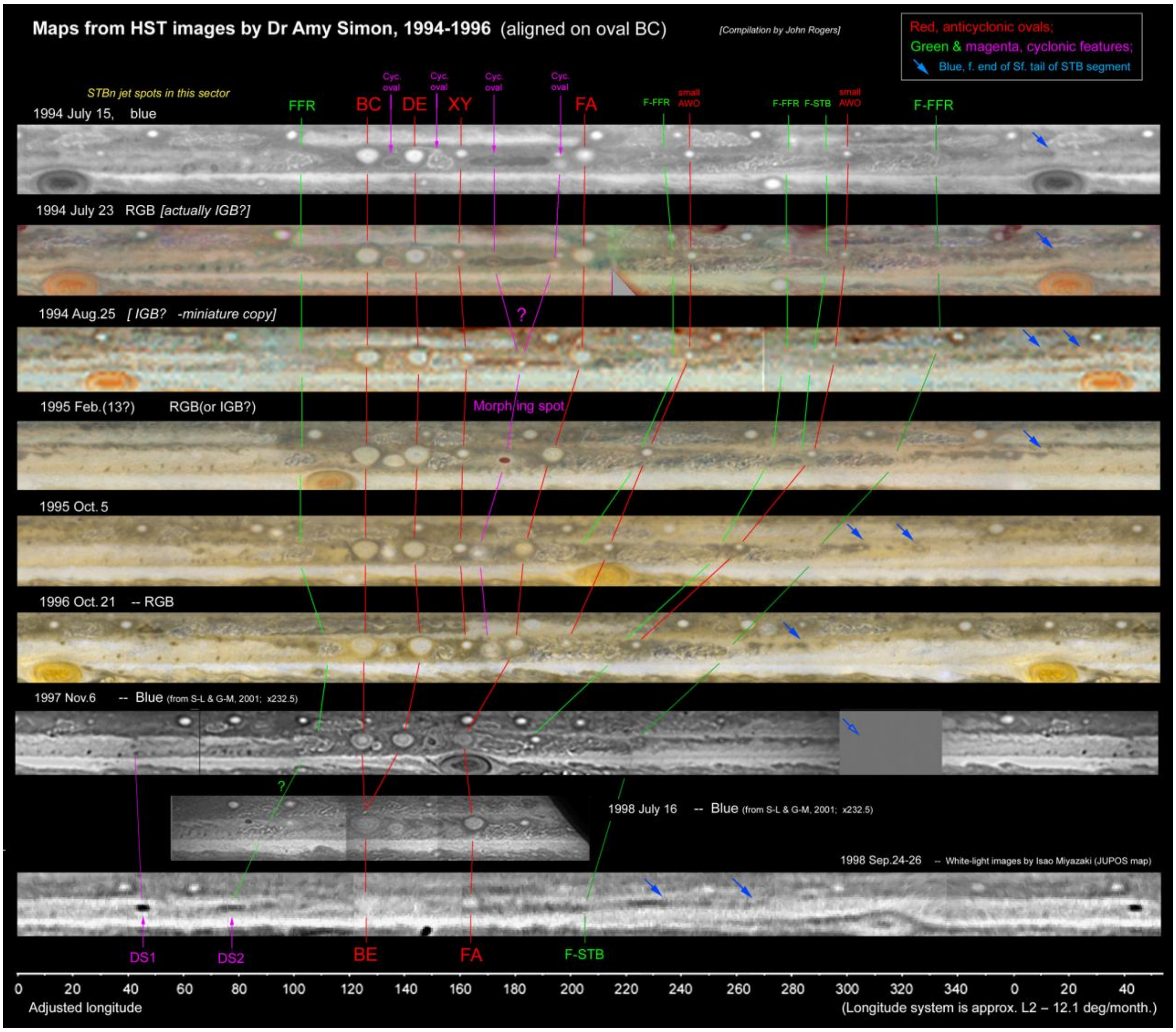

Figure 2. Maps of the S. Temperate domain from HST, 1994-1998 [refs.23-25]. Maps from 1994-1996 are by courtesy of Dr Amy Simon. (Dr Reta Beebe was principal investigator for the maps in 1995 and 1996.) Monochrome maps were in blue light; colour maps used various filters, sometimes with near-infrared instead of red, so the colours should not be taken as realistic. At bottom is a JUPOS map made by H-J. Mettig from white-light images by I. Miyazaki in 1998 [ref.11]. Identifications of features are confirmed by the chart in Fig.3. South is up in all maps.

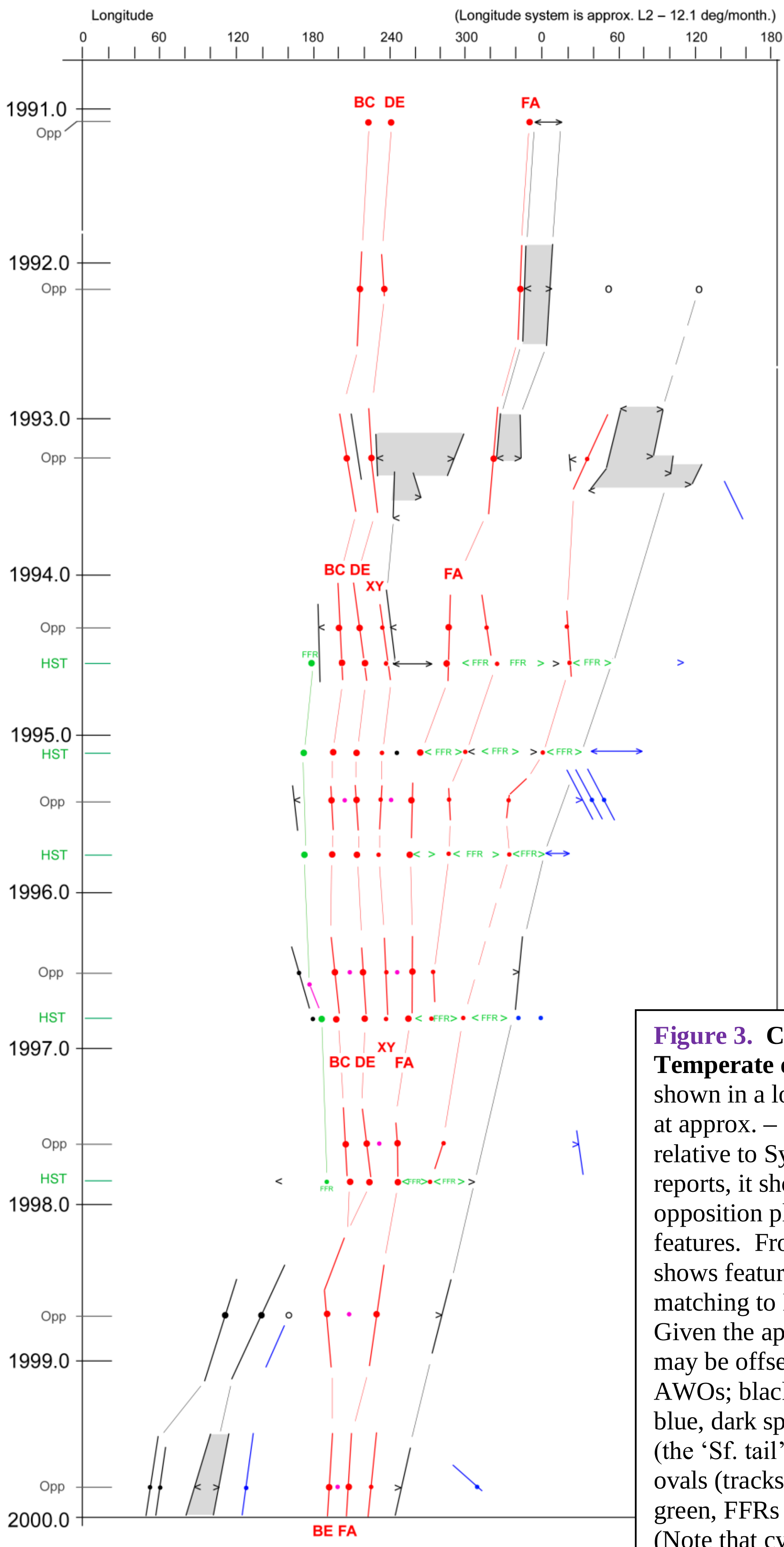

Figure 3. **Chart of features in the S. Temperate domain, 1994-1998**, shown in a longitude system moving at approx. – 12.1 deg per 30 days relative to System II. From the BAA reports, it shows longitudes at opposition plus mean drift rates of features. From the HST maps, it shows features measured after matching to L2 longitude scales. Given the approximations made, there may be offsets of a few degrees. Red, AWOs; black, dark segments of STB; blue, dark spots and f. ends of STB(S) (the 'Sf. tail'); magenta, cyclonic ovals (tracks omitted for clarity); green, FFRs (from HST maps only). (Note that cyclonic dark spots, ovals, and FFRs can interconvert.)

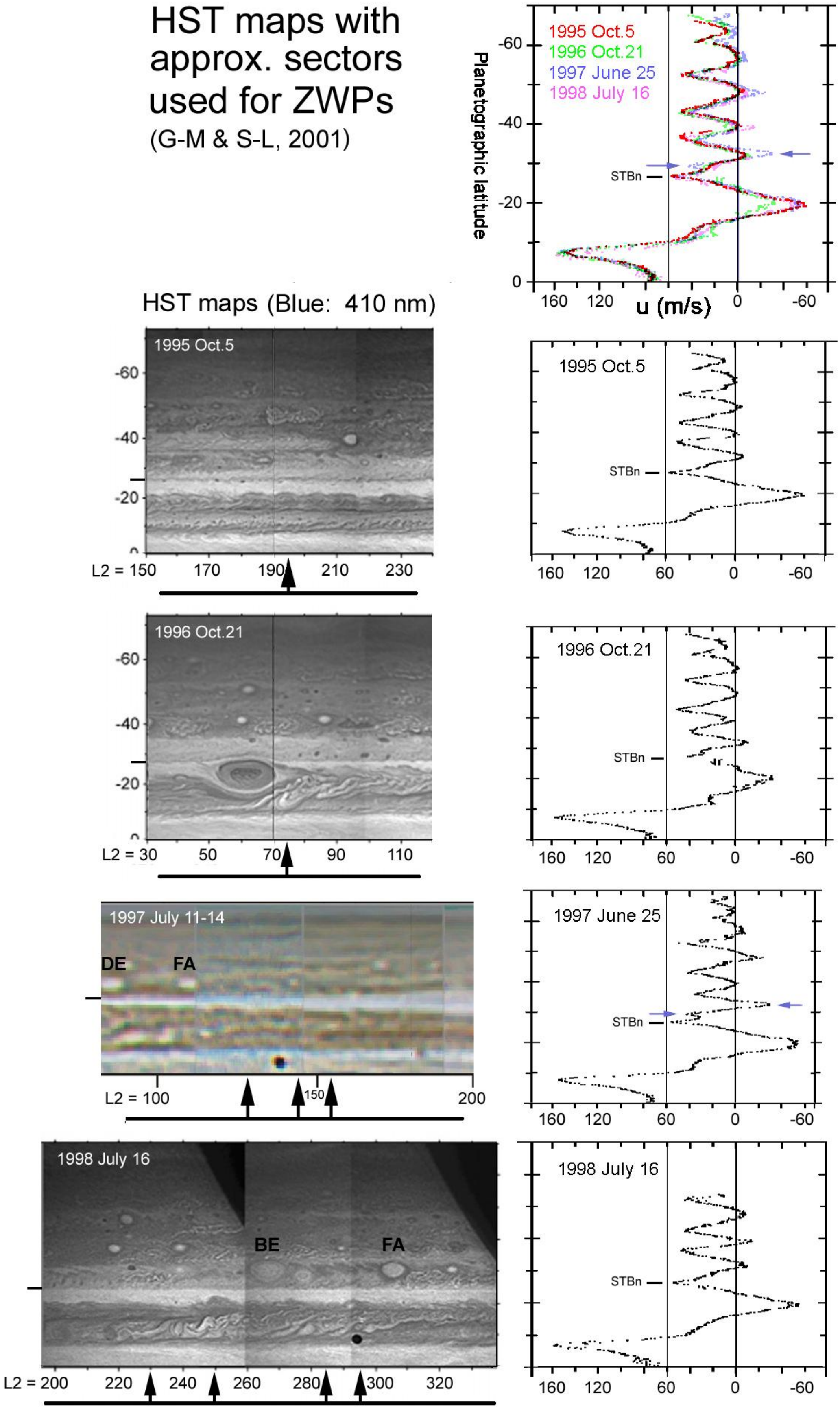

Figure 4. **Maps and zonal wind profiles (ZWPs) of the southern hemisphere from [ref.25].**
[Caption continued on next page]

[previous page:]

Figure 4. Maps and zonal wind profiles (ZWPs) of the southern hemisphere from [ref.25]. The maps are from HST, in blue light, except for 1997: the full map of 1997 June 25 was not published so we show a JUPOS/BAA map from 1997 July, made by H-J. Mettig and G. Hahn from images by I. Miyazaki [ref.10]. Arrows below the maps indicate approximate CM longitudes of HST images used for the ZWPs, in blue and near-IR light [information kindly given by E. Garcia-Melendo], so the dark bars indicate the approximate longitude span of the ZWPs. Longitudes have been converted to System II. South is up. ZWPs are shown in metres per second in System III. A bar indicates the constant STBn jet peak at 26-27°S; purple arrows indicate the enhanced jet peaks on 1997 June 25.

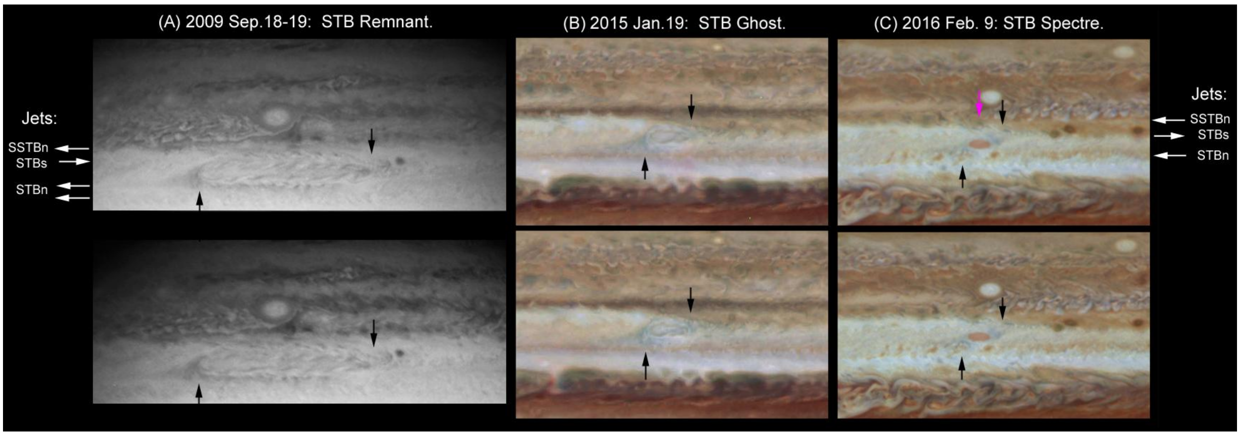

Figure 5. Pairs of HST images, ~10 hours apart, showing signs of circulation around the pale cyclonic structured sectors. These are best seen by 'blinking' the images in each pair: (a) top, (b) bottom. Arrows indicate the p. and f. ends of the structure, with the direction of circulation. South is up.
(A) 2009 Sep.18-19: STB Remnant. (Obtained to follow up the 2009 impact. Credit: M. Wong, I de Pater, C. Go, P. Marcus & X. Asay-Davis; NASA & ESA.) *Top:* Direct image, taken on Sep.18 at 15:35 UT, with the STB Remnant on the CM. *Bottom:* Image taken on Sep.19 at 02:01 UT, spherically rotated in Adobe Photoshop to put the STB Remnant on the CM. Red light, contrast enhanced. The small, very dark spot in STZ f. the Remnant was roughly stationary.
(B) 2015 Jan.19: STB Ghost. (From the OPAL project: A. Simon, M. Wong & G. Orton, NASA & ESA: https://archive.stsci.edu/prepds/opal/ .) A pair of maps, in equirectangular projection in L3, at reduced scale [published in ref.26]. Signs of cyclonic circulation are visible in the STB Ghost, but it is not clear that it interrupts the jets so as to produce anticyclonic circulation to the south, even though the oblique dark boundary suggests that there is a boundary here where recirculation has repeatedly been observed. The small dark ring in STZ f. the Ghost was roughly stationary. .
(C) 2016 Feb. 9-10: DS5, becoming STB Spectre. (From the OPAL project, as in (B). Colour maps kindly provided by Dr Amy Simon.) Dark cyclonic spot DS5 is red and fading at this time; the blue cyclonic loop around it seems likely to persist, and I propose naming it the 'STB Spectre'. Signs of cyclonic circulation are visible around the red oval, and a point of anticyclonic circulation due south of it (magenta arrow), agreeing with our observations.