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Jupiter's South Temperate Domain, 2012-2015

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1. Summary

In our long-term report on the S. Temperate domain from 2001-2012 [Ref.1], we described major phenomena which evolve or repeat on timescales of several years, and which account for the diverse appearances of this domain. Here we continue the account from 2012 to 2015, showing how our previous findings have been confirmed by subsequent developments. In this time, STB structured segment D has collided with oval BA, producing the same effects that we predicted on the basis of the two previous such collisions. These included an outbreak of spots on the STBn jet, similar to previous such outbreaks (which we review in detail here), and documented more accurately than ever before. Zonal wind profiles revealed the form of the STBn jet within the outbreak, and confirmed that the STBs and STBn jets are stronger alongside a STB structured segment. Meanwhile a new structured segment (E), called the 'STB Ghost' has arisen and developed, just like the earlier 'STB Remnant'. Recirculation occurs from the prograde SSTBn jet to the retrograde STBs jet following the STB Ghost, and in the reverse direction ~20-60º p. oval BA. These recirculations, though presently inconspicuous, may presage the development of the next generation of large white ovals.

Figure 1 presents maps of the domain from 2011 to 2015. **Figure 2** shows the jets and circulations that are present in 2015. **Figure 3** combines the JUPOS charts of the domain over this period, and the track of oval BA is shown more succinctly in **Figure 4**.
Appendix 1 is a report on this domain in 2014/15, and includes **Figures A1-A7**, which show more details of the phenomena described in the main report.

2. Oval BA.

Oval BA has retained its reddish annulus throughout these years. Excerpts from our interim reports summarise variations in its appearance:

> *Jupiter in 2012/13: Interim report no.9 (2013 Jan.):*
> Oval BA (Fig.12). This had regained quite strong orange colour at the start of the apparition, which has intensified even further since then; it is now as strongly red as anything gets on Jupiter, even more so than the GRS. ...It passed the GRS on Sep.17. It had DL2 = -12 deg/mth before then, and -10 deg/mth after.
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> *Jupiter in 2013/14: Interim report no.4 (2013 Dec.21)*
> Oval BA is still strongly orange (with a white centre), and the STB segment f. it is long and dark with internal turbulence in v-hi-res images. Oval BA accelerated greatly during solar conjunction, as predicted, and has maintained this high speed of DL2 = -14.3 deg/month....
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> *Jupiter in 2014/15: Interim report no.3 (2015 Feb.8)*
> Oval BA has some red colour though weaker than last apparition. It passed the GRS last autumn [on 2014 Oct.1], and since it did so, much dark material has accumulated chaotically in the STropZ between BA and the GRS,...

*Jupiter in 2014/15: Interim report no.8 (**Appendix 1**, below))*
Oval BA had a moderate red colour throughout the apparition, with a white core as always. It still had a narrow dark grey collar around it throughout.
The rapid speed and the dark collar of BA, as well as the continuing dark spots on the STBn jet p. it and in the STZ f. it, are all consistent with continuing microturbulence of the STB segment f. it, however small that segment is (see below).

Fig.5A is a chart of the latitudes and speeds for oval BA and for small AWOs in the STZ, i.e. the zonal drift profile (ZDP). The small AWOs follow a ZDP which coincides with the Cassini ZWP (see below). Oval BA follows a ZDP ~0.5º further north and slightly shallower, in agreement with our previous results [**Fig.5B**; Refs.1&2]. This ZDP has not changed over the interval 2011-2015, suggesting that oval BA has not been shrinking any more.
Indeed, measurements of the length of the oval show that it has not shrunk further since 2012 (**Table 1 & Fig.6**).

Small AWOs in STZ:
There is usually a small AWO or ring tens of degrees f. BA, within the 'Sf. tail' of STB segment A or at its f. end. Sometimes it initially appears as a prominent very dark spot (e.g. in 1999-2000 ('DS3') and in 2014-15), within which a tiny white core can eventually be seen. Sometimes this spot is seen to form by merger of slow-moving or retrograding dark spots in the Sf. tail, and it then intercepts subsequent spots in the same series [Ref.1]. This seems to have happened again in 2014 October (**Figs.1&3**, & figures in **Appendix 1**).

In addition to the AWO f. BA and STB segment A, there was a second small AWO f. STB segment D in 2011-12-13.
The ZDP for these small AWOs coincides with the ZWP from spacecraft (**Fig.5A**). The AWOs have followed essentially the same ZDP whether they were f. segment A or D.

3. The collision of STB structured segment D with oval BA, and its subsequent development.

This collision was the major event in the domain during these years (**Figs.1 & 3**). The background and the events have been described in the following excerpts from our interim reports. (References and figure numbers therein are those of the original reports.)

Jupiter in 2012/13: Interim reports no.9 (2013 Jan.) & no.10 (2013 March):
The only broad dark segment of STB [segment D] is 60 deg. long and, with DL2 = -18 deg/mth, is rapidly converging on the cluster of ovals f. oval BA. Its p. end is now very close to the cyclonic white oval, so interaction could start at any time. This type of collision has been observed twice before, once in 2003/04 and once in 2010, and each time, it produced a remarkable outbreak of activity [ref.7]. The expected consequences are:
-- Rapid and perhaps spectacular small-scale changes in the region (methane images may be valuable), until the long dark STB f. BA stabilises;
--Oval BA suddenly accelerates (indeed it has already done so in early December, according to the latest JUPOS chart, although that might have been due to its passage past the GRS);
--A substantial outbreak of small dark spots prograding on the STBn jetstream p. oval BA;
--Dark spots or streaks spreading in the opposite direction Sf. the merging STB complex.

F. oval BA there is an unusual pair of quite stable cyclonic ovals (Fig.12). The first, on the f. edge of oval BA, is a small, extremely dark spot with a white collar. The second, 13 deg. f. the dark spot in Sep-Oct. but only 10 deg. f. in Nov-Dec after it passed the GRS, is a white oval, bordered by variable faint blue-grey streaks. Both must be cyclonic as they are at lower latitude than BA, and methane-dark (Fig.12).

(2013 March): Now that the STB dark segment [D] has actually collided with the cyclonic structures on the f. edge of BA, a new bright anticyclonic white oval has appeared, and rapid changes are occurring in the region.

Jupiter in 2012/13: Report no.11, (2013 May 14)
The long dark STB segment [D] is now colliding with oval BA. Remarkably, in contrast to the previous such collisions in 2003/04 and 2010, the STB segment has not remained dark and turbulent, but apparently converted to a chain of cyclonic ovals associated with a standing wave on the STBs. [These developed at the start of March, 2013.]
...Instead of the usual S.Temperate drift rates of DL2 ~ -11 to -15 deg/month, the new cyclonic features are moving slowly (DL2 ~ -2 deg/month), and oval BA and the features f. it have all decelerated as well. This behaviour is surprising and contrary to my predictions in the last bulletin! I suspect that the formation of cyclonic cells has caused BA to decelerate. But they may break up again into a typical microturbulent dark STB segment, which would then cause BA to accelerate during solar conjunction, as previously predicted.

Jupiter in 2013/14: Interim report no.1 (2013 Sep 3.)
We can now see the aftermath of the collision with STB dark segment D in the last apparition. As we predicted, oval BA has accelerated dramatically! Initially, last apparition, it did not do so – indeed it may even have slowed down (from DL2 = -12 deg/month to ~-9 deg/month). This was probably because, when the incoming STB dark segment arrived f. oval BA, it did not form a long turbulent dark segment as in previous such events, but instead broke up into a chain of cyclonic ovals. Since solar conjunction, this chain has been replaced by a long dark segment after all, and accordingly, oval BA has accelerated at last (to DL2 ~ -16 deg/month). Moreover, the other expected consequences of the collision are also evident: a very dark collar around oval BA, and dark spots emitted on the STBn jetstream p. it, and in the STZ f. it. The attached image set shows how the STBn p. oval BA, which was tenuous last year, is now much darker with tiny prograding spots (red arrow).

Jupiter in 2013/14: Interim report no.4 (2013 Dec.21) & no.6 (2014 March)
Oval BA is still strongly orange (with a white centre), and the STB segment f. it is long and dark with internal turbulence in v-hi-res images. Oval BA has maintained an almost constant speed DL2 = -14.3 deg/mth since 2013 Sep., with a long dark STB segment f. it [Figs. 1, 4, 5]. This is still emitting a chain of slow-moving small dark spots in the f. direction in the STZ, and a chain of rapidly-moving very dark streaks and spots in the p. direction on the STBn jet.

Jupiter in 2014/15: Interim report no.3 (2015 Feb.8)
The pattern has not changed much since last apparition. Oval BA passed the GRS last autumn, and since it did so, much dark material has accumulated chaotically in the STropZ between BA and the GRS, while very dark streaks have looped around the GRS and a prominent S.Tropical Band has formed.
The STBn jet outbreak p. oval BA is now intermittent.....

Jupiter in 2014/15: Interim report no.8 (2015 Aug.) = **Appendix 1 (below)**

4. The new STB structured segment E ('STB Ghost').

These interactions, when a STB structured segment drifts up to join the complex that includes oval BA, occur every few years, and a new STB feature always forms to fill in the gap that has opened up. Structured segment E arose in 2011, as a small cyclonic dark spot called DS4, and it developed into a pale, expanding feature which we call the 'STB Ghost'. In its origin, appearance, and behaviour, it is an exact replica of the 'STB Remnant' of 2004-2009.

The origin as DS4 was described in our 2011/12 final report (see Section 5(ii) below), and was summarised in our long-term report [Ref.1], thus:

> **(E)** Meanwhile another small v.d.s. (named DS4) appeared in 2011, in a small cyclonic faint blue patch, where there was also temporary disturbance of the SSTBn jet [ref. 2011/12 report]. It became remarkably dark in 2011 Nov., until 2012 Sep. Then it faded and turned white, within a faint cyclonic streak, just like other v.d.ss. have done, and we have predicted that it will become the next STB structured sector. (If it remains faint like the STB Remnant, we will suggest naming it the 'STB Ghost'.)

V-hi-res images showed turbulence around it in 2011 Nov. (Fig.1).

DS4 gradually faded from 2012 Aug. to Oct., and by late Nov. it had turned into a tiny, light pink spot, which was white in early 2013 [Ref.1, & 2012/13 report no.9]. All this time it was embedded in a faint grey or blue-grey oblique streak. Its structure has been unchanged from 2013 to 2015 [Figs.2-4, & 2013/14 report no.4, & **Appendix 1** below]: the faint blue-grey streak extends from a darker grey triangle at its Np. end on STBn, to a variable Sf. end in the STZ, and it appears to be a loop surrounding a white core – probably a cyclonic circulation. In methane-band images, it is conspicuously methane-dark.

It passed the GRS in 2013 Nov-Dec.
Although it is essentially cyclonic, it induces anticyclonic circulation on its south edge, in that SSTBn jet spots are unable to pass it, occasionally recirculating into the STZ (see below).

5. Recirculation across the STZ.

(i) Recirculation from SSTBn to STZ/STBs, at the STB Remnant or Ghost.
Recirculation in this sense, anticyclonically from the prograding SSTBn (S2) jet* into a slow flow in STZ or retrograding flow on the STBs jet, has been recorded repeatedly at the f. edge of the STB Remnant [ref.1] and now at the STB Ghost (2013/14, 2014/15).

*(called the S2 jet in our new nomenclature; but still referred to as the SSTBn jet in this account as a reminder that these spots are on the visible SSTBn edge).

The earlier data were summarised in [ref.1], and similarly in [ref.3] as follows:

> What happens to these S2 jet spots? They mostly disappear at or near the f. parts of STB structured segments: the STB Remnant (2004-2009), or segment A f. oval BA. We recorded ~10 spots which disappeared at or near the Sf. end of the STB Remnant, plus at least 7 which actually recirculated there, to become slow-moving in the STZ or retrograding in the STBs jet [Ref.1]. We also recorded ~14 S2 jet spots which disappeared near or alongside the dark-spotted region of STZ that comprises the Sf. 'tail' of the dark STB segment A, often decelerating and drifting north before they disappeared, plus 4 which actually recirculated into this spotty STZ. These may have been caught up in anticyclonic eddying associated with the dark spots of the Sf. tail. A few S2 jetstream spots also recirculated into undisturbed sectors of STZ, or just disappeared for no obvious reason.

The STB Ghost is a duplicate of the STB Remnant and likewise presents a barrier to SSTBn jet spots, which either disappear or recirculate when they encounter it.

> The first such recirculation occurred in **2012 Aug.**, when it was still a very dark spot, DS4 [ref. 2012/13 report no.11]. (At the same time, new SSTBn jetstream spots were appearing on the p. side of DS4. DS4 faded soon after this.)
> A second recirculation was observed in **2013 Oct.** [ref. 2013/14 report no.4, Figs.2&3]. (The resulting dark spot in the STZ oscillated for several months before resuming prograde drift.)
> Subsequent events in **2013/14** are shown in the JUPOS charts (Fig.3). Of four slow-moving dark spots which emerged in STZ f. the STB Ghost, two seem to have arisen *de novo* from the Ghost, whereas the next two were probably recirculated SSTBn jet spots.
> In **2015** April-May, similar events were observed (Figs.3 & A4): one SSTBn jet spot recirculated, very suddenly alongside the Ghost, to retrograde with DL2 ~ +22 deg/mth; and two new dark spots developed on a brown streak running Nf. down the S edge of the Ghost [see **Appendix 1**].

(ii) Recirculation from STBs to SSTBn, p. oval BA.

A dynamical feature appears to have developed tens of degrees p. oval BA, which is inconspicuous and not yet understood, but appears to be persistent (Fig.2). First, SSTBn jet spots have repeatedly arisen at this location ~60-80º p. oval BA, in 2006, 2007, and 2011/12 [ref. 3]. Also, cyclonic dark spots in STB have arisen here, and recirculation from STBs to SSTBn has been observed twice. In **2011/12,** quoting from our final report [Ref.6]:

> [This sector of SSTBn] included a bulge from SSTBn into STZ, which in Sep. developed the appearance of a recirculation across the STZ, ~60º p. oval BA (Fig.12); a pair of jetstream spots arose at this point. There seems to have been a significant dynamical feature spanning the SSTB-STZ at this location but its nature was unresolved....
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> Another change happened ~60º p. oval BA, just as oval BA decelerated and STBn jetstream activity ceased, so we have investigated it in detail, but why any of these phenomena happened is still not clear. It is shown in maps (report no.3 & chart JUPOS-S1). A faint small blue patch here in Aug. was probably a small cyclonic circulation (Fig.12), and it gradually condensed to become a tiny dark grey spot (DS4) by mid-Sep, presumably cyclonic from its latitude. The pattern south of it looked transiently like anticyclonic hemi-circulation from STBs to SSTBn (see maps: report no.3), and indeed in early Sep. a second tiny dark spot appeared here, at lat.~34.5ºS, which accelerated and moved S anticyclonically until it was moving in the SSTBn jet at ~35.5ºS, one of a small volley of SSTBn jetstream spots that appeared at this point (see above).
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> Meanwhile the first tiny dark spot (DS4) persisted and became remarkably dark in Nov.... This turned out to be the origin of new STB segment E ('STB Ghost') which was followed in subsequent years.

Exactly the same has happened in **2014/15**. A new dark spot arose here in 2014 Dec., presumably cyclonic, developing into a very dark spot ~35º p. BA from 2015 Feb. onwards which we call DS5 (Fig.2, & **Appendix 1**). In 2015 April, a tiny dark spot on the STBs jet retrograded past DS5 to ~25º p. BA where it recirculated to prograde on the SSTBn for few days; a similar spot had followed part of the same course in March (see **Appendix 1**). From here to BA, the STZ and STB latitudes were somewhat darkened, consistent with a circulation across the STZ ~25º p. BA.

No other recirculations were mentioned in our interim reports for 2012-2014. However, this sector p. BA was just where the STBs jet was found to be weaker in ZWPs obtained in early 2014 [see below, & ref.4] – consistent with a tendency to recirculation here, and with the fine texture of the STZ in the HST images [ref.4]. This seems to be a recent development, as there was no such recirculation in 2000 in the Cassini movie.

The origin of dark spot DS5 in 2014/15, p. oval BA, was just like the origin of dark spot dsA in 2002/03, which became the STB Remnant, and DS4 in 2011, which became the STB Ghost. These were STB structured sectors C and E; and sector D also arose $\leq$70º p. BA, but during solar conjunction in 2007-08. In contrast, similar very dark spots which arose elsewhere (in 2006 p. sector C, and in 2011 p. sector D) did not persist long. Thus, the dark spots which have formed p. BA are the ones which have developed into STB structured sectors. Perhaps DS5 in 2015 will become sector F?

6. The STBn jet: The outbreaks in 2004-05 and 2010-11 and 2013-15

Outbreaks of numerous dark spots and streaks on the STBn jet occur when a STB structured segment catches up with the dark patch f. oval BA [Ref.1]. The resulting collision and turbulence in the merged segment destabilises the STBn jet, creating the chain of prograding dark spots. This process has been observed in 2004-2005 and 2010-2011, as described in [Ref.1], and again in 2013/14. In our long-term report [Ref.1], we showed detailed ZDPs for the STBn jet outbreak in 2010 and 2011, though the 2010 analysis covered only data from Italian observers. Here we present analysis of all the JUPOS data for this outbreak, and also for the other two outbreaks. The data are presented in **Figure 7,** as in Figs.16 & 17 of Ref.1, with a ZDP for each apparition, and lat-vs-long. charts for selected spots which drifted northwards in 2004. Mean parameters are in **Table 2**.

These results confirm that the STBn jet spot outbreaks in 2004-05, 2010-11, and 2013-14, have all behaved in exactly the same ways. The outbreak is initiated when a STB structured segment collides with the dark patch f. oval BA. Initially the jet spots drift comparatively slowly (mean DL2 ~ 75-83 deg/mth), but later they drift faster (~90-100 deg/mth), close to the peak jet speed. They fall on a cyclonic ZDP across the STBn jet: in globally averaged profiles they are between the latitudes of the two sub-peaks, but ZWPs for this sector (in early 2014: see Section 7 below & Ref.4) are actually the same as the local ZDP, as the southern sub-peak becomes weak or absent while the spots drift north. Many spots drift northward without change of speed during their lifetimes.

If the spots reach the GRS, they are temporarily deflected southwards and accelerated, confirming that that the STBn jet is deflected around the GRS. They are often disrupted while passing the GRS, and many fail to survive the passage. If spots reach the STB Remnant (2005) or Ghost (2013-14), they mostly do not survive either, and those which do are are usually deflected north and decelerated, suggesting that the jet's profile is altered here.

The outbreak in 2004-2005

This outbreak began in early Feb., 2004, during the prolonged collision of STB segment B with oval BA [Ref.1, Figs.6 & 14 therein]. Dark spots emerged from the Np. edge of oval BA, forming a very dark STB(N), and prograding to the GRS, which was only tens of degrees p. the source of the spots. Most of these spots passed the GRS, and after March, as the source at oval BA approached the GRS, the STBn jet spots could only be tracked beyond (p.) the GRS. (Oval BA began to pass the GRS in June as the apparition ended.)
Exactly as in 2010 and 2014, the early spots had slower drifts; all spots fell on a cyclonic ZDP across the STBn jet; some spots (tracked p. the GRS) drifted northward without change of speed during their lifetimes (**Fig.7A,B**). Also, four were tracked as they passed the GRS: they attained very high speeds as they did so, and three of them shifted to very high latitude (29.8 to 30.2ºS).

In 2005 there were still many spots arising just p. oval BA. The mean speed was slightly faster than in 2004, and again some drifted northwards, but without any overall gradient in the ZDP chart (**Fig.7B**). Many of them disappeared on reaching the STB Remnant. Two which did survive the passage accelerated as they approached it and decelerated as they passed it, also shifting north (**Fig.7B**, & see Fig.7B in Ref.1).

The outbreak in 2010-2011

The outbreak p. oval BA started abruptly in 2010 July, apparently as a consequence of the collision of the STB Remnant (STB segment C) with oval BA in mid-June. However, there was already an equally high density of spots in the other sector of the jet, emerging p. STB segment D, which had developed in the previous months. We suggested that this may have been connected with the concurrent fading of the SEB. Thus by autumn, 2010, the STBn had an unprecedented high density of dark jetstream spots all around the planet [Fig.3 in Ref.1]. The behaviour of the spots was described in our long-term STBn report [Fig.16 in Ref.1], on the basis of Italian observations only. Here we present the ZDP derived from all images measured by JUPOS (**Fig.7C**). It agrees well with the previous version, but also shows that the two sectors of the STBn had different ZDPs. Both had the usual cyclonic gradient, but the outbreak p. segment D was slower, with DL2 ~ -76 deg/mth at 28.0ºS, while the outbreak p. oval BA had DL2 ~ -84 deg/mth at 28.0ºS (similar to 2004). Both speeds are slower than the typical jet speed [Ref.1].

In summer, 2011, dark spots in the STBn jetstream were still numerous but smaller than in 2010; they were arising ~40º p. oval BA and again disappearing at the GRS. The behaviour of the spots was fully analysed in [Fig.17 in Ref.1]; the ZDP is reprinted here for comparison (**Fig.7D**). The profile had now shifted to even faster speeds, DL2 ~ -93 deg/mth at 28.0ºS, which is typical of STBn jet spots except at the beginning of an outbreak.

The outbreak in 2013-2015

The outbreak in 2013/14:
This outbreak followed the collision of STB segment D with oval BA in early 2013. It is fully described in our 2013/14 report no.6 and report no.9 [Ref.5], which are summarised here.
The outbreak was still in its early stages at the start of the apparition in 2013 August, and the darkening of the STB(N) p. BA was not entirely resolved into spots [see figures in our 2013/14 report no.4]; it had a diffuse p. end which reached the STB Ghost (just f. the GRS) in Sep. Distinct jet spots did not reach the GRS until early Dec., when the STB Ghost had moved alongside the GRS. By this time an intense outbreak of dark spots had developed, appearing on the STB(N) just p. oval BA. They initially moved comparatively slowly (DL2 ~ -75 to -86 deg/mth), but speeded up to the usual jet speed (~ -94 deg/mth) within months **(Table 2)**. Their ZDP followed a shallow cyclonic gradient from ~28.5ºS to 27ºS, shifting to higher speed as the outbreak developed. Many of the spots drifted north through this range during their lifetimes without change of speed (which accounts for some of the scatter in the ZDP). (Tracks for some of the best-recorded spots are shown together in **Fig.7E**, including some passing the GRS.) In all these characteristics, the outbreak was essentially identical to the previous examples.

Interactions with the GRS:
From Dec. onwards, the images showed that the spots were dramatically disrupted while passing the GRS, typically being drawn into long streaks. Most of these probably dissipated chaotically p. the GRS; sometimes an irregular bright white area expanded p. the GRS like a 'splash' between the streaks derived from two successive spots. Hi-res images sets showed these distortions and disruptions in detail [Ref.5]. (Similar behaviour was seen in our reports for 2010.)
As the spots were stretched alongside the GRS, they also accelerated massively for the duration of the passage: the maximum speed was typically DL2 ~ -5.0 deg/day (u_3 ~ 61 m/s) for only a few days. At the same time, each spot moved south suddenly as it began to pass the GRS, reaching a maximum latitude of 28.7 (±0.3) ºS [1.2º (±0.3º) higher than before]. If the spot survived, its latitude declined just as rapidly as it ended its passage. This confirms that the STBn jet is deflected around the GRS.

In some cases, remnants did re-emerge after passing the GRS, reverting to approx. their original speed and latitude.

Interactions with the STB Ghost:
STBn jet spots which survived passing the GRS generally did not survive a subsequent encounter with the STB Ghost, but a few did pass it, when they drastically decelerated to DL2 = -86 (±2) deg/mth (u_3 = 34 m/s). (Their latitudes did not show a consistent trend.)

Continuation in 2014/15:
The outbreak has continued up to 2015 May, though varying in intensity; see **Appendix 1** for details and illustrations. As always, the spots fell on a cyclonic ZDP, and many of them drifted northward during their lifetimes, whether they accelerated or not. Unusually, most of the spots were born with comparatively slow speed (DL2 ~ -80 deg/mth) but then accelerated individually (to DL2 ~ -100 deg/mth). Only two spots survived past the STB Ghost; only one of them decelerated, but both moved north to ~26.2ºN.

7. Zonal Wind Profiles

Previous ZWPs from spacecraft have shown that the STBn prograding jet has two sub-peaks (at ~29.5 and ~27ºS), which we have shown to vary with time and longitude. In particular, the 29.5ºS sub-peak is faster alongside STB structured sectors, such as the dark segment following oval BA, than in undisturbed sectors [Ref.1]. In some data sets the STBs retrograde jet is also faster alongside STB structured sectors [Ref.1].

An earlier example of the same phenomenon can be found in [Ref.7], dating from the 1990s, when the organisation of the S. Temperate domain was different. The STBn sub-peak at 29.5 S and the STBs jet peak at 32.5 S were much faster alongside a dark turbulent sector of STB in 1997 June than alongside a pale undisturbed sector in 1995 Oct.

A ZWP had never been determined in a sector with a vigorous outbreak of STBn jet spots, such as was occurring in 2013/14. Grischa Hahn has achieved this from five pairs of amateur images taken in 2014 Feb., and from HST images taken on 2014 April 21 [Ref.4].

In his ZWPs [Ref.4], the northern jet component at 26-27ºS is present as a similar peak in the ZWPs at all longitudes, with a fairly constant mean speed of ~37 m/s, in both ground-based and HST data. The southern sub-peak at 29.5ºS is found to be faster alongside the STB dark sector (in agreement with previous results). In the sector with the STBn spot outbreak, the mean ZWP is found to match the ZDP (Fig.7F), as the southern sub-peak at 29.5ºS becomes weaker with decreasing longitude from BA to the GRS: just f. the GRS, on three different dates, it is rather slow (~20-23 m/s), so this sub-peak is weak or absent in the p. part of the STBn outbreak sector. Thus the ZWP agrees with the drift profile of the visible dark spots, and the southern sub-peak declines as the spots drift northwards while running towards the GRS.

8. The future of the S. Temperate domain.

In the near term, we expect oval BA to decelerate sharply as the STB segment f. it shrinks to a small quiescent 'barge'. In a '3-year forecast', posted in 2015 March [Ref.8], I assumed that the deceleration around 2014 Dec.31 would be sustained, but this proved not to be the case as the STB segment remained dark and micro-turbulent up to 2015 May [**Appendix 1**]. I predict that the definitive deceleration will happen in summer 2015 – during solar conjunction, if it has not already happened in 2015 June. In this case, the next major event – the collision of the STB Ghost with oval BA – will probably not occur until 2017 or 2018.

Meanwhile we will find out next year how the new dark spot DS5 p. oval BA will evolve; whether it will redden and fade, and/or, whether it will develop into another STB structured segment.

In the longer term, the future scenario outlined in our previous report [Ref.1] is supported by the recent observations of recirculation f. the STB Ghost and p. oval BA (Fig.2).

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Table 1. Oval BA, 2012-2015

time interval	***ΔL2(°/30d)***	*lat.*	***Length (colour)***	***SD (colour)***	***N***	Redness
2011 Aug - 2012 Jan	-11,2	-32,9	8,8	0,8	29	+
2012 Jul 21 - Sep 22	-11,7	-33,2	6,7	0,53	16	+++
2012 Sep 29 - Nov 16	-10,8	-33,0	7,0	0,83	12	
2012 Dec 5 - 2013 Apr 4	-11,7	-33,2	7,2	0,61	13	
2013 Aug - 2014 April	-14,4	-33,2	7,3	0,68	52	++
2014 Aug 21 - Nov 10	-13,4	-33,1	7,5	0,86	17	+
2014 Nov 15 - Dec 27	-17,7	-33,4	8,2	0,41	16	++
2014 Dec 30 - 2015 Mar 17	-11,7	-32,9	7,8	0,55	36	+
2015 Mar 19 - May 21	-13,3	-33,0	7,6	0,59	11	+

Table 2. STBn jet spots: Average speeds & latitudes.

		DL2	u3	Lat
2004 Feb-Mar.	Mean	**-75,1**	**28,8**	**-28,64**
(BA to GRS)	SD	1,3	0,5	0,13
	N	5	5	5
2004 Apr-Jun	Mean	**-87,2**	**34,1**	**-28,14**
(p. GRS)	SD	4,5	2,0	0,41
	N	15	15	15
2005	Mean	**-89,8**	**35,2**	**-28,26**
	SD	6,0	2,6	0,33
	N	22	22	22
2010	Mean	**-74,7**	**28,7**	**-28,18**
(f.BA)	SD	4,5	2,0	0,53
	N	81	81	81
2010	Mean	**-85,6**	**33,4**	**-27,95**
(p.BA)	SD	5,3	2,3	0,41
	N	32	32	32
2011	Mean:	**-93,2**	**36,7**	**-28,0**
	SD:	5,25	2,3	0,46
	N:	24	24	24

(Low-speed outliers have been omitted from means for 2004 and 2011.)

		DL2	U3(m/s)	Lat.
2013 Sep-Nov	**mean**	**-83,3**	**32,5**	**-28,3**
(BA to GRS)	SD	8,2	3,6	0,29
	N	8	8	5
2013 Nov-Dec	**mean**	**-90,1**	**35,5**	**-27,8**
(BA to GRS)	SD	4,7	2,1	0,42
	N	9	9	9
2013 Dec -	**mean**	**-94,3**	**37,2**	**-27,9**
2014 Apr	**SD**	4,0	1,8	0,36
(BA to GRS)	N	48	48	49
2014 Jan-Mar	**mean**	**-95,0**	**37,7**	**-27,3**
(p. GRS)	SD	7,6	3,3	0,41
	N	10	10	7
2014 Sep--2015 Mar:				
(early parts	**mean**	**-79,6**	30,7	**-28,5**
of tracks)	**SD**	5,1	2,2	0,20
	N	17	17	17
(late parts	**mean**	**-100,1**	39,8	**-27,7**
of tracks)	SD	5,7	2,5	0,16
	N	7	7	7

Figure legends

Figure 1. Maps of the southern hemisphere from 2011 to 2015, with major features labelled in the S. Temperate (S1) domain (arrows) and S2 domain (small AWOs named A0 to A8). South is up in all figures.

Figure 2. Diagram of the jets and circulations in the S. Temperate domain, as described in this report. Lines mark the peak latitudes of the fastest jets. The base map is from early 2015, by Damian Peach.

Figure 3. JUPOS chart of longitude (L2) vs time for all features measured in the S. Temperate domain, 2012-2015. See key at top. 'R' marks recirculation events from the SSTBn jet (grey points) into the STZ (black points), at the STB Ghost.

Figure 4. JUPOS chart for oval BA. Longitude scale is L2 – 0.45 deg/day.

Figure 5. Zonal drift profiles (ZDPs) for oval BA.
(A) Oval BA in 2011-2015, and small AWOs (rings) in these and earlier years.
(In 2006 the small AWO was oscillating, as shown by 4 yellow points connected by yellow lines. The anomalous latitude for the small AWO in 2000 is unexplained, possibly related to the recent formation of oval BA, although these early measurements could be less accurate.)
(B) Oval BA in earlier years, from Ref.1 (Fig.11). The ZDP shifted southward at ~0.1 deg per year, probably due to shrinkage of the oval. This trend has not been continued in (A).

Figure 6. Length of oval BA vs time, from JUPOS measurements in all wavebands (mostly RGB). (Measurements on red and infrared images did not differ significantly.)

Fig. 7. STBn jet spots in three separate outbreaks: Tracks of spots, and ZDPs.

(A,B) STBn jet spots in the 2004-2005 outbreak.

(A) Tracks of some spots which were moving northward in 2004, plotted as longitude (in a system moving at -10 deg/month to minimise motion of oval BA) versus latitude. All were p. the GRS. The spots move from right to left; trend-lines (fitted by Microsoft Excel) show the decline in latitude. (Similar northward shifts have been seen in all apparitions analysed.)

(B) ZDPs for all spots in 2004 and 2005. In this and other ZDP charts, the mean ZWP from Cassini (Porco et al., 2003) is shown for comparison.

(C,D) STBn jet spots in the 2010-2011 outbreak: ZDPs for (C) 2010 and (D) 2011. [The latter was previously posted in Ref.1.] Downward-pointing arrows indicate the range of latitudes through which five spots migrated over time.

(E,F) STBn jet spots in the 2013/14 outbreak.

(E) [from Ref.5] Tracks for 6 well-tracked spots, plotted as longitude (L2) vs latitude. Positions of the GRS and the STB Ghost are indicated schematically. The spots move from right to left; trend-lines (fitted by Microsoft Excel) show the decline in latitude down to the GRS. Note the marked increase in latitude as each spot passed the GRS, and for those which survived, return to an approximate extrapolation of the previous track.

(F) ZDP. For early spots (blue), the mean speed and the ZDP were slower than for later spots (red). Trend lines have been drawn by eye. Spots which had passed the GRS (open diamonds) had lower latitudes and a range of speeds; spots which then continued beyond the STB Ghost (open triangles) had much slower speeds. For charts broken down by month, and more individual tracks, see [Ref.5]. For ZDP in 2014/15, see **Appendix 1.**

APPENDIX 1:
Jupiter in 2014/15, Report no.8:
S1 domain (S. Temperate region)

John Rogers & Gianluigi Adamoli, using information from the JUPOS team
(Hans-Jorg Mettig, Michel Jacquesson, Marco Vedovato, & G.A.)

This follows on from our 2014/15 Report no.3. See Figures A1 & A2 for sets of maps, and Figure 3 of the main report for the JUPOS chart. Table A1 lists the positions and speeds of the main features and main currents.

The STB Ghost is the same as it was in 2013/14 (Fig.A3): a pale bluish loop (dark in methane-band images) that appears to be a cyclonic circulation, with a fairly dark grey Np. end, and a more variable Sf. end where streaks sometimes appear and prograding S2 jet spots occasionally recirculate from the SSTBn to the STZ/STBs.
One such recirculation was observed in 2015 April-May (Fig.3 & Fig.A4 & Table A1): a SSTBn jet spot recirculated, very suddenly alongside the STB Ghost, to retrograde with DL2 ~ +22 deg/month. Also, two new dark spots developed on a brown streak running Nf. down the S edge of the STB Ghost. One of these then remained fixed 20º f. the Ghost, and absorbed one and perhaps both of the other two spots as they retrograded to it. This small dark spot may well have been an anticyclonic vortex; so a pattern was developing that resembled, in miniature, the Sf. tail of a STB segment.

Oval BA passed the GRS on 2014 Oct.1 (Fig.A1). It had a moderate red colour throughout the apparition, with a white core as always (Fig.A5). It still had a narrow dark grey collar around it throughout.

Oval BA made several sudden changes of speed during the apparition, for unknown reasons (Fig.4 of main report, & Table A1). Initially it was travelling fast, as usual when there is a dark, micro-turbulent STB segment f. it, and I expected it to decelerate in summer 2015 when this STB segment would shrink to become a quiescent oval. In fact, BA decelerated around 2014 Dec.31 – but then accelerated again, travelling fast at least up to 2015 May. The last few observations suggest that the expected deceleration may have occurred in June, but we will have to wait until next apparition to find out for sure.

The persistent rapid speed, and the dark collar of BA, as well as the continuing dark spots on the STBn jet p. it and in the STZ f. it, are all consistent with continuing microturbulence of the STB segment f. it, however small it is (see below).

STBn jet and STropZ:
As BA moved ahead of the GRS in autumn 2014, much dark material accumulated in the STropZ, alongside and f. it [Fig.A1, & 2014/15 report no.3]. This was comprised of the ongoing STBn spot outbreak p. BA, chaotic dark spots alongside BA, and a new broad irregular S. Tropical Band (STropB) emerging from very dark streaks around the GRS. The STropB was at ~24-26 S, and dark spots within it had DL2 ranging from ~-24 to -62 deg/mth. Production of new dark material eased off in 2015 Jan., though the STBn jet (‘cold grey’ dark streaks) and STropB (‘warm grey’ dark streaks) continued to prograde, spanning around 1/3 of the planet’s circumference.

STBn jet: A prominent volley of dark spots on the jet had arisen from BA in Sep-Oct. [Report no.3, inc. Fig.9]. Activity was then modest in Nov., but re-intensified during Dec. to produce a long, very dark STB(N) in 2015 Jan. Spots and streaks from this outbreak, tracked in Feb-Mar., behaved exactly as in Sep-Oct., i.e. they mostly began with DL2 ~ -80 and accelerated to ~-100 (see Table A1 & Fig.A7). The zonal drift profile (ZDP: Fig.A6) showed the usual cyclonic gradient within the jet, similar to previous years (Fig.7 of main report). Many of the spots, including all the best-characterised ones, showed the usual drift northwards, not only when they accelerated, but also during periods when the drift was constant.

Only two spots survived past the STB Ghost, and although only one decelerated [Report no.3], both moved north to ~26.2ºN, north of the jet peak (Fig.A6).

STBn jet spots were still appearing in May.

Locus of circulations p. oval BA:
New spots tend to arise and/or recirculate tens of degrees p. BA. In 2014/15:

1) A new cyclonic dark spot, here called **DS5**, arose ~25º p. BA [all distances are to the centre] in 2014 Dec. Its early stages were shown in Report no.3 (Fig.2); note small-scale turbulence here. Maps (Fig.A1) show that it was still a small turbulent feature throughout Jan. and Feb. In March it settled down (Fig.A5), and in April and May it was a coherent dark spot 40º p. BA, very dark in May (Fig.A2) I suspect it may develop into a new STB structured sector, F (see main report).

2) Recirculation from the STBs to the SSTBn was again observed here, ~25º p. BA. In 2015 April (Fig.A5), a tiny dark spot retrogading on the STBs jet (DL2 = +35) retrograded from DS5 to ~25º p. BA, where it shifted S to the SSTBn and prograded, though it only survived a few days. In March, a similar tiny spot had followed the same track from DS5 to ~20º p. BA where it shifted S, but it was then destroyed by turbulence in the SSTB (Fig.A5).

3) In the sector of ~25º p. BA, in April, the STZ was occupied by very dark streaks, and the whitened STB latitudes were slightly darker than further p. This sector became even darker and more complex during May (Fig.A5).

Dark segment f. BA:

The STB proper (formed from STB sector D in 2013/14) was 25-30º long in 2014 Oct. (Fig.A1), gradually shrinking. It remained dark and, in v-hi-res images, micro-turbulent, throughout the apparition up to May (Figs.A2 & A5), even as it became very short. In May it became a compact dark ring only 7º long; but the ongoing STBn jet outbreak p. BA suggested that the turbulence had still not ceased.

The 'south-following tail' (Sf. tail) of the STB segment was initially ~70º long, but shortening. It contained retrograding dark spots close to STBs jet speed (Fig.3 & Fig.A6), but also three dark spots formed within it with prograding speeds similar to BA, slightly further S at ~33ºS, which blocked progress of almost all retrograding spots. One of these was a prominent dark spot which developed ~45º f. BA in 2014 Oct., and remained ~55º f. BA for the rest of the apparition (Fig.3). This was evidently an anticyclonic ring, which may have been formed by merger of slow-moving or retrograding dark spots in the Sf. tail, as has happened before (see main report). Hi-res images in Nov. showed a tiny lighter core, but the spot was not methane-bright [images by Akutsu, Go, Maxson; Nov.15-23]. The white core was more easily detectable from 2015 Jan. onwards, as it evolved into an AWO.

After this ring formed, a straight dark segment of STB(S) persisted f. it, but changeable spots retrograding from the STB dark segment did not pass it. They typically had DL2 = +19.0 (±3) deg/mth, at 31.7°S, close to the retrograding jet peak (Table A1 & Fig.A6). There were still some dark spots in this Sf. tail up to 2015 May, though becoming sparser.

Table A1. Positions and speeds of spots and currents in the S. Temperate domain, 2014/15. (JUPOS data analysed by G. Adamoli.)

Current / Spot		*Lat.*	*SD*	*N*	*ΔL2 (deg/30d)*	*Dates / (±SD; N)*	*Notes*
							L2(O) = L2 on 2015 Feb.6.
SSTBn jet d. spots (f. Ghost)	**Mean**	**-35,0**	0,15	3	**-71,6**	(±2,7; 3)	
STZ retrograding d.ss f. BA	**Mean (all)**	**-31,7**	0,40	9	**16,7**	(±7,3; 9)	
	Mean (subset)	**-31,7**	0,36	5	**19,0**	(±3,0; 5)	
Recirculating spots:							
SSTBn d. s. (f. Ghost)	DS6	-35,1	0,44	8	-73	Mar 20 - Apr 16	
		-32,5	0,35	4	22	Apr 25 - 30	Recirculating
STZ d.s. (f. Ghost)	DS27	-33,9	0,55	21	-12	Apr 11 - May 22	
STZ d.s. (p. BA)	DS26	-31,8	0,29	4	35	Apr 2 - 7	Between DS5 and BA
		-34,8	0,84	3	-55	Apr 10 - 13	Recirculating near SSTBn jet
Dark spot p. BA (cyclonic)	DS5	-31,0	0,38	38	-17,6	Dec 6 - Mar 16	L2(O) = 124
		-31,1	0,31	49	-13,9	Mar 30 - Jul 8	
Oval BA	BA	-33,1	0,36	33	-13,4	Aug 21 - Nov 10	
		-33,4	0,21	29	-17,7	Nov 15 - Dec 27	
		-32,9	0,31	58	-11,7	Dec 30 - Mar 17	L2(O) = 156
		-33,0	0,31	44	-13,3	Mar 19 - May 21	
F. end of dark STB segment		-30,7	0,28	43	-16,1	Oct 5 - May 6	L2(O) = 180
Ring (small AWO)	W1	-33,5	0,25	9	-12,7	Dec 28 - Feb 14	L2(O) = 209
		-33,0	0,20	15	-8,4	Feb 19 - Mar 17	
		-33,5	0,25	11	-16,0	Mar 27 - May 16	Accel. along with BA
Grey triangle (Np. end of STB Ghost)		-29,5	0,70	119	-15,7	Aug 20 - Jun 12	L2(O) = 340
STBn jet d. spots	**Mean (all)**	**-28,0**	0,70	37	**-87,1**	(±10,5; 37)	
	Mean (early)	**-28,5**	0,20	17	**-79,6**	(±5,1; 17)	Tracks 40-80 deg. p. BA
	Mean (late)	**-27,7**	0,16	7	**-100,1**	(±5,7; 7)	Tracks 108-150 deg. p. BA

Figure legends for Appendix 1:

Figure A1. Maps of southern latitudes, 2014 Sep. to 2015 Feb. All maps were produced by Marco Vedovato using WinJUPOS, from images by the named observers, unless otherwise stated. Arrows indicate the grey triangle at the p. end of the STB Ghost, and the dark condensation which became an anticyclonic ring in the Sf. tail of the STB dark segment. The AWOs in the S2 domain are also named (A0 to A8).

Figure A2. Maps of southern latitudes, 2015 April-May. (As Fig. A1.)

Figure A3. Images of the STB Ghost, 2015 Feb.21 to March 1. Little systematic motion can be detected in it, except for a probable clockwise (cyclonic) circulation of the pale blue ‘loop’ on Feb.21-22. (The dark spot at the Sf. end is approx. stationary.) A dark spot is approaching in the SSTBn jet (red arrow). At bottom, methane image: note the STB Ghost is methane-dark.

Figure A4. Images of the STB Ghost, 2015 April-May, showing small spots moving alongside it as described in the figure and the text.

Figure A5. Images of oval BA and environs, 2015 March-May. Interesting features are described on the figure and in the text. The ‘new cyclonic dark spot’ is DS5.

Figure A6. Zonal drift profile for the S. Temperate domain, 2014/15, with the Cassini ZWP for reference. Note that major features (named) drift with the classical S. Temperate Current, i.e. DL2 ~ -10 to -20 deg/mth, while smaller spots follow more extended ZDPs consistent with the ZWP or (for the STBn jet) a regional variation thereof. The grey triangle of the STB Ghost appears anomalously northerly because it was the Np. end of a coherent feature that spanned several degrees to the south. Conversely DS5 appears anomalously southerly, for unknown reason – perhaps another clue to the complex dynamics of its location.

Figure A7. STBn jet outbreak, 2014/15.
(A) JUPOS chart of the dark spots, showing how they arise just p. oval BA, drifting with DL2 ~ -80 deg/mth, then accelerate to DL2 ~ -100 deg/mth.
(B) Chart of DL2 vs distance p. BA (for the mid-point of each measured track segment).