Report for BAA Jupiter Section web site, 2025 Jan.17

Jupiter's S2 (South South Temperate) domain, 2012-2023

John Rogers[1], Gianluigi Adamoli[1,2], Robert Bullen[1,2], Grischa Hahn[2], Michel Jacquesson[2], Marco Vedovato[2], Hans-Joerg Mettig[1,2], Gerald Eichstaedt[3], Candice Hansen[4,5], Glenn Orton[5,6], Tom Momary[5,6].

(1) British Astronomical Association, London, UK. (2) JUPOS team. (3) Independent scholar, Stuttgart, Germany. (4) Planetary Science Institute, Tucson, AZ, USA. (5) JPL, CalTech, Pasadena, CA, USA. (6) NASA JunoCam team.

References & Figure legends are at the end of this file.

Tables and Appendices are in separate files. (Tables are also inserted into this text.)

Figures are in a separate PDF file (miniatures) and ZIP file (full-size).

***Abbreviations used*:**	PJ, perijove
AWO, anticyclonic white oval	FFR, folded filamentary region
CWOa/CWOb, cyclonic white oval/oblong	d.s., dark spot
F., following = planetary west (left in images)	P., preceding = planetary east (right in images)
ZDP, zonal drift profile	ZWP, zonal wind profile
SSTB, South South Temperate Belt	SSTZ, South South Temperate Zone

--and other standard abbreviations for belts and zones, given on the BAA web site.

Summary

The S2 domain lies between the prograde jets at 36ºS (S2 jet) and 43ºS (S3 jet), encompassing the traditionally named South South Temperate Belt (SSTB) and Zone (SSTZ). The most distinctive features here are 6 to 9 long-lived anticyclonic white ovals (AWOs), while cyclonic features include white oblongs, dark oblongs, and folded filamentary regions (FFRs). Here we review the features and phenomena of this domain, following our previous review up to 2012 which was based mainly on amateur observations. Since 2012, amateur images have improved further, and since 2016, they have been complemented by hi-res imagery from JunoCam on almost every orbit of NASA's Juno orbiter. Combining these two data streams gives us a more complete and detailed understanding of this domain, particularly of cyclonic features which were not well resolved in earlier ground-based images.

The general conclusions of our previous review are confirmed and updated by the subsequent 12 years of observations. The present work also presents some new findings, as follows.

Jet streams and currents:
--The S2 jet has accelerated after 2000, while the S3 jet has slightly decelerated.
--In the middle of the domain, a modest retrograde jet can usually be detected, with a peak in one or both of two preferred latitudes (~39.3ºS, 39.8ºS).
--There is a much faster retrograde jet along the wavy south edge of some cyclonic circulations and FFRs.
--The S.S. Temperate Current (SSTC: mean drift of the larger features such as AWOs) has speeded up in recent decades. ('Fast' and 'slow' refer to prograde flow unless otherwise specified.)
--Cyclonic features are mostly trapped between AWOs and share their drift, but there is limited evidence that untrapped FFRs drift more slowly. Small cyclonic dark spots sometimes also move slowly, but this may often be due to interaction with larger structures.

Anticyclonic white ovals:
--In these twelve years, no new long-lived AWOs have appeared, and two have disappeared by merging with others, confirming a nominal mean lifetime of ~56 years. Large AWOs have never been observed to disappear except by merging, so there may be no intrinsic limit to their lifetime.
--Mergers of AWOs usually occur when they are close to or passing oval BA.
--There is evidence that growth of a smaller AWO was assisted by mergers with smaller anticyclonic vortices that emerged westward from the turbulence of a large FFR.

Cyclonic features [summary adapted from EPSC 2024 abstract]:
By combining data from JunoCam and ground-based images, as well as occasional Hubble data, we present a history of the large-scale cyclonic structures in Jupiter's S2 domain from 2015 to 2023, thus establishing the range of lifetimes of FFRs for the first time. In addition to the three well-defined types (white oblongs, dark oblongs, and FFRs), JunoCam images reveal long, pale fawn-coloured sectors of the SSTB that resemble white oblongs in structure and can develop into them or from them.

Any of these types can last for as little as ~4 months. White oblongs often last longer, ranging up to 2.8 years in this survey, and nearly 6 years in earlier records. FFRs also have a large range of lifetimes, although they may sometimes be temporarily weak; two have existed for at least 8 years. Some sectors (delimited by AWOs) have shown repeated changes between the cyclonic types: any of three types can convert into any other over a matter of months, sometimes via a pale ochre oblong as intermediate.

White oblongs sometimes brighten rapidly in their early stages; two examples were very bright white and also bright in the methane band, which is very unusual for a cyclonic oval on Jupiter. Their longitudinal expansion rates are confirmed. Their termination is usually gradual, becoming less white and sometimes visibly disturbed.

Dark oblongs may form when a FFR becomes inactive. Dark spots or oblongs often end their lives by becoming redder and then lighter in colour, sometimes becoming white.

FFRs appear and disappear about once a year. A young FFR is usually small and expands, though they do not grow indefinitely. In the few examples where we have seen a likely convective outbreak initiating a FFR, they have been very small and only occasionally methane-bright, thus much less energetic than examples recorded in the S. Temperate domain.

1. Introduction & Methods

Jupiter’s atmosphere is divided into dynamical domains lying between the permanent eastward jet streams, as explained in Ref.1 and shown in Figure 1. The S2, or South South Temperate, domain, is defined as lying between the S2 jet (mean planetographic latitude from 4 spacecraft = 36.3ºS) and the S3 jet (mean latitude = 43.1ºS) [Ref.1 & **Table 1**]. It thus includes the canonical S.S. Temperate Belt (SSTB), with various cyclonic circulations to be described below, and S.S. Temperate Zone (SSTZ), with anticyclonic white ovals (AWOs). However, a dark belt or bright zone in the appropriate latitudes is infrequent [Ref.2]. Sometimes, the whole domain may be dark or light, or there may be a visibly dark belt in the canonical SSTZ latitude (~40-43ºS), which has been called a (S)SSTB [Ref.2] or SSTZB. (Thus the AWOs are often loosely described as being ‘in the SSTB’.)

The speeds and positions of the jets, as measured from maps from spacecraft, are in **Table 1**. This is our previously posted table [Ref.1] plus speeds for the SSTBs “retrograde jet” and (in the lower row) speeds from more recent Hubble data, as explained in section 4 below. The S2 domain is one of the narrowest on the planet. This may be why the usual retrograde jet in the middle of the domain is weak or, in some data sets, merely an eastward-velocity minimum.

Table 1: Latitudes and speeds of jets in S.S. Temperate latitudes, from spacecraft

Latitudes and speeds of S2 & S3 jets																	
from Ref.1:	**From Voyager, 1979**			**From Hubble (1995-1998)**			**From Cassini, 2000**			**From New Horizons, 2007**			**AVERAGE VALUES**				
	(Limaye, 1986)			(G-M & S-L, 2001)			(Porco et al., 2003)			[Cheng et al., 2008]			**(from 4 spacecraft missions)**				
	[From Rogers(1990 & 1995)						[Data from A. Vasavada]			[data from A.Cheng & A.Simon]							
Jet	Lat.	u3	DL2	Lat.	u3	DL2	Lat.	u3	DL2	Lat.	u3	DL2	Lat.	Lat.	u3	DL2	
	graphic	*(m/s)*	*(/mth)*	*graphic*	m/s	deg/mth	*graphic*	*(m/s)*	*(deg/mth)*	*graphic*	*(m/s)*	*(deg/mth)*	*graphic*	*centric*	*(m/s)*	*(deg/mth)*	
S2 (SSTBn)	-36.5	31.6	-88	-36.3	40.2	-109.4	-35.8	34.2	-94.0	-36.5	46.8	-126.2	-36.3	-32.8	38.2	-104.4	
SSTBs	*-39.8*	*3.5*	*-17.2*	*-39.0*	*-1.4*	*-4.3*	*-39.1*	*-8.4*	*13.9*	*-40.0*	*-0.2*	*-7.5*	*-39.5*	*-35.8*	*-1.6*	*-3.8*	
S3	-43.6	42.1	-125	-42.9	45.6	-133.6	-43.0	42.6	-125.8	-43.0	40.6	-120.1	-43.1	-39.4	42.7	-126.1	
New:	**From Hubble (2008)**			**From Hubble (2014)**			**From Hubble (2009-2016)**			**From Hubble (2019)**			**AVERAGE VALUES (all spacecraft data)**				
	(XAD et al.,2011)			(Hahn & Rogers, 2014)			(Tollefson et al.,2017)			(M. Vedovato, data in:)			Lat.	Lat.	u3	DL2	**Jet**
	[Data from M. Wong]			[2013/14 report no.10]			[Data from M. Wong]			[2019 report no.9]			*graphic*	*centric*	*(m/s)*	*(deg/mth)*	
Jet	Lat.	u3	DL2	Lat.	u3	DL2	Lat.	u3	DL2	Lat.	u3	DL2	**-36.1**	**-32.6**	**41.6**	**-112.7**	**S2**
	graphic	*(m/s)*	deg/mth	*graphic*	*(m/s)*	deg/mth	*graphic*	*(m/s)*	*(deg/mth)*	*graphic*	*(m/s)*	deg/mth	0.3	0.3	5.7	14.4	(SD)
													-39.4	***-35.8***	***-3.0***	***-0.2***	***SSTBs***
S2 (SSTBn)	-36.0	43.9	-118.5	-36.2	45	-121	-36.0	46.1	-123.9	-35.6	45.0	-120.6	0.4	0.4	4.6	12.0	(SD)
SSTBs	*-39.3*	*0.3*	-8.8	*-39-40*	*-3*	*0*	*-39.2*	*-4.4*	*3.5*	*-39.5*	*-10.3*	*19.0*	**-43.2**	**-39.5**	**40.3**	**-118.1**	**S3**
S3	-43.6	35.9	-108.0	-43.3	36	-108	-43.3	38.1	-113.6	-43.2	36.2	-108.0	0.3	0.3	3.5	9.5	(SD)

The long-term features and behaviour of this domain, up to 1991, were described in Ref.2, and from then until 2012, in Ref.1. So we present here a sequel to Ref.1, starting with the 2012/13 apparition. All the general conclusions of Ref.1 are confirmed and reinforced here, and we can give a more complete account of some phenomena.

Sources of data

Amateur images:

The ground-based data consists of huge numbers of images taken by amateur observers around the world, whose names are posted on the JUPOS web site (Ref.3). Figure 2 shows the best resolution that amateurs can now achieve.

The technology is essentially the same as in our previous report (Ref.1): webcam imaging with selective image processing (Refs.4 & 5). Images are taken with a variety of telescopes, mostly with apertures 200-410 mm, using webcams to record hundreds of images within several minutes. They are processed with software which selects and aligns the best frames and excludes those taken in poorer seeing. Further processing is done by each observer to enhance small-scale detail and contrast. Images have improved from 2011 onwards thanks to derotation in WinJUPOS (rescaling the images during processing to compensate for planetary rotation, allowing longer capture times), and more sensitive cameras (especially useful for imaging in the methane absorption band at 889 nm).

Positional measurements of ‘spots’ are done on-screen by members of the JUPOS team, using the WinJUPOS program (created by G. Hahn), which is fully described and available at Ref.3. The resulting database is used to create charts of spot longitudes vs time for each latitude band (belts, zones, jets), which are posted regularly on the JUPOS web site (Ref.3). The charts spanning 2012-2023 are provided in **Appendix A**, with annotations. In these charts, black points are dark spots, green points are bright spots, red points are reddish spots (infrequent in this domain), and < > indicate west and east ends of features.

From these data we derive eastward or westward drift rates, expressed in degrees per 30 days (deg/30d) in System 2 longitude (DL2), or in m/s in System 3 longitude (u_3) (see below). East is referred to as preceding (p.), and eastward motion is prograding; west is following (f.), retrograding. ‘Fast’ and ‘slow’ are used in the eastward (prograde) sense, unless retrograde speed is specifically stated.

Latitudes are planetographic. Uncertainty in latitude is estimated from the scatter of measurements: for each spot, standard deviation is typically ± ≤0.3° in the S2 domain, and standard error of the mean is typically <0.2° because many measurements are averaged for each spot. Uncertainty in drift rate is conservatively estimated as 2 x 0.5° divided by track duration in months; nominal uncertainty for a 1-month track is thus ±1.0°/month, but over longer intervals the precision is usually limited by real fluctuations in drift rate.

JunoCam images:

From 2016 onwards, we also have images from JunoCam, the camera on NASA’s Juno orbiter. As Juno is spinning, JunoCam takes images by scanning and time-delayed integration [Ref.6]. Because JunoCam’s prime justification was ‘public outreach’, the raw data and initial images are made publicly available on the JunoCam web site (https://www.missionjuno.swri.edu/junocam), and citizen scientists are invited to produce the full-quality images. In practice this is a challenging computational task, which has been done throughout the mission by Gerald Eichstädt. Almost all the images and maps shown in this report were produced by Gerald Eichstädt with further compositing and enhancement by JHR, as also shown in our regular reports on each perijove that are posted on the JunoCam web site (https://www.missionjuno.swri.edu/junocam) and the BAA Jupiter Section web site (https://britastro.org/sections/jupiter). A few images or maps by other citizen scientists are included here as acknowledged.

JunoCam images provide maps of most of the S2 domain on every orbit. These are collected in **Appendix B**, which also shows the dates of perijoves. (The complete JunoCam cylindrical maps are being posted on our web site at: https://britastro.org/section_information_/jupiter-section-overview/junocam-global-maps). From perijove (PJ) number 1 on 2016 Aug.27, Juno had an orbital period of 53 days (2017-2021) then 43-44 days (2021-22) then 38 days (2022-23). Since PJ47 on 2022 Dec.15, the S2 domain has only been imaged at a resolution comparable to the best ground-based resolution .

Hubble Space Telescope images:

The Hubble Space Telescope (HST) has produced at least one pair of global maps per year (in the OPAL project: ref.7), and additional imaging coinciding with some Juno perijoves (WFCJ project: ref.8). These are often posted as whole-planet cylindrical maps which can be blinked, so a huge amount of information about specific features and about zonal winds can be found in them.

Conventions in this report

This report is largely based on the amateur data, but also makes extensive use of JunoCam data (and occasionally Hubble data). The high resolution of the JunoCam maps complements the near-continuous imaging by amateurs, so that hi-res spacecraft images are available for most features and phenomena of interest, including features in the S2 domain that are difficult to resolve in amateur images, and JunoCam continues to track them during solar conjunctions.

Longitudes in maps are here given in System 3 (L3), unless otherwise specified. However, we still use System 2 (L2) for drift rates, for ease of comparison with all previous data. DL3 = DL2 + 8.0

deg/30d. For jet speeds and ZWPs, DL2 is also converted into wind speed u_3 (m/s). This is not convenient for routine observational data because it requires precise knowledge of the latitude, but as a general guide we quote the conversion for 40.0ºN:

$$u_3 = -(\mathrm{DL2} + 8.0) / 2.6433$$

A graph of this relationship is in Figure 3.

Latitudes are planetographic, unless otherwise stated. However, latitude scales on JunoCam maps are planetocentric. North is up in all images and maps. (In Refs.1 & 2, all images and charts were shown with south up, but we adopted the north-up convention in 2015, so in this work, all images are shown with north up.)

Structure of this review:

Sectors of the S2 domain with typical features marked are shown in Figure 4, from amateur images, and Figure 5 from JunoCam images, also marking the latitudes of the jets. Figure 6 is a selection of our ground-based maps – one of the best from each apparition, taken from our previously posted reports. The full set of JunoCam maps is in **Appendix B**.

We post reports on the BAA Jupiter Section web site (https://britastro.org/sections/jupiter), and this review is largely derived from them, though with some new analyses and results. The more substantial interim reports dealing with the S2 domain are listed and quoted in **Appendix C**.

Many of the illustrations (which were taken from interim reports with their original labelling) also happen to show important features in the adjacent S1 (S. Temperate) domain, notably the one large anticyclonic oval (oval BA) and two large pale cyclonic circulations (the STB Ghost and STB Spectre). These were fully described in our long-term reports on that domain [Ref.9], especially the 2015-2018 report.

In this review, as the features of the S2 domain are not cleanly separated by latitude, we start by describing the S2 and S3 jets (sections 2 & 3), then the overall zonal and local drift patterns (section 4). Then, moving from the edges of the domain towards the centre, we describe the AWOs (section 5), followed by the cyclonic circulations (section 6) and finally the slow-moving dark spots near the velocity minimum (section 7). Each section begins with a summary quoted from our 2001-2012 report (Ref.1), to set the context of the newer results. Small type is used for passages chronicling individual events which have contributed to the broader conclusions.

---

2. The S2 jet (SSTBn jetstream)

Summary from Ref.1: "**The S2 jet (36ºS)** carries small dark spots in every apparition, although their number appears to vary. In recent years their maximum speed averages DL2 = -110 deg/30d at 36ºS, close to the average peak from spacecraft zonal wind profiles (ZWPs). The spots show a great range of speeds, with a zonal drift profile (ZDP) showing that they are on the anticyclonic side of the jet peak, consistent with the lower-latitude paradigm of dark jet spots as anticyclonic vortices rolling along the flank of the peak."

The mean jet speed (from 4 spacecraft) was DL2 = -104.4 deg/30d, u_3 = +38.2 m/s.

\- - - - -

These jet spots continue to be detected in almost all apparitions, always small dark spots, but they have been uncommon except in 2016 and 2017 (see chronicle below). Examples of them are shown in Figure 7 in 2016, including images from Juno's first perijove. The JUPOS chart for the S2 jet is provided in **Appendix A**; the speeds measured are listed in **Table 2**, and the chronicle below gives some more information. We have not produced ZDPs for most apparitions, but Figure 8 shows ZDPs covering the S2 jet in 2014-2016. As in Ref.1, the spots are either on the jet peak or on its northern flank with an anticyclonic ZDP identical to the spacecraft ZWP.

Table 2 (continued from the table in Ref.1) (only listing DL2 faster than -50 deg/30d):

S2 jet: Speeds of SSTBn jetstream spots					(All are small dark spots.)	
Appar'n	*DL2 (deg/month):*			*N*	*Notes*	*Disappearance?*
	Min	*Mean*	*Max*	tracked		(D = disappeared, R = recirculated)
2012	-109	-111.9 (±2.8)	-116	5		
2013/14	-96		-113	3	Several	At STZ d.ss. Sf. dark STB (several); at STB Ghost (1 D, 1 R).
2014/15					Few	A few Sf. dark STB (several); a few at STB Ghost.
2015/16	-111	-113.5 (±3.7)	-119	4	Many	At STB Ghost or Spectre (many R)
2017	-68		-99, -116		Few	Some at Spectre (.R)
& 2017	-49	-58.2 (±6.4)	-66	6	Outbreak near A5a, possibly disappearing near STB Ghost.	
2018	-68		-88		Only 1 pair	
2020	-108		-102 --> -129	2	Few	
2021	-120		-129	2	Only 1 pair	
2022	-125		-134	2	Few	

The peak speed of the S2 jet throughout recorded history is plotted in Figure 9, from the JUPOS spot tracking (**Table 2**), and from spacecraft ZWPs (which will be shown in Section 4: Figures 13 & 14). This reveals an unexpected acceleration of the jet. No speeds faster than -100 deg/30d or 40 m/s were detected before 2005, apart from one in 1988/89, but from 2012 onwards these have become the predominant speeds. In spacecraft ZWPs, the mean speed of the S2 jet was between 30-40 m/s up to 2000, but between 40-50 m/s from 2007 onwards. This trend is unlikely to be an artefact of observational improvements, given that it is seen in spacecraft as well as ground-based data, and the S3 jet does not show the same trend (see below). In fact, the S2 jet was clearly slower than the S3 jet up to 2000, but the ratio was reversed from 2007 onwards, suggesting a temporal change.

We wonder whether this change could have been caused by the mergers of three S. Temperate AWOs to create oval BA in 1998-2000, and/or by the mergers of three S.S. Temperate AWOs in 2002 [Ref.1].

Are these spots anticyclonic vortices, as on other jets?
This question was discussed in Ref.1, and is supported by the fact that they usually lie on an anticyclonic gradient on the north side of the peak (Figure 8).

Images from Hubble and JunoCam give us higher-resolution views of these spots. As there were few of them except in 2016 & 2017, they were mainly seen in Hubble (OPAL) maps [Ref.8] [not shown here]. These showed a few with ring shapes, detached from the SSTBn in the southerly STZ, indicating that they are anticyclonic rings as on other fast jets; a few smaller ones appear more amorphous. JunoCam took closeup views at its first perijove (PJ1: Figure 7), although these were mainly test shots and much better views were obtained at PJ8 (see later Figure 27) (2017 Sep.1). (After PJ8 there were very few SSTBn jet spots on the JunoCam maps, agreeing with the JUPOS charts.)

How do these spots arise? [From Ref.1:] "They are not obviously related to the major features of the S2 domain; rather, they often seem to arise at specific locations in the adjacent S1 domain (STZ). In 2004 they were arising just p. oval BA. In 2006 and 2007, and again in 2011/12, they were mainly arising ~60-80º p. oval BA".

This was not a prominent source region in recent years, and although JunoCam took fine closeups at PJ11 and PJ24, there were no such spots there then (see later Figures 28 & 29).

What happens to these S2 jet spots? [From Ref.1:] "They mostly disappear at or near the f. parts of STB structured segments... some of [them] recirculated there..."

This was also the case during the large S2 jet outbreaks in 2016 & 2017, when many of the spots recirculated at the f. end of the STB cyclonic circulations called the Ghost or Spectre: i.e. they changed from moving prograde on the SSTBn to retrograde in the STZ via an anticyclonic 'recirculation loop', whose p. end was on the S edge of the Ghost or Spectre. (Details were in our Refs.9c &9d.) Throughout, all these spots changed their latitude along with their drift rate, adhering to the Cassini ZWP (Figure 8). They retrograded for only a few tens of degrees before they either disappeared or reversed their drift again. The 'recirculation loop' was sometimes visible as a pale grey line around an orange oblong in some v-hi-res ground-based images, and strikingly so in Fig.27 (JunoCam closeup images at PJ8). See Figure 7 and later Figures 23-27.

In 2016 Feb.-April, the jet carried an unusually large number of small dark spots, mostly arising at or just p. the incipient STB Spectre, mean DL2 = -113.5 (±3.7) deg/30d, which was faster than almost all previous measurements for this jet. None of them got past the STB Ghost. Many of the spots recirculated at the f. end of the STB Ghost or STB Spectre, to retrograde in STZ for a short distance in a 'recirculation loops'. This outbreak of small dark spots on the SSTBn jet was still active at Juno's PJ1 (2016 Aug.27):, between a large SSTB-FFR (possibly their source) and the STB Ghost (see Figure 7). [See 2015/16 no.13 (Final report)]

In 2017, initially there were few tracks, though several short-lived SSTBn jet spots were halting or recirculating south of the STB Spectre, and travelling around the 'recirculation loop'. Then from Feb. onwards, several quite prominent dark spots were prograding with rather slow speeds ([DL2 = -50 to -68) in a disturbed stretch of SSTBn over tens of degrees both p. and f. oval A5a and an adjacent dark 'SSTBn projection' (Figure 11). The reason for their appearance was not obvious, but could have been instability associated with mergers of tiny SSTB vortices into the growing AWO A5a. [See 2016/17 Report no.10; esp. Fig.9].

From 2018-2023, only one or two S2 jet spots were tracked in each apparition, with none in 2019.

For more details of S2 jet spots in 2013-2023, see **Appendix C (part 1)** for important passages from our already-posted reports plus some updates.

3. The S3 jet (S3TBn jetstream)

Summary from Ref.1: **“The S3 jet (43ºS)**, not previously detected from Earth, is recorded in every apparition from 2003 onwards in our data. Dark jet spots, which are infrequent, have a peak speed of DL2 = -101 deg/mth at 43.0ºS, with others following an anticyclonic ZDP, as for the S2 jet. Uniquely, though, the S3 jet mainly carries white spots, with the same speed but at ~43.7ºS, on the south side of the jet, with a cyclonic ZDP. They apparently arise from specific sectors in the S3 domain which may represent unresolved disturbances.”

Mean latitude was 43.1ºS, mean speed (from 4 spacecraft) DL2 = -126.1 deg/30d, u_3 = +42.7 m/s.

- - - - - - -

Spacecraft ZWPs (to be shown in Section 4) show that while the S2 jet became faster since 2000, the S3 jet appears to have become slower, although by a lesser amount (Figure 10 & **Table 3**, continuing from the table and figure in Ref.1.) For this jet, unlike the S2 jet, we have no ground-based measurements before 2002; our measurements since then show no trend, and are all slightly slower than the jet peak measurements from spacecraft (Figure 10 **& Table 3**). The JUPOS ZDPs (in Ref.1, & report 2013/14 no.6, & Figure 12 [2022/23]) show that white spots and dark spots which we measure travel with the same speed, but lie on opposite sides of the jet peak revealed by spacecraft, and not on that peak. Speeds have been very consistent, averaging DL2 = -94 to -103, usually about -98 deg/30d.

Table 3 (continued from table in Ref.1):

S3 jet: Speeds of S3TBn jetstream spots							
Appar'n	*DL2 (deg/month):*			*Lat*	*N*	White or	*Notes*
	Min	*Mean*	*Max*	*(S)*	tracked	dark spots?	
		(±SD)		(±SD)	(total)		
2012	-94				1	W	
2013/14	-85	-98	-102	-43.9 (±0.2)	5	W	Group of 5 WSs, conspicuous
2014/15						W	Few, short-lived
2015/16		-102.8 (±1.2)		-43.8	4	W	Group of 4
2016/17		**-98.0 (±1.2)**			12	W	Large outbreak, spaced 7-15 deg apart
2018	-96		-97		2	W	
2019	-98				1	D	
2020	-90		-94,-96		3	1 W, 2 D	
2021	-92	**-94.5 (±2.7)**	-98		8	4 W, 4 D	Many dark spots from July onwards, short irregular tracks
2022	-89	**-95.6 (±3.7)**	-98	-43.9 (±0.2)	6	W	
2022	-85	**-97.8 (±6.5)**	-104	-42.9 (±0.1)	15	D	Many dark spots, in 70-deg longitude band

From 2012 to 2018, only white spots were observed on this jet: usually only a few per year, but in 2013/14 there were five exceptionally prominent ones [2013/14 report no.6], and in 2017 Jan.-July there was a large outbreak of them with an average spacing of 10.5° [2016/17 report no.10] (Figure 11). From 2019 to 2021, while a few white spots were again recorded, there were also a few dark spots – then a large number of dark spots from 2021 July onwards. Mean speed 2018-2021 was DL2 = -94.8 (±2.7; N = 14).

In 2022 [2022/23 report no.8], the S3 jet was quite active. It carried six small round white spots in 2022 June-July, with mean DL2 = -95.6 (±3.7) at 43.9 (±0.2)°S, i.e. on the cyclonic side (Figure 12). And from June to Jan. it carried numerous small dark spots, which were tracked in a single 70°-long longitude band that moved with the SSTC. This band was alongside a sector in which the SSTZ was unusually clear and white, so these S3 jet spots, possibly emanating from the FFR p. AWO A1, were more visible here than they would have been elsewhere. They had mean DL2 = -97.8 (±6.5) at 42.9 (±0.1)°S, i.e. on the anticyclonic side.

4. Zonal and local drift rates

4.1 Zonal wind profiles (ZWPs) from spacecraft

During this period, the only spacecraft viewing Jupiter at close quarters has been Juno, whose orbit does not allow image sequences very suitable for deriving zonal wind profiles (ZWPs). However there has been much imaging by the Hubble Space Telescope (HST), annually in the OPAL project [Ref.7] and near the time of some Juno perijoves in the WFCJ project [Ref.8]; these imaging opportunities were planned to produce at least one global map, and when possible two ~10 hours apart, in order to produce ZWPs. Representative ZWPs are shown in Figures 13 & 14, and their mean jet speeds are entered in **Table 1**.

A large set of Hubble ZWPs was published by Tollefson et al.(2017) [Ref.8a], and they have been replotted for the S2 domain in Figure 13. There are seven ZWPs, for 2009 and 2012 (2 hemispheres each), 2015, & 2016 (2 dates).

Hubble ZWPs in addition to those shown here have also been published in Refs.10 & 11.

ZWPs have also been generated from Hubble images by JUPOS team members, as follows:

[i] Grischa Hahn measured ZWPs from the Hubble images on 2014 April 21 (Ref.17 = our report 2013/14 no.10; Figure 14C).

[ii] Marco Vedovato produced ZWPs from the Hubble OPAL images on 2019 June 26-27 (our reports 2019 nos.4 & 9). He studied two longitude sectors: Sector 1 (L3 = 205-305, p. the GRS, with long S2-FFRs: 2 pairs of rotations) and Sector 2 (L3 = 130-240, further p. including oval BA, with a fawn oblong in SSTB alongside it, & S2-FFRs: 1 pair of rotations). In Figure 14E, we have plotted one of the ZWPs, which has jet parameters close to the average (black points), over his collection of individual ZWPs (pale coloured spots).

The ZWPs from previous spacecraft, and from Hubble in this time period, all showed a simple curve across the S2 domain, but with two apparent variabilities (**Table 1**, above). First, the S2 jet was clearly slower than the S3 jet up to 2000, but the ratio was reversed from 2007 onwards (Sections 2 & 3 above; Figures 9 & 10). Second, detection of retrograding speeds in the middle of the domain was variable. Voyager 1 showed no retrograde jet here, just a minimum of eastward velocity. Subsequent spacecraft ZWPs have sometimes shown a retrograding jet, especially Cassini and some more recent Hubble data sets, but sometimes not. Here we show that almost all data sets since 2012 (all from Hubble) show a modestly retrograding jet, and it is often double-peaked.

The SSTBs retrograde jet or velocity minimum

A new finding is that this westward flow has two preferred latitudes. In **Table 1** of jet speeds, the latitude of the SSTBs peak is bimodally distributed between ~39.2 and 39.9ºS. In the ZWPs from the Hubble 2009-2016 study (Ref.8a: Figure 13), all 7 profiles have a westward peak between 39.1-39.4ºS (usually the strongest), but some also have a peak between 39.6-39.9ºS, confirming that there are often two peaks. There is no general tendency for the flow to be faster at one latitude than the other.

In the ZWPs from Hubble in 2019 (Figure 14E: M. Vedovato, in two longitude sectors), the SSTBs retrograde jet has a moderate component at 39.3ºS in both sectors, plus a faster one at 39.8ºS in Sector 1 only, where there was a long series of S2-FFRs. This suggests that the south side of the FFRs may entail a faster retrograde flow slightly further south than at other longitudes.

We can conclude that the westward flow usually peaks in either or both of these two latitudes. Further study of the sectoral data in Ref.8a could show whether the pattern depends on particular structures such as FFRs.

However, these retrograde speeds are very modest. Suspecting that closed cyclonic oblongs in the SSTB, like similar structured segments in the STB (Refs.9d & 12), might have *faster retrograding speeds on their S edges*, author JR looked for them by eye in Hubble and Juno map pairs. (Speeds in the modest range shown in the ZWPs would not be visible.)

Hubble map blinks (~10 hours apart): In HST OPAL map pairs, retrograde wind in the SSTBs is always visible in FFRs, and in white or pale oblongs when present, and occasionally in other sectors. Specifically, we can see a retrograde jet in 2016 Feb. on the S edge of very long cyclonic white oblong (& in FFRs); in 2016 Dec. at most longitudes, including a pale fawn oblong, FFRs, & a very long pale sector without closed circulation; in 2018 April in FFRs, but not clearly in non-circulatory sectors; in 2019 June in FFRs & a fairly short cyclonic white oblong, & in a few other sectors.

Juno map blinks (24 min apart): At PJ26 (2020 April), map-projected JunoCam images could be blinked to reveal winds in this domain, as plotted on a hi-res map in Figure 15. This included a light brown SSTB sector (between AWOs A7 & A8) which we described as a “a pale, closed cyclonic circulation.... The retrograding jet along its S side traces out substantial waves.” [PJ26 report]. JR has now made speed estimates from this blink of G. Eichstadt’s hi-res maps of images 39 & 42 (using coherent spots to N and S, with adopted DL2 = -16 deg/30d, for reference to optimise alignment; see section 7). The displacements were estimated on the SSTBn (broad band from 35.3 to 36.9ºS [31.8 to 33.5ºS ‘centric]) and SSTBs (N crest of waves along S edge of the pale brown oblong, 38.4ºS [34.8ºS ‘centric]). They were only +2 and -2 (±0.3) pixels in 23.6 min, respectively, but this amounts to DL2 = -137 deg/30d (u = +51 m/s) on SSTBn, and DL2 = +105 deg/30d (u = -44 m/s) on SSTBs, (±22 deg/30d, ±9 m/s). Despite the imprecision, these speeds are reasonable within the error range: compatible with previous ZWPs eastwards for the SSTBn, and much faster westwards than any ZWP for the SSTBs. (Similar waves along the S edge of a long pale circulation in the SSTB were visible in JunoCam images at PJ7 and PJ41/PJ43: see Figure 16 & Section 6 below.)

Thus, our PJ26 map blinks show that a fast retrograde jet does exist within a long closed SSTB circulation. This may be a general feature of mid-latitude domains. The STBs retrograde jet is sometimes faster along the edges of STB structured segments, both dark/turbulent and pale/quiescent [Ref.9, esp. 9d, & Ref.12]. Likewise in the NTB, G. Hahn’s ZWP from Hubble images in 2014 April showed unusually fast speed in the NTBn retrograde jet along a pale cyclonic cell [Report 2013/14 no.10.] (This was an example of very dark oblong which reddened and faded to become a bright cream-coloured or whitish oblong, much like the features that we describe in the SSTB: Section 6 below.)

4.2 ZWPs & ZDPs (amateur data)

JUPOS members have also produced **ZWPs** from amateur data (Figure 14), by plotting the speeds by correlation of all features and cloud textures between maps separated by 1-3 rotations (10-30 hours). They may not be as accurate as Hubble-based data, because a small error in image timing or limb-fitting can make a large difference to the derived winds, so the baseline sometimes has to be adjusted empirically. These profiles were posted in our reports 2012/13 no.9 (Appendix 5), 2013/14 no.10, 2019 no.4, and 2023/24 no.3 (Appendix 2). There are only minor differences between the various ZWPs in the S2 domain, mainly the shape of the velocity minimum, which is ‘blunt’ in all but one of these ground-based ZWPs, suggesting that the westward extreme is not detected. Thus, as in most domains, the ground-based profile is similar to the ZDPs that we obtain by tracking of small spots, whereas the Hubble ZWP is more sensitive to true wind speeds.

For two apparitions we had analysed the speeds and latitudes of white ovals in the S2 domain from JUPOS data, producing a **zonal drift profile (ZDP)** (Figure 8). In 2014/15 (Final report, no.12), the mean positions for the AWOs and also cyclonic white ovals fitted well on the Cassini ZWP (the cyclonic ones were trapped and rattling between AWOs at the time). In 2015/16 (Final report, no.13), the S2-AWOs were plotted individually and fitted perfectly onto the Cassini ZWP. (No other S2 spots were plotted.)

However there were no good tracks for dark spots in those two apparitions. In order to get a more comprehensive ZDP, we have now plotted the JUPOS data for 2022/23 (Figure 12). This figure, and the detailed description in the figure caption, are adapted from Report 2022/23 no.8 with new Appendix. While the ZDP largely parallels the Cassini ZWP, there are some systematic differences, including the 'blunted' velocity minimum as in most other domains. The slow-moving dark spots near that minimum (see Section 7 below) were most interesting. Many of these were in a long pale fawn sector of SSTB, either on its S edge (anticyclonic) or its interior (cyclonic), and those on the S edge corresponded to dark wave-like bulges; as at PJ26 (Figure 15), these waves probably marked the track of the retrograde jet (Figure 16). These spots had DL2 between -10 and -27 deg/30d, the same in the interior as on the S edge, showing how a zonal slow current can operate over both cyclonic and anticyclonic latitudes separated by a wavy retrograde jet.

4.3 S.S. Temperate Current (SSTC): Drift rates for AWOs

The most obvious and long-lived circulations in the S2 domain are the anticyclonic white ovals (AWOs) (see section 5 below). They have fairly consistent drift rates, which comprise the SSTC. There were always 7 to 9 long-lived AWOs during 2012-2023, which we tracked throughout. The full JUPOS charts are in **Appendix A** and a condensed, simplified version is in Figure 17.

Average speeds of the long-lived AWOs have been calculated from the JUPOS charts, as follows. (DL2, deg/30d):
2013 Jan.1 to 2016 May 1: -27.9 (±1.2) (N = 9)
2016 May 1 to 2019 Sep.1: -29.8 (±0.7) (N = 7)
2019 Sep.1 to 2023 Jan.1: -29.3 (±0.9) (N = 7)
The mean over the whole period is thus DL2 = -29.0 deg/30d.

We have inspected the data for any trends over this period, but none are apparent. The mean speed has not varied systematically. When there is an array of multiple AWOs closely spaced, they have often shown a steady collective drift with DL2 = -27 to -28 (thus A8-A0-A1-A2, 2012-2016, and A1—A4, 2019-2022). But at other times arrays have shown drift rates outside this range. AWOs that are not in arrays can also have a wider range of drifts, sometimes slower (A6 and A7 were an isolated pair moving slowly and steadily with DL2 = -27 --> -25 from 2013-2016) and sometimes faster; drifts up to -31 are common. AWOs just before and after merging do not show consistent trends.

DL2 values were given over shorter intervals in some of our apparition reports. They included apparition means for most or all AWOs, ranging from -27 to -30.5; and speeds for single AWOs or pairs, ranging from -25 to -40 over intervals which might be as short as one month. There was also one extreme speed of -48, for oval A7 in 2018 just before it merged with A6.

An interesting trend over time does emerge when these SSTC averages are compared with those from previous history (Refs.1 & 2): mean speeds since the 1980s have been faster than those in earlier years (Figure 18). The data before 1985 was mostly visual, and could be slower for two reasons: (i) it was derived from various features as the AWOs were rarely resolved – although recent experience shows that other features are usually trapped by the AWOs; (ii) visual drift rates have a systematic error of +0.6 deg/30d during apparitions

(Ref.2). Nevertheless, the increase in speeds since 2001 seems to be too great to be entirely artefactual.

Oscillations?

For most of the time, the AWOs have steady courses. However, a few of them (especially the smaller ones) occasionally oscillate in speed, and in Ref.1 we reported that AWO A0 (the smallest) tended to oscillate after it passed oval BA in the STZ. The JUPOS chart (**Appendix A**) shows A0 oscillating again from 2013 Nov. to 2014 Jan., with period ~38-45 days (much shorter than after previous passages); and again in early 2016, with longer period; but these oscillations were not associated with BA. Nor were various speed changes of other AWOs, whether periodic or not. On the other hand, in 2014/15 when A8 and A7a were rattling to and fro, close together but separated by a cyclonic white oval, this could have been initiated by their passage past BA.

4.4 Effects of oval BA in the S2 domain

The SSTC runs faster than the S. Temperate Current (STC) in the adjacent domain, so features in the S2 domain are always drifting eastwards relative to the large anticyclonic oval BA in the S1 domain. We have noticed several phenomena which have repeatedly occurred adjacent to oval BA, confirming similar tendencies in our previous review [Ref.1]:

1. In 2002, a pair of long-lived AWOs merged just as they were approaching BA, and in 2010 a long-lived one merged with a minor one shortly after they passed BA [Ref.1]. In 2012-2023, all three mergers of AWOs (see below) occurred during or just after they passed BA.

We also noted [Ref.1] that small AWOs tended to appear next to BA. This also happened in late 2014 and perhaps mid 2022 (& see Figure 15), but most small AWOs have appeared at other longitudes.

2. In 2000-2012 [Ref.1], the drift rates of some long-lived AWOs may have been affected by passing BA; most clearly, A0 repeatedly started to oscillate in drift rate when it passed BA. As noted above, in the present survey, this behaviour was not repeated by A0, but may have been by AWOs A8 and A7a in 2014/15.

3. In 2008 [Ref.1] we noted a cyclonic white oval next to a dark bar, both of which dissipated as they passed BA. In the present survey, cyclonic white oblongs did not tend to appear or disappear close to BA. But on three occasions, a small very dark cyclonic spot appeared while passing BA (2020 July, 2021 Aug., 2022 July) (see below). The 2020 and 2021 examples then lingered near BA for some time as they had slower drift than the SSTC.

4.5 Drifts of cyclonic features

Cyclonic features in the SSTB will be described in Section 6. Large ones are usually trapped by flanking AWOs, though they sometimes oscillate between them (changing latitude as well as speed, in accordance with the ZDP). We can enquire whether cyclonic features in sectors where they are *not* trapped tend to move more slowly than the AWOs, as is the case in some other domains [Refs.1 & 13]. Here we note a few cases that are consistent with such a tendency, but they are too few and inconsistent to be definitive.

FFRs are usually either trapped by AWOs, or too ill-defined to be tracked, but there are two examples in the JunoCam maps for 2017-2018 (**Appendix B** & Figure 17) which could be observed drifting freely over 4-6 months, and both had slower drifts than the nearby AWOs, at or slightly below the lower limit of typical SSTC drifts.

First, a large FFR in the sector between A5 & A5a was initially close to A5 (PJ1 to PJ7), but then migrated closer to A5a (PJ7 to PJ11) -- although this occurred mainly because the AWOs suddenly accelerated; the large FFR actually maintained a normal SSTC drift of DL2 ~ -27 deg/30d throughout.

Second, a small FFR appeared in the middle of the sector between A3 & A4 in 2017 July (PJ7) and drifted closer to A4 with DL2 ~ -25, until Dec. (PJ10).

Another minor example occurred in 2021 April-July (PJ33-PJ35), f. A5; it drifted with DL2 ~ -26 towards the larger FFR p. A7 and merged with it.

Moreover, it is common for a FFR to remain just p. an AWO for a long time, but the only ones to have developed f. an AWO are those just mentioned which then had slower drifts than the nearby AWOs. All this suggests that the FFRs do tend to drift more slowly than AWOs in the S2 domain as in higher-latitude domains, although they are rarely free to do so. This contrasts with the behaviour of FFR-like turbulent STB segments in the S1 domain, which routinely drift more rapidly than the large anticyclonic oval BA [Ref. 9].

There are occasionally small, **very dark cyclonic spots** not trapped by AWOs, which could be relevant. The JUPOS chart has good tracks for such spots in 2018, 2020, 2021 (two), and 2022 (two). Most of these drifted more slowly than the AWOs, but not consistently. Those in 2018, 2020, and 2022 (ds1) all appeared adjacent to oval BA [all described below], so this may have had a local effect reducing their speeds, and one of the tiny spots in 2021 was temporarily trapped alongside BA (later Figure 32). But there are also some similar spots with different speeds, including some that match the AWOs, so there is not sufficient evidence for a systematically different drift rate.

---

5. Anticyclonic white ovals (AWOs) (40-41ºS)

Summary from Ref.1: "The most conspicuous and long-lived features... are **anticyclonic white ovals (AWOs)**. Three or four have been tracked for 27 years in the S2 domain (40.5ºS)...and may have existed for much longer, before modern imaging could detect them. In the S2 domain, from 1986 to 2012, there were always 6-9 long-lived AWOs, among which three disappeared (probably all by mergers) and five appeared; the nominal mean lifetime is ~50-60 years but this may be limited only by occasional, stochastic mergers....

In contrast, transient AWOs also appear (seven recorded, but the recent frequency has been about one every two years), but do not last more than 1-2 years; and they can disappear either by merging, or by shrinking to invisibility. It is notable that the number of the [long-lived] AWOs has remained between 6 and 9 throughout the 27 years reviewed, suggesting that the number is somehow regulated....

[An] hypothesis is that these ovals develop to take up surplus energy and vorticity that cannot be accomodated in the jets, so a certain number of them may be required for this function, regardless of their spacing."

&: "The mean latitude of the AWOs was 40.6 (±0.4) ºS from Earth-based photographs (1950-1991), and 40.5ºS from Voyager. We do not have an independent measurement of their latitude from JUPOS, as 40.5ºS has been adopted for these AWOs as a reference for checking the calibration of other measurements."

- - - - - -

5.1. AWO life histories: Origins and mergers

In 2012, there were 9 AWOs, all long-lived, labelled A0 to A8.*

*[*Note*: The numbering is continued from the previous history of these ovals, given in Ref.1. In our 2011/12 & 2012/13 reports, some of the identifications were mistaken; they are corrected here.]

They can be tracked in the JUPOS charts (Figure 17 & **Appendix A**) and in ground-based maps (Figure 6) and in JunoCam maps **(Appendix B)**. Over the 12 years since 2012, two pairs of these ovals have merged (A0/A8 and A6/A7), so now in 2024 there are only seven: A1 to A5, A7 & A8. In the interim, several smaller, shorter-lived AWOs have appeared, but as we noted in Ref.1, they have not lasted; no new long-lived AWO has appeared.

Where the AWOs clustered together, the JunoCam team referred to them as the "string of pearls" (Figure 19). Figure 20 shows JunoCam closeups of two of them.

The mergers of long-lived AWOs, the first since 2002, were as follows.

--A0 and A8 merged on 2016 Nov.18-23, as they passed oval BA. [See 2016/17 report no.4]

--A6 and A7 merged in 2018 May. Both AWOs had accelerated in March, passed BA in April, then merged in late May (Figure 21). [See 2018 reports nos.5 & 6.]

Also, A5a (see below) was an intermediate case: it became larger and lasted longer than other short-lived ones, but after 4 years it merged with A6, in 2019 Dec., adjacent to oval BA (see later Figure 29).

Note that all three mergers occurred during, or just after, their passage past oval BA. From our previous records, so did the merger of an earlier A6&A7 in 2002; merger with A5 a few months later may have been due to continuing instability [Refs.1 & 14]; and in 2010, A7 merged with a minor AWO shortly after they passed BA [Ref.1]. Only the merger of A7&A8 in 1992 did not occur near a large STZ oval [Ref.1].

The overall budget of AWOs since 1986 is summarised in **Table 4**, continued from Ref.1. Over a span of 37 years, the mean number of large AWOs has been 7-8, and 5 have appeared while 5 have disappeared; this implies a mean lifetime of ~56 years. Some of them have existed throughout these 37 years (definitely A3 and A5, and probably A1 and A2 although the observations were insufficient to track them continuously before 1992: Ref.1). Notably, it is still the case that large AWOs have never been observed to disappear except by merging with others, so there is no evidence for any intrinsic limit to their lifetime.

Table 4: Budget of AWOs

Table: Budget of AWOs

(Table 3 in Ref.1 is here simplified and expanded)

	Long-lived Appeared	Long-lived Disappeared	Transient*
1986-2002	2 (A4,A8)	3 (A8,A6,A7)	1
2003-2012	3 (A0,A6,A7)	--	6
2012-2023	--	2 (A0,A6)	4

*Transient AWOs lasted 1-2 years, except A5a which lasted 4 years.

Few were observed before 2003 because of their small size.

Their mean frequency since 2003 has been 0.5 per year.

The four short-lived AWOs were as follows.

'A7a' appeared during solar conjunction in 2013, first seen in August. (There did not appear to be any substantial FFR adjacent to this location.) In 2013/14 and 2014/15 it repeatedly jostled against A8 (separated from it by a cyclonic dark spot which turned into a white oval). At the end of the 2015 apparition it was only 12° p. A8, so they seemed likely to merge, and indeed A7a disappeared during solar conjunction in late 2015.

'A5a' appeared during solar conjunction in late 2015. Initially it was oscillating with period ~78 days. Many small white spots were observed to merge with it during its life, coming from a large FFR p. it. It persisted until late 2019, but was only 9-14° from A7 in 2019 Sep-Oct.; then during solar conjunction, the two AWOs were imaged in the act of merging by JunoCam at PJ24 (2019 Dec.26). *[See below]*

'A4a' was only recorded from 2018 Jan.-June, f. a FFR and immediately p. A4 [see PJ11 report].

'A0', another new small AWO very similar to 'A4a', existed from 2021 Aug-Dec., f. a FFR and a short distance p. A1. It may then have merged with A1 as the FFR drifted up towards it. *[See below]*.

5.2. Transfer of anticyclonic vortices from a FFR to a new AWO

[Much of this section is adapted from Report 2016/17 no.8 (expanded version)]

In 2016-2017 we noticed repeated mergers of tiny AWOs, in which the most westerly partner was always a recently developed small AWO called A5a. The tiny AWOs were probably emerging as anticyclonic vortices from a large FFR further west. So the observations provide evidence for a dynamical pathway from the FFR via vortices into a growing anticyclonic oval.

A5a had an oscillating track and appeared to absorb the smaller white ovals that came towards it from the east (see chart, Figure 22). Six such mergers were probably recorded, in 2015 Dec., 2016 Feb., 2016 June (Figures 23 & 24), 2016 August (recorded only in the JunoCam PJ1 images: Figure 26), 2017 March (the best documented: Figure 25), and 2017 April.

We cannot be certain that the ovals merged; it is possible that one was just torn apart. This is an ambiguity that we have encountered repeatedly, particularly with encounters of larger AWOs in the N. Tropical domain. Atmospheric dynamics suggests that the ovals merged, at least partially, so we continue referring to such events as 'mergers'. This would suggest that these events would gradually reinforce the remaining AWO (A5a), to become a ninth long-lived one. A5a did grow larger over this period (Figure 26), but the growth was modest, and would not be sustained.

The tiny ovals were short-lived and unnumbered, and too small to have been reliably observed until recently. But there were a couple of similar events in 2010, contributing to the present long-lived ovals A6 and A7 [Ref.1].

The other interesting aspect of these tiny ovals is their relationship to a large FFR further p. (E) in the SSTB. It is increasingly evident that many jovian phenomena are generated by disturbance from such cyclonic turbulent regions [e.g. Ref.15]. We suspect that this is the case here: that these tiny ovals are generated repeatedly by waves or turbulence emanating westward (in the f. direction) from the giant FFR (Figures 22 & 27). The little ovals themselves are not always drifting west relative to the FFR; as shown in the JUPOS chart, some oscillate. Nevertheless, they eventually merge into A5a at the f. (W) end of the series. This behaviour is very similar to that in the S. Temperate (S1) domain, where spots emerge westward from turbulent dark sectors of STB, and often merge to form small anticyclonic ovals [e.g. Refs.9 & 15, & the Cassini map video Ref.16]. There is increasing evidence that much the same process happens in most domains on Jupiter [e.g. Ref.15].

JunoCam images at PJ8 (2017 Sep.1: Figure 27) showed this sector of SSTB f. the giant FFR, and the beautiful patterns f. the FFR supported our inference that small anticyclonic vortices were arising from the turbulence of the FFR, and drifting gradually westwards relative to it, eventually merging into A5a. Our PJ8 report includes an animation of three images of this region; the anticyclonic sense of the vortices can just be detected (although it is obvious anyway from their shape: Figure 27). We have also made animations from 4 pairs of Hubble maps ~10 hours apart [not shown]: OPAL, 2016 Feb.9; WFCJ, 2016 Dec.11 (at PJ3); WFCJ, 2017 Feb.2 (at PJ4); OPAL, 2017 April 3. All show turbulence extending from the west end of the FFR, with the Feb.9 and Dec.11 pairs perhaps best illustrating how this can generate anticyclonic vortices.

This process leading up to A5a must have ceased after early 2018 (after PJ11: Figure 28), when the FFR became so close to A5a that distinct vortices would not be identifiable. From PJ11 onwards, JunoCam maps showed that it had shrunk in size. After mid-2018, it drifted closer to A7, and was imaged merging with A7 at PJ24 (2019 Dec.26) (Figure 29). At that time the pair was approaching oval BA, but a more immediate cause for the merger might be the renewal of the large FFR p. A5a, which had been less active some months previously [see our PJ24 report].

A similar case occurred in 2021, with the new small oval dubbed ‘A0’ [Report 2021/22 no.10]. It was tracked 20-30° p. A1 from 2021 August onwards. It seems likely that A0 was created or sustained by mergers of smaller anticyclonic vortices emerging from a large FFR just p. it, just like A5a. Blinking of the Hubble OPAL maps (2021 Sep.4, ~10 hours apart; posted with Report 2021 no.5 as Animation-2) reveals a row of three such vortices leading from the FFR to the AWO A0. Also at PJ38 (2021 Nov.29), we noted a chain of four anticyclonic vortices likewise (Figure 30). But by PJ39 (2022 Jan.12), the FFR had moved closer to A1 and the chain of vortices had diminished, while A0 had disappeared; the JUPOS chart suggests that it merged with A1.

---

6. Cyclonic circulations (38-39ºS)

Three types of cyclonic features are recognised in most domains on Jupiter: white ovals or oblongs; dark ovals or oblongs, and chaotic areas known as folded filamentary regions (FFRs). The oblongs are closed, quiescent cyclonic circulations, whereas FFRs are turbulent and often emit disturbance to east and west. In the S2 domain they are clearly distinguished, all centred at 38-39ºS. JunoCam images have provided close-up views of all three types, and added a fourth: pale fawn-coloured oblongs, sometimes very long, which often appear dull whitish or nondescript in ground-based images.

Up to 2012, as covered in Ref.1, the white and dark features could be well documented by amateur observers, but the limitations of imaging meant that FFRs in the SSTB could not be reliably surveyed for much of an apparition, let alone between apparitions. Now, improvements in amateur imaging have made it possible to document the FFRs for several months around opposition, and – most importantly – the JunoCam imaging has given a hi-res map of much of the S2 domain on every orbit, including during geocentric solar conjunctions. There is also at least one global map from Hubble every year. So by combining JUPOS and JunoCam data, we can produce a complete history of the life cycles of S2 FFRs and the interconversions of different cyclonic structures over at least 7½ years.
The appearance and life histories of these types, from amateur and JunoCam images, have been summarised in our EPSC2024 abstract [Ref.18] (copied in **Appendix D**), which is a summary of this section.

We already identified all these cyclonic structures in our apparition reports covering early 2016 and the four apparitions from 2019 to 2023. Here we fill in the 2016/17 and 2017/18 apparitions, and combine all these data (from JUPOS and from JunoCam, as well as some from Hubble), and illustrate them with the full set of JunoCam maps (**Appendix B**). The result, spanning 7½ years, is summarised in Figure 17. Figures 4 & 5 identified the types of features, and as an example, Figure 31 shows a series of JunoCam maps of one sector which successively transformed between the four cyclonic types. A higher-resolution panorama from JunoCam is in Figure 32.

6.1. Cyclonic white ovals (CWOa’s) and oblongs (CWOb’s) (38-39ºS)

Summary from Ref.1: “Where the space between two AWOs is short, it is common for the SSTB there to turn into a **white oval or oblong** (elongated white sector), at 38-39°S. Their form and latitude imply that these are closed cyclonic circulations. They never develop simultaneously in adjacent sectors. Their lifetimes range from several months to nearly 6 years. They always expand progressively during their lifetime.... These are probably closed circulations, and always expand at rates which depend on their length. ... Expansion is barely perceptible when the oblong is <10 deg long, but once it is longer, it lengthens faster, [at ~0.3 to 1.4 deg/mth], although with some fluctuations. In three cases when the length exceeded 20-26 deg, the expansion suddenly proceeded even faster (1.9 to 2.6 deg/mth in two cases)."

- - - - - - -

A cyclonic white oblong (CWOb) as seen by JunoCam is in Figure 33. Equivalent but larger circulations in the S1 domain have been well studied, including the STB Ghost and the STB Spectre [Refs. 9c, 9d, 12], which appear in some of the illustrations herein.

CWOb's can be seen as light blue areas on the JUPOS chart in Figure 17. Here we refer to them according to the AWOs that flank them. First we describe their life histories from our interim reports and JunoCam maps:

A2-A3, up to 2012: In 2011/12, the sector p. A3 had been a persistent greyish-white cyclonic oblong. In late 2012 most of the long sector from A2 to A3 was a white oblong, 43° long and growing, but ill-defined at its f. end, and in early 2013 it was becoming less distinct.

A3-A4, 2013 Nov.—2014 May: Between A3 and A4, a cyclonic white oval developed in early Nov., which was surprisingly methane-bright and remained so into Dec. (Figure 34), fading somewhat in early 2014 but remaining very bright at visible wavelengths. From its appearance, nestled between AWOs A3 and A4, observers called it "the Mickey Mouse spot" (as viewed with south up). In 2014 April-May it showed signs of lengthening, but it broke up in late May, 2014, just before solar conjunction.

A4-A5, 2014 Aug.—2016 Feb.: A new cyclonic white oblong developed between A4 and A5 during solar conjunction, after 2014 May and Aug.; it was very bright in late Aug. when the apparition began. [We have no relevant methane images from that period.] In 2015 March it started to expand. It became less white in 2016 Feb, but then lingered for another year, gradually darkening: still whitish in amateur images but a long, pale fawn oblong in JunoCam and HST images.

A3-A4, 2016 Aug.—2017 April: There was a dark bar in this short sector in early 2016, which faded to a pale fawn-coloured loop as seen by JunoCam in August (PJ1) and Dec.11 to 2017 Mar.27 (PJ3-PJ5, & HST), though it appeared white in amateur images. It had expanded to be 40° long in 2017 March and April; but in April it began to be dimmed by thin grey streaks. A new small FFR appeared in this sector in 2017 July.

A8-A1, 2018 April—2019 Jan. JunoCam showed that this developed in 2017 Dec. from a dark reddish streak (PJ10) that faded. It was only pale fawn-coloured until 2018 April, when it brightened (Figure 35), becoming brilliant white in late May, and also methane-bright even up to mid-August. In 2019 Jan. it was a white oblong 23° long, elongating as the AWOs moved apart. In Feb. it became duller, and it remained dull white up to 2019 Oct, even as a dark strip of 'southerly SSTB' extended f. A8 from 2019 June.

A7-A8, 2019 Oct-Dec. This short-lived CWOb (not previously reported) became bright in Oct. and JunoCam showed it bright in Dec. at solar conjunction (Figure 31).

A1-A2, 2018 Sep.-2019 Oct. In early 2018 there had been a dark streak here, which faded in June-July. JunoCam first observed this white oblong at PJ17 (2018 Dec.21), during geocentric solar conjunction. It was bright white from 2019 Feb. to the end of May. In June it elongated and became duller, and was dull white up to Oct. (JunoCam viewed it closeup at PJ22 in Sep. and showed it was disturbed.)

A4-A5, 2021 May—2023 Aug (& thereafter). JunoCam showed a dull grey-brown oval at PJ31 & PJ32 (2021 Feb.21) which was slightly lighter at PJ33 (April 15). Amateur images in March-April showed it very light, slightly reddish, and by May it was fully white. Figure 6 shows it weakly methane-bright in 2021 Sep. It remained bright white thereafter, but did not expand: it was only 7-9° long up to 2021 Dec. In 2022/23 it remained bright white, growing in length from 10° to 14°, and methane-dark as usual (esp. towards the limb – Figure 36 -- & esp. in JunoCam maps). It was still bright white up to 2023 August, and still present thereafter although defaced by blue-grey streaks, up to 2024 Feb. In 2024 March it became white again, as confirmed in JunoCam images in solar conjunction up to PJ61 (May 12).

P. A2, 2022 April-August: The CWO p. A2 had begun as a small light spot in 2021 Dec, and was still dull in JunoCam images at PJ39 & PJ40, but was a distinct white oblong from 2022 April (PJ41) to August. But it was only dull white again in Sep. & Oct., and disappeared in Nov. Methane-dark (esp. in JunoCam maps).

- - - - - - - -

From 2014 to 2024 there were three examples of CWOb's which lasted for more than a year, and we have measured their expansion rates from the JUPOS charts (Figure 37). These largely agree with the two-threshold principle suggested in Ref.1.

A phenomenon not appreciated before the JunoCam imagery is that a closed oblong can spend up to a year as a dull or **pale fawn-coloured oblong**, sometimes before or after being fully white. An example was shown in Figure 15 and discussed in section 4.1 above. In amateur images such oblongs may look off-white, or just dull; in JunoCam or Hubble images they look more reddish. The difference may be partly due to contrast enhancement in amateur images, but largely due to the filters used on the spacecraft, as other features also are more likely to show reddish colour in JunoCam and Hubble images (e.g. oval BA and the EZ). Hubble OPAL images used a narrow-band violet filter (395 nm) for the blue channel, while blue filters used in JunoCam and in a typical amateur set (Chroma) extend up to 505 nm; conversely JunoCam's red filter extends further into the IR (to 800 nm) than typical amateur filter sets.

Onset of CWOb's: The CWOb's that began in 2016, 2017, 2018 and 2019 all developed where there was previously a dark streak that faded. Those that began in 2017, 2021 and 2022 all went through a phase of being a dull brown or fawn oval before becoming white (and others may also have done so unobserved).

The two that began in 2013 and 2014 were very bright white; so was the A8-A1 CWOb in 2018 May; and at least 2 of these 3 were, surprisingly, also bright in methane-band images. This was static brightness of the white oblong, not a convective plume within it; it is very rare for a cyclonic oval to be methane-bright except with a convective plume. But for most of their lifetimes, they are methane-dark (e.g. Figure 36), like equivalent circulations in the STB (e.g. Figure 42).

Lifetimes: We have recorded lifetimes as short as 4 months, and ranging up to 2.8 years in this survey, and up to nearly 6 years in earlier ground-based records [ref.1].

Termination: Four CWOb's whose later stages were observed by JunoCam (A4-A5, 2014-2016; A3-A4, 2015-2017; A8-A1, 2017-2019; A1-A2, 2018-2019) all ended gradually, changing from white to dull white or fawn, sometimes being very long but retaining the loop form suggesting continuing circulation; sometimes it was also visibly disturbed. This stage lasted for up to a year; then it was terminated either by a dark SSTZB extending alongside it (one case), or by a new FFR developing within its former boundaries (three cases).

JunoCam shows that these long pale fawn sectors may contain smaller cyclones (e.g. PJ3, PJ23, PJ25 – cf. STB Spot 8 developing within the old Spectre) or a convective outbreak probably initiating a new FFR (e.g. PJ3 & PJ26).

Smaller white ovals

Compact cyclonic white ovals are sometimes seen, usually trapped between pairs of AWOs. Sometimes, but not always, they form by fading of dark spots or oblongs (see below). Some eventually expand into white oblongs (listed above). Others do not; some of these were simply smaller, but one example was just as wide in latitude as a cyclonic white oblong. It sometimes takes many months before a white oval becomes large enough to expand into an oblong, and perhaps this process can be blocked by external pressures, or the oval does not live long enough.

6.2. Cyclonic dark spots & bars

Long dark bars at 38ºS sometimes occur, usually trapped between close pairs of AWOs. A JunoCam image of one is in Figure 38. The most distinct examples were as follows (see chart in Figure 17).

2016, A3-A4: This was a pale fawn oblong (ranging from pale brown to dull whitish), until it darkened more in June; then it turned into a white oblong during solar conjunction.

2017, A6-A7 (imaged at PJ6 & PJ7). It became a brown streak in Feb. then faded away.

2018, A5a-A6 (imaged at PJ11 to PJ13): Fading at PJ14 to PJ16 after the A6/A7 merger, becoming a pale fawn oblong. [There was also one p. A6, at PJ11 & PJ13.]

2018, A1-A2 (imaged at PJ13): Very dark grey or brownish-grey up to May, then faded in June-July, without detected reddening. But JunoCam saw it as reddish-brown on May 24 (PJ13), dull white on Sep.7 (PJ15).

2019, A7-A8; imaged at PJ18,19,21 (Figure 31).

Small, very dark cyclonic spots or bars ('mini-barges') at 38-39ºS are occasionally seen, as shown by dark blue points on the JUPOS charts (**Appendix A**). More have been recorded with the improved amateur imaging from 2018 onwards, as they are usually very small. Figures 30 & 32 show an examples in JunoCam images. JunoCam images sometimes show even smaller reddish cyclonic vortices in the middle of whitened SSTB sectors.

The JUPOS charts have good tracks for such small dark spots (d.ss.) in 2018, 2020, 2021 (several), and 2022 (two). Most of these drifted more slowly than the AWOs, but not consistently. Many of these developed adjacent to oval BA, as described here:

The 2018 d.s. (from 2018 report no.6, etc.): A long dark brown streak between A5a-A6 was passing BA in 2018 Feb., when its p. part condensed into this very dark brown 'mini-barge'. This drifted with DL2 = -28 at ~38ºS, shrinking. It turned lighter reddish-brown in March, then light fawn-coloured in May. Meanwhile the f. part was a longer brown oblong (Figure 21) which broke up, & faded to light fawn-coloured by PJ16 (Oct.).

The 2020 d.s. (from new 2020 no.10): There was also a slow-moving, very dark cyclonic spot, at ~38ºS, which was alongside oval BA when it first darkened in late June; it may have developed from a much fainter spot as it passed BA. JunoCam showed it as a small dark oval (PJ30, similar to STB-DS6 nearby); perhaps paler reddish-brown on Dec.30 (PJ31). It was well tracked by JUPOS from July 1 to Nov., with DL2 = -20.9 then -24.4.

A d.s. in 2021 appeared f. BA but then became trapped on its S edge (see JUPOS chart and Figure 32).

The 2022 'ds1' (from 2022/23 nos.5 & 8): ds1 was a small, very dark brown, cyclonic spot with typical SSTC drift. Its latitude ranged from 38.2 to 38.5°S in accordance with the cyclonic gradient. It first developed in early July as it was about to pass oval BA. At the end of Oct. it collided and probably merged with a very small cyclonic white oval f. it. Then it was fading in Dec., and during Jan. it dwindled to become a small, light brown spot with a white collar. By late Jan. it was a dull white cyclonic oval, likewise at PJ49 (March 1). So this was a typical example of a dark spot fading through reddish to white. (Figure B40).

Other smaller ones in 2022 are also shown on the ZDP [**Appendix A** & Figure 12].

Cyclonic dark spots turning red and fading:

Summary from Ref.1: "A recently recognised phenomenon is that dark cyclonic belt segments or barges in several domains sometimes become reddish just before fading away [Ref.19 p.215]. Three examples were recorded..."

In 2012-2023, more examples have been recorded in the S2 domain, and are visible on the JUPOS charts. (Colour sampling of some examples in Adobe Photoshop suggests that the visual impression of reddening is due to an increase in lightness rather than saturation.) Sometimes they convert to a CWO, sometimes they just disappear or are subsumed into a FFR. They were as follows:

Between A7a-A8, 2013 Nov.—2014 April, then a CWOa until 2015 May.)
Between A0-A1, 2013 Dec.—2014 May, then a CWOa until 2016 July.)

--In 2013/14, A very dark 'mini-barge' between A7a-A8 became lighter brown and shrank, then a brown streak between A0-A1 likewise shrank, until both appeared as light reddish ovals (Figure 39). Both of these became cyclonic white ovals (see 2015 map in Figure 6). They were sometimes bouncing between the flanking AWOs (see JUPOS charts, **Appendix A**). [Reports 2013/14 no.8 & 2014/15 nos.3 & 12.]

Between A5a-A6, 2018 Feb.—May: described above.

[Between A7-A8, 2019 Aug-Dec. (Figure 31) A bar 13º long was very dark brown till Aug., then it faded though without further reddening, and disappeared in Sep. It was a white oblong at PJ24 (Dec.26) but this did not persist. It was a fawn-coloured loop in early 2020.]

Between A7-A8, 2021 July-Aug.; the spot was then lost into a FFR after Aug. [2021/22 no.10: not a CWO as suggested on chart].

F. A7, 2022 Oct: A very dark brown spot was Nf. A7 in June-Sep. (well viewed by JunoCam at PJ44). It was red-brown at the end of Sep., fading in early Oct., and then lost into the adjacent FFR p. A8. [2022/23 no.8]

F. A8, 2022-23 ('ds1'): described above (Figure 40).

6.3. Folded filamentary regions (FFRs)

FFRs are a major constituent of all the higher-latitude domains, as shown by spacecraft imaging. Examples from JunoCam are in Figures 27-30 & 41. Animations of JunoCam images showing the winds in S2-FFRs were shown with our reports for PJ28 and PJ44.

FFRs were historically difficult or impossible for amateurs to observe. In 2000-2012, covered in ref.1, FFRs in the SSTB could be resolved in the best amateur images around opposition, but could not be reliably surveyed otherwise. Now, as outlined at the start of Section 6, combination of modern amateur maps and JUPOS charts with JunoCam data has provided a complete history of the life cycles of S2 FFRs from 2015 to 2023 (Figure 17).

Life histories of FFRs

This survey shows that two FFRs lasted throughout (at least 8 years, as both were still present in early 2024), while others lasted for several years or just months, which can be as short as ~4 months. We must note, though, that the level of disturbance can vary; some FFRs can be less turbulent for a shorter or longer time.

The large FFR f. A5 has existed throughout (at least 8 years). It was f. A5 up to 2017 Aug. (approx.), then drifted f. towards A5a (which had formed from vortices emerging f. the FFR, as described in section 5.2). From 2018 onwards, it was p. A5a and then (after the A7/A5a merger) p. A7 (Figure 17). A rejuvenation of it in 2023 Aug. is described below.

Other FFRs were also very long-lived:

- A2-A3 (throughout, at least 8 years, though sometimes weak: always a short sector).
- A3-A4 (new in 2017 July: persisted till 2023, though sometimes weak).
- A4-A5 (new in 2017 May, persisted till late 2020, then became a dull oval --> white oval in 2021).

Other sectors were more changeable:

A6-A7: FFR from ≤2016 Jan-June. Dark brown segment in 2017 March-July, which became a new FFR again in Oct., but disappeared as the AWOs converged towards merger.

A5a-A6: FFR may have started with a tiny convective outbreak in 2016 Dec.(PJ3) in a long pale ochre strip. The new FFR was present in 2017 March to Dec., but the sector was quiet in 2018 with a dark oblong, which faded in Oct.(PJ16) after the A6/A7 merger. Bright outbreak seen in 2019 Feb.(PJ18) (Figure 42); this new FFR seen again in 2019 March-June, then disappeared as the AWOs converged towards another merger.

A7-A8: FFR from ≤2016 Jan., but small and weakly active in 2017: quiescent in 2017 Oct., then a dark reddish streak in Dec. A small new FFR appeared in 2018 March, & expanded. But in 2019 there were again dark reddish streaks, which merged then faded away (Sep.); this was a whitish oblong in Nov-Dec.(PJ23, PJ24) then a pale closed cyclonic circulation in 2020 April (PJ26). A new FFR reappeared in 2020 May, beginning with a tiny methane-bright spot on May 3-5 and again in early June (PJ27) (see our new Report 2020 no.10, & Figure 43). The first was probably a small short-lived convective plume that initiated the transformation, though it was much weaker than the concurrent event in the STB called "Clyde's Spot. It became a large FFR p. A8 throughout 2021, still active till ≥Feb. 2023 though sometimes smaller.

A8-A1: After A0 merged with A8, there was a small low-activity FFR in 2017; dark reddish streaks in 2017 Dec. faded, and a CWO developed in 2018 April, & expanded. This oblong faded in 2019, then slow-moving SSTZB & dark spots ran across this sector p. A8 thereafter. In the f. part of the sector, a new FFR developed in early 2021, persisting till ≥2022 Sep.

A1-A2: Always a very short sector, alternating between all 4 cyclonic circulation types: dark and white and pale-fawn.

Inception of new FFRs

In the S1 domain, 'Clyde's spot' in 2020 showed that a vigorous convective eruption – strongly but briefly methane-bright – could initiate a new FFR [Refs.20 & 21]. Therefore we investigated whether young FFRs observed by JunoCam were ever methane-bright. Of the examples with sufficient observations, only one was methane-bright:

- A1-A2, PJ23: **No.**
- A5a-A7, PJ18: **No** (Figure 42).
- A7-A8, PJ27: **Yes** (like Clyde's spot nearby, though much fainter; see above, & 2020 report no.10, & Figure 43).

Also, f. A8, PJ26 (Figure 15) showed a small bright methane-bright spot, apparently initiating a convective outbreak, but it produced only a short-lived mini-FFR which became trapped S of BA.

While preparing this report, we noticed another outbreak initiating a small new FFR, in 2023 August, which turned out to be very similar to the one in 2020 May-June (PJ27). It was p. AWO A7, where the long-lived FFR shrank to be only ~14° long in 2023 May-July (PJ51-PJ53). The sector p. it became a somewhat disturbed 14°-long dark oblong. The PJ53 map showed a small reddish patch within it, and this was where the new outbreak first appeared as a tiny bright spot on Aug.13. Figure 44 shows how it developed. It was already proliferating within days, but a single bright spot reappeared on Aug.17, clearly methane-bright (so no doubt a convective plume), and had expanded into a three very bright white spots on Aug.18. These appearances rapidly faded but disturbance continued to proliferate there (Figure 44), and by PJ54 (Sep.7) it was established as a new small FFR, which could also be considered as a revival of the p. part of the long-lived one.

To summarise, new FFRs have appeared and disappeared about once a year in the S2 domain. A young FFR is usually small and expands, though they do not grow indefinitely. We have never noted a dramatically bright convective plume outbreak initiating a FFR, but two very small examples which were also methane-bright were observed, lasting only a few days, and events like this may have often passed unobserved.

6.4. Transitions between cyclonic types

The combination of amateur and JunoCam data allows us to specify how the various features begin and end, as described above for some individual examples. Sometimes (though not always) they turn directly, though gradually, from one type into another. Some sectors delimited by AWOs have shown repeated changes between the cyclonic types. Any of three types can convert into any other over a matter of months, sometimes via a pale fawn oblong as intermediate (Figures 31 & 45).

For example, dark spots or oblongs often end their lives by becoming redder and then lighter in colour, sometimes becoming white. These can become expanding CWOb's. A CWOb often ends by gradually turning into a pale fawn oblong. This in turn may be terminated when a new small FFR develops within its boundaries and expands. Finally, when a FFR becomes inactive, it may become a dark oblong.

All three types are equivalent to cyclonic features in most other domains, although their relative size and importance vary. To cite some well-known examples, dark spots or oblongs are smaller versions of ‘barges’ in the NEB; CWOb’s resemble structures in the STB; pale fawn sectors are sometimes seen in the NTB and NNTB; and FFRs are increasingly dominant in higher-latitude domains.

---

7. Slow-moving dark spots in the S2 domain (~40ºS)

Summary from Ref,1: “Sometimes, the JUPOS chart reveals a sector containing slow-moving dark spots at ~40ºS. These usually have DL2 ~ -21 deg/mth, sometimes as slow as -12 deg/mth, so they are slow relative to the AWOs which dominate this domain, but never retrograding. They can be seen in the charts, mainly in specific sectors, and on some of the maps.... Although these spots are often most noticeable f. AWOs, our results suggest that they are actually generated from persistent cyclonic turbulent sectors, which in S1 and S2 are trapped against AWOs....”

- - - - - - - -

Slow-moving dark spots at 40-41ºS are often recorded, though not always nor everywhere. Their tracks can be seen in the JUPOS charts [**Appendix A**: black dots or grey shadings], and our meaurements of their speeds are listed in **Table 5** below. Their properties in 2012-2023 are very similar to what we reported previously [Ref.1]. Their mean speed is DL2 = -15.2 deg/30d, with a typical range from ~-10 to -20. Their mean latitude is 40.3ºS, typically ranging from 40.0 to 40.6ºS, i.e. on the south flank of the velocity minimum (retrograde jet), in anticyclonic territory. We have worked out their ZDP for 2022/23 only (Figure 12); the penultimate line in **Table 5** gives mean values from this finer-grained study, including all the track segments shown in that ZDP between 40.0 and 40.6ºS.

Table 5. [from our previous reports and a few new measurements]

Slow-moving dark spots at 40-41°S					
Year	Region	DL2	(SD)	(N)	Lat.
2012/13	f. A7	-14		1	
2015/16	f. A5a & bet.A4-A5	-13.9		3	40.6
2016/17	(w.ss.) f. FFR, --> A5a	-15	3	3	
2019	f. A5	-15.8, -19.0		2	
&	f. A8 (STZB)	-17		1	
2020	f. A8	-11.6	4.2	6	40
2021	f. A8	-13.3	1.4	2	
	&	-20.1	1.9	5	
2022/23	f. A8 & f. A1: best tracks:	-15.3	3.4	8	
or:	*Track segments bet.40.0-40.6S:*	*-15.8*	*4.3*	*20*	40.3
All	Weighted mean:	**-15.2**			**40.3**

These spots generally appear just f. an AWO, and recent combinations of amateur images with JunoCam and Hubble images have shown more about their nature and origin. In Ref.1 we suggested that they were generated by turbulence from a FFR further p., on the other side of the AWO, and the present records are consistent with this in most cases, but not all. In some cases, they appear to be coupled to waves on the retrograde jet on the south edge of pale fawn sectors, which could be identified with slow-moving dark spots in 2020 (PJ26) and 2022 (PJ43) (see section 4.2, and Figures 15 & 16). As shown at PJ26, these waves mark the sinuous course of the rapid retrograde jet (see Figure 15 & the end of section 4.1). It seems possible that such waves commonly accompany the weakening of a CWOb, and can be induced either by that process alone, or by turbulence from a FFR further p.

In 2015/16, we recorded a few spots f. AWO A5a, and a few in the A4-A5 sector where a cyclonic white oblong had disappeared: these sectors did not have any FFRs p. them. Hi-res images in 2016 April suggested that in both these sectors, the slow-moving features may have been waves on the retrograding jet separating a whitened 'SSTB' from darkened 'SSTZ'.

In 2016/17, there were few slow-moving dark spots, but a notable series of slow-moving *white* spots (anticyclonic vortices) were emanating from a large FFR and ultimately merging into the growing AWO A5a (see section 5.2).

In **2019**, there was a large outbreak of slow-moving dark spots f. A5, which had a FFR p. it.

Also in 2019, there was a dark SSTZB whose f. end had a similar speed, extending f. A8 – again, several months after a CWO in this sector had broken up. There was no FFR p. A8 until 2020 May, when a new one appeared [see section 6.3, inc. PJ27 & Figure 43]. Then from **mid 2020 to late 2022** (at least), there was a large outbreak of slow-moving dark spots f. A8. JunoCam images often showed them as tiny rings or amorphous spots, or sometimes they were streaks; at PJ36 & PJ37 this sector was particularly disturbed and gave the impression of turbulence spreading f. from the FFR arround A8 [see these JunoCam maps in **Appendix B**]. In 2022 we noted that these were very small dark spots in a clear SSTZ, which arose from breakup of a long dark 'SSTZB'.

Finally, in **2022** there was also a large outbreak f. A1, which also had a FFR p. it. They were on the S edge of a long pale fawn sector, and corresponded to dark wave-like bulges (see section 4.1 above, & our new 2022/23 report no.8, & JunoCam images at PJ41 & PJ43: Figure 16). Notably, other small dark spots with approximately the same drift rates were in the cyclonic interior of this pale sector at 38-39°S, showing how a zonal slow current can operate over both cyclonic and anticyclonic latitudes separated by a wavy retrograde jet.

Appendices

A. JUPOS charts, 2012-2023 (S2 jet; S3 jet; S2 domain)

B. JunoCam maps, 2016-2023

C. Our principal reports, 2016-2023 (S2 jet; S3 jet; S2 domain)

D. EPSC abstract 2024

References

**[Paper in which "et al." includes amateur co-authors.]*

1. Rogers J, Adamoli G, Hahn G, Jacquesson M, Vedovato M, & Mettig H-J (2014). 'Jupiter's southern high-latitude domains: long-lived features and dynamics, 2001-2012.' http://www.britastro.org/jupiter/sstemp2014.htm

2. Rogers JH (1995). *The Giant Planet Jupiter*. Cambridge Univ. Press.

3. JUPOS web site: (http://jupos.org) or (https://jupos.hier-im-netz.de/index.htm); also for download & ZWPs, http://grischa-hahn.homepage.t-online.de.

4. Mousis O et 31 al.*, ‘Instrumental Methods for Professional and Amateur Collaborations in Planetary Astronomy’ *Exp.Astron.* **38**, 91-191 (2014). DOI 10.1007/s10686-014-9379-0

5. Kardasis E, Rogers JH, Orton G, Delcroix M, Christou A, Foulkes M, Yanamandra-Fisher P, Jacquesson M, & Maravelias G. ‘The need for professional-amateur collaboration in studies of Jupiter and Saturn.’ J.Brit.Astron.Assoc. 126 (no.1), 29-39 (2016). https://britastro.org/node/7134

6. Hansen, C., Caplinger, M., Ingersoll, A., Jensen, E. , Ravine, M.A., Bolton, S., & Orton, G. (2017). ‘JunoCam: Juno’s outreach camera.’ Space Science Reviews 213, 475-506. (originally published online in 2013). DOI 10.1007/s11214-014-0079-x

7. Hubble Space Telescope, the OPAL project. Description and maps are posted at: https://archive.stsci.edu/hlsp/opal/.

Reference: Simon AA, Wong MH & Orton GS (2015). ‘First results from the Hubble OPAL program: Jupiter in 2015.’ Astrophys.J.Lett. L. doi:10.1088/0004---637X/812/1/55.

Acknowledgement: "This work used data acquired from the NASA/ESA HST Space Telescope, associated with OPAL program (PI: Simon, GO13937), and archived by the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555. All maps are available at http://dx.doi.org/10.17909/T9G593."

8. Hubble Space Telescope, the WFCJ project Description and maps are posted at: https://archive.stsci. edu/prepds/wfcj/. *References:*

8a. Tollefson J, et al.* (2017) ‘Changes in Jupiter’s Zonal Wind Profile in Light of Juno.’ Icarus 296, 163-178. https://doi.org/10.1016/j.icarus.2017.06.007. &

8b. Wong, M.H. et al. (2020)‘High-resolution UV/Optical/IR Imaging of Jupiter in 2016-2019’. Astrophys.J.Supp., 247, 58. https://doi.org/10.3847/1538-4365/ab775f.

9. BAA/JUPOS reports on the South Temperate domain:

9a. Rogers JH (2016) ‘Jupiter’s South Temperate domain: Evolution 1991-1999 and dynamics of cyclonic structured sectors as seen in Hubble maps.’ https://www.britastro.org/node/7230

9b. 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

9c. Rogers J & Adamoli G (2015) ‘Jupiter’s South Temperate Domain, 2012-2015’. http://www.britastro.org/jupiter/2014_15report08.htm

9d. Rogers J (2019 Feb.), ‘Jupiter’s South Temperate Domain, 2015-2018’. https://britastro.org/node/17283

10. Johnson PE, Morales-Juberías R, Simon A, Gaulme P, Wong MH & Cosentino RG (2018) ‘Longitudinal variability in Jupiter's zonal winds derived from multi-wavelength HST observations.’ Plan.Space Sci. 155, 2-11.

11. Hueso R et 10 al.* (2017). ‘Jupiter cloud morphology and zonal winds from ground-based observations before and during Juno's first perijove’ Geophys. Res. Lett., 44, 4669–4678. DOI: 10.1002/2017GL073444

12. Iñurrigarro P. et 10 al.* (2020). ‘Observations and numerical modelling of a convective disturbance in a large-scale cyclone in Jupiter’s South Temperate Belt.’ Icarus 336, paper 113475 (online, 2019). [STB Ghost]

13. Rogers J, Adamoli G, Jacquesson M, Vedovato M, & Mettig H-J (2017), ‘Jupiter’s high northern latitudes: patterns and dynamics of the N3 to N6 domains.’ https://britastro.org/node/11328

14. 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

15. Rogers J & Adamoli G (2016) ‘Jupiter in 2015/16: Final report.’ https://www.britastro.org/node/8263

16. Cassini maps of Jupiter: NASA/JPL Photojournal, PIA02863 [time-lapse movie]. http://photojournal.jpl.nasa.gov/

17. Hahn G & Rogers J (2015) ‘Zonal wind profiles from ground-based and Hubble images, 2014 February and April.’ http://www.britastro.org/jupiter/2013_14report10.htm

18. J. Rogers, C. Hansen, G. Eichstaedt, G. Orton, T. Momary, G. Adamoli, R. Bullen, M.Jacquesson, M. Vedovato, H-J. Mettig (2024). ‘Longevity of cyclonic formations in Jupiter’s S2 (South South Temperate) Domain.’ EPSC Abstracts Vol. 18, EPSC2024-378

19. Rogers JH, Mettig H-J, Foulkes M, Peach D, & Cidadão A (2008 April), J.Brit.Astron.Assoc. 118 (no.2), 75-86 (Part I) and (no.4) pp.203-216. 'Jupiter in 2001/02.'

20a. C. Foster, J. Rogers, S. Mizumoto, G. Orton, C. Hansen, T. Momary, and A. Casely (2020). ‘A rare methane-bright outbreak in Jupiter’s South Temperate domain.’ EPSC Abstracts Vol. 14, EPSC2020-196. &

20b. C. Foster et al.* (2021) ‘The latest developments of Jupiter’s STB May 2020 outbreak (Clyde’s Spot).’ EPSC Abstracts Vol. 15, EPSC2021-121.

21. R. Hueso et 21 al.* (2022), ‘Convective storms in closed cyclones in Jupiter’s South Temperate Belt: I. Observations’ Icarus 380, 114994 (2022) [Clyde’s spot]. https://doi.org/10.1016/j.icarus.2022.114994

22. Porco CC et 23 al. (2003). ‘Cassini Imaging of Jupiter's Atmosphere, Satellites, and Rings’ Science 299, 1541-1547.

23. Rogers JH, Adamoli G & Mettig H-J (2011 Feb.), J.Brit.Astron.Assoc. 121 (no.1), 19-29. ‘Jupiter’s high-latitude storms: A Little Red Spot tracked through a jovian year.’ [NNTZ ovals]

24. Simon AA, Wong MH, Rogers JH, Orton GS, de Pater I, Asay-Davis X, Carlson RW & Marcus PS. ‘Dramatic Change In Jupiter’s Great Red Spot From Spacecraft Observations’ Astrophysical Journal Letters, 797:L31-L34 (2014 Dec.20) doi:10.1088/2041-8205/797/2/L31.

25. [on Fig.9]. Asay-Davis XS, Marcus PS, Wong MH & de Pater I (2011) Icarus 211, 1215-1232. ‘Changes in Jupiter’s zonal velocity between 1979 and 2008.’

Figures

Section 1

Figure 1. Jupiter's jets, domains, belts & zones, as defined in Ref.1 but shown with north up. (From Report 2022/23 no.8). The ZWP is from the Cassini flyby (Ref.22).

Figure 2. Images by Damian Peach in 2022 Sep., illustrating the best resolution that amateur observers can now achieve in this domain.

Figure 3. Relationship between DL2 vs u_3, for 40.0ºN (planetographic).

Figure 4. JUPOS map of part of the southern hemisphere with examples of typical S2 domain features labelled. 2016 April 5-9. Latitudes are planetographic.

Figure 5. JunoCam map at PJ17, showing part of the southern hemisphere with examples of typical S2 domain features labelled, as well a the prograde jets. The S2 domain lies between the S2 and S3 jets (red arrows). Latitudes are planetocentric.

Figure 6. A selection of our ground-based maps covering the S1 and S2 domains – one of the best from each apparition, taken from our previously posted reports.

Sections 2 & 3

Figure 7. SSTBn jet spots in 2016, from ground-based images (2016 April) and Juno's first flyby (2016 August). These images are near the STB Ghost, where SSTBn jet spots were moving from prograde on the SSTBn to retrograde in the STZ via an anticyclonic 'recirculation loop' just f. the cyclonic Ghost. (Adapted from our PJ1 report; as these were mainly test images, the quality was not as good as subsequently.)

Figure 8. Zonal drift profiles (ZDPs) from JUPOS data in 2014/15 and 2015/16, covering the S.Temperate Zone (STZ) up to the S2 jet. (Data for the rest of the S2 domain was not analysed in detail, apart from the AWOs, whose latitudes may be artificially constrained in the JUPOS data; but see Figure 12.)

Figure 9. Speed of the S2 jet. (A) Spot tracking in amateur images, since the first detections in 1989 (including data from Ref.1). (B) Peak of ZWP from spacecraft, since Voyager in 1979. (See further comments on the figure.)

Figure 10. Speed of the S3 jet. (A) Spot tracking in amateur images, since the first detections in 2002 (including data from Ref.1). (B) Peak of ZWP from spacecraft, since Voyager in 1979. (See further comments on Figure 9.)

Figure 11. JUPOS maps of the S1 to S3 domains in 2017, showing prograding spots on the S2 jet (blue arrows, dark spots) and the S3 jet (red arrows, white spots, presumably cyclonic). (By the time of Juno's PJ7 on July 11, the S3 spot chain had passed on p. the GRS. The chain can be seen in JunoCam maps from outbound images, but no closeups of it were obtained.) The black arrowhead marks a near-stationary spot in southern STZ. These maps also show the sector from A5a to the large FFR p. A5, but the FFR appeared to be rather quiet during April, so no vortices were tracked f. it.

Section 4

Figure 12. Zonal drift profile (ZDP) from JUPOS data for 2022/23. Adapted from Report 2022/23 no.8 with new Appendix. (q.v. for details).

There is little difference between dark and bright spots, or between longitude sectors. There may be a slight difference between large and small spots, but this could be an artefact. The JUPOS measurers sometimes use the AWOs in this domain as a latitude standard, checking that they are measured close to 40.5ºS, although their latitudes do vary. The AWOs on this chart (red points) show variations which parallel the ZWP, and suggest that the AWOs are at slightly lower latitude than smaller spots with the same drift rates -- consistent with what we have found for the S1 & N2 domains, due to large ovals deflecting the retrograde jet in the middle of the domain (Ref.9b Fig.11, & Ref.23). However, this could be an artefact of the adopted standard. The points for the other large feature, the cyclonic white oblong, also lie slightly off the mean ZDP, by ~0.2º.

Most of the smaller spots are slow-moving dark spots (*see section 7*). Many were in the A1-A2 sector, where there was a long pale fawn sector, though it did not clearly have a closed circulation. They were either on its S edge (anticyclonic) or in its interior (cyclonic). Both groups of spots had approximately the same drift rates (DL2 between -10 and -27). Those on the S edge corresponded to dark wave-like bulges; as at PJ26, these waves probably marked the track of the retrograde jet (see JunoCam images in Figure 16), and may have constrained spots on both N and S sides.

Figure 13. Zonal wind profiles (ZWPs) from Hubble images, from Ref.8a; also see Ref.8b. The data were kindly provided by Michael Wong. These ZWPs are also available on the WFCJ web site: https://archive.stsci.edu/hlsp/wfcj. Also see acknowledgement under Ref.7.

Figure 14. ZWPs made by JUPOS team members.

(A) 2012 Sep-Dec., by G. Hahn, several pairs of amateur images by W. Jaeschke, I. Sharp, D. Peach, D. Tyler, G. Walker, C.Go (with background curve from New Horizons). From report 2012/13 no.9 (Appendix 5).
(B) 2014 Feb., by G. Hahn, several pairs of amateur images by C. Go, D. Peach, B. Macdonald. From Ref.17 = report 2013/14 no.10.
(C) 2014 April 21, by G. Hahn, HST images (Ref.24) From report 2013/14 no.10.
(D) 2019 April, by M. Vedovato, two pairs of amateur images by C. Foster, T. Tranter, C. Go & T. Olivetti. From report 2019 no.4.
(E) 2019 June 26-27, by M. Vedovato, HST images. From report 2019 no.9, overlaid with a single ZWP close to the average of these data (data provided by Marco Vedovato).
(F) 2023 Nov.—2024 Jan., by G. Hahn, several pairs of amateur images by C. Go & E. Sussenbach. From report 2023/24 no.3 (Appendix 2).

Figure 15. Map of the S1 & S2 domains from JunoCam images at PJ26 (2020 April 10), with arrows marking the currents visible by blinking maps of separate images. From our PJ26 report (Figure 12), which also included the animated blinks on which this is based. The underlying map was made by Björn Jónsson. (Annotations include some features not mentioned in the present report.) Note the long pale fawn oblong between A7-A8, with a rapid retrograde current along its wavy south edge (see section 4.1); also a very bright white spot at left (see section 6.3).

Figure 16. JunoCam images at PJ7 and PJ41/PJ43, showing high-amplitude waves along the S edge of light brown sectors of the SSTB, apparently representing waves in the retrograde SSTBs jet as at PJ26 (Figure 15). (Asterisks mark northward crests). JunoCam images processed by Gerald Eichstädt.

Figure 17. Chart showing diagrammatically the tracks of the AWOs and the presence of different types of cyclonic structure between them, from 2015-2023. It is derived from the JUPOS chart (**Appendix A**) at 1/4 vertical scale, with approximate tracks of FFRs represented by texturing. [Adapted from Ref.18 (EPSC Abstract), with some corrections and additions.]

Figure 18. History of SSTC speeds. From Ref.2 (1887-1991), Ref.1 (1991-2013), and this work (2012-2023).

Section 5

Figure 19. JunoCam view from over the south polar region towards the S2 domain with five AWOs visible, the "String of Pearls". Excerpt from PJ6 image 126 (Gerald Eichstädt).

Figure 20. Two JunoCam closeups of S2 AWOs.

Figure 21. Merger of AWOs A6 & A7, 2018 May 24-28 (PJ13 map, May 24; Chris Go & A. Lasala, May 26 & 28).

Figure 22. Excerpt from the full JUPOS chart (in **Appendix A**) in 2016-2017, highlighting the small slow-moving white spots (green arrows) which appear to have merged into oval A5a (mergers circled). Green points are white spots, mostly AWOs; for key to some other features, see the full chart in **Appendix A**.

- - - - -

Figures 23-29 show SSTBn jet spots at the 'recirculation loop' f. the STB Spectre (or Ghost), and the SSTB sector between A5a & the large FFR, with small vortices within it.

Figure 23. Maps of part of the S2 domain, 2016 Jan.-March, showing mini-AWOs in the sector p. A5a (labelled A*), f. the large FFR. Also shows a dark spot (STB DS5) evolving into the STB Spectre, alongside the FFR with SSTBn jet spots recirculating in Jan-Feb. and becoming near-stationary in the STZ. [From report 2016/17 no.8.]

Figure 24. Amateur images, 2016 June, showing the sector from A5a to the large FFR, with mini-AWOs between them. Red arrows indicate A5a (left arrow) about to merge with a smaller mini-AWO (right arrow). Also shows the recirculation loop at the STB Spectre: pink arrow marks a dark spot retrograding f. the Spectre after recirculating. [Adapted from report 2015/16 no.13.]

Figure 25. Amateur images, 2017 March, showing merger of A5a with another mini-AWO in 2017 March (the best documented example) [Figure from Report 2016/17 no.8]. There is also a very dark spot on SSTBn keeping pace with A5a, interacting with smaller, faster-moving SSTBn jet spots. (There is no recirculation loop in this sector.)

Figure 26. JunoCam maps of the sector from A5a through the large FFR, 2016 Aug—2017 Sep.

Figure 27. [From PJ8 report Fig.11]. Shows the orange-tinted recirculation loop f. the STB Ghost. SSTBn jet spots are indicated by green arrows. There are also several near the limb, caught in the 'recirculation loop' just f. the STB Ghost. Also shows the SSTB from A5a to the large FFR, with many vortices in that sector.

- - - - -

Figure 28. (PJ11 image 25, 2018 Feb.7) The large FFR now extends closer to A5a but an eddy is still visible between them. There are no obvious S2 jet disturbances in this sector p. BA.

Figure 29. (PJ24, 2019 Dec.26: cylindrical map by Kevin Gill). Shows oval BA with ovals A7/A5a merging. The large FFR now extends up to A5a. There are no obvious S2 jet disturbances in this sector p. BA.

Figure 30. (PJ38 image 2021 Nov.29). A chain of four anticyclonic vortices f. a FFR, apparently leading towards the new (short-lived) AWO ‘A0’ (beyond the terminator). [PJ38 report Fig.S1].

Section 6

Figure 31. Excerpt from the series of JunoCam maps, showing one sector which successively transformed between the four cyclonic types.

Figure 32. PJ35 (2021 July 21; cylindrical map by Björn Jónsson). Map of a sector of the S1 & S2 domains, showing examples of cyclonic structures, including the small dark spot adjacent to BA.

Figure 33. JunoCam image of a CWOb (PJ20).

Figure 34. The “Mickey Mouse spots”: a bright new CWO (dark blue arrowhead) between A3 & A4. [New figure]

Figure 35. [From report 2018 no.6 Fig.12]. New CWO in 2018, brilliant white and methane-bright (bracketed).

Figure 36 . CWOb (bracketed) between A4 & A5 in 2023; bright white but methane-dark as usual (esp. towards the limb) (like the STB Spectre, Figure 42). [New figure]

Figure 37. Chart showing the expansion rates of three CWOb’s, measured from JUPOS maps.

Figure 38. JunoCam image of a dark brown oblong (PJ6).

Figure 39. [Adapted from report 2013/14 no.8] A very dark ‘mini-barge’ between A7a-A8 becomes lighter brown and shrinks within a pale collar, then a brown streak between A0-A1 likewise shrinks, until both appear as light reddish ovals.

Figure 40. [Adapted from reports 2022/23 nos.5 & 8] In 2023 Jan., ds1 turned into a small light brown spot in a white collar. By late Jan. it was a dull white cyclonic oval, as also shown in the PJ49 map (March 1). So this was a typical example of a dark spot fading through reddish to white.

Figure 41. PJ15 image 37: Example of a small FFR.

Figure 42. PJ18 cylindrical maps (by Gerald Eichstädt). A new FFR imaged at PJ18 (2019 Feb.12, arrowed blue), not methane-bright. In contrast, a much brighter point (convective outbreak, arrowed white) at lower right is very methane-bright. Note that the STB Spectre, like similar CWOb’s in the SSTB, is methane-dark. [New figure.]

Figure 43. [Adapted from Report 2020 no.10] Origin of a new FFR in 2023 May, with a transient methane-bright plume, also viewed at PJ27, along with a similar but much greater eruption in the STB called ‘Clyde’s Spot’.

Figure 44. Origin of a new FFR in 2023 August, with a transient methane-bright plume.

Figure 45. Diagram summarising the interconversions between the types of cyclonic features.
