Jupiter's southern high-latitude domains: long-lived features and dynamics, 2001-2012

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TABLES AND APPENDICES

Table 1

Table 1. Latitudes and speeds of jets from spacecraft

		From Voyager, 1979 (Limaye, 1986) [as in Rogers, 1995]			From Hubble, 1995-1998 (G-M & S-L, 2001)			From Cassini, 2000 (Porco et al., 2003) [Data from A. Vasavada]			From New Horizons, 2007 [Cheng et al., 2008] [data from A.Cheng & A.Simon]		
Jet	**Jet/belt**	Lat.B"	u3	DL2	Lat.B"	u3	DL2	Lat.B"	u3	DL2	Lat.B"	u3	DL2
S1	STBn	-27 to -29	44,3	-110	-26,4	56,8	-138,2	**-26,7**	**48,1**	**-118,6**	**29**	**46,7**	-115,7
	STBs	-32,6	-20,8	42	-32,3	-11,6	20,0	**-32,0**	**-16,1**	**30,7**	**-32,2**	**-17,0**	33,0
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
S3	S3TBn	-43,6	42,1	-125	-42,9	45,6	-133,6	**-43,0**	**42,6**	**-125,8**	**-43,0**	**40,6**	-120,1
S4	S4TBn	-53,4	36,3	-129	-52,4	44,8	-154,5	**-52,4**	**37,9**	**-132,3**	**-52,5**	**45,4**	-156,8
S5	S5TBn				-61,2	28,6	-125,3	**-60,8**	**22,0**	**-97,4**			

		AVERAGE VALUES			From JUPOS (this report)		
Jet	**Jet/belt**	Lat.B"	u3	DL2	Lat.B"	u3	DL2
S1	STBn	-26,5	49,0	-120,6	-27,8	42,4	-106
	STBs	-32,3	-16,4	31,4	-31,7	-21,7	44
S2	SSTBn	-36,3	38,2	-104,4	-36,1	40,5	-110
S3	S3TBn	-43,1	42,7	-126,1	-43,0	33,7	-101
S4	S4TBn	-52,7	41,1	-143,2			
S5	S5TBn	-61,0	25,3	-111,4			

B" = Latitude (zenographic)
u3 = Wind speed (m/s in System III)
DL2 = Wind speed (deg/month in System II)

This is an excerpt from the table on our website [Ref.5]. In addition to these 4 global spacecraft data sets, just before the Comet Crash in 1994, HST was used to establish hi-res ZWPs for these southerly domains, which largely agreed with the Voyager ZWPs [Ref.6].

Table 2.
S2 jet: Speeds of SSTBn jetstream spots

Appar'n	DL2 (deg/month): Min	Mean	Max	Lat.(S) (±SD of means)	N	Source	Notes (All are small dark spots.)
1988/89	-63	-79	-111	35,8	3		First ground-based record (Ref.8)
1989/90	-75	-79	-90	36,3	4		
1991/92		-90			1		A few spots detected.
1999/00		-85			1	*BAA report*	
2000/01	-50	-65,7	-77,5	-34,8	6	*BAA report*	Up to 60 deg.p.BA
2001/02						*BAA report*	None
2002/03		-71			1 (3)	*JUPOS (HJM)*	All ended at AWO at Sf.end of Sf.tail of STB sector B
2003/04						*JUPOS (HJM& GA)*	Several d.ss. p. BA; 5 prob. recirc. at the new STB Remnant (n=3)
(2004 Feb-Apr)		-64		-33,5	1 (5)		or just f. it (n=2)
			-78, 90		2		Two d.ss. elsewhere.
2005						*JUPOS (GA)*	Scattered d.ss., most appearing 60-70 deg.p. STB Remnant but
fastest:			-107	-36,5	1		some elsewhere. Most showed rapid decel. at end of track &
peak group:	-93	-94,8	-100	-35,5 (±0,1)	4		drifted N into STZ; one at f. end of STB Rem.(recirc.); 4 within
others:	-60, -69, -76, etc.(see ZDP)				7		Sf. tail of STB segment A; 2 alongside STB segment A.
							10 tracks show good anticyc. ZDP **(see Figure).**
2006						*JUPOS (GA & JHR)*	Small d.ss all appearing ~70-80 deg.p.BA. Speeds slower &
Jet speeds:	-62,5	-64,8	-67	-35,2 (±0,1)	3		more diverse than in 2005. One recirc. at STB Rem., another
Slower:	-37	-41,6	-49	-34,5 (±0,2)	4		elsewhere
2007	-41	-66	-97	-35,2 (±0,2)	9	*BAA/JUPOS*	Main group arising in long sector starting ~70 deg.p.BA.
inc:		-84		-35,2 (±0,3)	2	*report (online)*	Diverse & variable speeds; most decelerated suddenly.
[No.10:]	-50			-34,7 (±0,6)	1	*(see Fig.9)*	All disapp. at or approaching f. end of STB Remnant.
							No.10: Recirc. at. f.end of STB segment A, into its Sf.tail.
	All speeds recorded:						
2008	-47 (n=2)	-64 (n=1)	-73 (n=3)		6	*BAA/JUPOS interim*	Only a few spots, rather slow & diverse, so listed singly.
						report (online)	Two spots recirc. at f.end of STB Remnant.
2009	-60 (n=1)	-80 (n=2)	-110 (n=1)		4	*Interim (online)*	Only a few. Most disapp. on reaching STB Rem.(no recirc.).
2010	-63,-60,-67	-81 (n=1)	-112 (n=1)		5	*JUPOS (prelim)*	Just 5 d.ss., all arose just p. STB segment D & ran towards Sf.
							tail of STB segment A, where at least one recirc. or merged.
	Min	*Mean*	*Max*				
2011/12						*BAA/JUPOS*	Many spots, wide range of speeds, showing good anticyc. ZDP
All spots:	-59	-92,6	-114	-35,5 (±0,4)	24	*draft report*	**(see Figure)**. Arising in 2 sectors: (1) Alongside Sf. tail of STB
inc. peak:	-105	-110,5	-114	-36,0 (±0,1)	4	*(GA & JHR)*	segment; (2) p.BA (with unusual features).
	(& see ZDP)						

Averages:

		All spots	Peak groups
Mean	DL2 (deg/mth)	-77,6	-109,9
SD	DL2 (deg/mth)	11,1	2,1
Wtd mean	DL2 (deg/mth)	-81,0	
Mean	U3 (m/s)	27,9	40,5
SD	U3 (m/s)	4,4	0,8
Wtd mean	U3 (m/s)	29,3	
N		73	
Lat.		-35,3	-36,1
SD		0,3	

Speeds in DL2 (deg/month)
then in U3 (m/s).
Mean is from 1999-2012.
N, number of spots tracked.
Wtd mean is weighted by N.
Latitudes are zenographic.
SD, standard deviation of apparition means.

Table 3. Budget of AWOs.				
	Long-lived Appeared	Long-lived Disappeared	Possible extras	Transient (1-2 yr)
1986-2001	1 (A4)	1 (A8)	4 (A2 & A4)	1
2001-2002	1 (A8)	2 (A6 & A7)	--	--
2003-2012	3 (A0,A6,A7)	--	1 (A6)	6
1986-2012	**5**	**3**	**5**	**7**

Table 4:

Mean speed of SSTC	DL2	+/-SEM*
1887-1921	-25,3	1,5
1922-1946	-23,5	1,2
1949-1991	-25,9	2,0
1991/92 (A1-A3)	-26,2	0,7
1991/92 (A5-A7)	-28,8	1,6
1995-2001	-26,3	0,7
2003-2013	-28,5	

Table 5. Expansion rates of SSTB white oblongs

Location	First present	Last present	Dates for length measurements	Length (start) (deg.)	Length (end) (deg.)	Expansion rate (deg/mth)	Notes & illustrations
A2-A3	Late 2002 (cyc.w.o.)	Start of 2004	2003 Jan-2004 Jan	8	10	0,1	Suddenly broke up into FFR: Fig.7B.
A4-A5	Late 2002 (cyc.w.o.)	Mid 2008	2004 Feb.-2007 July	10	26	0,39	Start of expansion: Fig.7B.
	Expanded from 2004.		2007 July-2008 July	26	48	1,9	Later: Fig.7C.
A2-A3	Early 2005	Mid 2006	2005 Mar.-2006 Apr.	13	19	0,3	Replaced by transient
			2006 Apr.-2006 June	19	26	faster	dark barge in 2007.
A1-A2	Mid 2006	Spring 2008	2006 July-2007 Sep.	11	20	0,45	
			2008 Mar.-2008 June	23	34	2,5	
f-A6	Early 2006 (cyc.w.o.)	Mid 2008	2007 May-2008 Apr.	8	10	0,11	Early stage: Fig.7D.
	Expanded from 2007.		2008 Apr.-2008 June	10	13	faster	
A5-A6	Early 2009	Mid 2009	2009 Mar.-2009 July	15	20	1,26	
A7-A8	Mid 2009 (cyc.w.o.)	Early 2011	2009 July-2010 July	8	12	0,3	
			2010 July-2011 Feb.	12	21	1,4	
A0-A1	Early 2010	Early 2011	2010 Apr.-2011 Jan.	11	21	0,7 (irreg.)	

'Cyc.w.o.': These began as a cyclonic white oval, expanded later.

Table 6: Slow-moving dark spots in S2 domain
from our full analysis of two apparitions [GA & JHR, in preparation]:

Year	DL2 (±SD)	Lat. (±SD)	n
2006	-21.0 (±2.6)	-40.6 (±0.3)	11
2011/12	-15.7 (±3.7)	-40.0 (±1.0)	4

Table 7. S3 jet: Speeds of S3TBn jetstream spots

Appar'n	*DL2 (deg/month):*			*Lat.(S)*	*N*	*Overview*
	Min	*Mean*	*Max*	(±SD of means)	tracked	
					(total)	
2002/03	-92	-95,0	-99		3	One d.s., 2 w.ss.
2003/04	-95	-98,3	-102		10	Outbreak of d. & w.ss. spanning
	-89				1	~270 deg. in L2.
2005						Outbreak continuing at most longitudes,
d.ss:	-92,5	-94	-101	-43,0 (±0,2)	5	but sep. sectors of d.ss. and w.ss.
w.ss:	-89	-97,4	-102	-43,7 (±0,2)	8	Three w.ss. each lasted 75 d and covered
						190-220 deg. in L2.
2006						Again an outbreak of d.ss. & w.ss.,
d.ss:	-96	-97	-99	-43,0 (±0,2)	8	now in one sector ~120 deg.long
w.ss:	-93	-97	-99	-43,5 (±0,2)	6	
2007		-104		-43,8 (±0,5)	1 (~3)	Just a few w.ss. on S3TBn.
2008		-100			several	Again, just scattered sparse tracks for
						several w.ss. & v.short-lived d.ss.
2009		-93			7	Seven w.ss.
2010	-85	-92	-98		4	Just a few w.ss.
2011/12						Highly active:
W.ss:	-84	-93,6	-100	-43,8 (±0,2)	12	W.ss.(on cyclonic side: see ZDP), all
						emerging from a dark S3TB segment;
D.ss:	-101	-104,3	-109	-43,0 (±0,1)	3	mostly DL2 = -95.
						D.ss. (on jet peak: see ZDP), S of BA.

Averages:

	Min	*Mean*	*Max*	
Mean (DL2)	-91,3	-96,2	-101,2	Speeds in DL2 (deg/month)
SD	5,3	3,6	3,1	then in u3 (m/s).
Wtd mean		-95,9		Mean is from 1999-2012.
Mean (U3)	30,2	32,0	33,8	N, number of spots tracked.
SD	1,8	1,2	1,0	Wtd mean is weighted by N.
Wtd mean		31,9		Latitudes are zenographic.
N		66		SD, standard deviation of apparition means.
	(w.ss.)	(d.ss.)		
Lat.	-43,7	-43,0		
SD	0,1	0,0		

Table 8.	Speeds in the S3 domain										
Name of feature/ current	*Type of feature*	*Full name of location*	*Years*	*DL2* deg/30d	*(+/- SD)*	*u3* m/s	*(+/- SD)*	*Lat.* (estimates in brackets)	*(+/- SD)*	*N* groups; (spots)	*Ref.*
S4 jet	(spacecraft mean)	S4TBn jet	1979-2007	-143,2	14,5	41,1	4,7	-52,7	0,5	4	Table 1
AWO-A	long-lived AWO	(S3TZ)	2000-2012	-54 to +4				-51,1 to -49,3		1	This work
Sector of dark spots	sector	(S3TZ)	2005-2010	-7				-49		1	This work
--dark spots in it:	d.ss.	(S3TZ)	2005-2010	11,5	5,4	-6,4	1,8	-49,2	0,4	25	This work
Other dark spots	d.ss.	(S3TZ)	2011/12	13,0	4,5			-49,0	0,3	11	JUPOS/BAA report (in prepar'n)
Retrograde jet:		S3TBs jet									
Voyager	map correl'n		1979	16,6		-8,0		-49,4			Limaye 1986
HST	map correl'n		1995-1998	8,7		-5,6		-47,8			G-M & S-L, 2001
Cassini	map correl'n		2000	33,0		-13,8		-47,5			Porco et al., 2003
New Horizons	map correl'n		2007	22		-10		-48,4			Cheng et al., 2009 [note 3]
Retrograde jet	(spacecraft mean)	S3TBs jet	1979-2007	20,1	10,2	-9,4	3,5	-48,3	0,8	4	(Mean of values above)
S3TC:		(S3TB)									
--Ground-based	d.ss.(& a few w.ss.)		1900-1979	-8,3	5,7			(-43 to -50)		14 (54)	(Ref.2, Chap.12)
--Voyager	misc.		1979	-8,5	4,2			-46,8		7	(Ref.2, Chap.12)
--Ground-based	d.ss.		2002-2012	-9,9	3,6			-47,0	0,3	11	JUPOS (this report)
--and:	d.ss.		2007	-11				-47,1	0,7	5	JUPOS/BAA report (Ref.4)
Impact (SL9	black cores		1994	-2,0	4,9	-2,0	1,6	-47 to -48		6	Rogers (1996) JBAA 106, 125.
Comet Crash)	dark clouds [note 1]		1994	-18	12	3,4	4,0	(-43 to -57)		21	Rogers (1996) JBAA 106, 125.
S3 jet	w.ss., d.ss.	S3TBn jet	2003-2012	-95,9	3,6			-43,7 (w.ss),		12 (66)	This work (Table 7)
	(ground-based)	--inc. peak:	2003-2012	-101,2	3,1			-43,0 (d.ss)		9	
S3 jet	(spacecraft mean)	S3TBn jet	1979-2007	-126,1	5,6	42,7	2,1	-43,1	0,3	4	Table 1
	[Note 1] -- SL9 impact clouds: leading edges, peripheral clouds, & whole sites later; all in stratosphere.										
	[Note 2] -- rare features with rapid prograding drifts at ~46 deg.S are not included here.										
	[Note 3] -- ZWP from New Horizons images independently derived by G. Hahn.										

ON FOLLOWING PAGES: APPENDICES

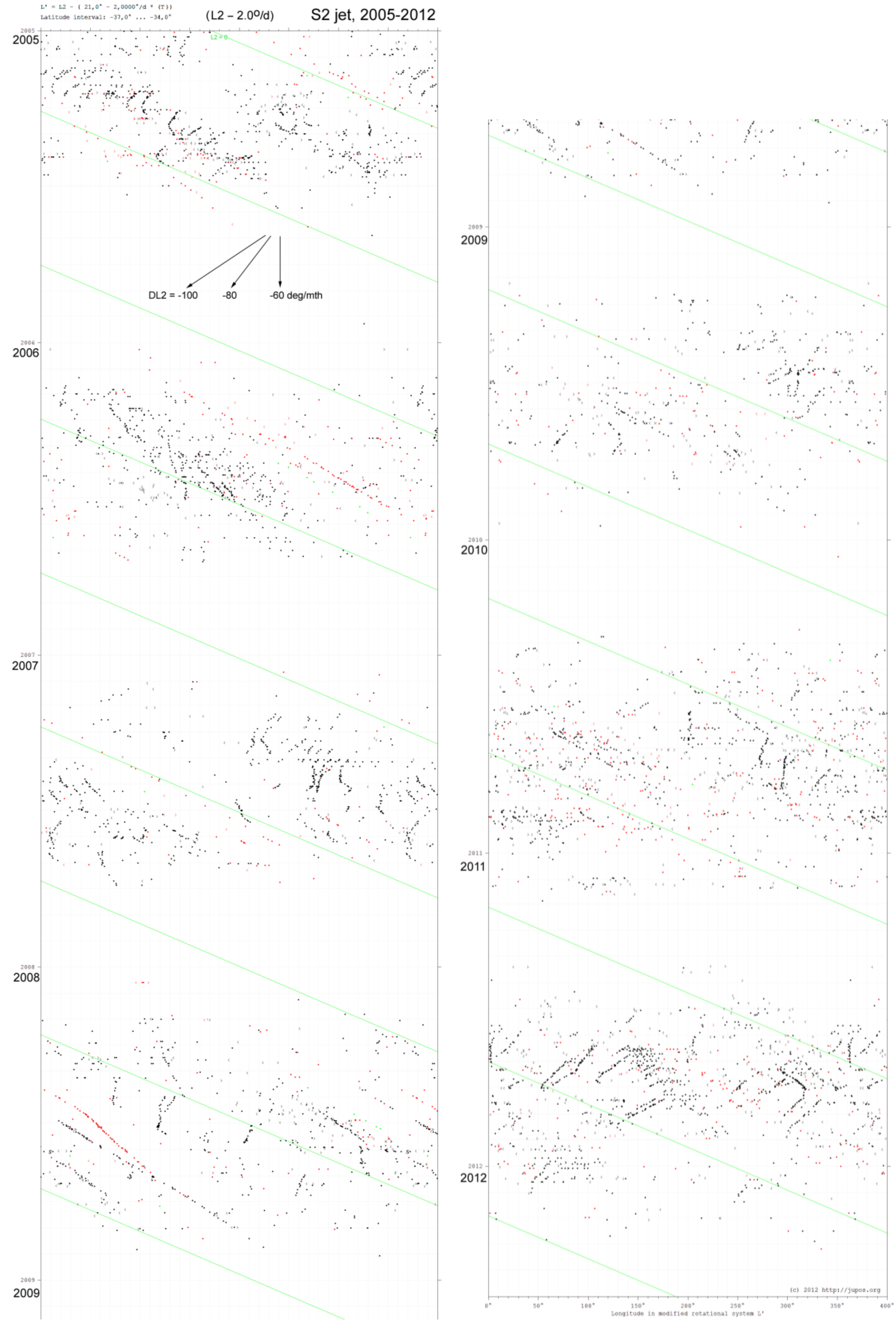
[Full-size figures are in a separate ZIP file.]

Appendix 1: JUPOS charts.

All cover 2005-2012, plus earlier years in some cases.
Charts of longitude (L2) vs. time. As in all JUPOS charts, times runs downwards and the start of each year is marked. Red, white spots; black, dark spots; < > p. & f. ends of streaks.

(a) Lats. -37/-34, L2 – 2.0 deg/day: S2 jet (SSTBn jet).
(b) Lats. -42/-39/-37, L2 – 1.0 deg/day: S2 domain (SSTC).
(c) Lats. -45/-42, L2 – 2.0 deg/day: S3 jet (S3TBn jet).
(d) Lats. -48/-45, L3 (= L2 – 0.2666 deg/day): S3 cyclonic domain.
(e) Lats. -52/-48, L3 (= L2 – 0.2666 deg/day): S3 anticyclonic white ovals (AWOs).
(f) Lats. -58/-54, L3 (= L2 – 0.2666 deg/day): S4 cyclonic domain.
(g) Lats. -61/-57 (left) or -62/-58 (right), L2: S4 anticyclonic ovals.
[all on following pages:]

Appendix 1 (a) Lats. -37/-34, L2 – 2.0 deg/day: S2 jet (SSTBn jet).



Appendix 1 (b) Lats. -42/-39/-37, L2 – 1.0 deg/day: S2 domain (SSTC).

JUPOS charts for the S.S.Temperate (S2) domain, including the long-lived AWOs.
Black points, dark features; red points, bright features at 40-42ºS (AWOs); blue points, bright features at 37-39 S (cyclonic ovals or lozenges); magenta points, bright features at 39-40ºS (including some values for AWOs when especially slow, e.g. A0 and A6b, in keeping with their ZDP). Long-lived AWOs are numbered. Oblique green line is the track of oval BA. < > indicate p. and f. ends of features; the more notable ones are shaded light blue (cyclonic white lozenges) or grey (dark bars).

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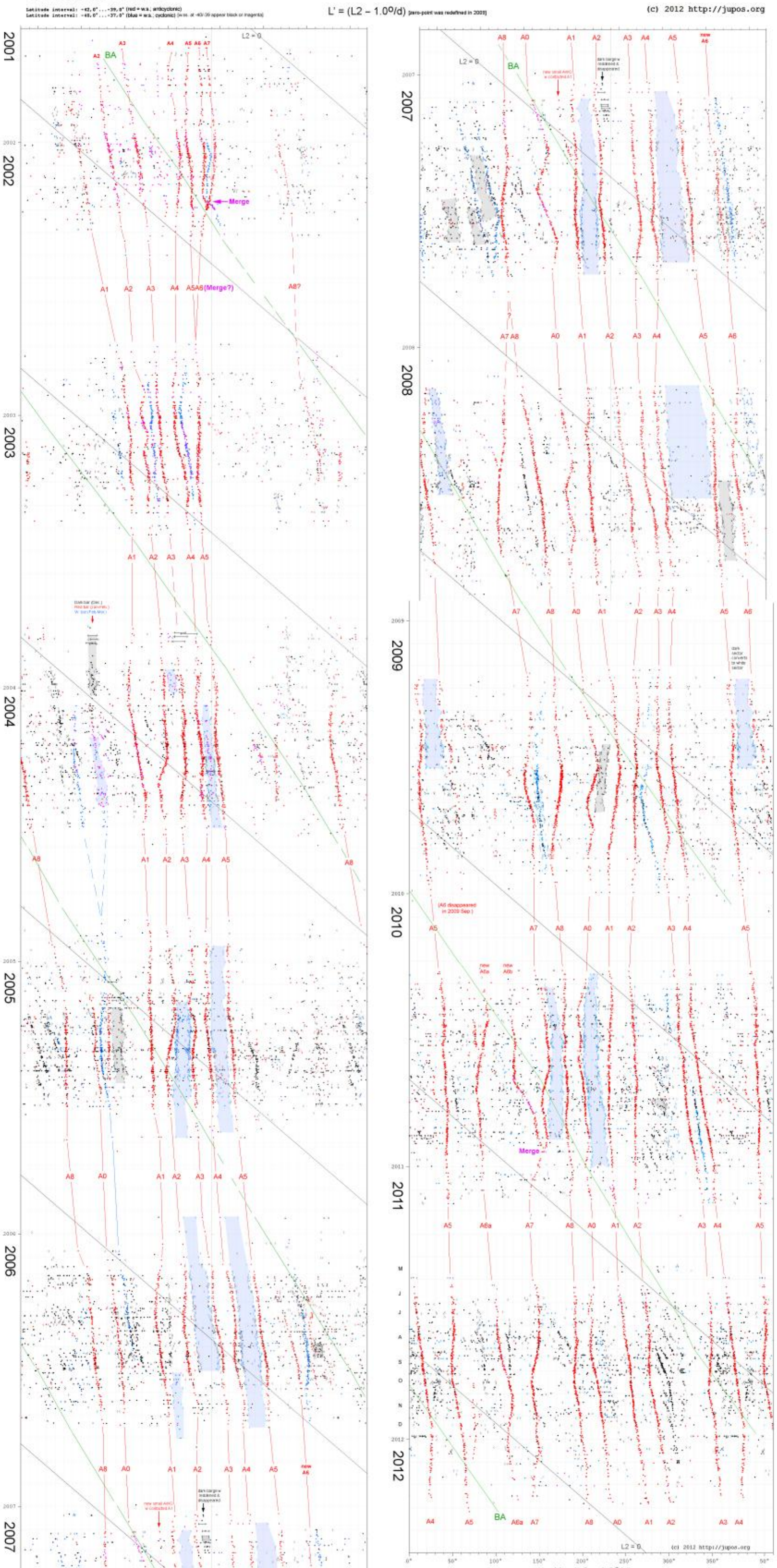
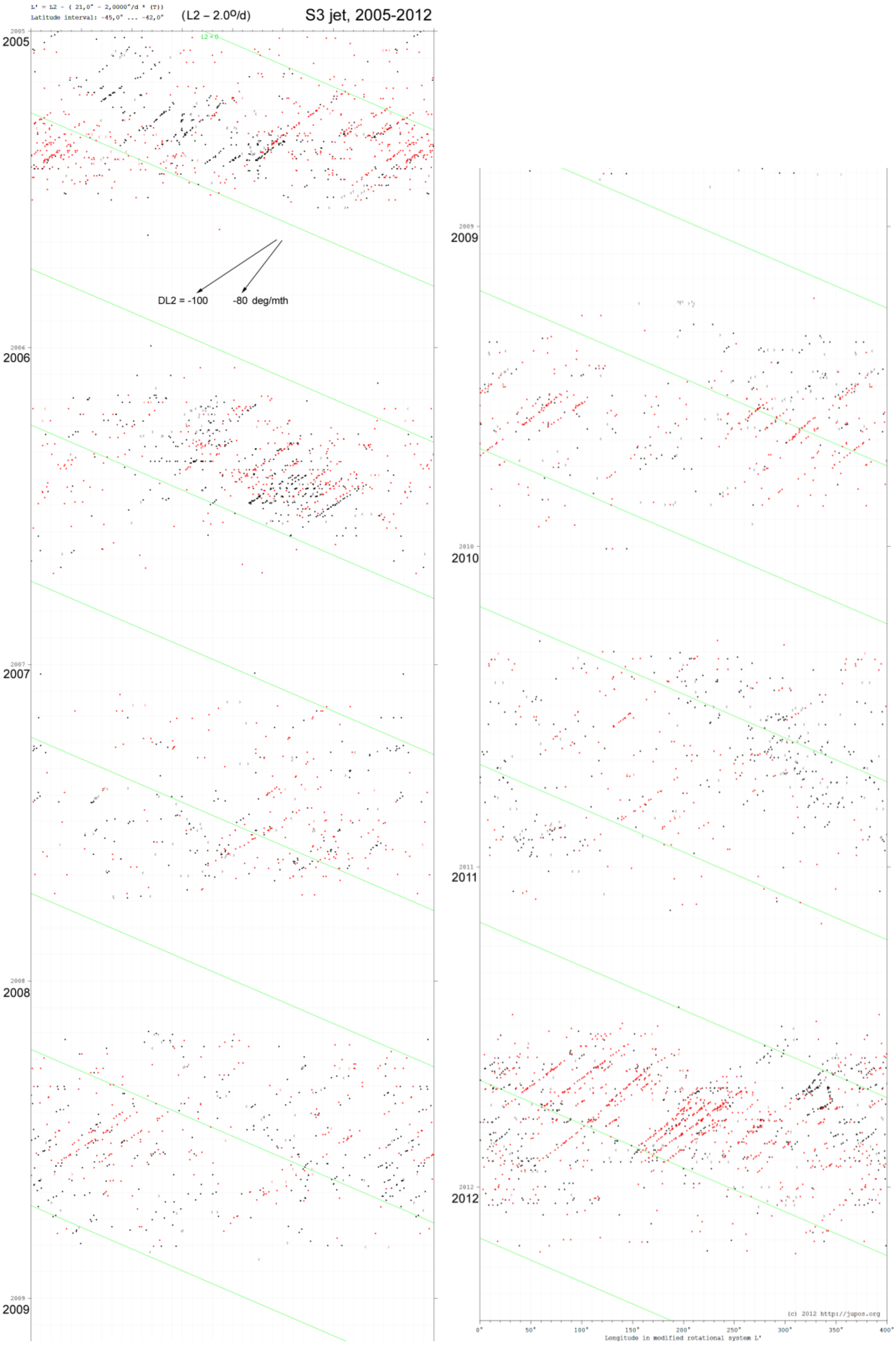
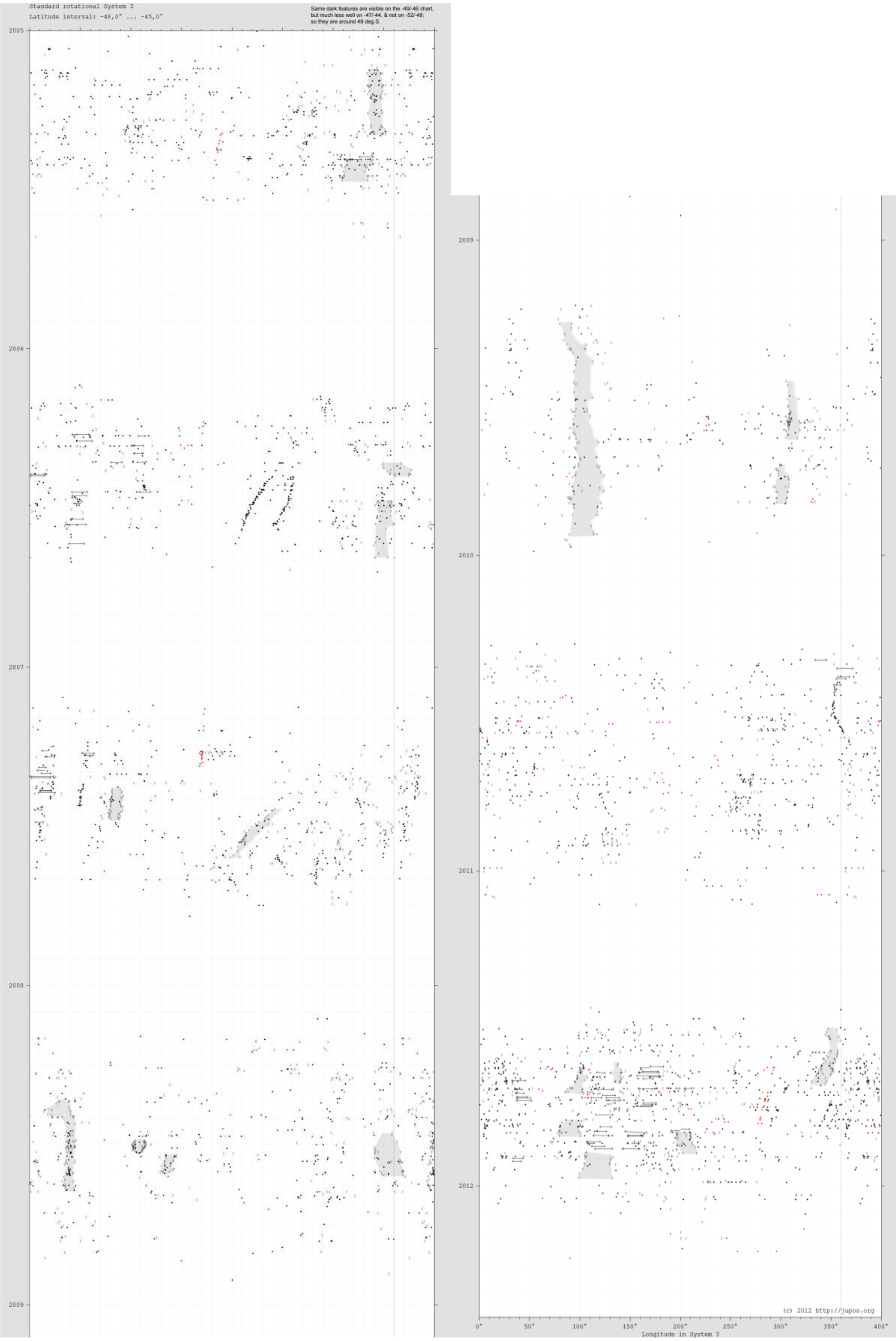
SSTC, 2001-2012



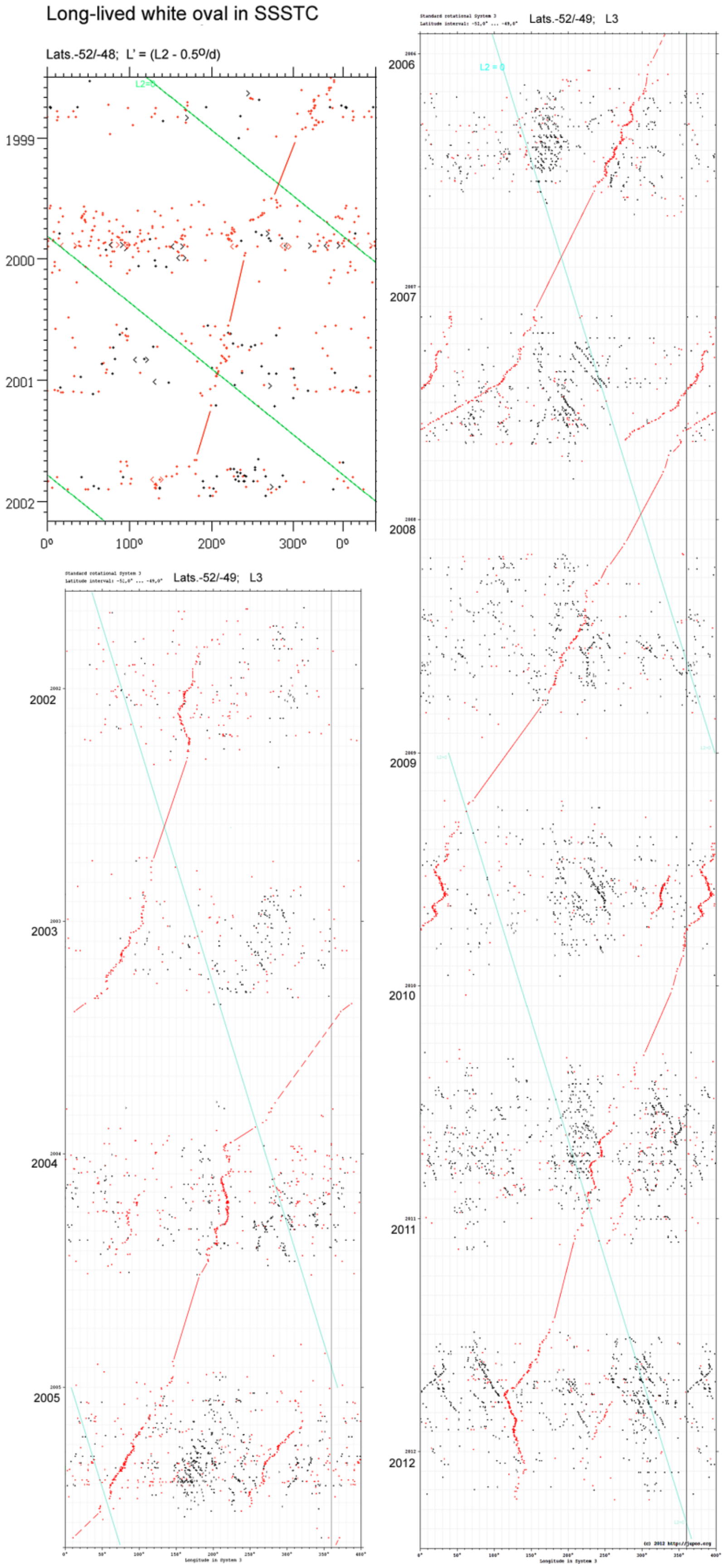
Appendix 1 (c) Lats. -45/-42, L2 – 2.0 deg/day: S3 jet (S3TBn jet).



Appendix 1 (d) Lats. -48/-45, L3 (= L2 – 0.2666 deg/day): S3 cyclonic domain.



Appendix 1 (e) Lats. -52/-48, L3 (= L2 – 0.2666 deg/day): S3 AWOs.



Appendix 1 (f) Lats. -58/-54, L3 (= L2 – 0.2666 deg/day): S4 cyclonic domain.

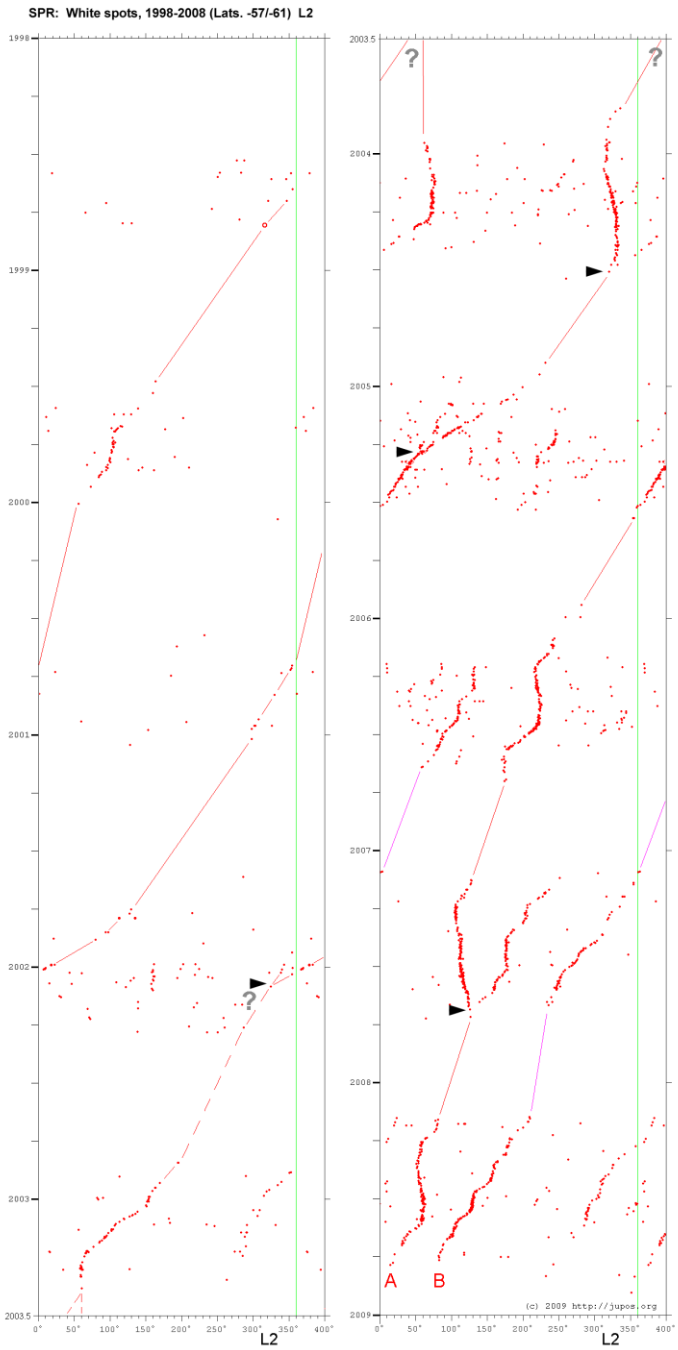
Appendix 1 (g) Lats. -61/-57 or -62/-58, L2: S4 anticyclonic ovals.

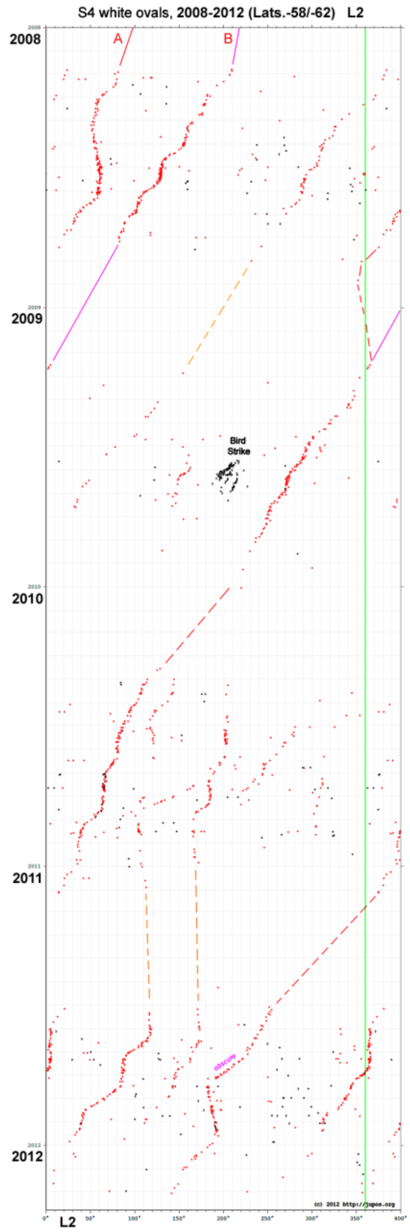
Tracks between apparitions are shown dashed where they appear to be uncertain. Track A is chosen to connect the largest oval in each apparition after 2008.

(Left & centre:) Chart for all bright spots between latitudes 57 and 61ºS, 1998-2008, showing the history of the SPR-WO [reproduced from Ref.12 (Fig.S9)]. Red connecting lines mark the probable track of the long-lived oval. Dark arrowheads indicate when it apparently merged with another spot.

> ***Note 1:*** In 2001/02, the long-lived WO was not the one listed in the BAA report, but a small inconspicuous one with a very rapid drift increasing to -46 deg/mth. In 2002/03, the oval was well tracked (with oscillations), but in 2003/04 there were 2 such ovals and it is not clear which was the long-lived one. However, this does not matter for our purpose as they merged in mid-2004.
>
> ***Note 2:*** Improved images in recent years allowed tracking of at least one other oval, which was smaller (purple connecting lines): it showed an oscillation with period 42-54 days throughout.

(Right:) Chart for all spots between latitudes 58 and 62ºS, 2008-2012.





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Appendix 2:
Excerpts from previous reports on our web site covering the S2 (S.S. Temperate) domain.

These include more details on some aspects esp. the cyclonic phenomena. Illustrations are not included here.

Reports in 2005-06 :

[4] Long-lived circulations in the S.S. Temperate domain (report, 2006 April 13).
http://www.britastro.org/jupiter/2006report04.htm [=Ref.9]

This bulletin reviews the history of the circulations in the S.S. Temperate domain over the last few years. Attached is a composite of JUPOS charts (prepared by Hans-Joerg Mettig and colleagues), and three montages of high-resolution images from 2004, 2005, and 2006, showing these long-lived spots

The first group of interest comprises the set of five anticyclonic white ovals (AWOs), named A1 to A5. Initially there were seven, but A6 and A7 merged in 2002 March, and the product probably merged with A5 in turn during the following solar conjunction, so there have been five AWOs since 2003.

A question of theoretical interest is whether they are separated by cyclonic circulations. These can be of several types: white ovals (WO), dark streaks or barges, red-brown barges, and 'folded filamentary regions' (FFRs). FFRs are turbulent chaotic circulations with thunderstorms, according to spacecraft imagery, but are difficult to detect from Earth because at low resolution they have low contrast. So where ground-based images suggest subtle grey streaks or spots, there may be a FFR.

The most conspicuous cyclonic circulations in this cluster are long white ovals between A2-A3 and between A4-A5. There were already cyclonic white ovals in these locations in 2002/03 [see images of the GRS in 2003 Jan., not included here], though the one between A4-A5 was invisible in late 2003; and the one between A2-A3 broke up in 2004 Jan. Then the WO re-formed between A4-A5 in 2004 Feb. From then until 2005 April it grew progressively longer, from ~10 deg. to ~20 deg. long; this is typical of elongated cyclonic circulations (such as historic STB Fades: Rogers, 1995). In 2005-2006 its length has fluctuated slightly. Meanwhile the WO between A2-A3 reappeared in early 2005 and likewise grew progressively longer, from ~11 deg. then to ~20 deg. now.

The second interesting cluster of spots precedes the AWOs, and includes at least one strikingly variable cyclonic circulation. This was a very dark brown streak or 'barge' from 2003 Nov. to 2004 Jan. Then it turned vivid red (2004 Feb.10) and disappeared (late Feb.) – reappearing as a bright white oval in June. This behaviour strongly resembled that of a similar cyclonic circulation in the STB from 1994 to 1998, which we called the 'Morphing Spot' [see BAA reports; the report for 1994, by Mike Foulkes and J.R., is still unpublished]. The STB Morphing Spot was preceding AWO FA. The SSTB morphing spot in 2004 was f. a newly forming AWO, which we here call A0.

In 2004/05, A0 and the resulting cyclonic WO still existed, and another spot pair formed immediately f. them: a small AWO, and a dark streak ('barge') which turned red-brown as it passed oval BA in 2005 Jan. These are no longer present in 2006.

Further v-hi-res images will be of interest. One aim is to see whether there are FFRs between other pairs of AWOs. Recent v-hi-res images do seem to show FFRs p. AWOs A0, A1, and A4, although these identifications are inevitably tentative. It has never before been possible to resolve these circulations adequately from Earth. Another aim is to document the transformations between different forms more consistently than before. Apart from the changes we have seen in 'morphing spots', we also know from Voyager movies that SSTB-WOs can turn into FFRs suddenly, so amateur imagers now have the opportunity to follow such events. Finally, we need to determine the complete life cycle of the AWOs, which used to be difficult for amateurs to detect at all, but are now striking landmarks on many of your images.

(*Add. note*: As the old AWOs merged leaving only 5 by 2003, new AWOs (A8 and A0) have appeared from 2004 onwards. Thus the number of S.S.Temp. AWOs has remained constant at 6-7 since 1986, in spite of several appearances and disappearances and mergers.)

[11] Interim reports on the SSTB (cyclonic white ovals break up) and STB (A remnant or a forerunner?) (Reports, 2006 July 30)
http://www.britastro.org/jupiter/2006report11.htm

SSTB: AWOs persist, cyclonic white ovals break up.

The set of S.S. Temperate anticyclonic white ovals (AWOs) continues to be an eye-catching feature of hi-res images: in order, A8-A0-A1-A2-A3-A4-A5. The attached image set shows this array in 2006 June and July.

Most or all of them are separated by cyclonic circulations, which are more variable in appearance. In these image there are two main types: white ovals (which tend to expand in length forming white lozenges, as has occurred between A2-A3 and between A4-A5), and folded filamentary regions (FFRs, which are like miniature versions of the rifted regions in SEB and NEB, and are hard to detect in ground-based images). The best images can now distinguish these cyclonic features and document their transformations.

In this series, a small white oval between A0-A1 disappears suddenly between June 5 and 10, becoming a FFR; actually it probably merges into a pre-existing FFR f. it. Then note the long, long-lived white lozenge between A2-A3, which seems to have lower contrast from June 8 onwards but is still present on July 2; but in the next images, July 21 and 26, it too has broken up to form a FFR. It may be significant that this happened as it was passing the STB Remnant (see below), which could destabilise the adjacent SSTB; perhaps the cyclonic white lozenge between A4-A5 will do likewise in a few months' time. These white lozenges tend to expand (like their equivalents in the STB: see my book pp.54 & 231), perhaps pushing the adjacent AWOs apart, and as the white lozenge broke up, oval A3 immediately rebounded from oval A4, to which it had been uncomfortably close.

Reports in 2008 :

[6] Jupiter in 2008: Full Interim Report. [2008 August].
http://www.britastro.org/jupiter/2008report06.htm [=Ref.13]

S.S.Temp.R:
The domain is largely shaded, punctuated by 9 AWOs, all but one dating back several years, drifting steadily with DL2 = -25 to -28. The sectors between the AWOs sometimes develop into white cyclonic circulations which always tend to grow longer, and in 2007 such white sectors existed between AWOs A1 and A2, and between A4 and A5. The A1-A2 white strip grew until it was 30 deg long in 2008 June, then broke up. The A4-A5 white strip has stabilised at a length of 40 deg.

A smaller cyclonic white oval existed f. AWO A6, separated from the AWO by a dark bar, and these broke up in July in an interesting manner [Fig.2]. The cyclonic white oval broke up suddenly in early July, just as it was passing oval BA which in turn was passing the GRS. Such close passages of large ovals are known to destabilise adjacent cyclonic circulations (for instance, similar events led to mergers of AWOs in the STB and the SSTB in 2000 and 2001) . At the same time, the dark bar that separated the cyclonic oval from AWO A6 became brown; then the dark bar itself faded away, leaving reddish-brown haze which drifted p. to surround A6 (as pointed out in late July by Fernando P. Guimaraes). Now the colour is gradually thinning. This seems to be another instance of a phenomenon that we have recently identified [see BAA 2001/02 report] – appearance of reddish haze over a dark cyclonic bar that is about to break up.

Appendix 3.
The S2 AWOs: Further notes

Note 1: Nomenclature

The S2 AWOs were named such that the array in 2001/02 consisted of A1-A7 in order. Thus, the ovals before and after that time are not necessarily named in sequence. As the number has increased and decreased, we have given numbers *ad hoc* to keep a semblance of order and simplicity, re-using numbers (A6, A7, A8) if the spot first denoted has been absent for several years. In fact, we sometimes cannot be sure whether a spot has really disappeared or not.

There is a discrepancy with the provisional nomenclature of 3 of the ovals as shown in the interim JUPOS maps and charts in 2011-12. It had been thought that oval A2 disappeared; however we now find that it persisted, so the ovals labeled A9,A0,A1 in the interim maps and charts were in fact ovals A0,A1,A2.

Note 2: Latitudes

Latitudes of the S2-AWOs could be subject to systematic error, because when the JUPOS measurers align images for measurement, they often use these AWOs as standards to check the optimal fitting of the disk, assuming that they are close to their historical mean latitude of 40.5ºS (and likewise for the GRS at 22.3ºS). The improved accuracy in latitude measurements over the rest of the disk is worth the sacrifice of absolute values for these well-characterised ovals. However, the canonical latitudes are not strictly enforced and small variations are accepted (and are sometimes clearly evident when there are several S2-AWOs on the disk together). So it is still possible to retrieve real variations in their latitude from the JUPOS data, although the sensitivity may be reduced. This is shown by the ZDP retrieved for these ovals in 2011/12 (**Fig.18**).

Note 3: History

It is unclear whether ovals A1 and A2 existed throughout the years 1986-1988, or whether there were shorter-lived ovals which were later replaced; later there was similar uncertainty about oval A4. The first oval A8 probably merged with A7 in 1992 March. In 1995, a new, minor oval was observed but only for this year. Otherwise, no ovals appeared or disappeared until 2001/02.

Exceptionally, in 2002, the last two in the chain merged (A6 and A7: Refs.3 & 11); and then the resulting oval probably merged with the preceding one (A5) during solar conjunction, leaving five (A1-A5), plus one new one which had already appeared in late 2001 (probably the future A8). Since then, three more new ones have appeared and none have permanently disappeared, leaving 9 major AWOs as of 2012.

The new AWOs were named A8 (present at start of 2004, probably the same one that appeared in late 2001); A0 (appeared at start of 2005); A6 (appeared in early 2006, alongside oval BA); and A7 (at start of 2008). This A6 disappeared in 2009 Sep., but reappeared or was replaced as oval A6a in 2010 May (again alongside oval BA) [**Note 4**]. So the 9 ovals in 2012 were A1-A5, A6(a), A7, A8, A0.

Note 4: Reappearance of A6.

In 2009 Sep., oval A6 was observed to disappear, although it seems plausible that it persisted as an undetectably small oval or eddy – possibly visible in the hi-res map in **Fig.4** - which nucleated the regrowth of the same oval. In mid-2010, there were three tiny ovals in this sector, two of which quickly merged to form the new A6, while the third merged with A7 **(Appendix 4)**.

Note 5: Lifetimes.

As 3 out of 7 ovals disappeared in 27 years, the mean lifetime was 27 x 7/3 = 63 years.
Or, assuming steady-state turnover, as 3/7 disappeared while 5/9 appeared in 27 years, the mean turnover was 4 out of 8 and the mean lifetime was 27 x 8/4 = 54 years.

Note 6: Threshold for merger:

Whenever two AWOs have come within <12º of each other, they went on to merge: A7 with A8 in 1992; A6 with A7 in 2002; and the short-lived A6b with A7 in 2010. Except, A4 and A5 were also only 10º apart at the start of 2002, but moved apart as A6 and A7 converged to merge.

Note 7: The SSTB white sector ('SSTBZ') between ovals A8-A0, 1991-1995:

In 1989/90, the SSTB was (unusually) a broad dark belt at almost all longitudes with no long-lived whitened sectors, compensating for the STB which was almost completely whitened; but the SSTB segment between ovals A8-A1 was lighter than elsewhere.

In 1990/91, oval A1 was exceptionally large and bright; the segment p. it was darker in Nov.-Jan., then lighter again in 1991 May-June.

In 1991/92, the SSTB was still faint between A8 and A1, especially when it was alongside the single dark streak of STB, in a typical compensatory albedo change. As it moved p. the dark STB steak, it became a sector of double SSTB with a bright strip down the middle: L2(O) 233-276. It had expanded to a length of 43º. Therefore, it may have been this expansion that pushed oval A8 to accelerate to DL2 = -28 and merge with oval A7, just 10º p. it.

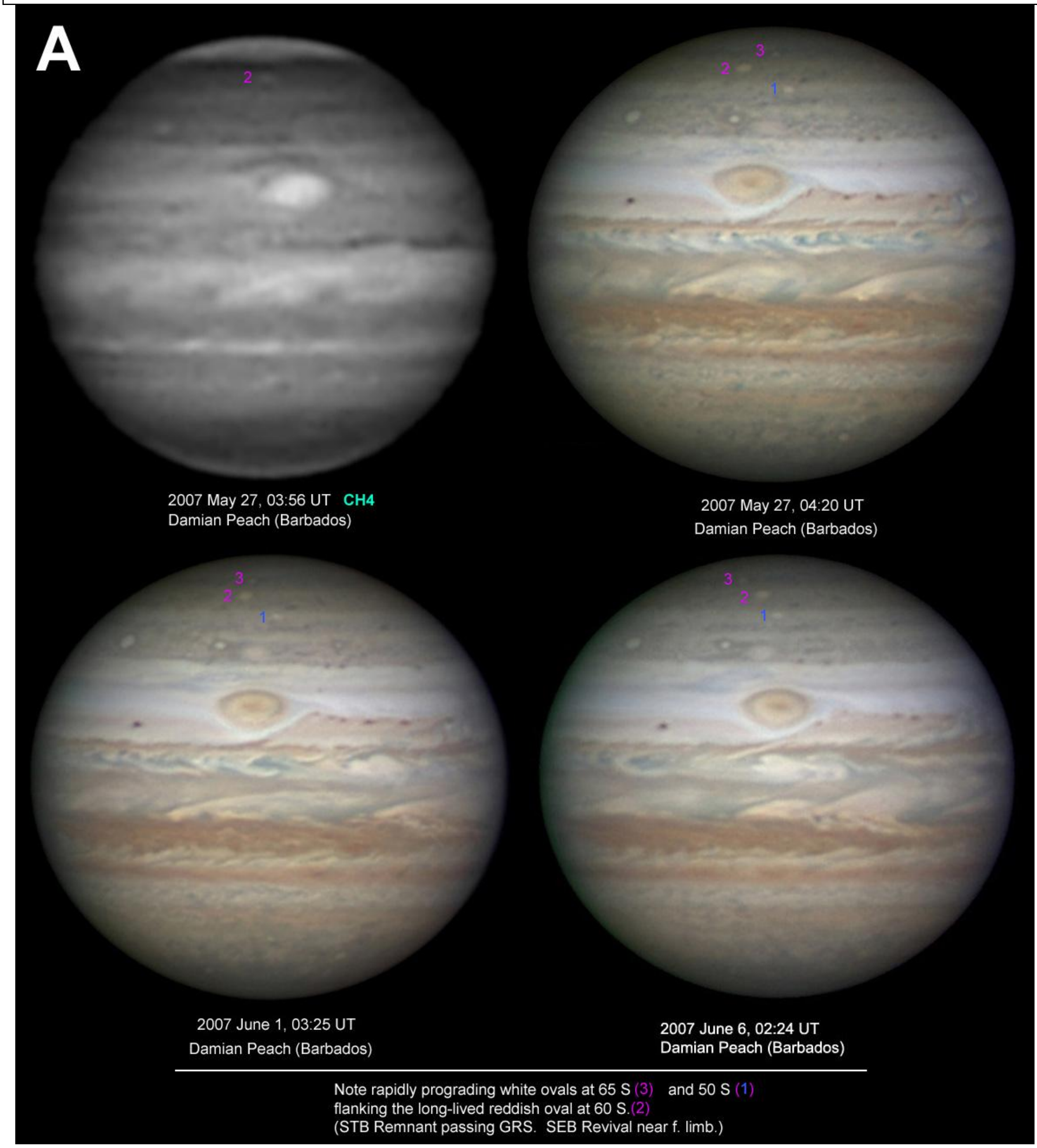
In 1994, this white oblong of SSTB had expanded still further and was just over 100º long; it was well shown in HST maps. In 1995 it had stabilised at ~110º long, still between A7 and A1. In 1996 it was no longer visible; but HST maps [in Ref.10] show that it had transformed into a long FFR, which remained exceptionally large up to 1999.

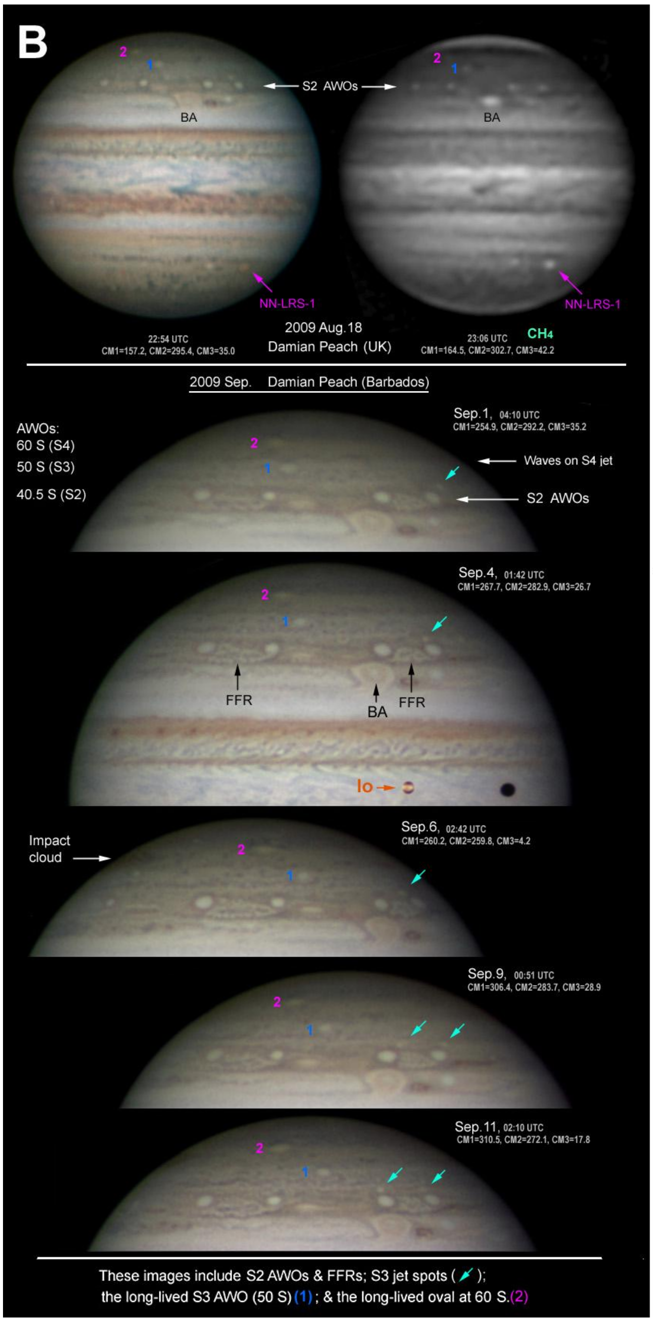
So it expanded at an average rate of ~2.1 deg/month (1992-1994), then stabilised when it exceeded 100º long.

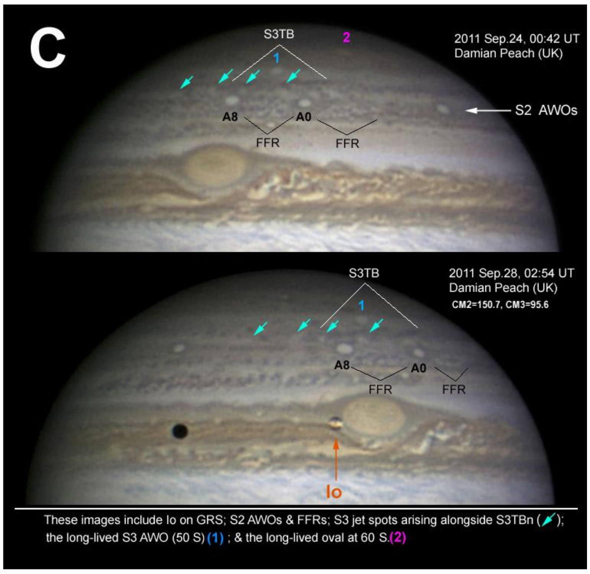
Appendix 4:
Original images showing the long-lived S3 and S4 ovals.

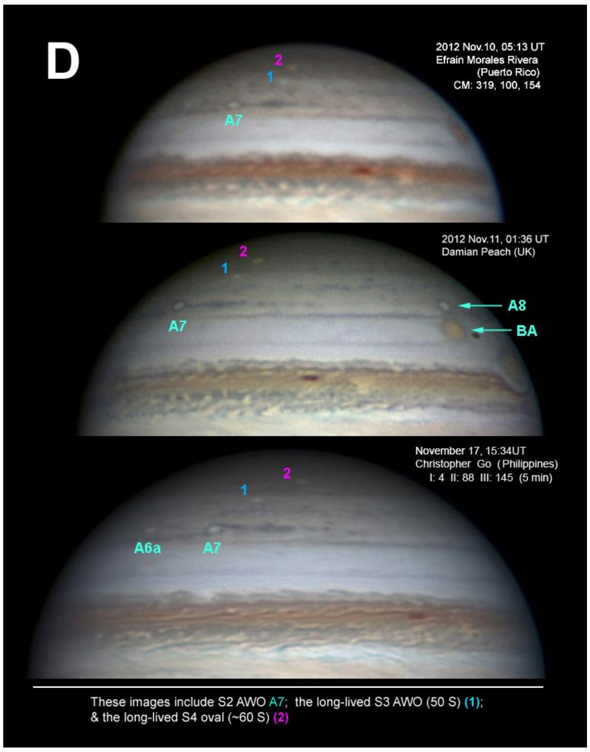
(A,B,C) All by Damian Peach & on some of the same dates as the polar projection maps (**Fig.12**), & including methane images:
(A) 2007 May 27 – June 6
(B) 2009 Sep.1-11 (& Aug.18, methane)
(C) 2011 Sep.24 & 28

(D) A set by several observers from 2012 Nov.10-17.




B
S2 AWOs
BA
NN-LRS-1
22:54 UTC
CM1=157.2, CM2=295.4, CM3=35.0
2009 Aug.18
Damian Peach (UK)
23:06 UTC
CM1=164.5, CM2=302.7, CM3=42.2
CH4
2009 Sep. Damian Peach (Barbados)
AWOs:
60 S (S4)
50 S (S3)
40.5 S (S2)
Sep.1, 04:10 UTC
CM1=254.9, CM2=292.2, CM3=35.2
Waves on S4 jet
S2 AWOs
Sep.4, 01:42 UTC
CM1=267.7, CM2=282.9, CM3=26.7
FFR
BA
FFR
Io
Impact cloud
Sep.6, 02:42 UTC
CM1=260.2, CM2=259.8, CM3=4.2
Sep.9, 00:51 UTC
CM1=306.4, CM2=283.7, CM3=28.9
Sep.11, 02:10 UTC
CM1=310.5, CM2=272.1, CM3=17.8
These images include S2 AWOs & FFRs; S3 jet spots ( );
the long-lived S3 AWO (50 S) (1); & the long-lived oval at 60 S.(2)


C
S3TB
2011 Sep.24, 00:42 UT
Damian Peach (UK)
A8
A0
FFR
FFR
S2 AWOs
S3TB
2011 Sep.28, 02:54 UT
Damian Peach (UK)
CM2=150.7, CM3=95.6
A8
A0
FFR
FFR
Io
These images include Io on GRS; S2 AWOs & FFRs; S3 jet spots arising alongside S3TBn ( );
the long-lived S3 AWO (50 S) (1) ; & the long-lived oval at 60 S.(2)


D
2012 Nov.10, 05:13 UT
Efrain Morales Rivera
(Puerto Rico)
CM: 319, 100, 154
A7
2012 Nov.11, 01:36 UT
Damian Peach (UK)
A7
A8
BA
November 17, 15:34UT
Christopher Go (Philippines)
I: 4 II: 88 III: 145 (5 min)
A6a
A7
These images include S2 AWO A7; the long-lived S3 AWO (50 S) (1);
& the long-lived S4 oval (~60 S) (2)

Appendix 5:
Impact clouds in the S3 and S4 domains

These domains have fortuitously been probed by two rare impacts: first the great Comet Crash in 1994, at 47-48ºS, and then the 'Bird Strike' in 2009, at 57ºS. The 1994 event was the first ever observed, and the 2009 event – fortuitously coming exactly 15 years later and in a similar position one domain further south – was immediately recognised as similar. In both cases the visible traces were extremely dark clouds, consisting of extended debris clouds in the stratosphere, as well as an almost-black core marking the site of the impact explosion below the cloud-tops.

The motions of these debris clouds were monitored over the weeks following the impacts, and compared with the known ZWPs of these domains. Because they were at very different altitudes from the weather features which we usually track, the motions of the impact clouds were most informative regarding the vertical shear rather than the zonal winds.

The Comet Crash in 1994

The impact of the shattered comet Shoemaker-Levy 9 in1994 occurred outside the time interval considered here, but should be mentioned as it provided a unique probe of these southerly domains. The 12 substantial fragments all impacted at 47-48ºS, in the **S3 domain**, where the zonal wind speed is almost the same as the S3TC slow current, and almost the same as System III. Therefore it was no surprise that, according to our measurements [Rogers, 1996] the average motion of the dark debris clouds was much the same (DL2 = -11 (±18) deg/mth), and we found little sign of any clouds being sheared by the ZWP. However the initial speeds of the black cores tended to be slower (DL2 = -2 (±5) deg/mth, representing the slow motion of the impact sites below the cloud-tops. But the leading edges and peripheral clouds, and whole cloud complexes later, moved faster (average DL2 = -18 (±12) deg/mth); these clouds were at very high altitude, so this apparently revealed a stratospheric current faster than the underlying cloud-top current [Rogers, 1996].

The Comet Crash also affected the **S4 domain**, as the ejecta of the largest impacts extended up to ~61ºS, giving rise to dark clouds spanning this latitude range, which shared the rapid drifts cited above (mean DL2 = -18 (±12), across a broad latitude range); the impact clouds were not obviously sheared by the ZWP [Rogers, 1996]. Although we did not have accurate latitude measurements for each cloud, we recorded drift rates for identified south-preceding components (derived from the ejecta arcs) for site D/G/S/R (DL2 = -11) and site H (DL2 = -36). The latter was at 54ºS and so may have been influenced by the S4 jet at 53ºS. [Rogers, 1996]

Similar speeds were deduced by Sanchez-Lavega et al.(2005), with higher resolution as they had hi-res measurements from Pic du Midi images as well as amateur images. They found that some of the drift rates did follow the ZWP (esp. just S of the jets at 43ºS [S3] and 53ºS [S4]), but no clouds achieved the peak speeds of the jets; there were also many features prograding with ~5 m/s (~-18 deg/mth) , and also rapid local motions.

The Bird Strike in 2009

On 2009 July 19, another, unexpected impact was discovered in the form of a new, nearly-black spot at 57ºS. It was dubbed the 'Bird Strike' (after its discoverer, Anthony Wesley), and he immediately recognised the spot as an impact cloud similar to the medium-sized ones of 1994 [Rogers, Wesley & Mettig, 2009]. With the improvements in imaging over the intervening 15 years, we were able to establish an accurate ZDP for this debris cloud as it expanded. While the black core at 56.5ºS had DL2 = +7, slightly faster than the zonal wind of DL2 = +12, a more northerly cloud patch detached at 54ºS and prograded rapidly, DL2 = -48, apparently influenced by the S4 jet at 53ºS. The p. end of the more southerly dark clouds, shifting from 58 to 58.5ºS, also prograded, with DL2 = -22, notably faster than the zonal wind which is close to zero; we suggested that this represented a prograding stratospheric current similar to that which governed the SL9 impact clouds.

Sanchez-Lavega et al.(2011) reached similar conclusions, with higher resolution, from measurements on HST and professional infrared images as well as the same amateur images. They agreed with our conclusions on the motion of the core. They reported that the impact cloud spread to N and S limits of 53.5ºS and 61.4ºS, i.e. limited by the adjacent prograde jets. All speeds measured from 55 to 60ºS were faster than those of the ZWP, by up to 5-10 m/s (18-36 deg/mth), with considerable variation, indicating faster speeds at the stratospheric altitude of the impact cloud.

Notable waves were imaged on the albedo boundary at 53ºS after the 2009 impact: we found that they developed from 2009 Aug.7 onwards [Rogers, Wesley & Mettig, 2009] . They were also noted by S-L et al.(2011), in HST UV images, July 23 to Aug.9: they reported that there was no change in the waves, though their Fig.10 suggests that the wavetrain possibly expanded over this interval. Further notes are in the main text.

References for Appendix 5:

Rogers JH (1996) JBAA 106 (no.3), 125-150. 'The comet collision with Jupiter: II. The visible scars.' [The Jupiter Section Report on amateur observations.]

Rogers JH, Wesley A & Mettig H-J (2009 Dec.) JBAA 119 (6), 311-315. Section report: ‘The 2009 impact on Jupiter’.

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Sanchez-Lavega A et al.(2011) Icarus 214, 462-476. ‘Long-term evolution of the aerosol debris cloud produced by the 2009 impact on Jupiter.’