Final version inc. figures, 2026 June 15

THE B.A.A. GUIDE TO JUPITER'S ATMOSPHERIC PHENOMENA SINCE 1990

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INTRODUCTION

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REFERENCE LISTS

These pages provide a guide to the major features of Jupiter's atmosphere, and to the major phenomena that have occurred since 1990, and an index to the studies that we in the BAA Jupiter Section have published or posted about them – including our best and most up-to-date references. Only a few professional references are included, mainly those in which the Jupiter Section was also involved, and a few landmark papers. Other professional references are given in some of our major reports. Our individual JunoCam perijove reports are not included except for a few special instances.

Our knowledge of Jupiter's atmosphere up to 1991 was compiled in *The Giant Planet Jupiter* (Ref.J1). An index to our subsequent publications and posts that gave substantial information about the major features and phenomena up to 2015 was posted on our old web site under 'Reference Articles'. This is an expanded and updated version of it.

References

References in this Guide are given both via a reference list (at the end), and via hyperlinks where available (underlined coloured text, e.g. brief name or title of the article; press Control & Click to go direct to the item online).
They are organised in four categories, as follows:
--Articles in journals and other print media, e.g. "Ref.J1..." – these include papers in the Journal of the BAA (JBAA) and in professional journals; most of the latter have the Section Director and sometimes other amateur(s) as co-authors.
--Major reports on our web pages, e.g. "Ref.R1..." -- these include long-term reports (which will include references to our interim reports on the same topic, so those will not all be linked here) and some apparition reports. [The most comprehensive are in **bold type**.]
--Other notable interim reports on our web pages, e.g. "Report 2024/25 no.7..." – the more important ones in bold type. They are not entered in the reference list but the underlined coloured references in the text are hyperlinks.
--EPSC abstracts, e.g. "EPSC 2025-55..." – these are convenient summaries of topics. Hyperlinks for these are not given in the text; please find the abstract in the reference list, with a link to it in the EPSC web sites. From 2020 onwards, abstracts posted by EPSC do not always show the figures or formatting adequately; our own properly formatted PDF versions are at:
https://britastro.org/section_information_/jupiter-section-overview/contributions-2020-onwards

Conventions and abbreviations

Our reports previously used historical conventions (south up in figures, System II longitudes (L2)) but since 2015 we generally use the more recent professional conventions (north up, System III (L3)). However, we still quote longitudinal drift rates in L2 (DL2, degrees per 30 days) in order to enable comparisons with earlier records. They can easily be converted to drifts in L3: DL3 = DL2 + 8.0 deg/30d. Sometimes, drift rates are also converted into wind speeds in System III (u_3, m/s).
Latitudes are given as planetographic, except in Juno reports where they are planetocentric.
Abbreviations used in our reports include the following:

***Abbreviations used*:**
F., following = planetary west
AWO, anticyclonic white oval
GRS, Great Red Spot
ZDP, zonal drift profile
P., preceding = planetary east
FFR, folded filamentary region [cyclonic]
PJ, perijove [Juno]
ZWP, zonal wind profile
--and other standard abbreviations for belts and zones, shown in Figure 1.

PART I. GENERAL ASPECTS

1. Belts, Zones, Jets, and Domains

Jupiter's disk appears divided into alternating **belts** (visibly dark) and **zones** (bright). Although there are variations, they tend to lie in reproducible latitudes, and have long-established names accordingly. The Voyager spacecraft showed that the average latitudes of the belt edges coincide with **jet streams (jets)**, running eastward (prograding) or westward (retrograding). These jets have fixed latitudes, and are the most significant divisions of Jupiter's atmosphere. Therefore, their latitudes provide the natural, modern definition of the **belts** (cyclonic) and **zones** (anticyclonic) **(Figure 1).**

The eastward (prograding) jets are, in most cases, the fastest and best-defined, and no substantial features cross them [with a limited exception described below]. So these jets form the boundaries of domains, each of which consists of a belt (low-latitude) and zone (high-latitude). The prograde jets are numbered going poleward in each hemisphere, and each domain has the same number as the jet on its equatorward side. In order to make the numbering compatible with the traditional names of the belts and zones, the numbering of jets starts with N1 = NTB south edge, so the N1 domain = North Temperate domain consisting of NTB & NTZ; then N2 = NNTBs jet, N2 domain = NNTB & NNTZ; and likewise in the southern hemisphere.
In abbreviations, we distinguish a belt edge (e.g. written NTBs, also referring to the N1 jet) from a belt component (e.g. written NTB(S), when the NTB is visibly double).

This scheme was described in our post:
Ref.R1 = 'Reference list of Jupiter's jets'.
This page gives the peak speed and latitude for each jet from each of the 4 major spacecraft data sets up to 2007 (Voyager, Hubble S.T., Cassini, New Horizons).
An updated table and diagram (copied here as **Figure 1**) are posted here:
Ref.R2 = 'Jet streams list'
The scheme was also described in our long-term report:
Ref.R3 = Jupiter's southern high-latitude domains...
[& in our 2022/23 Report no.8]

Further zonal wind profiles have been published since, largely from Hubble images, but also from amateur images by the JUPOS team (see our refs. below) and by:
Ref.J2 = Hueso et al.(2017).
An important study from Hubble images over many years produced global maps of both E-W and N-S winds, showing sectoral variations and circulations, reinforcing some of our own conclusions: Ref.J3 = Tollefson et al.(2017).

1.1. Zonal wind profiles & Zonal drift profiles

'Zonal wind profile' (ZWP) & 'zonal drift profile' (ZDP) refer to charts of east-west wind speed vs latitude.
A ZWP represents the smallest resolvable features and is taken to represent the winds (at cloud-top level, of course); these are derived from spacecraft images, or in recent years from the best amateur images by cross-correlation analysis, over a matter of hours (up to 30 hours).
A ZDP represents distinct 'spots', i.e. weather systems, that are individually tracked for longer time-spans; these are commonly derived from amateur images by the JUPOS team.

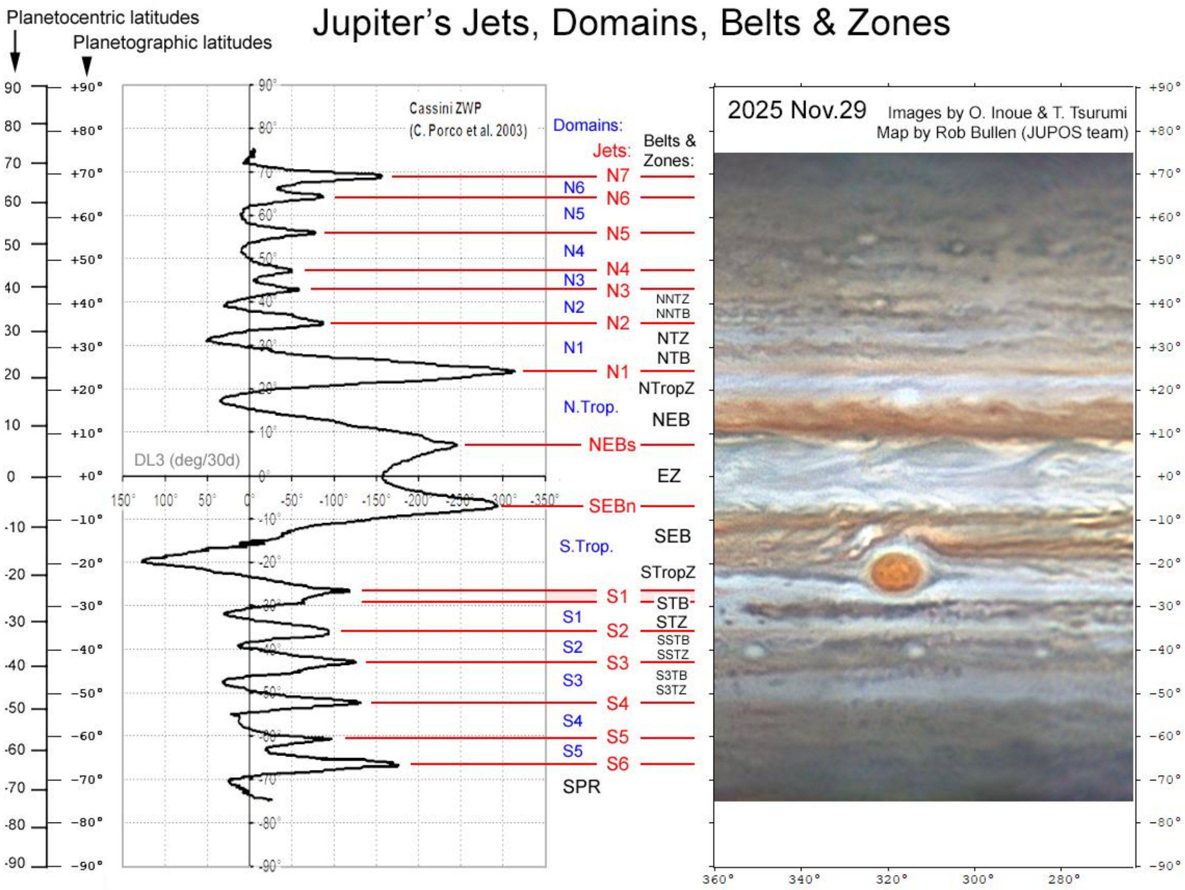

Figure 1: Definitions of Jupiter's jets, domains, belts & zones, by latitude. Jets and domains are not shown beyond S4 and N5, but actually go up to S6 and N7.

We routinely find that a ZDP is closely aligned with the ZWP, except:
--For retrograding features, the ZDP is 'blunt', i.e. retrograding speeds are slower than the ZWP.

--In some cases, on the anticyclonic slope, the ZDP is displaced by up to a degree latitude from the ZWP [e.g. STropZ (see refs. on SEBs jet below) and N5 domain (see: 2022/23 report no.6 [Ref.R13] & 2024/25 report no.7)].

--Large anticyclonic ovals sometimes follow a ZDP that is displaced from the ZDP for smaller ovals, probably because they distort the adjacent jet(s):

Ref.J4 = Rogers et al.(2011), 'A Little Red Spot tracked through a jovian year'
[inc. **Supplemental tables.**] for N2 & other domains;
Ref.R9 = Jupiter's long-lived N5 oval, 2015-2023, for N5-AWO;
Ref.R15 = 'Jupiter's S. Temperate domain.... 2001-2012' for S.Temp.AWOs.

Most substantial 'spots' have drift rates within a fairly narrow range, defining a **'Zonal slow current'** (ZSC) which is characteristic of each domain; these are the 'currents' that have long been recorded by amateur observers [Ref.J1]. Substantial spots tend to lie in latitudes where their ZDP is close to the ZSC.

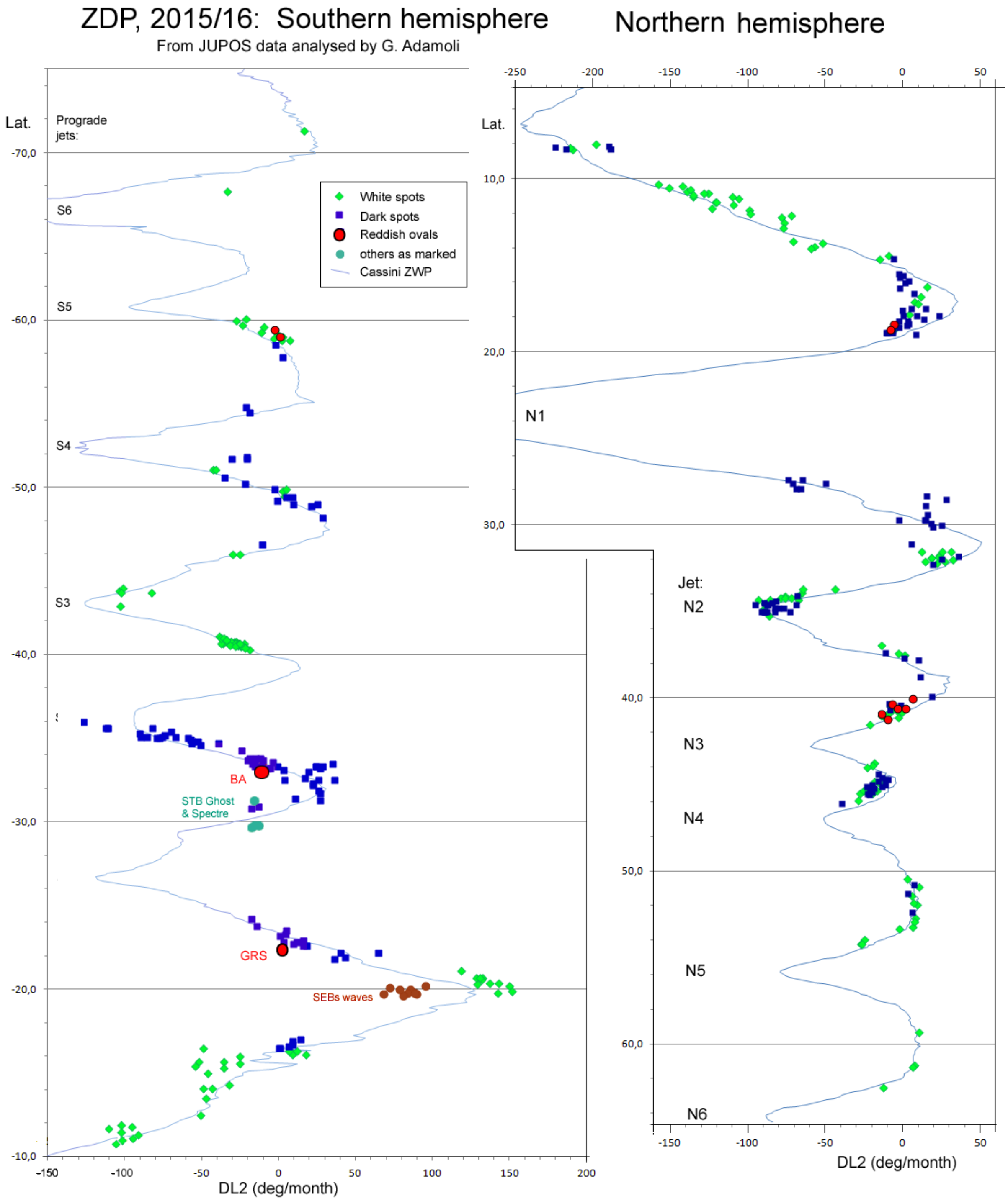

Figure 2. ZDP covering most of the planet, 2015/16, from JUPOS data (from Report 2015/16 no.13).

Zonal wind profiles from amateur work:

Ref.R4 = 'Longitudinal drift determination from image pairs with WinJUPOS'& follow: WinJUPOS/Tutorials/. [includes ZWP from amateur images in 2010 Sep] (Grischa Hahn).

Ref.R5 = 'Jupiter in 2012/13: Interim report no.9', Appendix 5 (Grischa Hahn) from amateur images in 2012 Sep-Dec.

Ref.R6 = Hahn & Rogers (2015), Report 2013/14 no.10: ZWPs from ground-based and Hubble images, 2014 Feb & April (These focussed on a S.Temperate sector with STBn jet spots, & a NTB sector.)

Report 2019 no.4: ZWP & maps from amateur images on 2019 June 19-21, by M. Vedovato.

Report 2019 no.9: ZWP & maps from HST on 2019 June 26-27, by M. Vedovato.

Ref.R7 = Report 2023/24 no.3, 'The major jets' (inc. Appendices): ZWPs in 2023/24 from amateur images, by G. Hahn.

Ref.R42 = Report 2024/25 no.5: ZWPs in 2024 Nov. & 2025 Feb. from amateur images, by G. Hahn. (Profiles for NTBs jet are shown; global profiles still unpublished.)

Zonal drift profiles from amateur work:

Ref.R26 = 'Jupiter in 2007: Final numerical report' – Part 1, Fig.1 (ZDP).

Ref.R33 = 'Jupiter in 2014/15, no.12: Final numerical report'.

Report 2015/16 no.13: ZDP from 62°N to 71°S

Since then, we have posted many ZDPs covering less-than-global latitude ranges, e.g. in our long-term reports on the N3 to N6 domains, the S1 domain, and the S2 to S4 domains [see refs. in regional sections below], and in our reports on the 2020, 2022/23 and 2024/25 apparitions. Our latest global example is in Figure 2.

1.2. General properties of the jets

Here we summarise the jets in general; see regional sections below for references. For summaries of the speeds and behaviour of all the fastest jets, and details in recent years, see:
Ref.R7 = Report 2023/24 no.3, 'The major jets' (inc. Appendices)
& earlier ones cited therein, inc:
Ref.R8 = Report 2021/22 no.10 inc. Appendix 1.

The NTBs, NEBs, and SEBn jets are by far the fastest, all with 'super-fast' maximum speeds in the range ~140-170 m/s, and there is evidence that the speeds are most rapid below the visible cloud-tops. There are large variations in the observed speeds which appear to be due to suppression of the 'super-fast' speeds by cloud-top meteorology, viz. the disturbances on the NTBs, and the North Equatorial dark formations (NEDFs: presumed Rossby waves) on the NEBs, and the comparable S. Equatorial Disturbance on the SEBn. The other prograde jets may also show speed variations but more modestly. A well-documented case is that the S2 jet has accelerated after 2000, while the S3 jet has decelerated [Ref.R20 = 'Jupiter's S2 domain, 2012-2023'].

The SEBs jet is the only rapidly retrograding jet, and it shares many properties with the prograde jets, including its sharp peak, its well-defined latitude, and its tendency to carry dark spots which are anticyclonic vortices, travelling less rapidly than the peak jet speed. Nevertheless, it does curve northward around the GRS forming the Red Spot Hollow, and exhibits multiple speed ranges as described below.

The other retrograde jets are slower and do not have such well-defined peaks. In low-latitude domains, the jet curves N and S around cyclonic and anticyclonic circulations. In the NEBn, these sometimes form an evenly-spaced series and the jet traces a wave-like pattern between them. In mid-latitude domains, notably the STBs, the retrograde jet is faster within long cyclonic circulations, whether chaotic (FFRs) or pale and quiescent (see below). Some narrow domains have no retrograde jet, just a minimum of eastward velocity, e.g. in N3 and N6, although in S2 there is a retrograde SSTBs jet even though early ZWPs did not show one [Ref.R20 = 'Jupiter's S2 domain, 2012-2023']. In high-latitude northern domains (N4, N5, & the northernmost and southernmost belts), there is not a continuous retrograde jet: the ZWP itself is blunt like the ZDP, with a modest retrograde speed that actually applies to the FFRs (the dominant features in these domains) and so is the ZSC for the domain. However, there are much faster retrograde speeds within the FFRs.

Further details on individual jets [these & more refs. are all in appropriate sections below]:

The NTBs jet:
Ref.J19 = JBAA 'NEB Paper III. The 'great northern upheaval' in 2012.'
Ref.R42 = Report 2024/25 no.5: 'The NTBs jet outbreak'.

The NEBs jet:
Refs.J17 & J18 = NEB Papers I&II.
Ref.R8 = Report 2021/22 no.10 inc. Appendix 1.
EPSC2022-17.

The SEBn jet:
Ref.J34 = JBAA 'Influence of Jupiter's South Equatorial Disturbance on jet-stream speed'
Ref.J35 = Icarus 'Longitudinal variation and waves in Jupiter's south equatorial wind jet.'
Ref.R7 = Report 2023/24 no.3, 'The major jets' (inc. Appendices)

The SEBs retrograding jet:
(See references in section below)

The STBn jet:
Ref.R15 = **'S. Temp. domain... 2001-2012'**
Ref.R16 = 'S. Temp. domain... 2012-2015'.

The S2 (SSTBn) to S5 jets:
Ref.R3=R19 = Southern high-latitude domains, 2001-2012.
Ref.R20 = S2 domain, 2012-2023.

The Juno spacecraft, mapping Jupiter's gravitational field, has shown that the major jetstreams (especially the NTBs jet) extend down to 2500-3000 km but no deeper, agreeing with theoretical predictions that they are restricted to this depth by magnetohydrodynamic effects where the deep atmosphere becomes electrically conducting, and they comprise a pattern of cylinders parallel to the planet's axis [Refs J5 & J6 = Kaspi et al., 2018, 2023].

Outbreaks of dark spots on jets:

On the NNTBs, NTBs, and (retrograde) SEBs jets, historical visual observers sometimes recorded outbreaks of small dark spots. Spacecraft images and modern amateur images showed that these were typically anticyclonic vortices, 'rolling' along the anticyclonic side of the jet peak with a drift rate ~10 m/s less than the peak jet speed [Refs. J1 & J7; & Ref.R26 = 'Jupiter in 2007...' (inc. Part 3, p.4, box: "The speeds of the SEBs and STBn jets"); & see refs. on individual jets below].
Our records suggest that they often appear in association with turbulent regions in the belts: some way downstream of FFRs in the NNTB [see section below], and of the perennial rifted

region of the SEB following the GRS. Apparently similar spots are sometimes observed on the SSTBn jet; and also on the STBn jet, downstream of turbulent dark segments of the STB, but those on STBn usually show little or no vorticity [Ref. J1; Refs. R15, R16, R18 = our long-term reports listed in S.Temp. section below].

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2. Local circulations

'Spots' (except in the equatorial region) are mostly organised circulations, either cyclonic or anticyclonic.

2.1. Cyclonic circulations

Those observable from Earth mainly fall into three categories, and spacecraft reveal a low-contrast fourth type. Most domains exhibit most or all of these types, for at least some of the time:
(i) Dark ovals or oblongs, often dark reddish-brown (including 'barges' in some belts and long belt segments in others);
(ii) White ovals or oblongs;
(iii) Turbulent convective regions (commonly called 'rifted regions' at low latitudes, 'folded filamentary regions' (FFRs) at higher latitudes, where they are the dominant features);
(iv) Pale oblongs (recognisable in spacecraft images as a stage in evolution of a dark or white oblong).
In conjunction with the JunoCam images, we have defined them most clearly in the S1 and S2 domains (STB and SSTB), where any type can convert into any other:
Ref.R18 = 'S.Temp. Domain, 2018-2024'
Ref.R20 = 'S2 domain, 2012-2023'
EPSC2024-362, EPSC2024-378.
For information on the lifetimes of FFRs, see those references and also the section on the NNTB below.

It is common for dark spots or oblongs in mid-latitude domains to turn reddish before fading away (sometimes persisting as pale oblongs) or turning white:
Ref. J13 = JBAA 'Jupiter in 2001/02.' [Part 2, p.215]
Ref.R15 = 'S. Temp. domain... 2001-2012'
Ref.R3=R19 = Southern high-latitude domains, 2001-2012.
Ref.R20 = 'S2 domain, 2012-2023'

In the SEB and NEB, brown 'barges' were observed to turn white in the 2010 SEB Fade and the 2021 NEB Fade (see sections below).

Jet speeds are faster on the edges of cyclonic oblongs, at least sometimes. This is consistently true for the STBn jet, and had also sometimes been recorded for the STBs jet. We have also found it to apply to a pale sectors of NTB [Ref.R6 = ZWPs, 2014 Feb & April] and SSTB [Ref.R20 = 'S2 domain, 2012-2023'].

Convective outbreaks, seen as bright white (and methane-bright) spots, are continually occurring on a large scale in 'rifted regions' of the SEB and NEB, and on a smaller scale in FFRs at higher latitudes. In the SEB (though not the NEB), they commonly begin with a plume erupting within a cyclonic circulation (see section below). Likewise, we have seen new FFRs initiated by bright plume outbreaks in the NTB [Ref.R21 = Report 2013/14 no.6], STB [2010, 2018, 2020, 2021, 2025 – see Refs R15-R18 in section below], and SSTB (2025: Report 2025/26 no.2.]

It is increasingly clear that convective or turbulent activity in cyclonic regions, including vigorous convective plumes, is of prime importance in driving weather phenomena on Jupiter, including *[for references see regional sections below]:*

--Driving the jets: A classic study of the SEB rifted region following the GRS, from the Galileo Orbiter, indicated that the white plumes are thunderstorms whose expansion generates vorticity that ultimately feeds into the SEBs jet [Refs.J14a&b]. This is believed to be a general process in many belts by which Jupiter's internal heat is transduced into energy to maintain the jets.

--Controlling speed of adjacent AWOs, viz. oval BA (S1 domain) & in high-latitude domains.

--Generating dark spots (vortices) on jets, some way downstream of a rifted region (SEBs) or FFR (STBn, NNTBs).

--Generating slow-moving or retrograde spots following FFRs, in many domains (e.g. N1, S1, S2, S3).

--Initiating and/or driving large-scale upheavals, viz.:

SEB Revivals and mid-SEB outbreaks: All recent examples have started with an intense convective outbreak within a mini-barge (SEB Revivals in 2007 and 2010, and mid-SEB outbreaks in 1979, 2016, & 2024), and this may be generally true. The ongoing convective outbreak (rifting) then generates other features of the Revival including the eventual revival of the dark belt.

NEB expansion events also involve convective outbreaks ('rifts') in the early stages but they occur in the NEB shear zone; curiously NEB rifts often appear adjacent to a barge but never inside one. Rifts can directly induce instability on the NEBn retrograding jet, and anticyclonic dark spots in the NTropZ, initiating the broadening of the dark belt [Ref.J1; Ref. R23 = 'Relationship of NEB rifts to NEB expansion events.'; Ref. J17 = JBAA NEB Paper I].

NTBs jet outbreaks consist of extremely intense plumes but on the peak of the jet. The wake of the plumes disrupts the whitened NTB leading to revival of the dark belt.

2.2. Anticyclonic circulations

These are the longest-lived circulations on the planet, present in almost all domains. The GRS is the largest one. The others are anticyclonic white ovals (AWOs) and reddish ovals ('little red spots', LRSs), and smaller darker vortices. The reddish ovals tend to be the largest and longest-lived, in the S1 domain (Oval BA), N2 domain (NN-LRS-1), and S4 domain (S4-LRS-1) [Ref. J4 = 'Jupiter's high-latitude storms: A Little Red Spot tracked through a jovian year.'], although their colour can fluctuate and shorter-lived LRSs are occasionally observed.

Large ones have never been observed to disappear except by merging with others (except in the N. Tropical domain). Small ones can be short-lived: in the S2 domain, where they have been best documented, they rarely last for more than 2 years. The longest-lived ones have been tracked back in the N5 domain (since 2015 or 2010) [Ref.R9], the N2 domain (NN-LRS-1 since 1993, & WS-4 since 2003) [Ref. J4], the N. Tropical domain (White Spot Z, since 1997) [Ref.R24], the S1 domain (oval BA, since 2000; its precursor AWOs dated from around 1940) [Refs.J1 & R14], the S2 domain (some since 1986) [Ref.R19], and the S4 domain (S4-LRS-1, since 1994 or 1987) [Ref.R19]; and of course the GRS (since 1831 or possibly 1665) [Ref.J1 & Ref.J45]. In most cases the ovals may have already existed long before ground-based observers were able to detect them.

Thus we have not observed the formation of new large anticyclonic ovals in modern times, except in the N. Tropical domain, where they commonly form after the periodic NEB expansion events, probably by instability of the retrograding NEBn jet [Ref.J1 & Ref.J17]. Medium-sized AWOs have been observed to form following turbulent cyclonic regions with merging of smaller vortices, in the S1 and S2 domains [see sections below]. Drifting and merging of smaller vortices can also contribute to reconnection of opposing jets that forms the large-scale hemi-circulation of a S. Tropical Disturbance [see Ref.J1 & section below]. Mergers of anticyclonic ovals were described in [Ref.J15], & subsequent mergers have been described in our interim reports in the N. Tropical, S2, and S4 domains [see sections below].

In high-latitude domains (N5, N4, N2; S3, S4), AWOs in the poleward side of the domain often move with fast drift rates, but show sudden unpredictable changes in speed, all related to latitude according to the ZWP. Circumstantial evidence suggests that some of these speed changes are caused by interactions with FFRs: specifically, that high-latitude AWOs naturally drift fast, but can be blocked by encounters with FFRs moving with the ZSC [Ref.R10 = 'Jupiter's high northern latitudes...']; likewise in the N2 domain: [Report 2015/16 no.13]. They can also be blocked upon encountering the leading spot in a chain of retrograding small dark spots, e.g. in the N2 domain [Ref.R25 = 'Jupiter in 2005 & 2006'] & S3 domain [in 2011: Ref.R19 = Southern domains..., & Ref.J16].

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3. Global Upheavals

The most impressive phenomena on Jupiter are cyclic upheavals in three of the major domains: the NTBs jet outbreak (NTB Revival), the NEB Expansion Event, and the SEB Fade/Revival. They are described in the sections below, but first we note their common features. All occur with periods of 3-5 years, although sometimes they cease for over a decade. All involve outbreaks of one or more vigorous convective storms, which initiate the NTB and SEB Revivals, and develop to revive or expand the dark belt after a period of quiescence. [See Ref.J19 = JBAA NEB Paper III, & Ref.J28 = Fletcher (2017).]
Another impressive cyclic phenomenon is the EZ coloration episode, which often overlaps with cloud clearing in the thermal-infrared with a period of ~7 years, but this does not involve any local storm outbreaks.

A Global Upheaval is a near-simultaneous occurrence of major phenomena in several domains. It was defined in the 1970s [Ref.J1], and recurred in 1990 and then again in 2007. With more detailed understanding of the various phenomena, we concluded that it essentially consists of three largescale phenomena that occur within a year or so, although they can also occur separately: a NTBs jet outbreak, EZ coloration, and a SEB Fade/Revival.
Our discussion as of 2007 was in these reports:

Ref.J37a [=R27] = **'Jupiter embarks on a global upheaval'**;
Ref.R28 = **'The NTBs jet ...& the nature of global upheavals.'**

Our main recent discussion of these phenomena is: **[Ref.J19 = NEB Paper III]**.

Since 2007 there have been no global upheavals as previously defined, but in 2012, a NTBs outbreak coincided with EZ coloration and a NEB Fade/Revival, producing a dramatic spectacle of colour and disturbance from ~0 to 40°N, which we nicknamed a 'Great Northern Upheaval'. Whether this was an organised disturbance across multiple domains, or just a coincidence, is undetermined. Similar coincidences of a NTBs outbreak, EZ coloration, and a NEB expansion event, occurred in 2016/17 and in 2020, although the relative timing of the events was not the same, and the inexact 3-5-year periodicities of the NTB and NEB cycles were maintained. There may also have been a 'Great Northern Upheaval' in 1926-27. **[Ref.J19 = NEB Paper III**; & see sections below]

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4. Multispectral imaging (Infrared, Methane-band, etc.):

Imaging in the 889-nm methane absorption band is particularly useful for showing the altitudes of the cloud-tops or hazes, and imaging in near-infrared continuum, ultraviolet, and some other wavebands also enhances our view of the planet.

For specific accounts of multispectral images, see our reports for the apparitions of 1997, 1999/2000 (Part II), and 2000/2001 (Part II), all available under 'Publications – Full Section Reports', as follows:

Ref.J21 = 'Methane band images of Jupiter, 1995-1997.' (Appendix).
Ref.J9 = 'Jupiter in 1999/2000, Part II: Infrared wavelengths.'
Ref.J11 = 'Jupiter in 2000/2001: Part II: A review of multispectral imaging...'

... and shorter summaries in recent interim reports:

Ref. R29: 'Jupiter in 2007: Multispectral Imaging'
Ref. R30: 'Multispectral imaging of the EZ and NTB coloration events'

Subsequently we have not posted reports specifically on non-visible wavelengths, but methane-band images are included in many of our regular reports.

An online BAA seminar on 2023 March 2 showcased four amateurs developing special techniques (C. Pellier, B. Adcock, A. Cidadao, S.M. Hill), and a video of it is on our web pages:

'Multispectral imaging for analysis of Jupiter's atmosphere' (2 hours)
https://britastro.org/videos/multispectral-imaging-for-analysis-of-jupiters-atmosphere

Also see Adcock's work in: EPSC2019-1843.

Ammonia distribution:
Ammonia is one of the most important vapours in Jupiter's atmosphere, though mostly sequestered below the clouds. Steve Hill (in Colorado) has developed a novel method for imaging and measuring the ammonia abundances above the clouds by imaging in weak absorption bands for NH_3 and CH_4. His paper on this, in collaboration with Prof. Patrick Irwin, is [Ref.J22 = https://doi.org/10.1029/2024EA003562]
and a follow-up by Irwin using his professional spectra confirms Hill's results: [Ref.J23 = https://doi.org/10.1029/2024JE008622]. It concludes that the visible cloud-tops are much deeper than is usually assumed, at 2-3 bar pressure, and cannot be made of pure ammonia ice. Also see Hill's EPSC abstracts:

EPSC2022-802. https://doi.org/10.5194/epsc2022-802.
EPSC2024-160. https://doi.org/10.5194/epsc2024-160.
EPSC2025-1174. https://doi.org/10.5194/epsc-dps2025-1174.

PART II. REGIONAL PHENOMENA

5. High northern domains (N3 to 'N7')

(For the north polar polygon, as observed by JunoCam, see final section herein.)

Little was known of the regions north of 47°N until spacecraft viewed the planet and then, from around 2010 onwards, amateur imaging became able to resolve numerous features in these high latitudes. We posted a detailed pre-Juno account covering the N3 to N6 domains [Ref.R10 below], and then full analyses for the apparitions of 2020, 2021/22, 2022/23, and 2024/25, combining JUPOS tracking data with feature identification on JunoCam and Hubble maps, covering the N4, N5 and N6 domains and all the way up to 75°N. References:

Ref.R10 = 'Jupiter's high northern latitudes...' (2017)
Ref.R11 = Report 2020 no.9
Ref.R12 = Report 2021/22 no.9
Ref.R13 = Report 2022/23 no.6
Report 2024/25 no.7
EPSC2022-16.

The N6 and N3 domains are both narrow, with only sparse features, all of which are prograding as there is no retrograde jet. The N6 domain approximately coincides with the 'Bland Zone' (~63-68°N) as seen in JunoCam images.

North of the N7 prograde jet (mean latitude 68.4°N) is the northernmost belt, comprised of FFRs; this may be called the 'N7 belt', but there is not a regular 'N7 domain' as no jets are known further north. We obtained the first ZDPs for this belt, up to 75-76°N, in 2022/23 and 2024/25 [Ref. R13 & Report 2024/25 no.7, & EPSC2022-16, links above]. The FFRs in the 'N7 belt' move with a weakly retrograding current as in the N5 and N4 domains [same references].

The N5 and N4 domains are broad, and largely filled with FFRs. They also produce the highest frequency of lightning flashes on the planet, as detected by spacecraft [Refs. R10 & J24]. In [Ref.J24 = Fletcher et al.(2025)], we have used Juno MWR and JunoCam maps to show that most or all of the strong flashes come from conspicuous bright white storms within the FFRs.

Our ZDPs for both domains coincide with spacecraft ZWPs (apart from a curious latitude offset in northern N5), and are 'blunt', with a modest retrograding speed over a wide range of latitude. This is the zonal slow current, representing the drift rate of the FFRs and other spots including low-latitude AWOs. No rapid-retrograde jet is detected, and perhaps does not exist outside the FFRs, although such speeds must be present in the northern edges of the FFRs. In the more northerly ranges of the N5 and N4 domains, AWOs move with faster or oscillating drift rates related to latitude. Possibly, northerly AWOs here (and in the N2, S3 and S4 domains, as noted above) always tend to move fast but are impeded by interactions with FFRs [Ref. R10 = 'Jupiter's high northern latitudes...' (2017); & Ref.R11 = Report 2020 no.9]. We show examples of these interactions in our reports, and [Ref.J25] shows an example in Cassini imagery. We have also recorded many interactions between AWOs, in [Refs.R10-R13; links above], and earlier in Report 2014/15 no.12 & Report 2016/17 no.10 (Appendix 3).

Some AWOs in N4 and N5 are long-lived, but difficult to track between apparitions due to their huge unpredictable changes of drift rate. The largest is one in N5 that has been tracked (with aid from JunoCam maps during solar conjunctions) from 2015 to 2025, and this must have been one of two that existed as far back as 2010 [Ref.R9 = AWO in N5, 2015-2023]. On four occasions, we have recorded an AWO moving from the N4 domain across the N4 jet into the N3 domain [Report 2011/12 no.9; Report 2017/18 no.6; Ref.R12 = Report 2021/22 no.9; Ref.R13 = Report 2022/23 no.6] – the only known instances of a coherent circulation crossing a prograde jet, except for one similar instance from N3 to N2 [Report 2021/22 no.9].

6. N.N. Temperate (N2) domain & jet

6.1. NNTZ ovals

In [Ref.J4], we analysed the anticyclonic ovals in the NNTZ, and identified one which has existed since 1993 or earlier, named NN-LRS-1. The interaction of the ovals with the wind speed gradient across the NNTZ, leading to offsets in ZDPs, is considered in detail.
Ref.J4 = **'Jupiter's high-latitude storms: A Little Red Spot tracked through a jovian year.'**
Follow-up report in 2012:
Ref.R31 = **'NNTZ: Anticyclonic ovals, 2008-2012'**

Subsequent follow-ups include Report 2020 no.9 and Report 2021/22 no.10. (The latter confirmed the ZDP offsets as shown previously, viz. LRS-1 < WS-6 < other AWOs).
As of late 2025, there are still two long-lived ovals: NN-LRS-1 which has been tracked since 1993, and NN-WS-4 which has been tracked since 2003. WS-6 existed from 2010 (or probably 2008) to 2024; it was reddish in 2016-17, and disappeared in 2024 July [Report 2024/25 no.7].

Timelines of FFRs and other NNTB sectors have been covered in our final reports for recent years: Report 2015/16 no.13; Report 2019 no.9; Report 2020 no.9; Report 2021/22 no.10, & Report 2022/23 no.6.

6.2. NNTBs (N2) jet

This jet can serve as a model for Jupiter's non-equatorial jets: it is uncomplicated, well-defined, and well-observed, and it usually carries typical dark spots (anticyclonic vortices) with reproducible speed. Spacecraft values for its peak speed are surprisingly diverse, perhaps depending on how much they are affected by the jetstream spots, but they are all faster than these spots, by an average of ~18 deg/30d (7 m/s), consistent with the jetstream spots being vortices 'rolling' along the S edge of the jet peak as was shown by Voyager. We have not done a systematic review of this jet, but results from apparition reports are as follows:
The mean speed (from jetstream spots) was DL2 = -77 (±5) deg/30d from 1929-1991 [Ref. J1], -78.7 (±1.5) from 1999-2004, and -84.8 (±1.7) from 2004-2008 (from JUPOS data in our reports). The increasing speed may be due to improving images and analysis. Thorough JUPOS analysis in 2005 & 2006 [Ref.R25 = 'Jupiter in 2005 and 2006: Final report.'] & in 2011/12 [Ref.R32 = Report 2011/12 no.9] & in early 2015 [Ref.R33 = Report 2014/15 no.12] showed similar speeds for the majority of spots, plus others slower and faster which followed an anticyclonic gradient from the jet peak southwards, again consistent with the dark spots 'rolling' along the jet peak. Taken together, these results suggested that the true peak speed of the N2 jet (at least in some sectors and epochs) is around DL2 ~ -104 (±5) deg/30d at 35.6 (±0.2)°N [Ref.R33 = Report 2014/15 no.12].

We have noted evidence [in Ref.21 = Report 2013/14 no.6; Report 2014/15 no.12; & Report 2015/16 no.13] suggesting that the jetstream spots tend to develop a short way downstream of a FFR in the NNTB, although this is not fully confirmed.

Whereas the older literature suggested that outbreaks of NNTBs jet spots were distinct events, often occurring a year or so after a NTBs jet outbreak, more recent data shows that a large number of NNTBs jet spots is normal, but they are usually suppressed when a NTBs jet outbreak occurs, only to recover a year or so later. This was noted in:

Ref.R34 = 'Progress of Jupiter's great northern upheaval 2012...'
Ref.J19 = NEB Paper III
Ref.R11 = Report 2020 no.9

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7. N. Temperate (N1) domain & jet

The phenomena of this domain are linked to the cyclic outbreaks on the NTBs jet (see below); but first we describe a phenomenon of the NTZ and NTBn retrograding jet:

7.1. N.Temperate Disturbance

This is a darkening of a sector of the NTZ, which can last for several years. Some NTD's have developed ~2-3 years after NTBs super-fast jetstream outbreaks, as happened in 2009:

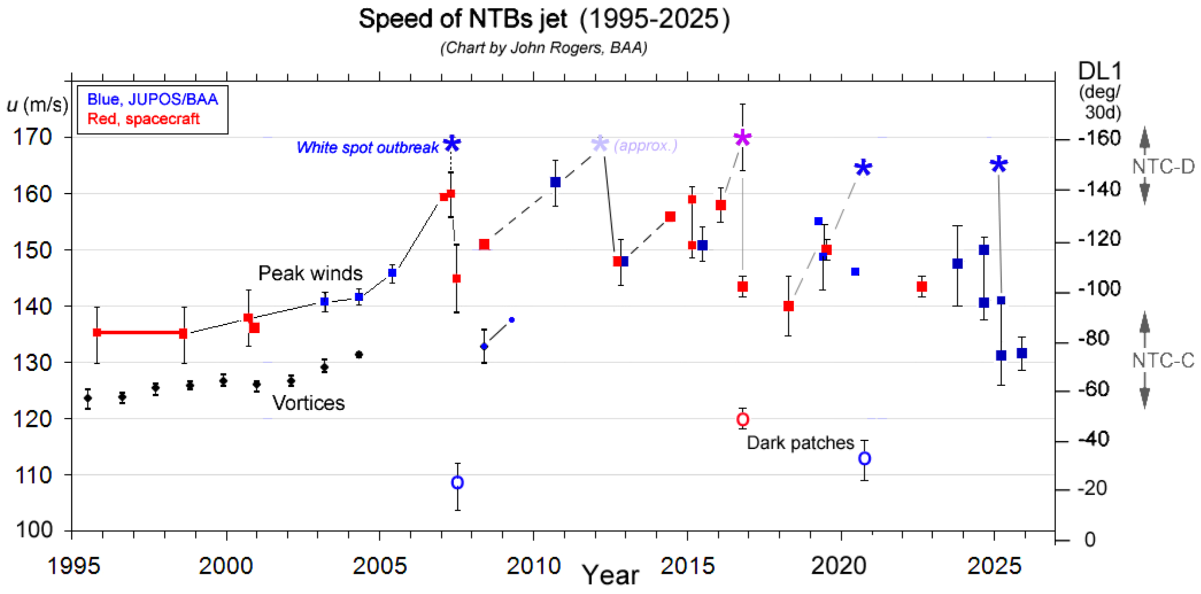
Ref.R35. 'Jupiter in 2009: Interim Report, with new insights into the NTZ disturbance, NEB expansion, and SEB fading.'
Ref.R36. 'Jupiter's North Temperate Region in 2009: The nature of the North Temperate Disturbance.'
Ref.R37. 'North Temperate Disturbance (NTD) in 2010, and a general conjecture about the behaviour of anticyclonic dark spots'
Ref.R38. 'North Temperate Disturbances: Is NTB rifting necessary?' (A historical survey showing that previous N.Temperate Disturbances have always been associated with 'rifts' in the NTB if photographed at sufficient resolution.)
Ref.R39. Life cycle of the North Temperate Domain and Disturbance, 2009-2012

Further examples began in 2013 and 2018, as follows. These recent well-observed examples showed that there is not generally recirculation in the NTD; it seems to be essentially a region of cloud disruption in the wake of a NTB rifted region. References: Report 2013/14 no.6 ; Report 2013/14 no.10; Report 2014/15 no.3 ; Report 2014/15 no.12; Report 2015/16 no.13. Ref.R6 (= Report 2013/14 no.10) showed that the ZWP was normal in the NTD (although an unrelated cyclonic pale oblong in the NTB had very rapid circulation).
Report 2015/16 no.13 showed the NTD still present following a rifted sector in 2015/16. This rifted sector survived through the 2016/17 NTBs outbreak, which also failed to eliminate NNTBs jet spots; and after the outbreak, there was again a NTD following the rifted sector in 2018 [Report 2018 no.6] & 2019, which regressed from 2020 March [Ref.R11 = Report 2020 no.9]. JunoCam gave several fine views of the NTB rifted sector from PJ6 to PJ14.

7.2. The NTBs jet stream (N1 jet) & NTBs outbreaks (NTB Revivals)

The NTBs jet alternates between two states. The 'fast' state was stable from 1991 to 2003 with long-lived vortices travelling along the jet at DL1 ~ -60 deg/30d (u_3 ~ 125 m/s). In contrast the 'super-fast' state comprises sudden energetic outbreaks of brilliant plumes at

DL1 ~ -150 to -160 deg/30d (u_3 ~ 165-170 m/s). These super-fast outbreaks occurred every 5 years from 1970 to 1990 (assuming one during solar conjunction in 1985) [Ref.J1], and then again, every 4-5 years, from 2007 to 2025. **Figure 3** gives a time-line of these cycles in terms of the cloud-top wind speeds:



The cycle begins with the belt faded to near-invisibility, then 2 to 4 super-bright elevated plumes erupt which prograde faster than anything else on the planet, with a turbulent wake forming behind each one. The disturbance takes several months to go to completion, with each plume disintegrating just after it catches up with the next wake ahead of it. This is followed by revival of the dark NTB with an orange S component and a dark grey N component. These then fade gradually over the subsequent years before the next outbreak. We reviewed these outbreaks up to 2012 in **[Ref.J19 = JBAA NEB Paper III].**

We tracked the gradual acceleration of the NTBs jet before the 2007 outbreak:

Ref.J26 = Icarus 'Renewed acceleration of the 24°N jet on Jupiter.'

The super-fast outbreaks started on the following dates:

-- 2007 March 25 (HST)/ 27 (ground-based); two major plumes appeared simultaneously; followed by thick orange aerosol over the revived belt from mid-2007 through 2008, then gradual fading. [See **'Reports 2007'**, & **Ref.R40 = 'The NTBs Jet in 2007 and 2008: Evidence on the structure of the jet and the nature of global upheavals.'**]

--2012 April 12 (estimated; discovered April 19); immediately before solar conjunction so most of the outbreak was unobserved. [See: Reports 2012/13 nos.1-4 , & **Ref.J19 = NEB Paper III.**]

--2016 Sep. 15 (estimated, ±5 days?), during solar conjunction. The earliest images were distant views from JunoCam on Oct.11-14, followed by the NASA IR Telescope Facility and amateur observers from Oct.16 onwards. 3 or 4 major plumes (we have re-interpreted the fourth as a wake-induced plumelet). [Ref.R41 = Report 2016/17 no.1; **Ref.J27 = GRL** **https://doi.org/10.1002/2017GL073421** (& see Ref.J28 = GRL https://doi.org/10.1002/2017GL073806); & EPSC2017-332.]

--2020 Aug.18. Three major plumes. This was the most thoroughly observed outbreak to date: initial account in Reports 2020 nos.6 & 7, and full analysis in **Report 2020 no.9**.

--2025 Jan.10. Three major plumes, plus numerous wake-induced plumelets (which can also be identified in the outbreaks of 2020, 2016 (possibly), and 2020). This was again thoroughly observed, and we obtained ZWPs just before and during the outbreak, contrasting cloud-top variations with the motions of the super-fast plumes, and reviewing previous ZWPs to show how they change consistently through the 4-5-year cycle. [**Ref.R42 = 2024/25 report no.5;** EPSC2025-45 & EPSC 2025-51]

8. N. Tropical domain & NEBs jet

8.1. AWOs in NTropZ/NEBn

White spot Z (anticyclonic white oval):

This long-lived AWO in the NTropZ appeared in 1997 and was initially the strongest and fastest-moving AWO in the domain. It is still present in 2025 although now little different from other AWOs. It briefly turned reddish in 2013.

Ref.R24 = ‘White spot Z: its history and characteristics, 1997-2013’

EPSC2015-82 = ‘The major circulations in Jupiter’s North Tropical domain.’

Mergers of anticyclonic white ovals, and of cyclonic barges in NEBn:

Ref.J15 = Rogers et al.(2006, Icarus) = **‘Merging circulations on Jupiter: observed differences between cyclonic and anticyclonic mergers.’**

Ref.R25 = ‘Jupiter in 2005 & 2006’

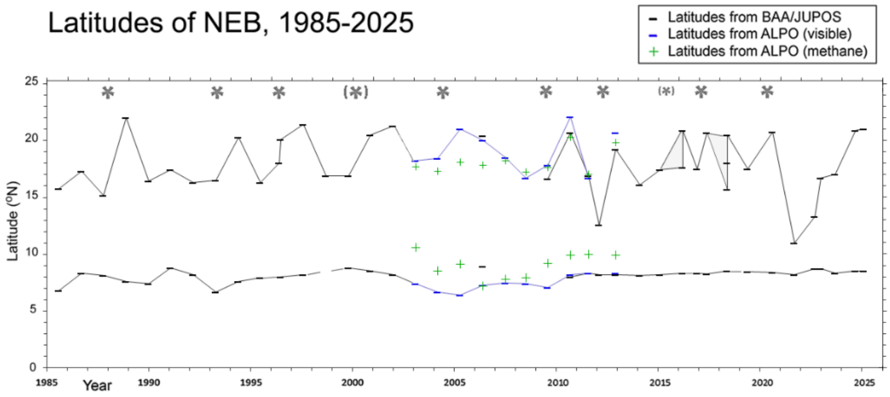
Ref.R5 = Report 2012/13 no.9, Appendix 2 = **‘NEBn: Dynamic interactions of spots’**

Further examples of well-observed mergers of AWOs include: Report 2024/25 no.2.

8.2. N. Equatorial Belt (NEB)

NEB cycles:

The NEB undergoes a cycle with period 3-5 years, marked by rapid broadening to the north followed by gradual recession [**Ref.J17 = JBAA NEB Paper I**]. The NEB Expansion Event (NEE) typically begins with an outbreak of a bright ‘rift’ that is more northerly and slower-moving than usual; this is often involved with the first ejection of dark material northwards, but typically the rift also expands southwards across the width of the NEB. NEBs dark formations (NEDFs) are also affected. After the dark belt has expanded north, an array of dark cyclonic ‘barges’ and AWOs develops around the planet. The dates of onset of NEEs were as follows, and **Figure 4** gives a time-line in terms of the width of the dark NEB:



Dates of onset of broadenings [from Ref.J17]*:*
1987/88 (began 1987 Dec)
1993 (began 1993 March) [Ref.R43 = Interim report for 1993.]
1996 (began 1996 April) [Ref.J29 = 'Jupiter in 1996' in JBAA]
1999-2000 (slow & irregular, from 3rdQ 1999 to late 2000)
[Ref.J8 = final report for 1999/2000, & Ref.J10 = final report for 2000/2001]
2004 (began 2004 Feb-April) [see Report 2003/04 no.5, inc. a ZDP, and notable colours including a greenish dark spot]
2009 (began 2009 May):

For a summary and discussion up to 2009/10, see
Ref.R35 = 'Jupiter in 2009: Interim Report, with new insights...'
Ref.R44 = 'Relationship of NEB rifts to NEB expansion events'
Ref.J17 = NEB Paper I.

Dates of onset of broadenings [continued; further details follow]:
2012 (began 2012 March) – exceptional fading & revival.
2016-17 (after incomplete NEE in early 2015, full NEE began in late 2016)
2020 (began 2020 Feb.)
2023-24 (after exceptional fading & revival, full NEE began in 2023 Oct.).

2012: A more extreme version of this cycle occurred: a **Fade and Revival of the NEB**, perhaps comparable to those of the SEB. These were common a century earlier, but none had occurred since 1926-27. During the Fade in 2011-12, the NEB became totally quiescent with no visible convective activity or rifts, and no NEDFs, and the NEBs jet accelerated dramatically (see below). The Revival apparently started from a white spot (rift) at 9.5°N on 2012 March 8, just before solar conjunction. Therefore most of the Revival was not observed, and the belt was mostly fully broadened and chaotic-looking when observations recommenced in 2012 June. Observations of another Fade & Revival in 2021-22 (see below) suggest that the process may have been more complex than a typical NEE.
[See **'Reports'** for 2011/12 (esp. nos.5 & 9) & 2012/13 (inc. Ref.R34); **EPSC2013-384; Refs. J18 & J19 = JBAA NEB Papers II & III**].

2015-16: There was some northerly rifting and disturbance from late 2014, leading to a slow and incomplete expansion event in mid/late 2015, but this extended only half way round the planet by 2016 Feb., then regressed. [Reports 2015/16 nos.3 & 13; & EPSC 2019-302]
2016-17: After northerly rifts appeared in 2016 Oct., a rapid and complete NEE occurred in early 2017, complete by June. [Reports 2016/17 (esp. nos.4,10,11) & **EPSC 2019-302 & Ref.J20** = Fletcher et al.(2017, GRL)]
The subsequent growth of AWOs and barges: Reports 2016-17 nos.10 & 11.

2020: A complete NEE occurred in the first half of 2020; it started in mid-Feb. when a bright spots at ~14°N initiated a complex expanding rift system, which led to NEBn broadening around the planet, complete by late June [Reports 2020 nos.4 & 9].

In 2021, the northern part of the NEB retreated again, normally at first but with exceptional fading from June onwards. This initiated a **NEB Fade & Revival in 2021-22,** as in 2011-12. Most of the NEB faded except for a narrow red-brown NEB(S), and the dark barges, which were faster-moving and slightly further south than usual, as in 2011-12 [Reports 2021/22 nos.2 & 10]. All convective and turbulent activity disappeared, as did all the NEDFs, and the NEBs jet again accelerated (see below). This time the revival was well observed, by Juno's

instruments as well as by amateurs, and it was not a dramatic upheaval. Instead, small short-lived bright outbreaks developed within a limited sector of the residual dark red-brown NEB(S), at 10°N, and these gradually led to dark material spreading northwards to produce a slow, partial revival of the dark belt. [Reports 2021/22 nos.2, 6, 7, 10; & EPSC2022-17, & Ref.J30 (ref. below)]. This was different from the usual NEE process, and perhaps unrelated to it, as a NEE then developed 3-4 years after the last one.
The small bright outbreaks that drove the slow revival were not unusual (similar outbreaks often occur in normal times), but in 2021-22 they were the only convective activity in the belt, and three of them were closely imaged by JunoCam (at PJ38, PJ39, PJ44). One was thoroughly documented as a vigorous thunderstorm [Ref.J30 = Icarus 'Multi-Instrument Sounding of a Jovian Thunderstorm from PJ38'].

2023-24: In 2023 Oct. a major NEB rift appeared, and gradually initiated a typical NEB Expansion Event, which was complete by mid-2024. [Reports 2023/24 no.4 & 5]

Thermal/methane-dark waves:

Slow-moving thermal waves over the NEB, previously reported from professional infrared observatories, were shown by the Cassini spacecraft in **2000** to coincide with methane-dark waves. We showed that these waves arose from large-scale eddies in the tropospheric cloud layer of the broadening NEB [**Ref.J11 = 'Jupiter in 2000/2001: Part II'**].

In **2009**, similar methane-dark waves appeared, but were just one aspect of high-contrast visible waves.

A notable methane-dark wave pattern reappeared during the NEEs of **2015-2018** [Report 2015/16 no.13; Report 2016/17 no.10; **EPSC 2019-302; Ref.J20** = GRL Fletcher et al.(2017)]. They appeared in 2015 and some persisted until the next NEE climaxed in 2017, and only diminished during 2018, as the NEB receded towards its normal width. There was no obvious correspondence with underlying visible circulation patterns in 2015-16 (although detailed analysis remains to be done), but by mid-2017 there was a striking pattern of waves that were both dark brown and methane-dark around most of the NEB.
During the **2020** NEE, there was only a short-lived, incomplete methane-dark wave-train in May, and a single very methane-dark patch later [Reports 2020 nos.4 & 9].

These waves represent clearances of high-altitude haze, probably coinciding with thermal waves, which may be forced by meridional waves in the retrograding NEBn jet in the main cloud deck [Ref.J11 = **'Jupiter in 2000/2001: Part II': EPSC 2019-302; Ref.J20** = GRL Fletcher et al.(2017)]. They appear in the later stages of some NEEs, but not all.

8.3. NEBs jet & NEBs dark formations (NEDFs) (= 'hot spots')

The NEBs is usually marked by up to 12 of the well-known, prominent NEBs dark formations (NEDFs), also known as infrared 'hot spots' because they are largely cloud-free and therefore warm at 5 microns wavelength. They were historically called 'projections' but this is inappropriate because they are distinct weather systems, not extensions of the NEB. They are believed to be Rossby waves, and they follow a suitable dispersion relation between their speed and their spacing [e.g. Ref.J31 = Arregi et al.(2006, JGR)], which was supported by our results in 2007: [Ref.R26 = 'Jupiter in 2007: Final numerical report' (Part 4), & subsequently **[Ref.J17 = JBAA NEB Paper I].**

Ref.J17 [= JBAA NEB Paper I] is our full account of the NEDFs and the NEBs jet behaviour, including the background from the professional literature, and defining three speed ranges that are observed for this jet: normal, fast, and super-fast.

The normal speed of the NEBs jet is close to System I (u_3 ~ 100-110 m/s); this is the speed of the NEDFs, but as Rossby waves they would be travelling more slowly than the wind speed. Sometimes there are also smaller, more closely spaced features moving with a faster speed (u_3 ~ 120 m/s); they fit onto the same dispersion relation so are probably smaller versions of the same wave type (**Ref.J17**). But rarely, all the typical NEDFs disappear and remaining small features develop a 'super-fast' speed of u_3 ~ 140 m/s. This occurred during the extreme NEB Fades in 2011-12 and 2021-22 [**Ref.J17**, & Report 2021/22 no.10, & EPSC2022-17].

The Galileo Probe descended into a NEDF and experienced a wind speed of u_3 ~ 170 m/s, so it is likely that there is a permanent super-fast wind of ~150-170 m/s below the visible clouds (just as in the NTBs and SEBn jets), but the NEDFs normally suppress it at cloud-top level. The concurrent loss of visible 'rifts' and NEDFs, in turn, suggests that convective activity in the NEB is necessary to sustain the NEDF wave pattern.

9. Equatorial Region

9.1. Equatorial Zone (EZ): Coloration episodes

Episodes of reddish or yellowish coloration of the EZ, either in a broad Equatorial Band (EB) or more widely, have been noted throughout observational history [Ref.J1]. While some episodes display obvious yellow or orange or duller ochre colour, and can last for several years, other episodes show only a brownish-grey shade changing to neutral dark grey, and only last for 1-2 years. Orange shading tends to be diffuse and sometimes (but not always) methane-bright and so high-altitude, whereas dark grey colour (which includes the NEDFs and associated festoons) denotes clearance of the usual white clouds. However, it now appears that these are both aspects of one complex phenomenon: they fit a cycle of 'equatorial disturbances' with period of 6-7 years proposed on the basis of EZ cloud clearances revealed as brightening in the thermal infrared at 5 microns [Refs.J32 & J33 = Antuñano et al., 2018 & 2019]; see **EPSC2026-392**, & **Figure 5** therefrom:

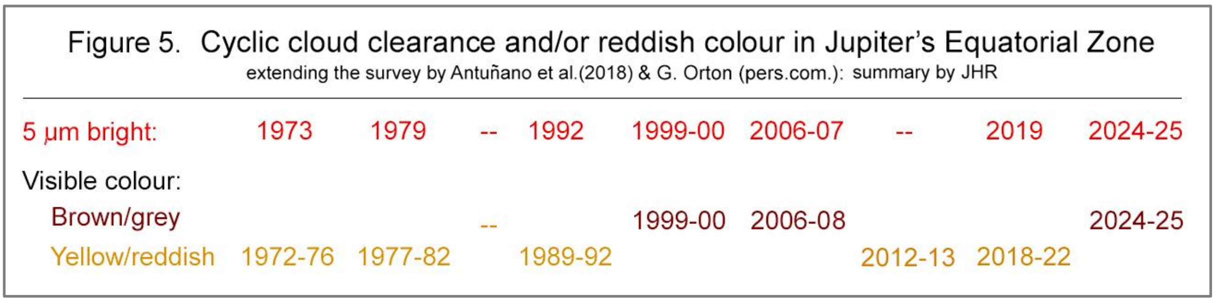


Figure 5. Cyclic cloud clearance and/or reddish colour in Jupiter's Equatorial Zone

extending the survey by Antuñano et al.(2018) & G. Orton (pers.com.): summary by JHR

5 µm bright:	1973	1979	--	1992	1999-00	2006-07	--	2019	2024-25
Visible colour:									
Brown/grey			--		1999-00	2006-08			2024-25
Yellow/reddish	1972-76	1977-82		1989-92			2012-13	2018-22	

List of coloration episodes since 1977:

(Those up to 1992 are described in Ref.J1; subsequent episodes were described in our interim reports and are summarised more systematically in **EPSC2026-392**.)

1977-82: Largely pure colour, strong yellow or ochre over most of EZ, but with grey EB component in 1978-79 and thereafter; then, yellow colour gradually retreating to EZ(S) and fading.

(1986: Although NEDFs and grey shadings were prominent, the EZ remained largely white so there was no coloration event.)

1989-1992: Started as pure yellow colour in late 1989, becoming brown or (eventually) grey in 1990-92, with the colour shifting southwards.

1999-2000: A brown EB developed in mid-1999, then became grey from 1999 Nov. to 2000 Jan.

(2002: Weak yellowish tint, not recorded as a distinct episode)

2006-2007: In 2006, dark features accumulated all across the EZ including a brown EB. In 2007, the whole EZ was largely grey-brown.

2012: Orange colour in an EB from June to August, coinciding with the vigorous revivals of the NTB and NEB (see above). It was not methane-bright. [**Ref.J19 = NEB Paper III**] & [Ref.R5 = Report 2012/13 no.9 Appendix 3].

2018-2022: Orange colour developed gradually in 2018 (March-May), and was intense in late 2018 and in 2019. It began on the equator then spread to most of the EZ except a narrow strip of white EZ(S). It was fainter in the first half of 2020, but revived in late 2020, and was intense during 2021. It faded away in the second quarter of 2022.
Stationary features in orange haze over EZ: During much of this episode, the orange EB was particularly methane-bright, and we detected waves on its S edge (in 2020) and large methane-bright patches (in 2021) that were almost stationary in System III (*sic*). [Report 2020 no.4 (Part III); & Report 2021/22 no.7; & EPSC2021-95] This is unprecedented, and suggests that the orange, methane-bright haze extended up to very high altitude.

2024-2025: A grey-brown EB gradually appeared from 2023 Dec. onwards, and was notable in 2024-25; it faded away in 2025 Dec.

9.2. SEBn jet & S. Equatorial Disturbance (SED)

The SED was a large wave-like feature in the SEBn jet, which existed from **1999 to 2009-10.** (A similar SED existed from 1977 to 1989.) We defined and characterised it in the following papers: the first 3 are available under **'Publications – Full Section Reports':**

Ref.J8 = Rogers et al. (2003), JBAA: 'Jupiter in 1999/2000, Part I...'

Ref.J12 = Rogers et al.(2005),JBAA: 'Jupiter in 2000/2001: Part III: The SED: A large-scale wave in a prograde jet.'

Ref.J34 = Rogers & Mettig (2008) JBAA: 'Influence of Jupiter's South Equatorial Disturbance on jet-stream speed' & supplementary materials HERE. Also see: EPSC2011-169.

Ref.J35 = Simon-Miller et al. (2012), Icarus: 'Longitudinal variation and waves in Jupiter's south equatorial wind jet.' or http://dx.doi.org/10.1016/j.icarus.2012.01.022

Ref.R45 = Rogers (2012): 'The life of the South Equatorial Disturbance, 1999-2010'.

Subsequent SED-like tracks have occasionally been recorded, mainly as a slow-moving gap in the array of spots on the SEBn edge, but not consistently visible nor long-lived (e.g. one in late 2012 [Report 2012/13 no.9, Appendix 4]).

New SED, 2022-2025:
A new SED appeared in 2022 June, mainly tracked as a gap in the SEBn 'chevrons' [Report 2022/23 no.3], but it was usually inconspicuous visually until mid-2024. From then until late 2025, it was often prominent, and again the SEBn jet speed was reduced p. the SED [Ref.R7 = Report 2023/24 no.3, 'The major jets'; Reports 2024/25 nos.1,2,7; EPSC2026-268].

SEBn jet speed: See [Refs J34 & J35] above, &:
[Ref.R7 = Report 2023/24 no.3, 'The major jets']: An overview of SEBn jet speeds since 1995 shows bimodal or trimodal distribution; and previous rapid speeds (DL1 ~ -100 to -115, u_3 ~ 150-160 m/s) have not been evident since 2016.

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10. S. Tropical domain

10.1. S. Equatorial Belt (SEB)

SEB Revivals

SEB Revivals, preceded by Fades, are among the most spectacular phenomena on Jupiter [Ref.J1]. They occurred in 1990, 1993, 2007 and 2010:

--1990: SEB fading in 1989; Revival started during solar conjunction in 1990 July (estimated) [Ref.J1].

--1993: SEB fading in 1992; Revival started on 2003 April 6. Our report is still unpublished; see [Ref.R43 = interim report; & Ref.J36].

--2007: Quiescence from 2006 Dec.; Fade started around 2007 March; Revival started on 2007 May 17. The Revival was somewhat atypical in that it started before the fading was complete, and the N. branch was blocked by the GRS, and the S. branch was blocked by one of two S. Tropical Disturbances. (See **Reports 2007** online [esp. **Ref.R26** = Final Report]; & News items in JBAA = Ref.J37 [esp. **Ref.J37b** = 'The climax of Jupiter's global upheaval']).

--2010: Quiescence from 2009 June; Fade started around 2009 August; Revival started on 2010 Nov.9. This was the best-observed cycle to date. The following papers give a full account of it, & comparison with previous examples revealing new common features, & up-to-date explanations of the whole SEB Fade/Revival phenomenon.

SEB Fade/Revival 2009-10: Our full reports:
EPSC2011-168 & EPSC2013-33.
Ref.R46 = Report 2010 no.22.
Ref.J38 = Rogers (2017, JBAA): 'I. The SEB Fade.'
Ref.J39 = Rogers (2017, JBAA): 'II. The SEB Revival.'
Professional papers in which we collaborated:
Ref.J40. Fletcher et al. (2011, Icarus). 'Jovian Temperature and Cloud Variability during the 2009-2010 Fade of the SEB.'
Ref.J41. Fletcher et al. (2017, Icarus), 'Moist Convection and the 2010-2011 Revival...'

Mid-SEB outbreaks

These are convective outbreaks in the SEB, similar to the perennial post-GRS rifted region and to SEB Revivals but intermediate in scale. There had been none since 1987/88, until mid-SEB outbreaks occurred in 1998, 2003, and 2005 Nov., all starting during solar conjunction. The earliest dates of observation were as follows (*see interim reports*):

--1998 (prior to 1998 March 31) – continued active till Oct.

--2003 (prior to 2003 Sep.) -- ended by Dec.

--2005 (two, one probably starting in Nov., second on Dec.10) – continued active in first half of 2006, before Fade/Revival in 2007.

--2008 (two, starting on March 8 & March 21).

After the SEB Fade-Revival of 2009-10, mid-SEB outbreaks were less common, occurring only in 2016/17 and 2024:

--2016 Dec.29. This proceeded until 2017 August with some spots even later. It was also well observed by Juno & by professional astronomers. See:
Reports 2016/17 nos.3,4,6,10, esp:
Ref.R22 = Report 2016-17 no.17: 'Summary of the mid-SEB outbreak';
Ref.J42 = de Pater et al. (2019, Astron.J.), '...Multi-wavelength study of convection'.

--2024 Nov.10 [see Report 2024/25 no.7].

It is possible that all SEB Revivals and mid-SEB outbreaks start with an intense convective eruption within a cyclonic mini-barge, as this was the case for all recent examples: viz.,
SEB Revivals in 2007 [Ref.R26. = 'Jupiter in 2007: Final Numerical Report.']
& 2010 [Ref.J39 = JBAA_Oct2017_ Rogers_SEBRev.pdf; Ref.J41 = Fletcher et al, 2017];
Mid-SEB outbreaks in 1979 (Voyager) [Ref.J1],
& 2016 [Ref.R22 = 'Summary of the mid-SEB outbreak'],
& 2024 [Report 2024/25 no.7]).

10.2. The SEBs retrograding jet

This is the only rapidly retrograding jet, and it shares many properties with the prograde jets, including its sharp peak, its well-defined latitude, and its tendency to carry dark spots which are anticyclonic vortices. Nevertheless, it does curve northward around the GRS forming the Red Spot Hollow. Its latitude has been constant in recent decades, but may have been altered during the years of the Great STropD (see below).

Refs: **Ref.R26** = **'Jupiter in 2007: Final numerical report'** –
(Part 3, box on page 4, "The speeds of the SEBs and STBn jets")
Ref.J43 = Rogers et al. (2016, Icarus) (SEBs waves; set of ZDPs in Fig.7);
Ref.R48 = Report 2015/16 no.13, Appendix 1 [see below];
Ref.J39 = Rogers (2017, JBAA) (SEB Rev.; set of ZDPs in Fig.10)
Ref.R7 = Report 2023/24 no.3.

The observed speed is usually around DL2 = +120 deg/30d, which is the typical drift rate of vortices (jet spots) on its S edge, though this depends on their size and latitude; this speed dominates some spacecraft ZWPs. However, small vortices and other features give DL2 up to +133, and we believe that +133 is the peak speed of the jet at cloud-tops. Thus the vortices run slower than the true wind peak by ~10-20 deg/30d (5-9 m/s), as they do on prograde jets.

There are other complications:
(i) The ZDP is systematically broader (to the south, where the vortices run) than the ZWP, possibly suggesting a different, deeper ZWP. [Ref. J39= Rogers (2017, JBAA).]

(ii) Occasionally, small bright spots run at DL2 ~ +150 deg/30d, and we suggested that this could be the true peak jet speed below the main cloud-tops.

Ref.R47 = Report 2012/13: Report no.12: 'The SEBs jet in 2012/13.' ; & update in:
Ref.R48 = Report 2015/16 no.13, Appendix 1: "The SEBs jet in 2016: Wave motions and super-fast motions".

(iii) In the 2010 SEB Revival, the SEBs jet spots were not vortices [Ref. J39].

(iv) The SEBs sometimes shows long trains of small-scale latitudinal waves with wavelength 4-10 deg, with phase speeds (tightly related to their wavelength) much slower than the jet speed; they can coexist with other features with full jet speed.

Ref.J43 = Rogers et al (2016, Icarus). 'A dispersive wave pattern on Jupiter's fastest retrograde jet at 20ºS.'

Further observations of these waves:

--Ref.R47 = Report 2012/13: Report no.12: 'The SEBs jet in 2012/13.' ; & update in:
--Ref.R48 = Report 2015/16 no.13, Appendix 1: "The SEBs jet in 2016: Wave motions and super-fast motions".
--Ref.R33 = Report 2014/15, no.12.
--Ref.R49 = Report 2019 no.10 (Box A).
--Ref.R7 = Report 2023/24 no.3. (Update on SEBs waves, with data from 2016, 2019, & 2023, extending the linear dispersion relation to shorter wavelengths with faster speeds.)

(v) When a STropD is or has just been present, the speed of visible jet spots can be much faster than DL2 = +120: the average for such years was +130 (±16) [Ref.J1], including notable mean values of +140 (1928-1934) and +144 (1979/80). This suggests that circulation at the STropD accelerated the SEBs jet in the long anticyclonic sector outside it [Ref. J1].

10.3. South Tropical Disturbances

Occasionally, a connection forms between the retrograde SEBs and prograde STBn jets so that material flows (recirculates) between them. The Great STropD lasted from 1901 to 1939 [Ref. J1; Ref.J44 = McKim (1997, JBAA) 'PBMolesworth's discovery of the great STropD... 1901.'; Ref.R50 = 'Historical records of the Great STropD passing the GRS, 1902-1913.'].

Others have existed since then, but only for about two years or less [Ref.J1]. The recent examples were:

1993: A STropD existed for several months, just before and during the SEB Revival; its p. end quickly contacted and began to flow round the GRS, before it was lost in the SEB Revival. [ref. R43 = interim report for 1993; & Ref.R14 = our S.Temp. report 1991-1999; & Ref.J36 (Sanchez-Lavega et al, 1996, Icarus].

2007: Two STropD's formed in or before 2007 Jan., about 2 months before the SEB Fade began, and one of them intercepted and recirculated all the retrograding dark spots in the SEB Revival: (See **Reports 2007** [esp. **Ref.R26** = Final Report, Part 3]; & Ref.J37b = 'The climax of Jupiter's global upheaval'.)

2017-18: A new STropD formed during solar conjunction and was discovered by JunoCam images at PJ9 (2017 Oct.24). Amateur images in August had shown some recirculating spots in the STropD that were precursors of it. Prograding as usual, it soon contacted the GRS and began to flow around it in early 2018, producing chaotic disturbance on the STBn jet. But it did not re-form as a STropD p. the GRS, although a faint remnant of the f. end did survive p. the GRS for 2 months [Ref. Reports 2018 no.1, 2, 5, 6, & our PJ9 & PJ12 reports, & **EPSC2018-562]**

10.4. Great Red Spot (GRS)

The GRS is the largest anticyclone in the solar system. It has been tracked since 1831, when it was first observed as a long 'hollow', but only became a great red oval in the 1870s [Ref.J1].

Drift rate and size:

Its drift rate has varied irregularly, with an overall trend to slower drift (more positive DL2). The GRS has also been shrinking, with fluctuations, since the early 20th century [Ref.J1, & **Ref.J45** = Rogers (2008, JBAA)]; see these refs. for charts of its historic longitude and length. Charts of GRS longitude in the 19th century & from 1964 onwards, from the JUPOS project, are at: http://jupos.privat.t-online.de/index.htm (follow: Drift charts & movies / Older drift charts).

The JUPOS project and the ALPO-Japan still continue to monitor the GRS drift rate and size. **Figure 6** presents charts for the past 50-60 years. Notably, the GRS decelerated (increased positive DL2) in 2009-10 during the SEB Fade, as is typical, and also resumed shrinking after several years 'standstill'; but acceleration during the 2010 SEB Revival was short-lived, and both the slower drift rate and the shrinking have continued up to 2024. Particularly abrupt shrinkages occurred in 2012-13 (which prompted Hubble observations in 2014 April) and in 2019 (associated with 'flaking' activity) [see refs. below]. Shrinkage has been mainly in longitude, but also slightly in latitude. Both the JUPOS project and the ALPO-Japan still post regular charts covering one or several apparitions, which are copied in some of our interim reports, e.g. Report 2025/26 no.4.

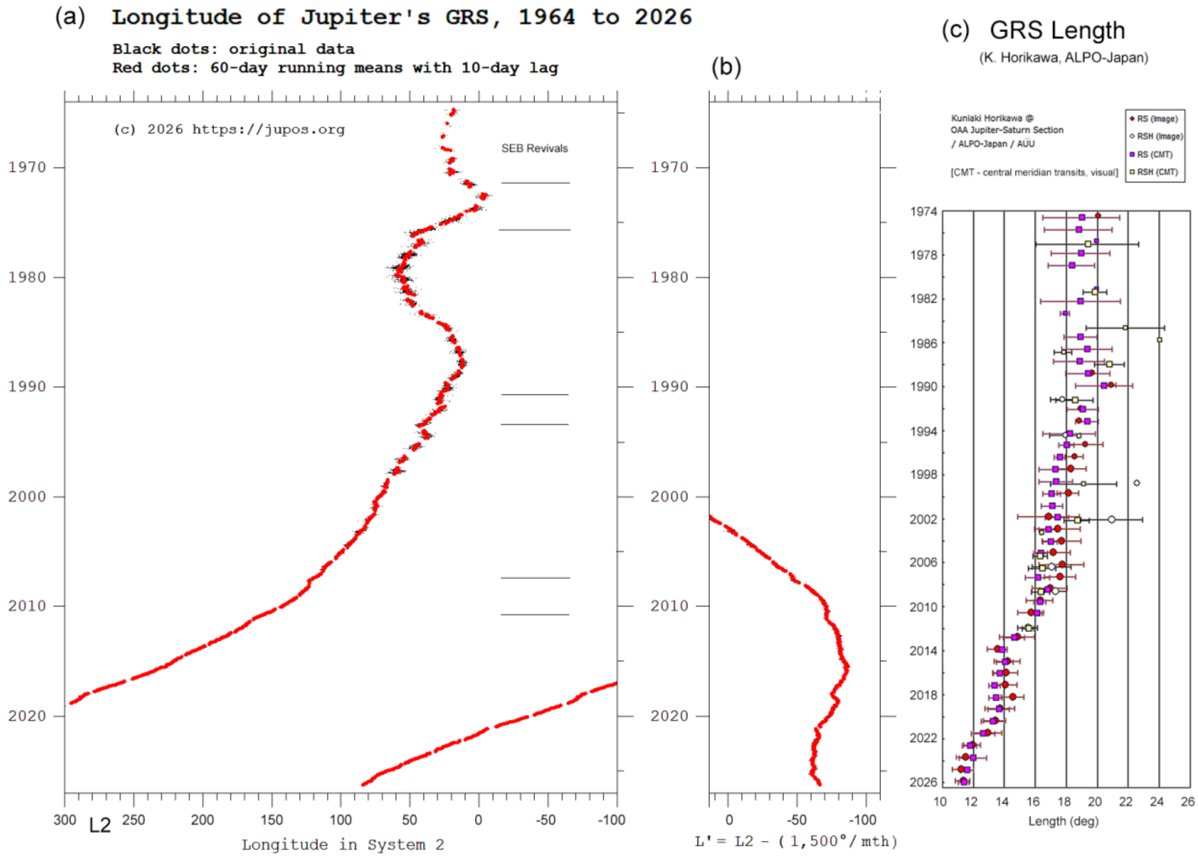

Figure 6. Drift and length of the GRS. (a) Longitude (L2) since 1964, from the JUPOS team (new chart from H-J. Mettig); (b) part of the same in a system moving at +1.5 deg/30d in L2. (c) Length since 1975, from the ALPO-Japan (new chart by K. Horikawa).

Internal circulation:

Amateur images have also been used to measure the internal rotation of the GRS from 2006 onwards, & esp. from 2014 onwards; see refs. below. The internal rotation period has decreased as the GRS has become smaller, and there is some evidence for the wind speeds accelerating as well.

Ref.J45 = Rogers (2008, JBAA) **'The accelerating circulation of the Great Red Spot.'**

[This paper includes a summary of the history of the GRS, its progressive shrinkage over the decades, interaction with SEBs rings, and its 90-day oscillation.]

--under 'Publications – Full Section Reports'.

Follow-up report in 2012: Ref.R51 = 'The accelerating circulation of the Great Red Spot.'

& subsequently:

Ref.R52 = Report 2013/14 no.7: 'The GRS in 2013/14: Faster shrinkage and evidence for faster wind speed.'

Ref.R53 = Report 2013/14 no.9: '... Further analysis of amateur images, 2013/14'

Reports 2014/15 nos.2,3,7,12 (these give M. Jacquesson's measurements of rotation period in 2014/15, averaging 3.7 days througout the apparition);

Ref.R54 = Report 2015/16 no.13, Appendix 2: 'Mapping the circulation within the GRS'.

Our report of the shortened internal rotation period (Ref.R52) led Dr Amy Simon to observe the GRS with the Hubble Space Telescope (HST) in 2014 April. Although the images were impaired by the shadow of Ganymede, results were published in:

Ref.J46 = Simon et al.(2014) 'Dramatic Change In Jupiter's GRS...'

--and the GRS rotation period was tracked from these and other HST images in:

Ref.R55 = Rogers (2016) 'The circulation of the GRS, 2009-2014: preliminary analysis of HST images.'; also see: EPSC2015-46.

A thorough professional study of the GRS internal winds from Hubble imaging is:

Ref. J47 = Wong et al.(2021, GRL) 'Evolution of the horizontal winds in Jupiter's GRS...'

(but note that an average ZWP across the domain has been subtracted from the GRS profiles and speeds, which must be considered when comparing these results with others).

JunoCam took closeup images of the GRS at PJ7. See our PJ7 report, &:

Ref. J48 = Sanchez-Lavega et al. (2018) (GRS dynamics from JunoCam).

Other aspects of the GRS:

Many of these aspects have been closely studied by our colleagues in the ALPO-Japan, esp. K. Horikawa & S. Mizumoto. We use some of their results in our reports, and others are posted on their web site. A full account of all the following aspects is in our Report 2021/22 no.8. Recent examples of their charts, including items (i), (ii) & (iv) below, are in our Report 2025/26 no.4.

i) The 90-day oscillation in longitude. This has been continuous since the 1960s and probably much earlier; it is now routinely observed by JUPOS and ALPO-Japan.

Ref.J50 = Hahn (1996, JBAA), 'The 90-day oscillation of the jovian GRS.' &

Ref.J45 = Rogers (2008, JBAA) 'The accelerating circulation of the Great Red Spot.'

ii) The 'Chimney'. This is a white spot or rift that sometimes appears in the N edge of the Red Spot Hollow (RSH), both in normal times (when it looks like a plume of white smoke) and when the SEB is faded [Ref. J38 = Rogers (2017, JBAA) The SEB Fade]. K. Horikawa has shown that it appears regularly at a specific phase of the 90-day oscillation:

Ref. R56 = K. Horikawa (2018), 'On the Periodic Rifting in GRS Bay': Video of talk, on the ALPO-Japan website: http://alpo-j.sakura.ne.jp/kk21/j210106r.htm

The 'Chimney' is summarised in: Ref.R49 = Report 2019 no.10 (Box B).

iii) 'Flakes' around the GRS, in 2019 & other years:
These are flakes of red, methane-bright material that appear to be torn out of the edge of the GRS a few days after a SEBs jet spot has entered the RSH; they often circulate around from the f. end to the p. end. They were first noticed when prominent in 2019:
[EPSC2019-546; Ref.R49 = Report 2019 no.10, & Ref.J49 = S-L et al.(2021, JGR-P).

Some red flakes have also been observed in subsequent years, though not frequent nor large: esp. see Report 2020 no.4 (Part II); Report 2021/22 no.8; Report 2022/23 no.8.

Previous records of SEBs jet spots entering the Red Spot Hollow were noted (but no flake was recorded), e.g. in 2003 March-April [Report 2003/04 no.4] and 2006 April [Ref.J45 = Rogers (2008, JBAA) GRS]; and in 2015 Feb-Mar., a typical flake was shown though not identified as such [Ref.R33 = Report 2014/15, no.12 (Fig.6)].

iv) The 'Hook' and S. Tropical Band. The 'Hook' is a dark projection from the SEBs around the f. edge of the GRS, which on average develops every two years or so [unpublished survey mentioned in Report 2021/22 no.8]. It was esp. documented during the 2019 flaking events but seems to be unrelated. It typically extends anticyclonically around the S edge of the GRS then extends eastward (p.) in the STropZ p. it, forming a dark S. Tropical Band. E.g. Report 2019 no.10; Report 2021/22 no.8; etc.

10.5. Anticyclonic rings in STropZ

Sometimes a substantial anticyclonic oval develops in the STropZ: usually a dark ring, which we call **'Spot Q'**, with weak westward drift so that it usually ends by entering the Red Spot Hollow.

There was a notable long-lived one from 1987-1997, which transiently became a Little Red Spot when the GRS intensified in 1990 and 1993, then a bright white spot in 1996. It merged into the Red Spot Hollow in 1997 May-June. [Ref.J1; Ref. J21 = 'Jupiter in 1997' (final) in JBAA; Ref. J51 = 'Jupiter in 2007' (interim) in JBAA; Ref.J52 = S-L et al. in Icarus].

Others were observed in 1998/99; 1999-2001 (reached Red Spot Hollow in 2001 March); 2001/02; 2005 & 2006; 2008 (another red one; see below); 2016 Jan.-May (it was a SEBs jet spot which drifted south, but did not survive long [Report 2015/16 no.13]); 2022/23 [ditto]; 2025 Sep. onwards. These were all noted in our interim reports.

The red oval in 2008 (nicknamed the 'Baby Red Spot') had developed from a STropD in 2007, and was large and prograding; its collision with the GRS in 2008 was impressive [Reports 2008 nos.4 & 5; Ref. R37d; Ref.J53].

11. S. Temperate (S1) domain & jet

11.1. The STBn jet

Uniquely, this jet is double, with a continuous northern sub-peak at 26.5°S, and a variable southern sub-peak at ~29°S which we have shown is strong alongside STB structured sectors, but weak or absent outside them [Refs.R14 to R18 = our long-term reports below, including our detailed studies of its ZWP & ZDP; & Ref.J3 = Tollefson et al,(2017)]. The STBn jet is deflected slightly southward around the GRS. The northern sub-peak always shows small-scale, high-amplitude wavy structure in JunoCam images, which could represent deviations of the peak winds [Ref. R18 = S.Temp. 2018-2024].

Small dark spots are commonly seen on this jet, sometimes very sparse, but sometimes abundant as they emerge from the preceding end of a turbulent STB segment [see our long-term reports below]. In spacecraft images they show little or no vorticity. STBn jet spots commonly drift northward while prograding at constant jet speed; this is because they arise near the southern sub-peak, then drift northwards towards the northern sub-peak [Ref. R16 = S.Temp. 2012-2015].

11.2. S. Temperate (S1) domain

This includes the STB, STZ, and one large anticyclonic oval called oval BA. Oval BA formed by merging ovals in 2000 [Ref.J15 = Rogers et al. (2006, Icarus). 'Merging circulations...'], and turned reddish in 2005/06. The behaviour of other structures in these years was reported in: [**Ref.R14 = S. Temp. 1991-1999**] (& see professional refs. therein). In those years the STB was a substantial belt containing turbulent sectors like FFRs, and in this report we showed that those sectors behaved in ways comparable to those in the subsequent decades, despite their different appearance.

From 1998-2020 the South Temperate domain showed a consistent cyclic pattern of behaviour, entirely different from cycles in other major domains. This has been fully documented in our series of combined reports, as follows:

Ref.R14: 'Jupiter's South Temperate domain: Evolution 1991-1999 and dynamics of cyclonic structured sectors as seen in Hubble maps'
Ref.R15: 'Jupiter's South Temperate domain: Long-lived features 2001-2012 and systematic variations in latitude'
Ref.R16: Jupiter's South Temperate Domain 2012-2015
Ref.R17: Jupiter's South Temperate Domain 2015-2018
Ref.R18: Jupiter's South Temperate Domain 2018-2024
[Very few of our interim reports are cited here, although some of them were very substantial; all are summarised or referenced in these combined reports.]

Also see EPSC abstracts: **EPSC2013-385**; EPSC2020-196; EPSC2021-121; **EPSC2024-362.**

From 1998-2020, the STB was whitened around most longitudes, with just one large anticyclonic oval (BA), and a dark sector of STB following it (STB Segment A). Other structured, cyclonic sectors of STB (six in succession) arose periodically shortly preceding BA, then expanded and prograded until they collided with Segment A. Some of these were dark, turbulent segments of STB (Segments B, D & G); the others were pale quiescent circulations (Segments C, E & F, also called the STB Remnant, Ghost, and Spectre). When they collided with Segment A, they underwent vigorous transformation and merger with it, in

2003/04 (B), 2010 (C), 2013 (D), and 2018 (E). The 2010 and 2018 events involved a sudden bright convective outbreak within the STB Remnant and Ghost respectively as each contacted Segment A, converting it into a turbulent sector that then merged with Segment A [Report 2018 no.2; & Ref.J54 = Iñurrigarro et al.(2020)]. These events also triggered acceleration of oval BA, and emission of dark spots prograding on the STBn jet and retrograding or slow-moving in the STZ. **Figure 7** is our long-term chart summarising this behaviour [from EPSC2024-362]:

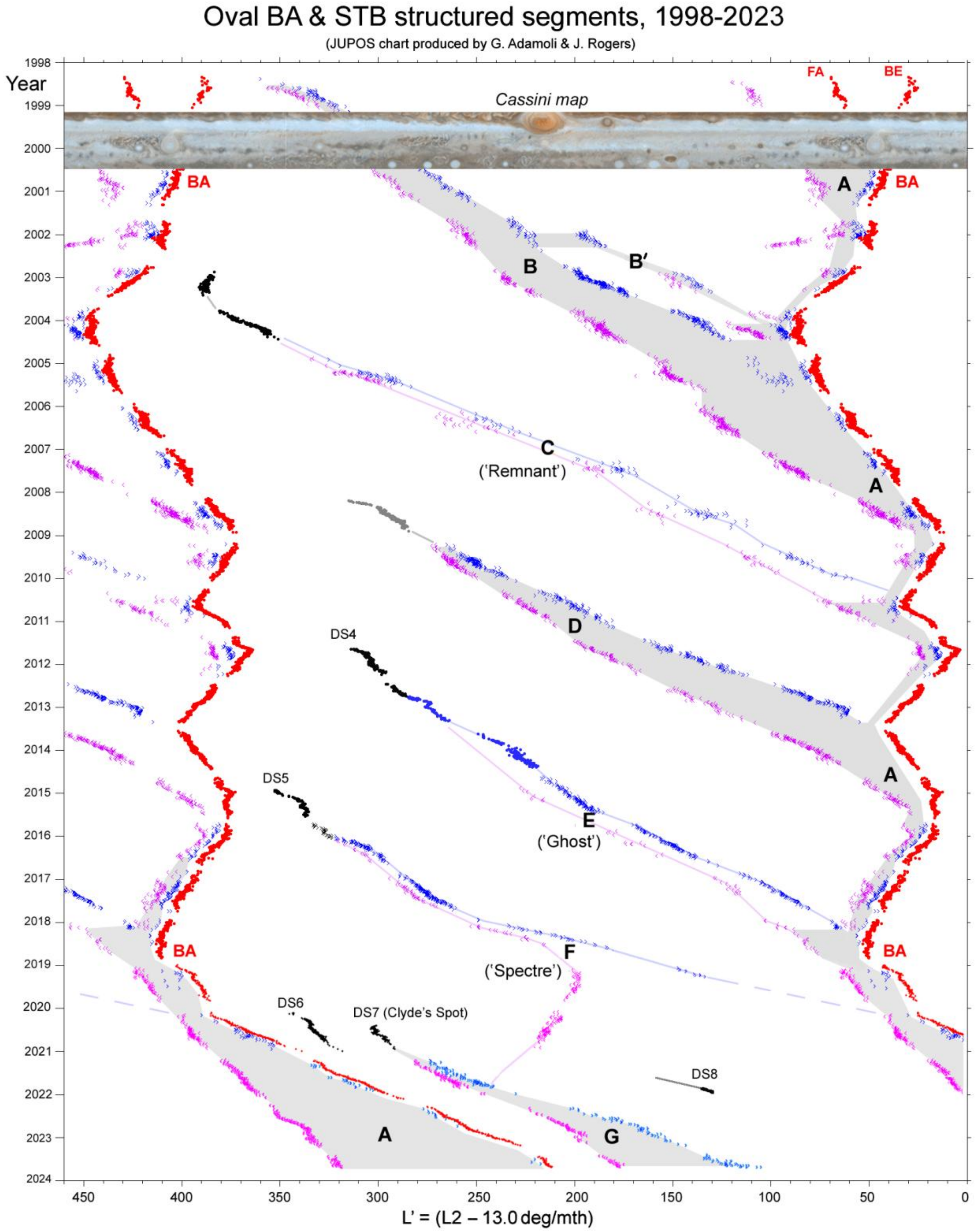

Figure 7. JUPOS chart of S.Temperate sectors, 1998-2024.

A transition to a different pattern of behaviour began in early 2020, when the preceding end of the STB Spectre arrived at Segment A: it did not transform internally but Segment A itself grew more active and longer. Meanwhile, we were expecting one or more new cyclonic spot(s) to arise some way p. BA to initiate the next structured sector, and this happened in 2020, when two small pale cyclones developed into two dark spots. One of these began as 'Clyde's Spot', when a sudden convective outburst transformed the cyclone into a turbulent feature which darkened and expanded from that time onwards to become the new STB Segment G [**Ref.R18 = 'S.Temp.domain 2018-2024'**; Ref.J55 = Hueso et al. (2022, Icarus); Report 2021/22 no.5 = S.Temp.domain ; Ref.R8 = Report 2021/22 no.10 (Final); EPSC2020-196; EPSC2021-121]. A year later, a similar outburst produced dark Spot 8, but that eventually became a pale cyclonic oval [Ref.R18]. Oval BA no longer drifts slower than cyclonic features; instead, Segment A and the new dark Segment G both continued expanding and emitting streams of dark spots on the STBn and STBs jets, re-creating a visibly dark STB around much of the circumference, which had not happened since the mid-1990s. Thus the cycle of successive segments has been broken, and the domain has moved into a new regime.

Wind speeds in large circulations:
Measurements of circulation in oval BA from JunoCam images: **PJ17 report**.
Measurements of circulation in the STB Ghost from Hubble & amateur images:
Ref.R17 = 'S.Temp. domain 2015-2018', &
Ref.J54 = Iñurrigarro et al. (2019/20, Icarus).

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12. S.S. Temperate (S2) domain

We have combined all our results on this domain in two long-term reviews, covering all long-lived features including the S2 jet and the AWOs:
Ref.R3=R19= Rogers et al.(2014) 'Jupiter's southern high-latitude domains... 2001-2012';
Ref.R20 = Rogers et al.(2025), 'Jupiter's S2 domain, 2012-2023' (inc. JunoCam maps).

[Previous detailed interim reports are mostly not referenced individually in this present review, but are cited in these long-term reports.]

The domain is distinguished by an array of prominent AWOs, described as the "string of pearls". Over a span of 37 years (1986-2023) there have always been between 6 and 9 large AWOs, with a mean number of 7-8, and a nominal mean lifetime of ~56 years. Some of them have existed throughout these 37 years, and they have never been observed to disappear except by merging with others, so there may be no intrinsic limit to their lifetime. Smaller, shorter-lived AWOs have appeared but rarely lasted for more than 2 years.

One that did, in 2015-2019, was apparently 'fed' by smaller anticyclonic vortices emerging from an FFR preceding it, but it eventually merged with a larger AWO [**Ref.R20** (above); details were in Ref.R57 = Report 2016/17 no.8 , & Report 2016/17 no.14, & our PJ1 & PJ24 reports]. Another such small AWO that probably formed from vortices from a FFR, but was short-lived, was described in [**Ref.R20,** & Report 2021/22 no.10].

Between the AWOs are cyclonic formations, formerly obscure but now well characterised thanks to high resolution of JunoCam and Hubble and modern amateur images. We have shown that they fall into 4 categories (dark ovals or oblongs, white ovals or oblongs, FFRs, and pale oblongs), any of which can transform into any of the others. Their lifetimes range from months to years, with two FFRs having lasted for 8 years. Details are in:
Ref.R20 = 'Jupiter's S2 domain, 2012-2023', & **EPSC2024-378.**

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13. High southern domains (S3 to 'S6') & S. Polar Region

All long-lived features including the jets and the AWOs were described in:
Ref.R3=R19 = 'Jupiter's southern high-latitude domains... 2001-2012';
The more detailed subsequent interim reports, including JunoCam data, are:
Report 2022/23 no.8; Report 2024/25 no.7.

The S3 and S4 domains always contain one or more anticyclonic ovals, including one long-lived one (S4-LRS-1 in S4). As in the N4 and N5 domains, they have very variable speeds which are faster on the poleward side of each domain. The FFRs are not generally trackable from amateur or JunoCam images, but JunoCam images suggested that in S3 they move with the historical zonal slow current (ZSC: here, S3TC) with DL2 ~ -8 deg/30d. No consistent ZSC has been established for S4.

Also in the S3 & S4 domains, JUPOS charts normally show many retrograding dark spots, at 49°S, which we have analysed in:
[Report 2013/14 no.6; 2015/16 no.13; 2018 no.6; 2022/23 no.8; & 2024/25 no.7].
These are not FFRs, but small spots which may be retrograding following FFRs (as in the N2 and S1 domains, but in contrast to N4 and N5). A long-lived AWO, prograding, sometimes halts its prograding motion when it encounters them, as in 2011 Oct. & 2013 Dec. [Ref.R3=R19, above; Ref.J16 = Schmude (2014); Report 2013/14 no.6; & Report 2019 no.9]. These spots occurred in limited sectors which persisted for several years drifting with the S3TC, from 2005-2010 [Ref.R3=R19, above] and again from 2014-2016 [Report 2014/15, no.12; & Report 2015/16 no.13] and 2017-2018 [Report 2018 no.6]. Our suggestion that they were produced from long-lived FFRs, not resolved from Earth [Ref.R3=R19, above], was supported by the observations in 2018.

The S4 jet: A sinuous wave pattern has been recorded on this jet at about 52°S, with very consistent phase velocity and group velocity, in 2016, 2022, 2023, and 2024/25 [Report 2015/16 no.13 & Report 2022/23 no.8; & **Report 2024/25 no.7** & refs. therein]. This is the lowest-latitude prograde jet in which such latitudinal variations have been recorded; they are more usually present in the S5 and especially the S6 jet, as observed by Juno [**Ref.J56** = Rogers et al.(2021/22, Icarus) 'Flow patterns of Jupiter's south polar region.'].

S4-LRS-1, the long lived oval at 60°S, has very likely existed since at least 1994 or (other authors) 1987; it may well be the same 'grand spiral' that was imaged by Voyager in 1979. Its reddish colour probably fluctuates but is not well documented.
Ref.J4 = '**Jupiter's high-latitude storms....**' inc. Appendix & **Supplemental tables**;
Ref.R3=R19 = 'Jupiter's southern high-latitude domains... 2001-2012';
EPSC2019-1130.

South polar region: Flow patterns in the higher latitudes have been revealed by a combination of JunoCam and amateur imaging, as the JUPOS team can now track features up into the southermost belt. These studies revealed that the southernmost (S6) jet is sinuous with waves that define the edge of the methane-bright South Polar Hood. Poleward of it is the **'southernmost belt'** of FFRs at ~68-74°S, which could also be called the S6 belt, but there is not a well-defined S6 domain because there are no continuous jets further south.

Ref.J56 = Rogers et al.(2021/22, Icarus) 'Flow patterns of Jupiter's south polar region.'].
EPSC2020-151; EPSC2020-153.

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14. Polar polygons (from JunoCam)

Only Juno can observe the poles themselves, and in its the first four perijoves, JunoCam and JIRAM discovered remarkable polygons of cyclones at each pole: a pentagon of 5 cyclones surrounding a sixth at the south pole, and an octagon of 8 cyclones surrounding a ninth at the north pole. The polygons and the individual cyclones have remained stable from 2016 to 2025, despite the rapid and chaotic changes around them. JunoCam's observations of them have been published as follows:

Ref.J57 = Adriani et al. (2018, Nature) **'Clusters of Cyclones Encircling Jupiter's Poles.'**
Ref.J58 = Tabataba-Vakili et al.(2019/20, Icarus) **'Long-term tracking of circumpolar cyclones...'**.
EPSC abstracts:
EPSC2018-702. 'Long-term behavior of Jovian polar vortices from JunoCam observations.'
EPSC2019-300. 'Jupiter's north polar region from Pioneer 11 to Juno.'
EPSC2021-57. 'Behaviour of Jupiter's polar polygons over 4 years'
EPSC2024-154. 'Counter-rotating cores in Jupiter's circumpolar cyclones...'
EPSC2025-711. 'Morphological and Positional Changes in Jupiter's Northern Polar Cyclones'
EPSC2026-710. 'Tracking Jupiter's North Polar Vortices.'

REFERENCE LISTS

References are organised in three groups as follows, listed below in order:
(i) Articles in the JBAA and professional journals and other print media, e.g. “Ref.J1...” – most of the professional ones have one or more amateur(s) as co-authors.
[JBAA = *Journal of the BAA*. JGR = *Journal of Geophysical Research*. GRL = *Geophysical Research Letters*.] (Many of these are behind paywalls so URLs may not give full access.)
(ii) Major reports on our web pages, e.g. “Ref.R1...” -- these include long-term reports (which include references to our interim reports on the same topic, so those are not all linked here) and some apparition reports.
(iii) EPSC abstracts, e.g. “EPSC 2025-55...” – these are the most convenient summaries of topics.

J1. J.H. Rogers (1995), ***The Giant Planet Jupiter*** (Cambridge Univ. Press)

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