Jupiter in 2021/22, Report no.10: Final report (Summary)

John Rogers (BAA) (2022 August 2)

This completes our account of the atmospheric phenomena on Jupiter during the 2021/22 apparition. We have already posted interim reports covering large parts of the planet and the most interesting phenomena [*2021 reports nos.5-9*]. Here we fill in the gaps and add speeds and latitudes for spots. This Extended Summary covers all regions of the planet, including material in previous reports; it will also be published in the Journal of the BAA. The full report with new material comprises **Appendix 1** (co-author G. Adamoli: 10 pages and 19 figures)**. Appendix 2** is a brief review of the speeds of the fastest jets, for comparison with the speeds measured in 2021.

Overall, the planet was rather quiet; none of the belts underwent major upheavals, and the only circumglobal disturbance was the ongoing (and reintensified) ochre coloration of the EZ. The NEB, though, drew much attention as it quietened, faded and narrowed to an extreme degree, leaving only a narrow dark brown NEB(S), and setting the scene for a future NEB Revival. The other region of great interest was the South Temperate domain, where several cyclonic features evolved in ways that have led to a widespread restoration of the dark STB. Streams of prograding spots continued on the STBn, SEBs and NNTBs jets.

N3 to N6 domains *[Report no. 9, & EPSC 2022 abstract]*

Movements of spots in the N3 to N6 domains have been analysed more thoroughly than ever before, from amateur images and JunoCam images. The JUPOS team tracked numerous spots here, even including several in the N6 domain, all of which were rapidly prograding. The drift rates and latitudes in all these domains lie close to the zonal wind profile (ZWP) known from spacecraft, and confirm that in both the N5 and N4 domains the broad retrograde flow represents the bulk motion of the cyclonic folded filamentary regions (FFRs) as well as anticyclonic white ovals (AWOs). Both in N5 and in N4, AWOs can last for months or even years – in spite of many sudden shifts of latitude and drift rate – just as in the N2, S3 & S4 domains. Cyclonic features (FFRs or smaller cyclones) are evidently less stable than AWOs.

We documented several notable interactions of AWOs. Two N5-AWOs approached each other but then rebounded and exchanged their drifts and latitudes. The largest N5-AWO suddenly reversed its drift when it approached a smaller white spot further north. Most remarkably, we have one or (very likely) two examples of AWOs crossing prograde jets. An N4-AWO swung rapidly southwards after it approached another AWO, and was last seen straddling the N4 jet and split into two lobes -- the third time that this has been observed. Likewise, a N3-AWO swung southwards and crossed the N3 jet into the NNTZ – the first time that a spot has been seen to cross a prograde jet other than the N4 jet.

N2 & N1 domains *[Report no.10]*

Three long-lived anticyclonic ovals persisted in the NNTZ, although more easily tracked in methane band images than in visible light. NN-LRS-1 was quite reddish, and conspicuous with a very dark rim until October. NN-WS-4 was inconspicuous. Only NN-WS-6 was a bright white oval. The NNTB varied in nature with longitude and time. One dark sector faded to light ochre in the autumn; two other sectors, initially pale, turned dark in August. Two FFRs are documented, one of which developed in 2020.

There were many dark spots on the ***NNTBs jet***, especially from July onwards; they may have been created by turbulence emanating from one or both FFRs.

NTB: Initially, much of the NTB(N) was very dark grey with prominent waves on its N edge, f. a distinct boundary; p. this there were just a few short dark mini-barges. But all of this faded during the year, along with the reddish NTB(S), until in Dec. the NTB consisted of just a narrow dark grey component in its mid-latitude (26°N) with a faint reddish southern fringe.

N. Tropical domain *[Reports no.2 &10]*

The most notable development of the apparition was the fading and quiescence of the NEB. Following the NEB expansion event in 2020, the dark NEB narrowed again, not just to its normal width but much narrower as it all became faint and calm apart from a set of dark barges in the northern NEB and a narrow dark brown NEB(S). The usual 'rifts' were absent. The normal NEBs dark formations disappeared and were replaced by very fast-moving minor features. The appearance was very similar to 2011-12, which preceded the NEB Revival in 2012. But small bright plumes began to appear in a sector of the residual NEB(S).

In 2021 April the NEB was still fully broadened, although the northern extension was beginning to fade. It contained a series of AWOs and barges, a classic appearance at this stage after the expansion event. By mid-June, the northern extension of the NEB had faded almost completely, and the mid-latitudes of the NEB had also begun to fade rapidly. From August onwards, most of the belt was exceptionally faint, leaving only a narrow, very dark brown NEB(S), and the very dark brown barges.

In April there were 9 barges and 9 AWOs of various sizes; by late Sep., after some mergers of barges and fading of AWOs, there were 8 barges and 6 AWOs. The barges remained very dark, although some became small. The AWOs became difficult to see, with irregular pale grey shadings, although most of them were methane-bright, to varying degrees.

The drift rates of these barges and ovals spanned a wide range of speeds in March-June, but all consistent with the usual zonal drift profile (ZDP). These diverse speeds are normal while new barges and ovals form. Subsequently they became more stable. The speeds late in the apparition were faster than in most recent years, but essentially the same as in 2011/12 during the previous fading of the NEB; in both apparitions, this was because the barges lay slightly further south than usual. Presumably this is an aspect of the fading process.

The belt was also completely calm, with none of the normal convective or turbulent 'rifts'.

NEB(S) [Reports no.6 & 7, & EPSC abstract]:

Most of the usual NEBs dark formations (NEDFs or 'hot spots') became ill-defined and less conspicuous by 2021 June. The last ones disappeared in August, and around that time, much faster tracks appeared on the JUPOS chart, for elusive smaller features on the NEBs. In Nov-Dec., fast speeds were seen all around the NEBs, with drift in L1 (DL1) ranging from -40 to -79 deg/30d (u = 125-143 m/s), matching the 'super-fast' speeds in 2011.

Despite the general quiescence of the NEB, occasionally a small brilliant white spot would erupt in the narrow dark NEB(S). From May to Oct. there were 5 in 6 months, and the frequency was increasing so from 2021 Nov. to 2022 Jan. there were 4 in 3 months (thoroughly tracked by Shinji Mizumoto of the ALPO-Japan). All these outbreaks appeared in a single short sector with slow drift in increasing L1.

The typical course of each outbreak is as follows. It begins with a small brilliant white spot in the NEB(S) at ~10°N, which is also transiently methane-bright, identified as a convective plume. After about a week it extends tenuous white streaks to Sp. and Nf., and the dark brown NEB(S) may become broadened Nf. the plume, giving the impression of a wake that disrupts the whitish cloud cover of the mid-NEB. Also after about a week, an extremely

methane-dark spot appears adjacent to it. Initially the plume is retrograding (DL1 ≈ +1 to +2 deg/day), but then it moves south to the NEBs edge and reverses its drift to prograding (DL1 ≈ –1 to -2 deg/day), joining the superfast features. Eruptions at ~10°N are actually quite common in normal times, but in 2021 they were notable as the only convective features in the belt. With great good luck, the JunoCam PJ38 and PJ39 image sets both captured an active plume and other features in the heart of the outbreaks.

Equatorial Zone *[Report no.7]*

In the EZ, the ochre colour that began in 2018 had re-intensified since 2020 and remained strong throughout 2021. It also remained very bright in the methane band at 889 um, indicating high altitude. In 2020 methane images had led to the remarkable discovery of a pattern of waves on the EZ that were almost stationary in L3, and thus disconnected from the fast equatorial current. In 2021, similar features were again observed, but instead of extended wave-trains, they were large isolated methane-bright patches that extended across the whole EZ. Again they moved only slowly in L3. This year they were also detectable as very dark patches in UV images, though not usually in RGB images because of interference from streaks of other colours.

The leading hypothesis for these slow-moving features is that they are at very high altitude. The fast equatorial jets are expected to weaken with increasing altitude until they reach almost zero speed. The zero-speed level is uncertain and may be variable, but is estimated to be in the range ~20-200 mbar; it is plausible that the methane-bright orange haze over the EZ could extend up into that range.

SEBn *[Report no.10]:* The SEBn jet showed a wide range of speeds, which fell into two spatially interspersed groups, with mean DL1 = -82.2 (±6.1) and -42.3 (±11.3) deg/30d. We have noted similar bimodal speeds before, but they were faster.

S.Tropical domain *[Report no.8]*

The South Equatorial Belt (SEB) in 2021 was essentially the same as in the previous two years, viz:
--the northern SEB largely quiet and pale, with only a narrow SEB(N);
--a somewhat disturbed SEB(C) component p. the Great Red Spot (GRS);
--a substantial dark SEB(S), with many rings (vortices) retrograding on the SEBs jet with typical speeds;
--persistent but limited convective and turbulent activity just f. the GRS, in which there were usually one or two bright (and sometimes methane-bright) plumes.

The Great Red Spot (GRS) remained fairly dark and reddish, and a dark ‘hook, collar and band’ was present around it from Feb. to July (as in 2019). The GRS also resumed its shrinkage. In 2021 it again had the smallest size ever recorded, with a mean length of 12.3° (ALPO-Japan) or 12.9° (±0.7°) (JUPOS), sustained throughout the apparition.

S.Temperate domain *[Reports nos.5 & 10]*

The S. Temperate domain continues to evolve in a fascinating manner. All the features present in 2020 have persisted, transformed, and converged to constitute a darkened, disturbed sector of STB spanning ~130° longitude, with further darkening at other longitudes along the STBn (p. STB segment G) or STBs (f. STB segment A).

The longest coherent stretch, following the anticyclonic oval BA, is STB segment A, which remained turbulent and gradually expanded until it reached a length of 60° in 2021 Nov. Another such structure is STB segment G. This was observed to originate from a small pale cyclone in 2020 May, with a sudden convective outburst dubbed 'Clyde's Spot'; this expanded as a turbulent sector dubbed DS7, expected to become a well-established STB segment, as indeed it is in 2022. It has been emitting disturbance both p and f. it, so that the sector between segments A and G is also darkened and disturbed, and there are copious dark spots prograding on the STBn jet p. it.

Another site of activity appeared on 2021 Aug.7, with a convective plume outbreak in a small cyclone that we call Spot 8, exactly like the Clyde's Spot outbreak the previous year. This remained turbulent for some months, but failed to grow much, and in Dec. it turned into a quiescent dark spot.

Oval BA was 'off-white', with a slight warm tinge, and usually a dark rim. Consistent with the turbulent state of STB segment A, BA retained a rapid average drift of DL2 ~ -17 deg/30d, although with large fluctuations.

S.S. Temperate (S2) domain *[Report no.10]*

There are still seven stable AWOs in this domain. At the start of the apparition, AWOs A1 to A5 had closed up together to form a single chain, mostly separated by FFRs. A much smaller AWO, referred to here as A0, was probably created or sustained by mergers of smaller anticyclonic vortices emerging from a large FFR just p. it, just as we reported for a small AWO from 2015-2019. But this one disappeared by 2022 Jan., probably by merging with A1, which had moved closer to the FFR.

FFRs were all documented in the JunoCam maps and most of them also in the amateur maps. A white oblong developed between A4 and A5 at the start of the apparition.
