Jupiter in 2024/25, Report no.5: The NTBs outbreak

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Summary

The NTBs jet outbreak, predicted to occur in 2024 or 2025, duly appeared on 2025 Jan.10 (see Report no.4). These events are currently occurring every 4-5 years, and are among the most spectacular, energetic, and fast-moving phenomena on Jupiter. It has unfolded in exactly the same way as previous such outbreaks, and given us new insights into the processes.

It began, as always, with the appearance of a small bright spot which rapidly grew to be the brightest feature on the planet at all wavelengths from UV to IR and in the methane absorption band, indicating that it was a convective plume rising to very high altitude. This plume accelerated over the first few days, then maintained a constant drift of -5.0 deg/day in System 1 from Jan.14-31, which is typical for these super-fast outbreaks. Up to Jan.31 it was still super-bright at all wavelengths, esp. the methane band, and it created a long expanding wake following it like a comet's tail. The wake contained large dark patches which appeared periodically, and small bright spots on the north side, most of which moved with speeds close to System 1. There were also small bright, methane-bright spots arising at the following end, accelerating to speeds similar to the main plume but short-lived. We show that these "wake-induced plumelets" are a typical feature of these outbreaks.

On Jan.27 a second such plume appeared, only 20º preceding the first, and rapidly became as bright as the first, with almost identical speed.

On Feb.1-4, the first plume caught up with the wake of the second, and disintegrated within a few days, leaving plume 2 leading a very long turbulent dark wake. Meanwhile several more wake-induced plumelets appeared shortly following the wake, persisting for between 3 and 10 days , and on Feb.9, plume 5 appeared in a largely undisturbed sector, and grew to become another independent plume. In total, we numbered eight such storms, of which numbers 1, 2 and 5 were independent primary plumes, and the others were wake-induced plumelets, although number 4 could be an intermediate case. Plumes 2 and 5 persisted until late February, when each caught up with the wake preceding it and rapidly faded, both disappearing by March 1.

All three primary plumes first appeared at 24.0-24.6ºN, then drifted south and accelerated within a few days, to remain at 23.3 (±0.3)ºN with sustained speeds of -5.0, -5.1, and -4.6 deg/day (plumes 1,2,5 respectively). As usual, they all broke up within a few days when they caught up with the wake of the next plume ahead.

It is thought that these outbreaks occur when sufficient available potential energy has accumulated below the thick cloud layer that whitens the NTB, and the plumes are giant convective storms erupting from the water-cloud layer, well below the visible cloud-tops. In the 2025 outbreak, JunoCam on Jan.28/29 directly imaged lightning in plume 1. The convection can no longer be sustained where these storms have disrupted the pre-existing vertical atmospheric layering, so they break up when they reach the wake of the next plume. We suggest that the wake-induced plumelets (which we have also observed in some previous outbreaks) are similar plumes triggered by the approach of the following end of the wake, but in this situation they are less intense and are short-lived. The periodic dark patches in the wake appear to be wave features travelling more slowly than the jet.

The plumes and other white spots all fit a zonal drift profile which peaks at 23.3ºN, DL1 = -5.1 deg/day (u_3 = +166.6 m/s), thus extending to faster speed and lower latitude than most zonal wind profiles (ZWPs) from spacecraft. ZWPs have been produced by G. Hahn from amateur images just before and after the present outbreak. In 2024 Nov., the peak was 150 m/s at 23.5ºN (slightly faster than the long-lived grey streaks that were tracked at 23.3ºN). In 2025 Feb., the earliest profiles yet produced during an outbreak – covering the wake – range from a narrow peak at ~141 m/s to a broad peak at ~126-136 m/s. When compared with previous ZWPs from spacecraft, these profiles establish consistent behaviour of the jet through the 4-5-year cycle of upheavals. They confirm that the super-fast plumes and plumelets erupt from and move with a deeper super-fast jet, but other features at cloud-tops do not achieve this speed. The jet shows no systematic change during the year before the outbreak, and no detectable acceleration of the cloud-top ZWP during the outbreak apart from the plumes themselves, and broadening on the flanks of the wake; instead, it quickly collapses to a slower but sometimes broader state, then recovers over the next two years or so. In 2024-25 there was somewhat slower ZWP before the outbreak (as also in 2015-16) and somewhat slower plume speeds (as also in 2020) – perhaps connected to the reduced interval between outbreaks.

The NTBn retrograding jet also accelerated just before and during the 2025 outbreak.

(1) Introduction

1.1 Background

Outbreaks of activity on the jet stream on the south edge of the North Temperate Belt (NTBs jet) are spectacular, infrequent phenomena, which include the brightest and fastest-moving spots that Jupiter ever displays. Historically (1890-1943), the jet was known only from less dramatic outbreaks of small dark spots with a more modest fast speed ('NTC-C') [*see box*]. But from 1970-1990, it behaved very differently, with 5-year cycles in which whitening was followed by outbreaks of brilliant white spots travelling at much greater speed ('super-fast' or 'NTC-D'), generating dark turbulent wakes behind them and leading to revival of the belt [ref.1]. Another period of NTC-C dark spots activity ensued from 1991-2004 [refs.9a&9b]. Then the NTC-D cycles resumed again every 4-5 years from 2007 until the present. The dates of the initial outbreaks were as follows:

2007 March 25 (Hubble S.T.) / 27 (ground-based) [refs,2,3]
2012 April 12 (±3, estimated) / 19 (observed) [ref.4]
2016 Sep. 15 (±3, estimated) [refs. 5-7]
2020 Aug.18 (observed) [ref.8].

Refs.1-8 also give detailed accounts and discussions of past NTBs outbreaks up to those dates.

***Terminology in the North Temperate domain and NTBs outbreak** [from ref.8]:*

Zonal drift rates in the NTB latitudes fall into four groups, historically called the N. Temperate Current (NTC-) A, B, C & D. NTC-A is the (retrograding) zonal slow current. NTC-B is the prograding flow in the mid-NTB shear latitude. NTC-C is the fast NTBs jet (DL1 ~ -1 to -2 deg/day) which governed some historical NTBs jet outbreaks and also the dark spots in the wakes of the outbreaks in the present era. NTC-D (DL1 ~ -4 to -5 deg/day, here denoted 'super-fast'), is the full speed of the NTBs jet, and is the speed of the plumes in these outbreaks.

We use the term 'outbreak' to mean a vigorous meteorological eruption, either of a single convective plume or a larger stormy disturbance. In the NTB context it can refer both to the individual plumes, and to the upheaval as a whole.

A. Sanchez-Lavega and colleagues refer to NTBs jet outbreaks as NTB Disturbances. They are also sometimes referred to as NTB Revivals, which indeed corresponds to the upheavals of recent decades, but historically some NTBs jet outbreaks have not caused revival of the NTB, and some revivals of the NTB have occurred without a known jet outbreak.

We have long known that the observed ('cloud-top') peak speed of the NTBs jet varies through this upheaval cycle: just after a NTC-D outbreak it is lowest (similar to NTC-C), then it accelerates over the years before the next one (although perhaps not steadily); then the plumes in the outbreak travel faster, even faster than winds usually recorded for other features (except for v-hi-res Voyager imagery: see Discussion). We have shown this in various reports since 2008 [e.g. refs.4,6,9; see also chart in ref.10], and our updated chart of this behaviour is in Figure 1.

In 2023 we noted that the visibly dark NTB had faded again, and that the jet speed had returned to an intermediate level, so in view of the 4-5-year periodicity, we predicted another outbreak in 2024 or 2025 [ref.11]. This duly began on 2025 Jan.10. It has been one of the best observed ever, and reveals new details of the changes of the winds before and during the upheaval, as described in this report.

1.2 Before the outbreak

The NTB latitudes were all almost white, with only faint streaks, typical of the phase before a NTBs jet outbreak. An unusually persistent streak was recorded in the JUPOS measurements in 2024 July-August; its f. end had DL1 = -98 (u_3 = +142.1 m/s) at latitude 23.5ºN (see our 2024/25 Report no.2). Since then, the JUPOS charts have shown the f. ends of many more such streaks, persisting for up to two months (Figure 2), and the measurements give a mean DL1 = -95.9 (±2.9) deg/30d (u3 = +141.1 m/s) (N = 7), up to 2025 Jan.
Figure 2 also shows many very short tracks for similar streaks; the earlier JUPOS analysis of some of these gave an overall mean DL1 = -100.4 (±3.9) at the same latitude.
A new ZWP by G. Hahn from images on 2024 Nov.3-5 (see section below) gives a rather faster jet peak of +150 m/s (DL1 = -116 deg/30d) at 23.7ºN.
There was no sign of cloud-top acceleration during the year before the outbreak.

1.3 Conventions and Acknowledgements

The international community of amateur imagers are to be congratulated on their excellent coverage of this outbreak.

Maps of the outbreak (in L1) have been made by co-author S.M., on every day or sometimes every rotation, and are in Supplementary Figures S1-S4 **(Appendix 1).** An animation of these maps in January, dramatically showing the initial growth of the outbreak, is posted as Anim-1. Planet-wide maps have been made by S.M., R.B. and M.V.
The positional analysis was shared among the present co-authors. Drift charts of many spots throughout the outbreak have been produced by S.M. (Figure 6) and by the JUPOS team (Figure 7); charts showing specific features have been produced by G.A. using data from the JUPOS team (Figure 8), and by J.R. from S.M.'s maps and other images (Figures 9&10).
The drift rates and latitudes of the various features are summarised in Figure 6 and **Table 1** *[following the figures in a separate file]*.

Because of the high speed of the NTBs jet, maps and charts are plotted in System 1 longitude (L1) unless otherwise stated. Drift rates (DL1) are given in degrees per day; DL3 = DL1 - 7.364 deg/day. P. = preceding (east), f. = following (west). Latitudes are planetographic. North is up in all figures.

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(2) Description of the outbreak

2.1 Start of the outbreak: Jan.10-14

The outbreak began on 2025 Jan.10; the first few days were described in our 2024/25 Report no.4. The plume was extremely bright at all wavelengths, especially the methane absorption band (889 nm) (Figure 3). In Figure 3A, we see that the brightest cloud in the methane band (the head of the plume) was not the brightest in RGB and near-IR continuum, showing that different parts were at different levels. Some images from Jan.16-19 are in Figure 4, and maps on Jan.21-22 and 24-25 are in Figure 5 with plume 1 and features of the growing wake labelled.

The drifts of plume 1, and subsequent plumes, are shown in Figures 6-8. Note that plume 1 initially moved with DL1 ~ -2 to -4 deg/day **(Table 1)**, but accelerated over the first few days to reach a sustained speed of -5.0 deg/day for the rest of its life. The measured latitude of the plume head also changed during the first few days (Figure 8): it first appeared at 24.6ºN (±0.3), but then rapidly shifted to lower latitude, apparently because it expanded mainly to the south, over the jet peak. Thereafter, the mean latitude from Jan.14 to 29 was 23.2ºN (**Table 1**).

The two subsequent independent plumes would likewise move south and accelerate over the first few days (Figure 8); see the Discussion in section 4.2 below.

2.2 Jan.14-31: Growth of the outbreak from plume 1

Figure 4 shows selected good images from Jan.16-21 (continued in Figure 11.) S.M.'s complete sets of maps are in Suppl. Figures.
The growing outbreak consisted of the following four elements, which are marked on Figure 5. They were also seen in previous outbreaks, especially the best-observed one in 2020 [ref.8]:
1) Plume(s): riding the NTBs jet-stream and prograding at super-fast speed.
2) Dark spots (patches) formed on the following (f., west) side of the plume.
3a) Slower-moving white clouds on the northern side, and
3b) others at the f. end approaching super-fast speeds ('Wake-induced plumelets');
4) Slower-moving white clouds on the southern side: interacting with the NEBn.

Items 2 to 4 constitute the wake, which began to form within 1-2 days, and expanded rapidly, with the following end remaining near L1 ~ 160 until early Feb. It often looked turbulent, and thereafter it extended irregularly to around L1 ~290 by mid-Feb., and onwards to higher L1, while there was smaller-scale turbulence extending to even higher longitudes from the northern edge of the wake.

The phenomena described here can be seen in the set of maps by S.M. shown in the Suppl. Figures; these enable the growth of the wake to be examined in detail.

(2) The dark patches are the largest features in the wake, as also seen in previous outbreaks . They formed periodically, every 2-3 days, leading to a regular wave-like series of dark patches at ~23.5 to 24ºN with an initial spacing of ~10º, although they were sometimes more chaotic and sometimes complicated by the adjacent small white clouds. Thus new dark patches were apparent on Jan.18, Jan.20, Jan.23, and Jan.25, creating a chain of four by Jan.25 (see Figures 5&11), after which the regularity was lost. They are tracked in Figure 9. Their speeds were surprisingly ill-defined: for much of the time, close to System 1, but at other times (esp. the sparsely-observed Feb. 23 & 24) prograding with a mean speed around DL1 ~ -2.9 deg/day.

The periodic formation of these dark patches, producing a wave-like pattern, has been noted by A. Sanchez-Lavega in every well-observed outbreak from 1975 [ref.12] to 2016 [ref.7]. In these papers he also proposed that they are anticyclonic, as also supported by our observations in 2020. In 2020, we found that they formed every 4-5 days with mean spacing 14º, range 12-20º [ref.8]. Their appearances then were synchronised with the plume's passage along a series of waves on the NEBn edge, but no such waves were visible in 2025 until later (but see below).

(3) There were many small white spots and streaks along the N side of the wake and near the f. end, some of them being notably methane-bright. In order to establish their motions we have marked some of the more persistent spots on the maps in Suppl.Figs. and measured their positions; the results are shown in Figure 10 and summarised in **Table 1**. These spots only last a few days, but reproducible tracks are evident. They fall into two groups:

(3a) Spots on the northern side of the wake. They form very close to the plume and stream away from it with speeds that are fairly close to System 1; the best tracks in Figure 10 have DL1 = -0.3 deg/day (similar to the drift rate of the dark patches), at a latitude of 24.85ºN. However, a later one was faster with DL1 ~ -1.4 deg.day (Feb.7-11, lat.24.6ºN). Being methane-bright, they could be high-altitude clouds detached from the main plume. Conversely, one white spot near the f. end was much slower with DL1 ~ +2.9 deg/day, and short tracks suggest many more of these later.

(3b) Spots near the f. end of the wake, only slightly further N than the main plume. These too were bright white and methane-bright, though smaller than the main plumes. There was a succession of them, arising near the f. end of the wake, and accelerating to speeds faster than System 1 – sometimes as fast as the main plume. Hereinafter we refer to them as "Wake-induced plumelets". Tracks for an unnumbered pair of them in Figure 10A were irregular but evolved to have mean drifts of ~-3.9 to -4.5 deg/day, at 24.1ºN. Later there were more of them, designated as plumes 3,4,6,7,8 (see sections 2.3 and 4.3 below).

(4) White streaks on the S edge of the wake were too elongated to track, but may have been streaming behind the plume like those on the N edge. Their interactions with the NEB are of interest, as there were extensive interactions in 2020. In 2025 these mainly involved the NEBn anticyclonic white ovals (AWOs). Figure 11 shows images of the wake interacting with three AWOs in turn: WS-Z, WS-1 and WS-7. Two more interactions are shown in Figures 12&13: WS-E and WS-B (Feb.2-8). Most of these proceeded in the same way: a bright white spot or streak projected into the NEB just p. the AWO then became a long thin streak extending around the S side of it (along the retrograding NEBn jet).

The one exception was with WS-7 (Jan.25-27): a white streak projected *into or over* WS-7. Surprisingly, Chris Go's methane image suggests that the white streak was not methane-bright, but obscured or displaced the methane-bright cloud cover of WS-7 (Figure 11). Indeed it apparently travelled right over WS-7 and emerged as a small bright spot travelling Sf. from it on Jan.28-30 [see Suppl.Fig. map set 03].

Further examples occurred later in Feb. as the wake (then following plume 2) passed WS-B, WS-Z and WS-1 again. Up to late Feb., although the NTBs disturbance was perturbing the NEBn more extensively, these events did not result in long-lasting changes in the NEBn AWOs. White spots Z, 1, and E were already dull before the NTBs outbreak but have recovered slightly.

The second plume appeared on Jan.27, only 20º p. plume 1, which is probably unprecedented. It was first seen and noticed at 01:07 UT in images by Mike Karakas (in Curaçao), and grew bigger and brighter over the following rotations (Figures 12&14). Like plume 1, in its first few days it accelerated (from DL1 = -3.7 to -5.1 deg/day) and moved southward (Figure 8). Its initial latitude was 24.0ºN (clearly on the N side of the narrow grey band at 23.3ºN) but by Jan.29 it had expanded southwards to straddle this band, and its long-term latitude was 23.3ºN. It was already extending bright cloud material to Nf. within 20 hours, and over the next few days emitted bright and dark streaks to Nf. just as plume 1 had done.

Professional observations

Plume 2 in thermal infrared: Plume 2 was also fortuitously recorded on its first appearance by Dr Leigh Fletcher and colleagues, using the VLT in Chile, about an hour after Karakas' images. It appeared as a tiny dark spot in the thermal infrared waveband, which gives information about changes in temperature and ammonia abundance as well as cloud opacity.

This was the first time that the start of such a powerful eruption had been observed in this waveband.

Plume 1 with lightning: On Jan.28/29, Juno flew past Jupiter at Perijove-69 (PJ69). We knew that plume 1 would not be in the field of view of Juno's instruments during the sunlit inbound phase, nor near the sub-spacecraft track on the dark side at perijove. However, JunoCam routinely takes 'lightning search' images of the dark side, and one of these revealed two lightning flashes at 23.2ºN (20.6ºN planetocentric) near the edge of the frame; the brighter of these was on the edge of the head of plume 1! [See our report on PJ69.] While it is well known that many convective eruptions on Jupiter are thunderstorms [e.g., ref.13], JunoCam provided the first proof for this greatest of all convective plumes.

2.3 Feb.1-17: Further development

On or about Jan.31, plume 1 contacted the growing dark wake of plume 2, and on Feb.2, it began to disintegrate, as predicted. After Feb.4 it was no longer distinguishable from other small bright spots in the wake of plume 2. The disintegration can be followed in Figures 12&13.

There was also a change in the long wake following plume 1 around Feb.1: it changed from being a chain of dark patches to being a continuous long dark belt, though still uneven, still with many bright spots and streaks along its north and south sides, some of them still methane-bright (still the case up to late Feb.). On the south side, during Feb., bright streaks were increasingly perturbing the NEBn. (See Figures 13&18.) Global maps in Figures 15&16 give contextual overviews of the whole outbreak in Feb.

By Feb.7, the disturbance spanned ~180º longitude overall. The dark patches in the expanding wake had largely merged into a continuous dark grey NTB(S), but with irregular edges, and continuing bright intrusions into the NEBn. But on Feb.15&16 (e.g. Figure 18), this dark belt again contained a chain of darker condensations, with wavelength of ~6-7º increasing to ~10-12º longitude.

Wake-induced plumelets

Meanwhile, near or just f. the f. end of the wake, a succession of bright white, methane-bright spots with super-fast drifts continued to arise. We dubbed them plumes 3 (Feb.1-3), 4 (Jan.31-Feb.8), 6 (Feb.8-16), 7 (Feb.10-22), and 8 (Feb.14-22) (**Tables 1 & 2**). They sometimes began with irregular or slow drifts close to System 1, then accelerated like the main plumes, and they had a range of latitudes. Thus they resembled the main plumes 1, 2 and 5, so we designated them as plumes, but they appeared to be weaker and short-lived. These were all typical wake-induced plumelets, apart from plume 4 which was more separated from the wake.

Plumes 3 & 4 are shown in Figures 12&13:

Plume 3 appeared on Feb.1, 14º f. the f. end of the chain of dark patches at L1 =145, but some visible turbulence extended past its position, and although it was very methane-bright on Feb.3, it was absent thereafter, lasting no more than 3 days.

Plume 4, on the other hand, arose further f., where there was only small-scale turbulence to the north of its location from the wake of the existing outbreak. It may have developed from a slower-moving white spot on Jan.30, but it was well-defined from Jan.31 onwards, with steady super-fast speed of -4.6 deg/day for 5 days, although (like plume 3) it was never as intensely methane-bright as plumes 1 & 2. It was last identified on Feb.8, still methane-bright though stretched into a streak, when it had become involved with the main dark wake (Figure 11).

Plume 6 appeared on Feb.8, just f. the dark wake, just as plume 4 was dying. It developed from a higher-latitude, slower-moving white spot, then settled at DL1 = -4.5 deg/day. The latitude also changed steadily from 24.8 to 23.4ºN. Like plume 4, this was quite long-lived and largely behaved like a typical plume.

Plume 7, not well tracked, appeared on Feb.10, then *plume 8* on Feb.14, alongside the f. end of dark streaks in the tapered extension of the wake. Like the earlier wake-induced plumelets, these were often recorded as being slightly further north than the main plumes (Figure 18).

Most of the wake-induced plumelets (apart from plume 4) appeared in increasing order of longitude according to DL1 ~ +2.3 (±0.2) deg/d, so they were appearing increasingly further f. the main dark wake – but still in a sector with more northerly turbulence spreading from the wake. As discussed in section 4.3 below, we think there is no fundamental difference between the primary plumes and the wake-induced plumelets – the latter being weaker and shorter-lived because they arise in a sector which cannot sustain them stably -- and plume 4 can be regarded as an intermediate case.

Plume 5

Plume 5 erupted on Feb.9, in an essentially undisturbed sector. It was first recorded from 01:13 UT onwards by Efrain Morales Rovera and Ethan Chappel, then by many Japanese observers plus Anthony Wesley on the next rotation (Figure 17). Its growth over the next few days was well recorded, accelerating and shifting south and elaborating spots f. it exactly like plumes 1 and 2, and it became an equally impressive plume with a wake (Figure 18). On Feb.24 this wake comprised a chain of 4 dark patches, with plume 2 rapidly catching up with it. See Figures 6,8,10) for charts, and **Table 1** for drift rates.

2.4 Feb.25--March 2: Demise of the plumes

After plume 1 was destroyed in early Feb., plumes 2 and 5 persisted at full strength until Feb.25, when they each caught up with the expanding wake of the other and started to fade. They faded rapidly over the next few days and by March 1 only small remnants were left – possibly still identifiable on March 1-2 but not thereafter (Figure 19(A)). S.M.'s tracking showed that both decelerated after Feb.25 (Figure 6), and moved slightly south, to ~22.7ºN (plume 5 on Feb.27, when it was moving at DL1 ~ -3.3 deg/day).
This probably means that the surface current was still less than the super-fast speed of the plumes, so as soon as their deep convection was cut off, they began to be advected with the higher-level winds, like the small northerly bright spots earlier.

Juno's PJ70 occurred on March 2, and JunoCam would have had a fine view of plume 5: unfortunately, it had just disintegrated. So JunoCam obtained an excellent view of the turbulent wake just after the plumes had disappeared (Figure 19). A hi-res map of the images, and a comparable map from Hubble in 2007, are shown in our report on PJ70.

The demise of these plumes ended the active phase of the outbreak. Thereafter, in early March, the wake was prominent all round the planet. It was very turbulent but quickly transforming into a revived double NTB, with the northern and southern streams resolving into a thick brownish-grey NTB(S) and a narrow bluish-grey NTB(N). The NTB(S) was changing from grey to brownish (unevenly around the planet) and continued becoming more orange, as usual.

(3) Zonal drift profile (ZDP) & zonal wind profile (ZWP)

3.1 ZDP

In Figure A20, the drift rates and latitudes from **Table 1** are plotted as a zonal drift profile (ZDP). The large dark spots gave only very imprecise speeds, much slower than the speeds of white spots in the same latitude, supporting the view that they are waves. Conversely, all the bright spots – plumes, plumelets, and smaller white spots on the N edge of the wake – fit onto a consistent curve. While the northern part of this matches the typical zonal wind profile (ZWP) from spacecraft in quiescent states, the plumes themselves extend it to faster speeds and lower latitudes (see below: Figure 21(B)).

As the plumes are believed to be driven from a deep layer, their ZDP may represent the ZWP down at that level (to be discussed below). But this raises further questions. To what extent are the observed cloud-top winds affected by the deeper winds, either before or during the outbreak? Does the deep ZWP take over the cloud-top winds, or is it only manifested by the plumes themselves? Does the flank of the ZDP (including the one estimate for plume 5 as it was decaying) represent the same deep level, or only the cloud-top level, where white spots are shed from the main plumes or induced in the turbulent wake?

3.2 ZWPs

These issues could be clarified by establishing the speed not just of the peak but at all latitudes across the jet, i.e. the ZWP. Co-author G. Hahn has done this using hi-res amateur images taken two months before the initial outbreak and about one month after it, and we compare the results with those published by others for previous outbreaks.

The full planet-wide ZWPs are presented in **Appendix 2**, with further technical details. Here we show only selected portions covering the N. Tropical Zone and N. Temperate domain. For most dates, the analysis was done separately for different colour channels (red, green, blue, and/or white light). In Figure 21(A,B), for each of the best three dates, all channels were superimposed (including their error bars) and the composite for each date is shown in a different colour. In Figure 22(A,B), we show a few of the best single-channel ZWPs, i.e the most complete and smooth in this latitude band (omitting error bars). These are mostly from the red channel, probably because red light gives the best resolution and small-scale contrast in this region. (Particularly in November, the detail consisted of blue-grey streaks.) These figures include a reference profile made by G.H. from Hubble images on 2012 Sep.20 [ref.18]; this was in the concluding stages of a similar outbreak (see below).

ZWPs on 2024 Nov.3-5

This was 2 months before the outbreak. Four image sets were used:
(1) 2024-11-03, Casquinha_Oger_20hr. No offset.
(2) 2024-11-03/04, Morita_Mirabella_10hr. Offset +15 m/s.
(3) 2024-11-03/04, Tsurimi_Morita_20hr. Offset -10 m/s.
(4) 2024-11-04/05, Morita_Mirabella_10hr. Offset +12 m/s.

Profile no.1 is omitted as it appeared to have a systematic error in latitude and wind speed in the northern hemisphere, suggesting limb inaccuracy. The two 10-hr profiles (nos.2 & 4) are confirmed by the 20-hour one (no.3), though this shows more modest speeds than the 10-hour one, both eastward & westward, in many domains, as we have noted for previous ZWPs.

The NTBs jet peak speed is +150 m/s (in red light; +148 m/s in green) (2 profiles), or +145 m/s (red; +141 m/s in green) (1 profile). The ZWP agrees well with the shape of previous pre-outbreak profiles, but the peak speed is lower (see below).

ZWPs on 2025 Feb.4-17

The aim was to find out whether the cloud-top wind speeds had accelerated generally to match the super-fast plumes, or had changed in other ways. We selected images taken several weeks after the first plume appeared, showing long stretches of the complex wake with much detail -- not dominated by the wave-like dark patches nor by the later diffuse darkening, and without distinct plumes or plumelets. See Figure 7 for longitudes covered.

Four image sets were used:
(1) 2025-02-04, Kumamori-Karrer_10 hr (offset +15 m/s):
(2) 2025-02-08, Sussenbach-Go_10 hr (no offset, after time fixed by Europa position):
(3) 2025-02-10, Sussenbach-Portillo_20 hr (offset +5 m/s)
(4) 2025-02-16/17, Sussenbach-Miyazaki_10 hr (no offset).

(1) Feb.4: Peak ~126-136 m/s, broadened to S. This is at higher longitude in the wake than the others; it includes plume no.4 (L1 ~ 180) but this does not show up in the ZWP.
(2) Feb.7: Peak is quite narrow, ~141 m/s (red channel) but only 125 m/s (green).
(3) Feb.10: Jet not well defined (gaps in data): 129 m/s on N & S flanks, but not broadened. Omitted from composite figure.
(4) Feb.16/17: Peak is sharp and narrow: 131 m/s.

The peak jet speeds have diminished since the pre-outbreak profiles, and there is an unusual degree of variation in the speeds and shapes of the profiles. The jet is broadened to both N and S in some profiles, but not all. On the S side one profile has a strip adhering to the faster pre-outbreak profile. On the N side, two profiles are at least partially extended well N of the usual ZWP, but agree with the reference profile from 2012 Sep., which was about 5.5 months after the start of a similar outbreak.

3.3 Acceleration of the NTBn retrograding jet

The NTBn retrograding jet, at 31-32ºN, is also much faster than usual (see full ZWPs in **Appendix 2**). The previous mean peak from 4 spacecraft ZWPs was -26.8 m/s at 31.1ºN [ref. 14]. In our last posted set of ZWPs (2023 Nov. to 2024 Jan.) [ref.11] this retrograde jet was already faster than in previous spacecraft data. In the 2024 Nov. ZWPs it has -33 to -40 m/s, which is about the same as a year earlier. Then in 2025 Feb. it is even faster, -46 to -50 m/s in 3/4 profiles, specifically:.

(1) Feb.4: -46 m/s at 31.7ºN.
(2) Feb.7: -47 to -50 m/s at 31.0ºN, faster and further S.
(3) Feb.10: ~-31 to -35 m/s at 31.8ºN. (This 20-hr correlation may miss the highest speeds.)
(4) Feb.16/17: -48 m/s at 31.0ºN; like no.2.

We have not included the peak of the NTBn jet in Figure 21, but note that in early spacecraft ZWPs, the retrograding speed was moderately fast in in 1979 (Voyager: -32.0 m/s) and 2007 Jan. (New Horizons: -35.6 m/s), prior to NTBs super-fast outbreaks. In contrast it was slow in 1995-98 (Hubble: -14.7 m/s) and 2000 (Cassini: -24.8 m/s), in the decade when no such outbreaks were occurring [ref. 14]. So this jet undergoes variations that may be correlated with those of the prograde NTBs jet.

(4) Discussion

4.1 Background: Physical nature of the plumes

Professional studies have shown that the plumes in these outbreaks must be storms driven by moist convection from the water cloud layer, tens of km below the visible cloud tops [ref.3]. Juno's detection of lightning at PJ69 confirms that they are thunderstorms. Our observations in 2025 provide new data that may both confirm and constrain aspects of the existing models, which we briefly summarise first.

A long-standing model [refs.3&7] is that there is a permanent super-fast NTBs jet below the visible clouds; without this, the plumes cannot be supported. The cloud-top speed is slower and varies during the 4-5-year cycle of outbreaks. During the quiet phase, the NTB becomes visibly faint as it is increasingly covered with white cloud. This cyclic process may be modelled by progressive stratification of the atmosphere in the NTB latitude: as convection weakens and cloud forms, the air below it (constantly supplied from below with heat, water, and ammonia) becomes more humid and therefore dense, while the air above it cools. Thus the cloud layer continues to thicken and convection above it is blocked, and 'convectively available potential energy' (CAPE) builds up below it (see ref.15 and refs. therein for application to Jupiter's SEB, and ref.16 for application to Saturn). In the whitened NTB, we suppose that this upper layer gradually becomes more affected by the deep super-fast current. When sufficient CAPE has accumulated, the convective plumes erupt from the deep, super-fast level (the water-cloud layer) and travel with it, while their turbulent wake disrupts the overlying layering, restoring a steep decline of wind speed with altitude so that the cloud-top speed quickly diminishes (Figure 23).

Juno's gravity expt has shown that this jet, in particular, extends thousands of km below the cloud tops, and also confirmed that the jet peak descends obliquely with depth, parallel to the planet's rotation axis as expected theoretically [ref.17]. However this slope may apply only at deeper levels, below the weather layer, so may not be relevant to the phenomena that we observe.

4.2 Initial stages of plumes

We have found that all three plumes in 2025 both accelerated and moved southward during their first few days. We observed similar acceleration for all three plumes in the 2020 outbreak, although without any systematic change in their latitude [ref.8]. What can explain these changes?

The simplest expanation is that the early acceleration is due to the change in latitude, following a fixed subsurface ZWP. In fact, our measurements of the plumes and other white spots are consistent with a continuous ZWP across the jet: as the plume arises at 24.0 to 24.6ºN and drifts south, the speed changes accordingly (Figure 20). This behaviour supports the theoretical model of such outbreaks by Sanchez-Lavega et al. [ref.7]. They were able to model the plumes as convective storms rising from the super-fast jet in the water-cloud layer, initiated with an arbitrary heat pulse; but they required this initial source to be at about 24.5ºN, not at the mature plume latitude of 23.0--23.5ºN. This is just what we have observed for all three plumes in 2025.

Modelling has not yet shown why the storm would arise at this latitude, on the cyclonic side of the jet peak. But there might be some similarity with the appearance of much smaller plumes just north of the NEBs jet, as recently analysed by Brueshaber et al. [ref.13] with data from ourselves and from Juno. They studied convective plumes which occasionally erupted in the southern NEB in 2021-22, while all the rest of the NEB was quiet and whitened, comparable to the NTB before its outbreak. The speed of the NEBs jet below the nominal cloud level is ~170 m/s, as experienced by the Galileo Probe (although local weather may have affected this), and the plumes arose on the cyclonic side of this jet and moved south and accelerated over their first week [ref.13], like the NTBs plumes. Brueshaber et al. suggested that these plumes were triggered along the 'dry-line' where the cool, moist (NH_3- and H_2O-rich) air of the EZ would push under the warm, dry air of the NEB, causing an updraft which could trigger moist convection and liberate accumulated CAPE. There are some major differences: the humidity contrast across the NEBs jet is vastly greater than across the NTBs jet according to Juno data; the NEBs jet carried disturbances which were absent from the NTBs jet; and the convective plumes in the NEBs were much smaller and weaker than those in the NTBs. Nevertheless, as Brueshaber et al. did not consider velocity differences in detail, while Sanchez-Lavega et al. did not consider horizontal humidity gradients, theoretical modelling to combine all these aspects could be of interest.

It remains puzzling that we did not find any shift in latitude in 2020, despite high-quality observations. So it might still be worth considering other hypotheses for the acceleration, which are not mutually exclusive:
(i) That the storm travels with constant speed, but in the first few days, the rising plume is dragged westwards by the slower overlying winds, until it becomes powerful enough to punch vertically upwards. However, the lag in longitude would be several thousand km, which seems an excessive distance for shearing a coherent plume.
(ii) That the storm is initiated at a certain level in the water cloud layer, but as it grows it extends deeper, to a level where the speed is slightly faster.
(iii) That the growth of the storm itself causes acceleration of the jet locally.

4.3 Wake-induced plumelets

We showed in section 2 that the super-fast speed governs not only the main plumes, but also smaller, short-lived bright spots that arise near the f. end of the wake, which we call 'wake-induced plumelets'.

This is the first demonstration that they are a systematic phenomenon, but we have actually recorded such spots in previous outbreaks:

--In 2020, after some weeks, at the f. end of the wake of *each* of the three plumes, the westernmost bright cloud became a very small methane-bright white spot which accelerated to almost the same speed as the plume, just as the next-following plume approached within 10-17° f. it; this initiated the weakening of both the white cloud and the next-following plume, and thus the collapse of that plume [ref.8].

--In 2007, at the f. end of the longest-lived plume wake, a super-fast bright spot appeared ('WS-3') which only lasted 49 hours, and the JUPOS chart suggested that several equally short-lived ones appeared subsequently (not close to any next-following plume) [ref.2].

--In 2016, very distant JunoCam images provided the first record of the outbreak, showing four brilliant plumes. One of these, plume B, was seen in the final JunoCam images on Oct.13 & 14, between plumes A and C and slower than either. Then, when first observed from Earth on Oct.19, B or C had disappeared [refs.5-7]. It now seems possible that 'plume B' was a wake-induced plumelet f. plume A, and was associated with the demise of plume C in that interval; 'plume B' itself only survived a few days longer.

These plumelets are the only features ever recorded with speeds as fast as the plumes in these outbreaks [but see Footnote 1] So what are they? If they were merely high-altitude clouds, it is difficult to see how they could have such super-fast speeds, given that all other visible features in that latitude move more slowly once the outbreak has started. As they can be as fast, and almost as methane-bright, as the main plumes, we might suppose that they are the same type of storm; however, they only last for a few days and their speeds are not stable. We suggest that the intense disturbance along the wake of the outbreak, while suppressing the speed at cloud-top level, leads to instability in the super-fast water layer which is able to erupt into short-lived plumes just beyond the f. end of the wake, but these are much less stable than the main plumes. This could be because plumes require unperturbed atmosphere preceding them in order to sustain them; or because they are destabilised as they advance into the disturbed wake preceding them. These ideas could be tested by theoretical modelling.

Thus, our overall picture of the outbreak is summarised in Figure 23.

4.4 ZWPs: Comparison with previous NTBs cycles

Professional authors have studied the ZWP of this jet in many papers, based on ZWPs from spacecraft (Voyager, Cassini, and Hubble): see [refs. 9b,21,22,24,25,26] for comparisons and discussions of the changes in it in relation to the upheaval cycles. Here we assemble those published ZWPs and compare them with our new data.

Footnote 1:
There is a long-standing duality in measurements of the NTBs jet peak in the Voyager images from 1979, which were taken about a year before the 1980 NTBs outbreak. Limaye [ref.19] obtained 163 m/s but Maxworthy [ref.20] obtained 182 m/s; Simon [ref.21] confirmed Maxworthy's measurement. [They both used images 80 min apart to validate motions 8 hr apart.] However, all subsequent profiles taken within a year before an outbreak have closely resembled the Limaye one (Figures 21 & 22). The Voyager images had higher spatial and temporal resolution, but Simon [ref.21] found that this was more important for correctly matching features than for detecting them, and the issue really lay in the correlation method. (She also reported a speed 'near 180 m/s' in HST near-IR images from 1998, which was not detected by ref.22.) Nevertheless, the consistent agreement with the Limaye profile shows that this method does produce reproducible results, and we will continue to regard it as the peak wind speed. The question remains, what does the higher speed detected in the Voyager images represent? It could be a wind speed shown by a type of clouds that cannot be reliably tracked in lower-resolution images; or perhaps a wave phenomenon with a phase speed faster than the wind speed (e.g. inertia-gravity waves: see ref.28).

Most published ZWPs of this jet are shown in Figures 21 & 22 [but see Footnote 1]. They can be summarised as follows.

(i) From 1994 to 2000 (HST 2004-07, Cassini 2000): During these years there were no super-fast (NTC-D) outbreaks, but a stable situation with anticyclonic vortices travelling at more modest speed (NTC-C) along the jet. These profiles all have substantially lower peak speeds than those in the NTC-DD years, although the profiles away from the peak are very similar. They peak at 23.5 to 23.9ºN.

(ii) From 2007 to 2025, when NTC-D outbreaks occur every 4-5 years:

--*ZWPs between outbreaks* (2009 Sep., 2015 Jan.): These are similar to the Voyager (Limaye) profile and others in the next group.

--*ZWPs before outbreaks* (1979, T – 1 yr, where T denotes date of start of next outbreak; 2016 Feb., T – 7 mth; 2007 March 25, T=0, the outbreak began on this date): These include the Voyager (Limaye) profile and the others agree with it; all show the peak speed of the jet as 156-163 m/s, at latitude 23.8ºN apart from 2007 at 23.6ºN. The peak speed was slightly slower in 2015 and 2016 Feb. than in 1979 and 2007 and 2009, and definitely slower in our profile in 2024 Nov. (T – 2 mth; 145-150 m/s), although it has the same shape and latitude. (It was similar in our ZWP a year earlier, not shown – ref.11.) This could perhaps be a trend connected with the shortened inter-outbreak interval and lower plume speed in recent outbreaks (Figure 1). (Alternatively, the speed reduction in 2015-2016 could be within the range of uncertainty, and in 2024 could be related to the predominance of exceptionally long-lived streaks.)

--ZWPs after outbreaks:
Our ZWPs in Feb. are the earliest ever obtained after an outbreak. Relevant ZWPs are as follows:

2025 Feb. (T + ~1 mth: our new data): peak ~126-141 m/s.

2016 Oct-Nov. (T + ~1.5 mth) (ref.7: mostly ~121 m/s at 24.2—25.3°N, and ~106 m/s at 23.3–24.3°N) (obtained by spot tracking, including the large dark patches, but using some images from large telescopes so probably comparable to our ZWPs).

2007 June (T + 2.3 mth) (peak 146 m/s, 23.5°N)

2016 Dec. (T + 3 mth) (144 m/s, 23.9°N)

2012 Sep. (T + 5.3 mth) (149 m/s, ~23.8°N)

[G.Hahn's profile is similar to Tollefson's but not exactly the same: peak 147 m/s, 24.0°N. M.Vedovato also produced a profile from the same HST images, with similar results: ref.4]

2008 May (T + 14 mth) (151 m/s, ~23.6°N).

These all show reduced peak speed, with a clear indication of gradual recovery over time. Otherwise, they are quite varied in speed and latitude. The 2007 and 2008 peaks are shifted south to lower latitude (~23.5°N), as is one of the peaks in our 2025 data. Several of these profiles are broadened to the north (at <135 m/s) - especially the earliest post-outbreak profiles, viz. 2025 (ours) and 2016 Oct-Nov. (ref.7), but also 2016 Dec. and 2012 Sep. The complex and variable structure of the wake is reflected in these variable but low-speed ZWPs.

Note that the large wave-like dark patches have speeds slower than other spots in our ZDP (Figure 20) and in ZWPs (Figure A21). Their speeds in 2025, although ill-defined, are consistent with mean speeds given for them in our reports for 1975, 1990, 2007, 2016, and 2020, ranging from DL1 = -23 to -49 deg/mth (u_3 = 108 to 120 m/s). This strengthens the evidence that they are waves, slower than wind speeds.

Otherwise, there is little change in the ZWPs outside the jet peak. Along the northern flank of the jet, our ZDP for white spots (Figure 20) follows the same line as the ZWP, including plumes in their early stages, and plumelets, and spots on the northern side of the wake. The mature plumes in the outbreak, though, typically occupy a faster and more southerly position on this chart – consistent with an extension of the usual profile to faster speed at depth – as plotted for 2007 and 2016 (refs.3&7), 2020 (our data – ref.8), and 2025 (our data) (Figure 22(B&D)). Thus the plumes in 2025 first appeared close to the usual pre-outbreak ZWP, not suggesting any faster sub-surface current, so there may have been no vertical speed gradient where they first arose; but then they migrated to a faster, more southerly place as they matured. The only sign of other features lying similarly far south of the usual ZWP is a cluster of points in one of our ZWPs in 2025 Feb., possibly part of the wake that was stripped off from the main plume.

So the evidence does not suggest any general change to a new, faster cloud-top ZWP that might represent the current at a deeper level; the plumes themselves (including the plumelets) are the only clear indication of that current. The broadening of the jet can be understood as a cloud-top phenomenon, arising from the disturbances streaming behind the N and S side of the plume head in the wake.

The conclusions from the ZWP analysis can thus be summarised:
--The jet shows no systematic change during the year before the outbreak, even up to the day of the outbreak.

--There is no detectable acceleration of the cloud-top ZWP during the outbreak apart from the plumes themselves, and broadening on the flanks; instead, it quickly collapses to a slower but sometimes broader state, then recovers over the next two years or so.
--In 2024-25 there was somewhat slower ZWP before the outbreak (as also in 2015-16) and somewhat slower plume speeds (as also in 2020) – perhaps connected to the reduced interval between outbreaks.
--The periodic dark patches in the wake are wave features with a slower phase velocity.
--The NTBn retrograding jet also accelerated just before and during the 2025 outbreak.

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Figures

Figure 1. Speed of the NTBs jet from 1995 until now. This is the latest version of a chart which we have been posting since 2008, including in ref.4. It includes conversion between u_3 (m/s) and DL1 (deg/30d) Large asterisks denote the outbreak plumes; those in 2020 and 2025 were slightly slower than in previous outbreaks. In the well-observed outbreaks of 1975 and 1990, most plumes had DL1 ranging from -159 to -165 deg/30d (-5.3 to -5.5 deg/day) (ref.1).

Figure 2. JUPOS chart of the NTBs before the outbreak, in a longitude system moving with L3 – 10.0 deg/day.

Figure 3. Multispectral image sets showing the plumes. (A) P. Casquinha's images on Jan.12, when plume 1 was 2 days old. (B) C. Pellier's set on Feb.1, with plumes 1 & 2.

Figure 4. Selected good images of plume 1 from Jan.16-19. The series is continued in Fig.11.

Figure 5. Maps of the whole NTBs and NEB on Jan.21-22 and 24-25. On Jan.21-22, X marks an AWO (near-stationary in L3) that was duplicated because images from different rotations were combined in L1. Below are copies indicating Plume 1 and various spots in its wake. Black arrows mark the large dark patches.

Figure 6. Drift chart of all the white spots in the outbreak, by S.M., up to March 2. Different colours indicate plumes (including plumelets), and northerly and southerly white spots in the wake. *Inset:* Measured drift rates in L1.

Figure 7. Drift chart of white and spots in the outbreak, by the JUPOS team, in a longitude system moving with L3 – 10.0 deg/day. Mauve bars indicate longitudes covered by the ZWPs in Section 3.

Figure 8. Charts of longitudes and latitudes for the early stages of the three primary plumes, plotted by G.A. from JUPOS measurements (mostly by G.A. himself). Longitudes are plotted in a system moving with L1 – 4.667 deg/d.

Figure 9. Drift chart of the larger dark patches in the wake, measured by J.R. from S.M.'s maps and a few other images.

Figure 10. Charts of selected features that were tracked in S.M.'s maps (some indicated in Suppl.Figs.), measured from those maps and from other images.

Figure 11. Images of the wake interacting with three AWOs in turn WS-Z, Jan.18-21; WS-1, Jan.21-25; WS-7, Jan.25-27. The AWOs are labelled on the whole-planet images at right.

Figure 12. Strip-maps from Jan.27-29 and Feb.1-4, excerpts from S.M.'s Suppl. Figs. They show: The first appearance of plume 2 (Jan.27), then of its wake, and subsequent decline of plume 1 (green arrows); plumes 3 & 4 (white arrows); a northerly white spot (magenta arrow); and interactions of the wake with NEBn WS-E & WS-B from Feb.2 onwards.

Figure 13. Hi-res images in early Feb., showing the same phenomena as Fig.12, especially the origins of plumes 3 & 4 (wake-induced plumelets), and the long wake running past NEBn WS-E & WS-B, with perturbations of NEBn.

Figure 14. Images of the first appearance of plume 2 on Jan.27, just to the right of plume 1.

Figure 15. Global map by M.V., 2025 Feb.4-5.

Figure 16. Global map by M.V., 2025 Feb.15-16.

Figure 17. Set of images showing the origin of plume 5 on Feb.9.

Figure 18. Some of the best images from Feb.14-26, showing the greatly extended wake, and main plumes 2 & 5, and wake-induced plumelets 7 & 8.

Figure 19. The NTB around the time of Juno's PJ70. (A) Ground-based maps up to March 2, showing how plumes 2 & 5 both disappeared in the previous few days; (B) JunoCam's PJ70 image 27 showing the region where the remains of plume 5 would have been, adjacent to the NEBs AWO called WS-6; (C) Ground-based map on March 3-4, with the area of image 27 (B) outlined in red.

Figure 20. Zonal drift profile for the 2025 outbreak from our data in **Table 2** and Figure 10.

Figure 21. Zonal wind profiles of the NTBs jet, all adjusted to the same scale.

(A, B) Amateur data from 2024 Nov. and 2025 Feb.; ZWPs by G.Hahn. Each panel is a composite of three dates, shown in different colours, each of which is the sum of all channels. The black line is a ZWP from HST on 2012 Sep.20, by G.H. [ref.18]. (The same HST data were also used for ZDPs by M.Vedovato [in our ref.4], and by ref.25 (see Figure 22(C)), with very similar results. Both G.H. and M.V. have also produced ZWPs in other previous years, posted with our on-line reports, which are not included here.)

(C) Published spacecraft ZWPs from the following sources:

Voyager in 1979 (red line): Limaye (ref.19) & Maxworthy (ref.20).
HST in 2016 Feb. (black line) (ref.27).
HST in 2007 March & 2007 June (green lines) (ref.3).
Cassini in 2000 (ref.23).
HST in 1995-98 (ref.22).

Green circles represent the main plumes in 2007 (ref.3) and 2016 (ref.7: panel D)

(D) Published data for the 2016 outbreak, showing the pre-outbreak ZWP from HST in 2016 Feb. (ref.27), and spot tracking 1-2 months after the outbreak began (ref.7).

Figure 22. Zonal wind profiles, showing only the jet peak, all adjusted to the same scale and aligned.

(A, B) Amateur data from 2024 Nov. and 2025 Feb.; ZWPs by G.H. Each panel shows two of the most complete and reliable profiles in red light. (B) also shows one profile in white light, and our ZDP from spot tracking in Fig.20. The grey line is G.H.'s ZWP from HST on 2012 Sep.20.

(C) Published ZWPs from HST images, 2009-2016, from Tollefson et al.(ref.25), plus the 2008 profile from ref.24.

(D) Overlay of all the published ZWPs from Figures 21(C) & 22(C), relabelled to relate them to the phase of the outbreak cycle. The blue profiles, peaks enclosed by a pale blue box, were from 1995-2000 when no cycles of super-fast outbreaks were occurring, and have low speeds. The profiles in shades of red and grey, peaks enclosed by a pale orange box, were between or before super-fast outbreaks, and have consistent super-fast speeds. In between are four profiles labelled by year with green arrows, which have intermediate speeds increasing with time since the outbreak as indicated in brackets. Green circles and diamonds represent the individual plumes in 2007 and 2016 (as in Figure 21(C,D)) and 2020 (our data: ref.8).

Figure 23. Diagram of the proposed structure of the outbreak, shown as a vertical profile (vertically much exaggerated) along the latitude of the NTBs jet. Arrows indicate the eastward wind strength. This is only a qualitative sketch, and is not intended to suggest any specific dynamical processes in the wake. Read from right (east) to left (west).