Jupiter in 2016/17: Report no.1

First report on the 2016 NTBs outbreak

--John Rogers (British Astronomical Association), 2016 Oct.26

The new apparition has begun with a bang! On Oct.19, just as Juno was drifting passively through its second perijove, infrared imaging from Hawaii by Dr Glenn Orton revealed a new NTBs jet outbreak – fulfilling a prediction made on these pages early last year. The outbreak was already widespread and had probably been going for several weeks. Using images obtained by JunoCam at long range, and by amateurs in the dawn skies, it has been possible to characterise the outbreak. It consists of three super-bright, super-fast plumes, and a chain of very dark spots, spreading around the planet, fully consistent with previous examples.

This type of outbreak is defined by the appearance of one or more super-bright white spots embedded in the super-fast jet on the south edge of the North Temperate Belt (NTBs). They are known to be cloud plumes erupting from well below the cloud-tops to well above them, and thus they are bright in methane-band images. By combining amateur and professional imaging with theoretical simulations, a consistent physical model of these outbreaks has been developed [refs.1,2]. Such outbreaks often occur at intervals of 5 years, so as the last one occurred in 2012, and the jet speed was increasing again (Fig.1), and the NTB was largely light-coloured, another such outbreak was forecast for late 2016 or early 2017 [ref.3].

[Box]: Nomenclature: We refer to this phenomenon as a NTBs jetstream outbreak, or NTB jet outbreak for short. Dr Agustin Sanchez-Lavega and colleagues [ref.1] refer to it as a North Temperate Belt Disturbance; this should not be confused with the North Temperate Disturbance, which we have described extensively, and is an entirely different phenomenon [refs.6&7].

We reserve 'Disturbance' as a capitalised name for a sector of a zone which shows darkening and/or interruption of the usual jet pattern, by analogy with the historic South Tropical Disturbance. (This has been the BAA's practice for many years, e.g. as stated by B.M. Peek in a footnote to a BAA Memoir [ref.8]. I recently came across his manuscript of this footnote on his proof copy of the Memoir (Fig...).

Another possible designation is 'NTB Revival'. This is less appropriate because historical NTB jet outbreaks have not always entailed revival of the dark NTB; for example in 1975 the NTB had not faded beforehand. However, the last four outbreaks have all done so, and the term 'NTB Revival' does highlight the emerging similarities between these outbreaks and SEB Revivals and NEB Revivals.

Here we are only referring to outbreaks with super-fast jet speed ('North Temperate Current D' –ref.6). Outbreaks consisting solely of small dark spots with moderately fast speed ('North Temperate Current C'), which comprise all the outbreaks recorded from 1890 to 1965 plus a long-lived set of spots in the 1990s, are not considered here.

On Oct.19, Glenn Orton discovered two very methane-bright plumes in 2.2 micron images taken at the NASA-IRTF on Hawaii, and he also found 'hot spots' at other longitudes in a 5-micron image, indicating that the outbreak had begun during solar conjunction and was already extended. These observations were intended to complement the Juno spacecraft's observations at perijove-2, but with cancellation of the main engine burn due to a sticking valve, and then an unplanned shut-down ('safing event'), no close-up observations were obtained. Nevertheless, JunoCam had taken (v-lo-res) images up to Oct.14, and these showed that the NTBs outbreak was already widespread as early as Oct.11. Then, some amateurs were able to obtain the first images since solar conjunction, showing some of the brilliant plumes and one very dark spot (Oct.16-23). T. Eguchi and Isao Miyazaki in Japan were able to obtain (v-lo-res) colour images; Phil Miles and Anthony Wesley in Australia took near-infrared images after sunrise; and Thomas Ashcraft in New Mexico acquired the first methane-band images.

Acknowledgements: This outbreak would not have been discovered so early without NASA's Juno spacecraft; without this mission, it is unlikely that either Glenn Orton or amateurs would have attempted observations just 3 weeks after solar conjunction. Glenn Orton has organised intensive ground-based observations to complement the mission and these may provide excellent coverage of the later stages of the outbreak. The early stages were only covered because the JunoCam team (led by Dr Candy Hansen) were taking distant images. The images are credited to NASA, and the Southwest Research Institute, and Malin Space Science Systems. Analysis of these images was only made possible thanks to Gerald Eichstädt who did the laborious initial processing. Finally, the amateur observers mentioned above have made exceptional efforts to obtain images with Jupiter just 15-20 deg from the Sun – which were essential to follow up the early discovery.

Results (1): JunoCam images, Oct.11-14.

JunoCam was taking a colour image every 30 minutes (18 deg jovian rotation); thus a full rotation is covered by 20 colour images (all odd-numbered; interspersed with 20 methane images, which are even-numbered) – actually, 362.7 deg in exactly 10 hours.
The JunoCam raw images (like those from previous spacecraft) have south up, and I have left them this way. South-up has the intrinsic advantage of compatability with longitude-vs-time charts and with previous reports on NTBs outbreaks. Therefore, south is up in all figures in this report.

The raw images were provided by the JunoCam team, and Gerald Eichstädt did 'Level 1' processing – assembling the strips, and aligning and merging the three colour channels. (He also assembled the methane-band images, but due to the great distance from the planet and the long exposures required, these were too blurred and noisy to show any NTBs plumes. More sophisticated analysis might or might not extract something from these images.) I then did further processing in Adobe Photoshop: increased the brightness of the R,G,B channels individually to make the zones nearly white; enhanced the contrast of the left half of each image and blended it with the right half, then applied unsharp masking. The resulting set of 20 images covering the final rotation on Oct.14 has been posted on the JunoCam 'Image Processing' page [https://www.missionjuno.swri.edu/junocam/processing] and is shown, with labelling, as Fig.2. I measured NTBs features on images back as to Oct.11, when the disk was so small that only a few features were visible.

Because of the low resolution, crescent phase, and extreme changes in relative intensities as features rotate towards the limb, it will be very difficult to make a good photo-mosaic map from these images. Instead, I made a map of the final rotation on Oct.14 by the good old-fashioned method of pencil drawing (Fig.3).

I fitted the 20 images to 360 deg; and to establish longitudes, I used the GRS as a reference, assumed to be at L2 = 256, L3 = 329. Systematic errors due to these factors, plus random errors in drawing by eye, could amount to ~10 deg. However, the adopted longitude scale agrees to within 1.5 deg with the stated sub-spacecraft longitudes, and the directly measured longitudes of spots are all within 3 deg of the positions on the hand-drawn map, so it appears that actual errors are within tolerable limits.

I then measured positions of all major spots on the NTBs, directly from images, in L3; also converted these to L1; and plotted the results as shown in Figs.4 & 5. Consistent tracks emerged for several white spots ('plumes') and a long chain of very dark blue-grey spots. Four white spots have been named as plumes A to D. They were visible over a wide range of rotational phase, and sometimes appeared distinctly oval. Some other white spots were less consistent in appearance and were probably just gaps between the very dark spots. 'Plume B' may in fact have been such a gap, as it was only visible on two rotations and had a slower speed; but see below. Plumes A and D had drifts (DL3) of -12.7 to -12.8 deg/day, closely matching the previous speeds for such plumes, while plume C moved slightly faster: -13.4 deg/day (**Table 1**).

The best-tracked dark spots had drifts (DL3) of -9 deg/day; these were a single very dark spot f. plume D (named ds1), and the p. and f. ends of the f. half of the longer chain f. plumes A,B,C. Short tracks for other spots within that chain suggest more diverse drifts, ranging from DL3 ~ -7.4 to -11 deg/day, but they are very imprecise and might merely represent changing shapes of the features. These drift rates are also typical of those found for similar chains of dark spots in previous outbreaks.

Results (2) Ground-based images, Oct.15-23.

(The first image was taken on Oct.15, by T. Eguchi, and showed a striking bright white spot in the NTropZ; but this does not correspond with any other sighting of a plume, and I think it was probably a transient feature associated with a gap in the chain of dark spots.)

Glenn Orton's IR images on Oct.19, and subsequent images by Isao Miyazaki, Phil Miles, Anthony Wesley, and Thomas Ashcraft, despite the wide range of wavebands and low resolution, show that three bright plumes were persisting, with at least one methane-band image of each one. All these images were measured manually; the results are plotted in Fig.5. Plumes A and D show reasonably steady speeds similar to those measured on the JunoCam images. The third plume is more mysterious: is it B or C or a merger of both? In the JunoCam images up to Oct.14, C was the more persistent and had a suitably rapid drift; however it would have to have speeded up to DL3 = -16 deg/day to connect with the plume on Oct.19, which is far beyond any speed previously recorded and may not be realistic. It may be impossible to resolve this issue unless more images emerge from that period; however, analogy with 1975 suggests a possible explanation (see below).

The average drift rate for all the well-established plumes is DL3 = -12.7 deg/day (DL1 = -160 deg/mth; u_3 = 170 m/s) (Table 1). (Since this analysis was completed, only two methane-bright plumes remain: plume D at least to Oct.25, and plume A to Oct.27, maintaining similar drifts.)

The ground-based images have also tracked dark spot ds1, with DL3 = -8.9 deg/day, consistent with the other dark spots. On Oct.23-24, observers also recorded the long chain of dark spots in the outbreak, but analysis of these will wait until more data have been obtained.

Discussion: The outbreak in historical perspective

NTBs outbreaks of this type almost certainly occurred every 5 years from 1970 to 1990, and again from 2007 to 2016, so this is the 7th or 8th of them. (The outbreaks up to 1990 were described in [ref.6], and the subsequent ones in our on-line reports.) However, the 1970 event comprised just a single white plume and little disturbance, and only 3 of the subsequent events have been well observed: in 1975, 1990, and 2007. All the others have occurred at very unfavourable times. In 1980 and 2012 they started at the end of the apparition, and in 1985 an outbreak probably went unobserved during solar conjunction.* So the 2016 outbreak continues this run of bad timing.

Fortunately we have enough information to compare the present outbreak with the well-studied ones of 1975 [refs.9,10]*, 1990 [refs.11,12], and 2007 [refs.13, 2]. In all 3 cases the outbreak started with two super-bright, super-fast plumes at widely separated longitudes, on the same day (1975, 2007) or 7 days apart (1990). (In 1975, 2 or 3 more plumes then appeared shortly f. plume A, alternating in visibility over subsequent weeks. Identical behaviour may well explain the apparent longitude shifts of plumes B and C in 2016.) The plumes have speeds of DL3 = -12.5 to -13 deg/day (DL1, -154 to -169 deg/mth). A dark bluish spot forms on the f. edge of each plume within a few days. From there, conspicuous disturbance spreads in the f. direction, including some large dark bluish-grey spots, often a regular chain of them; these spots have a DL3 ~ -8 to -9 deg/day [DL1 ~ -24 to -53 deg/mth (1975), -12 to -39 deg/mth (1990), -11 to -31 deg/mth (2007)].

**Footnote 1:* However, in 1985 the NTB did revive with notable orange colour. This was mainly documented from visual observations [ref.6], but was also shown in colour-filter images in [ref.9] (see Figs.5&11, taken from Calar Alto on 1985 July 1).

**Footnote 2:* On a personal note: Ref.10 was my first scientific paper, published exactly 40 years ago, in the JBAA. It was a BAA report on the NTBs outbreak of 1975, and also built on the work of Wynn Wacker to introduce the concept of 'global upheavals', i.e. when NTBs jet outbreaks occur at the same time as SEB Revivals and other phenomena. This paper is posted herewith.

The 2016 outbreak appears to be behaving in exactly the same way. Can we establish the start date (T) from the rate of growth of the disturbed sector f. the plume(s)?
In all three previous events, the disturbed sector grew f. the initial plume(s) from a few days after T = 0, though in 1975 there was not enough information to establish a firm growth rate. In 1990, the dark spots developed slowly at first but then proliferated on the f. side with a range of speeds, so extrapolation from the track of the f. dark spot would have given T - 3d. In 2007, dark spot tracks were quite irregular but the f. end of the disturbance as a whole would have given T +2d. Therefore, such extrapolation may give a good estimate, but may be confounded by the variable drift rates of the dark spots and possible proliferation of them beyond the initial disturbance.

For the present long chain of dark spots f. plume C, which was already 120 deg long on Oct.13, extrapolation leads back to T = Sep.15, which is therefore the best estimate of the start of the outbreak, subject to the caveats above. For the very dark spot f. plume D, extrapolation leads back to T = Oct.6-8, so this secondary outbreak may have started after a delay.

When will the plumes disappear? Considering the two principal plumes in each of the three outbreaks, their lifetimes have ranged from 2 to 7 weeks. Usually they then disappear, though in one or two cases the plume suddenly decelerated (to DL3 = -8 deg/day), joining the ordinary spots in the chaotic sector. In most or all cases, the plume's life ended as it caught up with the chaotic dark disturbance following the other plume(s). This was the case for both plumes in 2007; probably (less precisely) in 1990; and possibly in 1975.

As of 2016 Oct.25, plume D seems to have caught up with the main chain of dark spots so it may disappear within a few days. Plume B is only doubtfully detectable in a methane image (Oct.25, T, Ashcraft), and may be at the end of its life, while plume A is still bright in this image. But plume A is only ~36 deg f. the very dark spot, which it will catch up around Nov.4, at which time the outbreak will have spread all round the planet.

Characteristics shown by most or all of these outbreaks, after the initial super-fast plumes and chains of dark spots, include the following:
--The chaotic sectors overlap, until the disturbance completely encircles the planet, leading to turbulent revival of the dark NTB;
--A diffuse orange NTB(S) develops;
-- NNTBs jet spots are suppressed for a year or so [ref.14].

We are likely to see these phenomena in the coming apparition. Then in the years following, we may see a complex but stereotyped sequence of intricate disturbances in the revived NTB and the NTZ, including prominent waves and dark streaks and a N. Temperate Disturbance in the NTZ. We have recently described this sequence which occurred following the outbreaks of 2007 [ref.7] and 2012 [our on-line reports], and there is evidence that similar sequences occurred following some previous outbreaks, but possibly not all of them. It will be interesting to see whether this sequence is repeated after 2016.

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Figure legends:

Figure 1. Chart of NTBs jet peak speed over recent decades. This is an update of our previously posted version [ref.3] with addition of the present outbreak, and of a Hubble measurement from 2016 Feb.9, which was derived in [ref.4] from HST maps in [ref.5].

Figure 2. The last 21 JunoCam images, on Oct.14, processed as indicated, and labelled to show the NTB features. South is up in all images.

Figure 3. Map of the NEB and NTB drawn from the JunoCam images in Fig.2.

Figure 4. Charts of longitudes (L3 with arbitrary offsets) measured from the JunoCam images.

Figure 5. Charts of longitudes (L1) measured from the JunoCam images as in Fig.4, and from the ground-based images shown in Fig.6.

Figure 6. Ground-based images showing the outbreak.

Figure 7. Map of the NEB and NTB, in L1, prepared using WinJUPOS by Marco Vedovato, from red or infrared images on Oct.23-25 as indicated (including some which post-date the analysis in this report).

Figure 8. B.M. Peek’s footnote in his proof copy of the BAA Memoir [ref.8].