***Jupiter in 2016-17, Report no.17:***
**Summary of the mid-SEB outbreak**

**--John Rogers** (British Astronomical Association;  2018 Dec.27)

**A ‘mid-SEB outbreak’ began on 2016 Dec.29, the first since the SEB Revival in 2010-11.** Such an outbreak consists of convective storms appearing in a tightly confined region, similar to those of a SEB Revival or to the perennial rifted region following the GRS.  In these outbreaks, the source remains approximately fixed in L2 (not L3), and produces successive bright spots (convective plumes) at intervals of several days, which prograde (drift eastwards) and thus form a line of bright cells. The source typically remains active for several months, then when it switches off, the remaining white spots or cells continue prograding and there may be residual convective activity in that prograding disturbance.  This was the case in 2017.

Its progress was described in our interim reports (2016-17 nos.3, 4, 6, 10), which included galleries of images and maps.  This final report on the outbreak includes:
1) A summary of its history, adapted from our interim reports;
2) More detailed spot tracking from ALPO-Japan and from the JUPOS group;
3) The JunoCam image at perijove-4.

## 1.  Summary of its history, adapted from our interim reports

The outbreak began in typical fashion, with a brilliant new white spot discovered by Phil Miles in Australia on Dec.29, at L2 = 208, 16.5 deg.S.  It coincided with a pre-existing pale white spot, probably a cyclonic oval. This was one of two or three tracked since the previous apparition, when they were at 16.1 to 16.3 deg.S, and a Hubble map showed such spots to have oval shape. So the new outbreak apparently erupted within such a circulation, as did a similar mid-SEB outbreak in 1979 (closely viewed by Voyager) and the SEB Revival outbreaks of 2007 and 2010, although in two of those cases the cyclonic circulation was dark reddish-brown.

It was unusual for such an outbreak to appear not far preceding (east of) the GRS (currently at L2 = 261), but the subsequent development of the outbreak was typical. The first white spot was twisted and stretched to lower longitudes and latitudes by the wind gradient across the SEB, then other white spots appeared at the original source on Dec.31 (perhaps just a persistence of part of the first spot), Jan.8-9, Jan.12-16, Jan.22, etc. – all within a few degrees of the same L2 -- and behaved similarly. However, rather than erupting suddenly, most of them developed over several days from a swirl or tiny spot, ot by splitting of the previous white spot.

By April the main disturbance spanned ~120º longitude.  Maps showed:
--Bright white spots (plumes) were appearing at the source (L2 ~ 208) up to mid-Feb.  Then the f. end of the disturbance prograded very slowly (DL2 = -6 deg/mth) until early April, and faster thereafter.
--Successive plumes or cells spread in the p. (E.) direction, as usual, forming a long, very turbulent sector across almost the whole SEB, whose p. end* moved steadily with DL2 = -26 deg/mth [L2 ~ 195 (Jan.10), 160 (Feb.18), 130 (Mar.30), 110 (Apr.19)].
--Bright white plumes were also erupting near the p. end* of this sector.
*[This was designated ‘source 2’ by S. Mizumoto; see below.  Likewise in the SEB Revival in 2010-11, the leading edge was also an important location of bright white plumes.]

--Further p.(E.), large-scale disturbance ('the NE extension') was prograding rapidly in the N half of the SEB, often in the form of a regular array of large cells (conspicuous on March 11), but with no bright plumes.
--The scale of turbulence in the main disturbance was gradually getting smaller.

In methane-band images, the white plumes appeared bright, both within the mid-SEB outbreak or its p. end, and in the post-GRS rifts. Also, there were some notable methane-dark features in the NE extension of the mid-SEB outbreak; visibly, these were pale blue streaks.

After March, no further white spots were produced at the original source (L2 = 208); the f. end prograded since then with DL2 ~ -13 (approx. keeping pace with oval BA), though even in August the large white spots (cells) in the NE extension were still conspicuous and travelling faster. But a new white spot appeared further f. at L2 = 146 on July 8 (Miyazaki), and another at L2 = 146 again on July 22 (Carvalho & Miyazaki), indicating renewed activity at the f. end. The prograding disturbance gradually became less conspicuous, though it was still visible with some small bright spots in it in the Juno PJ9 map at solar conjunction on 2017 Oct.24.

## 2. Analysis by ALPO-Japan and by JUPOS

A full display of the outbreak was posted on ALPO-Japan:
**'2016-2017 Mid-SEB Outbreak Final Report', by S. Mizumoto,**
**<alpo-j.asahikawa-med.ac.jp/kk17/j170923s.htm>**

This comprises a comprehensive set of strip-maps of the SEB (including methane-band maps), tracking the development of the outbreak, typically every 1-3 days; plus drift charts for all the spots. (All are in System II with south up.) These show the complete history of the white spots in the outbreak. Mizumoto noted that in addition to the original source, two of the white spots prograding from it became themselves sources of further eruptions; he called these sources 2 and 3. Mizumoto's chart (Figure 1) shows excellent agreement with the independently measured JUPOS chart (Figure 2; see below).

White spots appeared at the original source on:
2016 Dec.29, & 31 (as described above);
2017 Jan.8 (split on Jan.12 into 2 spots, labelled 'Source 1' at the source and 'Source 2' p. it);
Jan.12-16 (it was slow to expand);
Jan.22 (but it remained compact until Jan.28-29, when it enlarged as a new one appeared f. it);
Jan.28 (it became 'Source 3', which prograded);
Feb.13 (but it remained very compact at L2 ~ 207, within a sinuous rift that extended p. & f., until being disrupted on Feb.23-24);
Feb.23 (at L2 = 206, until March 1-3 when it expanded then prograded).
This was probably the last at the original source.
Thus the source produced only 8 white spots altogether, appearing about every 8 days on average. Most of them were slow to expand and move away from the source.

But meanwhile, as the white spot from Jan.9 prograded, new white spots began to appear f. it, from a location with DL2 ~ -30 deg/mth ('source 2'). They arose on Jan.17 (L2 ~ 197), 22 (193), and 30-31 (184), at similar latitude to the original source, and were likewise methane-bright when they were very bright in visible light. The sector between sources 1 and 2 comprised the main disturbance as described in my interm reports, spanning the whole width of the SEB, and a few other white spots and streaks on a smaller scale appeared within this sector in Feb.-March (one locus being designated ‘source 3’ by Mizumoto), along with even smaller-scale turbulence.

**Table of drifts (Analysis of JUPOS data by Gianluigi Adamoli)**

| White spot(s) | Dates | DL2 | Lat.(ºS) | |
|---|---|---|---|---|
| Precursor spot | Oct.25-Dec.27 | +12.4 | 16.6 | (Cyclonic spot where outbreak started) |
| Source 1 | Dec.30-Feb.1 | +0.5 | 15.7 | (White spots at original source) |
| | Feb.12-Mar.24 | -4.4 | 15.8 | |
| | Mar.27-May 1 | -14 | 14.9 | |
| Source 2 | Jan.12-Feb.5 | -30 | 15.2 | (White spots at source 2) |
| Source 3 | Feb.14-Mar.11 | -16 | ~16 --> 13.6 | |

All these white spots, as well as the rapidly prograding cells (see below), lay close to the usual zonal wind profile determined by Cassini.

Almost every one of the white spots from these sources evolved into a light or whitish cell in the northern SEB, and the set formed a rapidly prograding array. Sometimes this was quite regularly periodic, with spacings of approx.10 deg. However the cells were not permanent, and few could be tracked for more than 20 days. In Feb. the early ones lost their identities, and the latest ones (between sources 1 and 2) were too turbulent to track, so those from source 2 formed the most distinct array. The array of cells was most regular at some later times, notably the maps of June 19-20 (8 cells in 2 sectors) and July 24-28 (one row of 8). Altogether, more than 20 of these cells prograded in the northern SEB up to mid-July, on both the Mizumoto and the JUPOS charts (Figures 1 and 2). The JUPOS data have now been analysed by G. Adamoli. Only a minority of the tracks were adequate to measure, but they appear to be representative of the majority. Typical drift rates (from Adamoli) had mean DL2 = -102.6 (±1.7) deg/mth, at 11.2 (±0.25)ºS.

### 3. JunoCam’s image at Perijove 4.

The mid-SEB outbreak was successfully captured by JunoCam at Perijove 4 on 2017 Feb.2 (Figure 3). In fact, JunoCam’s image shows Source 2: the white spot labelled X is a recently-born plume at that source which appeared on Jan.30-31 within the whitish complex swirl, and Z is the white spot expanding from the previous plume. The image shows the varied colours and textures of the cloud layers that form the outbreak, and ubiquitous streaks of higher-level hazes crossing over the clouds at different angles. The image just captures the outer part of the new plume (X) which carries lanes of white clouds protruding above the main white cloud deck. Some of the cloud lineations may be stream-lines, while others may be waves, so the image may not be easy to interpret. It may be useful to compare it with other images of such vigorous outbreaks. Fortunately JunoCam at PJ4 also obtained a comparable image of vigorous white rifts in the NEB, which shows similar complex cloud features.

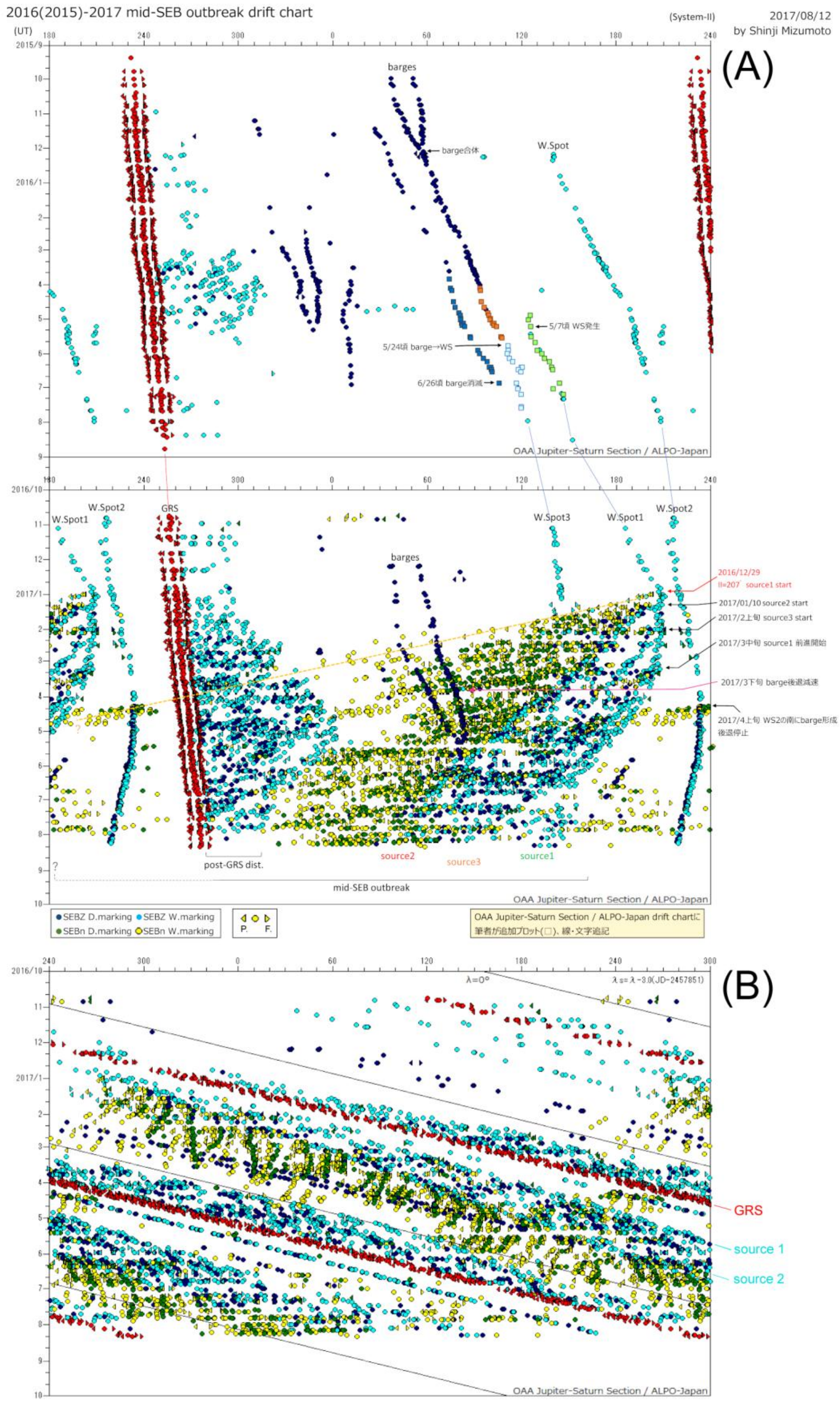


**Figure 1.** Charts of the disturbance, (A) in System II longitude (L2), and (B) in a longitude system moving at -3.0 deg/day relative to System II. By S. Mizumoto, posted on ALPO-Japan: **<alpo-j.asahikawa-med.ac.jp/kk17/j170923s.htm>**

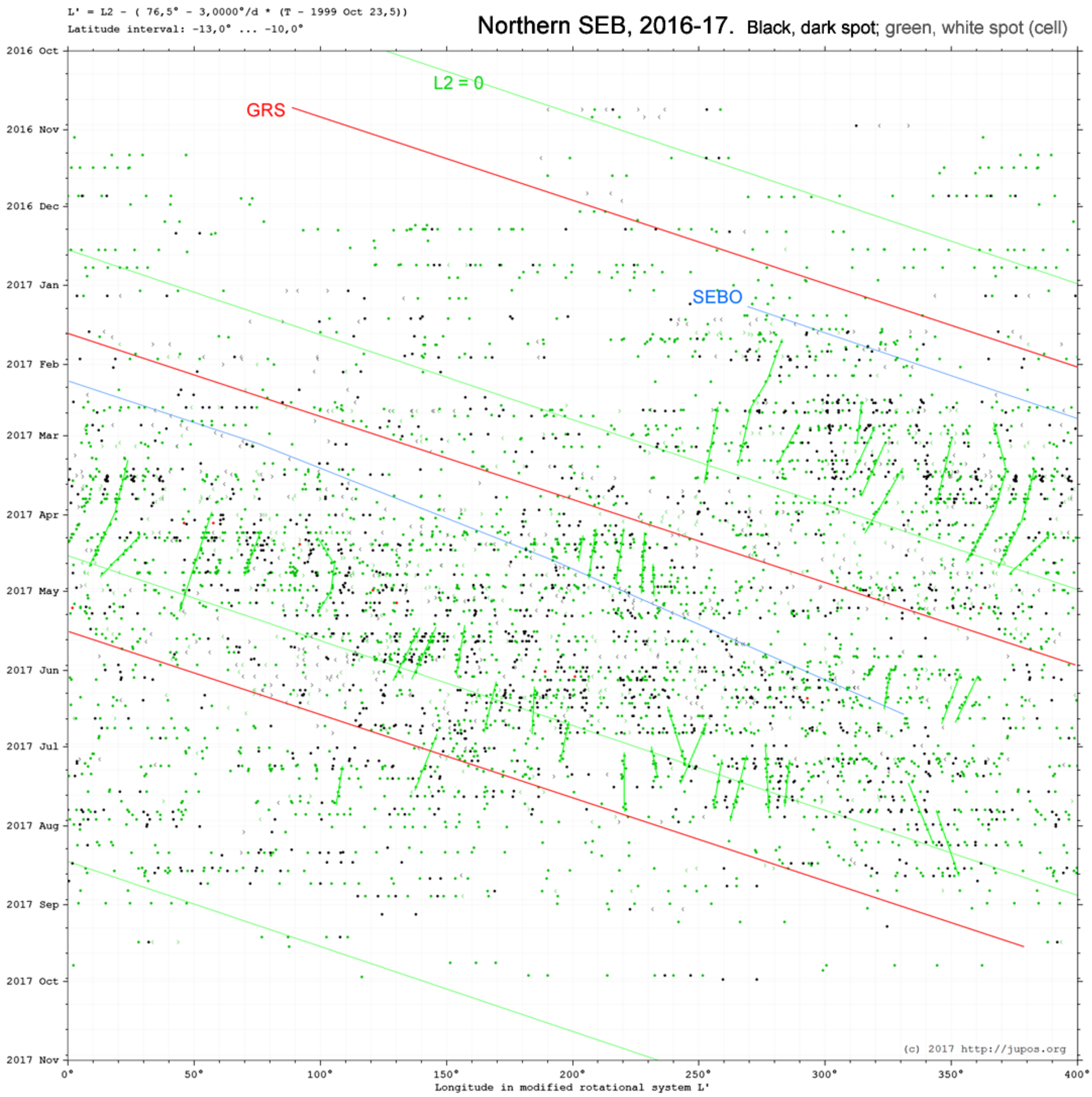


**Figure 2.** Chart of the northern SEB (10-13ºS) in a longitude system moving at -3.0 deg/day relative to System II, i.e. the same as Figure 1B though with a different zero-point. Chart of JUPOS data.

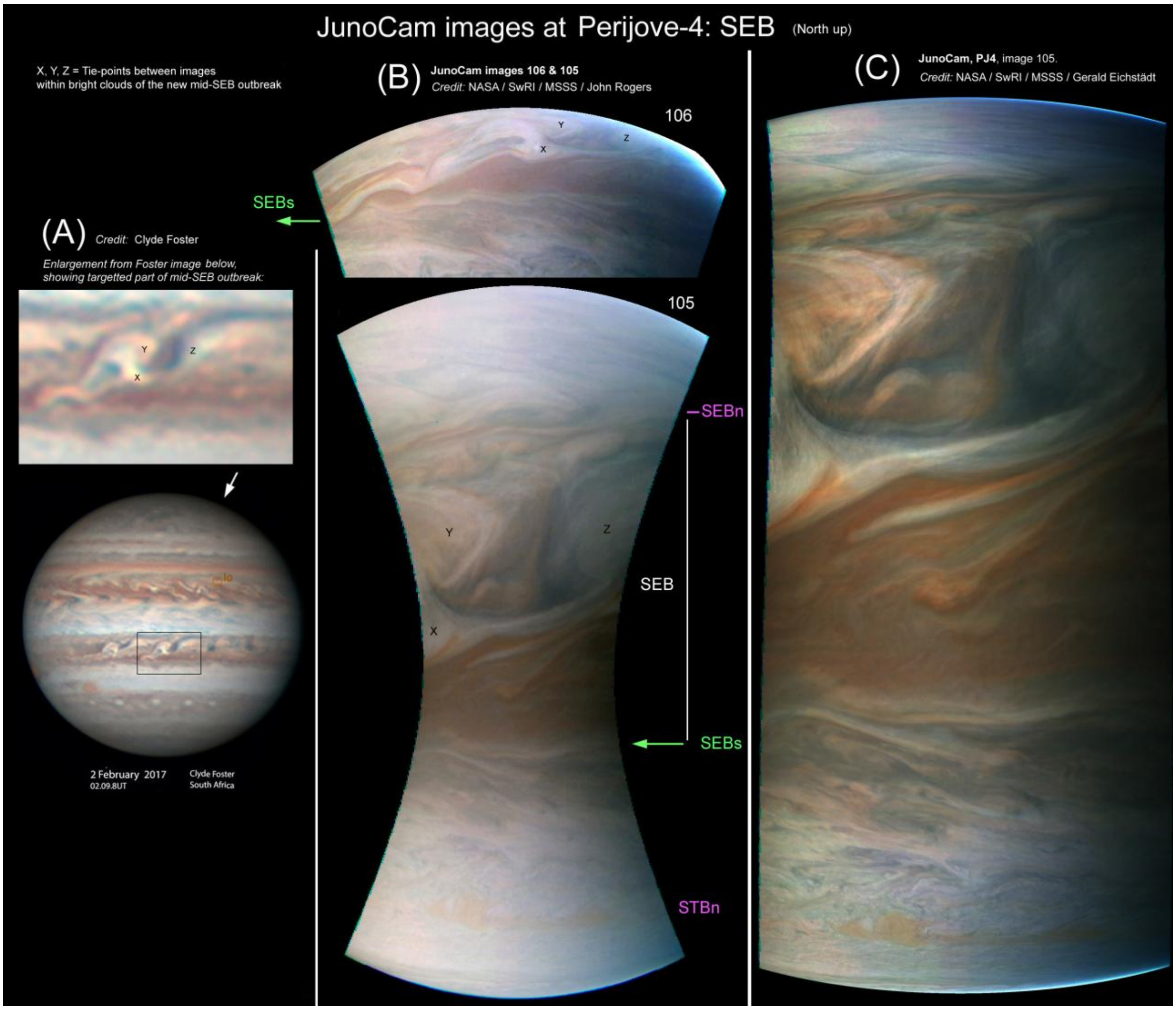


**Figure 3.** JunoCam image of the SEB outbreak at Perijove 4 on 2017 Feb.2.
(A) Ground-based image taken 12 hours earlier by Clyde Foster, which was key to putting the closeup image in context.
(B) JunoCam images 105 & 106 (preliminary versions from JunoCam web site, adapted from our report on PJ4 on these web pages).
(C) JunoCam image 105: Gerald Eichstädt's later processed version (shown at half scale).