Jupiter in 2011/12: Final report up to 2012 February

Appendix 2:
The acceleration of the North Equatorial jet-stream to super-fast speeds

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Note: Speeds may be quoted both as DL1 (degrees per 30 days relative to System I, as measured), and as *u* (m/s relative to System III, referenced to latitude 7.0°N).
For our observations below, only DL1 is used. *u* = — (DL1—221) x 0.47763.
All figures for this Appendix are in the main report: Figs.22-24 and the JUPOS chart, JUPOS-NEBs.

Summary:

The major jet on the North Equatorial Belt south edge (NEBs, at 7°N) normally carries large dark formations which travel with the usual speed for this latitude ('normal speed': DL1 ~ 0 deg/mth, u ~ 105 m/s). In most apparitions since 2000 we have also detected smaller, faster features ('fast speed': DL1 ~ -30 deg/mth, u ~ 120 m/s). However, most of the large formations disappeared in 2008 and again in 2010-11, and the last remaining ones disappeared in 2011-12. In the sectors of NEBs thus vacated, smaller dark features all moved with 'super-fast' speeds (DL1 ~ -70 deg/mth, u ~ 140 m/s), which were modulated by the few 'normal' features as long as they lasted, and then accelerated further to DL1 = -70 to -95 deg/mth (u = 139-151 m/s).

This remarkable change has several profound implications for understanding the dynamics of the region. First, the NEBs has taken on the same appearance, dynamics, and speed, as the equivalent jet at 7°S (SEBn). This is further evidence that the two jets are essentially symmetrical, with an underlying jet in the range ~150-170 m/s. Secondly, the manifestation of this jet at the surface is suppressed by the presence of large slow-moving formations, which are probably Rossby waves. In the SEBn jet, there was no such formation in 2011/12; in other years there has been just one (the South Equatorial Disturbance) which partially suppresses the super-fast speed. In the NEBs jet, there are usually many such formations, which normally suppress the super-fast speeds completely, but they have disappeared in 2011/12. Thirdly, the change in the NEBs in 2008-2012 is evidently coupled to the cycles of NEB narrowing, and seems to be an historical reversion to the situation that existed before 1912.

Super-fast features, 2008 and 2010:

In 2008 July, most large formations were replaced by smaller fast projections, and in one sector, small, tenuous projections/festoons moved with average DL1 = -60 [u = 134 m/s] (range ~-45 to -66 deg/mth) -- faster than ever before observed on the NEBs. [Ref.A1]

In spring, 2009, the NEBs was still devoid of large formations and all the drifts recorded were in the fast, but not super-fast, range. This state ended dramatically in July during the NEBn expansion event, when a vigorous rift system in the NEB apparently induced the formation of many retrograding dark spots on NEBs, including large ones which developed into a regular array. However, they did not last through the next year. [Ref.A2]

By 2010 Sep., only five major dark formations remained – long low plateaux – and these too were subsiding. As the major formations diminished, a few dark features appeared with DL1 = -29 to -36 deg/mth; and then, some much faster. The first super-fast one, in July, was a small projection/festoon with DL1 = -78 [Ref.A3]. After 2010 July [our unpublished data], the last slow-moving projection in the sector L1 ~ 180-310 disappeared, leaving only small tenuous festoons. At least some of these were moving with DL1 = -75, and the trend of other points on the chart suggests that this was the dominant drift rate throughout the whole sector in Aug-Sep. Overall, from July to Dec., we obtained 9 drifts ranging from -57 to -78: mean DL1 = -68 (±8), mean lat. +7.0 (±0.2) ºN. However, from mid-Sep., more normal and slow drifts took over most longitudes again, as low blue-grey humps reappeared on NEBs, developing into substantial NEBs formations in Oct. Thus, the super-fast drifts only applied where there were no normal NEBs formations.

Super-fast features, 2011/12:

In the 2011 apparition, the disappearance of the normal NEBs formations resumed and the NEBs became completely taken over by super-fast speeds **(Fig.22 & chart: JUPOS_NEBs)**. From 2011 June to Oct., there were only 2 or 3 slow-moving features at any one time, which were small blue-grey NEBs projections with DL1 = +26, accelerating to DL1 ~ +15 to +11 in their final stages. All other tracks were super-fast: 113 tracks gave a mean DL1 = -70.6 (±14.4) deg/day. These features had the typical appearance of small dark blue-grey NEBs projections with festoons **(Figs.22&23)**; only their speed was exceptional.

Detailed study of the JUPOS chart reveals even more remarkable aspects of these speeds, summarised in **Fig.24**. The speeds were gradually accelerating during 2011, and they were modulated by the few remaining slow projections, although these were very small. New super-fast projections generally appeared on the p. (east) side of these slow projections, usually with DL1 ~ -49 (±5) deg/mth, then they accelerated or were replaced by faster-moving projections, with DL1 ~ -76 (±10) deg/mth. These accelerations were usually abrupt, and occurred ~70º p. the slow projections (range, 60-95º). Sometimes the track split at this point. In several cases, though, the super-fast projections oscillated in motion during the transition, accelerating to DL1 ~ -90 before settling down to -78; three of them performed a complete cycle of oscillation with P ~ 20-30 days.

After all the slow projections had disappeared, the super-fast projections continued to accelerate, and in 2012 Jan-Feb., had a mean DL1 = -83 deg/mth (u = -145 m/s), and maximum of -95 deg/mth (u = 151 m/s).

The latitudes for all these dark spots in 2011/12 were the same as for normal dark formations, thus:
Slow spots (n=5): 7.7ºN (±0.2, SD); Super-fast spots: 7.5ºN (<0.1, SEM);
Oscillating super-fast spots: 7.5 ºN (±0.2, SD) [analysis of JUPOS data by G. Adamoli].
For the oscillating spots, there may be a weak oscillation with latitude between 7.1—7.7ºN, in the sense that latitude is highest when relative longitude is lowest; i.e. latitude would correlate with acceleration, not speed. However we cannot be confident of the significance of this suspected variation in latitude.

Nor was there any correlation of the speed and spacing of super-fast features. Where regularly spaced groups could be identified, all groups with speeds of DL1 from -54 to -82 (u = 131 to 145 m/s) had spacing of 11-13º, while one group moving at DL1 = -45 (127 m/s) had a spacing of 8º. As we found for the chevrons on SEBn [Ref.A4], there was no general correlation.

Discussion:

Since 2008, with the disappearance of the usual large formations from large sectors of the NEBs, unprecedented super-fast speeds have been detected (~140 m/s). In 2011/12, this culminated in the complete disappearance of all large or slow-moving features, leaving only super-fast speeds with a mean of 145 m/s. The super-fast speeds (~140 m/s) are much faster than anything reported in this latitude before 2000: nothing had been reported faster than DL1 = -29, except for one spot-pair with DL1 = -50 recorded visually, and a single record from HST. There were no such speeds in most imaging data from HST or other spacecraft. But since we reported the super-fast motions in 2008 [Ref.A1], two teams have analysed HST images from that year, and confirmed that super-fast speeds (jet peak ~131-155 m/s) were widespread over large sectors [Refs.A6 & A7].

This remarkable change has several profound implications for understanding the dynamics of the region. Firstly, the NEBs has taken on the same appearance, dynamics, and speed, as the equivalent jet at 7°S (SEBn). This is further evidence that the two jets are essentially symmetrical, with potential peak speed of ~145-155 m/s at the cloud-tops.
(For the NEBs, at least, we know that the speed below the cloud-tops is even faster, as it was ~170 m/s as measured by the Galileo Probe (at one location). This speed has never been detected in spacecraft images either, except for bright spots in near-infrared (756 nm) images from Cassini [Ref.A7], which were thought to be deep clouds visible only where the upper clouds were thinned.)

Secondly, the manifestation of this jet at the surface is suppressed by the presence of coherent slow-moving formations. This is shown for the NEBs by the speed gradients seen in 2008 and 2011, the speed being slower p. (east of) the few remaining NEBs projections. It is remarkable that such small projections had such a robust effect; presumably in normal times, the typical, much larger NEBs formations suppress the super-fast speeds completely. In the SEBn jet, there was no such formation in 2011/12; in other years there has been just one (the South Equatorial Disturbance), and we have shown that it partially suppresses the super-fast speed, especially to its east [Refs.A4 & A8], just as we have now found for the NEBs formations. On both jets, these slow-moving formations are probably Rossby waves [Ref.A9; Ref.A4 & refs. therein].

Thirdly, the changes in the NEBs in 2008-2012 are evidently coupled to the cycles of NEB narrowing, and seem to be an historical reversion to the situation that existed before 1912. As we suspected in early 2012, the exceptional narrowing of the NEB in 2011/12 was indeed part of a cycle leading to a full-scale 'NEB Revival', such as used to occur in the 19th century, and especially every 3 years from 1893 to 1912 [Ref.A10, chapter 8.5]. Likewise, before 1912, the NEBs edge generally had few or no projections, except during the Revivals. As noted below, the NEB was also devoid of convective rift activity in 2011/12, and we hypothesise this was what led to the fading, and also to the disappearance of large NEBs formations, and thus to the acceleration of the jet to super-fast speeds. Such speeds were not detected a century ago because visual observations did not track the small tenuous festoons that have now revealed them. But the present analysis implies that super-fast speeds of ~140-150 m/s are a normal aspect of the quiescent state of the NEB during such cycles, just as they are of the SEBn for most of the time.

References:

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A4. Simon-Miller AA, Rogers JH, Gierasch PJ, Choi D, Allison MD, Adamoli G, Mettig H-J (2012). ‘Longitudinal variation and waves in Jupiter’s south equatorial wind jet.’ Icarus 218, 817–830. [doi:10.1016/j.icarus.2012.01.022]

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A10. Rogers JH (1995) *The Giant Planet Jupiter* (Cambridge Univ. Press, 1995)

Figures [all in main report]:

Chart JUPOS_NEBs. JUPOS chart, with tracks marked.

Fig. 22. Maps in 2011, aligned in L1 or (for closely spaced maps in Nov.) in L1 minus 2.0 deg/day to identify individual super-fast projections. The few remaining ‘normal-speed’ projections are indicated by green arrows, from the JUPOS charts; there is nothing to visibly distinguish them from the super-fast ones.

Fig. 23. Hi-res images tracking some super-fast NEBs projections in 2011.

Fig. 24. Chart of speed ranges vs time for the NEBs projections in 2011/12. For Aug-Sep., the projections are divided into those p. the few remaining slow projections (a) and those f. them (b), and a few outliers (individual values very different from most of the group) are shown separately.
