Life cycle of the North Temperate Domain and Disturbance, 2009-2012

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In 2007, a great NTBs jetstream outbreak led to revival of the NTB, repeating the cycles that occurred periodically from 1970 to 1990, and we were then able to follow the evolution of the N. Temperate domain during the subsequent years, with images of unprecedented quality and frequency. These studies revealed sequential developments which clearly had parallels in previous cycles, and may well be a standard aftermath of a great outbreak and revival. In particular a North Temperate Disturbance (NTD) developed, i.e. a persistent darkened sector of NTZ, and we were able to identify its nature and origin [see Box 1 below, especially Ref.2, whose abstract is copied in Box 2]. Here, we summarise the features of the N.Temperate domain and especially the NTD throughout its lifetime from 2009 to early 2012.

Overview of the domain:

After the spectacular revival in 2007, the NTB(S) was dark orange in 2008, and gradually faded over the next 4 years, while retaining its orange tint. By 2011/12 it was just a light fawn-tinted strip between the darker N. Tropical band and NTB(N).

The NTB(N), in contrast, revived with a remarkable wave pattern in 2008, and then developed an elaborate arrangement of sectors, which persisted from 2009-2012, although with varying boundaries and intensity. These were:
(1) An oblique sector of small-scale turbulent bright spots in the NTB (rifted region), which first appeared in 2009 – too small to have been detectable by amateurs before modern hi-res imaging.
(2) P. the rifted sector, a string of tiny dark streaks or spots rapidly prograding with the N. Temperate Current B (NTC-B; see below). These evidently represented disturbance emanating from the rifted region.
(3) Alongside and/or f. the rifted sector, several very dark streaks or longer segments of NTB(N). At 30ºN, they are presumably cyclonic belt segments. They did not last individually for more than a year, but as old ones faded, new ones often appeared nearby. The first ones were observed forming within the NTBn projections in 2008; longer, darker ones formed in 2009, and were also present in 2010. Then most of them faded away in early 2011 during solar conjunction, leaving just a pair of very dark streaks which faded in turn, although less intense dark streaks continued to appear up to early 2012 when the next cycle began. When these very dark streaks are about to fade away, they typically turn reddish; we have reported that this is typical behaviour for cyclonic dark streaks or barges just before they disappear, in other domains as well. When such a streak fades away, it sometimes turns into a light, pale orange strip with a distinct rim.
(4) Also alongside and f. the rifted sector, the darkened sector of NTZ which we call the N. Temperate Disturbance (NTD). We have shown that it arises because the rifted sector disturbs the retrograding NTBn jet, and these disturbances recirculate into the NTZ at various points, tracking dark material into the NTZ. The extent of the NTD varies according to the extent and activity of the rifted sector, and perhaps randomness of recirculation.

These developments have been described in detail in our interim reports [refs. in Box 1], and particularly in ref.2 (2009) [abstract in Box 2], in which we expounded a detailed model of the dynamics of the NTD. This model was summarised in a diagram in ref.2, which is reproduced here as Fig.A3. This model has been thoroughly confirmed by subsequent observations, both of the present NTD in 2010 and 2011/12, and also in a subsequent one that is being observed in 2013-2015 [ref.5]. It is also consistent with the sparse hi-res images available from previous cycles [ref.4]. Therefore, the reader is referred to ref.2 for a full explanation.

Speeds in the domain:

A) N. Temperate Current A (NTC-A) (29-33ºN).
This is the normal slow current for the domain, with historical mean speed DL2 = +17 (±4) deg/mth [ref.7]. From 2008-2012, the drift rates for most features in the domain ranged from +13 to +31 deg/mth. Many features had speeds around +20 (at the upper end of the historical NTC-A range), but there were also some with more positive (retrograding) speeds up to +31. The significance of the latter group is unclear; they were not any single class of feature; they were more rapidly retrograding than the historical NTC, but not up to the full speed of the NTBn jet measured by spacecraft. As in other domains, the current covers both the belt and the zone, and the speeds do depend on latitude but less steeply than in the ZWP [see our ZDPs in refs. 2 & 3 & our 2011/12 report].

B) N. Temperate Current B (NTC-B) (~28ºN).
This denotes rapidly prograding speeds in the NTB which have historically appeared in years following NTBs jet outbreaks: mean speed DL2 ~ -112 (±23) deg/mth [ref.7]. Small dark spots in this speed range duly reappeared in 2009-2012, and we find that they comprise disturbance generated from rift activity in the NTB. Preceding the rifted region and NTD, in 2009, v-hi-res maps showed narrow, dark blue-grey streaks and spots rapidly prograding within the NTB. They were too ill-defined to be tracked by JUPOS, but the maps implied a speed of DL2 ~ -70 to -80 deg/mth, i.e. NTC-B. These dark spots were tracked routinely from 2010 onwards: in 2010, DL2 = -62 to -72 deg/mth; in 2011, -45 to -66 deg/mth.

C) NTBn retrograde jet (31ºN).
This is the retrograde jet of the domain, hardly ever detected from Earth, and variable according to spacecraft. Several spots with the full speed of the NTBn retrograde jet have been detected, mainly within the NTD: several in 2009 with DL2 = +39 and +72 and (briefly) +97!; and three in 2010, with DL2 = +52 (June) and +75 (July) and +56 (Nov). We believe these represent disturbance of the jet by the rifted region. At least 5 of these 6 spots then recirculated into the NTZ, attaining prograding drifts.

D) NNTBs prograde jet (35ºN).
This jet, forming the northern boundary of the domain, resumed its activity of carrying dark spots from summer 2009, and continued to 2012 Feb, when the last few spots disappeared.

The evidence indicates that the NTD does not involve major alteration of the ZDP or ZWP. Spots inside and outside the NTD follow the same ZDP, which agrees well with the Voyager ZWP for speeds faster than the NTC-A [see ZDPs in refs.2 & 3 & our 2011/12 report]. (There were a few exceptions in 2009, prograding NTZ spots which drifted exceptionally fast for their latitude.) All the recirculating spots from the NTBn jet followed the normal ZDP. The fact that prograding NNTBs jet spots sometimes disappear at the NTD represents the enhanced tendency to recirculate in this region, and the presence of vortices in the NTZ which disrupt the jet spots.

Summaries of previous reports on the N.Temp. domain, 2008-2012:

By 2008, both components of the NTB had revived, with pale reddish colour between them and strong orange colour on the NTB(S). The NTB(N) was reviving as a sinuous grey band, faint at the start of the year but quite strong by the summer. Its remarkable wavy pattern became conspicuous as the belt darkened, and dark grey streaks or barges were seen forming in some of the waves. The wave-like pattern, all around the circumference, had DL2 = +21 to +31. These NTBn projections were at lats.30.5 to 32ºN, so they probably coincided with the NTBn retrograding jet.

The extreme waviness in the NTBn latitude was actually present, at low contrast, in Voyager and HST images before the NTBs jet outbreaks, but was made obvious by the revival of dark material in the NTB.

Up to 2008 Nov., the NTBn was still obviously wavy and had some long, very dark grey streaks along it, but the NTZ was still generally clear and white.

In 2009, the remarkable pattern of wave-like projections persisted, with cyclonic dark grey streaks and sometimes red spots, forming in the northward-pointing projections. The dark streaks (at 30ºN) varied over months but from July to Sep. there were four: two in the NTD, and two very dark ones (Streaks 3 and 4) elsewhere. Streak 3 became fainter and redder, then disappeared suddenly in early Nov. Speeds were typical NTC, ranging from DL2 ~ +14 to +26 deg/mth for most features. But speeds varied from DL2 ~ -23 to +30 in the most complex region of the NTD (see below).

The NTD was a sector of the NTZ, ~100º long, which was largely occupied by many dark streaks, some in NTZ as well as on NTBn, as well as general shading. It appeared as though some of the projections and streaks on the NTBn edge had spread dark disturbance right across the NTZ. The NTD had quite well-defined ends, drifting with the NTC. From the best observations, in 2009 July-Sep., we could divide the NTD into two parts:

---*P. sector*: This consisted of two long dark streaks at 30ºN (DL2 ~ +23 deg/mth), with small bright spots in NTB alongside them, i.e. small-scale 'rifting' representing intense cyclonic turbulence in the belt.

---*F. sector*: This sector revealed several unusual motions:

a) A dark spot with DL2 = +72, the full speed of the retrograding NTBn jet, at lat.~30.5ºN.

b) Several unusual dark anticyclonic spots were appearing in the NTZ, all at lats. 32-33ºN although they were moving with a wide range of speeds, mostly in accordance with the ZWP. At least some of them resulted from recirculation of spots from the retrograding NTBn jetstream when they encountered a dark NTBn projection. These spots underwent various encounters and mergers until they encountered another dark feature and then disappeared.

c) A volley of NNTBs jetstream spots. The NNTBs jetstream was not deflected and its spots entered the NTD, but they were then intercepted and eliminated by individual spots in the NTZ.

The boundaries of the NTD were not fixed, but could vary according to changes in NTB rifting. In 2009 Oct-Nov., some distance following the NTD, new NTB mini-rifts apparently generated small dark NTBn spots, which then merged in pairs and recirculated into the NTZ at the projecting p. end of Streak 3 (which was fading and reddened). During Nov., the f. end of the NTD extended up to this position, as this sector of NTZ became cluttered with little dark spots. Earlier, in 2009 May-June, there had been a 'mini-NTD' at other longitudes, generated from a mini-rift in NTB. These events imply that the NTD was not necessarily unique, but that similar phenomena could arise in various sectors of the N.Temp. region (as would be seen again in 2011/12).

In 2010, the picture was initially much as in 2009. There were still dark spots prograding in mid-NTB with the NTC-B, and there were numerous spots on the NNTBs jetstream. Otherwise, almost all features in the NTB and NTZ were moving with the NTC-A, DL2 ~ +18. They included some very dark streaks of NTB(N): dark grey ones around the p. end of the NTD, and a long, extremely dark brown one within the NTD, and several shorter ones at higher longitudes. One of these (outside the NTD) was fading in 2011 Jan.

The NTD still existed up to 2010 August, and at its p. end there was still active though small-scale rifting in the NTB. One spot was seen retrograding in the NTBn jetstream, but otherwise there was no sign of the abnormal prograding and retrograding motions previously recorded in the NTD. Perhaps as a consequence, the NTD had largely cleared by 2010 Sep.

Only two recirculation events in NTZ were observed in 2010, both outside the NTD. One began with a pair of small dark spots which merged, in 2010 May, forming a dark spot which oscillated in speed and latitude, until it contacted a NTBn projection in July-August and reversed its drift from retrograde to prograde. Later, in 2010 Nov., one spot recirculated from the NTBn jet to prograde in the NTZ.

In 2011/12, most of NTB was pale, and the only conspicuous features were a pair of very dark brown streaks on NTB(N), which became redder in August and faded away in Sep. The rifted sector seems to have been quite short and quiescent in 2011 July-August, with no remaining NTD; but it was much more extensive from Sep. to Jan.(at least), and a short NTD reappeared near its f. end. In Sep., after the rifting revived, two grey spots recirculated in the NTZ at the p. end of the dark brown streaks (just as in 2009), and this was where the NTD revived in Nov. So although NTB rifting is small-scale and the recirculations are infrequent, their co-occurrence supports our hypothesis that these are the events which lead to the appearance of a NTD.

NTD: Discussion:

In summary, the NTD is an anomalous sector comprising NTB rifts (in its p. part) and NTZ spots and shading (in its f. part). The source of the NTD is a region of cyclonic turbulence, manifested as small-scale rifting in the NTB, which produces disturbance on the NTBn jet, which leads to formation of vortices in the NTZ.

The ZDP is not substantially altered within the NTD, and the adjacent jets are not deflected away from it. Like earlier examples, this NTD intercepted some NNTBs jetstream spots, but only because they interacted with NTZ spots or projections generated within the Disturbance. However, there was repeated eddying and recirculation of spots within the NTD, which seems to be how it develops.

The NTD turns out to be similar, in essence, to phenomena that are also observed in the other domains on the planet, all of which involve cyclonic rifting in the belt which leads to disturbance on the retrograde jet which leads to dark anticyclonic eddying in the zone. In a NEB broadening event, NEB rifting leads to appearance of dark ovals in the NTropZ. In the SEB, a mid-SEB outbreak (e.g. 1979) or Revival outbreak (e.g. 2007) generates anticyclonic vortices on the SEBs jet which can recirculate in a S. Tropical Disturbance. In the S. Temperate domain, we see the closest parallel, as a turbulent dark STB segment generates retrograding dark spots which can merge to form an anticyclonic oval [ref.6], so a dark STB segment and its 'tail' are analogous to a NTD. We have also suggested that similar processes occur in the higher-latitude S2 and S3 domains, although on a smaller scale which is not fully resolved by present observations [ref.6].

This is the first time that it has been possible to follow the evolution of the NTB at high resolution after a NTBs jet outbreak. We find that it evolved systematically over several years,

so that previously unconnected phenomena can all be seen as sequels of the great outbreak in 2007 [ref.2]. These included the formation of dark spots and streaks within the NTBn projections in 2008, which was comparable to the formation of barges in the NEBn after a NEB broadening event, indicating large-scale eddying due to destabilisation of the retrograding jet. This process developed even further in 2009, generating the very dark streaks in NTBn, and the NTD. This sequence appears to have happened before. In particular the NTBs jet outbreak in 1970 was followed by the NTD of 1972-75, and the suspected outbreak in 1985 was followed by very dark NTBn streaks and then the NTD of 1988-92. The same phenomena have also been observed again after the latest NTBs jet outbreak in 2012 [ref.5]. We therefore believe that this is a characteristic cycle of atmospheric changes following such outbreaks.

BOX 1: REFERENCES:

Text from our Reference Article page at
http://www.britastro.org/jupiter/reference.htm

N.Temperate Disturbance:
This is a darkening of a sector of the NTZ, which can last for several years. Some NTDs have developed ~2-3 years after NTBs super-fast jetstream outbreaks, as happened in 2009:

1) 'Jupiter in 2009: Interim Report, with new insights into the NTZ disturbance, NEB expansion, and SEB fading.'
http://www.britastro.org/jupiter/2009report07.htm

2) 'Jupiter's North Temperate Region in 2009: The nature of the North Temperate Disturbance.'
--Adamoli G. & Rogers JH: http://www.britastro.org/jupiter/2009report08.htm *[Abstract below]*

3) 'North Temperate Disturbance (NTD) in 2010, and a general conjecture about the behaviour of anticyclonic dark spots'
in: 'Jupiter in 2010: Interim report: Northern hemisphere': Appendix
http://www.britastro.org/jupiter/2010report09.htm

4) 'North Temperate Disturbances: Is NTB rifting necessary?'
--Rogers J (2010): posted here. [A historical survey showing that previous N.Temperate Disturbances have always been associated with 'rifts' in the NTB if photographed at sufficient resolution.]

Additional references:

5) Our interim reports, 2013/14 nos.4 & 6, and 2014/15 no.3, at:
http://www.britastro.org/jupiter/section_reports.htm

6) Our long-term reports on the S1 (S. Temperate) domain and the S2-S5 domains, at:
http://www.britastro.org/jupiter/reference.htm

7) Rogers J.H., *The Giant Planet Jupiter*; Cambridge University Press (1995).

BOX 2:
Report 2009 no.8 [2010 July]:
Jupiter's North Temperate Region in 2009: The nature of the North Temperate Disturbance
by Gianluigi Adamoli (JUPOS team) & John Rogers (BAA)

Summary
The N. Temperate domain in 2009 showed many striking features, including an array of projections from NTBn, some of which developed very dark streaks inside them, and unusual dark spots in the NTZ. These features have been analysed from the complete JUPOS database. Most features followed the normal currents in spite of their unusual appearance. However some of the NTZ spots moved unusually fast, especially in a darkened sector called the N. Temperate Disturbance (NTD). The NTD was analysed in detail, providing the first full account of its dynamics. In its p. half, there were dark cyclonic streaks and bright 'rifts' displaying intense small-scale turbulence. In its f. half, unusual dark anticyclonic spots were appearing in the NTZ and moving with a wide range of speeds. At least some of these spots resulted from recirculation of spots from the retrograding NTBn jetstream. The NNTBs jetstream was not deflected and its spots entered the NTD, but they were then intercepted and eliminated by individual spots in the NTZ. We infer that the NTD is created by conjunction of two phenomena: convective 'rifting' in the NTB, which defines its p. end and leads to disturbance of the retrograding NTBn jetstream; and recirculation at a NTBn projection, which defines the f. end and generates dark spots and streaks in the NTZ. This is the most detailed analysis yet of a suite of phenomena that have occurred on previous occasions after energetic NTB outbreaks like that of 2007.

[9 pp. & 6 Figures]

FIGURES:

Fig.A1: JUPOS chart 2009-2012 in L2, labelled, compiled from our published apparition charts.

Fig.A2: JUPOS from 2008-2012, with L' = L2 + 1.0 deg/day, unlabelled.

Fig.A3: Diagram of the NTD and its dynamics as described in our reports.

Fig.A4: Set of maps showing the N. Temperate domain from 2008-2012, with the rifted region and the NTD marked.