The opposition of Mars, 2010: Part I

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A report of the Mars Section (Director: R. J. McKim)

This report summarises over 8,000 observations by 149 observers between 2009 March and 2010 September, covering martian northern late autumn to winter, spring and early summer (Ls= 232–156°). Part I discusses dust storms and albedo features. The apparition was marked by a sequence of well-observed small dust storms in the northern hemisphere. Activity from the N. polar hood on 2009 Aug 22 produced a brief cross-equatorial storm in the longitude of *Nilokeras*. Another storm briefly veiled *Casius–Utopia* in part, as events from 2008 and earlier had done. Another veiled the N. polar cap and its borders around Dec 20 in the longitudes of *Propontis*. The next storm fortuitously commenced close to opposition (2010 Jan 29), when fronts from both *Baltia* and from the opposite hemisphere impinged upon the polar cap, enabling a detailed groundbased study (and offering historical parallels). There was no planet-encircling storm during the apparition. Certain developments in the albedo markings persisted, such as the broad and dark *Mare Serpentis* which extended across SE *Noachis*, and a streaky marking crossing *Aethiopis* resulting from the 2007 global event, but *Margaritifer Sinus* and *Solis Lacus* were already returning to normal. The concluding Part II of the report will deal with white clouds and the polar regions.

Introduction

Second in the present series of aphelic encounters, the planet was undergoing mid-northern spring at its closest approach. Opposition occurred on 2010 Jan 29 at Ls= 44°, when Mars lay in Cancer with a favourable declination of +22°, with the latitude of the sub-Earth point (or of the centre of the disk, D_e) equal to +14.7°. The planet was closest on Jan 27, at a maximum disk diameter (D) of only 14.1 arcsec. D remained above 6" from 2009 Sep 9 till 2010 Jun 1. Key seasonal dates are given in Table 1.

The value of D_e varied from –25° in 2009 Mar to 0.0° on Aug 15, then increased northwards to a maximum of +18.8° in early Dec, falling to +12.1° by 2010 late Feb, and rising to +26° in July.

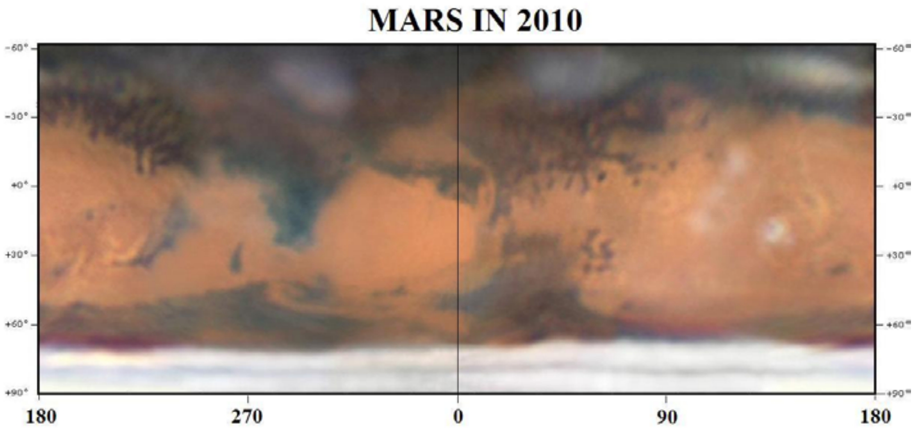

Figure 1A. Map of Mars from his best near-opposition images with 355mm SCT and Lumenera SkyNyx 2-0M camera, 2010 Jan–Mar, *Damian Peach*. Simple cylindrical projection, with latitude and longitude indicated.

Compared with 2007–'08, the winter of 2009–'10 was bitterly cold throughout Northern Europe and America, frequently bringing heavy snowfall and very low temperatures, particularly around Mars' opposition. The Director often had to trudge through deep snow to reach his observatory in 2010 Jan–Feb. Nevertheless, with 149 contributing observers (Table 2) there were few gaps in our coverage, and detailed analysis of the results has again proved to be very time-consuming.

The first records comprised images for 2009 March 23 (Ls= 232°, D= 4.2") by Tomio Akutsu, and the final record was a disk drawing by Gianluigi Adamoli dated 2010 Sep 29 (Ls= 156°, D= 4.2"), covering 79% of a martian year. There were 8,258 observations: 7,474 images and 784 drawings. Days per month logged (actual/possible) were: 2009 Mar 5/31, Apr 7/30, May 9/31, Jun 9/30, Jul 13/31, Aug 28/31, Sep 29/30, Oct 30/31, Nov 30/30, Dec 31/31, 2010 Jan 31/31, Feb 28/28, Mar 31/31, Apr 30/30, May 31/31, Jun 28/30, Jul 16/31, Aug 10/31, Sep 3/30.

Table 1. Physical details of the 2010 apparition

Solar conjunction	Ls= 169°	2008 Dec 5
N. autumn/S. spring equinox	Ls= 180°	2008 Dec 25
Perihelion	Ls= 250°	2009 Apr 19
N. winter/S. summer solstice	Ls= 270°	2009 May 21
N. spring/S. autumn equinox	Ls= 0°	2009 Oct 26
Opposition	Ls= 44°	2010 Jan 29
Aphelion	Ls= 70°	2010 Mar 28
N. summer/S. winter solstice	Ls= 90°	2010 May 13
N. autumn/S. spring equinox	Ls= 180°	2010 Nov 12
Solar conjunction	Ls= 230°	2011 Feb 4

The state of contemporary image-processing at this epoch was usefully reviewed by Sean Walker.[1] Long series of images were provided by Akutsu, Maxson, Morita, Peach, Poupeau, Tasselli and Yunoki. Abel, Adachi, Adamoli, Bailey, Biver, Grego, Macsymowicz, Smet and the Director each contributed 30 or more drawings, and of the latter group Adamoli, Bailey, Biver and the Director also took digital images. We much regret the deaths of contributors Peter Grego, Willem Kivits and Dr Donald Parker since the period covered by this report.

The Director previously issued Interim Reports[2,3] and e-Bulletins.[4] Further images were published in an early review of 2011–'12.[5] The ALPO,[6] the International Marswatch,[7] JALPON,[8] OAA,[9] and UAI[10] all maintained online image collections; the ALPO published some observations[6] while the OAA[9] produced its regular bulletins. Schmude has discussed his whole-disk photometric brightness measurements of the planet.[11]

NASA's twin rovers *Spirit* and *Opportunity*[12] remained active

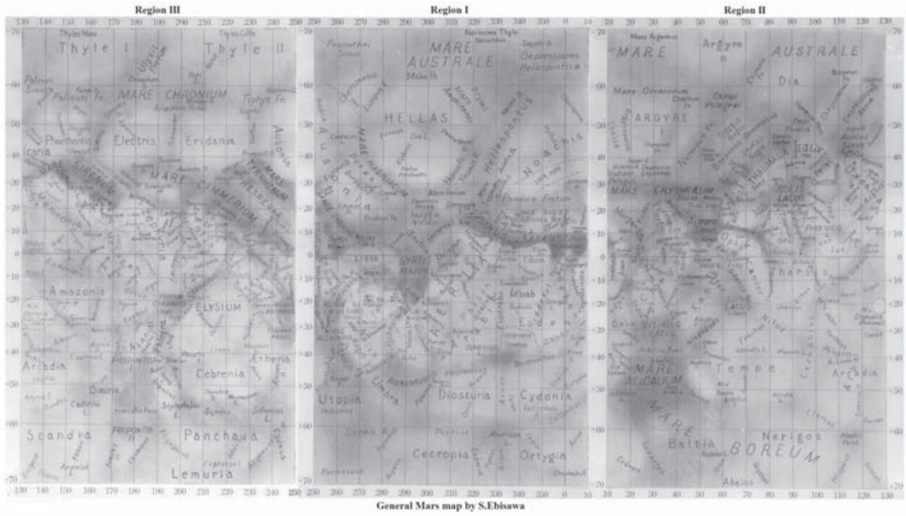

Figure 1B. Nomenclature adopted by the Mars Section shown upon this reproduction of S. Ebisawa's Mars chart.[31] Note: All illustrations have south uppermost.

more like its typical appearance during 1986–2005, but not fully recovered, and the transient double streak across *Aethiopis* remained visible. *Nepenthes* remained invisible, and the configuration of the markings around *Nodus Alcyonius* (stable since 1982) had not altered. *Ismenius Lacus* remained small, with *Propontis I* much less marked than upon the Ebisawa map (Figure 1B).

Martian colours

McKim during 2010 Jan–Apr generally found the S. hemisphere markings and *Syrtis Major* a dark blue or blue-grey. *Mare Acidalium*, *Aetheria* and *Casius–Utopia* (all in the N. hemisphere) often appeared grey,

on the surface, but after 2010 *Spirit* fell silent, never to be revived. *Mars Reconnaissance Orbiter* (MRO)[13] continued to provide valuable data. In particular, its Thermal Emission Imaging System (THEMIS) and Mars Colour Imager (MARCI) data will be cited in this report. Yet more spacecraft were launched towards Mars late in 2011, and of these the *Curiosity* rover would prove to be spectacularly successful.[14] A comprehensive list of space missions up to 2013 is available elsewhere.[15] Here we refer only to spacecraft data strictly relevant to our programme.

The present apparition was seasonally similar to the following oppositions monitored by the Mars Section since 1892: 1995 (Ls= 58°),[16] 1978 (37°),[17] 1963 (50°),[18] 1946 (29°),[19] 1931 (Ls= 42°; the closest match),[2,20] 1916 (56°)[21] and 1899 (35°).[22]

Notes about observing the current apparition were also published by others.[23–25] Since publication of our previous reports on 2005–'06[26] and 2007–'08,[27] several relevant papers have appeared. In particular, Hinson & Wang[28] have reported on the 2005 Jan–Aug MGS observations of N. hemisphere dust storms, and Wang & Richardson discuss the evolution of large dust storms during 1999–2011, whilst Thansen[29] and Thomas[30] further discussed the S. polar phenomenon that involves the venting of dust and CO_2 onto the spring cap.

This analysis is in continuation of the BAA report for 2007–'08.[27] As usual we mostly use the telescopic nomenclature of S. Ebisawa, whose map is reproduced for reference in Figure 1B.[31] We use CM(L) to mean Central Meridian (Longitude), λ to denote the actual longitude of a marking and Ls for the areocentric longitude of Mars in its orbit (commencing at Ls= 0°, the N. Spring Equinox, with each season spanning 90°).

Surface features

General

Maps were made by Abel,[25] Kumamori (Part II, Figure 11), M. R. Lewis[3] and Peach (Figure 1A). Animated rotating globes were constructed by Barry and Peach. Here we concentrate upon special features and significant changes, rather than repeating detailed past descriptions.

The planet's albedo markings were still returning to normal following the 2007 global dust storm.[27] The streaky post-storm aspect of *Syrtis Major* and the very faded appearance of *Margaritifer Sinus* had now disappeared, as these areas returned to normal. The broad and dark *Mare Serpentis* still invaded the SE part of *Noachis*, with *Pandorae Fretum* still absent. *Solis Lacus* was now

brown or reddish-brown. Minami made similar notes: during 2009 Oct–2010 Jan the S. markings generally appeared dark blue. *Margaritifer Sinus* in early 2009 Nov looked bluish, and it contained a sky blue patch on 2010 Jan 10 (the latter he attributed to an opposition effect). *Sinus Sabaeus* (2009 Dec) was dark bluish (or greenish). In the north, Minami saw *Mare Acidalium–Nilokeras* (2009 Oct–Dec) to be brown in general, but its E. half looked reddish on Dec 12; *Utopia* (2010 Jan) appeared brownish. Abel also saw *Acidalium* and *Nilokeras* as brown, and further described *Maria Cimmerium* and *Sirenum* as grey. Near opposition Giuntoli saw *Syrtis Major*, *Mare Cimmerium* and *Mare Erythraeum* bluish-grey in contrast to the brown tint of *Mare Acidalium*.

We describe the incidence of the so-called *Syrtis* Blue Cloud in Part II: the presence of equatorial cloud influences the colour intensity of the *Syrtis*, but it can affect other markings too. For example the *Aetheria* secular darkening was also rendered bluish by diurnal cloud presence on the morning side to S. Walker on 2010 Apr 3, likewise *Niliacus Lacus* to Morita on Jun 16, and the morning *Niliacus Lacus* to Morita on Jul 21.

Phase-dependent markings

Since the 1990s we sometimes remarked that half-tones around *Cerberus*, the apparent linear streak N. of *Maria Sirenum* and *Cimmerium* (unofficially called *Valhalla* by the ALPO) and another streak N. of *Sinus Sabaeus*, as well as *Nilosyrtis*, *etc*., were best seen in the months well removed from opposition, seemingly on account of greater surface roughness. This is also the case with *Olympus Mons* and the *Tharsis Montes*, at least when these are visible upon mid-disk as halftones and not covered by cloud. Such again proved to be the case in 2009–'10: thus *Valhalla* and the streak N. of *Sabaeus* were well seen in 2009 Aug–Oct, *etc*. We can add *Phlegra*, the E. boundary of *Elysium*, to the list, while Minami further adds *Nilokeras*, which was very dark at the evening terminator in Oct but fainter in Jan.

Real changes in markings since previous oppositions are discussed in the following text.

Region I: long. 250–010°

See Figures 1A, 2 and 3 particularly. *Hellas* and environs looked normal. Following dust activity in 2009 Mar–Apr (see later), and with better resolution, *Peneus* and *Zea Lacus* on the basin floor were observed from late Jun till late Sep, after which the value of D_e and white cloud hindered their visibility. Diurnal cloud activity over *Hellas* was seasonally normal. *Hellas* became very bright late in the apparition, when ground frost covered its floor (2010 Apr onwards).

As in 2007, *Trinacria* (*Ausonia Borealis*) remained dull. *Mare Tyrrhenum* was normal. The dark band extending south from *Mare Serpentis* (which had not been much affected by the 2007 storm) and crossing part of *Noachis* diagonally persisted throughout. *Yaonis Fretum* was distinct from *Mare Serpentis* and formed a dark W. border to *Hellas*. As late as 2010 Sep 10 Adamoli found *Mare Serpentis* still dark and crossing *Noachis*, and no trace of *Pandorae Fretum*.

Syrtis Major appeared normally dark again having recovered its form of 1982–2006: it had been irregularly faded (particularly on the E. side) by fallout from the 2007 global storm. To its southwest was the customary dark spot within the *Huygens* crater.

The best images showed that the southern part of the long-invisible *Nepenthes*, a curved streak that once connected *Moeris Lacus* at the *p*. edge of *Syrtis Major* to *Casius*, had become very faintly and diffusely visible in its southern part only, running NE from the tip of the former, particularly to D. C. Parker on Dec 8 and to Casquinha, Feb 9. But this was apparently just another phase-dependent effect, for this S. part of the marking was invisible around opposition. Central *Nepenthes* was always totally absent south of *Nodus Alcyonius* (which marks its N. end). *Nodus Alcyonius* was teardrop-shaped, drawn out further to the south than in 2007. *Nilosyrtis* was faintly visible. *Casius–Utopia* and other northern markings looked little different from 2008.

As in 2007 *Ismenius Lacus* remained small, and visually inconspicuous. *Deuteronilus*, however, was as easy to see as usual.

Region II: long. 010–130°

See Figures 1A, 2 and 4 in particular. By 2009 May, *Mare Erythraeum* and *Margaritifer Sinus* could be seen to have already recovered their normal darkness after dust deposition during the last apparition.

By 2009 Jun it could already be seen that the *Solis Lacus*, whose albedo pattern and orientation had been altered by the 2007 global dust storm, was starting to return to its typical aspect, with an E–W orientation. As early as Oct 18 Flanagan had resolved several nuclei, but the NE part had not yet dark-

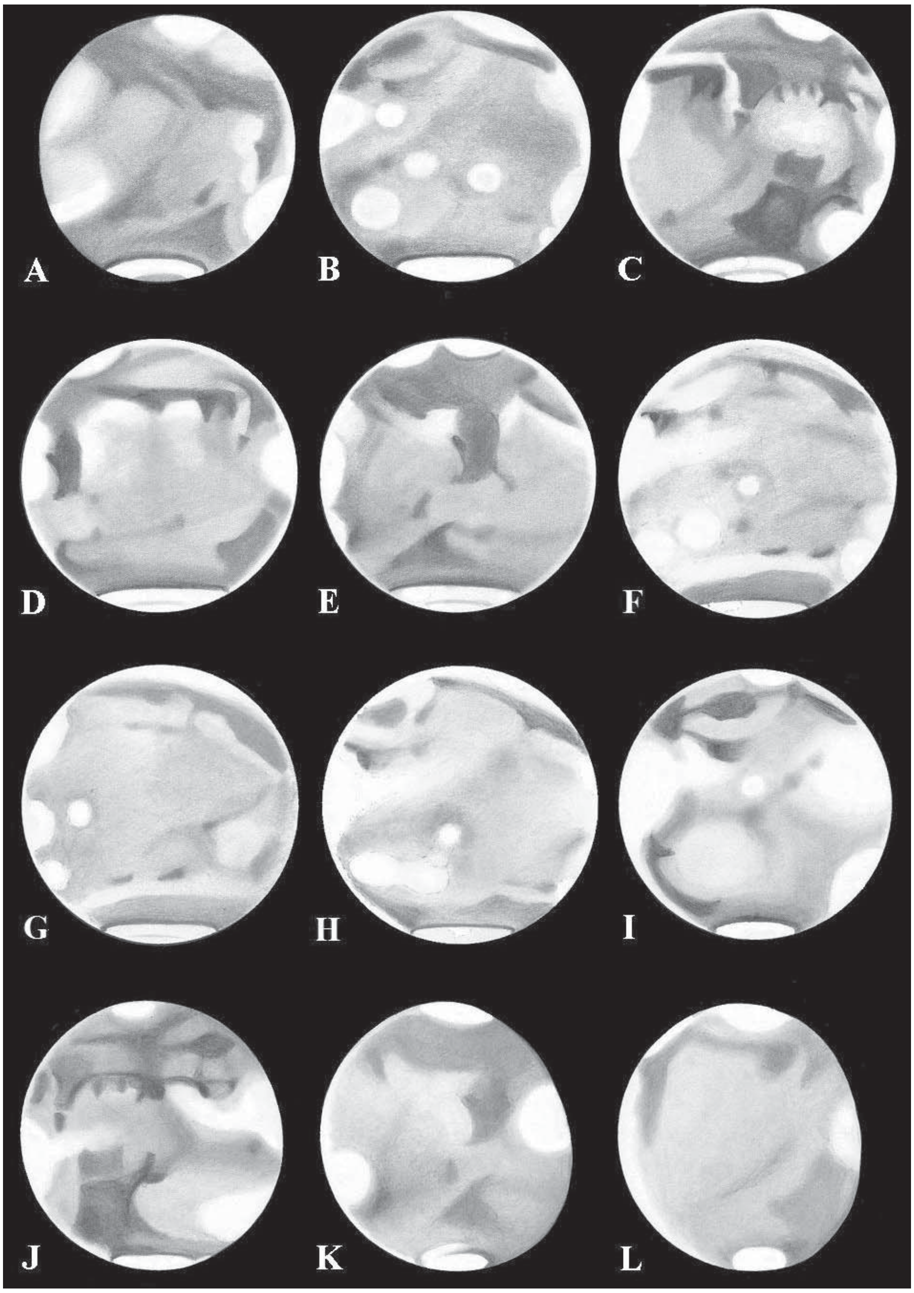

Figure 2. Drawings by R. J. McKim with a 410mm DK Cass., ×265, ×410, integrated light and/or W21 orange filter.
First row: **(A)** 2010 Jan 3, 21h 55m, CML= 236°. *Aethiopis* albedo streak appears double; a.m. and p.m. clouds. *Syrtis* Blue Cloud effect.
(B) 2010 Jan 17, 22h 20m, CML= 119°. Some orographic clouds including *Olympus Mons*.
(C) 2010 Jan 26, 21h 00m, CML= 021°. Compare with the writer's near-simultaneous webcam image in Figure 4. NPC bright spot, as well as the annular rift (also A, D, E, G); fine southern *Chryse* details; very bright *Argyre*.
Second row: **(D)** 2010 Jan 31, 20h 45m, CML= 334°. *Pandorae Fretum* absent; *Ismenius Lacus* small; the *Syrtis* Blue Cloud effect was evident.
(E) 2010 Feb 5, 20h 15m, CML= 283°. Note *Nodus Alcyonius* and the *Aetheria–Aetheria* secular dark markings. The longitude of *Olympia* is bright within the NPC *p*. the CM.
(F) 2010 Feb 19, 19h 05m, CML= 142°. *Bathys* (also in H, I); *Tharsis Montes* and *Olympus Mons* clouds (see also G, H); partial ECB on *p*. side.
Third row: **(G)** 2010 Feb 19, 21h 20m, CML= 175°. *Propontis* and *Trivium Charontis* both small.
(H) 2010 Feb 20, 18h 10m, CML= 120°. Small details *f*. *Solis Lacus* including *Gallinaria Silva* and *Phasis*. Orographic clouds at *Alba Patera* and *Ascraeus Mons*. NPC bright spot.
(I) 2010 Feb 26, 20h 45m, CML= 104°. *Solis Lacus* at the CM has normal orientation and shape. Cloud at *Ascraeus Mons*. The other *Tharsis Montes* show as weak patches amidst extensive a.m. cloud.
Fourth row: **(J)** 2010 Mar 5, 21h 50m, CML= 057°. *Ascraeus Mons* is a dark patch amidst morning *Tharsis* cloud. *Hyperboreus Lacus* at the NPC border. In I and J the ECB is nearly complete.
(K) 2010 Apr 26, 20h 35m, CML= 275°. *Olympia* is separated from the NPC (D= 7.5").
(L) 2010 May 27, 21h 05m, CML= 345°. *Hyperboreus Lacus* on *f*. edge of NPC (D= 6.1").

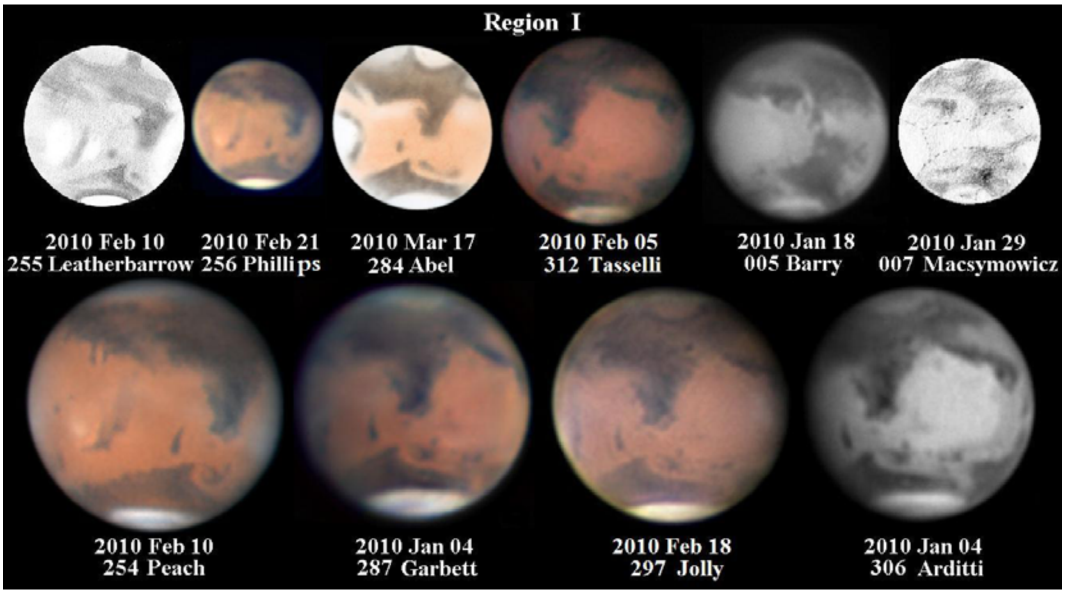

Figure 3. ***Region I: longs. 250–010°***
Drawings and images by Abel (203mm refl., ×312), Arditti (red filter, Lumenera SkyNyx 2-0M camera), Barry (IR 807+ nm filter, DMK 21AU04.AS), Garbett (SkyNyx 2-0M), Jolly (SkyNyx 2-0M), Leatherbarrow (×261), Macsymowicz (150mm OG, ×281, W56 filter), Peach (SkyNyx 2-0M), Phillips (SkyNyx colour) and Tasselli (DMK F04AS). Date and CML are indicated in this and subsequent figures.

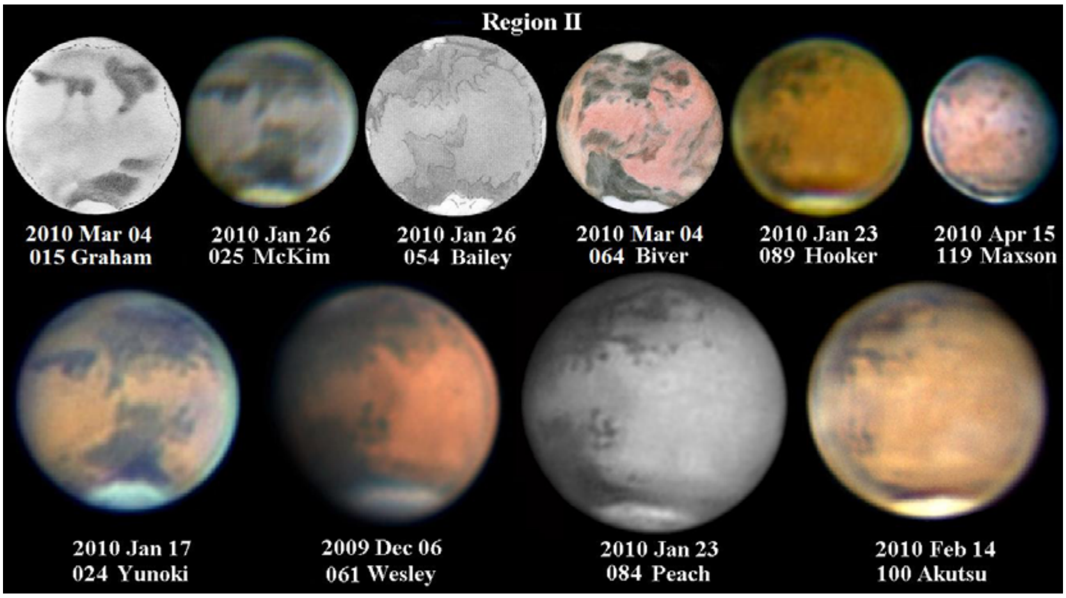

Figure 4. ***Region II: longs. 010-130°***
Drawings and images by Akutsu (DMK 21AU04 camera), Bailey (composite digital camera image with eyepiece drawing, ×400), Biver (380mm OG, ×632), Graham (230mm MKT, ×310, W21 orange filter), Hooker (DMK 21AU04.AS), McKim (Celestron NexImage), Maxson (Lumenera SkyNyx), Peach (red filter, SkyNyx 2-0M), Wesley (Dragonfly 2 camera) and Yunoki (DMK 21AF04).

ened to its 2005 boundary by the end of the apparition, nor had the two little spots on the S. edge reappeared.

The surroundings of *Solis Lacus* also showed some changes. The dark band *Nectar* on its eastern edge had been faded in its N. part by dust, and had not yet returned to normal. To the S. and SW respectively, the dark spot *Ambrosia Lacus* and the streak *Bathys*, both originating with the 2007 storm, remained conspicuous. The *Phasis* streak (and the little dark patch *Gallinaria Silva*) was similar to its previous appearance. A thin streak ran west from *Solis Lacus* to *Gallinaria Silva*.

Seasonal cloud activity over the *Tharsis Montes* and *Olympus Mons* was normal (Part II). Red light images near local noon at opposition show the large, circular caldera of the latter well, with some albedo variation across it and a light spot marking the summit: see in particular Casquinha's work on Jan 20 (Figure 5). Not long after opposition, the volcanoes began to show up as dark patches against a sea of morning cloud: see Part II. (As in recent reports we discussed *Olympus Mons* together with the *Tharsis Montes* because its longitude was marked as 130° on the old IAU map, though it is actually within Region III.)

Argyre was well seen, and the white cloud activity there is described in Part II.

As ever, the *Mare Acidalium–Niliacus Lacus–Nilokeras* complex was large, dark and complex, and very much like the 2007 map. By 2010 Mar the NPC had retreated far enough to uncover the dark area *Hyperboreus Lacus* adjacent to the N. polar collar.

Region III: long. 130–250°

See Figures 1A, 2 and 5 in particular. By the start of the apparition *Mare Sirenum* had largely regained its form prior to the 2007 global storm, though this was by no means the classical contour, for the *Mare* still ended on the west at $\lambda \sim 160^{o}$. *Mare Cimmerium* and its surroundings were similar in form to 2005.

Since the previous opposition a small yellowish streak of dust fallout running N–S became visible upon the NW corner of *Elysium*. It was visible in the very best images, probably as early as 2009 Aug, and as late as 2010 May. There was a hint of an opposition brightening in Flanagan's images of Jan 22, seven days before opposition. Given the lack of an encircling storm over the next few oppositions, this little patch would remain a permanent fixture up to and beyond the time of writing (2016 Sep), and at the 2016 opposition, with a lower value of D_e bringing it closer to the subsolar point, it would show a more pronounced opposition brightening. *Elysium Mons* is mentioned in Part II.

The most conspicuous marking to border *Elysium* was the long-running *Aetheria* dark patch, though still faded on the NW after the 2007 storm. The linear, double dark streak running from the S. tip of the latter across *Aethiopis* towards *Mare Cimmerium* (also caused by the 2007 storm) persisted. Compared to 2008 the latter feature had weakened and now consisted only of small isolated fragments at high resolution. Visually, McKim again saw the *Aethiopis* streak as apparently double. *Trivium Charontis* was still a tiny dark area compared with the classical maps, and *Cerberus* was all but absent.

Propontis I was neither large nor conspicuous, and it no longer had the double aspect of 2005 and 2007, as the eastern component had faded out: a significant inter-apparitional change.

Dust storms

Introduction

We would not have expected to have seen any major event in 2009–'10 except during the very early months. The season near opposition favoured smaller northern hemisphere events associated with north polar hood activity or with the retreat of the NPC.

A classical southern Regional dust storm, 2009 March–April

A regional dust storm, whose origin was deduced from the enhanced temperatures recorded by Mars Climate Sounder (an instrument carried aboard *Mars Reconnaissance Orbiter*), commenced on 2009 Mar 30 (Ls= 237°).[2,32,33] According to this source, by early April thin dust apparently encircled Mars, but optically thick dust was limited to the locus of a classic Regional storm from *Ausonia* to southern *Hellas* through southern *Noachis* that reached the N. edge of the SPC. MRO-MARCI had also shown dust near *Solis Lacus* on Mar 27; MRO-THEMIS showed increased dust in *Hellas* on April 1, and MRO-MARCI a brightening in *Hellas* on Apr 4 or 5, soon subsiding. Perihelion occurred on Apr 9 (Ls= 250°). The temperature-sensitive instruments are highly responsive and can detect suspended dust before it may become optically thick. A map showing the maximum extent of the event is readily available.[32]

Observations taken every ten Sols by the PANCAM camera upon the *Spirit* rover at *Gusev* crater revealed first of all a 20% loss of power on account of the storm[32] followed by a 'cleaning event' (when wind blows dust off the solar panels) from Ls= 259°.[34] (With smaller continuations until Ls= 294°, the event increased the available solar power nearly threefold. It was less significant than the cleaning event that took place prior to the 2007 global storm.)

As to groundbased work, Akutsu's Mar 23–29 lo-res images (D= 4"; CML= 50–108°) do not suggest any storm, but the longitudes only partly correspond: on Mar 24–28, *Argyre* was light in the evening, but not in infrared, so this was evening cloud. Minami on Apr 10 caught the SPC, *Syrtis Major* and *Hellas*, the latter lightish rather than yellow, and the disk colour normal; Buda's Apr 12 image (Part II, Figure 18) showed all these markings normally, but *Mare Hadriacum* was faint: indeed, it had been obscured by the storm.[32] Pellier's image of Jun 1 already suggests recovery, and Maxson's images of Jul 15–20 make it certain.

Cross-equatorial Regional dust activity, 2009 August–September

The announcement of dust over *Hellas* to *Argyre* on 2009 Aug 6 by the ALPO[6] proved to be a false alarm, the region being light but not dusty on a drawing by Macsymowicz and in images by Poupeau.

But a further Regional event definitely occurred on 2009 Aug 22 (Ls= 326°) when according to Morita (Figure 6), activity from the NPH initiated dust between *Mare Acidalium* and *Nilokeras*, specifically in E. *Tempe* and over *Xanthe* (aka *Chryse Planitia*) the area being brightest in red and infrared (and light in green). Nothing had been seen on Aug 19, and nothing remained of the activity on Aug 24. *Chryse* too looked bright to Morita on Aug 22–26, particularly in red and IR. At such high phase angles it often looks bright in red light, and care is necessary before pronouncing suspended dust, but on this occasion it is likely that dust had really propagated south from the storm. Moreover, this was the right season for the cross-equatorial activity which can be initiated by an NPR front.

Pellier on Sep 6 (Figure 6) still found the region brilliant, especially in the infrared, and remarked that MRO-THEMIS had recently caught dust in the NPR. All was normal to Peach on Sep 9–10, but his high quality images revealed an anomalous albedo pattern of *Nilokeras-Ganges*, with a dark patch within *Ganges*, quite different from the near-opposition appearance of Figure 1A, confirming that dust had been raised nearby. The area later returned to normal.

Figure 5. ***Region III: longs. 130-250°***
Drawings and images by Adachi (450mm OG, ×563), Biver (407mm refl., ×700), Casquinha (red filter, Lumenera SkyNyx 2-0M camera), Clitherow (blue filter, Neximage), Gray (×365), Lawrence (SkyNyx 2-0M), Melillo (Toucam Pro II), Olivetti (Lumenera LU075M), D. C. Parker (SkyNyx 2-0M) and Peach (SkyNyx 2-0M).

Regional dust activity over Casius–Utopia, 2009 November

On Oct 29 Garbett obtained an excellent image showing veiling of the northern part of *Utopia* (Figure 7). His blue filter images prove this was white cloud adjacent to the NPC (part of the remaining hood at its boundary: see Part II). On Nov 3 Flanagan (Figure 7) and Maxson imaged this white cloud activity to the west of *Utopia*, extending as far as the morning limb: similar results had been obtained on Nov 1 and 2 by himself and Maxson, and by

Table 2. Observers of Mars, 2009–'10

P. Abel	V	Leicester	203mm refl.
		Selsey, West Sussex	381mm refl.
G. Ackermann		Zaberfeld–Michelbach,	310mm DK Cass.
& J. Ackermann		Germany	
M. Adachi	V	Otsu, Japan	310mm refl.
		Kwasan Obs., Kyoto, Japan	450mm OG
G. Adamoli		Verona, Italy	125mm MK & 235mm SCT
J. Adelaar		Arnhem, Netherlands	235mm SCT
L. Aerts		Heist-op-den Berg, Belgium	254mm SCT
T. Akutsu		Cebu City, Philippines	355mm SCT
J. Albert	V	Lake Worth, Florida, USA	279mm SCT
D. L. Arditti		Edgware, Middlesex	355mm SCT
K. N. L. Bailey		Swindon, Wilts.	127mm OG & 254mm refl.
T. Barry		Broken Hill, Australia	406mm refl.
D. Bates		Cypress, Texas, USA	254mm refl.
R. M. Baum	V	Chester	152mm refl.
& J. Baum			
J. D. Beish	V	Lake Placid, Florida, USA	410mm refl.
N. D. Biver		Versailles, France	407mm refl.
		Paris Observatory, France	380mm OG
G. Boots		Selsey, West Sussex	381mm refl.
& K. Peters			
R. Bosman		Enschede, Netherlands	279mm SCT
M. Brown		York	254mm refl.
S. Buda		Melbourne, Australia	405mm DK Cass.
P. Casquinha		Palmela, Portugal	355mm SCT
R. Chua		Singapore	127mm OG
D. Clitherow		Fife, Scotland	254mm refl.
M. Cole		Keighley, Yorks.	279mm SCT
M. Collins		Palmerston N., New Zealand	203mm SCT
E. Colombo	V	Gambarana, Italy	150mm refl.
D. G. Daniels	V	Hampstead Obs., London	150mm OG
H. J. Davies	V	Swansea	203mm SCT
M. Delcroix		Tournefeuille, France	254mm SCT
D. Dierick		Ghent, Belgium	254mm refl.
P. Edwards		Horsham, West Sussex	279mm SCT
C. Fattinnanzi		Montecassiano, Italy	250mm refl.
W. D. Flanagan		Houston, Texas, USA	355mm SCT
		Eldorado, Texas, USA	
M. Foulkes		Henlow, Beds.	203mm SCT
M. Frassati	V	Crescentino, Italy	203mm SCT
A. Friedman		Buffalo, New York, USA	254mm MKT
P. J. Garbett		Sharnbrook, Beds.	355mm SCT
S. Ghomizadeh		Tehran, Iran	279mm SCT
M. Giuntoli	V	Montecatini Terme, Italy	203mm SCT
C. Go		Cebu, Philippines	279mm SCT
E. Grafton		Houston, Texas, USA	355mm SCT
D. L. Graham	V	Catterick, N. Yorks.	152mm OG & 230mm MKT
D. Gray	V	Kirk Merrington, Co.Durham	415mm DK Cass.
P. T. Grego	V	St. Dennis, Cornwall	203mm SCT
M. Green		Holywell, Flintshire	203mm refl.
P. Haese		Blackwood, South Australia	355mm SCT
A. W. Heath	V	Long Eaton, Notts.	203mm SCT & 254mm refl.
C.E.Hernandez	V	Miami, Florida, USA	229mm MKT
R. Hill		Tucson, Arizona, USA	355mm SCT
D. A. Holt	V	Chipping, Herts.	355mm refl. & 152mm OG
C. J. Hooker		Didcot, Oxon.	203mm MKT
K. C. Howlett		Cwmbran, Gwent	250mm refl.
		Wroughton, Wilts.	203mm SCT
P. Hudson		Bedford	102mm OG
T. Ikemura		Nagoya, Japan	380mm refl.
W. Jaeschke		West Chester, Penn., USA	355mm SCT
N. D. James		Chelmsford, Essex	72mm OG
S. Johnson	V	Plymouth, Devon	203mm SCT
G. Jolly		Gilbert, Arizona, USA	355mm SCT
M. Kardasis		Athens, Greece	254mm SCT
A. S. Kidd		Welwyn, Herts.	254mm refl. & 355mm SCT
B. A. Kingsley		Maidenhead, Berks.	355mm SCT
W. Kivits		Siebengewald, Netherlands	355mm SCT
S. Kowollik		Ludwigsberg, Germany	203mm refl.
		Zollern–Alb Obs., Germany	800mm Cass.
T. Kumamori		Osaka, Japan	203mm DK Cass.
P. R. Lawrence		Selsey, West Sussex	355mm SCT
P. R. Lazzarotti		Massa, Italy	410mm Cass.
W. J. Leatherbarrow		Sheffield	305mm MKT
M. R. Lewis		St. Albans, Herts.	222mm refl.
R. N. B. Lewis		Cardiff	254mm SCT
A. Loghmari		Hampstead Scientific Soc.	180mm MKT
N. Longshaw	V	Oldham, Lancs.	78mm OG
P. Lyon	V	Birmingham	203mm SCT
T. McCague	V	Chicago, Illinois, USA	333mm refl.
R. J. McKim		Oundle, Northants.	355mm SCT
		Upper Benefield, Northants.	410mm DK Cass.
S. Macsymowicz	V	Ecquevilly, France	150mm OG & 305mm Cass.
P. W. Maxson		Surprise, Arizona, USA	254mm SCT
F. J. Melillo		Holtsville, New York, USA	254mm SCT
J. Melka		St. Louis & Chesterfield, MO, USA	305mm refl.
L. E. Mercer		Malta	279mm SCT
C. Meredith		Prestwich, Manchester	203mm SCT
M. Minami	V	Fukui City Obs., Japan	200mm OG
E. Morales Rivera		Aguadilla, Puerto Rico	310mm SCT
Y. Morita		Hiroshima, Japan	254mm refl.
P. J. Neville	V	Maidenhead, Berks.	102mm & 152mm OGs
D. Niechoy	V	Göttingen, Germany	203mm SCT
T. Olivetti		Soiano del Lago, Italy	410mm DK Cass.
P. W. Parish	V	Rainham, Kent	152mm OG
D. C. Parker		Miami, Florida, USA	254mm DK Cass. &
			410mm refl.
T. J. Parker		Los Angeles, CA, USA	152mm refl. &
			320mm Cass.
D. A. Peach		High Wycombe, Bucks.,	355mm SCT
		Maidenhead, Berks.,	
		Selsey, W. Sussex & Barbados, W. Indies	
C. Pellier		Paris, France	254mm Cass.
J. H. Phillips		Charleston, S. Carolina, USA	203mm & 254mm OGs
M. Porter		Petts Wood, Kent	178mm MK Newt
J.–J. Poupeau		Pecqueuse, France	350mm Cass.
A. R. Pratt		Leeds	203mm MKT
A. Robertson	V	Broome, Norfolk	305mm DK Cass.
M. Salway		Central Coast, NSW, Australia	305mm refl.
J. R. Sánchez		Córdoba, Spain	279mm SCT
R. W. Schmude	V	Barnesville, Georgia, USA	120mm OG
I. D. Sharp		Ham, West Sussex	279mm SCT
I. Sharp		Carlisle, Cumbria	254mm SCT
W. P. Sheehan		Willmar, Minnesota, USA	279mm SCT
K. Smet	V	Bornem, Belgium	203mm & 305mm refls.
D. Storey		Isle of Man	410mm SCT
J. Sussenbach		Houten, Netherlands	279mm SCT
A. Tasselli		Lincoln	254mm & 305mm refls.
R. Tremblay		Québec City, Canada	203mm OG
& J. Bergeron			
D. B. V. Tyler		Flackwell Heath, Bucks.	355mm SCT
G. Walker		Macon, Georgia, USA	203mm OG
S. Walker		Manchester, NH, USA	317mm refl. & 355mm SCT
J. Warrell		Vänge, Sweden	254mm SCT
J. Warren		Amarillo, Texas, USA	279mm SCT
A. Wesley		Murrumbateman, NSW, Australia	369mm refl.
S. R. Whitby	V	Hopewell, Virginia, USA	152mm refl.
W. J. Wilson	V	Grange-over-Sands, Cumbria	203mm & 279mm SCTs
P. B. Withers		Romsey, Hants.	355mm SCT
J. Young	V	Co. Louth, Ireland	410mm MKT
K. Yunoki		Osaka, Japan	260mm refl.

Abbreviations: OG= object glass (refractor); refl.= reflector; Cass.= Cassegrain; DK= Dall-Kirkham; MKT= Maksutov–Cassegrain & SCT= Schmidt–Cassegrain (Telescope).

As in previous apparitions, many observations by the following 15 observers in Italy were kindly communicated by UAI Mars Coordinator P. Tanga: G. Barattia, G. Bartolini, M. Cardin, M. & F. Cecchini, L. Comolli, I. Dal Prete, A. Di Stazio, M. Guidi, R. Mancini, A. Medungo, M. Morini, G. Starace, C. Zannelli and M. Zorzenon. In addition, Mr W. Paolini of the Astronomy Sketch Of the Day (ASOD) website sent a compilation of drawings by himself and other contributors, including J. Eads, S. Robbins, M. Semmler, U. Pilz, J. De Wit, M. Seibold, E. Rix, J. Scheuerle, R. Forgacs and E. Roel.

Pic du Midi Mars images (1.08m Cassegrain) by François Colas and Jean–Luc Dauvergne were contributed by J. H. Phillips.

All observers sent images except those marked V (for visual observations only).

Poupeau on Oct 26–29, *etc*. Perhaps the white cloud was the precursor to the dust activity that would begin on Nov 4.

On Nov 4 (Ls= 004°) Flanagan and Maxson found an inverted V-shaped yellow dust cloud obscuring *Boreosyrtis*, which cut off the S. part of *Casius* with tiny patches of dust to its north. On Nov 5 Flanagan found dust distorting the shape of *Utopia*, a finger of dust projecting southward as far as western *Nodus Alcyonius*, with more diffuse dust to its eastern side towards *Cebrenia*. Activity now declined, and on Nov 5 *Utopia* and *Boreosyrtis* were recovering. On that date to Melka the configuration of the dust cloud and albedo patches coupled with a transitory darkening of the desert just N. of the *Syrtis* (seen on Nov 4 and 5) combined to give the impression of the transitory feature *Nilosyrtis*, the classic northward 'tail' to the latter. (In Figure 7 we give an old drawing to show the classical form of *Nilosyrtis*.) The next available really good observation at this longitude was by Maxson on Nov 9 (Figure 7, CM= 236°); a normal view with no suspended dust remaining.

Other longitudes had remained normal during this event, though the white cloud just S. of the NPC had not been limited to the above longitudes. For example on Oct 30 Maxson saw the polar hood invading N. *Mare Acidalium* on the morning side, and on Nov 3 Akutsu saw a strip of cloud from N. *Tempe* to the west.

MRO-THEMIS data showed there had been a small dust cloud inside *Hellas* at some point between 2009 Oct 27 and Nov 4. Although many images such as Garbett's RGB one of Oct 29 show a lightish yellow or orange-toned *Hellas*, filter work by Kingsley (Oct 18–22), Poupeau (Oct 19–28), Peach (Oct 23), Flanagan (Nov 1–5), Melka (Nov 5–8) and Morales Rivera (Nov 5) suggest the groundbased work was only catching the warm-tinted basin floor.

North polar local dust activity, 2009 December

On 2009 Dec 16 Peach (Figure 8; Ls= 024°) imaged a delicate orange diagonal tendril of dust stretching from the S. NPC at longitude ~130–140° to the dark adjacent *Scandia*. (Note: These delicate observations have only been possible as a result of improved imaging techniques: they could simply not have been secured during the aphelic oppositions of the 1990s or earlier!). On Dec 17 Jolly (Figure 8) just caught the same event at the *p*. limb, with more widespread activity west of longitude ~180°. Morales Rivera on Dec 20 under CM= 143° showed the cap dusky orange *p*. the CM (Figure 8). Confirmation came from the MRO. On Dec 21, Peach under CM= 64° showed this activity to be darkening the cap on the morning side, and Bailey visually had the impression of a divided cap near CM= 91°. Images by Flanagan and Grafton at higher CML on Dec 21 (CM~ 170°) showed the N. polar surroundings overlaid by atmospheric dust near the CM, imparting an orange tint. This dust extended in the form of a streak (darkest in blue light) to the NW over the NPR. Thus there were two simultaneous local dust outbursts.

North polar Regional dust storm, 2010 January–February

The storm commencing in 2010 late Jan was conspicuous enough to make it a memorable event in the telescopic annals. On Jan 16 and 17 Akutsu, Kumamori and Morita imaged a bright southward protrusion of the cap at *Baltia*, clearly a front blowing off the cap. It did not yet raise any dust, but occurred at the very place where

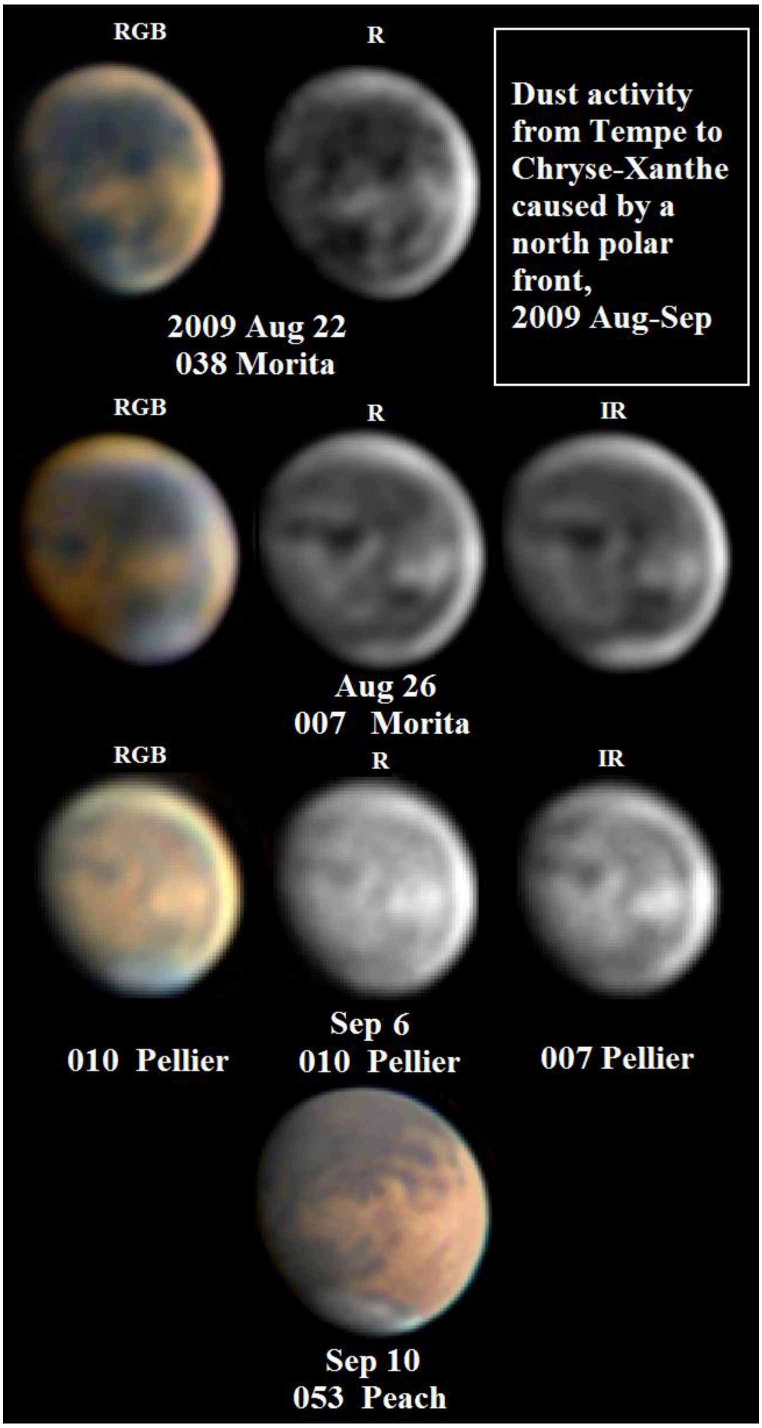

Figure 6. 2009 Aug–Sep: Regional dust storm activity over E. *Tempe* and *Xanthe* (aka *Chryse Planitia*) initiated by an advancing N. polar front; dust spread to *Chryse* in general after Aug 22, according to RGB, R and IR (700nm+) images by Morita (Lumenera 075M camera), Peach (Lumenera SkyNyx 2-0M) and Pellier (Lumenera SkyNyx 2-0M).

a widespread storm would begin on Jan 29 (see Figure 9B), as announced in BAA e-Bulletin No. 472.[4]

On the night of 2010 Jan 29/30 (the double terrestrial date is needed to avoid ambiguity with the UK observations taken around midnight UT), a deep orange-coloured patch of dust was seen to indent the S. edge of the NPC over *Baltia*, close to the location of the *Chasma Boreale* rift. This caused the Director to send out an alert. Subsequently an image was received from Casquinha for Jan 28/29. Edwards, Leatherbarrow, M. R. Lewis, Morales Rivera, Peach, the Pic du Midi observers and Tyler also obtained especially good

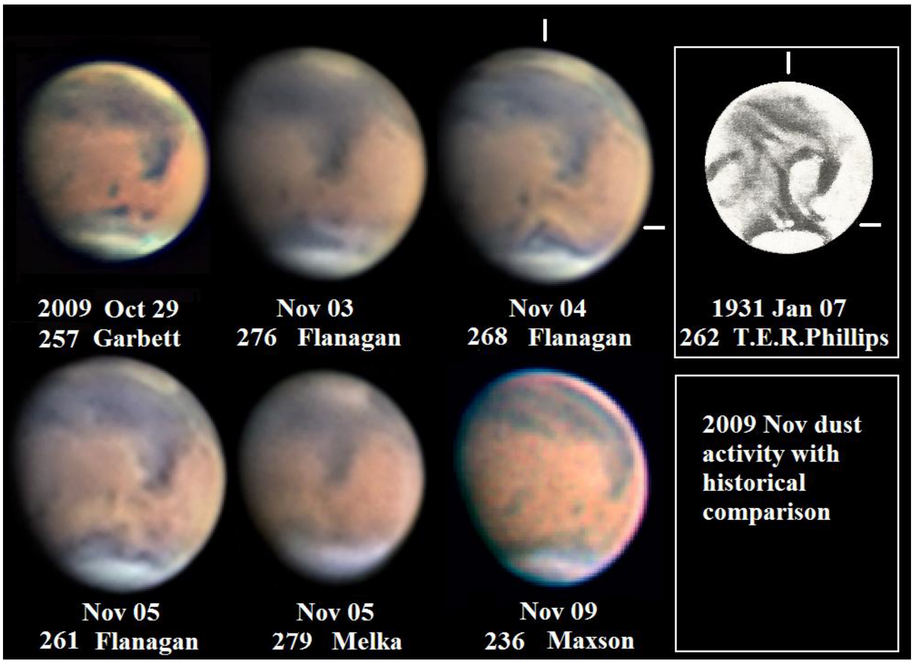

Figure 7. The N. hemisphere dust storm of 2009 Nov, with dust over *Utopia* initiated from a front off the N. polar cap, according to images by Flanagan (Lumenera LU-075M camera), Garbett (SkyNyx 2-0M), Maxson (Lumenera SkyNyx) and Melka (DMK21AF04.AS). We add a previously unpublished comparison drawing from 1931 Jan by the Rev. T. E. R. Phillips (Headley Observatory, Epsom, 20cm OG and 46cm refl.), showing the sweeping curve of *Nepenthes p.* the *Syrtis*, and the thinner *Nilosyrtis* to its north. Dust is arrowed for the 2009 Nov 5 image and upon the drawing by Phillips.

images of this event: confirmatory views came from Biver, Meredith and others, whilst Baum and Longshaw found the NPC collar broken or apparently indenting the cap at the location of the storm. We return to this event shortly.

Next day, activity began at nearly exactly the opposite side of the cap, indicating a common atmospheric disturbance over a wide range of longitude. On that side, Akutsu and Go on Jan 31 (Figure 9A, CML=226–240°) found activity in the longitude of *Utopia*, when an elliptical part of the cap had become outlined both on east and west by orange dust, shown strikingly in an animation made by the latter observer. This was approximately in the longitude where *Olympia* would later separate (2010 Apr). Akutsu and Kumamori still saw a belt of dust darkening the cap on Feb 2 and 3 around longitudes 180–190°. On Feb 5 McKim found the elliptical area still conspicuous. The settled dust outside the polar cap later patchily discoloured northern *Utopia*: it shows up as a lighter reddish-brown tint upon Peach's images of Feb 5 and 10, *etc.*, and it was still apparent in March. Peach's high resolution work in early Jan had shown the region more uniform.

The Jan 31 images of Akutsu and Go show that the dust was also raised south of the NPC S. edge, in the guise of a deep orange comma-shaped formation extending more to the east (as far as longitude *ca.* 230°) than to the west, with the northern end protruding as far north as the annular rift in the cap, then curving south east to reach the cap edge at λ~ 180–190°. Akutsu had shown nothing at these longitudes on Jan 28 or 29. On Feb 2 and 3 the dust was still visible but fading.

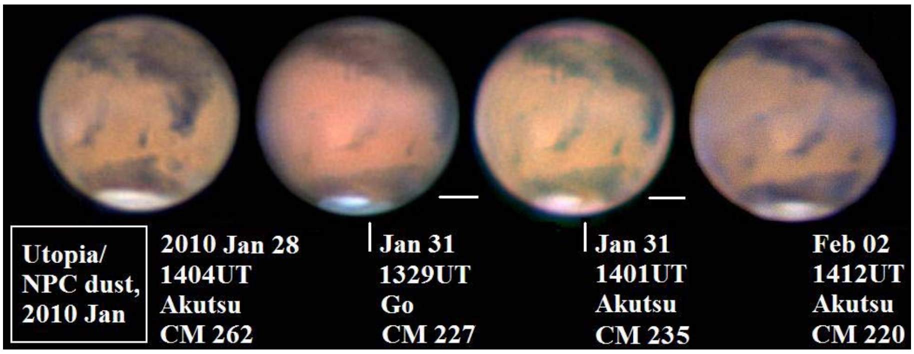

Figure 9A. Dust storm over N. *Casius–Utopia* and the NPC, 2010 Jan. Images by Akutsu (DMK21AU04 camera) and Go (DMK21BF04).

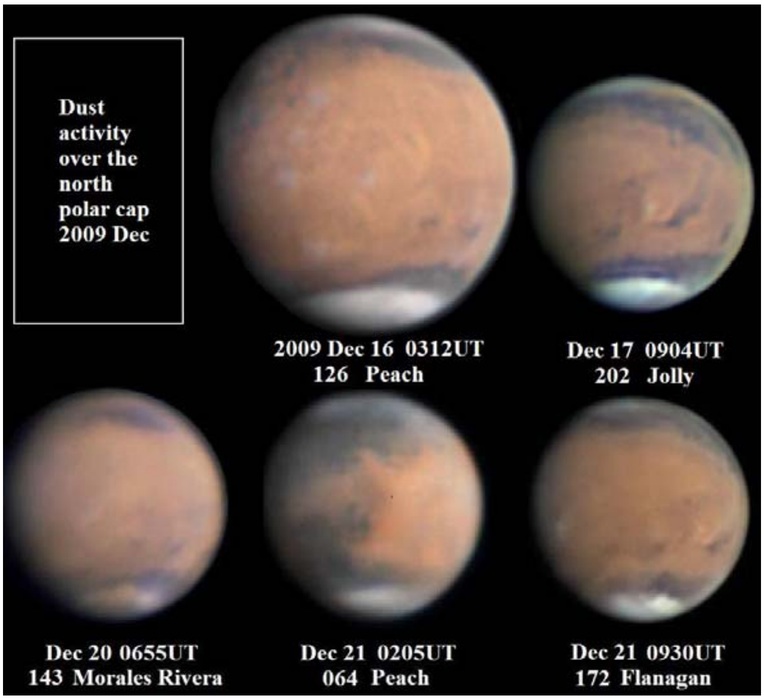

Figure 8. Dust activity upon part of the N. polar cap, 2009 Dec, extending over the adjacent terrain, according to images by Flanagan (Lumenera LU-075M camera), Jolly (SkyNyx 2-0M), Morales Rivera (DMK21AF04) and Peach (SkyNyx 2-0M).

This activity combined with the more significant outbreak on the *Baltia* side of the cap. Seen from the latter side, events progressed as follows, as illustrated and polar projected in Figure 9B. (We did not try to make polar maps of the opposite hemisphere's activity [or of the entire cap] as there were fewer images, of generally lower resolution, available.)

- Jan 26/27 (Peach): A normal, control image. There are some tiny, lighter orange patches south of the cap in this high resolution view, but we assume they lay upon the surface. Earlier in the evening McKim (Figure 2C) under CM= 21° saw a small bright area at the edge of the NPC: this is projecting at the cap edge in Peach's image (at λ~ 010°) and may have been a small 'front' off the cap.
- Jan 28/29 (Casquinha): A tendril of dust extends from the cap edge eastward over *Baltia*, meeting a smaller dust cloud which has impinged upon the cap.
- Jan 29/30 (Peach): Both dust tendrils have penetrated the cap, especially the western one (which seems larger outside the cap). They now join to form an arc. The overall picture looks complicated; dust is visible as a dark veneer upon the cap in all visible wavebands. (Similar images from Tyler on Jan 29 from 22:04UT, Poupeau on Jan 30 at 00:04UT, and Lawrence at 01:01UT.) Note again the small bright spot at the cap edge (at λ~ 000°).
- Jan 30/31 (Poupeau): A dark orange train of dust is attached to the periphery upon its western edge only, and there is a little activity still outside the cap at both the east and west ends. The eastern part of the storm, instead of being attached to the cap periphery, is now

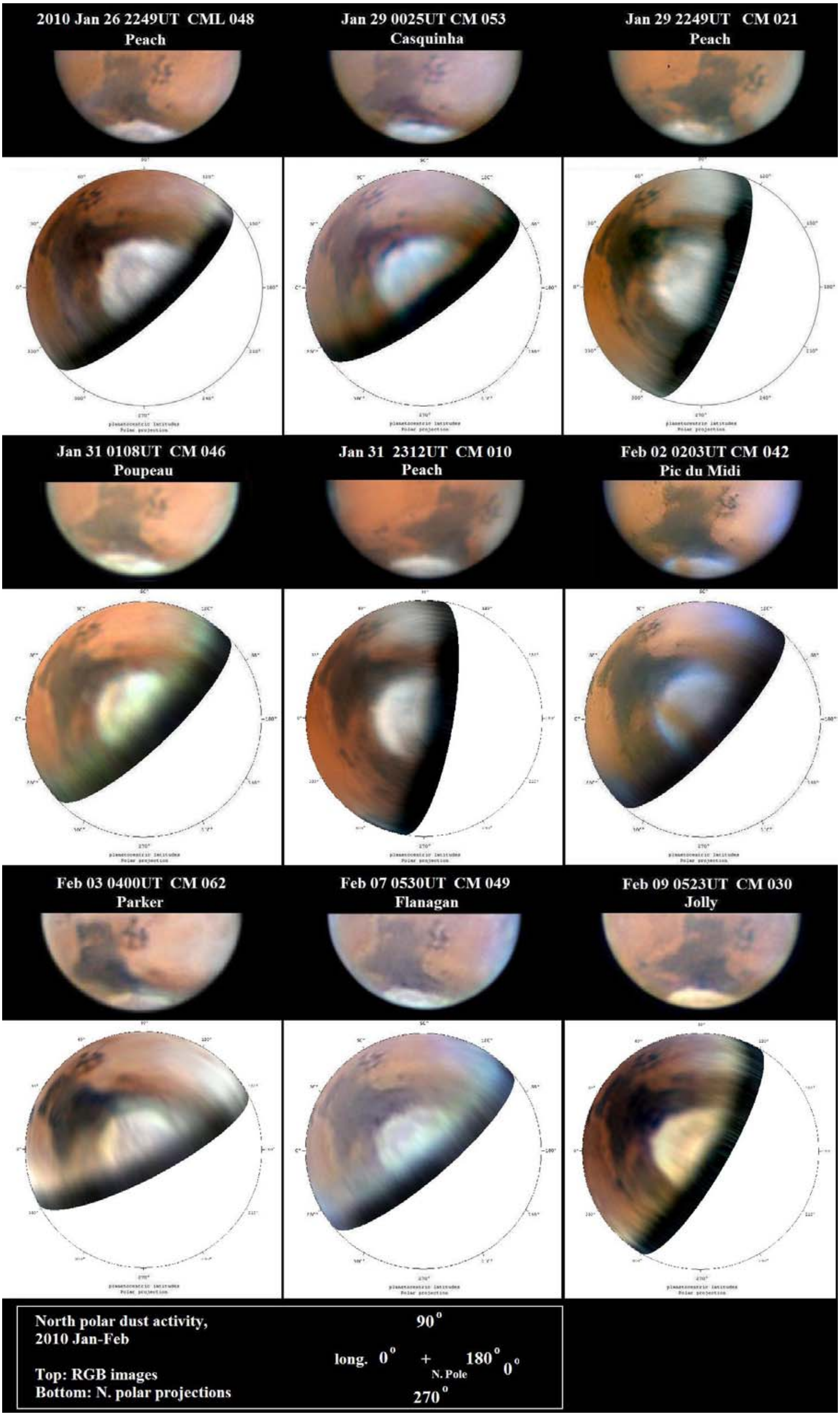

Figure 9B. Dust storm at the border of the NPC, which propagated across the cap, 2010 Jan–Feb. **(A)** Jan 26–31; **(B)** Feb 1–9. *Top row:* Images of the storm on the Baltia side; *Bottom row:* North polar projections of images from the top row. All polar projections made by D. A. Peach.

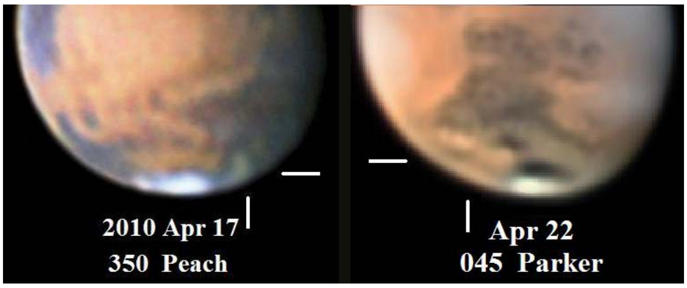

Figure 10. A local polar dust storm (arrowed), 2010 Apr, over NW *Mare Acidalium* according to images by Peach (Lumenera SkyNyx 2-0M camera) and D. C. Parker (SkyNyx 2-0M).

curved round to follow the course of the annular rift in the cap as far as the sunset terminator. (Good images were also secured by Pellier.)

– Jan 31/Feb 1 (Peach): The area was close to the morning terminator for European observers, but activity appears similar to Jan 30/31 and with the annular rift perhaps enhanced in visibility. (Good images were also supplied by Casquinha and Sharp.) On Feb 1 at 02:23UT Melka noted that the dust visible three days earlier south of the SPC had declined; in fact there were only traces outside the cap now.

– Feb 1/2 (Dauvergne & Colas, Pic du Midi): The most dramatic images of the event show the dust much more intensely dark and forging a broad, linear course from the original eastern tendril across part of the annular rift to reach the sunset terminator. More diffuse dust continues around the annular rift to the west, but the connection to the periphery on the west has disappeared. (Similar results came from Lawrence at 21:40UT, Sanchez at 01:00UT, Casquinha at 02:05UT and Morales Rivera at 03:16UT.) Some activity is still evident outside the cap, but less active than several days previously.
  Recall that more dust had originated on the other side of the cap on Jul 31; dust from that source probably added to the density of the remarkable orange streak running from one side of the cap to the other on the polar projection. The storm's maximum extent (exceeding 34° on its longest axis) classifies it as a Regional event.

– Feb 2/3 (D. C. Parker): Some atmospheric dust is seen between the now visibly darkened annular rift and the initial activity site on the western side of *Baltia*. (Images were also made by Morales Rivera at 02:58UT.) Slightly earlier, Tasselli (Feb 2 22:24UT) and Gray (Feb 3 03:20UT) had seen (albeit at low resolution) that the eastern part of the storm, not visible to Parker, was still active. There was probably no longer any activity outside of the NPC on the *Acidalium* side, and the event seemed to be dying.

Dust now quickly dispersed or settled, leaving a pale yellow tint over part of the cap. On Feb 5 Aerts at 22:41UT and M. R. Lewis at 23:40UT showed orange dust (settled?) tinting the *f.* part of the cap, which Tasselli (Figure 3) also captured. At higher resolution on Feb 7 at 05:30UT Flanagan shows what we may assume to have been dust fallout apparently broadening the annular rift, and on the same morning D. C. Parker observed the same coloured dust fallout. An image by Jolly from Feb 8/9, normal apart from the orange tint of the annular rift completes our series in Figure 9B. On Feb 12 Parker (CM= 335°) commented upon a trace of dust upon the *f.* side of the cap

We can see that the dust activity upon the opposite sides of the cap quickly joined to produce a belt of dust across the entire cap. We assume that on Jan 29/30 the dust had moved as far north as the annular rift (see Part II) on both sides, and that these sources met at the centre on Feb 1/2. However, we cannot easily deduce any velocities from the data.

Peach's work shows the feature was complex outside the cap on the *Chasma Boreale* side, throwing a two-pronged loop of dust over the cap. Fine tendrils of dust were also seen to disperse over *Baltia*. The dust dispersing over the NPC was close to the location of where *Chasma Boreale* would later cut into the cap, suggesting a possible topographic influence or at least a thermal gradient in action.

NW *Mare Acidalium* showed an odd yellowish-brown tint to Peach on 2010 Mar 5–6 and to D. C. Parker on Mar 15, suggesting dust fallout in that location.

Northern local dust activity, 2010 April

On 2010 Apr 17, Peach's image shows a dull yellow cloud over *Baltia–Mare Boreum*: see Figure 10. That a dust storm really had occurred is confirmed by Parker's image of Apr 22 upon which there is a temporary dark streak at the edge of the yellow cloud, equivalent to part of classical *Iaxartes* (Figure 1B), together with some dust patches (Figure 10). We can also see this streak in Parker's May 27 image.

General discussion

The 2009 Nov event (Ls= 4°) may be compared with earlier events over *Casius–Utopia* or *Neith Regio* from 1943 Nov 2 (Ls= 330°, witnessed by E. C. Slipher[19]), 1961 Jan 19 (Ls= 23°, by S. Miyamoto[19]), 2006 Feb 4 (Ls= 007°, in the BAA report[26]) and 2008 Jan 22 (Ls= 21°, again in the BAA report[27]). These were all short-lived, but well documented. To the writer the 2009 November images also strongly invoked a one-off previously unpublished observation by the Rev T. E. R. Phillips (BAA Archives) on 1931 Jan 6 (Ls= 32°) and 7, when he sketched a small 'white' spot in northern *Utopia* (Ebisawa; but called *Boreosyrtis* at the time) near λ= 262°, close to the edge of the NPC, which had not been present on Jan 5. At the next UK presentation on Feb 6, Phillips recorded several albedo changes in the surroundings. This event was not included in the BAA dust storm catalogue published in 1999: at the time, it was thought to have been a small white cloud. Only with the benefit of hindsight is it clear that it was really a small burst of dust.

The NPR events that commenced on 2009 Dec 16 (Ls= 25°) and 2010 Jan 29 (Ls= 45°) help interpret earlier BAA polar dust storm records where detection was merely by change of cap brightness and colour. During part of 1946 Jan,[19] A. F. O'D. Alexander, E. H. Collinson and M. B. B. Heath found the NPC unusually dull and/or yellowish. Commencing at Ls= 28° this had surely been the same type of event (albeit witnessed at lo-res). We are also reminded of the specific dust streak caught by the Hubble Space Telescope on 1996 Sep 18 at Ls= 11°, and of some NPR events in 2007–'08.[27] Finally, the bright spot at the NPC periphery on 2010 Jan 26 and later may have been a 'front' off the cap which had raised dust.

As to the 2010 Apr event, similar events were witnessed during the 1990s aphelic oppositions, when both white and yellow clouds were sometimes active at the same longitude. Within certain Ls limits, the development of the N. polar hood can throw up surface dust. ▸

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8 JALPON (ALPO Japan) website: **http://alpo-j.asahikawa-med.ac.jp/Latest/index.html**. By 2009–'10 this and the OAA website[9] had become the most generally useful repositories of online amateur Mars images.
9 OAA website: **http://www.mars.dti.ne.jp/~cmo/ISMO.html**. The OAA continued to publish its bulletin *Communications in Mars Observations* (issues from 2009–2012 are relevant). Since our final report on 2007–'08 appeared,[27] M. Minami has published further accounts of his own and T. Nakajima's visual work, from 2003 (M. Minami, *Bull. Fukui City Museum of Nat. History*, **59**, 16 (2012)), and 2005 (M. Minami, *ibid.*, **60**, 1–10 (2013), **62**, 1–12 (2015) and **63**, 1–10 (2016)).
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