# The 2018 opposition of Mars & the global dust storm: Part II

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

In Part I, we described the evolution and behaviour of the global dust storm and its complex interaction with the Martian surface. In Part II, we discuss the lesser dust storms observed, white cloud activity and the behaviour of the polar regions. Several minor dust storms at high latitude were associated with the recession of the S. polar cap (SPC), while a large Regional event in 2019 January stretched from *Hellas* to *Claritas*, having originated in southern *Chryse*. The Equatorial Cloud Band and the *Syrtis* Blue Cloud showed standard seasonal behaviour, until all diurnal and orographic clouds were interrupted for months by the global storm. As described fully here, the early spring recession of the SPC was accelerated by the deposition of dust upon the cap, but its recession was otherwise extremely close to that in 2003, a year with no global storm. The seasonal separation of *Novus Mons* at *Ls* = 237° was marginally early. The SPC was observed until *Ls* = 345°, and the NPC first appeared at *Ls* = 346°, in 2019.

## Dust storms

Part I described and illustrated the 2018 global storm.[41] The Director's drawings in Figure 13 portray that event and later phenomena. Here, we review the lesser dust storms: see Figures 14–15.

### *2017 November – 2018 May*

On 2017 Nov 1–3, Foster's image (disc diameter (*D*) = 3.9″) showed the NPC apparently divided N–S by a rift at CM = 135–155°. As the *Rima Borealis* rift (which Foster would only resolve days later) runs E–W at that CM, it was surely a dust streak, and the season would have favoured it, though the evidence depends upon small red-filter images. On 2017 Dec 1 and 2018 Jan 12 (*D* = 4–5″), Foster imaged further dust streaks upon the NPC at right angles to the detached *Olympia*. These latter events were observed by the MRO; its weekly weather reports referred explicitly to *Olympia*.[9]

In 2018 March, a small Regional storm – shown in Figure 14A – began near *Solis Lacus*. MRO images of Mar 16, 17 & 21 show a small dust cloud NW of that marking, and dust expanded into *Valles Marineris* for some days from Mar 22.[9,37] Valimberti's Mar 21 image and Kumamori's of the following day confirmed a small cloud NE of *Solis Lacus*, weakly brighter in red light. On Mar 29, Valimberti saw a bright nucleus at the E. end of *Valles Marineris* and others in S. *Chryse* (Figure 14A). Adachi, Iwamasa, Kumamori and MacNeill also followed the event that covered E. *Valles Marineris* during Mar 23–31; by Mar 28 a specific bright cloud lay over W. *Margaritifer Sinus*, and there were brighter dust clouds over *Chryse*. From Mar 29, *Margaritifer* began to recover, but bright dust continued to be visible in *Chryse–Xanthe* and, less obviously, in E. *Valles Marineris* for several days. (The Apr 2–8 MRO bulletin mentions dust at E. *Marineris*.) MacNeill's Apr 4 image showed *Margaritifer* still a little faint, with a large, bright dusty area to its NW. Upon Foster's Apr 14–16 images, *Margaritifer* was normal, but *Chryse* alone was bright and yellowish, its static nature suggesting fallout. Peach on Apr 27 showed only E. *Chryse* bright.

MRO data for Apr 5 showed a very small dust cloud in *Amazonis*,[9,42] NW of *Olympus Mons*. Images by Morales and Peach actually confirmed the cloud (brighter in red light), but without MRO data it might have been overlooked.

Iwamasa's RGB image of Apr 20 showed the W. part of *Mare Sirenum* (which had been normal, Apr 17–18) faint, while red and IR images emphasised a number of small dust clouds obscuring it, and others on Apr 21 confirmed obscuration. Images during April 20–25 showed a brighter dust cloud over central *Zephyria* at –7°, 186°, adjacent to this activity (indicated in Figure 14B). *Mare Sirenum* looked normal to Yunoki and others on Apr 22, when further dust activity to the SW at *Electris–Eridania* was seen (indicated in Figure 14B). A bright dust cloud recorded by Justice on Apr 25 at –24°, 180° in S. *Zephyria* at W. *Mare Sirenum* / E. *Mare Cimmerium* was the most conspicuous feature (Figure 14B). MRO images showed the latter began on Apr 24 (when we had no record of that longitude),[43] reached a maximum next day and disappeared after Apr 27 (as we confirmed).

Foster's images of Apr 23 suggested a tiny dust cloud in W. *Hellas*, at the time of an SPH incursion in its south part. The dust disappeared next day; a resurgence on Apr 29 is described below.

On 2018 Apr 30, under CM = 198°, Foster detected a minute projection on the evening terminator at +30°, 153°, over N. *Amazonis*, bright in red light. MRO verified it was a local storm, long axis *ca*. 520km. By May 2 it had dissipated.

From late April onwards, we saw three separate events at the N. edge of the SPC. To quote the May 7–13 MRO bulletin: 'Large local-scale dust storms occurred along much of the seasonal south polar ice cap edge'.[9]

The first was detected on Apr 29 by Carvalho. A storm in S. *Hellas*, it was reobserved by Peach on May 5 when it

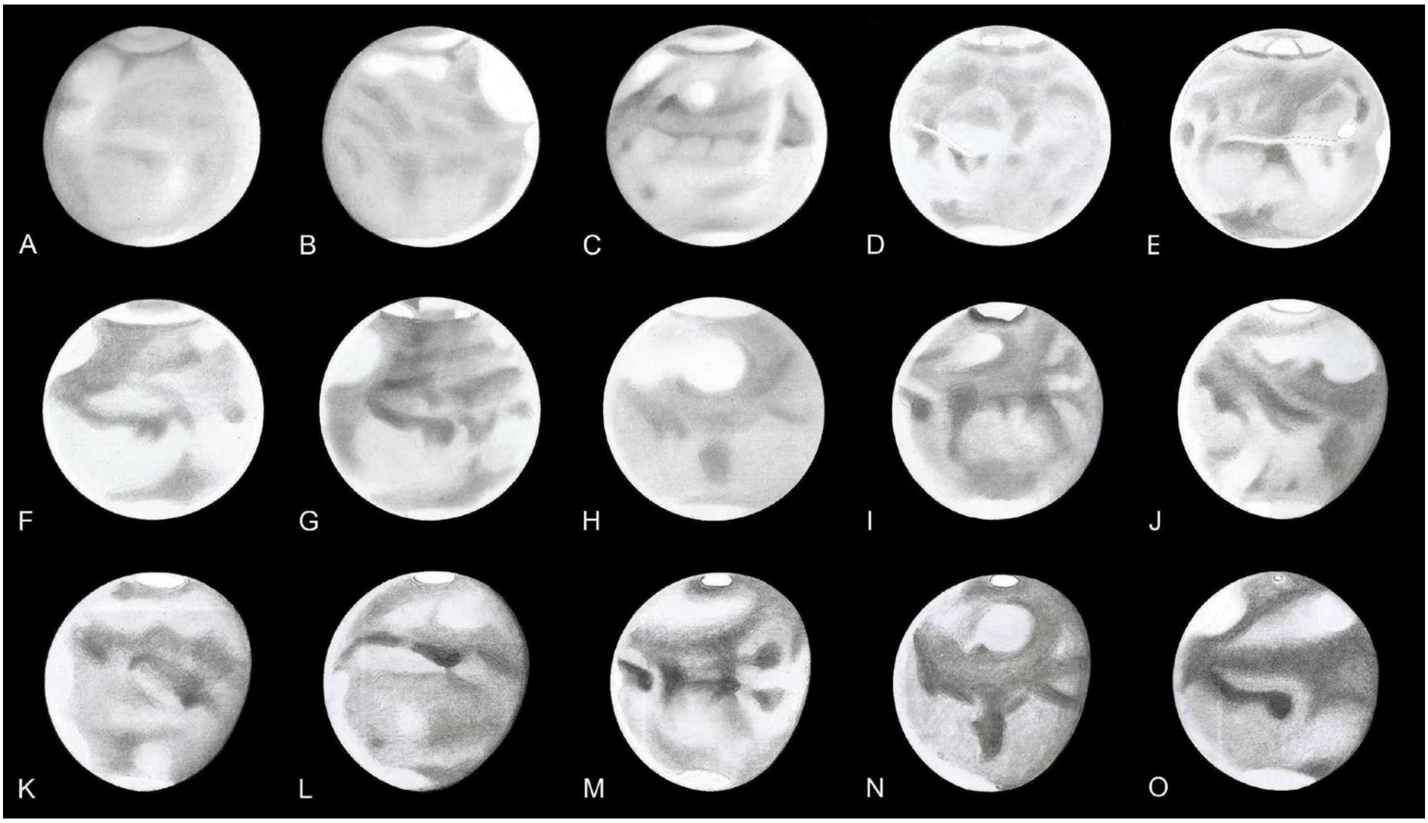


**Figure 13.** Drawings made by R. J. McKim in 2018–'19 with a 254mm refl., ×188 (H) and 410mm DK Cass., ×265, ×331 & ×410 (the rest), showing the global dust storm in 2018 June–July and its clearing during August. White light and a W23A orange filter were used. **(A)** Jun 27, 00:40 UT, CM = 007°. **(B)** Jul 8, 00:48 UT, CM = 250°. **(C)** Jul 15, 00:20 UT, CM = 180°. **(D)** Jul 24, 23:55 UT, CM = 085°. **(E)** Jul 25, 22:55 UT, CM = 060°. **(F)** Jul 31, 22:25 UT, CM= 001°. **(G)** Aug 2, 22:30 UT, CM = 345°. **(H)** Aug 9, 22:35 UT, CM = 284°. **(I)** Sep 2, 21:20 UT, CM = 049°. **(J)** Sep 17, 21:05 UT, CM = 266°. **(K)** Sep 21, 19:15 UT, CM = 202°. **(L)** Sep 26, 20:15 UT, CM = 160°. **(M)** Oct 9, 19:22 UT, CM = 033°. **(N)** Oct 18, 19:05 UT, CM = 303°. **(O)** Jan 28, 17:30 UT, CM = 000° ($D$ = 6.3″).

overlapped the SPC edge. Next day, Peach imaged dust in S. and W. *Hellas*. W. *Hellas* continued bright and dusty, slightly overlapping the cap, on May 10–12; it faded on May 14–17 and disappeared on May 18. See Figure 14C. The second event occurred during May 6–13, when Australasian observers recorded a local dust storm over *Argyre* that extended onto the edge of the SPC. It seemed at maximum development on May 12 (Figure 14C). The third storm, which reached Regional status, occurred during May 12–14 with light orange streamers and patches of dust at high S. latitude, over W. *Phaethontis* and *Electris*, that partly overlapped the cap and ran S*p*.–N*f*. from $\lambda \sim 150–200°$, breaking up into small bright patches over SW *Mare Sirenum* to SW *Electris* on the last date. (This somewhat recalls a dust storm south of *Mare Sirenum* in 2016 June.[1]) See Figure 14C.

### The global storm, 2018 May – August

See Part I.[41]

### Further dust activity, 2018 September – October

Peach's high-resolution Sep 17 Chilescope image revealed a minute storm at the NW tip of the rapidly subliming westernmost component of *Novus Mons*, as mentioned in an MRO bulletin.[9] See Figure 17I. An equally fine Sep 8 image (Figure 17H) had not shown the cloud. It would appear to have been the result of a 'cascade', where rapid sublimation at a sharply pointed outlier lifts dust. Such phenomena were more common during 2003, when there was no global storm.[45]

A dust storm at high southern latitude occurred during Oct 1–5 and was followed by observers in the USA.[13] A small elliptical cloud – bright and strongly yellowish – was seen to the south of *Mare Sirenum*, displaying boundary changes from night to night. Brightest in red and green light, the storm was also obvious in blue: at relatively high latitude, it may have possessed a water ice component. Shown here in Figure 14D is a collage of images by Hood and Walker. From Oct 2–4, its centre moved from –41°, 178° to –42°, 156°, at 20km $h^{-1}$ to the east.

### A large Regional storm, 2019 January

On 2019 Jan 2 ($Ls$ = 317°), what would become a large Regional storm had begun in S. *Chryse–Xanthe* / E. *Valles Marineris*, west of *Margaritifer Sinus*. The first images were taken by Maxson from the USA on Jan 2, and by Ito from Japan on Jan 4.[13] The initial cores on Jan 2 were located at *ca*. –6°, 042° and –12°, 053°. The Director issued an e-mail alert on Jan 8. The event – shown in Figure 15 – developed in a familiar fashion, but was challenging to observe upon the seven-arcsecond disc. It spread along E. *Valles Marineris* by Jan 6 and had extended west along the canyon at least as far as *Melas Lacus* next day. At higher resolution on Jan 6 & 7, there were several bright cores to the north and south of *Chryse–Xanthe*. By Jan 7, dust had propagated southward over *Mare Erythraeum* as far as *Argyre*.

Images from Jan 8 & 9 show that the storm spread west across *Bosporus* to pass just south of *Solis Lacus*, while another core centred at the N. edge of *Solis Lacus* itself had formed on Jan 9. The latter core, however, does not seem to have developed much further, and *Solis Lacus* was faintly visible again on Jan 11. By that date, UK observers caught the storm at the evening limb, and a map made by Haigh from his images shows that dust reached as far west as *ca*. 110°. Dust still covered *Thaumasia*, *Solis Lacus* and *Claritas* (with several bright nuclei on the W. side), while *Phasis* marked the western limit. The W. end now decayed, and by Jan 17, UK observers (including Abel, M. R. Lewis, Nuttall and the Director) could faintly recognise markings around *Solis Lacus*, though dust clouds resided over *Argyre* and *Chryse*. With a large aperture, Abel sketched a further dust streak over W. *Valles Marineris*.

Meanwhile, to the east, another core had formed at *Aram* on Jan 8, and had expanded to hide *Meridiani Sinus*. It merged with dust spreading SE from the original source, so that the storm covered *Noachis*, *Pandorae Fretum*, *Deucalionis Regio* and W. *Sinus Sabaeus*. Within the affected longitudes, the limb brightening – particularly in the south – became paler, more diffuse and yellowish.

Arakawa and Kumamori on Jan 11 showed that dust had reached *Hellespontus*. A new core was visible in NW *Noachis*, but by now the original storm centre was decaying. By Jan 12, *Hellespontus* had been covered in the north, and dust reached *Hellas* and *Iapigia*. The next week found *Hellas* very bright in red and IR images, especially in its northern portion.

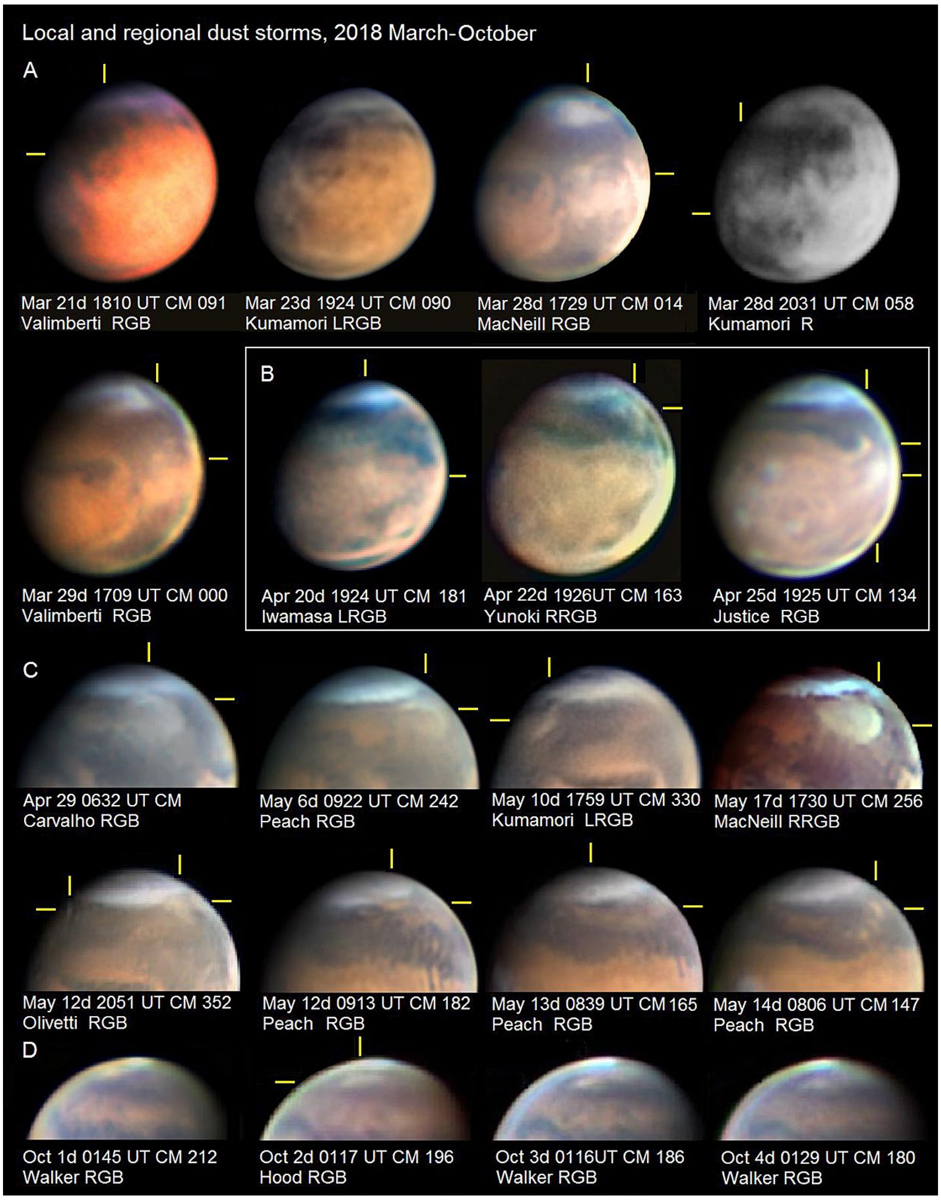


**Figure 14. (A)** Regional dust-storm activity, 2018 March. **(B)** Local dust activity at S. *Zephyria* and environs, 2018 April. **(C)** Local dust activity at the edge of the SPC, 2018 May (images by D. A. Peach with 355mm SCT). **(D)** Local dust storm south of *Mare Sirenum*, 2018 October.

On Jan 20, N. *Hellas* was still bright yellow, probably due to fallout, with equally static dust fallout visible in *Argyre*. By Jan 25, the latter area had faded appreciably and *Solis Lacus* seemed normal, according to a fine image by M. R. Lewis. A remarkable image by Peach on Jan 21 showed a tiny dust cloud over *Juventae Fons*, though *Valles Marineris* to its south was normal: the final sign of activity. The Director (Figure 13O) and Abel found *Hellas* still noticeably yellowish on Jan 28–30. The NPH had been unaffected. Adachi mapped the event.[16]

This event propagated like many previous Regional storms (such as 2003 December and 2017 February–March). Its seasonal commencement was just too late for it to have become encircling.

### *Summary*

The longitudes involving *Chryse* and *Valles Marineris* were very active this opposition, producing a small Regional storm in 2018 March, a global storm in May and a large Regional event in 2019 January. In comparison, *Hellas* was weakly active. A rarely observed source in S. *Zephyria* was active in 2018 April. There was evidence for dust streaks crossing the NPC in 2017 November to 2018 January, the latest in association with the seasonal separation of *Olympia*. At the N. edge of the SPC there was seasonal local dust activity, prior to the global storm in April–May, associated with the early recession of the SPC. Although 'cascade' phenomena were limited to a single record, one must recall the long duration of the global storm.

## White clouds & blue-violet light phenomena

The following section will show that white cloud activity was seasonally normal until interrupted by the 2018 global dust storm. Figure 16 shows aspects of this activity.

## Equatorial Cloud Band (ECB) & the *Syrtis* Blue Cloud

### *Phenomena in MY 34*

Mars was too distant in 2017 to time seasonal commencement. Upon his first image of 2017 Oct 12 ($D$ = 3.5″, $Ls$ = 73°), Foster recorded a bright morning (a.m.) cloud over *Chryse–Xanthe* which was part of the ECB, and a bright E–W band was also seen there by Adachi on Oct 31. On Nov 26 ($Ls$ = 93°) & 27, Foster's blue images showed continuous ECB characteristically dimming *Syrtis Major* near the CM. The ECB also appeared complete to him and Olivetti on Dec 9, and there were many other records now. During Dec 23 – Jan 6, Peach found the ECB strong in blue light, near maximum development. The Director found it present on Jan 7, dimming the morning *Syrtis Major*.

On Mar 16 ($Ls$ = 144°), the ECB was still apparently complete to Foster, veiling *Syrtis Major* at the CM. But it appeared patchy on Mar 20, under CM = 228° at $Ls$ = 146°, when the *Syrtis* Blue Cloud (see below) was hardly visible. This was the Section's final sighting of a more or less continuous ECB: a typical final $Ls$. A discontinuous ECB lingered briefly: for instance, Peach on Mar 25 under CM = 295° showed a chain of disconnected patches with no *Syrtis* Blue Cloud visible, and only short fragments on Mar 27 – Apr 1 under CM = 229–281°.

The *Syrtis* Blue Cloud can be seen when the ECB is thick enough and the viewing geometry optimal. This opposition, it was first seen by Foster on 2017 Dec 28, when a finger of white cloud invaded central *Syrtis* from the east (Figure 16). Other views by Foster in the a.m. or p.m. occurred on Jan 4–6 and Feb 2: we do not attempt a comprehensive list. A colourful sighting was logged by Peach on Feb 23.

### *Phenomena in MY 35*

Too few suitable images were available, but during a series of late observations with a 60cm Cassegrain, Adachi found a stretch of ECB present in *Chryse–Xanthe* on 2019 May 4 ($Ls$ = 020°), which M. R. Lewis imaged faintly as late as May 14 ($D$ = 4.0″).

## The *Tharsis Montes, Olympus Mons, Alba Patera & Elysium Mons*

Mars was too distant in 2017 to time seasonal commencement.

### Elysium Mons

As early as 2017 Oct 8–10, Iwamasa and Kumamori found evening orographic cloud over *Elysium Mons*. This cloud was seen to continue for months, being bright throughout 2018 January to early April; it then faded and was not seen after May 7.

### Olympus Mons

Foster caught evening cloud here from 2017 Nov 6 onwards. By late December it was very bright, remaining so into 2018 early April, then fading. It was not seen after May 13.

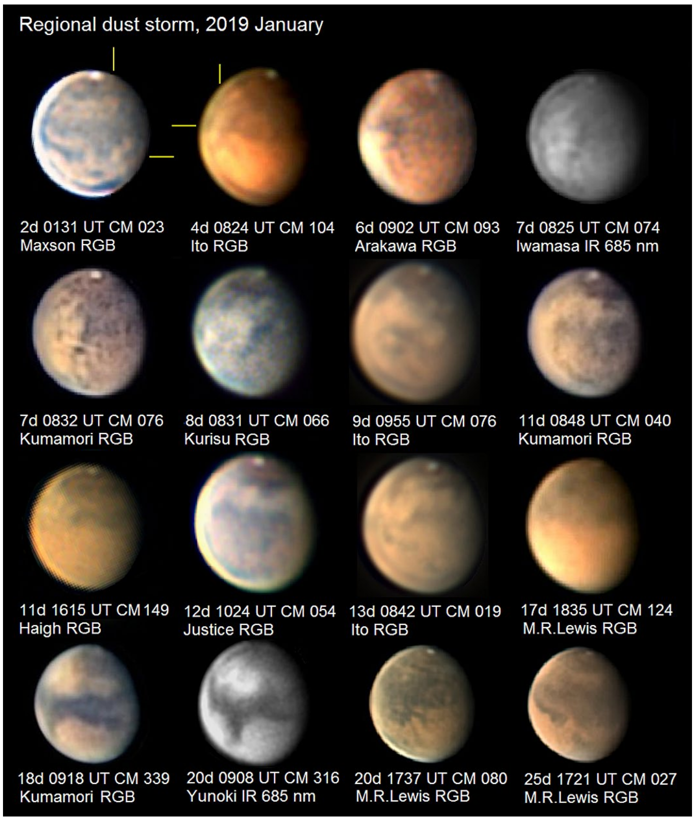


**Figure 15.** The large regional dust storm of 2019 January.

### *The Tharsis Montes*

On 2017 Oct 26, Iwamasa first resolved evening cloud over the *Tharsis Montes*. Due to latitude differences between the *Montes* clouds, their seasonal behaviour differs.

On Nov 1 ($Ls$ = 82°), Foster first recorded a large evening white cloud over *Ascraeus Mons*, which Maxson confirmed on Nov 16. In December, all three *Montes* had orographic clouds, with *Ascraeus* the most prominent, *Pavonis* less so and *Arsia* barely visible. On 2018 Jan 5, Miles found the same pattern, with the *Arsia* cloud present but tiny; this month and next, the orographics looked brighter than in December.

On 2018 Mar 2–3, Peach found the same behaviour, but by Mar 21, Valimberti observed a different pattern: *Arsia* was most prominent, *Pavonis* very faint, and *Ascraeus* moderate. On Apr 25, Justice saw the same brightness order, with the *Pavonis* cloud barely visible in blue light, but all were weaker than in March, as MRO data confirm.[9] In May, *Arsia* was the brightest, *Pavonis* stronger than in April, and *Ascraeus* similar to the latter. All three *Montes* clouds were still visible on Jun 1–3: see the following under 'The 'W' cloud'.

### *The 'W' cloud*

On May 26 – Jun 3 in blue light, Casely, Heffner, Justice, Kumamori, MacNeill and Yunoki clearly imaged the 'W' cloud in whole or in part (with clouds at all three *Tharsis Montes* and at *Ophir–Candor*, *Phoenicus Lacus* (*Nox Lux*) and *Tempe* making up the SE, S. central and NE spots) towards the evening terminator. See Figure 16. All the orographics then abruptly vanished as the growing global storm warmed the atmosphere.

## Alba Patera

On 2018 Jan 5, Miles was the first to record cloud at *Alba Patera*; it had not been present earlier. It was seen, but not conspicuous, in February. It looked brilliant to Carvalho, Morales and Peach on Mar 1–7 ($Ls$ = 137–140°), even around local noon. (Cloud at *Alba* shows different seasonal behaviour to the *Montes*, with two peaks, the second near $Ls$ = 140°.) BAA and MRO data showed *Alba* still active in late March, but by Apr 5 it was faint and it remained so till mid-May, after which it was not recorded.

## *The morning* Arsia Mons*, 2018 September–December*

As noted in Part I, the first telescopic signs of returning diurnal cloud occurred around Aug 21. MRO observed water-ice clouds over *Arsia Mons* from mid-August, which existed through September and October (though not over the other *Tharsis Montes* till November).[9] By now, ground-based observers could not check for evening cloud there, as the sunset terminator was well beyond the evening limb. However, they could watch the morning terminator.

White cloud above *Arsia Mons* when just off the morning terminator was caught by several BAA observers. Foster on Sep 30 imaged a morning cloud and its shadow here, while on Oct 22–25, Kumamori's images (Figure 16) showed a distinct shadow arising from the presence of a long cloud sweeping away from the volcano. Iwamasa on Oct 24, and Olivetti on Oct 29, also recorded it clearly. This phenomenon has been seen at other perihelic oppositions and the mystery is solved by means of these superior images taken in 2018. (The writer is always sceptical about seeing cloud shadows for dust storms, since such events must always leave a dark, shadow-like streak on the surface as dust is lifted. But here, the evidence for a real shadow is convincing.)

By early November, diurnal cloud activity was picking up further. Foster's Dec 11 image showed that white cloud remained at *Arsia Mons*, along with general a.m. cloud along the terminator. But resolution was now becoming an issue, and in 2019 January a large Regional dust storm – described earlier – again impeded such studies.

## *The morning* Olympus Mons *& the* Tharsis Montes

Maxson's image of 2018 Oct 11 was one of several that showed *Olympus Mons* as a conspicuous dark spot near the terminator, its caldera poking through a layer of white morning cloud: in the

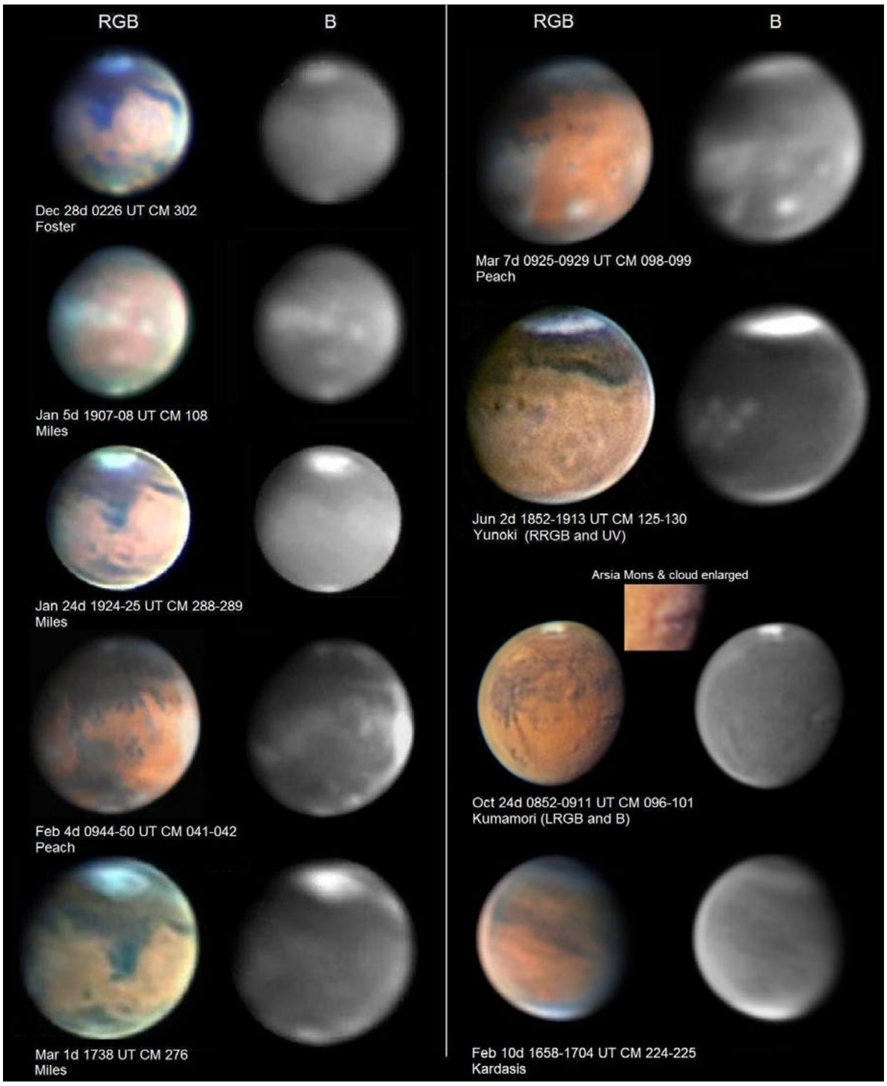


**Figure 16.** Paired colour (RGB) and blue-filter (B) images of various meteorological phenomena, 2017–'19. Images by C. Foster (ASI 290MM camera), M. Kardasis (ASI 190MM), T. Kumamori (ASI 290MM and ASI 224MC (enhanced and derotated images)), D. A. Peach (1m RCT, ASI 174MM), P. Miles (GS3-U3-32S4M) and K. Yunoki (ASI 290MM). (Not to scale.)

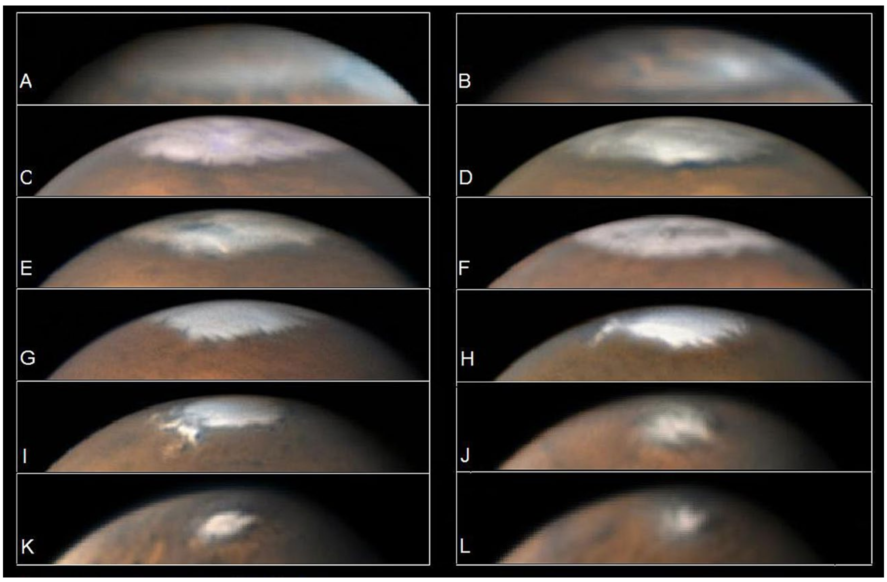


**Figure 17.** The S. polar cap recession, 2018, with 1m RCT and ASI 174MM camera, by D. A. Peach. **(A)** Jun 28, 09:26 UT, CM = 107°, (B) Jul 10, 08:24 UT, CM = 343°. **(C)** Aug 6, 06:28 UT, CM = 075°. **(D)** Aug 9, 05:03 UT, CM = 028°. **(E)** Aug 16, 05:20 UT, CM = 329°. **(F)** Aug 19, 01:05 UT, CM = 240°. **(G)** Sep 7, 00:07 UT, CM = 053°. **(H)** Sep 8, 23:39 UT, CM = 028°. **(I)** Sep 17, 01:28 UT, CM = 340°. **(J)** Nov 21, 00:12 UT, CM = 057°. **(K)** Nov 27, 01:35 UT, CM = 019°. **(L)** Dec 25, 00:52 UT, CM = 093°.

mornings the *Montes* were often more conspicuous for that reason, but we do not analyse the sightings any further here.

### N. polar spiral clouds

On 2018 Feb 1 ($Ls$ = 123°), despite the tiny disc diameter and $D_e$ (+8.2°) being only slightly favourable, Foster recorded a morning polar cloud at *Baltia – Mare Boreum*. Peach (Figure 16) imaged these morning clouds during Feb 3–13: none exhibited vorticity, though the one on Mar 3 comprised two short, curved streaks as if the N. and S. parts of a circle. Adachi, Maxson and Valimberti also made a few sightings of a morning polar cloud at this longitude until Mar 5 ($Ls$ = 139°).

On Apr 16 (CM = 80°, $Ls$ = 160°), Peach imaged a long, curved E–W streak of white cloud, but this was not like a cyclonic cloud, covering far too large a range in longitude. It fragmented the following day.

Past BAA data record these clouds commencing at virtually the same $Ls$ value (and continuing as late as $Ls$ = 161° in 2016.[1])

# Polar regions

## North polar region

### N. polar cap (NPC) recession & fragmentation

Our first image, obtained on 2017 Sep 26 at $Ls$ = 66°, showed the NPC recession far advanced. Even upon the tiny 3.7″ disc of Oct 9 ($Ls$ = 72°), Iwamasa's image suggests duplicity of the cap, due to the seasonal separation of *Olympia*. Upon a larger disc, separation would have been clear. (BAA data for 1995–2014 give separation at $Ls$ = 72 ± 2°.) By Nov 5–6, Foster confirmed the separation, and caught *Olympia* again on 2018 Feb 18. Kumamori's image of 2017 Oct 31 was one of the first to show *Hyperboreus Lacus*.

### The NPC–NPH transition in 2018

This was hard to follow, owing to the small disc and the sign of $D_e$.

The ground cap was definitely recorded until 2018 Mar 2 (Adachi) & 4 (Foster, $Ls$ = 138°). But from Mar 5, the value of $D_e$ became increasingly negative, rendering the summer remnant invisible, and later it became covered by seasonal cloud. Peach showed a specific bright cloud on Mar 30, which had widened across the whole N. limb by Apr 1 ($Ls$ = 152°), but the moment of transition could not be determined. Streaks of E–W white cloud were sometimes seen to the south of the hood (see the observations of Peach on Apr 16–17 under 'N. polar spiral clouds'), while Iwamasa and Kumamori on Apr 20 & 21 recorded a parallel E–W cloud belt under CM = 170–181°.

In 2016, the cap–hood transition had occurred during $Ls$ = 162–173°;[1] in 2014 during $Ls$ = 153–162°.[44]

The later observations of the hood sometimes revealed a few small, brilliant spots within it: *i.e.*, on the N*p*. side to Adachi, Apr 21 (CM =187°) and to Morales and Peach, May 10 (CM ~ 190°).

### The NPH after the global storm

The behaviour of the hood during the storm was described in Part I.[41]

Following the cessation of the storm, from Aug 19 onwards there was a belt of light, faint E–W white cloud slightly separated from the hood. Sometimes it consisted of several narrow cloud bands. By late August, the NPH – having become temporarily more active during the global storm – was faint, and the foregoing phenomenon had ceased. At this time, the hood sometimes showed an exceptionally dark border.

The hood was hardly to be seen by Sep 1 but was brighter again after mid-November. On Nov 2, the Director found the NPH expanded quite far south up the morning terminator under CM = 151°. By late December the hood was bright white, wide and conspicuous.

### The reappearance of the NPC in 2019

The NPH looked rather thin around CM = 130° to the Director on 2019 Feb 21–22. On Feb 24 ($Ls$ = 346°), M. R. Lewis was probably the first to image a well-defined ground cap with dark border. The images by Kardasis and Kidd on Mar 18 ($Ls$ = 357°) confirmed the narrow, bright limb arc of NPC. The hood lingered at some longitudes. On Mar 24 Maksymowicz and on Mar 28 the Director visually confirmed a narrow, bright NPC with darker edge.

Excellent late images by M. R. Lewis on Apr 10,[13] May 21; Ito on Jun 3; and Hillebrecht on Jun 29 ($Ls$ = 46°, $D$ = 3.7″) showed the cap clearly diminishing. Accurate measurements were impossible.

## South polar region

Figure 17 illustrates aspects of the 2018 SPC recession.

### South polar hood (SPH) to south polar cap (SPC) transition & the spring SPC

The S. polar hood was observed during the earlier part of the apparition and, as described in the later subsection 'S. hemisphere cold traps', it sometimes extended to lower latitude over *Argyre* and *Hellas*. There was sometimes a brighter morning region around the longitude of *Aonius Sinus*. After early March of 2018, the value of $D_e$ became negative, allowing a better view of the S. polar area. Here we briefly describe the transition from hood to cap during 2018 April–May.

On Apr 7 (CM = 067°), Foster saw a large and obviously bluish SPH extending to low latitude, as it does at that season and CM, though in red (and infrared) light the polar region was smaller and much less bright: the first suggestion of a ground cap at $Ls$ = 155°. By mid-April, the cap was seen to be darker in its southern parts in all wavebands, as it always is at this season. Peripheral hood persisted at some longitudes – for example, in its incursions into S. *Argyre* and *Hellas* – at which CM latitude measures of the ground cap could not yet be made. The last trace of the hood was

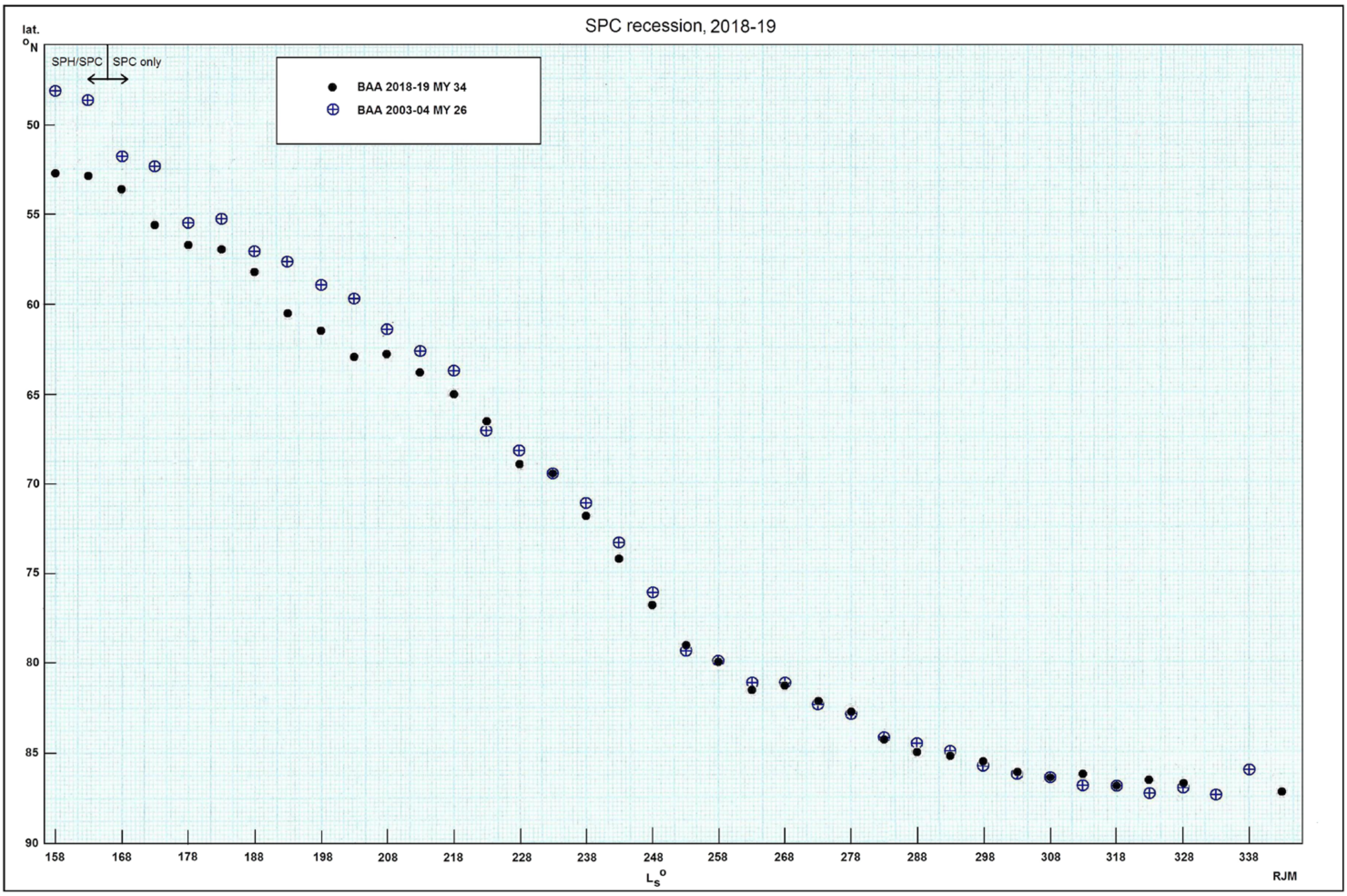


**Figure 18.** SPC recession curve, 2018–'19, with latitudes plotted for 5° intervals in *Ls*. The 2003 recession is also shown. Both caps were hood-free from *Ls* = 166°, as indicated at top left. *(R. J. McKim)*

seen in S. *Hellas* on about Apr 27. Thus, during *Ls* = 155–166°, cap and hood were simultaneously present. In 2003,[45] the corresponding interval was *Ls* = 152–166°.

The interior features of the cap are next described. The interaction between it and the global storm was discussed in Part I.

## *SPC fragmentation:* Novus Mons

In 2003, the separation of *Novus Mons* (the 'Mountains of Mitchell') by the *Rima Australis* rift from the cap had been completed by *Ls* = 238°.[45] In 2018, this areocentric longitude was reached on Aug 26, when the recession curve was following 2003 very closely; the 2018 mean cap diameter was then at most a mere fraction of a degree smaller than in 2003.

From Australasia, circumstances were ideal for viewing this area upon the evening limb – the best position for judging separation. Valimberti's excellent image sequences for Aug 22 & 23 do not quite show it separated, but images by Casely, Milika & Nicholas and Valimberti for Aug 24 (*Ls* = 237°) & 25 appear to show complete separation, the tiniest fraction in advance of 2003. Cantor (2006) found from spacecraft data that *Novus Mons* was more extensively defrosted than usual in 2001 following that year's global dust storm: evidence of a warming effect.[46]

At separation time, the SPC east of the rift was locally still faded by dust deposition, making it harder than usual to judge separation. Late July images had shown more extensive fallout of orange-tinted dust east of and partly over *Novus Mons*. At that time, *Rima Australis* was already well developed in its western part, but not complete. As early as Jun 26, their work had revealed the commencement of the rift on the west. The Director on Aug 1–6 had observed *Novus Mons* as a bright spot within the cap: just a few of many such sightings.

The fragmentation of *Novus Mons* was typical. Peach on Sep 8 resolved a trail of remnants in finer detail than in any previous Earth-based image. On Sep 17 (Figure 17I) & 24, he secured extraordinarily fine details of the enfolding fragmentation, when there were six discrete nuclei: one in the main, preceding component and perhaps five in the secondary, following one. Flanagan and Valimberti on Sep 25 & 26 also showed the main division into two parts. The W. fragment was barely detectable to Foster on Oct 8–11. In 2003 this fragmentation event had occurred close to opposition, but in 2018 the disc diameter was much smaller.

*Novus Mons* dwindled in size as the planet receded; for instance, a dull remnant was imaged as late as Dec 21 by Olivetti and Dec 24 by M. R. Lewis.

## *SPC fragmentation: other features*

The SPC N. edge was obviously irregular from an early stage: for example, Heffner (Apr 28) and Valimberti (Apr 30) both show the effect well. Static bright patches observed from late April indicated regions subliming faster than their surroundings, and these were well seen despite the interference of the global storm. *Novus Mons* and *Argenteus Mons* were only two such areas.

The seasonal appearances of other features, such as *Magna Depressio*, *Thyles Collis*, *Thyles Mons*, and an unnamed rift facing *Solis Lacus* that ultimately divides the summer cap remnant in two, were all well observed in 2018 and are particularly shown in Figure 17. Detailed descriptions were given in the 2003 report.[45]

*Argenteus Mons* appeared as a bright point within the cap in early May, later protruding at its edge, but – unlike *Novus Mons* – it does not separate to form an outlier. McKim saw it well in July–August (Figures 13D, E, G).

The rift facing *Solis Lacus* had appeared as a small indent in the cap edge by early August. Peach (Nov 22 – Dec 26) showed its development in unprecedented detail as it extended into the cap. By Dec 1, it had cut the summer remnant in two; one half sublimed and dwindled faster than the other (Figure 17J–L).

## SPC quantitative recession, 2018–'19

On account of the axial asymmetry of the summer remnant, we prefer to measure the SPC by its E–W diameter, but prior to opposition the planet's phase hindered such measurements and the global dust storm commencing on May 30 often rendered its E–W limits indistinct. Thus, from 2018 Apr 8 to Aug 30 (*Ls* = 156–240°), we measured the latitude of the N. edge of the cap upon the CM. We took E–W measurements from Aug 31 till 2019 Feb 21, *Ls* = 241–345°. As a check on the agreement between methods, data for *Ls* = 241–245° were measured both ways, and the mean latitudes found to agree within 0.6°. Red images were used in preference whenever available, and the data grouped in bins of 5° in *Ls*. We measured 1,368 images from 60 observers: see Table 3 and Figure 18.

Prior to 2018, the best images for accurate ground-based measurement of the SPC recession had been from 2003. That year's apparition exhibited two large Regional dust storms, but no encircling one. Table 3 and Figure 18 compare latitude data for both apparitions. The agreement is in general extremely close. The late winter cap in 2003 was obviously a little larger than in 2018, but by *Ls* ~ 178° they were of similar size and remained so till *Ls* ~ 188°. Then the diameter difference between the years (Table 3) became consistently greater than 5° during *Ls* = 191–205°, decreasing quickly thereafter. This very significant deviation from 2003 arose as dust from the global storm (which had commenced at *Ls* = 184°) had begun to cover the SPC from *Ls* = 190° onwards, and falling out upon the cap. This lower albedo fallout accelerated the 2018 recession relative to 2003. Dust deposited upon the cap decreases its albedo and this facilitates absorption of solar radiation, accelerating the recession.[47] After *Ls* = 220°, interannual differences were not significant, and never exceeded the standard deviations of *circa* 0.5–1° within each data set.

Prior to 2003, we had to make use of micrometer data and measurements upon photographs or drawings. The two such years best observed were 1988 and 1956. It may be of interest to summarise our BAA photographic data from 1988,[48] with the writer's own treatment of 1956 photographic data published by A. Dollfus.[49] These more time-limited data are included in Table 3.

The only previous opposition with a global storm for which images suitable for SPC latitude measurement are to hand is 2001. The storm did not cover the SPC as extensively as in 2018. At *Ls* = 262° in 2001, Cantor (2006) found that those longitudes affected by fallout regressed faster in that year.[46] There was however only a small effect upon the overall recession curve.[50] BAA 2001 data also suggested an accelerated recession,[28]

### Table 3. SPC latitude data, 2018–'19

| *Ls* (°) range | *Ls* (°) mean | *Mean latitude of south polar cap north edge (°)* | | | | *Mean SPC diameter difference (°)* |
|---|---|---|---|---|---|---|
| | | *1956* | *1988* | *2003* | *2018* | *2018 – 2003* |
| 156–160 | 158 | | | 48.2 (3) | 52.7 (6) | – |
| 161–165 | 163 | | | 48.4 (2) | 52.9 (19) | – |
| 166–170 | 168 | | | 51.8 (8) | 53.7 (26) | – |
| 171–175 | 173 | | | 52.4 (13) | 55.6 (29) | –6.4 |
| 176–180 | 178 | | | 55.6 (20) | 56.9 (10) | –2.6 |
| 181–185 | 183 | | | 55.2 (11) | 57.0 (28) | –3.6 |
| 186–190 | 188 | | | 57.0 (25) | 58.3 (46) | –2.6 |
| 191–195 | 193 | | | 57.7 (41) | 60.8 (58) | –6.2 |
| 196–200 | 198 | | | 59.0 (45) | 61.6 (56) | –5.2 |
| 201–205 | 203 | | | 59.8 (40) | 63.0 (65) | –6.4 |
| 206–210 | 208 | | | 61.6 (50) | 62.8 (87) | –2.4 |
| 211–215 | 213 | | | 62.8 (43) | 63.9 (112) | –2.2 |
| 216–220 | 218 | | | 63.7 (66) | 65.0 (91) | –2.6 |
| 221–225 | 223 | 67.8 (2) | | 67.1 (58) | 66.6 (98) | +1.0 |
| 226–230 | 228 | 67.8 (4) | | 68.2 (48) | 68.9 (64) | –1.4 |
| 231–235 | 233 | 67.6 (9) | | 69.6 (64) | 69.3 (88) | +0.6 |
| 236–240 | 238 | 70.2 (10) | 73.5 (6) | 71.1 (48) | 71.8 (65) | –1.4 |
| 241–245 | 243 | 72.5 (7) | 72.0 (3) | 73.3 (57) | 74.2 (52) | –1.8 |
| 246–250 | 248 | 76.1 (10) | 76.5 (9) | 76.2 (74) | 76.8 (18) | –1.2 |
| 251–255 | 253 | 77.8 (7) | 78.5 (7) | 79.4 (36) | 79.0 (29) | +0.8 |
| 256–260 | 258 | 79.5 (2) | 79.5 (14) | 79.9 (52) | 80.0 (28) | –0.2 |
| 261–265 | 263 | 80.6 (10) | 81.5 (5) | 81.1 (53) | 81.6 (29) | –1.0 |
| 266–270 | 268 | 81.5 (5) | 81.5 (14) | 81.1 (29) | 81.3 (26) | –0.4 |
| 271–275 | 273 | 82.4 (13) | 82.0 (11) | 82.3 (24) | 82.3 (18) | +0.0 |
| 276–280 | 278 | 83.3 (5) | 82.5 (9) | 82.9 (38) | 82.7 (27) | +0.4 |
| 281–285 | 283 | 84.3 (11) | 83.0 (7) | 84.2 (22) | 84.3 (42) | –0.2 |
| 286–290 | 288 | – (0) | 84.0 (3) | 84.5 (12) | 85.0 (22) | –1.0 |
| 291–295 | 293 | – (0) | 84.0 (4) | 85.0 (24) | 85.2 (21) | –0.4 |
| 296–300 | 298 | 86.0 (2) | 84.5 (3) | 85.8 (9) | 85.5 (37) | – |
| 301–305 | 303 | 85.5 (2) | 85.5 (4) | 86.1 (18) | 86.0 (18) | +0.2 |
| 306–310 | 308 | 85.7 (1) | 86.0 (4) | 86.4 (8) | 86.5 (13) | – |
| 311–215 | 313 | | | 86.9 (13) | 86.2 (11) | +1.4 |
| 316–320 | 318 | | | 86.8 (22) | 86.8 (16) | +0.0 |
| 321–325 | 323 | | | 87.3 (1) | 86.4 (9) | – |
| 326–330 | 328 | | | 87.0 (1) | 86.7 (3) | – |
| 331–335 | 333 | | | 87.5 (1) | – (0) | – |
| 336–340 | 338 | | | 86.0 (2) | – (0) | – |
| 341–345 | 343 | | | – (0) | 87.2 (1) | – |

For each *Ls* bin, the derived mean latitude is followed by the number of measurements in brackets.

In the final column, the difference in *diameter* between 2018 and 2003 is calculated for when each *Ls* bin contains *10 or more* observations in each year.

Photographic data are given for 1956 (mostly from Pic du Midi and Johannesburg) and 1988 (BAA); electronic images for 2003 (BAA) and 2018 (BAA). Dollfus published individual 1956 cap radius measures graphically,[49] which the writer measured and grouped into the same *Ls* bins used for the BAA data.

The mean standard deviations within each *Ls* bin are *circa* 1° (2003, 2018) and *circa* 2° (1956, 1988).

but the value of $D_e$ was positive for a considerable time, greatly limiting the Earth-based measurements.

The comparison of 2018 with 2003 shows rather convincingly that it is likely that interannual differences in previous cap recession curves are likely to be due to the effects of deposited dust. In the past, several authors have sought a link between recession rate and the solar cycle.[51] Dust storms are less common over the NPC and cause less obscuration. The year 2010 saw a remarkable dust cloud across the NPC, but it was short-lived, with no acceleration of the cap recession.[54]

The 2018 summer cap remnant average latitude (*Ls* = 306–345°) was 86.6°, corresponding to a diameter of 6.8°. In 2003 over the same period, its average latitude was 86.8°, which is insignificantly different.

### The return of the SPH in 2019

On 2019 Feb 7 (*D* = 5.9″), in good seeing, the Director saw the SPC clearly as a minute point: his last definite sighting. On Feb 10 he saw only a small diffuse whiteness, an aspect confirmed with a higher-resolution image by Kardasis (Figure 16), who from now onwards also imaged a partial E–W band of white cloud north of the pole.[13] On Feb 13 the Director saw the polar cloud clearly, but by Mar 28 it appeared small and weak, as the sign of $D_e$ no longer favoured observation. Kidd also imaged the cloud on the latter date, and Adachi saw it visually on Apr 4–6 (600mm Cass.).

A few further sightings of the tiny asymmetric cap were made, but visibility depended strongly upon CM: it was faintly resolved in Maxson's images up to Feb 12, while excellent images for Feb 19–21 (*Ls* = 345°) by Kidd and M. R. Lewis showed a tiny cap and a patch of cloud north of it. Kardasis could still image the cloud belt to the north in early March, as could Lewis till Apr 10.

Thus the polar cloud appeared at *Ls* = 338°, while the ground cap was followed till *Ls* = 345°, but we emphasise the difficult conditions of observation.

### S. hemisphere cold traps

#### *Hellas*

Seasonal frost deposition – greatly brightening the basin in the visible waveband – is completed by *Ls* = 90°. Mars remained very distant at that season, but observers still were able to detect it. On Oct 8–9 (*Ls* = 071–072°), *Hellas* near midday was not yet bright to Iwamasa or Kumamori, but IR images by Maxson on Nov 2–3 (*Ls* = 082–083°) showed it light and therefore frosted, and it was obviously bright in white light to him on Nov 3–5. (MRO first detected ground frost in late October.[9]) Foster's IR image of Nov 21 also showed it rather light, while in his Nov 26–27 colour images it was bright around local noon (and light in R and IR).

In December–January, *Hellas* was brilliantly white (Figure 16), the brightness extending beyond the confines of the basin to the east. On Feb 2–5, Foster showed a small dark patch of bare ground west of its centre. The dark area had broadened considerably on Feb 6, though diurnal cloud in the morning and evening often masked this sign of frost clearance (Figure 16, Mar 1). By Mar 16, to Foster the basin floor was mostly dull, but a small whitish patch to the SE showed that the SPH remained in part of the basin. This invasion persisted till late April.

Following the global storm, there were sometimes signs of weak diurnal cloud along the morning terminator at *Hellas* (first recorded by Bertrand in UV on Sep 18), but it was never strong.

#### *Argyre*

*Argyre* was a weakly lighter area within the SPH in 2018 January. A better-defined small bright area (surrounded by weaker polar clouds) in the south of the basin was visible from February to late March, indicating surface frost: see the image by Peach of Feb 4 in Figure 16. The MRO bulletin for Feb 26 – Mar 4 confirmed that frost had reached latitude 50° (the mid-latitude for *Argyre*).[9] Like *Hellas*, it was strongly affected by diurnal cloud. By late April it was no longer bright, apart from the effect of a slight incursion by the SPH. Both *Hellas* and *Argyre* were involved with dust storms occurring at the edge of the spring polar cap: see earlier.

## Martian satellites

Both satellites were imaged by Kardasis on Jul 11, by Tatum on Aug 11, and seen visually by Abel from Flagstaff.[5]

## Conjunctions & the sky around opposition

The close conjunction of Mars with Jupiter during 2018 Jan 4–7 was observed by Abel, Eagle, McKim, Peach and Radice. Closest approach (separation 10 arcminutes, or 0.2°) was on Jan 7.[55] To the writer, the strong reddish naked-eye tint of Mars was enhanced by the event.

On 2018 Dec 7, Mars was separated from distant Neptune by just 0.04°; a superb image of the conjunction was sent by Kardasis

**Figure 19.** Telescopic view of the conjunction of Mars and Neptune, 2018 Dec 7, 16:59 UT. Prime-focus image with ASI 178MC. *(M. Kardasis)*

(Figure 19). The Director saw the conjunction with binoculars, and observed Neptune's limb darkening and tiny, featureless, bluish disc telescopically.

By photographing the planet's 'glitter trail' upon the sea on 2018 Aug 5, D. Strange (Salcombe Regis) enhanced its coloration. See Figure 20A.

Finally, on a visit to Chile in 2018 August, Peach created an evocative image showing Mars, the Chilescope domes,[39] the Milky Way, and the Greater and Lesser Magellanic Clouds (Figure 20B).


**Figure 20.** Mars in the sea and sky. **(A)** A 'glitter trail' in the sea on 2018 Aug 5 (Canon 40D), photographed from Salcombe Regis, Devon. *(D. Strange)* **(B)** Still close to opposition on 2018 Aug 6, Mars shines brilliantly above the Chilescope domes, with the Milky Way and Magellanic Clouds on the left of this seven-frame composite photograph. *(D. A. Peach)*

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Dominic Ford, Callum Potter and Stuart Morris helped greatly with migrating and reconstructing the Section website in 2018, while Andrew Morris reformatted many PDF files of past BAA Mars reports, which are now available for downloading. We thank all our observers, a number of whom are shown with their telescopes in Figure 21.

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## Notes & references

41 McKim R. J., 'The 2018 opposition of Mars & the global dust storm: Part I', *J. Br. Astron. Assoc.*, **132**, 285–301 (2022)
42 Some of these MRO images are available in the OAA Mars Section's *Communications in Mars Observations*, no. 468 (2018).
43 *ibid.*, no. 469 (2018)
44 McKim R. J., 'The opposition of Mars, 2014', *J. Br. Astron. Assoc.*, **131**, 105–112 (2021)
45 McKim R. J., 'The Great Perihelic Opposition of Mars, 2003', *ibid.*, **120**, 280–295 & 347–357 (2010)
46 Cantor B. A., *Icarus*, **186**, 60–96 (2006)
47 The same phenomenon is used to good practical effect on Earth, where soot is spread over unwanted snow to cause it to melt faster. Suspended dust that remains for a long time in the atmosphere would however block sunlight, and cause cooling of the surface (the 'Nuclear Winter' hypothesis). It seems dust fallout upon the SPC must have happened quickly.
48 McKim R. J., 'The opposition of Mars, 1988', *J. Br. Astron. Assoc.*, **101**, 264–283 (1991)
49 A. Dollfus, *Annales d'Astrophysique*, **28**, 722–747 (1965). This paper used high-quality double-image micrometrical and photographic latitude results from the worldwide 1956 Mars campaign.
50 Benson J. L. & James P. B., *Icarus*, **174**, 513–523 (2005)
51 E–M. Antoniadi was convinced that there was a relationship between solar activity and the recession rate of the polar caps. His friend the Abbé Moreux also explored this theme.[52] Much more recently, G. di Giovanni again found evidence for an apparent solar connection.[53] The writer feels that interannual changes in recession must be largely due to the effects of dust fallout, as the 2018 data prove that dust deposition accelerates recession.[41]
52 Abbé Th. Moreux, in *La Vie sur Mars* (Chez Gaston Dion, Paris, 1924, p.85), even produced a graph that showed an apparent correlation between the deviation in size of the Martian polar caps from the mean, solar activity, and the number of terrestrial icebergs, 1888–1911.
53 di Giovanni G., *J. Br. Astron. Assoc.*, **122**, 349–355 (2012)
54 McKim R. J., 'The opposition of Mars, 2010', *ibid.*, **128**, 231–239 (2018)
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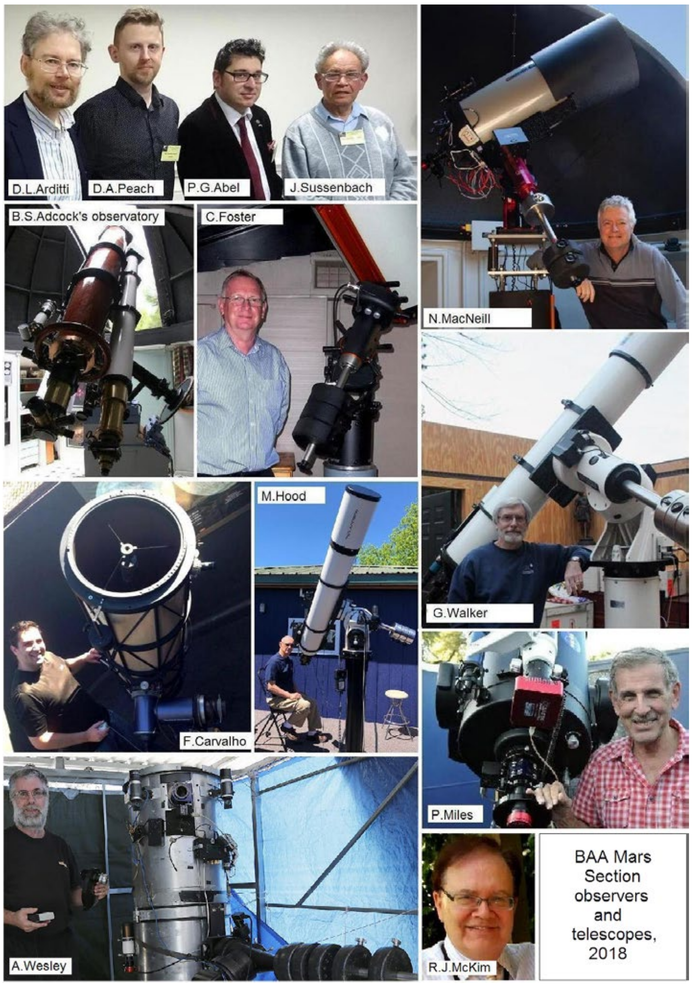


**Figure 21.** Some observers and their telescopes, 2018.