The opposition of Mars, 1999

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

The 1999 martian apparition was followed by BAA members while *Mars Global Surveyor* was monitoring the planet from martian orbit. The planet's surface showed little change from 1997, indicating the absence of any great dust storm since solar conjunction. The long period of telescopic coverage enabled us to conclude that neither was there any planet-encircling storm in the southern martian spring or summer in 1999–2000. Three small telescopic storms were followed along the *Valles Marineris*, and two were seen at the edge of the summer N. polar cap. Dust storms commencing at the historically rarely-active *Margaritifer Sinus* emergence site (*MGS* data) point to ongoing changes in the fallout pattern of atmospheric dust. White cloud activity was high before and around opposition time – in northern midsummer – with morning and evening limb hazes, the equatorial cloud band (ECB) and orographic clouds. The ECB 'season' was identical to 1997, pointing to an equally low level of atmospheric dust-loading. Comparison with historical records suggests that the seasonal 'wave of darkening' may be partly attributable to the annual disappearance of the ECB. A 'polar cyclone' imaged by the *Hubble Space Telescope* between *Mare Acidalium* and the northern cap was followed over several days. The seasonal behaviour of the NPC, including its transition to the polar hood, was well observed. Its recession (observed from northern mid-spring) was a little slower than usual. The formation of the SPC from its winter hood, and its early recession, was also recorded. This report covers the period 1998 September 12 (Ls = 28°) to 2000 March 13 (Ls = 318°).

Introduction

Mars came to opposition in Virgo on 1999 April 24. The planet was closer than in 1997,[1] being 87.4 million km distant with an apparent disk diameter reaching 16.0 arcsec on opposition day, but its declination then was –11.7°, placing it lower in northern skies. The planet was closest to Earth on 1999 May 1 (D = 16".2). Compared with 1997,[1] the observations made from the UK were fewer. Nevertheless, coverage was still excellent.

Physical data for the 1999 opposition

Solar conjunction	1998 May 12	Ls = 326°
Spring Equinox N. hemisphere/ Autumn Equinox S. hemisphere	1998 Jul 14	Ls = 0°
Aphelion	1998 Dec 14	Ls = 70°
Summer Solstice N. hemisphere/ Winter Solstice S. hemisphere	1999 Jan 29	Ls = 90°
Opposition	1999 Apr 24	Ls = 129°
Autumn Equinox N. hemisphere/ Spring Equinox S. hemisphere	1999 Jul 31	Ls = 180°
Perihelion	1999 Nov 24	Ls = 250°
Winter Solstice N. hemisphere/ Summer Solstice S. hemisphere	1999 Dec 25	Ls = 270°
Spring Equinox N. hemisphere/ Autumn Equinox S. hemisphere	2000 May 31	Ls = 0°
Solar conjunction	2000 Jul 01	Ls = 15°

At opposition the latitude of the centre of the disk as seen from Earth was +18°. In late 1998 it had ranged from +21 to 25°; it decreased to +15° by early 1999 March, rose to +23° by June, then decreased again to reach 0° in mid-October, attaining –22° by the year's end.

We received 4,079 observations: 1,139 drawings, 2,936 CCD images and 4 photographs from 88 observers, between 1998 September 12 (Ebisawa, Ls = 28°) and 2000 March 30 (Minami, Ls = 327°). Most UK observers stopped work after 1999 mid-August due to the extreme low altitude of Mars at sunset: the Director's last view from the UK was from Cornwall on August 10, the evening before the total solar eclipse. Some could still continue; by late December the declination was less southerly. The planet could not be viewed at the precise moment of the new millennium from Europe, but Martin Gaskell observed from the USA on 2000 January 1d 00h 00m: appropriately enough, *Mare Chronium* (the Sea of Time) was on view.

The numbers of days covered, by month, were as follows (actual/possible): 1998 Sep 4/30, Oct 20/31, Nov 17/30, Dec 17/31; 1999 Jan 22/31, Feb 24/28, Mar 30/31, Apr 30/30, May 31/31, Jun 30/30, Jul 30/31, Aug 25/31, Sep 11/30, Oct 12/30, Nov 12/30, Dec 17/31; 2000 Jan 13/31, Feb 11/29, Mar 7/31. Some of the BAA data were presented in a meeting talk,[2] in an Interim Report,[3] and in Section *Circulars*.[4]

Especially long runs of CCD observations came from Tomio Akutsu, Toshihiko Ikemura, Frank Melillo, David Moore and Don Parker: Parker sent over 900 images, and several have already been reproduced in colour in the *Journal*.[3] Maurizio Di Sciullo and Antonio Cidadão,[5] both new contributors, sent superb high resolution images. High resolution monochrome images also came from Stefan Buda and Bratislav Curcic, and Jean Dijon. The best UK imaging was done by Terry Platt.[3] Makoto Adachi, Gianluigi Adamoli, Nicolas Biver, Ed Crandall, Mario Frassati, David Gray, Walter Haas, Masatsugu Minami, Dan Troiani and the Director managed good series of drawings.

During the previous opposition, *Mars Pathfinder* had operated for 84 sols from 1997 July 4 onward; two months later, *Mars Global Surveyor (MGS)* had arrived in Mars orbit, and has operated nearly continuously since then. *MGS*, in its Sun-synchronous polar orbit, can image only strips of the disk at once, and its daily range of observable longitudes is limited. Contact with the ill-fated *Mars Climate Orbiter* was lost upon its arrival at the planet in 1999 September,[3] and *Mars Polar Lander* likewise in December.[3] Relevant *Hubble Space Telescope* (*HST*) data were not numerous in 1999; *HST* and *MGS* images may be viewed online.[6] Groups other than the BAA also followed the planet: the OAA (Japan) published bulletins,[7] and the ALPO (USA) issued observing hints[8] and *Circulars*.[9] Schmude has published personal observations,[10] as have Nakajima and Minami.[11] Several observers supported *Marswatch* by uploading images or drawings to an online database.[12] Dr S.Ebisawa monitored the apparition by visual and polarimetric techniques.[13] Ebisawa's general chart[14] remains the standard for telescopic nomenclature. Studies of the seasonal water-ice clouds by Benson *et al*.[15] and by Glenar *et al*.[16] are relevant to our discussions of white clouds. Cantor *et al*.[17] and Smith & Pearl[18,19] present essential *MGS* data concerning dust storms. Clancy *et al*.[20] have continued their microwave studies of atmospheric temperatures. James & Cantor have also studied the NPC recession in 2000.[21] A Section *Memoir*[22] enables comparisons of historical dust storms with contemporary data.

The present Report is a continuation of those for 1997[1] and 1995.[23]

Observations

Surface features

Generalities

With each previous report (1980 to 1997) the Director published a hand-drawn apparition map. Lack of variation in the albedo features hardly demands a new chart for 1999. Instead we take the opportunity to publish a chart impersonally synthesised from *MGS* imagery (Figure 1).

Indeed, very little change in the martian surface features has taken place throughout the 1990s. To the Director, a close comparison of the best 1999 CCD work with 1997 showed only meteorological differences. We therefore focus upon selected areas with a history of change, and apparent colours. For Mars, E. and W. are used areographically: in the normal inverted telescopic image the *p*. side of an albedo feature is its E. side. We refer readers to the 1995 and 1997 reports[1,23] for current reference maps.

Martian colours

Colours in the dark markings are apparent in the images reproduced here (Figures 1–2). The reporting of visual martian colours – important for historical continuity – is hindered by subjective colour contrast. Colours may also be modified by the martian atmosphere. Nonetheless, systematic recording does help in the interpretation of atmospheric phenomena. At the appropriate season, the white equatorial cloud belt (ECB) crossing *Syrtis Major* strongly scatters blue light, an effect further enhanced under oblique lighting. The presence of the ECB (until about Ls = 145°) gives rise to the classic '*Syrtis* blue cloud', which was again well seen in 1999. In 1984, F. C. Butler[24] found a darkening of the N. part of *Syrtis Major* from Ls = 156° onwards, and subsequently a southward darkening of the rest. Although unconfirmed by the other BAA observations that year, similarity in seasonal date makes it entirely possible that the 'wave of darkening' reported in the past may simply be associated with the seasonal disappearance of the ECB.

Features north and south of the ECB are generally only affected by diurnal cloud. The effect of the latter upon colour is nicely shown by the following: in 1999 April, the *Aetheria* secular darkening appeared brown to the N. and blue to the S. to Minami, when the S. portion was partly hidden beneath morning cloud. On mid-disk in June–July it all appeared brown.

Several observers commented upon the deep blue tint seen in the darker markings of the S. hemisphere. *Syrtis Major* was the bluest feature to McKim (May–June), though he also noted less strong blue tints in *Mare Cimmerium* and *Mare Tyrrhenum*. Biver habitually showed *Mare Tyrrhenum*, *Syrtis Major*, *Sinus Sabaeus*, *Sinus Meridiani*, *Aurorae Sinus*, *Mare Cimmerium* and *Solis Lacus* as dark bluish on his sketches. Devadas found the S. markings bluish-green under CML = 57°; Peach (May 20) drew *Syrtis Major* as blue. Minami also found *Aurorae Sinus* and *Sinus Sabaeus* bluish generally, but *Mare Sirenum* looked greenish in the evening in April.

Minami made more detailed notes: in 1999 February, the *Syrtis Major* appeared blue-green in the evening, where it was covered by white cloud from *Libya*. In the morning it also looked blue-green. It was of course dark upon mid-disk. In late March–early April it looked light blue

Figure 1. MGS 1999 composite map.
A mosaic of 24 red and blue *MGS* MOC wide angle camera images taken on a single northern summer day in 1999 April. A cylindrical projection with 90°N latitude at the bottom, 60°S at the top, and 180° longitude on both the right and left sides. The high southern latitudes were in total winter darkness at the time the data were collected. *NASA/JPL/Malin Space Systems*.

or bluish in the a.m; later in the morning it became blue-green, then finally upon mid-disk the dark blue colour appeared. In May the *Syrtis* appeared darker, a dull blue in the a.m., sometimes tinged with white. No doubt it had become darker due to the seasonal fading of the white belt of equatorial cloud. In June Minami found it dark blue even in the morning, the ECB now gone.

In the north, Biver also showed *Mare Acidalium* and *Utopia* as bluish, but most observers saw the northern features as less obviously blue. Indeed, McKim (June) and Minami (January and March) found *Utopia* definitely brownish. *Mare Acidalium* was brownish to Minami from 1998 October to 1999 March; Devadas and McKim, less sensitive to colours, simply saw *Mare Acidalium* as grey. Some other northern features were brown: Frassati and Minami found *Propontis I* to be dark brown. To Minami, *Phlegra* was densely reddish in March, dark brown in August; *Nilokeras* was also brown.

The OAA again remarked upon 'densely reddish areas' following *Mare Acidalium*, and these were noted from 1998 December onwards. Specifically these regions extended from *Mareotis Lacus* to *Ascraeus Mons*; Biver on March 7 also saw them reddish.

Fewer comments about the light desert areas were generally made. McKim habitually saw these as a brickdust orange. To Minami, *Cebrenia* was specifically reddish.

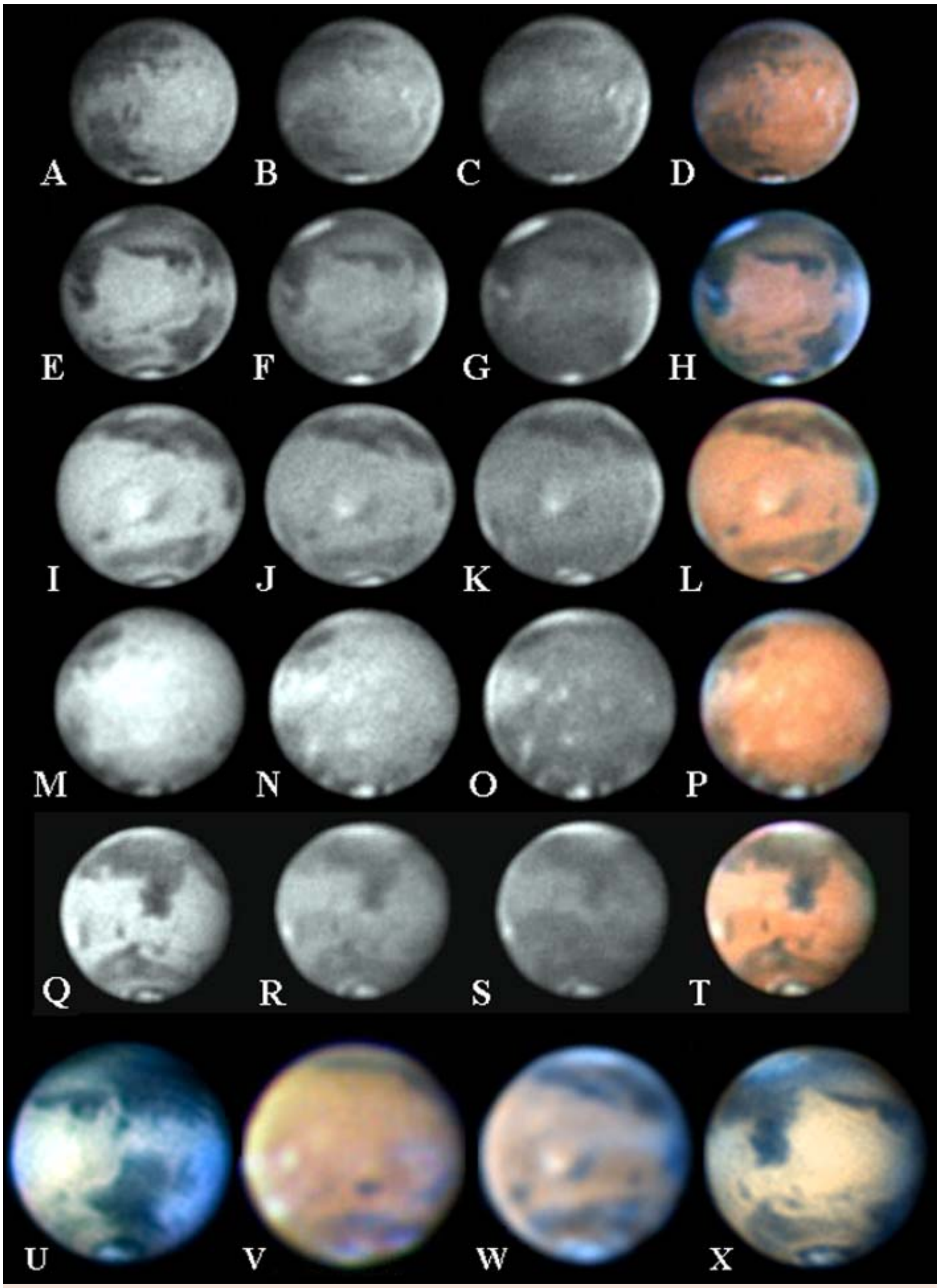

Figure 2. CCD images.
***Top five rows*:** Mars 1999 filter images and colour composites by M. Di Sciullo with 254mm refl. and Starlight Xpress HX-516 CCD camera at f/48. (Red filter 610–720nm, green filter 490–590nm, blue filter 400–510nm, with IR-block.)
A–D: April 3d 07h 23–27m, CML= 7°. Orographics; *Solis Lacus* fine details.
E–H: April 11d 05h 37–39m, CML= 337°. *Libya* p.m. cloud cuts across *Syrtis Major*; *Syrtis* blue cloud.
I–L: April 24d 05h 52–55m, CML= 226°. *Olympia*; *Syrtis* blue cloud.
M–P: May 3d 03h 49–54m, CML= 118°. Orographics.
Q–T: May 23d 02h 54–59m, CML= 279°. ECB faintly crosses disk.
***Bottom row*:** Composite CCD images by T. Akutsu (V) with 320mm refl., and Teleris 2 (SSI) CCD camera, and by A. Cidadão (U, W, X) with 254mm Schmidt–Cass., and ST-5C CCD camera with SBIG filters. U and X are RRGB composites; V is a RGB composite; W is a R(G)B composite.
U: 1999 May 7d 23h 59m, CML= 18°. Extensive a.m. clouds.
V: 1999 May 12d 13h 06m, CML= 174°. Orographics.
W: 1999 May 19d 21h 31m, CML= 235°. Bright *Elysium Mons*; ECB from *Elysium* to *Libya*; *Syrtis* blue cloud.
X: 1999 May 10d 21h 41m, CML= 318°. *Chasma Boreale*; *Huygens* in *Iapigia*.

Region I: long. 250–010°

Refer to Figure 4 in particular. The *HST* pictures of this region are closely similar to 1997, and the tiny details around the periphery of *Syrtis Major* looked more or less identical. Only *Hellas* looked different upon first sight,

Table 1. Observers of Mars in 1999

Name	*Location*	*Instrument(s)*
P. G. Abel	Burton-on-Trent, Staffs.	114mm OG
M. Adachi	Otsu, Japan	310mm refl.
G. Adamoli	Verona, Italy	108mm OG
B. S. Adcock**	Melbourne, Australia	300mm refl.
L. Aerts	Heist-op-den-Berg, Belgium	175mm OG & 250mm SCT
T. Akabane**	Steward Observatory, Univ. of Arizona, USA	1.52 & 1.55m refls.
T. Akutsu**	Tochigi, Japan	320mm refl.
S. Beaumont	Windermere, Cumbria	300mm refl.
N. Biver	Oahu, Hawaii, USA	256mm refl.
M. Bosselaers	Berchem, Belgium	254mm refl.
A. G. Bowyer	Epsom Downs, Surrey	300mm refl.
S. Buda & B. Curcic**	Melbourne, Australia	250mm Dall–Kirkham Cass.
T. R. Cave	Long Beach, California, USA	325mm refl.
A. Cidadão**	Oeiras, Lisbon, Portugal	254mm SCT
E. Colombo	Milan, Italy	254mm refl.
B. Colville**	Cambray, Ontario, Canada	300mm SCT
T. Corstjens	Bocholt, Belgium	150mm Mak–Cass.
E. Y. Crandall	Winston–Salem, North Carolina, USA	254mm refl.
W. Cuppens	Gruitrode, Belgium	355mm refl.
I. Dal Prete	Verona, Italy	200mm refl.
P. Devadas	Madras, India	355mm refl.
J. Dijon**	Champagnier, France	500mm refl.
C. Ebdon	Highams Park, London	254mm refl.
F. Feys	Izegem, Belgium	508mm refl.
D. Fisher	Sittingbourne, Kent	215mm refl.
M. Foulkes	Hatfield, Herts.	254mm refl.
M. Frassati	Crescentino, Italy	203mm SCT
M. Gaskell**	Lincoln, Nebraska, USA	203mm SCT
M. V. Gavin**	Worcester Park, Surrey	305mm SCT
D. Gazdik	Brooklyn Centre, Minnesota, USA	203mm refl.
D. L. Graham	Brompton-on-Swale, N. Yorks.	150mm Mak–Cass.
D. Gray	Kirk Merrington, Spennymoor, Co. Durham	415mm Dall–Kirkham Cass.
P. Grego	Birmingham	150mm refl.
W. H. Haas	Las Cruces, New Mexico, USA	203 & 320mm refls.
A. W. Heath	Long Eaton, Notts.	203mm SCT & 254mm refl.
M. J. Hendrie	Colchester, Essex	152mm OG
C. E. Hernandez	Miami, Florida, USA	203mm SCT
E. J. Hysom	Cambridge Univ. Observatory	300mm OG
T. Ikemura**	Nagoya, Japan	310mm refl.
H. Ishadoh	Naha, Okinawa, Japan	310mm refl.
T. Iwasaki	Fukuoka, Japan	210mm refl.
G. F. Johnstone	Birdingbury, Warwicks.	203mm SCT
D. P. Joyce	Chicago, Illinois, USA	254mm & 457mm refls.
D. W. Knisely	Beatrice, Nebraska, USA	254mm refl.
E. Lo Savio	Catania, Italy	203mm SCT
P. Lyon*	Birmingham	203mm SCT
G. Marino	Catania, Italy	203mm SCT
R. J. McKim	Colchester, Essex	152mm OG
	Upper Benefield, Northants.	216mm refl.
	Truro, Cornwall	203mm SCT
F. J. Melillo**	Holtsville, New York, USA	203mm SCT
C. Meredith**	Manchester	216mm refl.
M. Minami	Fukui City Observatory, Japan	200mm OG
D. M. Moore**	Phoenix, Arizona, USA	362mm Cass.
P. A. Moore	Selsey, W. Sussex	320mm & 390mm refls.
H. Munsterman**	Meppel, Holland	356mm SCT
M. Murakami	Fujisawa, Japan	200mm refl.
D. Niechoy	Göttingen, Germany	203mm SCT
P. W. Parish	Rainham, Kent	102mm OG
D. C. Parker**	Coral Gables, Miami, Florida, USA	410mm refl. & 410mm SCT
	Chiefland, Florida, USA	152mm refl.
D. Peach**	King's Lynn, Norfolk	305mm SCT
T. C. Platt**	Binfield, Berks.	320mm refl.
T. J. Richards**	Melbourne, Australia	180mm OG
F. Salvaggio	Catania, Italy	203mm SCT
R. W. Schmude	Barnesville, Georgia, USA	90mm OG
	Villa Rica, Georgia, USA	254mm & 510mm refls.
R. Schulz**	Vienna, Austria	203mm SCT
M. Di Sciullo**	Coconut Creek, Florida, USA	254mm refl.
J. D. Shanklin	Cambridge Univ. Observatory	300mm OG
E. Siegel	Malling, Denmark	203mm SCT
R. M. Steele	Leeds	80mm OG
I. Stellas	Athens, Greece	102, 130 & 635mm OGs
D. Storey	Douglas, Isle of Man	80mm OG
D. Strange**	Worth Matravers, Dorset	508mm refl.
T. Stryk*	Jefferson City, Tennessee, USA	114mm refl.
Wei-Leong Tan**	Singapore	280mm SCT
P. Tanga**	Pino Torinese Observatory, Turin, Italy	420mm OG
G. Teichert	Hattstätt, France	279mm SCT
	Helen Sawyer Hogg Observatory, Ottawa, Canada	380mm OG
R. Topping	Tredegar, Gwent	300mm refl.
D. M. Troiani	Schaumberg, Illinois, USA	444mm refl.
M. Valimberti & G. McKenzie**	Melbourne, Australia	203mm SCT
H. Vandenbruaene	Gent, Belgium	250mm refl.
A. Van der Jeugt	Gent Univ. Observ., Belgium	200mm SCT & 230mm OG
F. Van Loo	Genk, Belgium	100mm OG
A. Vincent*	Worthing, West Sussex	203mm SCT
J. Warell	Uppsala, Sweden	160mm OG
M. E. Wasiuta**	Spotsylvania, Virginia, USA	157mm OG
S. Whitby	Hopewell, Virginia, USA	152mm refl.
	Bon Air, Virginia, USA	178mm OG
J. Wojack	Wilmington, Delaware, USA	152mm refl.

* denotes the submission of photographs; ** CCD images

Note: The work of McKenzie and Valimberti was contributed via Barry Adcock and Tom Richards. Observations by Bosselaers, Corstjens, Feys, Munsterman, Van Loo and Vandenbruaene (VvS) were contributed by Wim Cuppens. Akabane's images were forwarded by Dr S. Ebisawa. Observation notes by Knisely came from Prof. Martin Gaskell. The work of Gazdik was contributed via Maurice Gavin. Observations by Ishadoh, Iwasaki and Murakami (OAA) were sent by Dr Masatsugu Minami. The images by Schulz were contributed by Damian Peach. The work of Dal Prete, Lo Savio, Marino and Salvaggio (UAI) was forwarded by Paolo Tanga. Drawings by Joyce (ALPO) were sent by Dan Troiani.

due to differences in white cloud or ground frost. After opposition in 1999 it was possible to see the southern maria better than in 1997. *Hellespontus* was dark, and in 1999 October Minami and Nakajima[11] recorded *Depressiones Hellesponticae* north of the spring S. polar cap. The ensemble of observations showed that *Nodus Alcyonius* (Figures 2Q, 3G, 4A–E, *etc*.) had the same tear-drop shape of recent years, appearing as an isolated spot S. of *Casius–Utopia*. *Syrtis Major* was blunted to the north, with *Nepenthes* still invisible between it and *Nodus Alcyonius*. Minami (from 1999 April) thought the area around the dark spot on the floor of *Huygens* had darkened since 1997 so that the latter was harder to define. *Huygens* (Figures 2Q, 2D, 4C, F) was reported by a number of other visual observers and was widely imaged.

In 1999 January and later, in contrast to 1998 December and earlier, OAA members found *Utopia* to be distinctly less dark than *Syrtis Major*. In 1999, northern summer be-

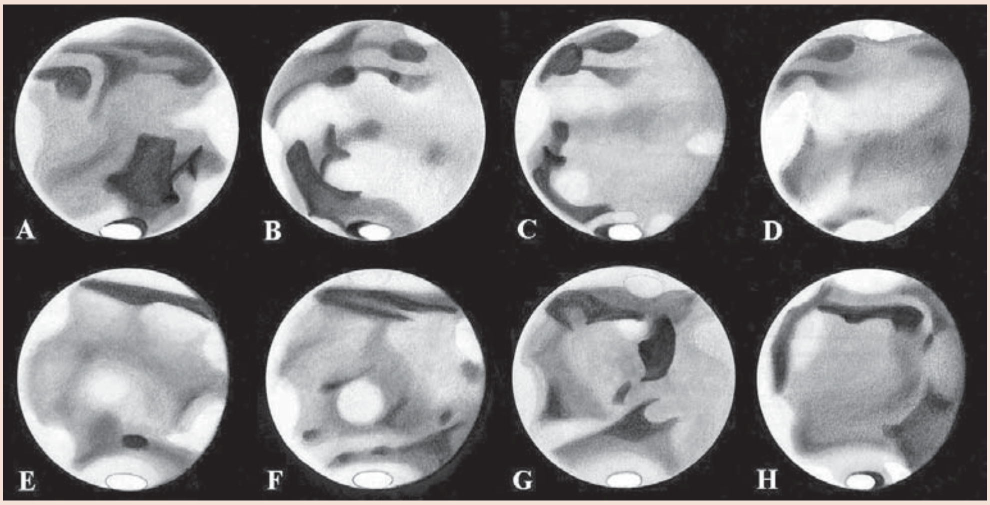

Figure 3. Drawings by the Director.
152mm OG (D); 216mm refl. (A–C, E–H). Bright haze surrounds the NPC in E–H, and the hood covers it in D. *Hyperboreus Lacus* is shown in A–D and H.
A: 1999 May 2d 21h 10m, CML = 20°, ×180. A.m. cloud over *Chyse-Xanthe* and *Tempe*.
B: 1999 April 29d 23h 25m, CML = 79°, ×232, W15. *Argyre* and *Claritas* bright; *Ascraeus Lacus (Mons)*.
C: 1999 June 3d 21h 10m, CML = 95°, ×232. *Solis Lacus* on CM. *Claritas* bright. Morning cloud at *Nix Olympica*. Small dust-cloud S. of NPC: compare Figure 7F.
D: 1999 July 9d 20h 35m, CML = 110°, ×330. *Claritas* is brightest spot amidst large SPH.
E: 1999 May 25d 20h 45m, CML = 170°, ×232. Evening *Alba* cloud; *Elysium* bright.
F: 1999 May 20d 21h 40m, CML = 229°, ×232. Morning cloud over S. *Syrtis Major*.
G: 1999 May 16d 21h 30m, CML = 262°, ×360, W15, 25, 44A. *Hellas* is brightest patch at S. limb. *Nodus Alcyonius* tapered to the south.
H: 1999 June 15d 21h 05m, CML = 343°, ×232. *Baltia* a.m. cloud.

gan in late January. In the last apparition[1] this phenomenon was also noticed in northern summer.

Ismenius Lacus (Figures 2E, U, X, 4C–I) was again inconspicuous, and as in 1995–'97 was faded in the east. Adachi wrote that it did not appear well defined visually even in good seeing. *Edom* was only slightly white at opposition. Minami found *Mare Serpentis* not so dark, and rather patchy. In late May, *Mare Serpentis* extended S. via the dusky *Pandorae Fretum* (again displaced slightly S. of its normal course, and not quite complete in longitude) to the S. polar hood to form a dark 'arch' across *Noachis* that ended on the W. side at *Mare Erythraeum*.

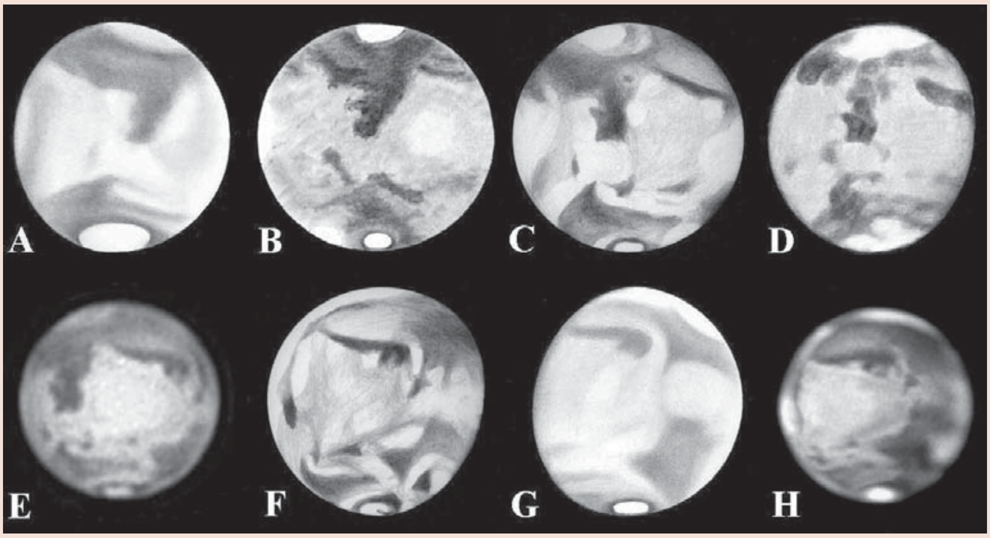

Figure 4. ***Region I:*** **long. 250–010°.**
A: 1998 November 17d 06h 40m, CML = 277°, 415mm Dall–Kirkham Cass., ×663, W15, W25, *Gray*.
B: 1999 May 23d 02h 54m, CML = 287°, 380mm OG, ×233, *Teichert*.
C: 1999 April 29d 13h 50m, CML = 299°, 200mm OG, ×480, *Minami*. *Huygens* in *Iapigia*.
D: 1999 July 4d 06h 05m, CML = 306°, 256mm refl., ×507, *Biver*. NPH.
E: 1999 April 24d 12h 32m, CML = 324°, 250mm Dall–Kirkham Cass., f/48, CCD image, *Buda & Curcic*. *Ismenius Lacus* is small; *Huygens*.
F: 1999 May 30d 11h 50m, CML = 355°, 200mm OG, ×480, *Minami*. *Chasma Boreale* halfway across the cap.
G: 1999 January 21d 05h 40m, CML = 356°, 415mm Dall–Kirkham Cass., ×663, W15, W25, *Gray*.
H: 1999 May 15d 02h 56m, CML = 359°, 410mm refl., CCD image (original in colour), f/48, *Parker*. Bright limb clouds; SPH over *Noachis* to *Argyre*.

Region II: long. 010–130°

Refer to Figure 5 in particular. *Mare Acidalium* and its surroundings were identical to 1997. *Acidalium* was full of small, complex details. *Solis Lacus* was again large and dark, its longest axis running E–W. Internal detail was apparent in some drawings (Figure 5E) with the two usual parallel E–W elongated parts and a lighter tract between them, whilst the best images show two southward protrusions in the S. component (Figures 2A, 5D, G, 7E). *Gallinaria Silva* (Figures 2M, 5G, 7E) was a small dark spot, inconspicuous; a pale streak ran west from it. *Phasis* was at best very faint, probably invisible. *Juventae Fons* was seen well visually by a number of observers. Cave sketched it as a small black dot, and Adachi, Biver and Gray reported it also. The southern *Chryse–Xanthe* deserts again contained the usual dark spots and streaks (Figures 2A, U, 5B–D, 7D) north of *Aurorae Fretum*. An intensification of *Hydaspes* was noticed in late February in conjunction with a regional dust storm along the *Valles Marineris* and southern *Chryse–Xanthe* (see the 'Dust storms' section below).

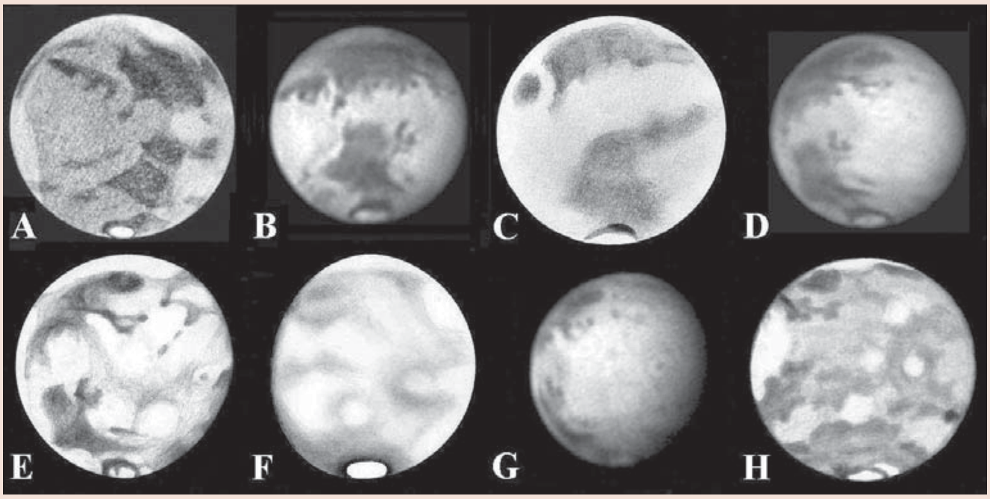

Figure 5. ***Region II:*** **long. 010–130°.**
A: 1999 May 5d 22h 20m, CML = 11°, 160mm OG, ×330, *Warell*.
B: 1999 May 14d 04h 53m, CML = 36°, 410mm refl., f/48, CCD red filter (RG 610) image, *Parker*. S. *Chryse* fine details.
C: 1999 April 30d 21h 20m, CML = 40°, 152mm OG, ×330, *Hendrie*.
D: 1999 May 7d 03h 38m, CML = 79°, 410mm refl., f/48, CCD red filter (RG610) image, *Parker*. Fine details in *Solis Lacus*; *Chasma Boreale*.
E: 1999 May 21d 12h 10m, CML = 81°, 200mm OG, ×480, *Minami*. *Tharsis Montes* as small dark albedo features.
F: 1999 January 10d 06h 10m, CML = 108°, 415mm Dall–Kirkham Cass., ×663, W15, *Gray*. *Alba* bright cloud; *Olympus Mons* identified by its dull surroundings.
G: 1999 June 10d 02h 22m, CML = 116°, 410mm refl., f/48, CCD red filter (RG 610) image, *Parker*. *Olympus Mons* as a dark spot with lighter ring; *Gallinaria Silva* W. of *Solis Lacus*.
H: 1999 May 11d 08h 35m, CML = 117°, 256mm refl., ×507, *Biver*. *Olympia*; orographics.

Nix Olympica and the *Tharsis* volcanoes were recognised by their bright afternoon orographic clouds (Figures 2A, M, V, 3E, 5F, H, 6B, D–F), but they were sometimes bright at dawn, too (Figure 3C). From early April to mid-June the upper slopes of the *Tharsis Montes* (*Ascraeus, Pavonis* and *Arsia Mons*) and *Olympus Mons* appeared as small dark spots on the morning side of the disk (Figures 5E, G, 7F, 8B). This highlighting is seemingly due to their lower slopes being hidden by a.m. cloud. Later in the day, as orographic clouds formed on their flanks, the volcanoes largely disappeared as albedo features. This behaviour mirrored that noted in 1995 and 1997. On an *HST* image *Olympus Mons* at the CM was surrounded by a narrow ring of white cloud. Minami visually (Figure 5E) and some CCD images (Figures 5G, 7F) recorded *Olympus Mons* as a small dark spot with a lighter surround.

In 1999 March-May the evening *Nix Olympica* was seen to be separated from the evening *Tharsis* cloud by a dark band (Figures 6B, E), as in seasonally similar, earlier, oppositions. This darkening was most apparent in blue light and must arise from a high transparency in that waveband, due presumably to a lack of white cloud: any water vapour having been frozen out over the high slopes of the volcanoes.

In the north *Hyperboreus Lacus* was well seen. Nearby, ground-based, *HST* and *MGS* data revealed a number of polar cyclones in 1999 April to June, the *HST* imaging a dark core in the clouds over *Baltia–Mare Boreum* (Figure 9A): for further discussion, see the 'White cloud' section. On two occasions these cyclones almost certainly initiated local dust storms.

Region III: long. 130–250°

Refer especially to Figure 6. The *Elysium* shield was sometimes light, with a still brighter specific orographic cloud over the west slopes of *Elysium Mons* (*e.g.*, Figures 2I, Q, W, 3E–G, 6H). With the exception of the *Aetheria* darkening (exactly as in 1997, a wedge-shaped shading running N*p.* to S*f.*), its surroundings were all very faint, though the *HST* images – perhaps due to the narrow-band filtration used – tend to exaggerate this faintness. *Cerberus* (Figures 2I, W, 3E–F, 6D–H) was an almost invisible streak, consisting at the highest resolution of two tiny dots (Figure 6F); one near its SW end and the other near where classic *Trivium Charontis* would be. The former marking was generally not seen by BAA members, but on June 11 Minami found a dark patch at the SW end of *Cerberus*, checked by Akutsu's CCD image of June 13. *Phlegra* too was a weak halftone. However, some months from opposition, *Phlegra* and *Cerberus* looked considerably darker, even though *Elysium* was not then bright. Observers remarked upon this in 1999 July when the features were visible on the morning side, and in September-October on the evening side. Discounting subjective contrast, this darkening must be a phase effect, with rougher terrain selectively darkening under oblique lighting. (Figures 6E and 6F of the 1995 Report[23] show that the boundaries of *Elysium* also then appeared darker far from opposition.)

The southern maria were much the same as in 1997. In good seeing, more or less continuous dusky shading ran in a narrow band roughly east-west just north of *Mare Sirenum* and *Mare Cimmerium*, as it has done since the late 1980s. *Mare Cimmerium* again contained two prominent northward spikes (*Cyclopum Sinus* and *Cerberi Sinus*; Figure 6F), but the dark feature (*Sinus Gomer*) formerly uniting their N. extremities that had been prominent in the late 1980s, has gradually faded – as our successive apparition maps show – and is now invisible even to the *HST*. South of *Mare Sirenum* and *Mare Cimmerium* it was possible to observe *Mare Chronium*.

The martian atmosphere

White clouds

General

Although it was impossible to make high resolution observations in the early martian N. spring, orographic clouds and equatorial cloud bands (ECB) were seen long before opposition. Figure 1 shows the wavelength-dependence of these white crystal clouds. The orographics were recorded by the Mars Section between Ls = 47° and *ca.* 150°, though they would likely have been detected slightly earlier had the disk diameter permitted more detailed views. (According to analysis of *MGS* data (1999–2001) by Benson *et al.*,[15] the *Ascraeus Mons* and *Olympus Mons* orographic clouds can be active during Ls ~0–200°, though some activity may be too small for our telescopes.) Of the orographic clouds in 1999, that associated with *Arsia Mons* was the least conspicuous to BAA observers, probably owing to its more southerly latitude.

In our BAA data, ECB (10°S to 30°N) were visible from Ls = 50° onward, but disappeared after about Ls = 145°. Thus, D. M. Moore's images up to and including May 28 (Ls = 145°) are the last to show uninterrupted ECB crossing the *Syrtis Major* hemisphere (see Di Sciullo's images of May 23 (Figures 2Q–T)). After June the '*Syrtis* blue cloud' was not noticed. In the 1997 apparition[1] the corresponding limits for ECB were *ca.* Ls = 51–141°. ECB are likely to be a delicate indicator of atmospheric heating, so we may infer very similar atmospheric dust loading (minimal) in two successive northern spring and summer seasons from these nearly identical results. In any case, the *MGS* TES data[19] point to the same conclusion. Glenar *et al.*[16] mapped atmospheric water-ice absorption at 3.0–3.5µm in the ECB. *MGS* data also indicate an abrupt termination of the ECB after Ls = 145°.

As the ECB and orographics dwindled during late N. summer, the concomitant increase in N. polar clouds – the so-called 'polar cyclones' of *HST* and *MGS* – and the growth of the N. polar hood were seen to maximum advantage.

The martian disk diameter exceeded 6 arcsec from 1998 late December till 1999 mid-November. Records of the principal white clouds follow.

1998 September to December (incomplete data)

September: To Biver, morning cloud was apparent over *Aeria*, *Cebrenia*, *Elysium*, *Meroe* and *Neith Regio*, but not over *Hellas*.

October: The S. limb was habitually covered by whitish haze, amidst which *Argyre* appeared as a specific bright patch. *Arabia*, *Chryse–Xanthe* and *Elysium* were light in the morning (abbreviated hereafter as a.m.). *Hellas* was lightish around the CM and in the evening (p.m.), and *Aeria*, *Arcadia*, *Chryse–Xanthe*, and *Libya* were bright in the p.m. *Elysium* was dull at the CM. *Tharsis* was bright in the a.m. and p.m.

An early record of the nascent ECB was drawn by Gray under CML = 80° on Oct 31 (Ls = 50°) where a bright tract ran from *Tithonius Lacus* across *Tharsis* to the a.m. limb, and the same observer was the first to record the bright afternoon cloud at *Nix Olympica* on Oct 23 (Ls = 47°), and to see the orographic cloud over *Alba* at the CM on Oct 28.

November: The S. limb was again generally light, sometimes complex. It extended further N. at *Hellas* (Figure 4A) and over S. *Thaumasia*. *Aeria* and *Meroe–Neith Regio* were light in the a.m., contributing to more widespread morning cloud which partly effaced *Syrtis Major*. *Alba* was again bright in the p.m., and imaged by Peach on Nov 29. *Cebrenia* and *Elysium* were light in the a.m. *Elysium* was dull at the CM but bright in the evening. *Aeria* and *Chryse–Xanthe* were light in the a.m. and p.m., *Tempe* in the morning and *Eden* (which we habitually write in lieu of the IAU *Moab*) in the evening. *Hellas* was light around the CM and especially in the p.m., but was dull in the morning, *e.g.*, to Patrick Moore (Nov 17). *Noachis* was light at the CM and in the p.m. *Tharsis* was light in the p.m.

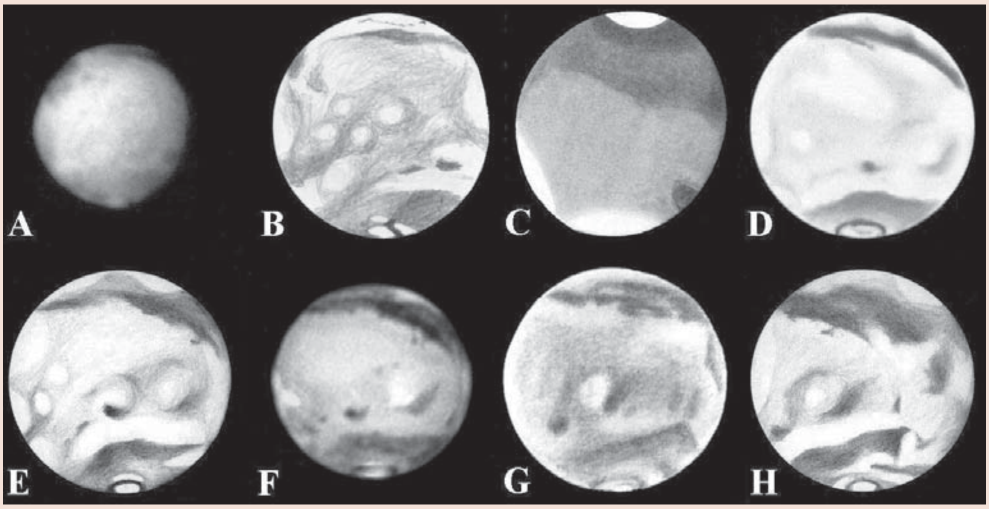

Figure 6. ***Region III:*** **long. 130-250°.**
A: 1999 May 30d 21h 09m, CML = 131°, 500mm refl., f/25, CCD image, *Dijon*.
B: 1999 May 16d 13h 40m, CML = 148°, 200mm OG, ×480, *Minami*. *Ierne* and *Olympia* detached from NPC; orographics; a.m. cloud over *Cebrenia-Elysium*, *etc*.
C: 1999 November 24d 16h 20m, CML = 149°, 203mm Schmidt–Cass., ×400, W8, *Frassati*. SPC.
D: 1999 April 17d 23h 50m, CML = 176°, 415mm Dall–Kirkham Cass., ×348, W15, *Gray*. Note orographics, *Olympia* and the shape of *Propontis* in D–F.
E: 1999 May 8d 11h 30m, CML = 186°, 200mm OG, ×480, *Minami*.
F: 1999 April 24d 03h 51m, CML = 197°, 410mm refl., f/48, CCD image (original in colour), *Parker*. *Cerberus* comprises two tiny dark spots.
G: 1999 May 6d 13h 20m, CML = 230°, 310mm refl., ×500, *Adachi*. Wedge-shaped *Aetheria* darkening in D–H.
H: 1999 May 6d 14h 20m, CML = 245°, 200mm OG, ×480, *Minami*. A.m. white cloud partly covering N. *Utopia*; *Olympia*; *Elysium Mons*.

Gray's drawing of Nov 10 (CML = 348°) indicates ECB, as does Parker's image of Nov 19 (CML = 315°).

***December*:** The S. limb was often light, brightness extending north over *Hellas* and *Thaumasia*. Gaskell found *Argyre* bluish-white. *Aeria* was light in the a.m. and p.m. *Chryse–Xanthe* was light in the a.m. and p.m. *Arabia* and *Eden* were light in the p.m. *Isidis Regio–Libya* was also a bright region in the p.m., crossing the *Syrtis Major* and so causing the *Syrtis* blue cloud (Parker, Dec 25, Figure 8A). *Eden*, *Edom*, W. *Cydonia*, *Libya*, *Tempe* and *Thymiamata* were light in the a.m. *Elysium* was dull at the CM but light in the a.m. and p.m. *Hellas* was again light around the CM and p.m., but dull in the a.m. *Tharsis* was light throughout the day. Gray saw *Alba* and *Nix Olympica* bright in the afternoon (Dec 2).

Gaskell (Dec 8, CML = 175°), Minami (Dec 28, CML = 72°) and Parker (Dec 23, 25, CML = 310–346°) recorded ECB right across the visible disk. (Thus *Aeria*, *Eden* and *Arabia* were also light at the CM.)

1999 January

A.m. limb: *Aeria*, *Arcadia*, *Cebrenia* (and surrounding *Propontis*), *Chryse–Xanthe*, *Elysium*, *Hellas* (slightly white (sw)), *Isidis Regio–Libya* (with the *Syrtis* blue cloud imaged by Akutsu (Jan 18) and Parker (Jan 1)), *Memnonia*, *Meroe*, *Nix Olympica*, *Tempe*, *Tharsis*, *Thymiamata*.

p.m. terminator: *Aeria*, *Alba*, *Arcadia*, *Candor–Ophir*, *Cebrenia*, *Chryse–Xanthe*, *Cydonia*, *Elysium*, *Hellas*, *Isidis Regio–Libya* (causing the *Syrtis* blue cloud), *Nix Olympica*, *Tempe* (sw), *Tharsis* (including other orographic clouds), *Zephyria*.

mid-disk: *Candor–Ophir*, *Elysium* (sw), *Hellas*. Parker's images show polar haze over *Cecropia-Ortygia* (at Ls = 90°). On Jan 10, Gray (Figure 5F) found *Alba* to be bright at the CM, but *Nix Olympica* appeared dull at midday, recognised only by its surrounding dusky ring.

Argyre (Figure 4G), *Ausonia* and *Noachis* were light at the S. limb.

Hellas had increased in brightness since December, now appearing lightish from late morning.

ECB was widely seen, complete in longitudinal extent. It could be

Table 2. Martian intensity estimates

Feature	*Adamoli*	*Frassati*	*Heath*	*McKim*	*Meredith*	*Schmude*	*Ave.*	*s.d.(±)*	*No.*
	Observer								
Achillis F.	–	4.8	–	5.8	–	–	5.3	(0.5)	7
Acidalium, M.	4.9	4.8	5.0	5.4	4.6	4.8	4.9	0.3	50
Aeolis	–	–	–	1.6	–	–	1.6	–	4
Aeria	–	1.2	1.0	1.4	–	1.5	1.3	0.2	14
Aetheria	–	3.0	–	2.8	–	–	2.9	(0.1)	5
Aethiopis	–	–	–	2.7	–	–	2.7	–	5
Amazonis	–	–	–	1.9	–	–	1.9	–	6
Amenthes	–	–	–	2.3	–	–	2.3	–	5
Arabia	–	–	–	2.0	–	–	2.0	–	6
Arcadia	–	1.5	–	2.0	–	–	1.8	(0.2)	12
Argyre	1.0	1.1	–	0.7	–	1.0	1.0	0.2	16
Ascraeus L.	–	–	–	4.2	–	3.5	3.8	(0.4)	4
Astaboras	–	–	–	3.0	–	–	3.0	–	1
Aurorae F.	–	–	–	5.0	–	–	5.0	–	1
Aurorae S.	–	5.5	5.0	5.8	4.2	4.7	5.0	0.6	21
Ausonia	0.8	0.6	–	0.7	1.0	2.0	1.0	0.6	14
Baltia	–	–	–	2.2	–	–	2.2	–	2
Boreosyrtis	–	–	–	4.8	–	–	4.8	–	2
Boreum, M.	4.0	5.5	–	3.1	3.9	2.8	3.9	1.0	22
Brontes	–	–	–	3.0	–	–	3.0	–	2
Callirrhoes S.	–	–	–	5.8	–	–	5.8	–	3
Candor	–	1.0	–	1.3	–	–	1.2	(0.2)	9
Casius	–	4.0	4.3	5.1	–	–	4.5	0.6	10
Cebrenia	–	2.0	–	1.3	–	–	1.6	(0.4)	6
Cecropia	4.2	5.0	–	3.8	3.0	2.3	3.7	1.0	21
Ceraunius	–	3.0	–	4.0	–	–	3.5	(0.5)	3
Cerberus	–	–	–	3.5	–	–	3.5	–	4
Chaos	–	–	–	3.0	–	–	3.0	–	2
Chryse	–	1.8	0.5	1.5	–	1.6	1.4	0.6	17
Cimmerium, M.	5.7	5.0	5.8	6.1	4.4	5.0	5.3	0.6	34
Claritas	–	1.0	–	0.1	–	–	0.6	(0.4)	5
Coprates	–	–	–	6.0	–	–	6.0	–	1
Cydonia	–	–	–	2.6	–	–	2.6	–	8
Daedalia	–	–	–	2.3	–	–	2.3	–	3
Deucalionis R.	2.0	3.5	–	2.3	–	2.5	2.6	0.6	8
Deuteronilus	–	–	–	3.2	–	–	3.2	–	2
Diacria	–	2.0	–	1.0	–	–	1.5	(0.5)	4
Dioscuria	–	–	–	2.5	–	–	2.5	–	7
Eden	–	–	–	1.6	–	–	1.6	–	8
Electris	1.7	1.3	–	0.6	–	1.0	1.2	0.5	10
Elysium	–	1.0	–	0.9	–	–	1.0	(0.1)	9
Eridania	1.3	0.7	–	0.4	1.2	–	0.9	0.4	14
Erythraeum, M.	5.2	5.1	5.0	5.4	5.0	4.2	5.0	0.4	32
Eumenides-Orcus	–	–	–	3.0	–	–	3.0	–	1
Ganges	3.0	–	–	3.5	–	–	3.2	(0.2)	3
Gehon	3.5	–	–	–	–	–	3.5	–	5
Hadriacum, M.	–	–	5.0	6.0	–	–	5.5	(0.5)	2
Hellas	0.7	1.1	0.0	0.0	0.9	0.6	0.6	0.5	29
Hesperia	–	–	–	3.5	–	–	3.5	–	2
Hyblaeus	4.5	3.9	4.5	5.0	–	4.0	4.4	0.4	15
Hyperboreus L.	–	–	6.0	6.6	–	5.8	6.1	0.4	12
Iapigia	6.3	4.8	5.5	4.2	3.7	4.2	4.8	1.0	27
Idaeus F.	–	4.8	–	5.8	–	–	5.3	(0.5)	7
Isidis R.	–	–	–	0.9	–	–	0.9	–	8
Ismenius L.	4.5	–	–	–	–	–	4.5	–	1
Libya	–	1.7	2.0	1.1	–	1.3	1.5	0.4	15
Lunae L.	–	–	4.0	4.7	–	4.0	4.2	0.4	7
Margaritifer S.	4.0	4.8	–	5.2	–	4.4	4.6	0.5	19
Melas L.	–	4.5	–	6.0	–	–	5.2	(0.8)	4
Memnonia	–	–	–	2.0	–	–	2.0	–	6
Meridiani S.	–	5.4	5.6	6.1	–	5.9	5.8	0.3	23
Meroe	–	1.5	–	2.0	–	–	1.8	(0.2)	6
Nectar	–	–	–	5.5	–	–	5.5	–	3
Neith R.	–	–	–	1.4	–	–	1.4	–	9
Niliacus L.	–	6.0	–	5.4	–	–	5.7	(0.3)	9
Nilokeras	4.0	5.1	–	4.4	4.2	4.0	4.3	0.4	20
Noachis	0.4	1.2	–	1.2	–	2.5	1.3	0.9	13
Nodus Alcyonius	–	3.5	–	4.8	–	–	4.2	(0.6)	3
Olympus Mons	–	–	–	4.2	–	–	4.2	–	3
Ophir	–	0.5	–	1.3	–	1.8	1.2	0.6	10
Ortygia	4.1	4.2	–	3.1	3.0	2.6	3.4	0.6	20
Oxia Palus	–	5.0	–	–	–	–	5.0	–	1

Table 2. Martian intensity estimates (continued)

Feature	Adamoli	Frassati	Heath	McKim	Meredith	Schmude	Ave.	s.d.(±)	No.
	Observer								
Panchaïa	4.4	5.0	4.3	4.1	3.2	3.5	3.9	0.7	27
Pandorae F.	4.6	5.0	–	4.7	–	5.0	4.8	0.2	13
Phaethontis	1.3	1.0	–	0.4	2.0	–	1.2	0.7	16
Phlegra	–	3.8	–	3.2	–	–	3.5	(0.3)	6
Propontis (I)	–	6.5	–	5.1	–	–	5.8	(0.7)	5
Protonilus	–	–	–	3.0	–	–	3.0	–	1
Pyrrhae R.	–	–	–	3.8	–	2.5	3.2	(0.6)	5
Sabaeus S.	5.1	5.1	5.6	5.9	4.0	5.6	5.2	0.7	37
Scandia	3.9	–	–	4.0	3.0	–	3.6	0.6	15
Serpentis, M.	–	–	5.0	5.0	–	5.0	5.0	0.0	5
Sirenum, M.	5.3	4.8	5.0	5.9	3.0	5.0	4.8	1.0	26
Solis L.	5.0	5.2	4.5	6.4	3.2	5.0	4.9	1.0	18
Syrtis Major	5.1	5.5	6.8	6.3	4.9	5.9	5.8	0.7	45
Syrtis Minor	–	–	–	6.8	–	–	6.8	–	4
Tanais	–	–	–	6.6	–	–	6.6	–	6
Tempe	–	0.8	–	1.9	–	1.5	1.4	0.6	15
Tharsis	–	–	–	1.6	–	2.0	1.8	(0.2)	7
Thaumasia	–	–	–	2.0	–	–	2.0	–	5
Thymiamata	–	–	–	2.4	–	–	2.4	–	4
Tithonius L.	–	–	–	4.0	–	3.0	3.5	(0.5)	3
Trivium Charontis	–	3.7	3.5	3.5	–	–	3.6	0.1	9
Tyrrhenum, M.	6.0	4.9	5.5	6.6	4.2	5.4	5.4	0.8	34
Uranius	–	–	–	3.2	–	–	3.2	–	5
Utopia	5.7	4.8	4.0	5.0	3.0	4.8	4.6	0.9	26
Xanthe	–	1.4	–	1.3	–	1.6	1.4	0.2	17
Yaonis F.	–	–	–	6.0	–	–	6.0	–	1
Zephyria	–	–	–	1.4	–	–	1.4	–	4
No. of useful estimates	160	204	62	452	70	113		*Total:*	1,061
Period of obsn.	*Jun 30– Aug 25*	*Feb 13– Nov 7*	*Feb 23– Jun 25*	*Apr 13– Jul 29*	*Apr 9– Jul 27*	*Apr 2– May 25*			

seen to be composed of a number of intersecting or overlapping cloud belts.

1999 February

A.m. limb: *Aeria*, *Aetheria*, *Arabia*, *Cebrenia*, *Chryse–Xanthe*, *Eden*, *Elysium*, *Hellas*, *Isidis Regio–Libya* (partly effacing *Syrtis Major*, which exhibited the blue cloud), *Meroe*, *Neith Regio*, *Noachis* (sw), *Tempe* (partly covering *M. Acidalium*), *Tharsis*.

p.m. terminator: *Aeria*, *Alba*, *Amazonis*, *Candor–Ophir*, *Chryse–Xanthe*, *Eden*, *Elysium*, *Hellas* (with optical projection at terminator), *Isidis Regio–Libya* (causing the *Syrtis* blue cloud), *Nix Olympica*, *Noachis* (sw), *Tharsis* and the orographic clouds generally, *Thymiamata*, *Zephyria*. *Tempe* was not bright.

mid-disk: *Aeria*, *Candor–Ophir*, *Elysium* (dull, but with the bright patch *Elysium Mons* [the latter sometimes extended southward]), *Hellas*, *Isidis Regio–Libya*. The orographic clouds were also bright at the CM.

Hellas was brighter than the NPC by Feb 1, having brightened during Ls = 85–91°, and was very bright all day, indicating a frosted surface (also overlain by diurnal haze). *Noachis* at the S. limb was light. ECB could be detected at all CML, as last month.

Biver, Gaskell and Gray all found evidence of haze south of the NPC (Feb 13–27).

1999 March

A.m. limb: *Aeolis*, *Aeria*, *Aetheria–Aethiopis* (sw), *Alba* (sw), *Arabia*, *Argyre* (with haze extending to the west), *Candor–Ophir*, *Cebrenia*, *Chryse–Xanthe* (partly covering *Mare Acidalium–Niliacus Lacus*), *Claritas*, W. *Cydonia*, *Eden*, *Elysium*, *Hellas*, *Isidis Regio–Libya* (partly effacing *Syrtis Major,* which again exhibited the blue cloud), *Memnonia* (sw), *Meroe*, *Neith Regio*, *Tempe*, *Tharsis*, *Thaumasia*, *Thymiamata*.

p.m. terminator: *Aeria*, *Alba*, *Amazonis*, *Arabia*, *Argyre*, *Candor–Ophir*, *Chryse–Xanthe*, *Claritas*, *Elysium*, *Hellas*, *Isidis Regio–Libya* (with the *Syrtis* blue cloud), *Nix Olympica* (brightening further from early p.m.), *Tharsis* (and the orographic clouds), *Thymiamata*.

mid-disk: *Aeria*, *Alba*, *Amazonis* (sw), *Arabia*, *Argyre*, *Candor–Ophir*, *Claritas*, *Elysium* (sw, but brighter at *Elysium Mons*, the whole area brightening in the afternoon), *Hellas*, *Isidis Regio–Libya*, *Nix Olympica*, *Tharsis* (and the orogaphic clouds). N. polar haze over *Cydonia–Ortygia* was again seen.

The S. limb was often bright when areas such as *Argyre*, *Hellas* or *Noachis* were in the visible hemisphere. *Hellas* (again extremely bright) was associated with a partial S. polar hood when on the disk.

On March 7 and 10 Parker imaged a band of bright p.m. cloud from *Isidis Regio–Libya* partly cutting the *Syrtis* in two: compare the April 11 observations reported later.

Minami regarded the lightish *Cebrenia* on mid-disk as being merely ground-lit, in contrast to *Elysium*.

The ECB appeared slightly weaker than in February. Around CML = 200° (*e.g.*, to Parker, March 20) there were isolated patches of haze but no continuous ECB. Stellas on March 25 (CML = 17°) found the ECB (which stretched from limb to limb) best seen with a W80A blue filter, through which it already showed hints of patchiness.

There was again some haze just south of the NPC.

1999 April

A.m. limb: *Aeria*, *Aetheria*, *Aethiopis*, *Arcadia* (including *Alba*), *Ascraeus Mons* orographic, *Baltia*, *Candor–Ophir*, *Cebrenia*, *Chryse–Xanthe* (partly covering S. *Mare Acidalium*), *Claritas* (Figure 3B), W. *Cydonia*, *Eden*, *Edom*, *Elysium*, *Hellas*, *Isidis Regio–Libya* (partly effacing *Syrtis Major* and again forming the *Syrtis* blue cloud (Figures 2I–L)), *Meroe*, *Neith Regio*, *Nix Olympica*, *Pavonis Mons* orographic, *Tempe*, *Tharsis*, parts of *Thaumasia*, *Thymiamata*.

p.m. limb: *Aeria*, *Aethiopis*, *Alba*, *Amazonis*, *Ascraeus Mons* orographic, *Baltia* (see note below; an evening cloud was also seen on Cidadão's April 28 image), *Candor–Ophir*, *Cebrenia*, *Chryse–Xanthe*, W. *Cydonia*, *Daedalia* (due to afternoon extension of the SW *Thaumasia* cloud), *Eden*, *Edom*, *Elysium*, *Hellas*, *Isidis Regio–Libya* (partly effacing *Syrtis Major* to form the blue cloud (Figures 2E–H)), *Meroe*, *Nix Olympica* (becoming harder to see in the evening as the phase angle changed (Figures 6D, F)), *Ophir*, *Tempe*, *Tharsis* (including all the orographic clouds), SW *Thaumasia*, *Thymiamata*, *Zephyria* (a small cloud extending from *Elysium*, crossing *Cerberus*).

mid-disk: *Aeria* (sw), *Candor–Ophir*, *Cebrenia* (sw), *Edom*, *Elysium* (the cloud shape changing daily, and brighter at *Elysium*

Mons (Figures 2I–L, W)), *Hellas*, *Isidis Regio–Libya* (sw), *Nix Olympica*, *Candor–Ophir*, SW *Thaumasia*.

The S.limb was bright and covered by SPH (uneven in latitude) in the longitudes of *Argyre*, *Electris*, *Eridania*, *Hellas*, *Noachis*, *Solis Lacus*. A substantial hood S. of *Solis Lacus* had first been noted by the OAA around April 9, indicating northward expansion. The SPH was seen to be independent of Hellas by OAA members from April 21, but was not continuous at all longitudes.

On April 11 Di Sciullo (Figures 2E–L) and on April 21 Minami caught a tongue of the *Libya–Isidis Regio* p.m. cloud protruding across *Syrtis Major*.

On April 2–3 Di Sciullo imaged a bright S-shaped cloud lying between the morning orographic clouds over *Ascraeus Mons* and *Olympus Mons*. (Figures 2A–D)

The ECB was weakening but still visible at all CML, even if it sometimes seemed fragmented rather than continuous. For example, Parker's images centred on *Elysium* do not show it as continuous, but across *Syrtis Major* it was still apparently unbroken. It was still detectable visually, *e.g.*, to Troiani on April 13 (W47, W80A filters) under CML = 330°.

Morning clouds over *Baltia* (between *Hyperboreus Lacus* and *Mare Acidalium*) were first seen this month. Adachi (April 20–21) found one such cloud, after which others observed them into early May. From the UK, Topping drew and Meredith imaged the cloud on April 27. The clouds formed daily over several days at the a.m. limb from around CML = 304°. As they dissipated later by each martian afternoon they left the area slightly hazy and NW *Mare Acidalium* ill-defined, *e.g.*, to McKim, April 27. At the time inappropriately termed 'polar cyclones', they were first imaged by the *HST* on April 27, when one was located near +65°, 85°, measuring some 1600km across. At high resolution on April 27 and 30, these features had a small hole at the centre (Figure 9A). *MGS* data (2001 March, 2003 January and 2004 November) subsequently showed that these objects formed on a regular seasonal basis.

Haze was also noted around the NPC and over the NPC outliers, causing them to appear larger and more diffuse in blue light.

1999 May

A.m. terminator: *Aeolis*, *Aeria*, *Aethiopis* (joined with *Elysium* on Cidadão's May 25 image), *Arabia*, *Arcadia* (including *Alba*), *Baltia* (partly covering NW *Mare Acidalium*), *Candor–Ophir*, *Cebrenia* (and spreading around *Propontis* (Figures 6B, E)), *Chryse–Xanthe*, W. *Cydonia*, *Eden*, *Edom*, *Elysium*, *Hellas*, *Isidis Regio–Libya* (including the *Syrtis* blue cloud (Figure 3F)), *Meroe*, *Nix Olympica*, *Tharsis*, *Tempe* (extending partly over *Mare Acidalium*; Figure 4F), *Thymiamata*, *Utopia*.

p.m. limb: *Aeria*, *Alba*, *Amazonis*, *Arsia Mons* orographic, *Ascraeus Mons* orgraphic, *Baltia* (small cloud seen by Warell, May 30), *Candor–Ophir*, *Cebrenia*, *Chryse–Xanthe*, W. *Cydonia*, *Eden*, *Edom*, *Elysium* (*Elysium Mons* being brightest), *Hellas*, *Isidis Regio–Libya* (partly covering *Syrtis Major* and leading to the blue cloud effect once more), *Meroe*, *Nix Olympica* (Figures 2M–P, V, 3E, 5H, 6E, 7E; together with another bright cloud to the SW), *Tempe*, *Tharsis* (and all the orographic clouds), S. *Thaumasia*, *Thymiamata*, *Zephyria*.

mid-disk: *Aeria* (sw), *Alba* (sw), *Arsia Mons* orographic, *Ascraeus Mons* orographic (two clouds imaged here by Di Sciullo, May 3 (Figures 2M–P)), *Candor–Ophir*, *Cebrenia*, *Edom*, *Elysium* (less bright than in April, but still changeable daily and with *Elysium Mons* brighter), *Hellas*, *Isidis Regio–Libya* (sw), *Meroe* (sw), *Nix Olympica* (sw), *Tempe*, NW *Zephyria* (associated with bright cloud apparently spilling out of *Elysium*).

In early May the SPH was still not present at all CML, nor was it symmetrical or uniform in brightness, but it was very extensive, and present in the longitudes of *Argyre* (Figures 4H, 5A), *Daedalia*, *Electris*, *Eridania*, *Ausonia*, *Hellas*, *Noachis* (Figures 3A, 4H), *Dia* to *Phaethontis* (Figures 2O, 5H), *Solis Lacus*. It extended further north than in April, reaching down even to the south edge of *Solis Lacus* and filling *Claritas* (Figure 5E). By the month's end it was essentially complete.

The ECB was less obvious and no longer complete at all longitudes even at the start of the month. However even in late May there were long stretches of continuous cloud from limb to limb, *e.g.*, from *Elysium* to *Syrtis Major* and *Aeria–Arabia* (Figures 2Q–T), and Stellas still found the ECB complete under CML = 20° on May 4. As noted in the preamble, the images of May 28 were the last to show it continuous and conspicuous. Minami's colour observations imply that the ECB was much less strong over the *Syrtis* this month.

The morning *Utopia* cloud (Figure 6H) was very variable from day to day and was specially followed by Minami.[11]

Haze was again seen over the NPC outliers.

1999 June

A.m. terminator: *Baltia* (Figure 3H), *Cebrenia*, *Chryse*, *Cydonia*, *Elysium*, *Hellas* (sw), *Isidis Regio–Libya*, *Meroe*, *Memnonia*, *Tempe* (and *Mare Acidalium*), *Tharsis*, *Utopia*, *Zephyria*. *Nix Olympica* was light in the morning to McKim (June 3 (Figure 3C)) but it was not conspicuous.

p.m. limb: *Aeria*, *Candor–Ophir*, *Cebrenia*, *Chryse–Xanthe*, W. *Cydonia*, *Eden*, *Elysium* (including *Elysium Mons*), *Hellas*, *Isidis Regio–Libya* (including the *Syrtis* blue cloud in early June only), *Meroe*, *Nix Olympica* (weaker), *Tempe* (sw), *Tharsis* (and the orographic clouds), *Zephyria*.

mid-disk: *Arsia Mons* (sw), *Ascraeus Mons* (sw), *Candor–Ophir*, *Hellas*. *Elysium* was no longer light.

The (now complete) SPH contained brighter patches (SPC showing through). It was more constant in latitude but veered slightly north to form very bright incursions over *Claritas* (Figure 3C) and *Noachis* (Figure 3H). *Hellas* was differentiated from the SPH in good seeing.

Orographic clouds over *Olympus Mons* and the *Tharsis* volcanoes were less prominent and were not seen after this month.

By early June the ECB was fragmentary: portions were detected north of *Mare Cimmerium*. On June 20 with *Syrtis Major* central, McKim found the deserts whitened north of *Mare Tyrrhenum* and *Sinus Sabaeus*. The *Syrtis* blue cloud was no longer visible in the a.m., nor was it seen at all after June.

The a.m. clouds over *Baltia* declined in the afternoon, but regenerated at the a.m. terminator over several successive days.

1999 July

A.m. terminator: *Aethiopis–Aetheria*, *Baltia* (and part of *Mare Acidalium*), *Candor–Ophir*, *Chryse–Xanthe*, *Hellas* (sw), *Tempe* (sw; merged with the NPH in blue-violet light).

p.m. limb: *Aeria*, *Candor–Ophir*, *Cebrenia*, *Chryse–Xanthe*, W. *Cydonia*, *Eden*, *Elysium* (*Elysium Mons* only), *Hellas*, *Isidis Regio–Libya*, *Meroe*, *Neith Regio*, *Tharsis*, *Zephyria*.

mid-disk: *Candor-Ophir*, *Hellas*.

By early July the SPH had stabilised. Its atmospheric character is confirmed by the multicolour CCD images (*e.g.,* Parker, July 5–7, showing thick hood in blue and nothing in red). Japanese observers found the hood separated from *Hellas* by early July (Figures 7G, H); McKim confirmed this on July 23 and 26.

Claritas was an exceptionally bright part of the SPH, protruding considerably northward (Figure 3D). The SPH also extended further north in *Argyre* and *Noachis*. The first indications of the SPC as a sharp-edged bright feature were obtained by Minami on July 24 (Ls = 176°).

Fragments of ECB were reported only N. of *Mare Cimmerium*.

The polar cyclones over *Baltia* in the early part of this month (continuing from activity in late June) had a dull yellowish-white tone (July 4–9 (Figures 7G, H)) implying a dusty component. See under 'Dust storms' for more information. All these events ceased as the N. polar hood formed.

1999 August

A.m. terminator: *Candor–Ophir*, *Chryse–Xanthe*, *Isidis Regio–Libya*, *Tempe* (and again joined with the NPH in blue-violet light). *Elysium* was not bright.

p.m. limb: *Aeria*, *Chryse–Xanthe*, *Eden*, *Elysium* (just *Elysium Mons*), *Hellas* (sw), *Isidis Regio–Libya*, *Tharsis*, *Zephyria*.

mid-disk: *Candor–Ophir*, *Hellas* (now sw only), *Isidis Regio–Libya*. *Elysium* was not bright.

A weak fragment of ECB was reported by the OAA in *Tharsis–Amazonis*.

1999 September

A.m. terminator: *Aeria*, *Chryse–Xanthe, Hellas* (sw), *Libya*.

p.m. limb: *Aeria*, *Eden*, *Hellas*, *Candor–Ophir*, *Xanthe*. The *Syrtis* blue cloud was definitely not visible.

mid-disk: *Hellas* (sw).

The SPC now began to be visible, but on Sep 1 Parker imaged a large white cloud (part of SPH) over *Argyre* in blue light.

On Sep 9 and 13 *Mare Acidalium* was very pale even on the CM to OAA observers, suggesting coverage through N. polar hood expansion.

1999 October

A.m. terminator: (no record)

p.m. limb: *Hellas* (sw), *Isidis Regio–Libya*.

mid-disk: *Hellas* (sw or dull).

The NPH was still constantly present, and highly asymmetric.

1999 November to 2000 March (very incomplete data)

November: *Hellas* was lightish in the a.m. *Tharsis* and *Xanthe* were light in the p.m. Gaskell caught *Nix Olympica* at the *p.* limb. The NPH (Figure 6C) was less obvious on account of the greater southward tilt.

December: Parker imaged evening cloud over *Argyre* (sw) and *Chryse–Xanthe*. Gaskell found morning cloud over *Arabia* and evening cloud over *Aethiopis–Elysium*. *Hellas* was not bright on mid-disk (Frassati, Gaskell, Ikemura).

January–March: Despite the tiny disk it could be seen that *Hellas* was not bright near noon in January or March, and there was evening cloud over *Chryse* in January.

Blue Clearings

Here we describe the transparency of the martian atmosphere in violet light for historical continuity. We limit discussion to an approx. 6 second or larger disk.

Blue Clearing scale

0	No observable surface features
1	Some features visible with difficulty
2	Features easily seen and identifiable
3	Features are about as well defined as in white light

Adachi, Crandall, Gray, Haas, Heath, McKim, Schmude, Siegel, Troiani and Wasiuta made useful visual observations with the Wratten 47 filter, 1999 Feb 27–Aug 7. Where the recommended scale had not been correctly applied, the Director reassessed the BC rating from descriptions or sketches. A moderate BC (order 2) was the norm between April 6 and June 18. (On the latter date, the work of Crandall, Heath and McKim all points to a BC 2 rating.) Either side of opposition, on several dates between April 13 and May 15, the BC was rated as exceptional (order 3), but such sightings were limited to Troiani's large aperture. A weak BC (order 1) was sometimes seen throughout the whole period of observation, but after June 18 the BC was more often rated as zero.

Suitable CCD images were made by Akabane, Akutsu, Cidadão, Di Sciullo (Figure 1), Melillo, D. M. Moore, Parker, Schulz, Tan and Wasiuta (using either the Wratten 47, Schott BG 12, or the blue SBIG filter, in conjunction with an IR-blocking filter), 1998 Dec 23–1999 Sep 6. Some degree of BC (order 1 unless otherwise indicated) was more often evident than not, over the extreme date range. More importantly, the period of moderate BC (order 2, judging largely from the visibility of S. hemisphere features), occurred between 1999 March 10 and June 7 (Figures 2C, G, S). Order 3 was evident only between about April 22 and May 18 (Figures 2K, O). As usual, the estimates (especially for BC 3) are a little subjective.

Visual and CCD data agree pretty well, and a summary of extreme range is: BC 2: March 10–June 18; BC 3: April 13–May 18. In all of the filter work the invisibility of the N. part of *Syrtis Major*, due to veiling by ECB, was noticed. As usual, the darkening of parts of the N. hemisphere in violet light often made the exact shapes of *Utopia* and *Mare Acidalium* hard to distinguish (Figures 2C, G, S). The orographic clouds were especially well seen, as noted earlier. Around the orographic clouds several very dark patches were seen in violet light, which do not correspond to formal albedo features. As noted in the section on albedo features, these must instead represent unusually transparent regions of the atmosphere.

Dust storms (yellow clouds)

General

During 1998–'99 Ebisawa's polarisation data revealed no major negative anomaly due to dust.[13] A comprehensive analysis of the *MGS* MOC dataset between 1999 March 9 and Dec 31 (Ls = 107–274°) by Cantor *et al.*[17] describes a number of regional storms observed by imaging, while Smith

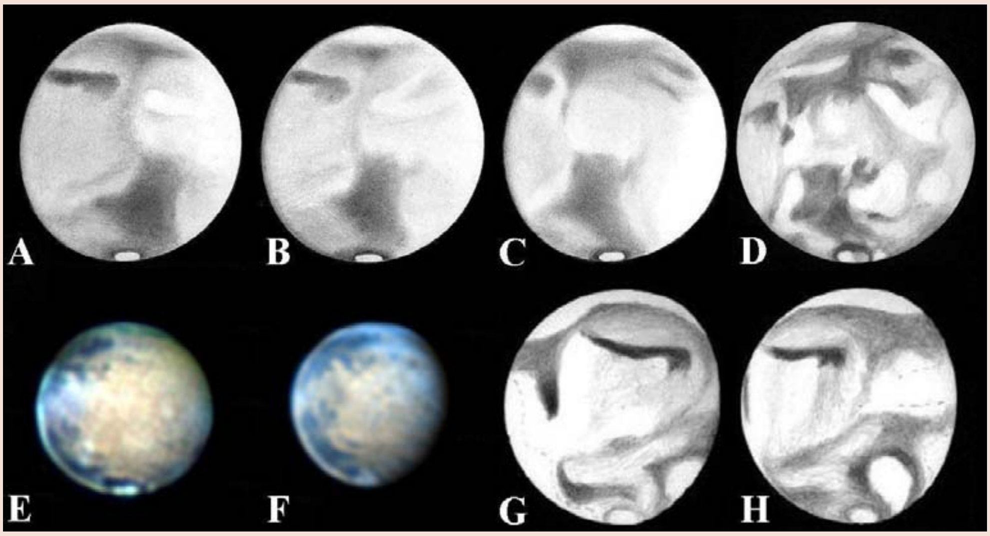

Figure 7. Dust storms.
A: 1999 February 21d 02h 10m, CML = 12°, 415mm Dall–Kirkham Cass., ×415, W15, 25, *Gray*. Bright dust over E. *Valles Marineris–Margaritifer Sinus*, etc.
B: 1999 February 21d 03h 00m, CML = 24°, 415mm Dall–Kirkham Cass., ×415, W25, *Gray*. Storm rotating with planet.
C: 1999 February 23d 05h 20m, CML = 40°, 415mm Dall–Kirkham Cass., ×348, W25, *Gray*. Storm decaying; dusty haze remaining.
D: 1999 April 16d 13h 30m, CML = 48°, 200mm OG, ×480, *Minami*. Bright yellow cloud streak in *Eos*.
E: 1999 May 2d 02h 21m, CML = 105°, 254mm Schmidt–Cass., and ST-5C CCD camera, RGB image with SBIG filters, *Cidadão*. Normal view with dark polar collar; *Ierne*, *Deucalidonius Lacus* and *Olympia* on *f.* side.
F: 1999 June 2d 20h 45m, CML = 98°, 254mm Schmidt–Cass., and ST-5C CCD camera, R(G)B image with SBIG filters ('G' = R+B average), *Cidadão*. Small dusty projection from NPC over *Baltia* obscuring NPCB. (Compare Figure 7E.)
G: 1999 July 8d 10h 30m, CML = 333°, 200mm OG, ×400, *Minami*. In G and H, a large yellowish-white cloud is extending from the N. polar region over *Mare Acidalium*. This event, similar to the 'polar cyclones', was larger, extended to the south, and partly dusty.
H: 1999 July 8d 13h 10m, CML = 12°, 200mm OG, ×400, *Minami*. The large yellow-white cloud is rotating with the planet. Also note extensive SPH.

& Pearl[18,19] used *MGS* TES data to extend the spacecraft's coverage of the martian year (Ls = 104–360°). Clancy *et al.*[20] present microwave data for comparison.

Early post-conjunction observations

Clancy *et al.*[20] inferred the presence of a regional storm commencing at Ls = 340° in 1998 June, very soon after solar conjunction, and according to Smith & Pearl[18] *MGS* TES data (available during Ls = 0–28°) indicate a gradual clearing of atmospheric dust following this event.

1999 February

As quoted in more detail in the Interim Report[3] and the Section *Circulars*,[4] on Feb 21 (CML = 10–29°) Gray observed and immediately reported a light V-shaped area on the morning side of the disk that rotated with the planet (Figures 7A–B). Bright in red light, it lay over southern *Chryse–Xanthe*; its E. limit overlaid an all but invisible *Margaritifer Sinus*, and at its S. boundary previously dark areas appeared pale. *Aurorae Sinus* was not seen. (There seems no question of error: upon the much smaller disk of 1998 Nov 7 (same CML) Gray had seen *Margaritifer* and *Aurorae* of normal darkness.) Under CML = 67°, Hernandez observed from the USA and found *Chryse–Xanthe* bright in red light in the afternoon. *Coprates* and *Solis Lacus* were not affected, but the *Aurorae Sinus* region appears shrunken in his drawing, and northern *Margaritifer Sinus* looks veiled. Next morning Gray had awful seeing: the S. hemisphere still looked veiled. Was Feb 21 the first day of the event? Devadas had found the region normal on Feb 16. However, Parker had observed visually on February 19 when a cloud with 'a peculiar hook shape, reminiscent of dust' lay over evening *Xanthe*.

On Feb 23 (Figure 7C) Gray found *Aurorae Sinus* particularly faded, the area to the E. including *Margaritifer Sinus* near-normal, *Mare Erythraeum* normal, and the bright cloud gone. (*Chryse* was still lightish: here, mainly seasonal white cloud and ECB?) Heath on the same morning, albeit in poor seeing, could not see *Aurorae Sinus* at all. Parker imaged the planet on Feb 22 and 24 but seeing was poor and CML too high; on the latter date *Chryse* was very bright in red and blue light; ECB evident. On Feb 23 Whitby found the evening *Chryse–Xanthe* enhanced in red light. The Director did contact the *MGS* team, but the region could not be imaged by the spacecraft.[4] (This was prior to *MGS* attaining its final mapping orbit, and MOC and TES data commencing.)

The event was soon over. On Feb 26 Gray and Parker showed *Aurorae Sinus* darker but not strong, the only atmospheric activity being the customary equatorial white cloud. Beaumont and Teichert found nothing unusual on Feb 26–27. On Feb 26, 28 and March 3, Parker imaged a small dusty white cloud (*e.g.*, bright in both red and blue) in southern *Chryse* near *Aromatum Prom.* that rotated with the planet. Significantly, nearby *Hydaspes* was more noticeable from Feb 28, as if newly intensified. Parker's March 3 images show the markings normal with little or no trace of dust. The *Aromatum Prom.* cloud was also weakly caught by Ikemura, March 13.

Thus we have a short-lived regional event associated with the E. end of the *Valles Marineris*, whose objectivity is strengthened by the darkening of *Hydaspes*, and which *may* have continued further in the form of a small nearby dusty-white cloud. Schmude's measured B–R colour indices for Feb 22, on the storm-centred hemisphere, are 0.05 magnitude higher than expected, consistent with a small reddening due to higher dust-loading,[12] but microwave measurements by Todd Clancy (communicated at the time) failed to show any widespread short-term atmospheric temperature rise. Conclusion: regional storm over *Valles Marineris* and environs, *ca*. Feb 19 (Ls = 99°)–Feb 26.

1999 March

On March 31 (04:10 UT, CML = 53°) Hernandez reported a bright streak running E–W along the S. edge of *Valles Marineris* as far E. as W. *Margaritifer Sinus*, and continuing into N. *Thaumasia*. (His drawing resembles Minami's for a similar event in April: see Figure 7D.) Hernandez had not noticed it earlier: it was well defined, and bright through a W23A red filter. The Director considers that the region was normal on an image taken 1h earlier by Cidadão. Hernandez on April 2 found that the area had already returned to normal.

A Pic du Midi image of March 24 shows the entire region normally. Strange took a CCD image on March 27 (CML = 43°). This shows a bright area in *Ophir* which apparently interrupted *Agathodaemon* (*e.g.*, *Coprates*, a part of *Valles Marineris*). However, *Candor–Ophir* was at the time habitually brightened by the ECB. In retrospect it seems that the event must actually have begun on March 31. Parker imaged the area on April 1 under very bad seeing. No dust storm was apparent. His work on April 2, 3 and 6 is hi-res, all being apparently normal; the small 'dusty-white' cloud near *Aromatum Prom*. was again recorded (see earlier). On April 5, Warell found a yellow tint to the S. *Chryse–Xanthe* a.m. cloud: slight dust diffusion? (Warell on March 29–April 1 found that the customary morning cloud over *Tharsis* and *Thaumasia*, *etc.*, also appeared yellowish, but this seems unrelated.)

MGS and *HST* imaging data again do not help. Also, atmospheric temperature measurements derived from *MGS* occultation data were only being obtained for high latitudes at that epoch. Conclusion: local storm along E. *Valles Marineris*, minor dust diffusion into S. *Chryse–Xanthe*, *circa* March 31 (Ls = 117°) –April 5.

1999 April

On April 16 Minami (Figure 7D) witnessed a light yellow E–W oriented streak just south of *Margaritifer Sinus*. There was no absolutely certain confirmation in the relevant images of April 16–21, nor in contemporaneous drawings in poor seeing. An event limited to one or a few days commencing on April 16 is most likely, because Minami himself did not see it on April 15 or 20, and good CCD images up to April 15 do not show it. Local storms here may last only a day or two. The location recalls the February and March storms described above, as well as earlier ones from 1984 April (Ls = 132°)[22,25] and 1997 July (Ls = 139°).[1] Again, *MGS* data did not record it.[19] Conclusion: another local storm over E. *Valles Marineris*, April 16 (Ls = 125°) only.

1999 May

An *HST* image obtained on May 6 (Ls = 134°) clearly shows a local storm around the N. slopes of *Elysium Mons*. Images by Akutsu and Ikemura could not reveal the small clouds imaged by *HST*, but showed the usual white cloud (with small daily changes) persisting around and over *Elysium* throughout. Neither Adachi nor Minami on May 6 and 8 (Figures 6E, G, H) made any special remark about *Elysium*: the event was again too small for ground-based detection. Cantor *et al.*[17] describe a N. polar local dust storm that began at Ls = 136°; it lasted only one day, a typical performance. It was below the resolution of our telescopes. Following three successive small *Valles Marineris* events, *MGS* imaged dust activity in the lower parts of the canyon (at the junction between E. *Ius Chasma* and W. *Melas Chasma*) on May 16 (Ls = 139°),[3] but again on much too small a scale for our telescopes to have resolved.

There were a number of 'false alerts' near opposition. For example, a possible local event in *Tempe* during May independently suspected by three observers in the USA was in reality no more than ground colouration coupled with white cloud and opposition brightening.

1999 June and July

As noted in the Interim Report,[3] a small arctic dust storm was observed by Cidadão and McKim in early June. It seems likely that the 'polar cyclone' activity over *Baltia* in late May disturbed some dust. Cidadão's red image of June 2 (Figure 7F) shows a dust cloud centred around λ = 100° interrupting the normally dark albedo features (witness Figure 7E) adjacent to the cap, running SE from the cap edge (latitude *ca.* +84°) to *ca.* 70° latitude in *Mare Boreum*: the cloud's *p.* edge seemed to coincide with the *Chasma Boreale* rift. The cloud was not imaged by Cidadão the previous day, nor was it visible in blue light. On June 3 Cidadão's image showed the NPCB again interrupted, but the cloud was more diffuse and paler. The same day, McKim (Figure 3C) sketched the feature near λ = 95°. Fortunately, Cantor *et al.* also list this event as a local storm (MOC imaged it at Ls = 148.96° (June 4; –70.2°, 99.2°)). Cidadão's June 5–6 images no longer showed the cloud, whilst on June 10 Parker's images showed that the NPCB had darkened again at these longitudes. Conclusion: local storm over *Chasma Boreale* to *Mare Boreum*, *circa* June 2 (Ls = 148°) – June 3.

Note the extreme similarity in seasonal date between the above event and earlier arctic dust storms in 1995[23] and 1997,[1] both at Ls = 145°.

The later polar cyclones over *Baltia* during July (continuing from the purely white cloud activity that had begun in late June) had a dull yellowish-white tone (July 4–9), suggesting a dusty component. Activity varied from day to day, peaking on July 4 and 8 (on the latter day according to Minami much of *Mare Acidalium* was effaced, even upon mid-disk: see Figures 7G–H). As illustrated and further detailed in the Interim Report,[3] *MGS* had imaged a dust storm near the NPC on June 30–July 1, the dust ejected near *Chasma Boreale* propagating south to obscure *Hyperboreus Lacus* and curving eastward. Minami considered that the odd shape of the NPC on July 4 recorded in OAA data was also due to this dust event, and we assume that the above narrative concerns just one event, rather than two interconnected ones. Conclusion: regional storm from *Hyperboreus Lacus* to *Mare Acidalium*, June 30 (Ls = 162°) –July 9.

Cantor *et al.*[17] have described *MGS* images of the above event, as well as for another similarly-located event commencing in early August at Ls = 183°, by which time the planet was too distant for ground-based detection.

1999 August to 2000 March

Despite the shrinking disk, good coverage was maintained throughout this period by those in lower latitudes. It is quite certain that there was no encircling dust storm, as *MGS* data[18,19] confirm. *Hellas* showed no anomalous behaviour, and *Hellespontus* remained dark and unbroken throughout, the SPC remained continuously visible, *etc*.

According to *MGS* data (summarised below) the most significant regional activity occurred during Ls = 223–245° (1999 Oct–Nov). By then the disk was only ~6" diameter, and the activity was not visible in the low-resolution ground-based data. The resultant atmospheric warming was enough to interrupt the *Tharsis* orographic water-ice cloud activity.

Minami and Nakajima[11] found a bright area cutting *Hellespontus* on 2000 Jan 5 (D = 5".1, Ls = 277°), from northern *Hellas* to *Noachis*. *Hellas* was again light on Jan 8. This was possibly dust associated with the circumpolar activity during Ls = 260–280°, as described by Smith & Pearl (see below).[19]

Regional dust storm observations by the MGS TES: a summary

Data cover Ls = 104–360° (1999 March 1–2000 June 1): five events of regional scale were identified[19] (which for completeness we record below). Cantor *et al*. identified 12 'regional' storms but redefined the term.[17] The following details are mostly taken from Smith & Pearl,[19] but the MOC data[17] yield a more comprehensive analysis of individual events.

I Ls = 160–200°. 50°S. General small-scale activity: all longitudes, SPR/SPC N. edge. (Normal seasonal behaviour, recorded from *Viking* onwards.)

II, III Ls = 223–243°. The largest regional event, comprising two centres simultaneously active.[19] (Cantor *et al.*[17] cite three centres and give greater detail of the events.) It left widespread haze in the S. hemisphere.

II Ls = 223–232°. Began over *Margaritifer Terra* (*Sinus*) at 0–20°S, long. 10–40°. Grew to 90° in longitudinal extent (E. *Valles Marineris* to NE *Noachis*).[17]

III Ls = 227–243°. Began at 0–20°N, long. 160–200° (W. *Amazonis*). Smith & Pearl[19] claimed that the event then migrated to high S. latitude (relocating at 60°S, long. 210° by Ls = 235°) before decaying, but this seems highly unlikely and in fact Cantor *et al.*[17] identified this latter arctic dust cloud as a separate event.

IV Ls = 260–280°. Regional event, poleward of 70°S, all longitudes (especially 90–270°) affected. Did not spread N.

V Ls = 321–345°. Same location as **III**(a) but smaller.

None of these events was potentially detectable telescopically because they occurred either well after opposition and/or at high S. latitudes. Smith & Pearl[19] have described how a low-latitude S. hemisphere event can cause concomitant dust-raising in the N. hemisphere (as the Ls = 224° event was observed to do) by increasing the strength of the Hadley circulation. Cantor *et al*.[17] comment that of the traditional emergence sites, *Solis Planum* (*Lacus*) and *Hesperia* were not at all active in 1999.

Discussion

The telescopic activity described above is entirely typical. The *Valles Marineris* events of 1999 February to April recall the three successive storms of late 1990 in the same area.[22] Detection of north polar dust storms adds to the scant historic records,[22] and confirms their seasonal character by virtue of the observations by *HST*[1] during the previous martian year. What is quite unusual is the activity at *Margaritifer Sinus*. Historically this has tended mostly to be a focus of secondary activity during planet-encircling storms,[22] but more recently it was the emergence source for the large regional storm that began in 2005 October. To become active in this way it is likely to have become a source of accumulated dust from dust storm fallout. On the other hand, the inactivity around *Solis Lacus* points to an opposite situation there. The evidence that emergence sources may follow a dormant-active cycle (due probably to net dust loss or net accumulation)[22] is therefore slowly growing. The absence of small dust storms in the southern subtropics in 1999[17] may explain the absence of any encircling storm. Cantor *et al.*[17] further comment that cross-equatorial dust-loading data suggest the southern subtropics require 2–3 Mars years to replenish their surface dust between planet-encircling events, giving weight to the writer's historical statistic[22] of such events occurring on average at one in every three Mars years.

North Polar Region

General description

Figure 8 illustrates the seasonal behaviour of the NPR. Observations could not commence early enough to document the transition from polar hood to cap. A dark collar (*e.g.* Figure 4A) was already apparent to Biver on 1998 Sep 20, to Schmude on Sep 27, and to Gray, Frassati and the CCD imagers in October. Circumstances were also unfavourable for seeing the annular rift (of 1993–97) within the spring cap. However, in excellent seeing and using high magnification on 1998 Oct 24 (Ls = 48°, CML = 290°), Biver recorded a sighting of part of the rift which coincided with its broadest and darkest part.[20] *MGS* images also show the annular rift clearly.

Cap fragmentation could be fairly well observed, but the modest northward tilt of the NPR at opposition did not help: limiting dates of some seasonal phenomena were not secured.

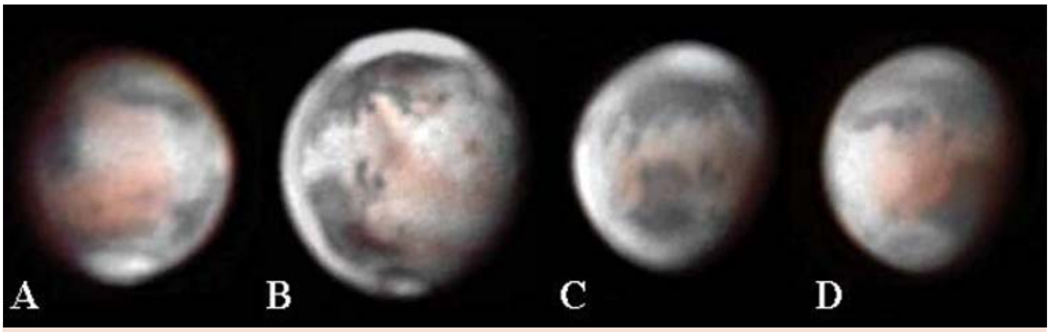

Figure 8. North polar region, 1998–'99.
CCD images with 410mm refl., f/48–55, *Parker*. Note the shrinkage of the cap (from A to B) and the short-term growth of the hood in the longitude of *Mare Acidalium* (C to D).
A: 1998 December 25d 10h 05m, CML = 318°, D = 6".0. Bright patch in large NPC.
B: 1999 June 14d 02h 32m, CML = 81°, D = 13".5. Summer NPC. *Hyperboreus Lacus*.
C: 1999 July 24d 01h 24m, CML = 47°, D = 9".8.
D: 1999 July 28d 01h 32m, CML = 11°, D = 9".5.

To Parker's CCD camera on 1998 Dec 25 (Figure 8A) the cap contained a brighter patch *f.* the CM. Buda & Curcic and Di Sciullo (April 11–22) imaged the same bright spot near long. 340°. A handful of high resolution CCD observations and drawings by Biver and Gray (March 10–May 23) revealed a notch near long. 330°, which lay on the *p.* side of the bright spot; this would be the source of the *Rima Tenuis* rift.

Table 3. NPC latitude measurements 1998–'99

	Visual drawings		CCD images	
Mean Ls (°)	*Latitude of S. edge of cap (°)*	*No. of measures*	*Latitude of S. edge of cap (°)*	*No. of measures*
38*	69.5	6	–	–
43	70.8	4	–	–
48	71.6	16	69.8	4
53	71.4	9	–	–
58	72.4	11	72.8	5
63	74.3	7	–	–
68	75.0	5	–	–
73	75.8	10	–	–
78	75.2	6	76.7**	6
83	76.4	7	–	–
88	–	–	77.9	7
93	81.2	5	78.9	14
98	81.4	7	–	–
103	80.0	6	78.1	13
108	78.9	12	77.9	13
113	80.8	12	81.1	26
118	77.7	22	78.8	23
123	79.3	41	79.4	14
128	81.5	73	82.7	36
133	83.0	79	82.3	59
138	83.3	79	81.8	26
143	84.1	43	82.9	13
148	83.4	25	83.6	33
153	83.5	23	84.1	7
158	81.2	22	–	–
163	74.4	14	–	–
168	76.2	13	–	–
173	71.9	10	–	–
178	72.4	11	–	–
183	69.9	9	–	–
188	71.0	6	–	–
193	67.2	4	–	–
198	65.4	5		
Totals		602		299

*5° latitude means (*e.g.*, Ls = 35–40° etc.), quoted when 4 or more measures were available
**averaged over Ls = 71–85°

As explained in our recent reports[1,23] this fissure tends towards the curved *Chasma Boreale* that enters the cap in the longitude of *Mare Acidalium* (see below), and does not bisect the cap along a meridian. Biver's and Minami's drawings (Figure 4F) and CCD images in May (Figure 2D) showed that *Chasma Boreale* terminated halfway across the cap. HST images at opposition (Figure 9) confirmed this, and showed a small indentation in the longitude of *Rima Tenuis*.

Parker's images of Jan 9 (Ls = 81°) and 15 showed *Olympia* detached from the cap by the *Rima Borealis* rift, an observation confirmed by Minami on Jan 17. (Better resolution would surely have revealed this earlier.) The inky-black spot *Hyperboreus Lacus* had become visible at the edge of the retreating cap by late December. *Chasma Boreale* was first shown on Di Sciullo's April 2 image, but became broader and longer in May and June. Adachi, Buda & Curcic, Cave, Cidadão, Di Sciullo, Minami, Parker and Tan all recorded it. All these NPC and peripheral features (variously illustrated in Figures 1, 2, 3A–C, H, 4C, E, F, H, 5A–E, 6D-H, 7D–F, 8B) existed until hidden by the NPH in early July.

By February the N. polar cap appeared small, and at some longitudes (*e.g.*, with *Sinus Sabaeus* on the disk) the dark rim was hard to see or absent. Indeed, there was often white haze just S. of the NPC during February to April. Despite this haze the outlying bright area of *Olympia* continued to be well visible. In violet light images such outliers seemed hazy and enlarged, perhaps specifically associated with volatiles. (Compare the red and blue images in Figures 2I–L and Q–T.)

The little outlier *Ierne* was quite elusive in 1999, and would no doubt have been caught earlier given a larger disk. Biver saw it on May 15 and on May 16–22 Minami also found it detached (Figure 6B); *Deucalidonius Lacus* formed a dark patch between it and *Olympia*. *Ierne* is just traceable upon the best images by Cidadão (May 2 (Figure 7F)) and Parker (March 26 (Ls = 115°) to May 7). It was of course imaged by *HST* (Figure 9B).

Around the cap in May the amount of polar haze increased, so that again the NPC had a more diffuse whitish surround. This was especially noted by Haas, Frassati and the Director (Figures 3E–G). From late April onwards discrete peripheral polar clouds had been seen, and *HST* images and *MGS* movies showed wispy streaks around the NPC summer remnant:

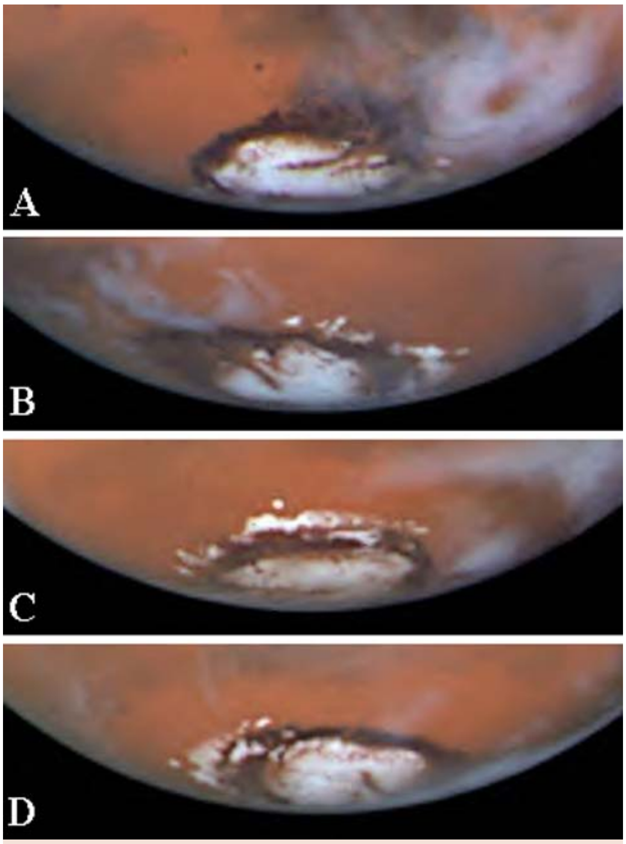

Figure 9. The summer NPR.
HST images of the summer NPC obtained with the WFPC-2.
A: 1999 April 27, CML *ca.* 20°. *Chasma Boreale* at the CM, with N. 'polar cyclone' following.
B: 1999 April 28, CML *ca.* 120°. *Ierne* at CM.
C: 1999 May 6, CML *ca.* 210°. *Olympia* at CM.
D: 1999 May 1, CML *ca.* 290°. Notice how *Chasma Boreale* enters the cap from the N*f.* side but fails to cut the cap in two. *Credit*: *STScI and NASA*

'polar cyclones' (see the 'White Cloud' section for details and Figure 9A).[5,6]

Signs of permanent polar hood were evident by late June: the 'polar cyclone' clouds may be seen as its precursor. Concerning the transition from NPC to NPH, the Director found: on June 18 (CML approx. 330°) the S. edge of the NPC was less sharp and bright than previously: overlying hood? The NPC seemed sharper on the 20th under CML *approx.* 295°, despite mediocre seeing. But on June 24, CML *approx.* 260°, the cap showed brighter haze to its south. Bad weather intervened. At Michael Hendrie's observatory on July 9 (Ls = 167°, Figure 3D) he had an excellent view, when an undeniable change was evident: the less bright hood was large and diffuse over the N. limb. The hood was brighter and larger still on July 11 at the same longitude, and in all later views. An increase in the NPR diameter was confirmed by Meredith (late June), Siegel (June 19) and Topping (June 25). Teichert on June 17–28 found the NPC faded, and blurred at the edges; Wasiuta found it hazy on June 27. Imaging by Cidadão, D. M. Moore and Parker (Figures 8B–D) shows a ground cap together with a polar haze patch on June 24, then overlying NPH present from June 25, over those longitudes accessible from Europe and the USA.

Japanese data[7] reveal bright NPC with dark edge, *Rima Borealis* and *Olympia* until June 18; NPC slightly less bright, fainter dark edge, pale internal/peripheral details up till June 27 (Ls = 161°); then slight expansion (overlying NPH), and internal and peripheral details (including *Hyperboreus Lacus*) no longer visible. The OAA reported both hood and ground cap during July 1–15, hood predominating, with the situation changeable daily and particularly with CM longitude. *MGS* TES data indicate a hood from *approx.* Ls = 160°.

As the hood had essentially entirely covered the cap by late June, we shall adopt June 27 (Ls = 161°) as the transitional date. BAA data from 1984[25] show that the hood also then appeared after Ls = 161°. The hood was highly asymmetric (Figures 3D, 4D, 8C–D). It continued to be seen until November (Figure 6C), after which time the southward tilt rendered it invisible.

It is rare to have the opportunity to watch the NPC to NPH transition both with favourable presentation in latitude and adequate disk diameter. A very well-documented previous apparition is that of 1905: see Percival Lowell's daily views in his charming published sketchbook *Drawings of Mars, 1905*.[26]

Polar dust storm phenomena are covered in the 'Dust Storms' section.

Quantitative recession

A recession analysis (5° means in Ls over the interval Ls = 36–200° (1998 Sep 28–1999 Sep 5) was made by the same methods described in recent reports[1,23] based upon measures upon 299 (mostly) red light CCD images (11 observers) and 602 drawings (42 observers): see Figure 10 and Table 3. Visual and CCD data agreed well: scatter may reflect the relatively small amount of data. The graph was drawn to include the beginnings of the NPH. (Red light CCD images do not show the hood, so these data end first.)

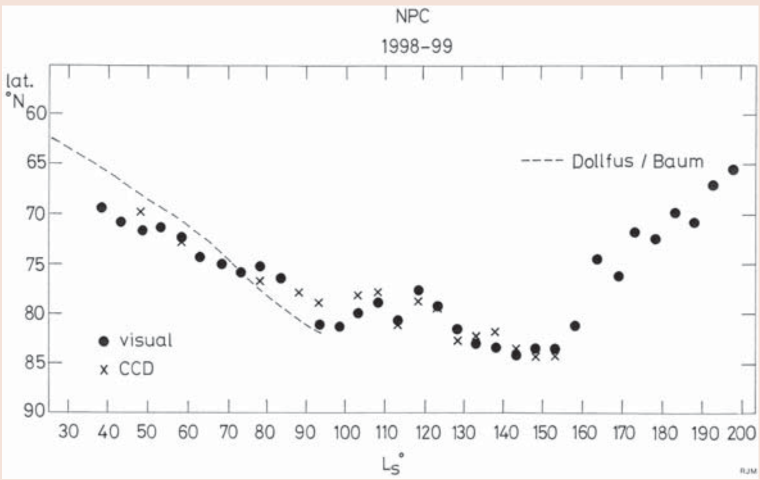

Figure 10. NPC regression curve, 1998–'99.
The latitude of the S. edge of the NPC plotted in 5° means in Ls, comparing visual and CCD measurements with the seasonal average curve of Dollfus and Baum. *R. J. McKim.*

The cap was a little smaller this year in mid-spring, as in the recent apparitions of 1995[23] and 1997,[1] and by comparison with the historical recession curve (1948–'52) of Dollfus.[27] Its recession was also a little slower than average so that the recession curves cross one another around aphelion. Significant differences in the past have been apparent only in the early recession, inaccessible this time. Both visual and CCD data independently point to an apparent cap regrowth – no doubt due to overlying cloud – during Ls *approx.* 101–125°. Over Ls = 126–155°, the summer NPC remnant was found to be 14° in diameter. Then the sudden increase in NPR diameter due to onset of permanent polar hood is clearly observable. After Ls = 165°, NPH growth continued rapidly (Table 3).

South Polar Region

The behaviour of the separate patches of hood constituting a S. pre-polar hood has been described in the white cloud section. As noted therein, we consider that a continuous SPH was formed in 1999 May, and Ebisawa[13] more precisely timed the transition to a single polar hood as being complete at Ls = 139°.

Given the presence of the SPH and the unfavourable tilt it is hard to be precise about the transitional epoch from ground-based work. However, *MGS* data reveal the SPC one week before the S. spring equinox (*e.g.*, at Ls = 176°: a typical result). Minami considered that a bright sliver of SPC was first visible, south of *Mare Sirenum*, on July 24 (also at Ls = 176°). Parker's red images suggest the SPC was present south of *Mare Erythraeum* on the same date, though in blue light an overlying hood still appears larger. Minami again saw the SPC on July 31 in the longitude of *Claritas*. Ebisawa drew it clearly on Aug 2, as did Crandall on Aug 6–7. It was confirmed visually by Adamoli, Biver, Frassati (Figure 6C) and the Director, being more constantly visible from late August, but since its shrinkage roughly matched the decrease in the northward value of D_e, it remained for some time as a bright limb arc. Later images by Ikemura and Parker record its shrinkage with time, but precise measurements were not possible. *MGS* data naturally reveal the cap fragmentation including the detachment of the Mitchell Mountains in 1999 August.[3]

By Oct 12 the sub-Earth point became southward: by then the cap was much smaller. By Oct 21 *Depressiones Hellesponticae* was visible to Minami[7] as a dark patch at its N. edge, as was *Magna Depressio* in the centre (by October 25). The cap was followed till 2000 mid-March, by which time disk diameter and solar elongation were very small.

Occultation of HIP 65927 by Mars

Ikemura's images of 1999 May 30 show that the star HIP 65927 passed behind the southern limb of the planet on that date; Adachi noted its reappearance at the morning terminator at 13:26 UT.

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