The opposition of Mars, 1990

Richard McKim

The surface of Mars in 1990 closely resembled its appearance in 1988, with only very small modifications in detail. Northern hemisphere features were seen to better advantage than in 1988. The martian atmosphere was generally very transparent, with normal white cloud activity and a moderate blue clearing about opposition. Yellow cloud activity was low, but three important local (or regional) dust storms began in the region of SW *Chryse* to *Pyrrhae Regio* in October, November and December. The recession of the S polar cap was followed, as well as activity in both polar hoods. Haze around the SPC formed unusually early and often obscured the cap. This report of the work of 74 observers covers the period 1989 December to 1991 June.

Report of the Mars Section *Director: R. J. McKim*

Introduction

With Mars again well-placed for northern hemisphere observers, the 1990 opposition was enthusiastically observed by the Section, though less intensively than in 1988. Opposition occurred on November 27 with the planet in Taurus, and was the third in the present series of perihelic approaches. Mars' apparent diameter reached 18.1 arcsec at closest approach to Earth on November 20 and 18.0 arcsec at opposition.

The south pole of Mars was tilted slightly towards Earth at opposition, and by November the S polar cap had almost completely evaporated. At opposition there was a large hood over the N pole. Physical data:

Latitude of centre of disk at opposition	... − 8°.9	
Declination at opposition	... +22°	
Spring equinox of S hemisphere / Autumnal equinox of N hemisphere	... 1990 March 6	(L_s = 180°)
Mars in perihelion	... 1990 June 30	(L_s = 250°)
Summer solstice of S hemisphere / Winter solstice of N hemisphere	... 1990 July 30	(L_s = 270°)
Mars in opposition to the Sun	... 1990 November 27	(L_s = 340°)
Autumnal equinox of S hemisphere / Spring equinox of N hemisphere	... 1991 January 5	(L_s = 0°)

The martian date at opposition was March 1. The S pole was tilted towards Earth from 1990 mid-January (increasing to −24°.9 in May, decreasing to −3°.3 in October and increasing to −13°.1 in December) till 1991 late March. The N hemisphere was displayed thereafter, the tilt increasing to some +20° by 1991 late June.

Observations from 74 observers in 12 countries covered the period 1989 December 21 (Schmude, L_s = 140°) till 1991 June 3 (McKim, L_s = 68°), contributing 1419 drawings, 189 photos and 32 CCD-video images; a total of 1670 observations, about 45% of the 1988 total. Special mention must be made of Piatt's CCD-video work: he achieved remarkable results in spite of the unfavourable UK weather. Miyazaki made systematic blue-violet light exposures; several are reproduced herein. Comprehensive series of observations were also made by Cave, Graham, Heath, Johnson, Minami, Moore, Parker, Rogers, Dal Santo, Schmude, Shirreff, Troiani and the writer. McKim visited Meudon for a week in December, at the invitation of Dr Audouin Dollfus; unfortunately, little observational work was possible. Daniel Crussaire of the Societe Astronomique de France sent some useful SAF observations of the November dust storm, and similar data were supplied by Dr Don Parker, Mars Recorder for the Association of Lunar and Planetary Observers (ALPO), by Christian Schambeck on behalf of the Bund der Sternefreunde (BdS), by Mark Bosselaers on behalf of the Vereniging voor Sterrunkunde (VvS) and by Jean Dijon, Mars Coordinator for the Groupement Internationale d'Observateurs des Surfaces Planetaires (GIOSP).

The observing prospects for 1990 were briefly reviewed by the writer,[1] and others also wrote about the apparition.[2-5] An Interim Report was issued in 1991 April.[6] Reports from GIOSP appeared in *Pulsar,*[7] and from the Oriental Astronomical Association (OAA) in its *Communications.*[8]

One of the most notable points about the present apparition was the lack of major change since 1988,[6] indicating the absence of dust storm activity during the intervening solar conjunction. This close comparison was remarkably well illustrated by post-opposition images with the Hubble Space Telescope[9]: irregularities in the contour of *Syrtis Major* in the HST images are comparable with those in 1988 CCD images by Larson and others. In addition to recording the general comparability in albedo features with 1988, BAA observers followed the activity in the polar areas and three local dust storms.

Since our previous report, other organisations have published reports covering 1986 and 1988.[10] The Section collaborated with overseas organisations as in the last apparition, together with the SAAF Planets Section (Sweden) via Johan Warell. This account is arranged in the usual way and is a continuation of the 1988 Report.[11] Comparison may be made with 1975-76,[12] when the martian seasons closely corresponded with

Table 1. Observers of the 1990 apparition.

Name	*Location(s)*	*Principal instrument (s)*
G. Adamoli	Padua and Verona, Italy	110-mmOG and 250-mm refl.
L. Aerts	Heist-op-den-Berg, Belgium	305-mm refl.
T. Akutsu	Tochigi-Ken, Japan	320-mm refl.
M. Alexescu	Bacau, Romania	200-mm Nasmyth-Cass.
T. M. Back	Seven Hills, Ohio, USA	152-mm OG
R. M. Baum	Chester	115-mmOG
S. Beaumont	Windermere, Cumbria	75-mm OG
J. D. Beish	Mauna Kea Observatory, Hawaii	610-mm Cass.
N. Biver	Chatenay-Malabry, France	200-mm refl.
M. Bosselaers	Berchem, Belgium	125-mm and 250-mm refls.
M. Boulton	Redditch, Worcs.	157-mm refl.
D. Boyar	Boynton Beach, Florida, USA	152-mm refl.
K. Brasch	Highland, California, USA	355-mm Schmidt-Cass.
R. Buggenthien	Liibeck, Germany	150-mm OG
F. C. Butler	London	221-mm refl.
N. Cabrol	Meudon Observatory, France	830-mm OG
G. Canonaco	Genk, Belgium	200-mm OG
T. R. and V. Cave	Long Beach, California, USA	320-mm refl.
	Ford Observatory, California	457-mm refl.
R. Cerreta	Colle Leone Observatory, Teramo, Italy	500-mm Cass.
	Nice Observatory, France	500-mm OG
J. Coates	Burnley, Lanes.	305-mm refl.
D. Crussaire*	Meudon Observatory, France	830-mm OG
H. J. Davies	Swansea	220-mm refl.
G. Denney*	Wisbech, Cambs.	254-mm refl.
J. Dijon	Champagnier, France	200-mm refl.
E. L. Ellis	St. Albans	90-mm OG
M. Falorni	Arcetri Observatory, Florence, Italy	360-mm OG
D. Fisher	Sittingbourne, Kent	215-mm refl.
J. Fletcher	Gloucester	254-mm refl.
M. Foulkes	Hatfield, Herts.	254-mm refl.
M. J. Gainsford	Burbage, Leics.	254-mm refl.
M. Gelinas*	ND-Ile-Perrot, Quebec, Canada	152-mm OG
M. Giuntoli	Montecatini Terme, Italy	100-mm OG
D. L. Graham	Brompton-on-Swale, N. Yorks.	152-mm OG
	Gilling West, N. Yorks.	406-mm refl.
A. W. Heath	Long Eaton, Notts.	300-mm refl.
N. D. Hewitt	Northampton	203-mm Schmidt-Cass.
H. Hill	Wigan	254-mm refl. and 208-mm Schmidt-Cass.
A. Johnson	Knaresborough, N. Yorks.	210-mm refl.
M. Jousset*	Meudon Observatory, France	830-mm OG
A. P. Lenham	Swindon, Wilts.	203-mm refl.
L. T. Macdonald	Newbury, Berks.	222-mm refl.
R. J. McKim	Cambridge University Observatory	203-mm and 320-mm OGs
	Oundle, Northants.	216-mm and 300-mm refls.
M. Marchand	Annemasse, France	400-mm refl.
K. J. Medway	Southampton	102-mm OG
	Norman Lockyer Observatory, Sidmouth	254-mm OG
C. Meredith	Prestwich, Manchester	216-mm refl.
M. Minami	Taipei, Taiwan	250-mm OG
	Fukui, Japan	200-mm OG and 200 mm refl.
I. Miyazaki*	Okinawa, Japan	400-mm refl.
M. P. Mobberley*	Bury St. Edmunds	356-mm Cass.
P. A. Moore	Selsey, Sussex	390-mm refl. and 125-mm OG
S. L. Moore	Fleet, Hants.	222-mm refl.
R. Neel	Venissieux, France	310-mm refl.
D. C. Parker*	Miami, Florida, USA	410-mm refl.
R. A. H. Paterson	Thame, Oxon.	320-mm refl.
T. Piatt**	Binfield, Berks.	320-mm refl.
G. Quarra Sacco**	Florence, Italy	300-mm Cass.
and D. Sarocchi	CIDA, Venezuela	1000-mm refl.
K. A. Read	Southend, Essex	152-mm refl.
R. L. Robinson	Morgantown, W. Virginia, USA	254-mm refl.
J. H. Rogers	Linton, Cambs.	254-mm refl.
M. Dal Santo	Saletto, Italy	200-mm refl.
C. Schambeck	Nassenhausen, Germany	150-mm OG
R. W. Schmude, Jr.	Tomball, Texas and Los Alamos, New Mexico, USA	356-mm Schmidt-Cass. and 254-mm refl.
D. Shirreff	Marlborough College, Wilts.	254-mm OG
P. Smith	Darlington	150-mm refl.
A. Snook	Dover, Kent	200-mm Schmidt-Cass.
K. M. Sturdy	Helmsley, N. Yorks.	216-mm refl.
D. M. Troiani	Schaumberg, Illinois, USA	254-mm and 444-mm refls.
H. Vandenbruaene	Beernem, Belgium	200-mm refl.
F. van Loo	Genk, Belgium	200-mm OG
E. Verwichte	Genk, Belgium	200-mm OG
D. Vidican	Bucharest, Romania	120-mm refl.
J. Warell	Ulricehamn and Uppsala, Sweden	152-mm refl. and 161-mm OG
A. W. Wilkinson	Worcester	241-mm refl.
D. Wright	Sanderstead, Surrey	133-mm OG

* indicates the submission of photographs; ** CCD images.

Observations by Cabrol and Jousset (SAF) were communicated by Crussaire; those of Beish, Boyar, Brasch and Robinson (ALPO) by Parker; those of Buggenthien (BdS) by Schambeck, those of Canonaco, Vandenbruaene, van Loo and Verwichte (VvS) by Bosselaers and those of Biver : and Marchand (GIOSP) by Dijon

1990-91. In 1991 October the Terrestrial Planets Section was dissolved and the two Sections which had been merged to create it in 1979 were re-formed. This is therefore the first Report of the new Mars Section.

Surface features

Note: nomenclature is after Ebisawa;[13] E and W are used areographically (E = *p;* W = *f*).

Apparition map

This is shown in Figure 1 and was drawn from the best November and December CCD images, photographs and drawings. The lack of large-scale modifications since 1988 enabled the 1988 chart to be used as a basemap. Details revealed in the high-resolution CCD images taken at the Pic du Midi observatory[14] have been included; HST images[9] were also used.

***Region I**: ω = 250-010°*

Refer to Figure 4 for observations specifically of this Region. Most of the *Syrtis Major* region appeared as in 1988," the *Syrtis* being broad and dark and blunted to the north, with the *Huygens* crater a dark spot in *Iapigia* (Figs. 3M, 4A, B, D). *Moeris Lacus* was again very small, somewhat altered in shape since 1988. To McKim, *Syrtis Major, Iapigia, Mare Serpentis* and *Mare Tyrrhenum* showed a bluish tint near opposition. Hill saw a brownish tint in *Syrtis Major* in November, but Minami saw it bluish in December. *Libya,* bordering the *Syrtis* on the SE side was habitually a bright round spot, but on October 23 to Minami (Figure 4E) and to Heath on December 14 and 16 this bright region seemed to extend across the S half of *Syrtis Major,* quite cutting it off from *Iapigia. Nepenthes* was not seen on the photographs nor on the CCD images; however, Crussaire showed it faintly on his drawing with the Meudon refractor on September 2 (Figure 4B), and some of Minami's observations show it faintly. *Nilosyrtis* was quite well visible as a faint tail to *Syrtis Major* (Figure 4D), and *Astaboras* was also seen. The regions to its northwest including *Coloe Palus, Protonilus, Ismenius Lacus, Deuteronilus* were better seen than in 1988 on account of the difference in tilt, and appeared normal. *Nodus Alcyonius* was again a dark detached spot, brownish to Minami (Figs. 2E, 3M, 4C); more of the *Casius-Utopia* region was seen than during the 1988 opposition, and the whole area does not appear to have altered significantly since 1982.

Hellas to the south was generally of intensity 2 and was therefore no brighter than the equatorial deserts. Sometimes it filled with morning or evening white cloud at the limb or terminator. In the martian afternoon its NW corner often showed an atmospheric brightening as in 1988. According to the OAA there was an extension of the bright patch in a SW direction towards the S polar region, which could sometimes be seen from October to January. Minami found this extension best seen in green light (Figure 4E). Floor details in *Hellas* were quite plain, and *Zea Lacus* was quite obvious, being a little darker than in 1988 (Figure 3M). *Mare Hadriacum* and *Peneus* were rather dark.

Yaonis Regio, Yaonis Fretum, Hellespontus and *Mare Serpentis* were well seen as in 1988 (Figs. 2E, F, 3A, M, O, 4). That these particular features were unchanged points to a lack of dust activity in *Hellas* during Mars' solar conjunction in 1989. *Pandorae Fretum* was slightly shaded throughout 1990-91, appearing much less dark than *Sinus Sabaeus.* Its lack of seasonal variation supports the foregoing: in 1988" it had darkened suddenly from invisibility following dust activity emanating from *Hellas. Sinus Sabaeus* was darkest in the part W of *Portus Sigeus.* As in 1988 the E half, though obviously connected to *Iapigia-Mare Serpentis* without a break, was less dark. *Sinus Sabaeus-Sinus Meridiani* was brownish to Minami in June-September, and brownish to Hill in November, while *Noachis* was somewhat more shaded than *Deucalionis Regio. Ausonia* showed similar diurnal behaviour to *Hellas. Neudrus* was thinner and fainter than in 1988. Finally,

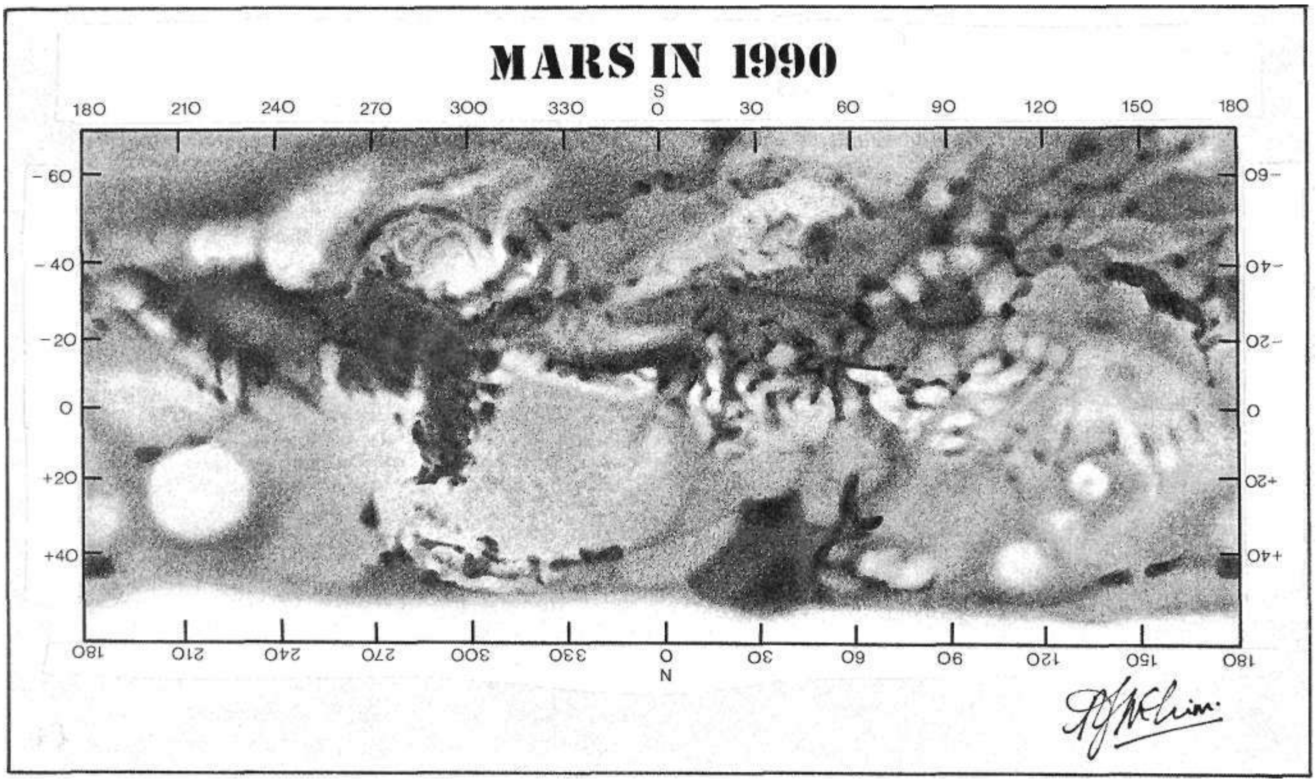

Figure 1. General map of the planet from observations in 1990 November-December. Professional CCD images covered most longitudes. The small remaining section from ω ~ 180-260° was mapped from photographs and drawings at lower resolution. The SPC is not visible; the NPH south edge is shown for the date of opposition, *R. J. McKim.*

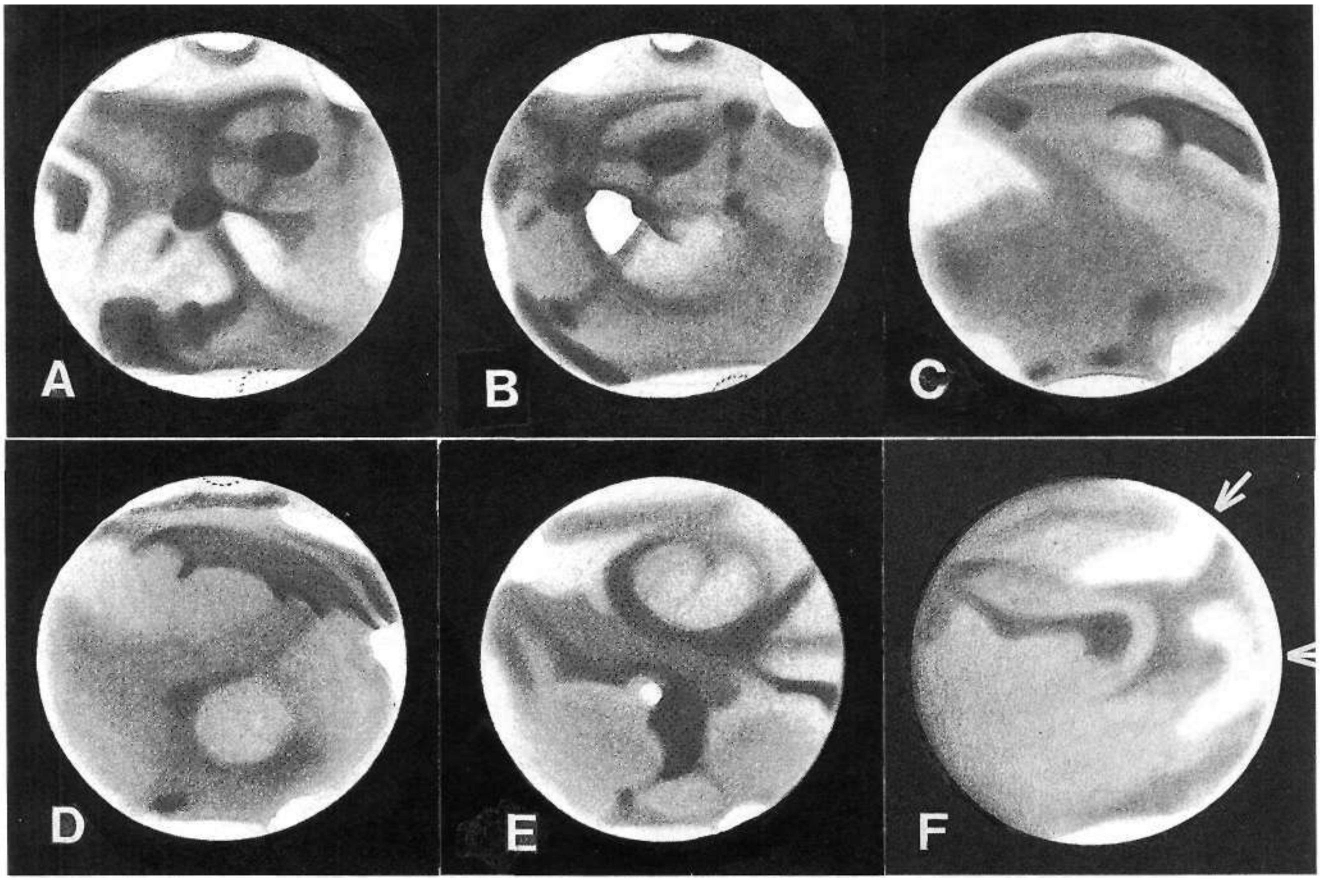

Figure 2. Drawings by R. J. McKim.
(A) December 5d 22h 23m, to = 68°, 216-mm refl., x232, **INT** (integrated light).
(B) December 5d 23h 25m, co = 83°, 216-mm refl., x 232, x 464, INT, W15, W25. *Phasis* and *Gallinaria Silva* noted/the large, dark *Solis Lacus;* bright spot in NPH; brightness at S pole.
(C) November 20d 21h 00m, co = 180°, 300-mm refl., x 141, x 303, INT, W15, W25. Bright *Memnonia* cloud; *Propontis (I)* and *Castorius Lacus* to the north.
(D) November 20d 22h 31m, ω = 202°, 300-mm refl., x 176, INT. *Aetheria* darkening; *Mare Cimmerium* details; *Cerberus (I)* and *{II)* seen.
(E) December 14d 18h 35m, ω = 293°, 216-mm refl., x 130, x 232, INT, W15, W25. Details in *Hellas;* note *Nodus Alcyonius* near Np limb.
(F) November 6d 00h 02m, ω = 357°, 216-mm refl., x 232, **INT,** W15, W25, *McKim.* Dust in *Chryse-Xanthe, Pyrrhae Regio,* etc. (arrowed).

Depressiones Hellesponticae was a dusky patch at the edge of the S polar cap in May-June, but it was less well seen later due to haze covering the S polar regions and the unfavourable presentation. However, it continued to be visible in the red-light CCD images at opposition.

Region II: co = 010-130°

The regions of *Mare Erythraeum, Margaritifer Sinus, Oxia Palus, Aurorae Sinus, Bosporos Gemmatus, Solis Lacus, Aonius Sinus, Chrysokeras, Thaumasia* and *Mare Australe* were all essentially unchanged from 1988 (Figure 5). *Aurorae Sinus* appeared greenish-grey to Hill in August. Local dust storm activity occurred nearby in October-December (see later). *Solis Lacus* was again large and dark, brownish to Minami, with similar structure and with a similar surrounding canal pattern to 1988 (Figures 2A, B, 3C, E, G, 5B-E). The only variable features were *Phasis* and *Phoenicis Lacus.* Since 1984, *Phasis,* a long-lost 'canal' has been visible, first appearing as a dusky streak between *Aonius Sinus* and *Phoenicis Lacus.* By 1986 its S part from *Aonius Sinus* to *Gallinaria Silva* had darkened. In 1988 *Phasis* was weaker but still visible. When re-observed in 1990 July by OAA members, *Phasis* was still weak. By late September, Piatt's CCD images suggested that *Phasis* was faint to the S of *Gallinaria Silva* but a little darker between it and *Phoenicis Lacus.* After the November dust storm, *Phoenicis Lacus* weakened, S *Thaumasia, Aonius Sinus* and S *Phasis-Gallinaria Silva* darkened appreciably: compare Figures 3E and G for October and November images. The newly revived *Phasis* was clearly recorded by Aerts, Buggenthien, Coates, Foulkes, Graham, Johnson, McKim, Minami, Miyazaki, Parker and Platt.

Ganges, Achilles Fons, Idaeus Fons, Nilokeras were again dark; *Lunae Lacus* was less conspicuous. All these features, together with *Mare Acidalium-Niliacus Lacus* had a brown tint according to Minami (September), but on October 22 Minami found *Mare Acidalium* to be bluish beneath the NP hood compared with the brownish tint of *Nilicaus Lacus:* on November 23 he found *Achilles Fons* dark bluish and *Lunae Lacus* brownish.

Due to the smaller southward tilt in 1990-91 more of *Mare Acidalium* could be seen to the S of the NPH than in 1988. *Niliacus Lacus* was again dark and partly separated from the *Mare* to the north. Several albedo features were seen in N and NE *Tempe* which are not

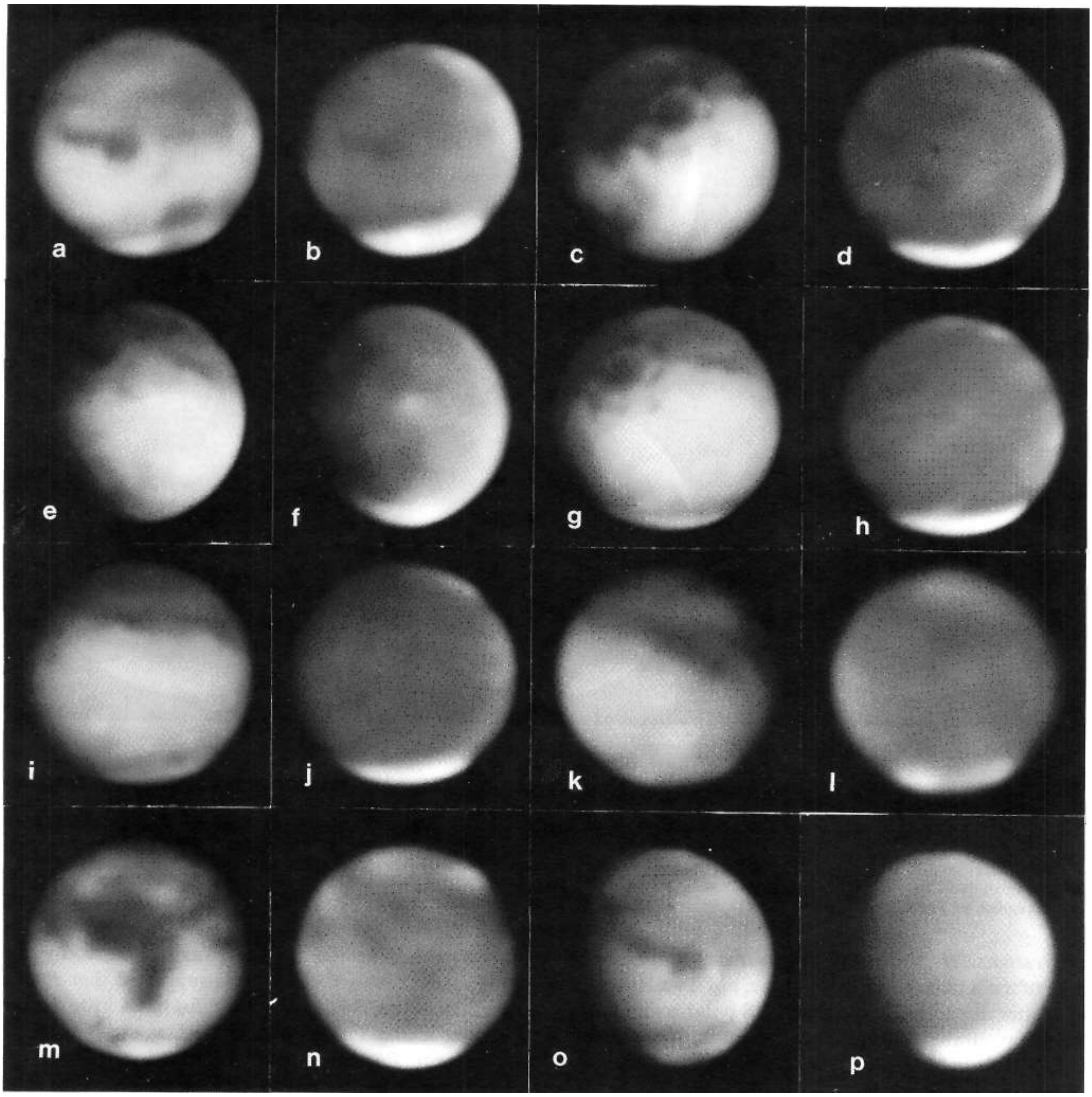

Figure 3. Photographs by I. Miyazaki, 400-mm refl., f/187, 2f-5 s for integrated light; f/187, 5 s for red light (R60 filter); f/130 15-20 s for blue-violet light (B390 filter); Kodak TP 2415 film. Arranged as pairs. The NPH is enlarged in the B390 filter photos: all these images except (P) reveal a partial Blue Clearing.

(A) November 26d 12h 57m, ω = 9°, INT. *Mare Acidalium* partly visible through the NPH
(B) November 26d 12h 54m, ω = 9°, B390 filter.
(C) November 19d 13h 42m, ω = 82°, R60 filter.
(D) November 19d 13h 38m, ω = 81°, B390 filter.
(E) October 13d 17h 47m, ω = 114°, INT. *Phasis* weakly visible.
(F) October 13d 17h 52m, ω = 115°, B390 filter. Bright orographic cloud W of *Phoenicus Lacus.*
(G) November 18d 15h 14m, ω = 113°, R60 filter. *Phasis* darker after November dust storm- compare (E)
(H) November 18d 15h 1 lm, ω = 112°, B390 filter.
(I) November 19d 18h38m,ω = 154°, INT. NW *Mare Sirenum* still faded; *Nix Olympica* near No limb, not enhanced in violet light (ωmpare (T>)
(J) November 19d 18h 41m, ω = 155°, B390 filter.
(K) December 13d 12h 26m, ω = 212°, INT. *Elysium* near CM.
(L) December 13d 12h 29m, ω = 213°, B390 filter. Brighter spots in NPH.
(M) December 5d 12h 43m, ω = 287°, INT. Note *Nodus Alcyonius, Huyghens, Zea Lacus.*
(N) December 5d 12h 44m, ω = 287°, B390 filter.
(O) September 23d 20h 39m, ω = 342°, INT. SPC visible with difficulty as a small dot; *Mare Serpentis* dark
(P) September 23d 20h 41m, ω = 343°, B390 filter.

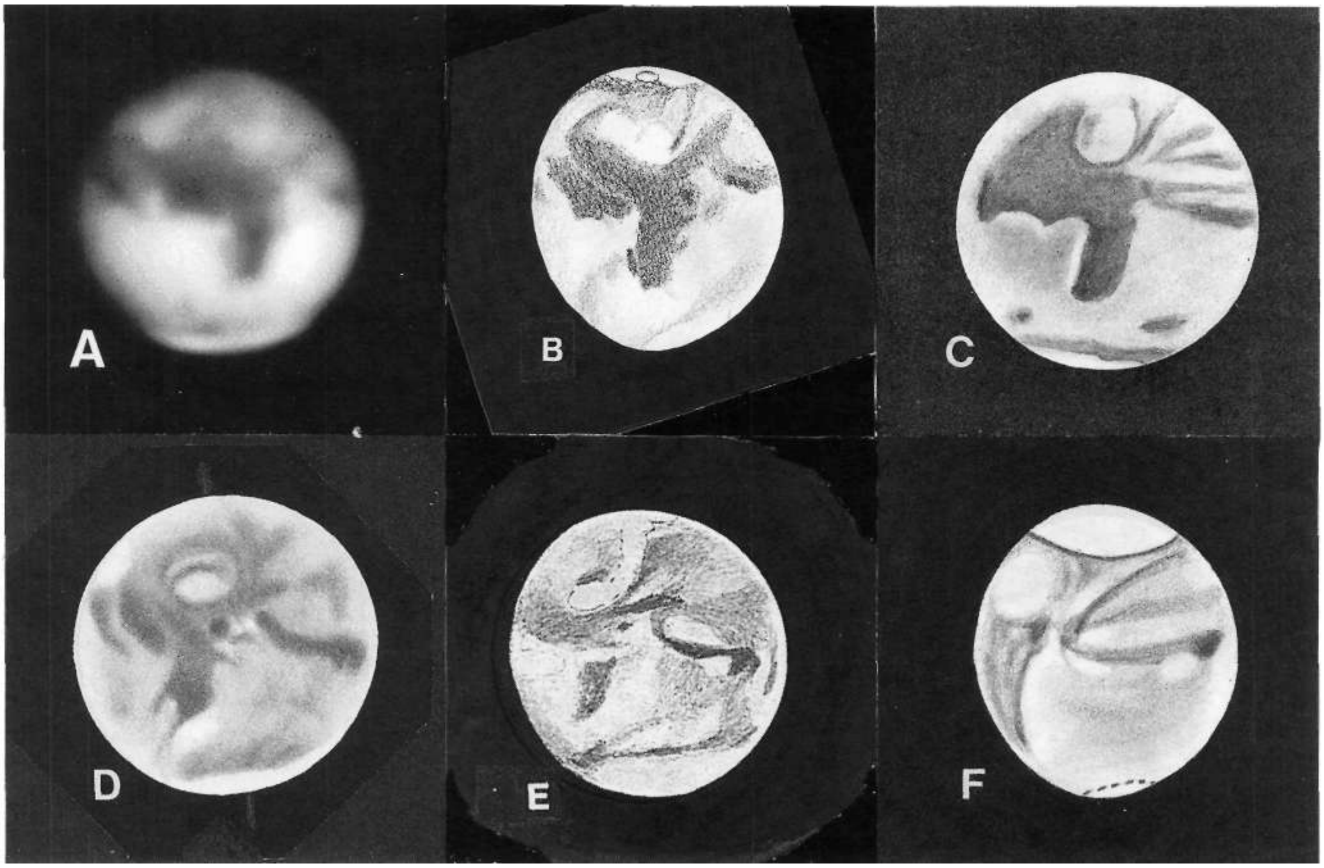

Figure 4. Observations of *Region I* by different observers, co = 250-010°. (INT if no filter stated.)
(A) November 23d 04h 55m, ω = 278°, 410-mm refl., f/164, TP 2415 film, 2.5 s, *Parker. Hellas* details; *Huygens* crater; *Nodus Alcyonius.*
(B) September 2d 02h 51m, ω = 281°, 830-mm OG, x 667, W21, *Crussaire. Hellas* details; *Nepenthes* faintly seen.
(C) November 21d 04h 30m, ω = 289°, 254-mm OG, x 250, *Shirreff. Ismenius Lacus* seen.
(D) December 14d 19h 10m, ω = 301°, 400-mm refl., x 286, W12, W22, *Graham. Huygens* crater in *Iapigia;* complex details in *Aeria-Arabia.*
(E) October 23d 13h 00m, ω = 313°, 200-mm OG, x 340, *Minami.* In green light the bright spot in NW *Hellas* extended up to the SPC. *Syrtis Major* looks cut off from *lapigia* by bright cloud.
(F) May 24d 12h 20m, ω = 327°, 457-mm refl., x 375-580, red filter, Cave. Large SPC; dark *Hellespontus-Mare Serpentis.*

marked on the reference maps: see Figure 1. They were best seen in the red-light CCD images. The desert areas were again similar to 1988, including the dark spots of the Martian volcanoes. *Nix Olympica* and the orographic clouds near *Arsia Mons* and *Ascraeus Mons* were seen (especially in the Martian afternoon but sometimes all day long) in October-December (Figures 3F, I, 5F, 6A, B). Some of the violet-light photos show parts of the Martian 'W cloud faintly visible, but it was never prominent in 1990.

*Region **III:** ω = 130-250°*

Again, there was little detectable change from 1988 and the detailed descriptions from our last report[11] will not be repeated here. Figure 6 illustrates Region III. There was some dusky shading in the *Amazonis* desert (especially to the NW: Figures 2C, D, 6A) and this tended to make *Elysium* more conspicuous. The latter feature was not especially bright during the period of observation, except in the early morning or evening. (Figs. 2C, 6B and F show *Elysium* in the morning and evening; Figs. 2D, 3K, 6C-E illustrate it near the CM.) Other subtle, low-contrast features were also apparent in *Amazonis.* The secular darkening in *Aetheria* still existed (Figs. 3K, 6C-E). *Trivium Charontis, Phlegra* and *Cerberus (I)* were all normal and appeared brownish to Minami in August. *Cerberus (II),* connecting *Cerberus (I)* to *Cerberi S.* was well-marked in 1990, more so than in 1988, but *Cerberus (III),* which had been well-seen in 1986, was invisible. *Mare Sirenum* was again truncated at its NW end: it appeared brownish to Hill in August, greenish to Dijon in September, bluish to Minami in October-November and bluish-green to Marchand in November. Much fine detail was seen in and around *Mare Cimmerium* (Figures 6D-E) and *Mare Tyrrhenum.* In December, Minami found *Mare Cimmerium* consisted of three components. The E part was dark brown, the centre light and brownish, the W part very dark bluish. *Mare Cimmerium* appeared blue-black to Minami in August and bluish-green to Marchand in November, while the *Mare Cimmerium-Mare Tyrrhenum* area was grey-green to Hill in June. *Hesperia* was again more shaded to the S and E.

In 1988 the little dark spot *Car alls Fons* reappeared after many years of obscurity. It was still visible in 1990, again somewhat W of its position on Ebisawa's map. Some shading was seen from S *Memnonia* to S

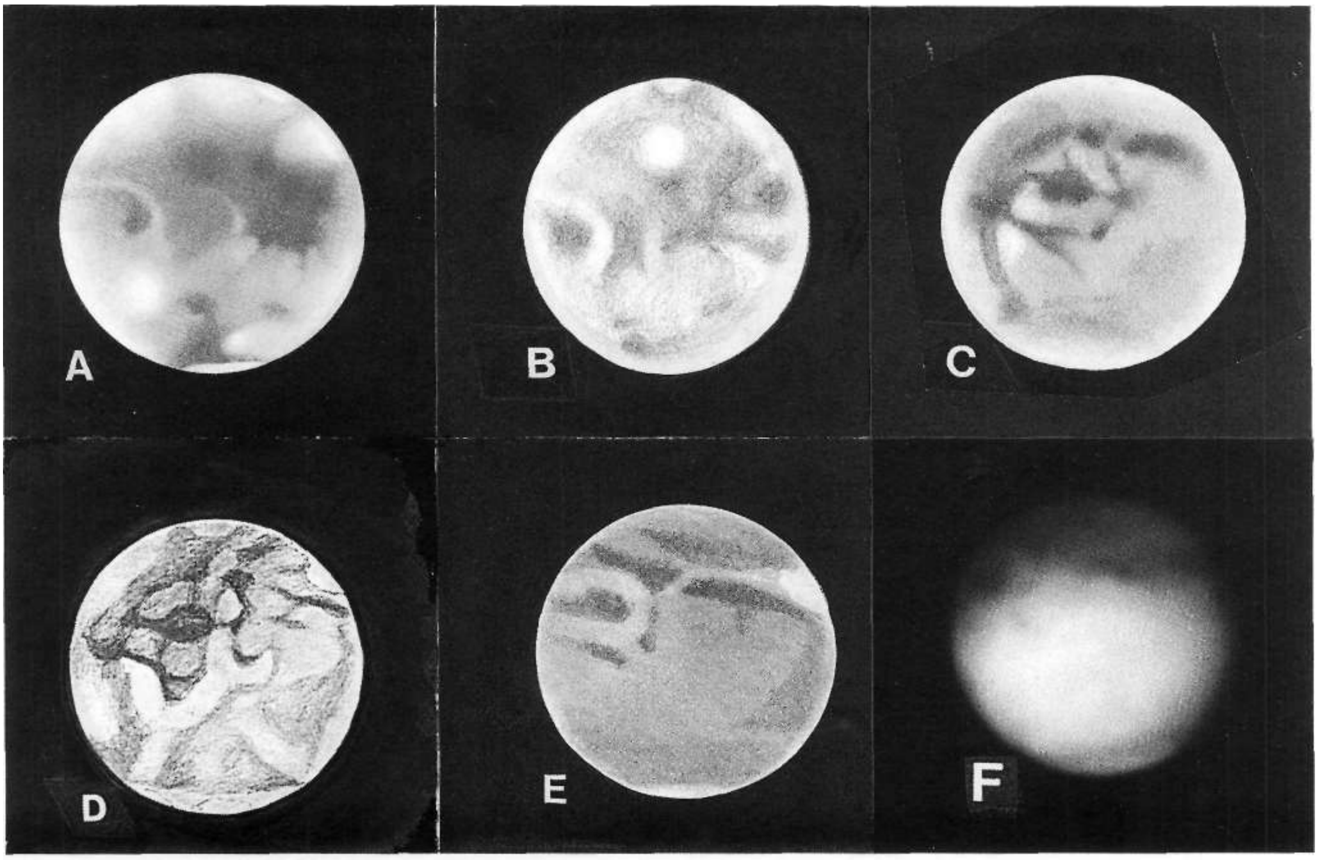

Figure 5. Observations of *Region II* by different observers, ω = 010-130°.
(A) December 5d 19h 30m, ω = 28°, 115-mm OG, x 186, *Baum.*
(B) 1991 January 12d 19h 40m, ω = 45°, 241-mm refl., x 300-400, *Wilkinson.*
(C) November 28d20h 15m, ω = 99°, 400-mmrefl., x 286, x333,W12, W22, *Graham.* Complex *SolisLacus* details; *Phasis* well seen in (C) to (F).
(D) November 17d 13h 50m, ω = 102°, 200-mm OG, x 400, *Minami.* A small segment of the *Memnonia* darkening of 1988 (arrowed) is still prominent. Y-shaped brightness in *Candor-Ophir-Tractus Albus.*
(E) November 28d 21h 45m, ω = 120°, 210-mm refl., x 195, *Johnson.*
(F) December 6d 03h 12m, ω = 139°, 410-mm refl., f/164, TP 2415 film, 1.5 sec, *Parker.* Shading is seen in S *Memnonia-Zephyria.*

Zephyria as in 1988 (Figures 2C, 5F, 6A; weakly indicated in 3E, G, I), but it was not very dark and did not have sharp boundaries. However, a short segment of the former, more conspicuous dark E-W band in *Memnonia* of 1988 July onwards was reported by the OAA (from 1990 September), just N of the E end of Mare Sirenum (Figure 5D). It was a small, inconspicuous feature, lying on the north border of the region of diffuse shading which extended from southern *Memnonia* to *Zephyria.* It was independently drawn by Cerreta with the 500 mm Nice refractor (November 27) and imaged by CCD by Sacco with a 1000-mm reflector (December 5). Some of the best photographs also show it vaguely. The shaded regions of southern *Memnonia-Zephyria* appeared darker than the maria to the south in some of Miyazaki's blue-violet light photos. In 1988 a deep red tint had been seen by McKim in the area between W *Mare Sirenum* and E *Mare Cimmerium;* these observations may be related. *Memnonia* was visually reddish to Minami.

To the north, *Propontis I* was well-seen and dark. Nearby, *Euxinus Lacus* was a small dark spot in the CCD images. Lying close to the NPH it was not well seen visually, but McKim recorded it on November 20 (Figure 2C). The W end of *Phlegethon* was also conspicuous. To the south, the features *Phaethontis-Electris-Eridania-Palinuri Fretum—Mare Chronium* seemed closely comparable to their 1988 appearances. *Scamander* was again noted throughout the apparition, while *Xanthus* appeared in December.

Intensity estimates

White-light data from ten observers are given in Table 2 in the usual way. Other observers sent intensity estimates but their data were either unsystematic, on different scales or received too late for inclusion.

The martian atmosphere

White clouds
General

The activity in the polar hoods is described elsewhere. White cloud activity seemed seasonally normal at all stages of the apparition, and is summarised below. The *Tharsis* orographic clouds were best seen in October-December. *Hellas* often showed diurnal white cloud in

Table 2. Martian intensity estimates.

Feature	Observer (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	Ave.	s.d. (±)	No.
Achillis F.	–	–	—	–	–	—	–	5.5	—	—	5.5	(-)	1
Achillis P.	–	–	–	–	–	–	–	5.0	–	–	5.0	(-)	1
Acidalium, M.	6.0	–	7.5	5.2	4.9	3.9	–	6.0	4.0	4.3	5.2	1.2	40
Aeolis	–	3.1	–	–	–	2.0	2.2	1.8	–	2.0	2.2	0.5	18
Aeria	–	2.2	2.3	1.9	–	1.9	1.6	1.6	–	1.5	1.9	0.3	34
Aether ia	–	3.0	–	2.5	–	–	–	3.0	–	–	2.8	0.3	6
Aethiopis	–	2.5	2.1	1.9	–	2.0	2.0	2.1	–	2.0	2.1	0.2	35
Agathodaemon	–	–	5.3	–	–	–	5.0	4.5	–	4.0	4.7	0.6	9
Amazonis	–	3.0	2.7	2.6		2.0	2.2	2.4	–	1.5	2.3	0.5	29
Amenthes	–	2.4	2.2	2.0	–	2.0	–	2.0	–	2.0	2.1	0.2	30
Aonius S.	–	–	7.0	5.7	–	4.2	–	5.7	–	–	5.6	1.1	10
Arabia	–	2.8	2.3	2.0	–	2.0	1.6	2.0	–	1.5	2.0	0.4	32
Arcadia	–	–	–	2.6	–	2.5	–	2.4	–	–	2.5	(0.1)	19
Argyre (I)	–	2.6	2.8	2.5	–	1.8	2.0	1.8	–	2.0	2.2	0.4	32
Ascraeus L.	–	–	–	–	–	–	–	3.5	–	–	3.5	(-)	1
Aurorae F.	–	–	–	–	–	–	–	4.1	–	–	4.1	(-)	8
Aurorae S.	5.0	5.3	7.3	4.5	5.3	3.9	6.2	5.9	–	3.7	5.2	1.1	38
Ausonia	–	2.9	2.8	2.0	0.5	1.7	1.8	1.4	–	2.0	1.9	0.8	37
Australe, M.	–	5.0	–	3.2	4.0	3.0	5.1	4.9	–	–	4.2	0.9	26
Bathys	–	–	–	–	–	–	–	4.0	–	–	4.0	(-)	2
Boreosyrtis	–	–	–	–	–	–	–	4.0	–	–	4.0	(-)	1
Boreum, M.	–	–	–	4.0	4.0	–	–	4.2	–	–	4.1	(0.1)	13
Bosporos Gemmatus	–	5.4	–	4.8	–	3.0	–	5.3	–	4.0	4.5	1.0	14
Candor	–	2.2	–	1.5	–	–	–	1.5	–	–	1.7	0.4	13
Casius	–	–	–	–	–	–	–	3.5	–	–	3.5	(-)	2
Cast or ius L.	–	–	–	–	–	–	–	4.0	–	–	4.0	(-)	1
Cebrenia	–	–	–	2.5	–	2.5	–	3.2	–	–	2.7	0.4	8
Cerberus (I)	–	4.0	–	–	–	–	5.2	3.5	–	–	4.2	0.9	9
Chersonesus	–	–	–	–	–	–	–	4.5	–	–	4.5	(-)	2
Chronium, M.	6.8	5.2	5.8	3.8	3.0	3.0	4.0	4.6	–	4.8	4.6	1.3	37
Chryse	–	2.5	2.0	2.0	–	2.1	1.9	1.7	–	–	2.0	0.3	23
Cimmerium, M.	5.8	6.2	6.7	5.2	5.1	3.9	6.1	5.8	4.7	4.8	5.4	0.8	65
Claritas	–	–	–	1.8	–	1.6	–	2.4	–	1.0	1.7	0.6	12
Cydonia	–	–	–	–	–	–	–	2.0	–	–	2.0	(-)	5
Daedalia	–	–	–	2.0	–	–	–	2.0	–	–	2.0	(0.0)	9
Deltoton S.	–	–	–	–	–	–	3.2	4.5	–	–	3.8	(0.6)	4
Deucalionis R.	–	3.5	–	2.4	2.0	2.2	3.3	1.9	–	2.2	2.5	0.6	25
Dia	–	–	–	–	–	–	–	1.5	–	–	1.5	(-)	2
Dioscuria	–	–	–	–	–	–	–	2.0	–	–	2.0	(-)	3
Eden	–	–	2.0	2.1	–	2.1	–	2.0	–	2.0	2.0	0.1	20
Edom	–	–	–	–	–	–	–	1.7	–	1.0	1.4	(0.4)	4
Electris	–	2.8	2.6	2.1	–	1.6	2.0	2.4	–	2.0	2.2	0.4	26
Elysium	–	1.2	–	1.5	–	–	1.6	1.6		–	1.5	0.2	13
Eridania	–	2.8	2.8	2.2	0.8	1.7	2.0	1.7	–	2.0	2.0	0.6	31
Erythraeum, M.	4.8	5.0	5.9	3.8	4.9	3.2	5.3	4.8	4.7	4.0	4.6	0.8	49
Gallinaria Silva	–	–	–	6.0	–	–	–	6.0	–	–	6.0	(0.0)	2
Ganges	5.0	4.3	5.2	4.0	–	–	–	4.3	–	–	4.6	0.5	17
Gehon	–	3.5	–	–	–	–	–	3.5	–	–	3.5	(0.0)	2
Geryon	–	–	–	–	–	–	–	4.0	–	–	4.0	(-)	2
Hadriacum, M.	–	4.7	–	4.8	–	–	4.5	5.8	–	3.7	4.7	0.8	17
Hellas	2.5	2.5	2.2	1.5	1.5	1.6	1.4	1.1	1.4	1.8	1.8	0.5	53
Hellesponticae D.	–	5.9	–	–	–	–	4.3	–	–	–	5.1	(0.8)	7
Hellespontus	–	4.8	–	4.0	–	–	3.9	4.5	4.5	4.0	4.3	0.4	16
Hesperia	–	3.2	–	2.0	–	1.9	2.2	2.7	–	2.0	2.3	0.5	15
Iapigia	–	4.7	6.2	4.8	5.0	3.5	6.2	4.8	–	4.3	4.9	0.9	35
Idaeus F.	–	–	–	–	–		–	5.5	–	–	5.5	(-)	1
Isidis R.	–	2.2	–	2.1	–	1.9	1.4	1.7	–	–	1.9	0.3	22
Ismenius L.	–	–	–	–	–	–	4.8	–	–	4.3	4.6	(0.2)	9
Libya	–	2.2	–	2.0	1.0	1.4	2.0	1.2	–	2.0	1.7	0.5	28
Lunae L.	–	–	–	3.8	4.0	–	3.0	4.8	–	–	3.9	0.7	8
Margaritifer S.	4.5	5.3	5.0	4.2	4.8	3.6	4.9	5.1	5.0	3.5	4.6	0.6	39
Melas L.	–	–	6.2	–	–	–	–	5.2	–	–	5.7	(0.5)	6
Memnonia	–	2.0	2.2	1.9	–	2.0	–	1.7	–	1.0	1.8	0.4	25
Meridiani S.	6.5	5.7	6.5	6.2	5.9	4.7	6.4	6.3	5.0	5.0	5.8	0.7	44
Meroe	–	–	–	–	–	–	–	1.8	–	–	1.8	(-)	6
Moab	–	–	2.0	2.0	–	2.1	1.8	2.0	–	2.0	2.0	0.1	27
Nectar	–	–	–	–	–	4.0	5.5	4.2	–	–	4.6	0.8	8
Neith R.	–	2.2	–	2.1	–	2.1	1.7	1.7	–	–	2.0	0.2	22
Nereidum F.	–	4.8	–	–	–	–	–	4.8	–	–	4.8	(0.0)	8
Niliacus L.		5.5		5.2	4.9		5.9	5.9			5.5	0.4	27

Table 2 (cont.)

Feature	Observer (J)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	Ave.	s.d. (+)	No.
Nilokeras		4.3	5.8	3.8			4.5	4.2		4.0	*AA*	0.7	17
Nilosyrtis	-	-	-	-	-	-	4.7	3.2	-	-	4.0	(0.8)	5
Noachis	-	3.0	2.0	2.8	-	2.2	2.1	2.4	-	2.5	2.4	0.4	31
Nodus Alcyonius	-	-	-	-	-	-	-	5.2	-	4.0	4.6	(0.6)	3
Ophir	-	2.2	-	1.5	-	-	-	1.8	-	-	1.8	0.4	13
Oxia P.	-	-	-	4.0	-	-	-	-	-	-	4.0	(-)	1
Palinuri F.	-	5.8	-	-	-	-	-	4.8	-	-	5.3	(0.5)	8
Panchaia	-	-	3.8	3.5	-	-	4.5	4.0	-	-	4.0	0.4	5
Pandorae F.	4.0	4.5	5.0	3.5	4.5	3.3	3.8	3.3	-	4.0	4.0	0.6	28
Peneus	-	-	-	5.0	-	-	-	4.5	-	-	4.8	(0.2)	2
Phaethontis	-	3.0	3.1	2.0	-	1.8	-	2.0	-	3.0	2.5	0.6	16
Phasis	5.0	-	5.0	-	-	2.5	-	4.0	-	-	4.1	1.2	6
Phlegra	-	-	-	-	-	-	-	3.8	-	-	3.8	(-)	3
Phoenicis L.	-	-	6.0	4.0	-	3.0	-	4.7	-	4.0	4.3	1.1	8
Phrixi R.	-	-	-	-	-	-	5.5	-	-	-	5.5	(-)	1
Propontis (I)	-	-	-	-	-	-	5.5	5.5	-	3.5	4.8	1.2	5
Protonilus	-	-	-	-	-	-	-	-	-	4.0	4.0	(-)	1
Pyrrhae R.	-	5.0	-	3.3	-	-	4.8	3.9	-	-	4.2	0.8	18
Sabaeus S.	6.4	5.7	5.2	5.8	5.9	4.6	5.9	5.5	4.2	5.4	5.5	0.6	64
Scandia	-	-	-	3.5	3.5	-	4.5	3.8	-	-	3.8	0.5	13
Serpentis, M.	5.8	-	5.0	4.7	5.0	3.2	5.5	5.4	-	4.0	4.8	0.8	30
Sirenum, M.	5.8	5.0	6.1	5.2	5.2	4.8	6.0	5.3	4.5	3.7	5.2	0.7	40
Solis L.	6.0	5.9	7.4	7.2	5.7	5.0	6.2	6.0	-	4.0	5.9	1.0	37
Symplegades Insulae	-	-	-	-	-	-	-	2.0	-	-	2.0	(-)	2
Syrtis Major	5.8	5.5	7.0	5.7	5.8	4.8	6.5	6.1	5.2	5.1	5.8	0.7	67
Syrtis Minor	-	5.2	-	-	-	-	-	5.8	-	-	5.5	(0.3)	10
Tartarus	-	-	-	-	-	-	-	3.2	-	-	3.2	(-)	2
Tempe	-	1.7	2.2	2.5	-	2.2	1.2	2.2	-	-	2.0	0.5	23
Tharsis	-	2.2	2.1	2.3	-	2.0	-	1.8	-	1.5	2.0	0.3	27
Thaumasia	-	2.1	2.0	1.8	-	1.6	1.8	2.6	-	2.0	2.0	0.3	26
Thymiamata	-	-	-	-	-	-	-	1.8	-	-	1.8	(-)	5
Tithonius L.	-	-	5.4	4.2	4.2	3.0	4.5	3.6	-	4.0	4.1	0.7	20
Trivium Charontis	-	-	5.0	-	2.5	-	6.5	4.3	-	-	4.6	1.7	10
Tyrrhenum, M.	5.8	5.2	6.9	5.7	5.0	3.8	5.2	5.7	4.8	5.0	5.3	0.8	58
Utopia	-	-	-	3.5	2.5	-	-	3.5	3.0	4.3	3.4	0.7	11
Vulcani P.	-	-	-	-	-	-	4.0	5.0	-	-	4.5	(0.5)	7
Xanthe	-	2.5	2.0	2.0	-	1.9	-	2.0	-	-	2.1	0.2	19
Yaonis F.	-	-	-	-	-	-	-	-	-	4.0	4.0	(-)	1
Zea L.	-	4.5	-	-	-	-	-	4.5	-	-	4.5	(0.0)	2
Zephyria	-	2.0	2.1	1.9	-	2.0	2.3	1.8	-	2.0	2.0	0.2	34
No. of useful estimates	79	186	154	285	99	246	193	500	46	132	Total	1,924	
Period of observation	8.9.90 -22.1.91	23.7.90 -6.11.90	3.9.90 -6.12.90	18.8.90 -22.1.91	13.10.90 -16.1.91	12.7.90 -22.1.91	2.9.90 -21.1.91	4.9.90 -14.1.91	7.8.90 -3.1.91	8.9.90 -17.1.91			

Key to observers: (1) Coates; (2) Dijon; (3) Foulkes; (4) Graham; (5) Heath; (6) Johnson; (7) Lenham; (8) McKim; (9) Meredith; (10) Shirreff.

the morning and (specifically in its NW corner) in the evening. Complete coverage of all longitudes was obtained from 1990 July to 1991 January, inclusive.

1989 December-1990 June

Tharsis was light in the evening in March, and *Ophir-Candor* was light to Schmude on March 3 on mid-disk. *Hellas* was not especially light in April-May. *Argyre (I)* was light in the evening in June.

7990 *July*

A.m. limb: *Amazonis, Hellas, Thymiamata;* p.m. terminator: NW *Ausonia, Elysium* (irradiating to Dijon, Figure 6F), *Eridania,* NW *Hellas. Hellas* was not normally light on mid-disk, but *Edom* and *Elysium* sometimes were.

1990 August

A.m. limb: *Amazonis, Argyre (I), Chryse, Eden, Elysium,* NW *Hellas* (irradiating to Hill and Johnson), *Memnonia, Moab, Tharsis, Thymiamata;* p.m. terminator: *Amazonis,* NW *Ausonia, Chryse,* NW *Hellas, Libya, Thymiamata. Tempe* was often light but probably involved with the N polar hood. *Argyre (I), Ophir-Candor* and NW *Hellas* were sometimes bright throughout the martian day.

1990 September

A.m. limb: *Argyre (I),* NW *Ausonia, Chryse, Hellas, Isidis Regio, Libya, Memnonia, Neith Regio, Tempe, Tharsis, Thaumasia;* p.m. terminator: *Aeria, Argyre (I),* NW *Ausonia, Eridania, Hellas* (especially to the

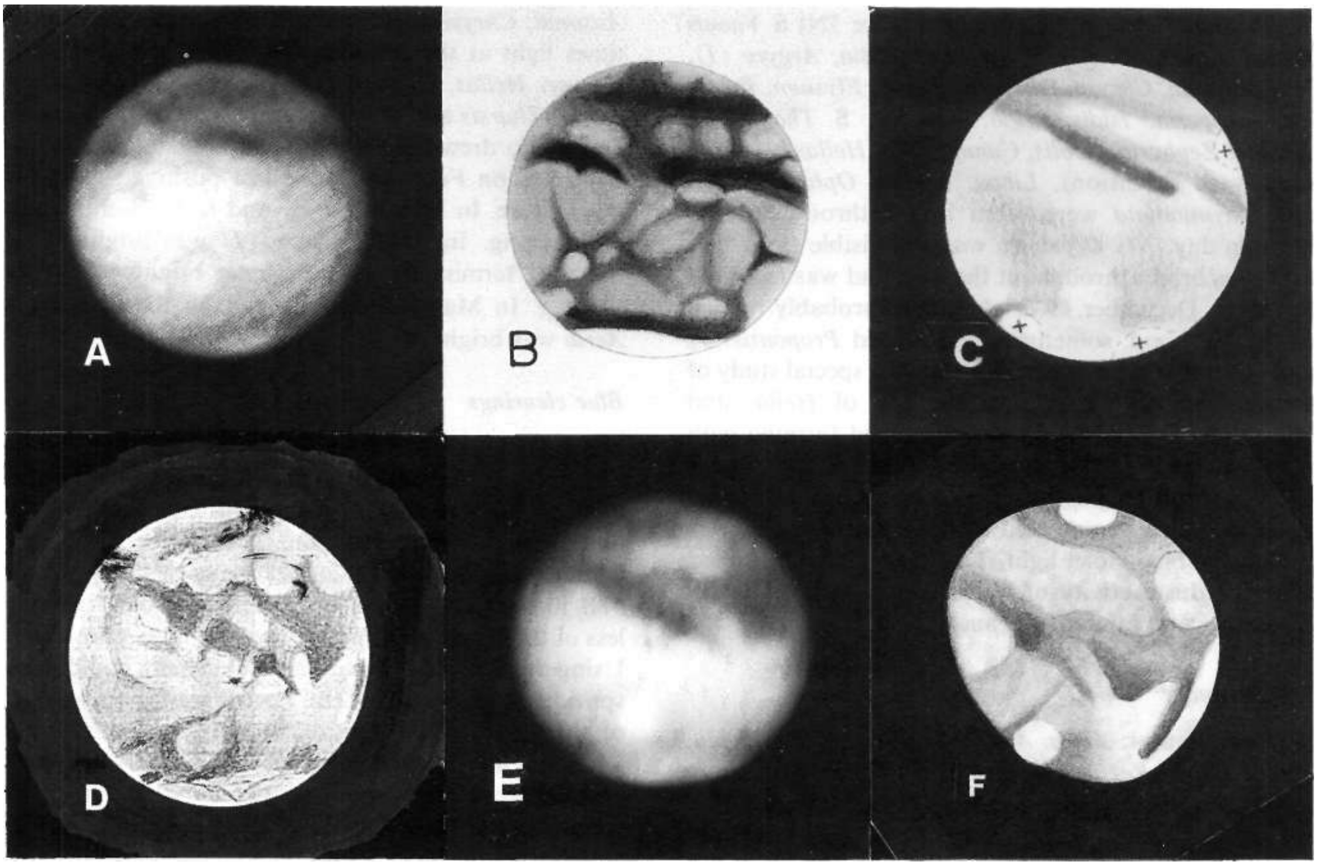

Figure 6. Observations of *Region III* by different observers, to = 130-250°.
(A) December Id OOh 21m, ω = 145°, 320-mm refl., CCD image, *Piatt. Nix Olympica* visible in (A) and (B).
(B) November 28d OOh 14m-01h 42m, ω = 165°, 500-mm OG, x 375, *Cerreta.*
(C) November 20d 23h 05m, ω = 210°, 254-mm refl., x 170, *Rogers.* Yellow cloud in *Electris-Eridania.*
(D) December lOd 1 lh 10m, ω = 220°, 200-mm OG, x 400, *Minami.* In (D) and (E), note complex *Mare Cimmerium* details; *Aetheria* darkening.
(E) November 26d 03h 09m, ω = 225°, 410-mm refl., f/164, TP 2415 film, 1.5 s, *Parker.* See (D).
(F) July 31d 02h 49m, ± = 239°, 200-mm refl., *Dijon. Elysium* bright on evening terminator.

NW), *Isidis Regio, Libya, Xanthe. Candor, Ophir* and *Tharsis* were generally light. *Nix Olympica* showed up as bright on Parker's September 25 photograph. Bright areas were also sometimes seen on mid-disk in *Chryse, Deltoton Sinus, Edom* and NW *Hellas.*

1990 October

A.m. limb: *Aeria, Amazonis, Arcadia, Argyre (I), Chryse, Daedalia, Electris, Eridania,* NW *Hellas, Isidis Regio, Margaritifer Sinus, Neith Regio, Phaethontis, Syria* (IAU), *Tharsis, Thaumasia;* p.m. terminator: *Aeria, Amazonis, Argyre (I),* NW *Ausonia, Chryse, Eridania,* NW *Hellas, Isidis Regio, Memnonia, Xanthe.* Minami, Miyazaki and Parker observed and photographed a light extension of the bright patch in NW *Hellas* running up to the S polar regions; this was certainly white cloud and not dust as it was recorded, unaltered, into 1991 January (Figure 4E). NW *Ausonia* and NW *Hellas* were sometimes bright throughout the martian day, as were all or part of *Aethiopis, Candor, Edom, Elysium, Libya, Ophir, Tempe, Tharsis* and *Thymiamata. Nix Olympica* was bright, especially in the evening. Orographic clouds were seen near *Ascraeus Mons* and *Arsia Mons* (Figure 3F).

7990 November

A.m. limb: *Aeria, Argyre (I), Ausonia, Electris, Eridania, Hellas, Isidis Regio, Memnonia, Meroe, Neith Regio, Phaethontis, Tempe;* p.m. limb: *Aeolis, Aeria, Arcadia, Argyre (I),* NW *Ausonia,* NW *Hellas, Memnonia, Sinai* (IAU), *Tharsis* and *Xanthe. Candor, Libya, Ophir, Tharsis* and *Thymiamata* were generally light, with the 'Y' of *Tractus Albus* being quite prominent in November-December (Figure 5D). On the other hand, Mi *Olympica* (Figure 5B) and the other orographic clouds were less bright, and *not* enhanced in violet light in Miyazaki's photos (Figs. 31, J): in November there was a dust storm in and around *Thaumasia* which may be related to this peculiarity. Light evening cloud-probably white-was also seen over *Claritas, Memnonia* (Figure 2C) and *Thaumasia:* see also the 'Yellow clouds' section. *Aeolis, Aeria, Aethiopis, Deltoton Sinus, Edom, Elysium,* NW *Hellas* and *Symplegades Insulae* were sometimes light on mid-disk.

1990 December

A.m. terminator: *Aeria, Amazonis, Argyre (I), Ausonia,* E *Deucalionis Regio, Elysium, Eridania, Hellas, Hellespontus, Isidis Regio, Neith Regio, Noachis, Phaethontis,* *Thymiamata* and (in violet light: Figure 3N) S *Yaonis Regio;* **p.m. limb:** *Aeolis, Aeria, Arcadia, Argyre (I),* NW *Ausonia, Chryse, Daedalia, Edom, Elysium, Eridania, Hesperia, Isidis Regio, Noachis,* S *Thaumasia, Xanthe, Zephyria. Aeolis, Candor,* NW *Hellas* (with the southward extension), *Libya, Meroe, Ophir, Tharsis* and *Thymiamata* were often bright throughout the martian day. *Nix Olympica* was still visible (Figs. 5F, 6A), was bright throughout the day, and was recorded as late as December 19. Light cloud, probably related to the NP hood, sometimes surrounded *Propontis (I)* and covered *Tempe.* The OAA[8] made a special study of the morning cloud seen to the SW of *Hellas* and *Noachis* in December, finding the cloud forming with the CML near 250° and splitting into two parts near CML = 310°, the patches remaining at the terminator. Ebisawa[20] also commented on this patch, which was brilliant in blue-violet light. This diurnal cloud formed after the dust activity of November, was brightest in December and fainter in January.

1991 January

A.m. terminator: *Aeria, Argyre (I), Ausonia, Eridania, Hellas, Isidis Regio, Libya, Ogygis Regio;* p.m. limb: *Aeria, Arabia, Ausonia, Candor, Chryse, Edom, Eridania, Hellas, Isidis Regio, Libya, Noachis, Phoenicus Lacus* (orographic cloud), *Tharsis, Xanthe* and *Zephyria.* The OAA also found a bright spot in NW *Hesperia,* while *Argyre (I)* (uncharacteristically) was seen as a bright patch on mid-disk by Johnson and Wilkinson (Figure 5B). *Hellas* was dull near the CM. *Nix Olympica* was not reported, but may have escaped detection as the number of observations declined.

7997 *February-June*

In February *Aeolis, Aethiopis, Arcadia, Argyre (I), Ausonia, Chryse, Eridania* and *Thaumasia* were sometimes light at the morning terminator and *Amazonis, Chryse, Hellas, Isidis Regio, Libya, Memnonia, Neith Regio, Tharsis* and *Zephyria* were light in the evening. Dal Santo drew light evening cloud at the site of *Nix Olympica* on February 2, the last positive sighting of this feature. In March, *Chryse* and *Hellas* were light in the evening. In April, *Argyre (I)* was bright at the morning terminator, and *Eridania* brightened in the evening. In May, *Hellas* was dull on the CM, while *Aeria* was bright in the morning.

Blue clearings

Miyazaki's series of photographs (August 14 to December 13) was taken as matched pairs of exposures in integrated and in blue-violet light. He uses the B-390 filter, which seems better than the Wratten 47. Parker[8] commented that the B-390 lies between the W47 and 47B in its transmission characteristics, but transmits less of the far-red and infrared wavelengths than either. Using the W47 or 47B with a CCD camera could cause spurious 'blue clearings' (BC) because of the sensitivity of the CCD to red light, although together with the W49 they are satisfactory when used visually or photographically. Parker now uses the B-390 for his blue-violet light photographs. The degree of BC was estimated from the blue-violet prints according to the usual scale:

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

Visual observations (W47, 47B) from 1990 April 7-1991 April 20 by Crussaire, Heath, McKim, Parker, Dal Santo, Schmude and Troiani (who all used apertures of 200 mm or more) were also analysed. Figure 7

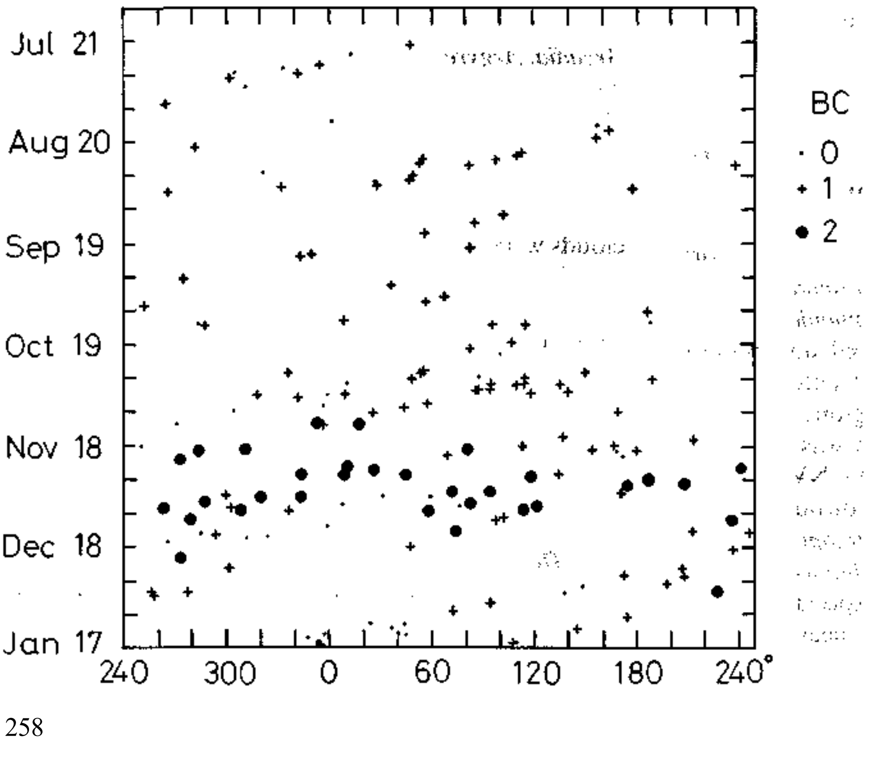

Figure 7. Blue clearing (BC) intensity as a function of date and CM longitude, 1990 July-1991 January. The BC scale is indicated.

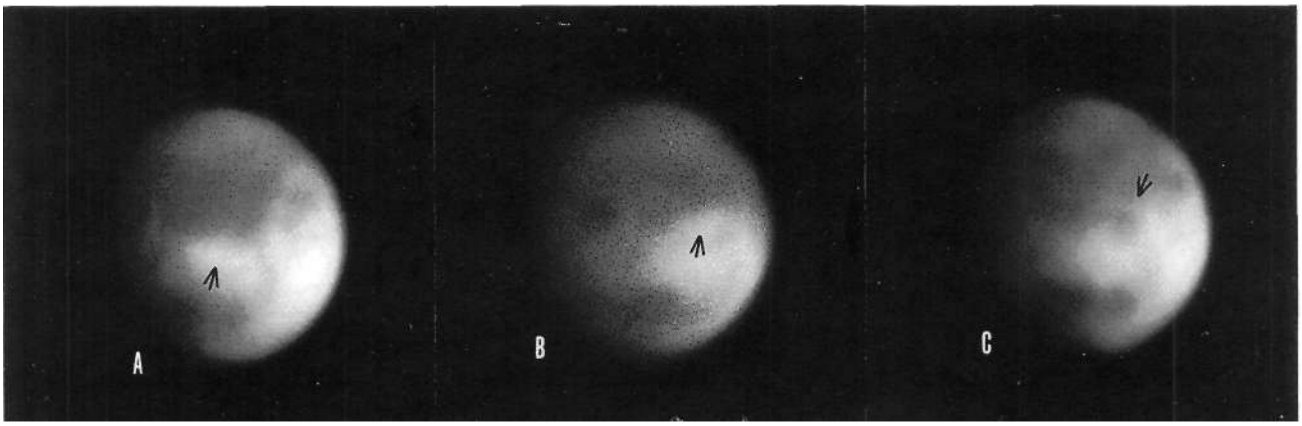

Figure 8. The 1990 October dust storm. Yellow clouds are arrowed.
(A) October 4d 06h 53m, ω = 37°, 410-mm refl., f/164, TP 2415 film, 1.5 s, *Parker.* The storm can be seen in S *Chryse.*
(B) October 5d 06h 00m, ω = 15°, 410-mm refl., f/164, TP 2415 film, 2 s, *Parker.* Most of *Aurorae Sinus* is now obscured.
(C) October 6d 07h 39m, ω = 29°, 410-mm refl., f/164, TP 2415 film, 2.5 s, *Parker.* Bright dust streak due south of freshly uncovered *Aurorae Sinus.*

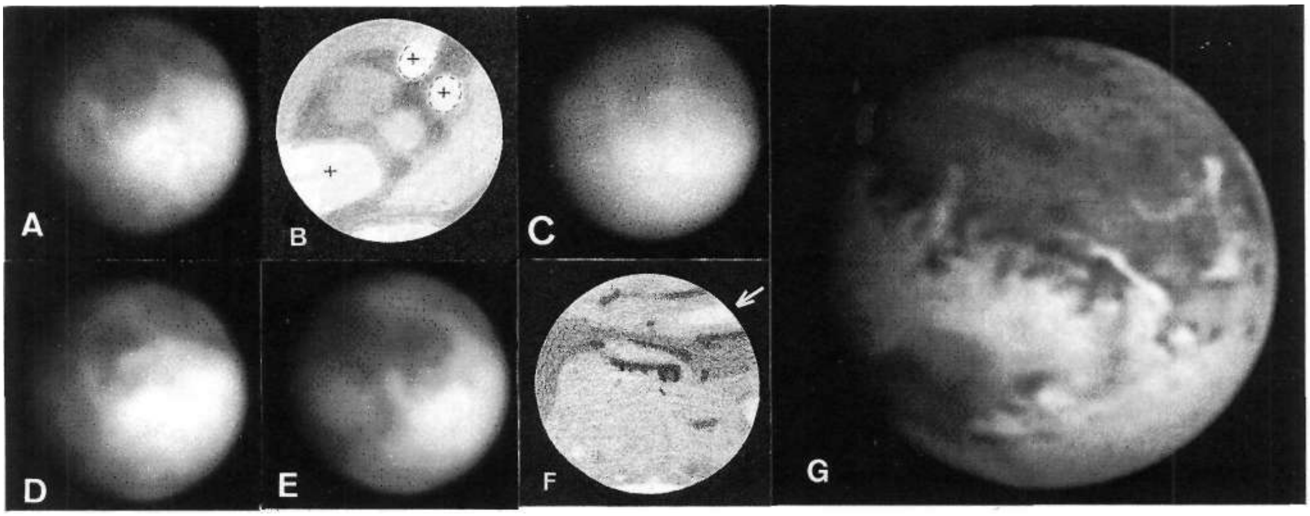

Figure 9. The 1990 November dust storm.
(A) November 5d 05h 43m, ω = 88°, 410-mm refl., f/164, TP 2415 film, 2.5 s, *Parker.* Darkening of NE *Thaumasia; Ganges* incomplete. Dust in *Ophir.*
(B) November 6d 04h 20m, ω = 60°, 254-mm refl., x 170, *Rogers.* Two bright dust-clouds, *Nectar* darkened, *Solis Lacus* hidden. Compare with (G).
(C) November 6d 05h 59m, ω = 84°, 830-mm OG, f/34,7, TP 2415 film, | sec, *Crussaire.* Ditto, (B).
(D) November 7d 07h 01m, ω = 89°, 410-mm refl., f/164, TP 2415 film, 2.5 s, *Parker.* Dust clouds W and NW of *Solis Lacus;* more dust in *Argyre (I)*-
(E) November 8d 06h 02m, ω = 66°, 410-mm refl., f/164, TP 2415 film, 1.5 s, *Parker.* Dust to S *of Solis Lacus;* darkening of E and NE *Thaumasia.*
(F) November 12d 02h 44m, ω = 343°, 254-mm refl., x 301, INT, W23A, W58, W80, *Schmude.* Dust remains in *Argyre (I)* on the eastern edge of the storm (arrowed).
(G) November 6d 02h 50m, ω = 38°, 1060 mm Cass., Pic du Midi Observatory, red-light CCD image, *J. Lecacheux andF. Colas, communicated by Dijon.* Note the fine detail in the yellow clouds which appear more sharply defined than in white light. The complex storm covers *Coprates, Eos, Solis Lacus, Thaumasia-Bosporos Gemmatus,* and *Nilokeras-Tempe* and *Chryse* to the north. Compare with (B) and (C).

is a graph of the degree of BC for the Martian disk as a whole versus date and CM longitude, for the period encompassing positive records of BC. Figure 7 shows that weak BC (order 1) was apparent from July till early January on a sporadic basis, with no preference for particular longitudes. Strong BC (order 2) was seen only between November 11 and January 1 (the opposition period), occurring at all or most CM longitudes. No confirmed BC of order 3 was reported. The violet light photos showed numerous white clouds invisible in white light: they also enhanced any clouds seen in white light, including the N polar hood in particular. Blue clearing varied from place to place on the disk, as Miyazaki's photos demonstrate (Figure 3).

Yellow clouds (dust storms)
General

During the 1990 apparition the martian atmosphere was very clear, as it had been during much of the 1988 campaign. Local (or regional) dust storms were followed in October, November and December. *Hellas* failed to exhibit any significant yellow cloud activity for the first time in several apparitions, but as in 1986 and

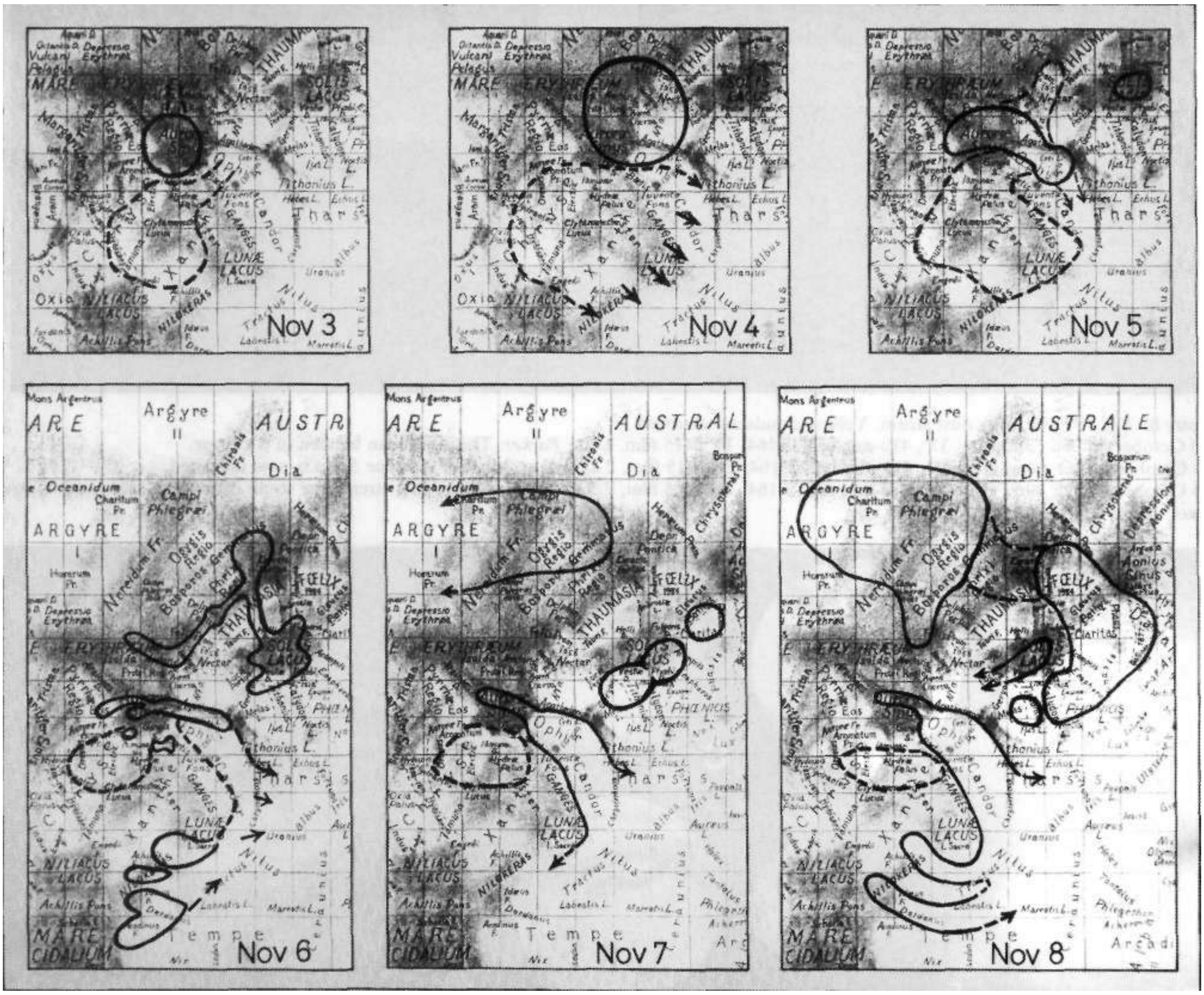

Figure 10. The 1990 November dust storm: daily charts on the Ebisawa basemap. November 3 means the night of November 2/3, and so on. The solid lines represent the outlines of well defined yellow clouds. The dotted lines represent less well defined clouds; in particular, the outlines of the *Chryse-Xanthe* clouds are very approximate. The November 7 map is incomplete in the region of *Nilokeras,* the latter region probably resembling neighbouring dates. The *Chryse-Xanthe* clouds on November 7 and 8, and the whole map for November 5 were drawn from charts communicated by Parker. All other details were independently drawn from the Director's measurements on the following observations: November 3: Piatt CCD images,[6] Dal Santo drawings; November 4: Rogers drawings; November 6: Pic du Midi[14] and Piatt[6] CCD images, Crussaire and Parker photos, McKim and Rogers drawings; November 7: Parker photos and Jousset drawings; November 8 Parker photos.

1988 it often developed a diurnal white cloud in its NW corner. Although no discrete yellow clouds were seen before October, Minami[8] noted that from early July the martian surface was losing its beautiful colour and becoming rather colourless and dirty: a similar phenomenon had been noticed by him in the last apparition.

1990 October

A small bright area over *Chryse* on the / limb was visible to Warell in red light (W25) on October 2 (L_s = 308°) at 01 h 55m. This new dust storm was also seen by Rogers and Smith on October 4. Our records do not show yellow cloud activity during September 28-October 1 (Meredith, Piatt, Sacco, Sarocchi, Smith, Vidican), so that activity must have begun on October 2. According to Parker (who first recognised and reported it in *IAUC* 5116) and Beish[8] the storm was first seen by them on October 3/4, centred near +5°, 45° in S *Chryse-Xanthe.* It had moved south on October 4/5, partially obscuring *Eos, Pyrrhae Regio* and E *Aurorae Sinus.* Some dust migrated into *Ophir.* Schmude and Troiani also saw the activity, some of Schmude's drawings suggesting that parts of the yellow cloud projected beyond the evening terminator. Parker's October 6 photograph shows the storm to be essentially over: *Aurorae Sinus* had returned to normal, with only a small bright streak of dust to its south. Placing the centre near —20°, 53° on October 6 suggests a velocity for the storm centre of some 32 km h^{-1} (about 1550 km in 49 hours) since October 4. (See Figs. 8A-C.) No trace of dust was visible by October 11th. During October 5-7, Beish and Parker remarked that the N polar hood had become dull.

1990 November

On November 2 (L = 326°) a more significant and better-followed storm broke out slightly to the southwest of the October event (Figs. 2F, 9). Piatt's CCD image of November 3 at 00h 46m[6] was the first to show the storm clearly; another CCD image on November 1 (00h 31m) had shown nothing of it. The most conspicuous part of the cloud was centred near — 12°, 47° on November 3 (and was about 800 km in diameter), when it was obscuring part of *Aurorae Sinus,* but there was also some more diffuse dust in *Chryse-Xanthe,* for a drawing by Dal Santo on November 2 (21h 40m) shows yellow cloud over *Aurorae Sinus-Chryse-Xanthe* at the morning terminator. It is not certain whether the storm began near *Aurorae Sinus* or in the deserts to the north, but the Director favours the *Aurorae Sinus* area, for he found *Eos-Pyrrhae Regio* abnormally light on November 1 (23h 50m). Observations immediately prior to November 2 show only normal evening cloud over *Chryse,* although Dal Santo noted a yellow colour there on October 27.

It was to be Rogers who first reported the November event when he found a striking bright yellow patch, now some 1600 km in diameter, over *Aurorae Sinus* and *Sinai* (IAU) on November 3/4.[6] Rogers also saw yellow cloud over *Chryse,* and noted that *Ganges* disappeared during November 3/4. McKim confirmed a dust storm in the area on November 4/5 and 5/6 (Figure 2F), and immediately informed other UK observers and overseas groups.

On November 4/5 Parker (Figure 9A) found dust spreading NW along *Agathodaemon (Coprates)-Ophir-Candor.* Some dust was spreading into SE *Thaumasia* while there was also a dust streak across *Solis Lacus; Aurorae Sinus* was still obscured and NE *Thaumasia* (i.e. *Sinai)* was as dark as *Solis Lacus,* making the latter appear greatly enlarged and distorted (Figure 9A). The *Thaumasia* darkening (which extended as far W as the *Geryon* canal) was at the exact site of the yellow cloud seen by Rogers on November 3/4. Such anomalous darkenings of the surface are interpreted by the writer and others as areas where dust has been temporarily excavated by the developing storm. Figure 10 plots the daily development of the storm.

Dijon, McKim, Piatt and Rogers found the E limit of the storm was still affecting *Chryse-Xanthe* on November 5/6 (Figure 2F). Southern *Mare Acidalium* may also have been dimmed, but *Ganges* reappeared. Although the dust activity in *Chryse-Xanthe* began to decline, the storm continued to spread to the south and west.

It was fortunate that other observers around the world quickly joined in the observations: SAF members had good conditions at Meudon from November 5-8 and the OAA could see the area from November 8 onwards. On November 5/6 there were two small, discrete bright clouds (whitish to Rogers with a reflector, yellowish to Crussaire with the Meudon refractor) at the W limit of the storm. One lay over *Solis Lacus* and the other was to the SE over *Bosporos Gemmatus-Phrixi Regio:* see Figs. 9B,C, 10. Parker described these clouds as being brilliant in red light. Crussaire's measurements on his photographs with the 830-mm OG and the writer's measurements on a Pic du Midi CCD image[14] show that the *Solis Lacus-like* spot near these clouds (Figs. 9B, C) was actually a darkened and enlarged *Nectar,* the *Solis Lacus* proper being mostly hidden. Further structure in the yellow clouds is indicated by the Pic du Midi image in Figure 9G, which reveals patches of bright cloud (very probably dust, which shows up well in red-light CCD images) as far N as *Nilokeras* and SE *Tempe.* The desert immediately north of these latter clouds in this image seems anomalously dark. Lighter dust streaks united the principal clouds, with dust invading western *Mare Erythraeum.* Although Figure 10 seems to represent the clouds quite well, it is not clear if the clouds which developed over *Solis Lacus* and *Bosporus Gemmatus* were independent outbreaks, or were simply dust having spread from the original source.

On November 6/7 Jousset and Parker observed and photographed the dust storm. Cloud remained over *Solis Lacus,* the *Nectar-Thaumasia* region remained anomalously dark, and a new dust cloud appeared over

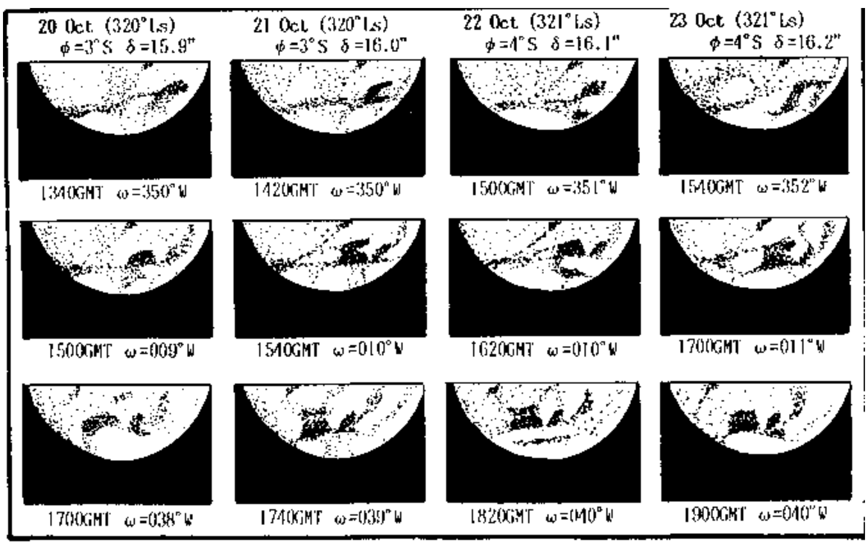

Figure 11. Sequential drawings by M. Minami with 200-mm OG, x 340, x 400 to show daily and diurnal variability of the N polar hood, October 20-23. Dates, times and CM longitudes are indicated beneath each sketch.

Claritas, covering *Phasis-Gallinaria Silva* for the first time. At the same time the southernmost cloud of the previous day had expanded to the east into *Argyre I.* On November 7/8 Cabrol and Moore sketched the storm at the morning limb, while Parker's images showed further changes in the clouds, which had probably reached their maximum extent. Fingers of dust stretched north from the southern band of cloud into western *Mare Erythraeum. Solis Lacus* and *Nectar* both remained very broad and dark in a N-S sense, the whole region still looking very unusual.

Parker's final image on November 9 showed the situation returning to normal in the region of the initial outbreak; there was less dust in *Chryse.* Schmude saw the residual yellow cloud moving further E into *Argyre (I)* on November 11; this had decreased substantially by November 14 (Figure 9F).

Japanese observers watched the storm region as it came into view at the evening limb. From November 8 the evening limb showed up as bright in the *Thaumasia* region (CML about 164°). Minami found the brightness of this evening cloud to decrease during November 11-14. Of related interest, on November 20 McKim (Figure 2C) saw an unusually large and brilliant white or cream-coloured cloud over *Memnonia* (from CML = 169°), which was bright in white, yellow (W15) and red (W25) light, but only marginally brighter than the surrounding desert with a W47 blue-violet filter. Did this unusually large diurnal cloud (and the brightness seen by the OAA) owe its origin to the dispersal of dust from *Thaumasial* On November 13 the OAA could view the storm region near the CM: all had returned nearly to normal, the disk looking hazy as a whole. On this date, Minami drew residual bright haze - no doubt dust-in S *Thaumasia-Argyre (I).* On November 14 and 15 only the brightness in *Argyre (I)* remained, this being the last trace of airborne dust. BAA data showed southern *Thaumasia* and *Aonius Sinus* to be a little darker than before and *Phoenicis Lacus* fainter than before. Furthermore, before the storm *Phasis* had been faint between *Aonius Sinus* and *Gallinaria Silva:* now it was darker.

Measurements from the CCD images and photos of the dust storm indicate a rate of propagation of about 34 km h^{-1} (2500 km in 74 hours) to the SW *(Aurorae Sinus* to *Solis Lacus)* during November 3-6. Other measurements for different dates and directions could be obtained from Figure 10. After November 7/8 the storm does not appear to have expanded further, with activity gradually dying out, but Rogers (November 20) and Troiani (November 24) found that some dust had apparently diffused westward into *Electris-Eridania,* leaving a yellow tint there (Figure 6C). It may be significant that Parker's photographs showed *Trivium Charontis* and *Cerberus (I)* faint in late November. The ALPO found that the N polar hood had become dull during the November storm from November 5; by November 7 albedo features in *Mare Boreum* could be seen through the hood. McKim, Moore and Rogers found the hood progressively less evident during November 3-8.

1990 December onwards

There was some brief dust activity in *Chryse* again in December. An isolated bright cloud was seen by Baum (Figure 5A), Lenham, Medway and Warell during December 4-5 in E or SE *Chryse,* while Marchand found *Chryse* bright in red light on mid-disk on December 5 and 7. On December 6-16 Cave and Dal Santo drew bright yellowish cloud over *Chryse* which moved S and SE, obscuring *Eos-Pyrrhae Regio* and southern *Margaritifer Sinus.* Parker's December 18 photo showed activity had ceased. Thus the *Chryse* source was again briefly active from December 4 (L_s = 355°), but the dust did not spread very far, moving SE and not to the west. This was the final outbreak in 1990-91; lack of photographic evidence prevents a reliable velocity estimate.

Discussion

The initiation sites for all the *Chryse-Pyrrhae Regio* events were unusual but not unprecedented ones for yellow cloud, being a few hundred km from the origin of a short-lived dust storm discovered by E. C. Slipher at a very different L_s on 1922 July 9.[15] The 1990 November outbreak, in NW *Pyrrhae Regio-Aurorae Sinus* corresponds well in position with the E end of the deep *Coprates* canyon *(Agathodaemon).* The 1988 November-December event originated further to the W in southern *Thaumasia.* The 1990 events were seasonally very late and it is probably for this reason that they were not self-sustaining and quickly died out. (L_s was 308° on October 2 and 326° on November 2: compare L_s = 314° for the 1988 November 23 event.)

The 1990 events again demonstrated the established phenomenon of short-period albedo changes in or alongside the affected regions: the darkening *of Nectar, Thaumasia* and southern *Phasis* were well seen, together with the possible anomalous darkening of the *Tempe* desert adjacent to the dust clouds in Figure 9G. The motion of the southern part of the 1990 November storm was somewhat similar to that of the 1988 November event. The 1990 November event was unusual in that dust activity may have arisen almost simultaneously in neighbouring regions, as the November 5-7 data would appear to indicate. The apparent increased incidence of diurnal cloud activity following the November storm may again be significant; such a relationship had been suspected from the 1988 November-December observations." Examples of the interrelationship between white and yellow cloud incidence can be seen in the late C. F. Capen's drawings of the 1956 dust storm.[16] Atmospheric dust particles cause a local cooling effect and can also act as nucleation sites for white cloud formation. It is also possible, as Ebisawa has suggested,[20] that the early onset of the S polar hazes which obscured the SPC during the current opposition were precipitated by dust activity in the S polar regions. During both the October and November events there was evidence for the thinning of the N polar hood. The SPC remained visible throughout, although it was often surrounded by haze.

From 1986 till early 1988 the preferred 'emergence source' for southern hemisphere dust storms was *Hellas,* but in late 1988 the *Thaumasia* region was favoured. Part of the 1988 November storm involved yellow cloud activity near *Aurorae Sinus,* while an isolated yellow cloud had been seen in 1988 August by Hill in N *Argyre I.*[u] These facts demonstrate the emergence source had changed its location, the new source being active three times in 1990 while *Hellas* was dormant. The historical record[17] reveals slow, secular changes in the preferred emergence sites.

North polar region

In the early months of the apparition, the N limb was tilted well away from Earth and the polar regions could not be examined. Before opposition, from May till November 1990, a variable white cloud or hood covered the N polar regions. Parker first reported the visibility of the NPH as early as May 18, but it was not well seen at all longitudes till August. The polar hood (NPH) extended down to approximately latitude +40-50°. Figure 11 is a sequence of drawings of the **NPH** by Minami which show its diurnal and daily variability: it often covered and uncovered *Mare Acidalium,* its southern limits varying considerably with longitude. The NPH was beautifully shown on violet-light photographs (Figure 3). From mid-October there were some brighter patches within the hood (e.g., Figure 2B). Minami on December 8 (L_s = 346°, CML ~ 272-321°) detected what looked like a well-marked surface cap, perhaps the first record of it, but other observations at different longitudes showed the hood was still present. In 1988," the NPC was also detected for the first time near L = 346°. On December 14 the writer (Figure 2E; L_s = 349°) felt that he was observing the surface cap (CML = 293°), but there was a patch of polar hood at the morning terminator, while on December 20 from Meudon he saw the edge of the hood deviating south to cover *Mare Acidalium* at the morning terminator. There were several other probable sightings of the true cap in December.

In 1991 January, observations of the hood still predominated. Ebisawa's polarimetric data[20] showed that the NPC gradually appeared after L_s ~ 6°, in mid-January. Moore first observed the NPC, with a dark border, during February 17-21 (CML = 329 - 20°), but the hood was seen at other times and longitudes. Probably the hood was not often visible after February; later observations showed the start of the shrinkage of the NPC. Accurate measurements were not possible.

South polar region

The SPC was large and well-marked to Schmude and the Japanese observers from 1990 mid-March (Figure 4F). It would probably have been visible earlier had the martian disk been large enough for high resolution observations. The SPC regression was shown by the pre-opposition observations, and a regression curve (Figure 12) has been compiled from measures of the cap's E-W diameter on 215 drawings from 1990 July 9-December 7 (L_s = 256-345°), averaged over 5° intervals in L_s. Figure 12 compares 1990 with 1988 and the historical results of Slipher[18] and Antoniadi.[19] It should be borne in mind that the early data in Figure 12 were obtained from drawings of a very small martian disk, less than 10 arcsec diameter before mid-August. In 1990, the SPC appears to have been a little larger than the seasonal average. It is possible this increased size was partly due to the presence of antarctic hazes making the cap appear spuriously larger (see later), though the writer tried to exclude drawings which showed the polar haze obscuring the cap.

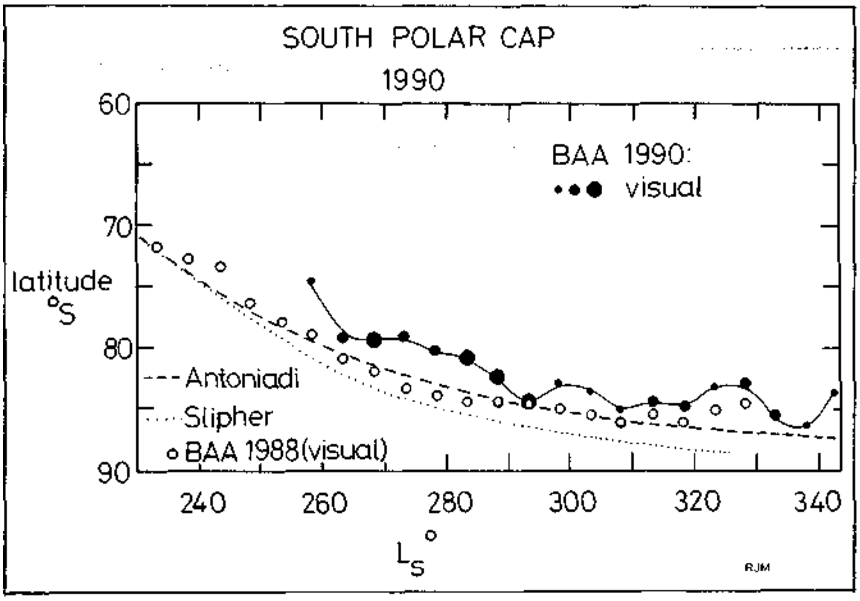

Figure 12. SPC regression curves. Filled circles represent 5° means in L_s. In ascending order of size the circles represent means of 2-9, 10-15 and 18-28 measurements. Average regression curves by Antoniadi (1856-1929) and Slipher (1798-1924), and **BAA** data for 1988 are added for comparison.

In June it was already apparent that the side of the cap facing longitude ~ 220° was evaporating much faster than the rest of the cap: such was also the case in 1988.[11] There was also a considerable amount of haze over the summer cap edge at some times and longitudes. Difficulty in defining the N edge of the cap was first noted by Beish, Minami and Parker in July, these observations mostly relating to the side of the cap which had regressed most rapidly, especially between longitudes ω ~ 220-280°. This haze, coupled with the small southward tilt of the planet meant that the summer remnant was very hard to see at some longitudes after August. (In 1988 August and September a similar phenomenon was seen,[11] but on a smaller scale.) Some observers, such as Dijon, Hill and Moore in August, found details in areas as far north as *Phaethontis-Electris* blotted out by haze from the SPC. From September, the SPC proper was only easily seen over the range co ~ 50-90°; although quite easy as late as December, it was generally surrounded by polar haze. It sometimes had a dark N edge. The variable S polar hood continued to be visible until the final observations. Probably no-one observed the true cap after 1991 mid-January; it was hard to tell whether the hood or cap was present. (See Figs. 2A, B which show the tiny *cap* near opposition; Figs. 6B, D show the *hood* at other times and longitudes.) Perhaps the last observation of the cap was by Wilkinson on January 12 (CML 45°), at L_s = 3° (Figure 5B): in 1988-89 the SPC remnant was followed till at least L_s = 6°. There was still some brightness in the S polar region in 1991 March but later the S hemisphere was turned away from the Earth and it could no longer be examined.

The onset of polar haze occurred rather early for the martian year. Ebisawa,[20] who first noticed its presence on July 5 (L_s = 255°) also commented it was unusual in *not* appearing brighter in blue-violet light in the first few months (before November), suggesting the hood composition to be abnormal. Ebisawa considers that dust storm activity in the martian antactic might account for the early onset of S polar haze, and would also explain the unusual polarimetric data he obtained. Furthermore, he found the hazy area visually somewhat yellowish (490-mm Cass.).

Because the regression phase occurred when Mars was distant from Earth only a few details of the cap fragmentation could be made out. Thus Parker reported the *Rima Australis* rift from L_s = 233°, and suspected the detachment of *Novus Mons* (the 'Mountains of Mitchell') on July 1 (L_s = 252°). Ebisawa[20] confirmed *Novus Mons* on July 5.

Acknowledgement

The writer again thanks Dr Dollfus for the allocation of telescope time at Meudon.

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Errata in 1988 report

Table 1 should have had the following footnote appended:

Observations by Bates and Boulton (JAS) were communicated by Graham; those by Canonaco, Cardoen, Diepvens, de Groote, Schroyens, van Durs, van Loo and Verwichte (VvS) by Aerts, those of the UAI by Falorni, those of Wakugawa (OAA) by Miyazaki, while observations by Beish, Cameron, Kenyon, Robinson and Troiani (ALPO) were sent by Parker. We also acknowledge receipt of a report of the Berlin Mars observing group by E. Freydank and E. Madlow from Herr Madlow. 'indicates the submission of photographs; **CCD images.

On page 270, penultimate and final lines: for 'Figures 2A, 3' read 'Figures 2A, 5'. On page 271, nine lines up from the bottom right-hand column, for '(front cover)' read '(page 264)'. Finally, on page 277, in the second paragraph, 13th line, for '*p* the end' read 'the *p* end'.

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