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Mars Observations in 2001. Part II

− *Observational Analysis on the 2001 Global Dust Storm* −

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(Abstract) This article is devoted to an analysis of the great dust storm which was observed in 2001 and a sequel to the preceding article, Part I, which dealt with a narrative review of our conventional observations of Mars in 2001 from 20 October 2000 through 23 May 2002 at the Observatory of the Fukui City Museum of Natural History (as well as in Okinawa). As was described in it, the planet Mars in 2001 was blessed with a global dust storm on the Martian surface in an unexpected season, which was entrained near Hesperia on 24 June 2001 and developed quite enormously from the day. Here in Part II we shall pick out the global dust storm and try to give a detailed analysis in several sub-sections of this unprecedented event from the observational point of view.

Key Words : Mars, Martian great dust storm, 2001 global dust storm, precursory phenomena, north polar hood during the dust storm, Observatory of the Fukui City Museum of Natural History

1 Introduction

It was an unforgettable fact that we encountered in the 2001 apparition of Mars an unexpected great event and another expected phenomenon. The first one was the occurrence of the great dust storm which was observed globally in an earlier unexpected season and the other was a Sun-glint phenomenon at Edom Promontrium predicted and observed in the US.

In this article, especially in the next section, we shall discuss the global dust storm based on the world-widely obtained data and give an analysis to the storm from several points of view, in Section 3 we shall see a possibility of some precursory phenomena of the global dust storm, and in Section 4 we shall pay attention to the activity of the north polar hood (nph) which might have been related to the activity of the dust storm. Section 5 is to give a summary and discussion. We shall have our review and discussion of the Sun-glint phenomenon at Edom in Part III in a coming issue of this Bulletin.

2 2001 Global Dust Storm

We shall give here several items of analysis concerning the global dust storm which started from Hesperia on 24 June 2001 in the following subsections.

2-1 The occurrence of the 2001 global dust storm

As was reviewed in Nakajima & Minami, 2007 (see also Minami, 2002i and McKim 2009) we encountered an unexpected global warming dust storm in 2001 which was first set out and found at Hesperia on 24 June 2001 at the Martian season $\lambda=184°$Ls. See also Minami, 2001a. This dust cloud revealed several new aspects and it was not only added to a list of historically observed yellow clouds but also can be considered to be a very new one which overthrew some established old concepts of the dust cloud. In a phrase it was an unprecedented different kind of dust clouds and as far as we are concerned there was not known hitherto such a different pattern of the dust disturbance.

First of all it was exceptional in the sense that it was entrained quite early in the season just after the southern spring equinox at $\lambda=184°$Ls, while the great dust storms in 1956, 1971, and in 1973 were set on around $\lambda=250°$Ls, $\lambda=260°$Ls, and at $\lambda=300°$Ls respectively, just before and after the southern summer solstice. Furthermore the dust cloud in 2001 did not burst out explosively compared with the preceding dust clouds in 1956, 1971, and 1973. On the other hand the 2001 dust began to rise very quietly. However the expansion of airborne dusts into the high-altitude sky was very rapid and frequently it generated a lot of resonances of local dust disturbances in the east. That is, its effect rather expanded towards the east while in the preceding three cases the emerged dust clouds were sent westwards by the easterlies. As to the fact that the dust cloud in 2001 was entrained on 24 June, the following information was

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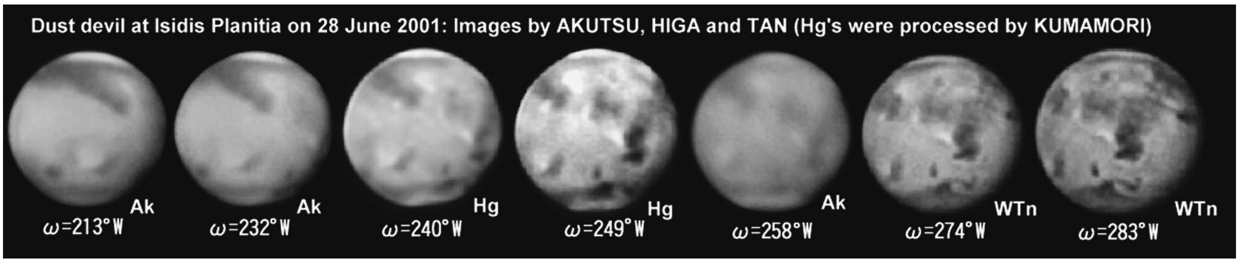

Fig. 1 Sequence of the resonant dust core images on 28 June, where Ak =AKUTSU, Hg=HIGA, and WTn= TAN.

kindly communicated to us by T. Z. MARTIN, based on the result of the Thermal Emission Spectroscopy (TES) onboard the Mars Global Surveyor (MGS) as follows:…

Subject: Mars dust storm report
Date: Thu, 5 July 2001 16:48:48 -0700
From: "Terry Z. Martin", NASA-JPL

The recent Martian dust storm occurred at a great time for terrestrial observation, and that is how I first heard of it - the reports from Japanese observers. Excellent work, and some fine pictures!

The thermal signature of the storm in the Mars Global Surveyor horizon sensor data (15 micrometers wavelength in the infrared; this is a bulk measurement of the atmospheric temperature, which rises as sunlight heat the dust) appears to develop along with the visual evidence of bright yellow clouds. I made a series of thermal maps, one per day, and they show a gradual warming in the northern Hellas region starting about day of year 175 (June 24). The attachment is a Quicktime movie of the days 175-181 [Martin, T. Z., 2001]. The data come from daytime hours only (0600 to 1800 hrs local time). I use west longitudes.

I would not expect the temperature to track the visual appearance of the dust storms exactly. What I am seeing is the heating due to dust that is mixed to considerable height in the atmosphere (many km). The behavior of the 1999 Ls 225 warming showed strong control by an existing thermal wave pattern rather than matching the dust storms seen in the MOC (MGS camera) image data.

The warming grows strongly after day 179, and begins to show up in the northern midlatitudes on day 180. The warming moves eastward in both the north and south after that. I will continue this movie as more data are processed. Because of this storm's early start within the dust storm season, it is particularly interesting.
Cheers, Terry

2-2 Trends of the dust cloud at the end of June

We next see the trends of Hesperia dust clouds and we shall state our views on its occurrence and its development. We first pick out the cases on 28 and 29 June since there were observed some characteristic phenomena.

On 28 June (Day 5 after the onset), as was reported in Nakajima & Minami, 2007, there was seen a bright resonant dust core at Isidis Planitia (275° W, 30° N). On the day it was first detected by Kent De GROFF at the Marshall Isles at 10:41 GMT, ω=204° W, and then 6 minutes later Tomio AKUTSU in Japan obtained another image at ω=205° W at the Wakugawa Observatory in Okinawa. AKUTSU then took images at ω=213° W and ω=232° W: In the latter case there is shown a brilliant cloud at Isidis Planitia and in the former case at ω=213° W there might be shown a symptom. This implies that the occurrence of the resonant core was caught quite early in the morning since the phase angle was ι=13° after opposition. Figure 1 shows the images on the day every 10 degrees from AKUTSU's image at ω=213° W through the image at ω=283° W made by TAN Wei-Leong in Singapore. The resonant dust thus was caught from the early morning until the time it passed the Martian meridian. One of the great characteristics was that it rose very bright in the early morning but it remained unchanged or did not develop so largely until the afternoon.

On 29 June (Day 6) we had another bright resonance of dust core at Mare Cimmerium. The first detection of this cloud was made by De GROFF at ω=201° W (11:04 GMT) and we here show the subsequent observations as Fig. 2 including the observations of AKUTSU, Hiroshi ISHADOH in Okinawa and others. The detection of the

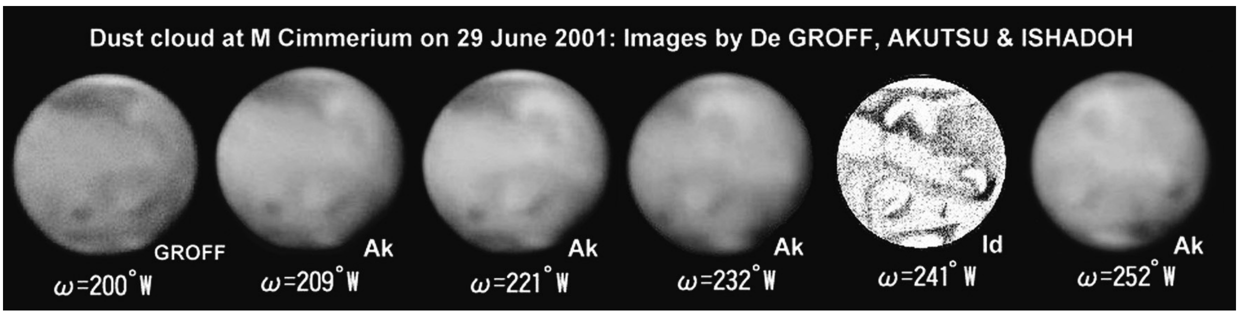

Fig. 2 Sequence of the resonant dust core images on 29 June, where Id=ISHADOH's drawing

clouds at the morning side was rather late, while they show that the resonant dust core did not prove so much variation in shape and strength even after moving to a deep afternoon.

From the observations on the two days (see Minami, 2002b), we are reasonably able to conjecture as follows: First we should say that the resonant dust cloud at Mare Cimmerium on 29 June (Day 6) was never the same dust that directly developed from the resonant core at Isidis Planitia which was seen on the preceding 28 June (Day 8). It is because the resonant dust on 28 June was still remaining on 29 June at the same place that it had occurred, and we can also consider that during the night time the activity of the early dust must have ceased to develop even if less active. If the resonant dust on 29 June is the one that moved from the place where the resonant core existed on 28 June, it implies that the dust core must have moved 65° in half a day at the black-box night, that is, it must have moved 10° within two hours during the severe night time. On the other hand on 28 and 29 June we chased the dust cores for about five hours in the daytime, while we have never observed any significant movement and hence it must be impossible for such a rapid movement to occur at night. We are rather of the opinion that the early dust must be the one entrained in the early morning, accompanied by a rapid ascending air, and it stays around the same place until the late evening and at night it subsides, and in the next morning another resonant dust is given rise to near the place.

2-3 Dust activity at Elysium at the beginning of July

As was reported in Nakajima & Minami, 2007 at page 9 we described our observations at the Fukui City Observatory from 1 July (Day 8) how the dust expanded from Southern Hemisphere to Northern Hemisphere in a few days. Here we cite a set of images made from the angle ω=212° W by Yukio MORITA in Hiroshima on 1 July (Day 8), 2 July (Day 9), 3 July (Day 10) and on 4 July (Day 11) as Fig. 4. See Minami, 2001b and 2002d. On the other hand we here also show AKUTSU's image on 30 June (Day 7) at ω=213° W as Fig. 3 for comparison. See also Minami, 2001a. These reveal well how the airborne dust expanded from the southern hemisphere to the area of Elysium in the northern hemisphere. In particular as shown on the blue images the water vapour was quite active on the morning side

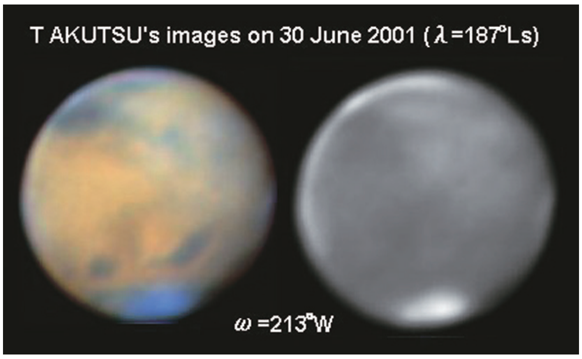

Fig. 3 AKUTSU's images on 30 June.

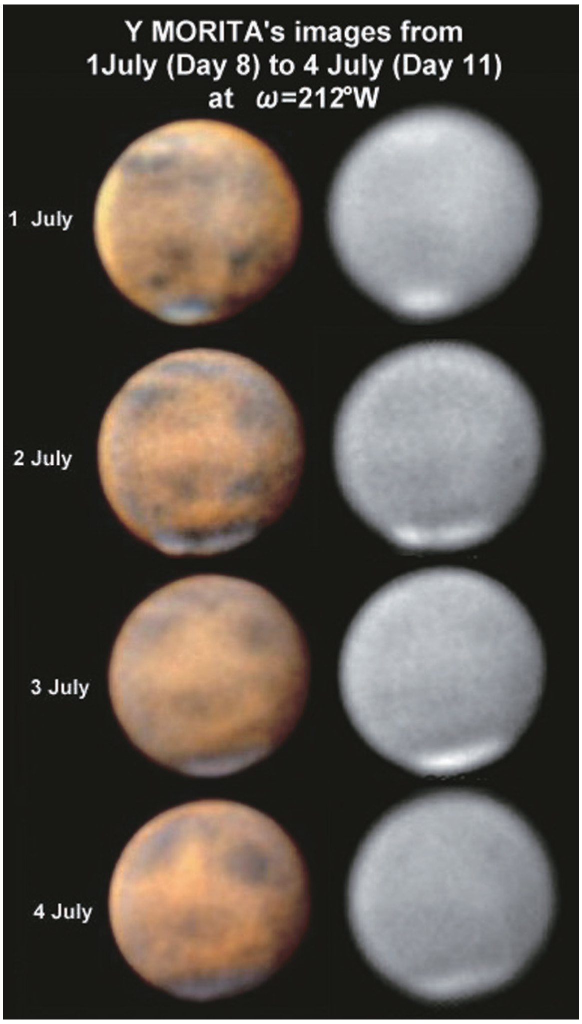

Fig. 4 MORITA's sequence images from 1 July to 4 July at the same angle

of the southern hemisphere. They also prove that on 30 June (Day 7) the thick expansion of dust was limited within the southern hemisphere while it reached down to the area of Elysium on 1 July (Day 8) and the airborne dust was active there on 2 July, 3 July, and 4 July, arousing several resonant dust disturbances at the area of Elysium. We here therefore consider that at the beginning of July the troposphere became produced and active at night and hence it indicated growing of the dust into a global dust storm. Note also that during these days the Ætheria dark patch was quite deformed especially on 4 July, as noted in Nakajima & Minami, 2007 as well as in Minami 2002d: The fact that a part of Mare Cimmerium looked quite darker than the other areas is also shown on MORITA's images on 4 July.

2-4 The darkening of Mare Cimmerium

As just abovementioned the main part of Cimmerium was considerably dark on 4 July: The image of Akinori NISHITA on the day at ω=225° W (see Nakajima & Minami, 2007, page 10) succeeds MORITA's set of images on the day at ω=192° W, 196° W, 200° W, 205° W, 212° W, 218° W, where the dark part is clearly shown. This part also looks darker than the very part of MORITA's images between 1 July and 3 July. See Fig. 4. However we can consider that the dust cloud must have expanded at high altitudes and so the very part was not darker than usual but it is possible that a hole of the dust cloud appeared at the very part. That is, we are of the opinion that it was not because the dark marking became much darker, but because the very whole part looked normally dark but darker than the other dusty dark markings.

We here note that the MGS-MOC results imply that already on 4 July (Day 11) the area of Sinus Meridiani looks quite dusty and so it was clear that the dust storm had already been global.

2-5 The resonant dust cores near Mare Sirenum

At page 11 of Nakajima & Minami, 2007, we described "The dust core to the south of M Sirenum which was found on 3 July until ω=191° W was caught thick again on 4 July from ω=152° W to around ω=200° W." Earlier on 3 July (λ=189° Ls, Day 10), Timothy PARKER in California caught clearly the resonant dust core to the southeast of Mare Sirenum on the morning side at ω=107° W, and also on the afternoon side it was shot by De GROFF at ω=147° W. This set of images is very significant in the sense that it proves the dust did not develop during the daytime (Fig. 5). However since it was again detected near the place on the following day, it is supposed the dust core remained alive at night on Day 10. On 4 July (Day 11), earlier than in Japan, Maurice VALIMBERTI in Australia already found the resonant dust core again at Mare Sirenum at ω=129° W & ω=147° W. See Fig. 5. On the same day De GROFF also shot it clearly at ω=146° W.

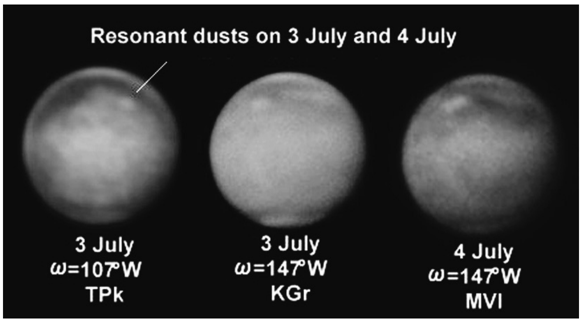

Fig. 5 Resonant dusts on 3 July and 4 July where TPk= Tim PARKER, KGr=Kent De GROFF, and MVI= Maurice VALIMBERTI

2-6 Dusts in the area of Solis Lacus on 5 July (Day 12) and 6 July (Day 13)

Next, on 5 July (Day 12) Edward GRAFTON in Texas imaged another (or the same) bright resonant dust core to the northwest of Solis Lacus and on the following 6 July (Day 13) Donald PARKER in Florida detected two developed streaks of dust disturbances in the area of Solis Lacus. Here Fig. 6 shows the variation of the dust disturbance on 5 July, 6 July, 7 July and 13 July (Day 20) seen from similar angles. We also here conjecture that the dust on 5 July (Day 12) made by Ed GRAFTON remained unchanged during the daytime, as in the cases on 28 June (Day 5) and 29 June (Day 6) as well as on 3 July (Day 10), and moved towards the evening side, and therefore the two-streak dust-disturbances on 6 July (Day 13) at Solis Lacus must have been newly raised there. However after 7 July (Day 14) we may consider that since already a fortnight passed, the upper dust must have been quite active during the night time because the stratosphere receded to the higher altitude. Apparently De GROFF's image on 13 July (Day 20) on Fig. 6 shows that the upper dust layer is quite thick. (It should be remarked at the same time that on the image there is seen a frost or quite a thick mist at the southern morning terminator and that the north polar hood (nph) is quite strong as to be discussed below).

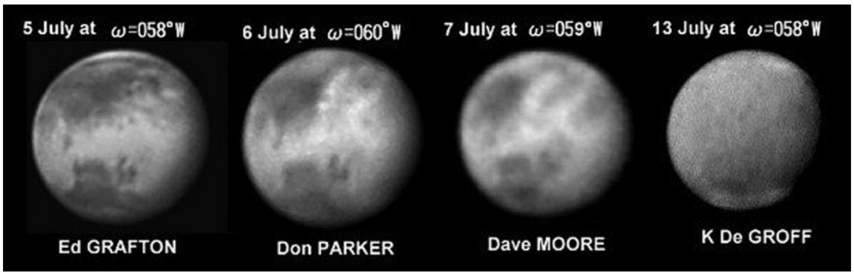

Fig. 6 Dust disturbance at the area of Solis L on 5 July, 6 July, 7 July and on 13 July.

The region began to face towards Japan as well as Oceania and Asia from around 10 July (Day 17) when the dust storm was already globally thick but the two streaks of dust at Solis Lacus remained quite visible. See the review in Minami, 2002c.

2-7 Olympus Mons as a dark spot

As reported in Section 7 of Nakajima & Minami, 2007, Olympus Mons and Tharsis Montes began to show up as dark spots from around 7 July (Day 14) and 8 July (Day 15, λ=192°Ls): This implies the flanks of the higher mountains were already covered with dust cloud except for their summits and therefore the usual meteorology of the Martian atmosphere was already broken down. Usually it is known that Olympus Mons is covered by a white cloud at the afternoon side until λ=200°Ls, while Arsia Mons remains to be covered by the white cloud in the evening even after λ=200°Ls. However this time because of the presence of the dust storm, these water-vapour phenomena ceased to be active and the mountain summits appeared dark from morning to evening. Dust activity must have been more active also at night during these days. As was stated in Nakajima & Minami, 2007, this phenomenon was observed until 17 July (λ=197°Ls) from Japan, and subsequently in August the dark spot phenomenon was quite visible from 9 August (λ=211°Ls) to 18 August (λ=216°Ls).

It should be noted here that in some cases the dark spots appeared very dark, but in reality the density of the darkness was not variable but it was because it depended on the brightness of the dust or the contrast. This must correspond to the above-mentioned irregularity of Mare Cimmerium on 4 July.

We note that the MGS-MOC images equally show the summit of Olympus Mons as a dark area but as time went by it became slightly fainter: It is thus apparent that the upper layer of the thick dust cloud finally exceeded the height of 27 km. See Minami, 2002g.

2-8 Trend of Phœnicis Lacus

The present dust storm was mild, but it was global in the sense that it concealed usual dark markings and hence it was sometimes not easy to identify the positions of dark markings. On the other hand such dark spots as the summits of Tharsis Montes were always observable because of contrast, and since these positions did never move, they were useful to grasp the situation of the surroundings around there. In particular the trend of Phœnicis Lacus (107°W, 13°S) was easily grasped, since it is located near Arsia Mons (121°W, 09°S).

According to the MGS-MOC, Phœnicis Lacus is visible on 30 June (Day 7), while a small dust washed it out on 2 July (Day 9) and it did not recover even on 6 July. The image produced by AKUTSU on 10 July (Day 17) at ω=134°W reveals a singular dark patch to the south of Arsia Mons (see Fig. 8 below): It does not imply the recovery of Phœnicis Lacus but suggests that the area around there is very complex. It appears however that the image of Teruaki KUMAMORI in Osaka at ω=110°W looks to disclose Phœnicis Lacus since the area of Syria Planum is darkened and it further shows another dark spot to the east of Phœnicis Lacus. At this time however the dust turned to be far thicker and there might have been another effect of light and shade of the dust cloud.

If we compare Don PARKER's set of images on 31 July (Day 38) at ω=134°W with AKUTSU's set of images on 10 July (Day 17) at ω=134°W, the dark markings around here prove to be not so changed but the activity of the dust cloud became stronger.

It was at the beginning of September that Phœnicis Lacus appeared to have restored: For example the images of Don PARKER on 6 September (Day 75) at ω=127°W seem to prove to show this fact. As we will state below the period corresponds to the half-life of the 2001 global dust storm.

Don PARKER's set of images on 14 October (Day 113) at ω=127°W shows clearly Phœnicis Lacus and Phasis and at the same time they show that a dark patch at Dædalia turns out to be quite exposed.

2-9 The dark patch at Dædalia and Syria

There must be two interpretations associated with the dark markings during the period the dust prevailed. One is the case where a slit or gap between the bright dusts looks dark and the other is the case where the dark ground is exposed because the superficial fine dust on the ground is washed out. In the latter case it becomes a new dark marking. The Dædalia dark patch is historically one of the representative examples of the latter case.

In 2001 Dædalia began to face towards Japan from around 9 July (Day 16). At this time already Solis Lacus had disappeared and there was seen a dark patch at the area from Dædalia Planum to Syria Planum. As stated before, the summits of Tharsis Montes and Olympus Mons were also detected as dark spots, popping out of the upper layer of the covering yellow cloud. On the other hand the dark patch at Dædalia was the one where the surface dusts were blown away. This difference appears to be proved on AKUTSU's excellent colour images made on 10 July (Day 17) at ω=134°W where the dark spots such as Olympus Mons was warm brownish, while the Dædalia dark patch looks cool bluish.

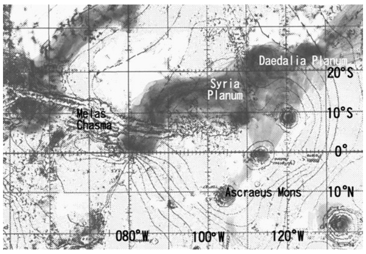

Fig. 7 Diagram of the Dædalia dark patch.

As to the situation how the Dædalia dark patch is located we here depict the location based on several data in Fig. 7. It is recognisable that the area of Syria Planum at 10°S~20°S, 090°W~100°W is darkened, and Phœnicis Lacus is faintly seen also on the HST image on 14 August (HST, 2001) : It is just suggested there was no drastic movement of local dust storms from mid-July to mid-August. As stated before, at the beginning of September, Phœnicis Lacus became more exposed, and the global dust storm welcomed the period of half-life.

2-10 The existence of the morning mist (frost) at the southern high latitude ground

It was particularly characteristic that a white matter was persistently visible at the southern high latitude morning terminator from mid-July (Minami, 2002a). It became evident on 7 July (Day 14, λ=191°Ls) and it became apparent on the visual drawings by MINAMI at ω=133°W~172°W and by Hiroshi ISHADOH at ω= 170°W as well as on MORITA's image at ω=171°W; It was also checked by Tadashi ASADA on 8 July at ω=151°W (G), and also on TAN's images on 9 July from ω=164°W and so on. It seems also existent thickly at the opposite side for example on Don PARKER's B image on 9 July at ω=353°W. It was also clear on AKUTSU's excellent image on 10 July (Day 17) at ω= 134°W. See Fig. 8. However it was shot on the G and B images but it was hard to find it in R images, and hence it must have been a ground mist at the morning terminator still at that time. See also Minami, 2001c.

This ground mist decreased by the end of August, but it was clearly visible until 17 August (Day 55, λ= 216°Ls) and it was notable that it was persistently existent irrespective of the longitudes.

When we compare this phenomenon with the observations

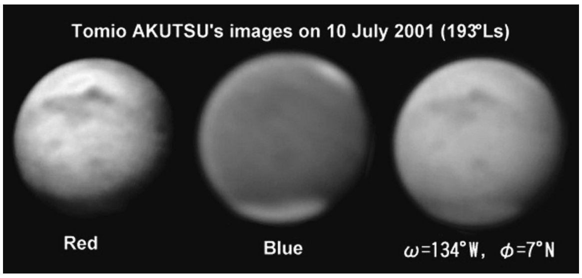

Fig. 8 Morning mist at the southern high latitude taken by AKUTSU.

in 1986, there was observed just a should-be frost at Argyre in 1986 also but was not so bright and furthermore any similar conspicuous phenomenon cannot be unearthed in 1986 at λ=193°Ls~205°Ls as seen in 2001. It is therefore highly possible that the persistent ground mist (or later frost) was not the seasonable one but was very deeply related with the present global dust storm. The persistent ground mist (or frost) at the morning terminator also implies that the dust storm destroyed the structure of the temperature distributions of the Martian atmosphere and that a certain amount of the morning water vapour or its condensate stayed at the same high latitude area for more than one month. This also implied the night side was already cold. It must have been in equilibrium with the fact that the white cloud activity halted from the equator to the northern hemisphere. It was another new example that the dust activity must sometimes be twined with the water vapour activity.

2-11 The dust storm and the south polar cap

Usually the great dust storm invades over the southern pole. The Noachis dust storm in 1956 which burst out on 20 August (λ=250°Ls) went westwards and, as was clearly proved by the images of W. S. FINSEN in the South Africa (Finsen, 1957), it concealed the south polar cap (spc) 9 days later on 29 August. The visual observation on the day of Audouin DOLLFUS (Dollfus, 1998) also shows a large covering of the dust over the south polar region. It was on about 16 September 1956 (λ=267°Ls, Day 30) that the spc cleared again on the sequence of images made by FINSEN.

In the case of 1971, the Noachis great dust storm (named 1971b) which was entrained on 22 September 1971 (λ=259°Ls) covered over the spc eight days later on 30 September 1971 according to Shotaro MIYAMOTO (Miyamoto, 1972).

The 1973 Solis Lacus great storm was set out on 13 October 1973 (λ=300°Ls) and ten days later it hid the spc on 22 October 1973.

However in the present 2001 case the dust itself was so mild that it did not necessarily thickly veil the area of the spc, while some images such as those made by AKUTSU on 28 June 2001 (Day 4) at ω=205° W ~ 239° W and 258° W ~ 271° W suggest that the dust went up to the spc to the south of Hesperia and Hellas after the occurrence of the dust storm. This implies that a part of the spc, as much as about 20%, was invaded by the dust but did not necessarily imply the grand process that it wholly covered the area. On the images of AKUTSU made on 29 June (Day 5) the spc is clearly seen from the side of ω=220° W. However on his images on 30 June (Day 6) at ω=213° W the spc looked rapidly shrunk compared with the case on 28 June. This must have been resulted because of the heat brought by the dust in the atmosphere or because of some partial precipitation or fallout of the dust. This was the aspect seen from our side but from the American side the spc seemed to be large enough and bright as usual as seen on the images of Don PARKER on 30 June (Day 6) at ω=098° W. Therefore this rapid retreat of the spc to the south of Mare Cimmerium has taken place because of the fallout of the dust. NB: The MGS-MOC result on the effect of the dust at the spc area is shown in Wang, 2004.

At the end of July the spc was narrowly visible at the southern limb since the spc itself quite shrank and the tilt ϕ increased to ϕ=7° N, and the spc was not completely affected by the dust on 1 August, where the season proceeded to λ=206° Ls and Day 39. The extension of the 2001 great dust storm was enormous, but compared with those in 1956 and 1971, it was less furious. Recall here that the season of the occurrence of the dust in 2001 was quite younger. But we should say that it was nevertheless extremely global and extraordinary no matter how it was outburst in the off-season.

2-12 Rise and decay of the global dust storms

The dust storm which burst out on 24 June 2001 belonged to one of exceptional global dust storms and was unprecedented in its occurrence time and its global scale.

As was abovementioned (and also as stated in Nakajima & Minami, 2007), the dust occurred very quietly at Hesperia, rose up into the higher latitude sky with an ascending air, was accompanied by several associated resonant dust disturbances, went eastwards at the beginning of July, and grew up to be quite a global dust storm. It must here be recalled that the dust storm in 2001 was entrained quite early in the season just after the southern spring equinox at λ=184° Ls, while several famous preceding dust storms all burst out in the summer; the earliest one being at λ=250° Ls in 1956 and the last one at λ=300° Ls in 1973.

Apparently there are large differences in the 2001 dust storm compared with those storms in the summer seasons in the form of development. The 2001 one was without furious activity and developed very quietly, but it grew very rapidly and, as stated in Nakajima & Minami, 2007, it was recognised that the dust expansion was from the deep south to the deep north on 2 July (Day 8) (see Nakajima & Minami, 2007, p9), and thus evident that the dust storm this time had showed quite early a capacity of a global dust storm. According to TES onboard MGS it is shown that the temperature rose up all over the Martian surface on 2 July 2001 because of the airborne dust; thus really proving that the dust storm itself was already global.

In July and August the dust storm largely covered the surface: According to Cantor, 2007, however, the MGS results suggest that the decay phase began around λ=200° Ls (around 23 July).

As September came in, a sign of large decay of the storm began to be seen: At Fukui we observed that Æria in the northern hemisphere was found already *reddish* on 5 September (λ=227° Ls) and recognised that the dust storm had already begun to subside. See Nakajima & Minami, 2007, p14. The day was Day 74 after the occurrence of the Hesperia dust storm and we knew that the half-life period of the dust had just passed.

Don PARKER's images on 24 October 2001 (λ= 259° Ls, Day 123) at ω=023° W ~ 040° W show clearly that the basic dark markings were apparent and it became difficult to distinguish the dust deposits from the floating dusts. KUMAMORI's images on 31 October 2001 (λ= 263° Ls, Day 130) at ω=074° W, 083° W also prove that the dark markings quite restored. Since AKUTSU's images taken before sunset on 11 November 2001 (λ= 270° Ls, Day 141) show Syrtis Major near the centre of the disk in IR, we may say the day 31 October (Day 130) was a very good candidate when the dust storm subsided. TES' result also proves that the temperature at the middle latitude began to be cooled down from the mid-October, and hence 31 October is an appropriate period of the subsidence of the dust storm. Taking the cooling down of the equatorial zone into account we may regard that the period from Day 110 to Day 130 belonged to the decay phase: See Minami, 2002e. As stressed there it also corresponded to the recovery period of the water vapour activity. In fact from the end of October the white cloud activity was frequently observed so that we could be aware that the water vapour became quite active. See also Minami, 2001d.

Here we can state that the decay phase of the 2001 dust storm is comparable with that of the 1971 largest dust storm (1971b). As stated in Minami, 2002e, the half-life period of the 1971b dust storm was studied in Conrath et al, 1975 and in Zurek 1982 where the half-life period was pinned down to have visited around Day 60. On the other hand the final period of the decay phase was studied in Leovy et al, 1972; Hartman & Price, 1974, where it was reported that it did come around Day 100.

In 1971 Shotaro MIYAMOTO visually observed the planet Mars and chased the dust storm until it became semi-transparent (Miyamoto, 1972). The dark markings of the Martian surface became quite visible to him at the end of December 1971 (the 1971 dust originally burst out on 22 September 1971), and he described on 18 January 1972 (λ=330°Ls) at ω=074°W that "Dark Surface clearly visible for the first time." So we may conclude that the final period visited MIYAMOTO around Day 120. See Minami, 2002e.

3 On Possible Precursory Phenomena

We here give some speculations concerning the possible causes why the 2001 great dust storm was eventually entrained so early.

3-1 Precursory disturbances seen before the 2001 great dust storm

As repeatedly stated the present great dust storm was given rise to near Hesperia on 24 June 2001 at λ = 184°Ls, and then developed into a global dust storm. It should be noted however that it was not necessarily entrained spontaneously but there were observed a few of symptomatic phenomena just before the southern spring equinox and so here we shall try to rake them up.

The atmosphere at the south polar region must keep 150K adjacent to the CO_2 frost cap and it is generally believed it will be warmed up due to the heat transportation from the lower latitude and the direct absorption of insolation to 190K and the moist air will raise the dust disturbance near the perihelion at around λ=250°Ls. This time however it can be considered that the warming-up of the south polar region was seen already just before the spring equinox, and some matters and latent heated water vapour which may constitute the basic of the dust storm were accumulated. Therefore we must here check some phenomena before the spring equinox which may suggest any ascending of the temperature.

First of all we note that the MGS-MOC already detected two mediocre local dusts near λ=143°Ls on 8 April 2001: One was seen at the eastern coast of Hellas and the other at Noachis (MGS, 2001). The latter dust had a width at 40°S and stayed to the west from 325°W. On the other hand the dust at the eastern coast took place more southern but to the north of about 50°S. These dust however dispersed completely on 10 April and any core disappeared. There was still seen a frost inside Hellas. It is well known Hellas was pure whitish at around λ=100°Ls but just before 150°Ls the frost inside Hellas suddenly sublimes. At around λ=150°Ls it is difficult to discriminate the border between the spc and the south polar hood (sph) but it must be located at the area of the dusts between 40°S and 50°S. Consequently we can thus suppose that there were occurring several small dust disturbances which must have contaminated the atmosphere. In addition there was observed an inter-relation between the southwestern part of Hellas and the sph.

Next we shall pay attention to the area of Hellas in mid-May: On those images made at λ=163°Ls on 17 May by MORITA at ω=292°W~326°W and by KUMAMORI at ω=282°W showed a strong interaction between the southwestern part of Hellas and the sph.

Subsequently at λ=164°Ls on 19 May 2001 a lot of observations were reported from the Asian area including all over Japan: The following observations were obtained:

Mn-359D	ω=248°W (at 14:00 GMT),
Mk-057D	ω=255°W,
Mn-360D	ω=258°W,
Mk-058D	ω=265°W,
Mn-361D	ω=268°W,
Mk-059D	ω=275°W,
Mn-362D	ω=277°W,
Ts-052D	ω=280°W,
Mo-ccd	ω=283°W,
Mk-060D	ω=285°W,
Mn-363D	ω=287°W,
Ts-053D	ω=289°W,

Mo-ccd	ω=293° W,
Mk-061D	ω=294° W,
Mn-364D	ω=297° W,
Ts-054D	ω=299° W,
Mo-ccd	ω=303° W,
Km-video	ω=306° W,
Mn-365D	ω=307° W,
Ts-055D	ω=309° W,
WTn-ccd	ω=309° W,
Mo-ccd	ω=313° W,
Mn-366D	ω=316° W,
Ts-056D	ω=318° W,
Mo-ccd	ω=324° W,
Mn-367D	ω=326° W,
Nj-083D	ω=331° W,
Mo-ccd	ω=333° W,
Mn-368D	ω=336° W,
Nj-084D	ω=341° W (at 20:20 GMT),

where the name codes imply: Mn=MINAMI, Mk=Masami MURAKAMI at Fujisawa, Ts=Hitomi TSUNEMACHI at Yokohama, Mo=MORITA at Hiroshima, Km=KUMAMORI at Osaka, WTn=TAN W.-L. in Singapore and Nj=NAKAJIMA. D stands for "drawing."

The interaction between the sph and the spc is really recognised between 270° W and 300° W. Obviously there were seen protrusions of vapour and dust from the sph, and in particular they were water vapour clouds or condensates mingled with some dusts since the part was well seen in Green light. It should also be noted that there were seen small dust disturbances at the southwestern part of Hellas. As reported in Nakajima & Minami, 2007, we had also good results on 20 May, but the distribution of the interactions was slightly different from that on the preceding days because the cloudy parts were movable. See Minami, 2003a as to a more detailed description of the interaction between the sph and the spc at this time.

This interaction continued afterwards : On 1 June (λ=171° Ls) Nicolas BIVER in France checked Hellas and the sph at ω=298° W and 317° W. On 11 June (λ=176° Ls) Don PARKER significantly shot in Green light a cloud belt which floated broadly from the southern Hellas to Mare Tyrrhenum; not so evidently in Red but somewhat in B. Since it appeared strongly in G we consider that much of the water vapour was provided enough to constitute a belt of crystalloid. On the same day GRAFTON however produced similar images in G but it was not so conspicuous. We additionally note that this kind of lower water vapour or crystalloid zone is also seen on AKUTSU's G image on 27 June (λ=185° Ls) after the occurrence of the germ of the great dust storm.

Summing up, it is an undeniable fact that the commonplace small dust disturbances near Hellas for example on 8 April must have made the atmosphere of the south polar region semi-transparent and, at the same time, made the surface temperature somewhat warmer and made the evaporation promote around there. And in this process a large amount of latent heat of the water vapour which contains melting heat and evaporation heat must be important as energy to constitute kinetic energy of the dust disturbances. Furthermore the interaction between the sph and the southwestern part of Hellas which was seen around 19 May 2001 also gave an impetus to a generation of water vapour as well as associated dust disturbances.

The early stirring up of the water vapour however does not necessarily imply the early recession of the spc. It is because what concerns here is the energy which each molecule of the water vapour has; this being more important than the absolute amount of the ice or molecules of the water.

The outer edge of the spc in latitude, denoted θ, is, according to the results of the MGS-MOC, θ=53° S in the range between 320° W and 330° W on 20 May 2001 (λ=164° Ls), θ=54° S on 6 June 2001 (λ=173° Ls) and θ=56° S on 11 June 2001 (λ=176° Ls). (Check Wide Angle Images in MGS-MOC, 2005.) The values are slightly different if seen from different longitudes, and θ=53° S at λ=176° Ls if seen from 030° W. Accidentally λ=176° Ls is the first season where the Viking began to operate: Figure 2 of the article based on the Vikings by P B JAMES et al (James et al, 1979) gives the value θ=53° S seen from 030° W at λ=176.4° Ls. It is eventually apparent that the recession of the spc was quite normal in 2001 and was not necessarily rapid just before the occurrence of the dust storm.

It is reasonably assumed now that the trend of the water vapour might have been richer around the perimeter of the spc in 2001. We should say it was perhaps because 1) since there has not been any great dust storm recent years, the residue of water at the south polar region must have continued to be much accumulated these years on the occasion of every annual migration of the atmospheric water more than usual, and 2) the warming up of the temperature and generation of water vapour must have been earlier than usual due to some external phenomenon of catastrophe (as to which we will speculate in the next sub-section).

We thus consider that the excessively accumulated H_2O near the peripheral area of the spc did resolve earlier than usual and the evaporated water vapour sent its energy as the form of latent heat to the dust around Hesperia. Hellas worked, as it were, as an anti-cyclonic blocking high pressure air-mass and hence the stormy dust got rid of Hellas, and the emergence of the storm rather rose at the eastern Mare Tyrrhenum and Hesperia and developed into the eastward great dust storm. The storm thus successively gave rise to several resonant dust cores as well as to stronger opacity and warming of the atmosphere and to further rapid expansion of the dust all over the Martian globe.

3-2 Possibility of the influence of the flare activity of AR#9393

Since the 2001 great dust storm was not usual and was in the onset quite early from the point of the season, it may be appropriate to take some unseasonal causes or spontaneous reasons into consideration. As stated before some mediocre disturbances near Noachis were known ever since April 2001 and furthermore several interactions near Hellas were observed in May and June 2001.

Although it is still obscure whether there is an interaction between the solar wind activity and the Martian dust activity, this time in 2001, we should remember that the period was in the midst of the 23rd solar cycle and so it is a way to speculate a decisive inter-relation.

We here follow the form of the National Oceanic and Atmospheric Administration (NOAA) and adopt the idea of the Active Region (AR) which describes an active area of the Sunspot as well as the Flare and the Coronal Mass Ejections (CME): It was introduced around 1973 and recognised world-widely in the 1980s.

We next especially pay our attention to the fact that, at the end of March 2001, a large AR#9393 showed up on the Sun. As notified to us by our colleague Hitomi TSUNEMACHI who was observing the AR by using a 12.5cm fluorite OG at that time, it emitted a big CME near the centre on 29 March, and on the following day ejected an X9 class flare (the solar flare is classified and ordered A, B, C, M and X based on their energy outputs −X the biggest−, and each also divided into nine grades; the larger ones above X9 will be classified as X10, X 11,⋯ X17,⋯ X20,⋯). Notably AR#9393 discharged a gigantic flare on 2 April at 21:51 GMT: As to this, TSUNEMACHI summarised as follows:

"On 28 March the sunspots in #9393 were near the CM growing big, and they showed clearly the contour of the big umbra as well as the small dark spots arrayed along the complex contour of the penumbra. On 29 March, the region passed the CM, and looked to grow further. Information then was got that AR#9393 had sent out several M type flares already from 23 March on, and eventually as the new month came in on 2 April at 21:30 GMT emitted a large X type flare and at 21: 50 GMT the biggest one: it was first reported to be X 17, but later re-estimated to X20, and nowadays some denotes X22. This is so called "Biggest Solar X-Ray Flare on Record" as seen in
http://sohowww.nascom.nasa.gov/hotshots/X17/
⋯. *A proton current was also associated with the flare in this case. From 23:00 GMT the proton flux augmented. Fortunately or unfortunately, the 2-April-2001 flare occurred quite near the limb of the Solar surface, and hence it was rather difficult for the ground-based observers to catch it, and the effect of the disturbance to the terrestrial ground remained quite limited since it did not point to the Earth: Even then it caused some electrical blackouts and radio-wave jamming as well as brought damages to some satellites. ⋯ At the Narita Airport, communications were impossible twice, and the ionospheric disturbance continued for six hours. The CME was shot beautiful by LASCO C2. AR#9393 was observed until 4 April."*

When the X-22 flare occurred, the planet Mars was before opposition and had the elongation of 111° from the Sun while the phase angle was 37°, and so the AR was seen from Mars more inside by 32° implying that a larger effect or influence of the flare or the associated CME must have more positively reached the planet.

It is hard to deduce the relation with the subsequent dust event on Mars, while since the dust occurrence was exceptionally unusual from the seasonal point of view, we consider it may be meaningful to speculate an intimate interplanetary relation between the two phenomena.

It is also difficult to put forward a reason why the solar wind will cause an extraordinary dust storm, but this may also be possible if there must be caused a potential difference between the upper sphere and the Martian ground due to a neutralisation of electric charge which may occur at the side of the ionosphere (though weak). That implies as if there would be given rise to a global circuit of electricity. If it is our terrestrial case, there must be aroused thunder lights to thunder storms associated with the vapour clouds. In the case of Mars, the airborne dust plays the role of water vapour, and hence even the distribution of the airborne dust should carry the electric potential difference. In the terrestrial case, we know the sand storm blown up by the Harmattan at the west coast of Africa is electrified, and sometimes associated with a thunder light. The electricity must be reasoned to be caused by the friction of sand particles, so triboelectricity. Since the sand particles on Mars are mostly composed of Silica powder SiO_2, the silicate ion SiO_3^{--} must be influenced by the friction. We here take into account the fact that the atmosphere is so thin enough to receive the effect from the interplanetary space. See Minami, 2003b for a further review.

4 The North Polar Hood Problem

We here discuss the behaviour of the north polar hood (nph) when the dust storm was prominent.

4-1 General relations between the dust storm and the nph

It is generally said that the occurrence of the dust storm makes the north polar hood (nph) retreat: In 1973 it was reported that the retreat occurred most on Day 18 (Martin M. J., 1975), and in the case of 1971b, the Viking results indicated that the temperature of the atmosphere at the north polar region reached the highest on Day 19 (Jakosky & Martin, 1987). Hence it is reasonably assumed that the density tendency at the northern polar region largely reduces, depending on the behaviour of the southern originated global dust storm. However in the case of 2001, as will be elucidated below, the relation looked reversed, and the stronger the activity of the southern dust storm, the thicker the density of the nph. The difference must have been caused by the difference of the season when the dust occurred. As has been said repeatedly, in the cases in 1971b and 1973, the entrainments of the dusts occurred in summer at λ=264°Ls and λ=300°Ls respectively, while the 2001 case was in the onset just after the spring equinox at λ=184°Ls when the Sun is seen quite lower from the northern polar region.

4-2 The nph when the dust storm set out

From the Oriental region, we were able to observe the windows from around ω=240°W through 270°W during the period from the Day 1 (24 June) to around Day 9 (2 July). As seen e.g. from MORITA's B images in Fig. 4, the nph did not show any particular behaviour at first. Generally speaking, we cannot say there was any large variation of the nph during the period. The nph cannot be said to have behaved weaker than during the period from 10 July onwards to be stated in the next sub-section, and hence we here stress that the occurrence of the 2001 dust did not make the nph inferior suddenly. Few data from the different angles are there, but on 26 June, 28 June and on 30 June there was no sign of the inferiority of the nph.

The nph on 23 June, the day before the dust occurred, was not stronger than the cases in July as stated below.

4-3 The nph in mid-to-late July

There was no observation on 5 July (Day 12) in Japan, and only a few at Okinawa on 6 July (Day 13). On 5 July however De GROFF observed on the Eastern Hemisphere and on 6 July TAN in Singapore observed in addition to De GROFF. On 7 July (Day 14) the weather in the main islands of Japan got better and the nph appeared thicker. On the side of the US, Don PARKER produced a set of drawings where the nph was described to be "conspicuous". On 8 July (Day 15) De GROFF produced images. On the day, one of us (MINAMI) went to Okinawa to stay there for a month where the weather continued to be fully fine. On 9 July (Day 6), as stated in CMO #248 (Minami, 2001b), the semi-worldwide observations were successively executed from Florida, Australia, the Japanese main lands, Okinawa and Singapore so that it was possible to trace the nph as much as 70% of the whole nph. Let us denote χ the latitude of the border of the nph. Then it lay in the range between χ=52°N and 60°N. After that, the nph looked further active, and on 13 July (Day 20) the nph appeared to make an uprush to the north of Olympus Mons around ω=110°W. On 14 July (Day 21, λ=195°Ls) the protrusion looked upto χ=46°N. It further developed and on 17 July (Day 24, λ=197°Ls) there was seen a bright protrusion near the centre at ω=090°W: Already at ω=065°W, the peripheral part of the nph at the morning side was very bright as if a frozen ice matter was glittering, and the dark fringe looked split into two right and left, and between them a bright plume was seen in the southwestern direction. The border was near around χ=47°N and the tip of the plume reached χ=42°N. We here show schematically the aspect of the border of the nph seen during the period between 15 July and 17 July in Fig. 9.

As a result we can say that obviously the nph was very active during the period and did never degenerate.

Even after that, the activity of the nph did not reduce, and several southern protrusions were seen from the border. Finally here we list up the values of the latitudes χ of the perimeter of the nph from a few of the domestic

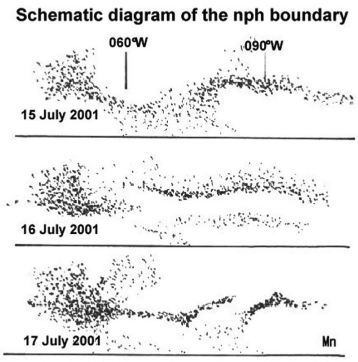

Fig. 9 Schematic diagram of the variations of the nph on 15, 16, and 17 July.

drawings made on 30 July (Day 37, λ=205° Ls):

Mn-617D	10:20 GMT	ω=269° W	χ=54° N
Ts-155D	10:40 GMT	ω=274° W	χ=56° N
Mn-618D	11:00 GMT	ω=279° W	χ=54° N
Hk-052D	11:10 GMT	ω=281° W	χ=56° N
Ts-156D	11:20 GMT	ω=284° W	χ=55° N
Mn-619D	11:40 GMT	ω=289° W	χ=54° N
Hk-053D	11:50 GMT	ω=290° W	χ=56° N
Ts-157D	12:00 GMT	ω=293° W	χ=53° N
Mn-620D	12:20 GMT	ω=298° W	χ=57° N
Hk-053D	12:30 GMT	ω=300° W	χ=56° N
Mk-129D	12:30 GMT	ω=301° W	χ=55° N
Ts-158D	12:40 GMT	ω=303° W	χ=55° N
Mn-621D	13:00 GMT	ω=308° W	χ=50° N
Ts-159D	13:20 GMT	ω=313° W	χ=51° N
Mn-622D	13:40 GMT	ω=318° W	χ=47° N
Ts-160D	14:00 GMT	ω=323° W	χ=53° N
Ts-161D	14:50 GMT	ω=335° W	χ=58° N,

where Mn=MINAMI, Ts=TSUNEMACHI at Naha, Hk= Toshiaki HIKI at Nagano.

As easily seen from the above table, the values are never weaker than those on 17 July (Day 24). Every scene shows Syrtis Major (though the dust was so strong that Syrtis Major looked very blurred), and its northern Utopia makes the nph weakened, but its morning western side was covered by a thick nph, and it came to the CM when ω=310° W. On the following 31 July (Day 38) Don PARKER's images at ω=131° W and 134° W prove that the narrow part was at χ=55° N, while the broad part at around χ=51° N.

The dark fringe of the nph was first seen to be most conspicuous on 7 July (Day 14) at ω=162° W. The nph was white, the morning side was not so bright, but the dark band of the afternoon side was eminent. Such a dark fringe henceforward appeared very frequently: The prominent border must have been the place where the dust and the nph competed with each other.

As thus seen, we should say that the dust storm did never suppress the nph, but rather worked as an element to make it more active. This was a remarkable and quite an interesting phenomenon which is very different from the cases in 1971b and 1973. See Minami, 2002f for a further review.

5 Discussion and Outlook

We thus far discussed the precursory phase of the 2001 great dust storm, its emergence on 24 June 2001, its expansion and persistent stage, and its decay mode. We have not discussed however much about its emergence, no more than the discussion in Nakajima & Minami, 2007. In some cases the entrainment is confused with some local dust disturbances which are piled up in the precursory phase, while we have fixed the day on 24 June 2001 of the onset of the 2001 great dust storm. A necessary warmup of the air just occurred on 24 June (Martin, T. Z., 2001).

It may be traditionally still believed that any large dust onset is related with the Hellas basin, but we do not adopt the idea that any great dust storm stems from the Hellas basin. It is quite natural that the ground of the basin suffers from several local dust disturbances, and they are swirled but not stirred high up to the rim side of the Hellas basin because the ground is governed by high pressure atmosphere (Minami, 2002h). We therefore sometimes have to distinguish the ground dust disturbances inside Hellas from the dust storm at the surroundings of the basin. In a case, if the upper atmosphere is full of the matured airborne dust over Hellas, the basin may look quite thickly dusty but it does not mean that much. It is quite normal at the final stage of the spc several small dust disturbances frequently occur at the peripheral part of the spc and also the sph interacts strongly with the local dust at the southwestern part of Hellas: They do not however necessarily develop into any great dust storm. It may therefore look straightforwards but may be unsuccessful if we pursue this way to approach the mechanism of the great dust emergences. We should rather note that the great dust disturbances occur outside Hellas, for example at the area of Noachis.

In the case of the 2001 dust storm it conveyed several anomalies. Usually such a kind of dust storm occurs near in summer, while this time it did just after the spring equinox. Second, it really got rid of the Hellas atmospheric column but it occurred at the opposite side of Noachis, namely at Hesperia through Mare Tyrrhenum.

Third, it was very mild but developed to be perfectly global. Fourth, its relation with the nph activity was opposite to the hypothesis hitherto conceived. These may change the traditional concept of the dust storms and it is expected that these may bring us some new ideas to make a breakthrough in the future.

We put forward in this article a proposition that any early dust core rises in the early morning, remains nearly unchanged in the daytime, and subsides at night: If circumstances allow, the remnant of the core will generate another resonant dust core at a slightly different (or the same) place in the next morning. If this process repeats several days and nights, the temperature at night augments so that the troposphere at night is generated. As a result, warmer nights will be realised and consequently a persistent dust veiling will be produced. Recently the observations by the MGS are frequently used and published, but unfortunately they are silent about the dust cores of disturbances which are seen in the morning because the MGS just kept watch on the segment of 2 o'clock PM: They also do not show us the activities of the water vapour at the early time on the morning side.

As to the scale of the dust storm, usually used is a method which classifies the scale as "local," "regional," and "global", but we are of the opinion that this classification is concerned with no more than the "area", while it is also important to take account of the depth or density or altitude of the dust core. That is, we must take the upwards motion of the dusty air into account. We also introduced the idea of "resonant" cores of dust, but we consider that it is not appropriate to regard the resonant dust simply as a local dust.

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http://www.mars.dti.ne.jp/~cmo/oaa_mars.html *or*

http://www.hida.kyoto-u.ac.jp/~cmo/cmo/oaa_mars.html

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2001年の火星観測報告.（その2）
― *2001年大黄雲・観測の分析* ―

南　政 次*・中 島　孝**

（要旨） この論攷では2001年に火星面で発生した大黄雲について詳しい分析を与えた．この大黄雲については既に前号（福井市自然史博物館研究報告第54号）の第I部において博物館天文台における観測を中心に詳述してある．従ってこれは第II部にあたる．

第2章では大黄雲の分析を幾つかのsub-sectionsに分けて述べた．**2-1**では2001年大黄雲の異常性を特筆し，発生についてその発生の季節的な特徴を1956年や1971年，1973年の大黄雲と比較して述べた．**2-2**では大黄雲発生の2001年6月24日（λ=184°Ls）以降の幾つかの共鳴黄塵の動向を当時の具体的なデータに基づいて論述し，われわれの見解を述べた．特に6月28日，29日に共鳴発生した黄塵について調べた．要は，黄塵は朝方に発生し，お昼においては殆ど発展がなく，初期においては夜間には活動は沈静化しているというのがわれわれの考えである．**2-3**では続く7月初めのエリュシウムにおける黄雲活動を博物館天文台の資料や広島の森田行雄氏のCCD画像によって論じた．**2-4**では7月4日に見られたマレ・キムメリウムの濃化について述べ，われわれの見解を加えた．**2-5**では，太平洋側で7月3日，4日に観測されたマレ・シレヌム東方の共鳴黄塵について，やはり黄塵は昼間発展しないという立場から述べた．**2-6**では次いでアメリカ側で7月5日（発生12日目）や7月6日に見られたソリス・ラクス領域での共鳴黄塵の発生について論じた．**2-7**では7月の上旬から観測されたオリュムプス・モンスやタルシス三山の暗点化の動向を述べた．これは黄雲発生後早くから高山の裾野が頂上を残して黄雲に蔽われていることを示しているが，同時に火星の通常の気候が既に破壊されたことを意味している．**2-8**ではタルシス山系などが黄雲の発達により不透明化が進むなかでポエニキス・ラクスを指標として周辺の動向を見極めたものである．**2-9**ではその近くのダエダリアやシュリアに現れた暗斑について考察した．タエダリア等の暗斑はオリュムプス・モンス等の暗点とは違い，地表の砂塵が洗われたものと考えられる．**2-10**では7月の7日頃から目立ち始めた南半球高緯度の朝方の地上霧（霜）の存在に注目した．7月10日の阿久津富夫氏の画像には黄雲の拡がりと共にこれが顕著に描写されている．これは8月後半まで殆ど経度に関係なく存在し，極めて特異な現象であった．この現象はこの緯度では夜間側に冷気があることと，赤道から北半球にかけての白雲活動が停止したことと平衡が取れていると考えられる．**2-11**では今回の大黄雲が南極冠を覆ったかどうかの議論を行った．通常の大域的黄雲はこれまでのところ1956年のノアキス黄雲も1971年のノアキス黄雲も，また1973年のソリス・ラクス黄雲も一週間程度で南極冠を隠してしまっていたが，今回の2001年の黄雲の場合，動きが温和で南極冠を完全に隠すということは起こらなかったように思われる．そこで，初期においてどのように南極冠に黄雲が作用したかをここでは調べた．**2-12**では今回の大黄雲の興隆と特に衰退期について論じた．6月24日に発生した黄雲が上昇気流に乗りながら7月上旬には早くも大域黄雲になった．しかも前例とは違い東方に移動して拡がるという動向を示した．7月，8月には猛威を奮ったが，9月上旬には半減期を過ぎたことが観測されている．衰退期は発生110日目から130日目に起こったと見做すことができる．120日目あたりから水蒸気の活動が回復したと結論した．なお，1971年の大黄雲との比較も行った．

第3章では2001年大黄雲にどのような前兆があったかについて論じた．**3-1**では特にヘッラスやノアキス付近での前兆的小黄塵を採り上げた．まず，MGSによって4月8日（λ=143°Ls）にヘッラスの廻りで小さくない局所黄塵が二つ観測されていることに注目した．二日後には核は消失してしまったがこの頃から南極冠の廻りでの黄塵が幾つか起きたこともあり，大気を汚染していることが考えられる．更に5月中旬にはヘッラスの南西側で南極雲との強い相互作用が見られることが日本の観測などで示された．この相互作用はその後も続き，6月には欧米で観測されている．ただし，われわれの考察の結果では特に南極冠が早期に溶解したとは考えられない．逆に言えば，ヘッラス南西部や南極冠の廻りの黄塵活動は季節的には常時見られることで，特別に今回のような大黄雲に発展するとは限らない．従って，何らかの外的な理由が付け加わった可能性がある，と考える．**3-2**ではその外的な要因の一つとして2001年の3月下旬から4月上旬にかけて太陽のAR#9393の活動領域が極めて異常な擾乱を起こしたという事実をここでは想起した．この太陽の活動領域は巨大なフレアや太陽風を発生させ，地球大気にも多大な障害を与えたことで知られているが，火星にも何らかの影響があったものと考えられる．太陽系惑星空間での太陽風がどのように火星に影響するかは未だよく知られていないが，今回の黄雲が季節的に異常であったことから考慮されてしかるべきものであると思われる．

第4章では大黄雲と北極雲との関係を論じた．**4-1**では北極雲と黄雲との過去の一般的関係を述べた．一般には大域的黄雲が発生すると北極雲は後退すると云われているが，**4-2**で示したように大黄雲発生時の北極雲は正常であり，**4-3**で示したように7月中下旬の北極

雲はむしろ後退とは反対に強い活動を示した．特に，7月中旬から7月終わりの黄雲の激しい頃には北極雲は濃いダークフリンジを示しながら本体の活動が際立っていた．これを観測資料に基づいて述べている．要は，それまで過去に見られた現象とは違っており，今期の黄雲の季節が早く，北極域では太陽の高度が未だ低いことによるのであろう．

第**5**章は纏めとしての綜合議論である．先ず，今回2001年の大黄雲では季節的に早期発生であったという異常性や，温和でありながら完璧なまでの大黄雲になったということ，あるいは黄雲の活動と北極雲の動きの相互作用が前例にないことなど異常尽くめであったが，これらは黄雲についての新しい知見を拡げる可能性がある．

最近では，MGSなどの活躍によって細かなデータが揃うようにはなったが，MGSに限れば火星の午後2時のデータしかなく，朝方から夕方までの記録については地球上からの観測が依然として欠かせない状態である．また相変わらず黄雲とヘッラス盆地との関係の信仰が盛んだが，われわれの考えではヘッラスは高気圧帯で黄雲はこれを避け，大黄雲はヘッラス盆地の外側から起こると考えている．本文において，われわれは黄雲の前兆的段階，発生時，発展の段階，崩壊の段階の四位相について述べたが，発生時についてはヘスペリアからマレ・テュッレヌムにかけて温度上昇を伴う大黄雲の萌芽があったと考えている．また，一般に黄雲を局所黄雲(local)，中域的黄雲(regional)，大域的黄雲(global)というように面積で分類する方法が見られるが，実は各黄雲の高さ，ないし厚さ，或いは密度を考慮しなければならないと考えている．また本文では共鳴黄塵の存在について何度も論究し，黄塵は朝方に起こり，お昼にはあまり発達せず，初期には夜には沈下するという新しい考えを述べた．これらは今後理論的にも実証的にも更に検証されるべきものである．

2001年の火星面の興味ある現象の中では，大黄雲の他にエドムの閃光現象が記録されており，これについては次回第Ⅲ部で論述したい．

最後に，われわれの火星観測に対してつねづね御支持いただいている福井市自然博物館の皆様にお礼を申しあげます．またCMO/OAA関係の諸氏にも資料その他でお世話になりました．末尾ながら感謝の意を表します．

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