EFFECTS OF ATMOSPHERIC DUST ON RESIDUAL SOUTH POLAR CAP

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Observations:

The Mariner 9 (M9) spacecraft was inserted into its orbit about Mars at L_S=293° in MY 9. The first M9 data showed an immense, planet-encircling dust haze that engulfed most of the planet; the south polar cap was barely discernable beneath the dust haze, which was the result of a major global dust event that started at L_S=260° in MY 9. As the dust cleared, M9 documented the summer recession of the south polar cap to its perennial or residual configuration in a series of images [1]. Figure 1 shows the residual cap in MY 9 at L_S = 315°.

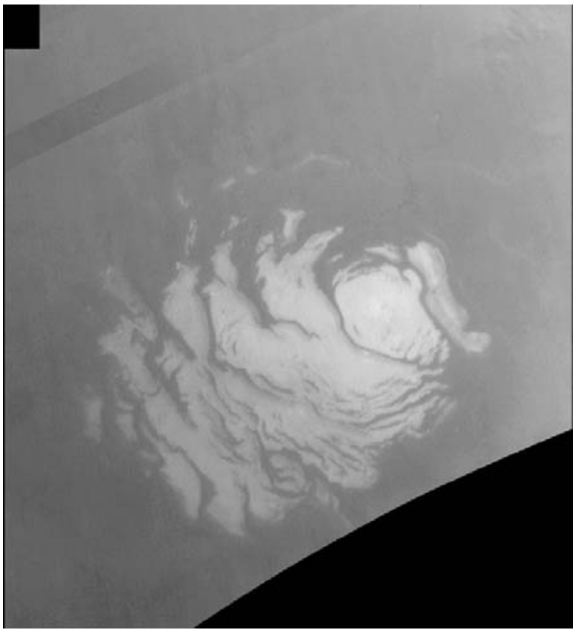

Figure 1: RSPC at L_S = 315° in MY 9 (M 9 091a21)

During the subsequent Viking Mission to Mars, Viking Orbiter 2 observed the same phases of south polar cap recession in MY 12 (Figure 2). One major focus in determining interannual variability in the summer south cap is the large CO_2 outlier located outside the main RSPC roughly at -83°S, 350°– 30°W. We regard this as the last part of the seasonal cap to sublime because it disappears by the end of summer in all of the Mars years that have been observed with sufficient resolution to make the distinction. The outlier disappeared before L_S = 320° in MY 9 images but persisted until late summer in MY 12. The other major focus is the "patchiness" of frost within the RSPC [2]. Comparison of the Viking and M9 observations in these two years revealed substantial differences in the visual appearance of the residual cap between the two years [3]; the recession recorded by Viking lagged that of M9, and some large areas that were frost covered in MY 12 were defrosted in MY 9.

Mars Global Surveyor (MGS) recorded the summer behavior of the south polar cap during four consecutive Mars years commencing in MY 24. Small changes during the twelve Mars years between Viking and MGS were almost exactly balanced between increasing and decreasing frost cover [2]. And the behavior of the cap in summer essentially did not change from MY 24-27 [4]. However, MARCI images of the south polar cap in the summer of MY 28 reveal a behavior similar to that seen by M9, while in MY 29 the cap again appears like it did in Viking and MGS observations [5]. Figure 3 displays a MARCI image of the RSPC, including the outlier, for L_S = 3133° in MY 28; Figure 4 shows the same area for L_S = 313° in MY 29. The accelerated sublimation of the outlier in MY 28 is readily apparent. The behavior of the outlier in MY 28 was qualitatively similar to that observed by M9 but returned to its "normal" pattern in MY 29.

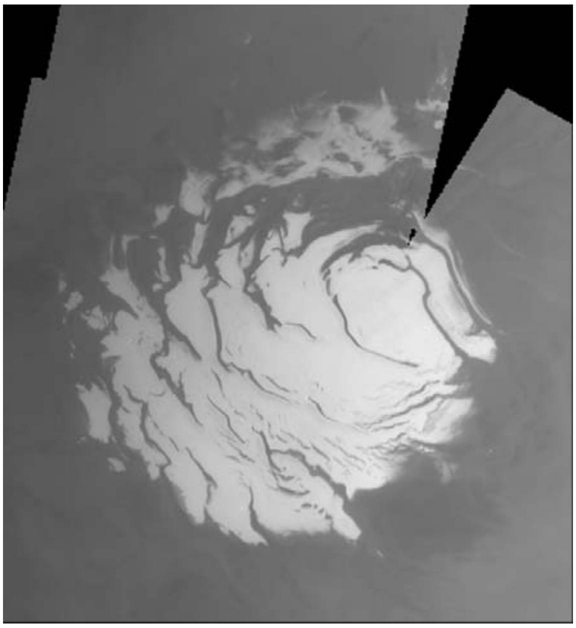

Figure 2: RSPC at LS = 315° in MY 12 (Viking 358B)

Processes affecting RSPC:

Seasonally averaged insolation at the South Pole would be sufficient to remove all CO_2 deposits condensed during winter if the albedo of the RSPC were similar to that of the seasonal cap. However, it has been known since Viking that the albedo of the RSPC was high and might stabilize the residual cap by limiting the amount of CO_2 that sublimed during summer [6]. Measurements of the RSPC albedo using HST [7] and MOC images [8] suggest that it is high enough to cause net annual condensation at the current epoch.

High-resolution MOC images of the surface of the RSPC revealed a variety of complex structures including broad pits in the CO_2 [9]. Observations of subsequent years have shown that these pits are growing in diameter at a rate per MY that seems to be fairly constant [10]. The physical erosion of the CO_2 contained in features represents a net annual loss of material from the RSPC that if not balanced by recondensation elsewhere suggests that we are currently observing the demise of the cap [10].

The growth of the cap in the three Mars years after the Mainer 9 observations suggested that there could be a cycle of net annual deposition and erosion of CO_2 with a period of several MY driven by processes unknown which could “reset” the cap and compensate for the erosion process.

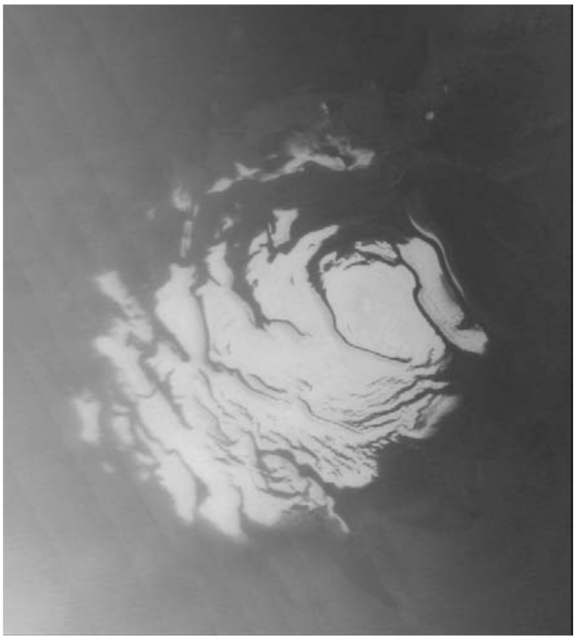

Figure 3: RSPC at L_S = 313° in MY 28. (MARCI P11-05305).

It was suggested in [3] that the radiative effects of the dust resulting from the 1977a early spring dust event in MY 12 slowed the MY 12 recession and resulted in the different RSPC. This idea was tested by the early dust event in MY 25, which was the first year since Viking that had both a major early spring dust storm [11] and spacecraft observations that could resolve the outlier and residual cap. The hypothesis did explain changes in the seasonal cap, in particular the more rapid disappearance of the Mountains of Mitchel in MY 25 than in MY 24 [12,13]; but the MY 25 storm did not affect the outlier or in the RSPC, so the hypothesis should be rejected.

Figure 4: RSPC at L_S = 313° in MY 29. (MARCI B11-014113.)

On the other hand, the diversion of insolation from the visible to the infrared, where the CO_2 surface is more absorptive, by atmospheric dust could be most effective near perihelion and solstice, when the seasonal cap has largely sublimed and insolation is largest. We previously estimated that a perihelic storm such as that in MY 9 could have produced an additional 40-110 kg/m^2 of CO_2 sublimation, where the range of uncertainty is due to the range of the surface models considered (various dust and water contamination as well as grain size) [14]. The amount of CO_2 sublimation that is equivalent to the time lag in the disappearances of the outlier in MY 9 and Viking is about 100 kg/m^2 for an albedo of 0.7; in other words, in a clear year that much CO_2 remains in the outlier after the date of its disappearance in MY 9 in order to preserve the outlier during the remainder of summer. The consistency of the two estimates suggests that a perihelic dust event could have been responsible for the accelerated disappearance of the outlier in MY 9. A major perihelic dust event MY 28 was the first observed by spacecraft since MY 9 [11]. The behaviors of the outlier in MY 28 and 29, which closely resemble those seen by Mariner 9 and Viking, support the hypothesis that large dust opacities in late spring accelerate the subsequent cap recession [5].

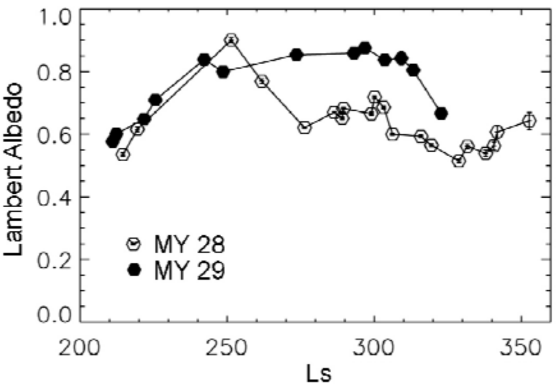

Figure 5: Albedo of a region in the “tooth” in MY 28 and MY 29.

MARCI images show that the residual cap was smaller in MY 28 than in MY 29, with the differences occurring mainly around the periphery. There were also changes within the RSPC. CTX images (5 m/pixel) acquired in MY 29 were compared to a series of MY 28 images of a particular region in the RSPC dubbed the “tooth,” which had shown a wide variety of albedo behaviors in the earlier year, including areas that were totally defrosted [15]. A comparison of the evolution of albedos in a small region clearly shows the effect of the dust event, which started shortly after L_S = 250° (Figure 5). The rapid decrease in observed albedo is consistent with the effects of atmospheric dust with optical depth ~ 1 [8]. The albedo remains depressed while the atmospheric dust clears, perhaps because of dust deposited by fallout. The comparison in Figure 5 shows that, at least at L_S =323°, the regions that were defrosted (dark) in MY 28 are still bright and frosted in MY 29. Unfortunately, MRO was in safe mode after L_S = 323°. Therefore the data suggest but do not prove that newly deposited frost survived summer, since the break-even point between condensation and sublimation is not until L_S=330° to 340°. On the other hand, the physical erosion processes continued at the same rate during the summer of MY 28, indicating that the atmospheric dust does not affect them (Figure 6).

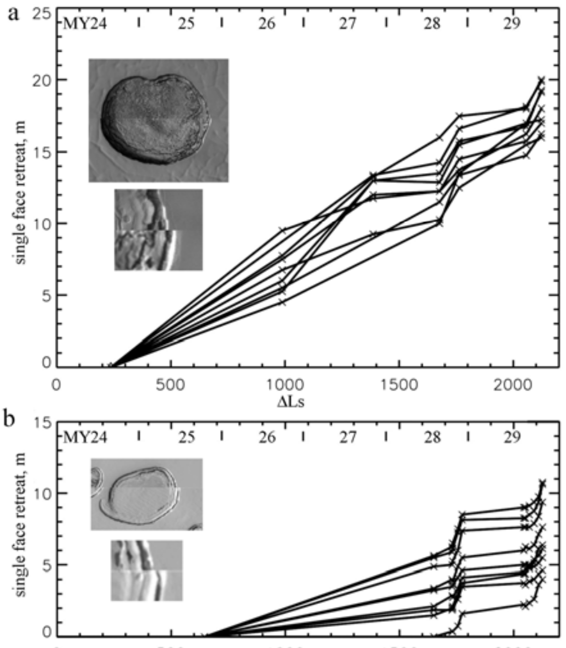

Figure 6: a: Changes in pit walls and septa between pits in thicker unit of residual south polar cap, unit A1 (Thomas et al., 2009) measured from HiRISE and MOC images. Changes are relative to initial MOC observation in MY24. The upper inset shows one of the depressions, ~200 m in diameter at Ls 323 in Mars year 28, top, and MY 29, bottom. The smaller inset expands single-wall change; the data are from 86.9S, 6.5W. b. Changes in thinner B unit (Thomas et al., 2005). The MOC data are from only MY25. The upper inset shows typical depression at Ls 315.7 MY28 (top) and Ls 309.4 MY 29, (bottom). The lower inset expands wall view. Images listed in supplemental data. Located at 86.2S, 9.8W.

Conclusions:

We conclude that interannual variations in dust opacity are a plausible explanation for the short-term (~ 10 Mars years) changes within the residual cap such as those seen by Mariner 9. Therefore it is not necessary to invoke any climate cycle with a period of several Mars years or decades or a secular trend in Mars climate to explain variations in the seasonal cap and RSPC observed by spacecraft over the last 20 Mars years. The observations reported here also suggest that net annual condensation of CO_2 may occur in relatively non-dusty years such as MY 29 (Figure 7). The physical erosion of features within the RSPC is unaffected by dust. It is not clear whether the net annual condensation in clear years can compensate for the erosion, and it is hard to imagine feedbacks that would stabilize the RSPC in its current configuration. Haberle and Kahre[16] show that surface pressure measurements are consistent with net sublimation since Viking at a rate consistent with Malin’s estimate [10], though his results are susceptible to systematic errors. We emphasize, however, that our data do not address the possibility of longer-term secular changes that could maintain perennial CO_2 deposits at the South Pole.

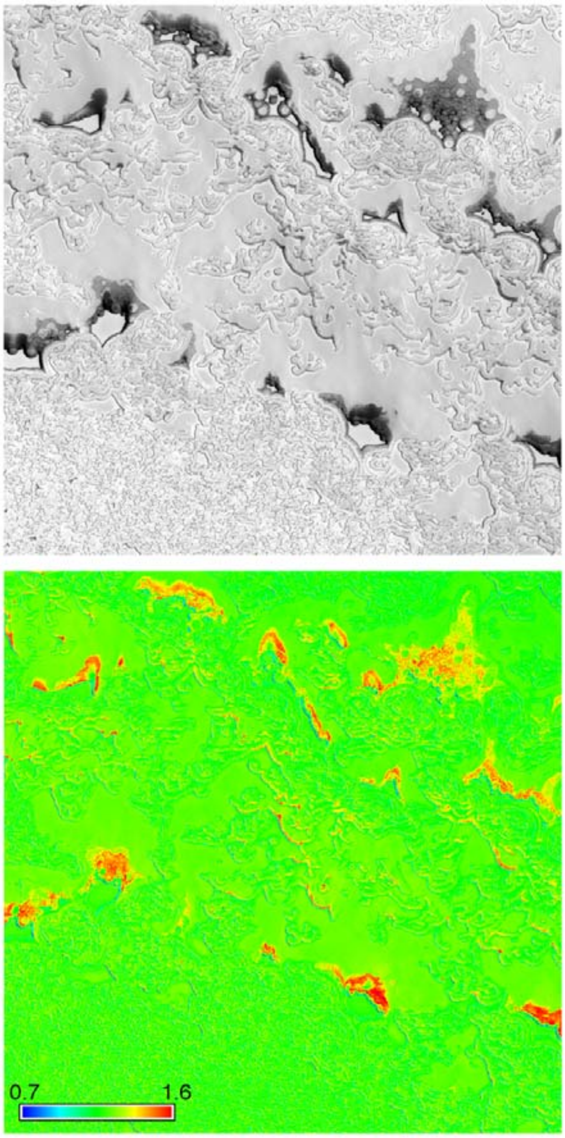

Figure 7: MY 28 CTX image (top) at Ls = 319° of a region of the RSPC that brightened between Mariner 9 and Viking (the feature in the top right hand corner is the “tooth.” Figure 3b is the ratio of a MY 29 image acquired at Ls = 323° and processed identically to the preceding image,

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