EFFECTS OF ATMOSPHERIC DUST ON THE RECESSION OF THE SEASONAL SOUTH POLAR CAP.

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Introduction:

The seasonal carbon dioxide cycle is the interaction between the martian atmosphere and the polar caps. Carbon dioxide, the principal ingredient of the atmosphere, condenses on the surface during the polar winter, and the latent heat released is a major source for the energy radiated to space by the cap. The solid carbon dioxide sublimes in spring, absorbing the latent heat from the insolation as it returns. The basic aspects of this cycle have been understood since the seminal paper of Leighton and Murray (1), and numerous models ranging from energy balance models to GCMs have been used to study the physical processes involved in the cycle.

Observational data that document this cycle are the boundaries of the seasonal CO2 caps, visible in both IR and visible wavelengths, and the seasonal pressure variations measured by the Viking landers. One of the enigmatic aspects of the seasonal CO2 cycle has been the apparent insensitivity of the cycle to atmospheric dust. Atmospheric dust affects the energy input to the polar cap surface in two ways: dust absorption in the visible reduces the insolation reaching the surface but also increases the energy load in the thermal infrared. The polar caps in martian years with very different dust histories seem to vary only slightly, and the pressure curves for years with large and with small dust activity are very similar.

In this work we used the most recent calculations of the albedos and emissivities of surfaces of solid CO2 by Hanson (2) and a Monte Carlo model for radiative transfer in a dusty atmosphere (3) to simulate the effect of atmospheric and surface dust on the south polar cap recession. The results support the hypothesis that the effects of the dust on the cap sublimation in the infrared and visible are nearly equal and opposite for a range of typical CO2 grain sizes and fractional dust admixtures that are encountered in the cap.

Observations:

Mars Global Surveyor began mapping observations in April of 1999 when $L_S \sim 120°$. During the next three terrestrial years, MGS has observed two complete recessions of the south polar cap. These observations include daily mapping in the visible by MOC and measurements of brightness temperature throughout a broad range of infrared wavelengths by TES. Though there were several regional scale dust storms during the first martian year, there were no major, planet encircling years during that recession. In contrast, a large global storm started shortly after equinox in the second year, $L_S = 184°$, and obscured large sections of the planet, including portions of the seasonal south cap, for 2-3 months. The observations of the cap in the two years with very different dust histories make it possible to determine the effects of the atmospheric aerosol on the CO2 sublimation process. Initial determination of the regression curves for 1999 and 2001 show little change in the mean cap radius that represents the large scale cap recession (Figure 1).

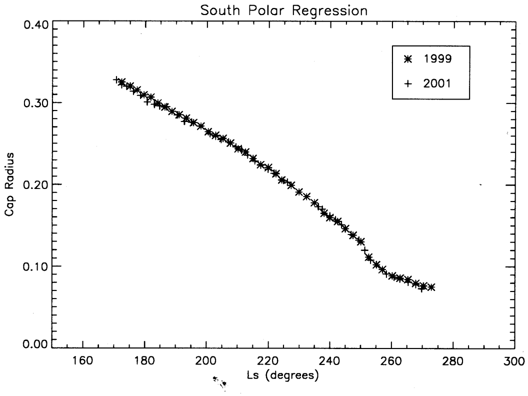

Figure 1: Preliminary comparison of regression curves for 1999 and 2001. The recessions are very similar despite the 2001 dust storm. Abscissa is the cap radius as originally defined in James and Lumme (1982).

Titus and Kieffer (4) compared the crocus dates, the dates at which the frost has sublimed. They observed that sublimation of the frost in the cryptic region, an area of CO2 frost with essentially the albedo of bare surface, was delayed by about 5° of L_S in the second, dusty year. They observed that high albedo regions, such as the Mountains of Mitchel suffered a more rapid sublimation by about the same amount in the second year. MOC observations of the Mountains of Mitchel throughout both seasons also clearly show the accelerated recession (Figure 2) (5).

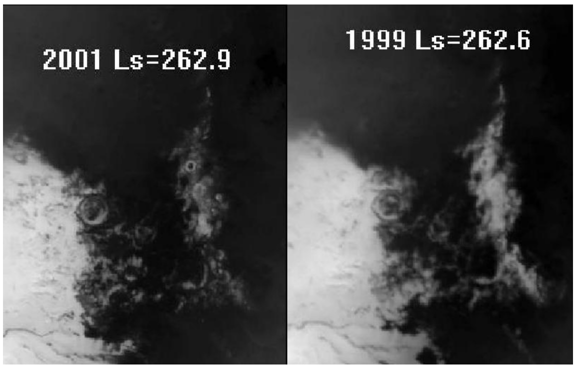

Figure 2: Comparison of the Mountains of Mitchel at the same seasonal date in 1999 and in 2001.

Calculations:

Bonev et al. (5) applied a non-iterative Monte Carlo model for radiative transfer (3), which was modified for the case of a plane parallel dusty martian atmosphere. The inherently three-dimensional code includes wavelength dependent dust opacity, anisotropic scattering, and thermal dust emission. The dust temperature is calculated from radiative equilibrium, and the model does not therefore need an input temperature profile. Two extreme cases were considered: pure CO2, to represent the Mountains of Mitchel; and dirty CO2 (1 wt % dust), to represent cryptic terrain. The results of these calculations indicated that the effects of increased atmospheric dust are to retard sublimation of low albedo areas and accelerate the recession of high albedo areas. The effect is due to a redistribution of flux incident on the ice from the visible portion of the spectrum to the infrared part of the spectrum.

More recently the model has been improved by considering varying incidence angles, the effect of varying the amount of diffuse versus direct incident radiation, and the dependence of albedo (emissivity) on the incidence angle (emission angle) (6). The properties of the CO2 ice depend mainly on the CO2 grain size, which has modest effects on the visual albedo but has large effects in the thermal IR, and dust content, which affects visual albedo as well as infrared emissivity. We have investigated the portions of the parameter space that should reasonably apply to the south polar cap: grain sizes of 100 µm, 1 mm, and 1 cm; and wt. % of dust from .01% to 1%. We do not include admixture of water ice because analysis of TES observations (2) indicates that water is only a minor contaminant compared to dust. The results of the calculations show that the curves that represent the effects of atmospheric dust vary continuously as a function of dust content between the two end members mentioned above. For a fixed grain size there is a large range of dust admixture for which the sublimation rate is nearly independent of optical depth. The location of this range depends on the grain size of the CO2. As an example we show the results of calculations with grain size of 1 mm (Figure 3).

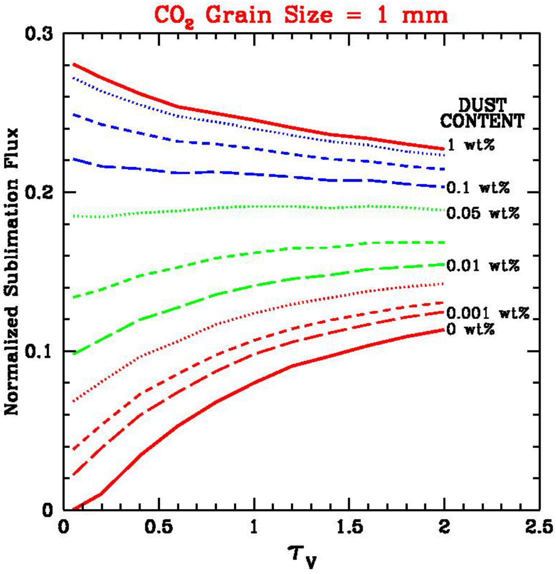

Figure 3: Sublimation flux is presented as a function of the visible optical depth for weight percentages of dust ranging from 0 to 1%; CO2 grain size is 1mm.

Conclusions:

There is a large amount of variation in the visible albedo of surface frost in the seasonal south polar cap ranging from ~0.8 for the Mountains of Mitchel to the albedo of martian soil in the cryptic region. The surface albedo is most sensitive to the weight percent of dust admixed with the ice but also depends on the CO2 grain size. The 2001 global dust storm accelerated the recession of bright regions, such as the Mountains of Mitchel, but retarded the recession of the darkest regions. Most dry ice deposits in the south polar cap have albedos, and therefore dust contents, between these end members and are therefore relatively insensitive to the dust opacity. Therefore, the observed insensitivity of the cap regression and the pressure curve to dust in the atmosphere is due to the near equality of the decrease in visible insolation and the increase of the infrared flux absorbed by the cap.

The question remains of whether the behavior of the perennial, residual south polar cap can be explained within this context. The residual caps were very similar in the two years observed by MGS. The residual cap has an even higher albedo than the Mountains of Mitchel, yet in terms of its large scale appearance it does not seem to have sublimed more in the dust storm year than in the first year. However, the albedo of the residual cap is actually relatively low when it first emerges into daylight and is increasing through the dust storm period; so it may be incorrect to consider this as a high albedo area during the dusty period. Observations of the cap during the 2001 global storm also suggest that not much dust penetrated to the residual cap. So it may be that the residual cap was protected from the dust by circulation resulting from seasonal cap sublimation and due to its high altitude relative to the seasonal cap. It may also be relevant that narrow angle MOC images showed that the "Swiss cheese" formations on the residual CO2 cap had expanded between the two years (7); it is conceivable that this evolution could be related to the different opacity histories.

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