SOUTH POLAR WARMING ON MARS: CLIMATE FORCING BY RECENT ALBEDO CHANGES.

L. K. Fenton[1], P. E. Geissler[2], and R. M. Haberle[3], [1]Carl Sagan Center, NASA Ames Research Center, Moffett Field, CA 94035, lfenton@carlsagancenter.org, [2]U.S. Geological Survey, Flagstaff, AZ 86001, pgeissler@usgs.gov, [3]NASA Ames Research Center, MS 245-3, Moffett Field, CA 94035.

Introduction: For hundreds of years scientists have tracked changes in the classical albedo patterns of Mars. Variations observed over the last few decades are generally attributed to removal and deposition of small amounts of relatively bright dust on the surface. Since the Viking era, up to 56 million km^2 of the surface has been observed to darken or brighten by 10% or more [1-3]. However, it is unclear how this surface forcing impacts the martian climate and polar cap stability. We present predictions from the Ames Mars general circulation model (MGCM) indicating that the observed decadal albedo alterations strongly influence the martian environment, indicating warmer south polar summertime air temperatures during the first Mars Global Surveyor (MGS) mapping year (1999-2000) relative to the Viking era (1976-1978). This predicted temperature increase likely contributes to observed scarp retreat in south polar residual CO_2 ice (i.e., the "Swiss Cheese" terrain).

Background: Erosion of depression walls in the southern residual polar cap has been observed by the Mars Orbiter Camera (MOC), suggesting that short-term climate change is occurring on Mars [4] in the form of insolation-driven erosion of residual CO_2 ice [5]. Further study has led to the proposal that over the last 100-150 martian years the southern residual polar cap has undergone a series of short depositional periods followed by longer periods (on the order of one or more decades) of erosion by scarp retreat, with the most recent CO_2 ice layer being deposited shortly after 1972 [6,7]. It is postulated that these periods of deposition and erosion may be linked to dust storm frequency or changes in surface albedo. In this work we investigate how observed albedo changes may be responsible for changing conditions during the southern polar summer.

Albedo Changes: Thermal Emission Spectrometer (TES) Lambert albedos are derived from calibrated broadband (0.3-2.9 μm) data obtained during nondusty periods during the first mapping year of the MGS mission (1999-2000) [8]. Infrared Thermal Mapper (IRTM) Lambert albedos between latitudes ±0-60º were produced from calibrated broadband (0.3-3.0 μm) data obtained during nondusty periods of the first and second years of the Viking mission (1976-1978) [1,9,10]. IRTM albedos between ±60-80º were derived using an atmospherically corrected subsurface conduction model [11-13]. Because IRTM albedos poleward of ±80º differed greatly from TES albedos (especially over the ice caps), we considered these very high latitude IRTM albedos to be suspect and substituted with TES albedos.

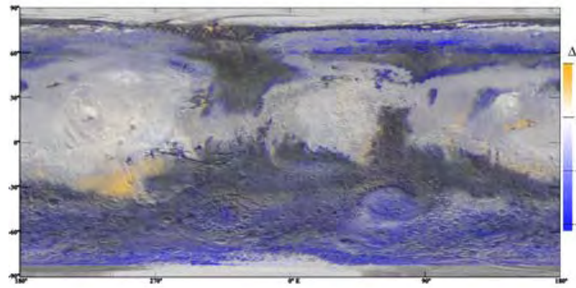

Figure 1. TES-IRTM albedo changes.

Figure 1 shows the albedo differences (TES-IRTM) superimposed on a grayscale TES Mapping Year 1 albedo map and Mars Orbiter Laser Altimeter (MOLA) shaded relief. Blue regions have darkened since the Viking era; yellow regions have brightened. Many areas have darkened, especially those associated with high thermal inertia [2]. Most of the areas that brightened are located on the southern edges of high albedo regions, such as Daedalia Planum. The only large regions that remain unchanged are the bright, dust mantled, low thermal inertia "continents" such as Amazonis Planitia and Arabia Terra. Northern dark areas, such as Acidalia and northern Utopia, expanded southwards.

Nearly the entire southern midlatitude zone between 40º-70º S darkened, including Argyre and Hellas Planitiae. Such broad regions of change have been attributed to global dust storms: southern hemisphere IRTM albedos were obtained just after the 1977b global dust storm, when dust fallout was fresh and may have brightened much of the southern hemisphere; whereas the MGS Mapping Year 1 occurred after many years devoid of large dust storms [3]. This darkening of the Southern Highlands is especially important because of the enhanced insolation during southern summer, when Mars is closest to the Sun.

Model Runs: The TES and IRTM albedo maps were applied to the NASA Ames Mars general circulation model [14], using Version 1.7.3 with an Arakawa C-Grid. In each case, the MGCM was run for a full year (following a spin-up year), with a horizontal grid spacing of 6º x 5º and 24 vertical atmospheric levels ranging from near the surface to 0.0005 mbar (~100 km). The visible dust opacity was set to a constant value of 0.3 on a 6.1 mbar pressure surface. Although a simplification of the martian dust cycle, this dust scheme ensures that differences in wind circulation and other parameters are caused solely by surface forcing from albedo change.

Results: Figure 2 shows modeled zonal mean air temperature differences (TES model run – IRTM model run) averaged over all times of day from the period L_s = 260-280º (southern summer solstice). The lower surface shows zonal mean topography underlain by zonal mean changes in albedo at the resolution of the GCM (i.e., 37 latitude grid points spanning -87.5º – 87.5º). Although no change in albedo was applied over the southernmost grid point, air temperatures over the pole are influenced by nearby high latitude darkening. Figure 2 shows that zonal mean air temperatures poleward of 85º S are 0.2-2 K warmer in the TES model run than in the IRTM model run from the surface up to an altitude of ~30 km. Warmer air temperatures lead to an increased emitted infrared radiation from the atmosphere onto the surface.

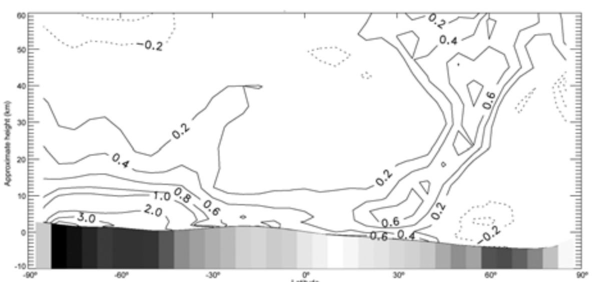

Figure 2. Zonal mean air temperature differences

Discussion: The subsequent summertime increase in emitted downwelling infrared radiation ($IR\downarrow$) predicted by the MGCM in grid points encompassing the residual polar cap is ~1 W m^{-2}. If this entire increase in infrared radiation goes into sublimating residual CO_2 ice, the potential seasonal mass loss by sublimation may be estimated by

$$M = \Sigma_{j,i,k} \left(L_{CO2} * IR\downarrow_{j,i,k} * \Delta t * A_{j,i} \right)$$

where M is the total potential mass loss through sublimation by latent heat transfer using the latent heat of CO_2 sublimation L_{CO2}, summed over grid points i and j over the residual cap and timesteps k spanning L_s = 250º-350º, the period during which the south polar cap is free of seasonal CO_2.

In both albedo cases, total potential summertime CO_2 mass loss from $IR\downarrow$ is on the order of 1.7x10^{14} kg, or ~0.8% of the total martian atmosphere. Because the atmosphere has *not* been observed to increase in mass on the scale of nearly 1% per year, it is clear that the sublimation process is not efficient (i.e., some of the $IR\downarrow$ is lost elsewhere) or it is counteracted by other processes (i.e., sublimation seems to largely occur along scarps, whereas other exposed surfaces seem protected). Indeed, it is direct solar radiation that appears to be largely responsible for eroding the CO_2 ice [5]. Although it is unlikely that infrared radiation plays a prominent role in sublimating the residual CO_2 ice, it could shift the balance from a state of accumulation to a state of erosion.

The estimated increase in south polar mass loss from the IRTM to the TES albedo model runs is ~5x10^{12} kg, or ~0.02% of the total martian atmosphere. This represents a ~3% increase in potential mass loss from the IRTM to the TES model runs. Previous estimates of summertime CO_2 mass loss, based on observations of scarp retreat, range from 8.4x10^{12} kg [7] to 2-4x10^{13} kg [4]. Our predicted increase is of the same order of magnitude as these estimates, albeit on the low side. *If the south polar residual CO_2 ice were in a state of equilibrium under conditions produced by IRTM albedos in the late 1970's, the predicted increase in infrared radiation caused by lower TES albedos in the late 1990's can account for a substantial amount of the observed CO_2 loss.*

It should be stated that our predicted 3% increase in potential mass loss is likely to be an overestimate, for reasons stated above. Furthermore, it is not clear whether the eroding CO_2 mass is being added to the atmosphere or recondensing elsewhere in cold traps. Finally, other variables such as atmospheric dust and polar clouds influence heat transport and redistribution. We intend to address these issues to further refine our estimate.

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