

Nature of the south pole on Mars determined by topographic forcing of atmosphere dynamics. A. Colaprete¹, Jeffrey R. Barnes², Robert M. Haberle¹, Jeffery L. Hollingsworth³, Hugh H. Kieffer⁴, Timothy N. Titus⁴, ¹NASA Ames Research Center, Space Science Division, Moffett Field, Mountain View CA, 94035, ²College of Oceanic and Atmospheric Sciences, Oregon State University, ³San Jose State University Foundation, ⁴U.S. Geological Survey.

Introduction: The observed Springtime (Ls ~ 200) surface albedo in the Martian southern polar region is shown in Figure 1. In general, the hemisphere west of Hellas is marked by relatively high values of surface albedo. In contrast, the hemisphere east of Hellas contains extensive regions of very low surface albedo. One of the brightest features within the western hemisphere is the South Pole Residual Cap (SPRC). The dark region, which dominates the eastern hemisphere, is the “Cryptic” region[1].

The nature of the SPRC has been the source of considerable debate since its identification as CO₂ ice by the Viking spacecraft. Two fundamental questions still exist regarding the SPRC’s formation, location and stability. First, why is the SPRC offset from the geographic pole? There are no local topographic features or surface properties that can account for the offset in the SPRC. Second, does the SPRC represent a large or a small reservoir of CO₂? If the former, then it could possibly buffer the surface pressure. If the latter, then the SPRC may not survive every year.

Just as mysterious as the SPRC is the region of “black” CO₂ ice which dominates the eastern hemisphere. Labeled the “Cryptic” region by Kieffer et al.[1], this region, first observed by Viking and later by Mars Global Surveyor (MGS), becomes visible during the recession of the seasonal cap. The Cryptic region is characterized by its very low visible albedo (< 0.2) and high 25 μm relative emissivity (> 0.95) and is believed to be composed of very clean CO₂ “slab” ice. It is the Cryptic region that first sublimates in Spring, leading to the observed asymmetric retreat of the Southern seasonal cap.

Other Observations: Independent observations from MGS indicate that the atmospheric circulation within the polar night produces two distinct climates which encompass the SPRC and the Cryptic region. These observations include cloud echoes from the Mars Orbiter Laser Altimeter (MOLA), ice grain sizes from the Thermal Emission Spectrometer (TES), and temperatures from TES and MGS Radio Science (RS).

The albedo and emissivity of the polar cap has been associated with the size of the ice grains that make up the surface ice deposits [2]. Small ice grains result in brighter surfaces, while larger grains result in darker surfaces. The “grain size index” is the difference between two IR bands (T18-T25). Regions with high

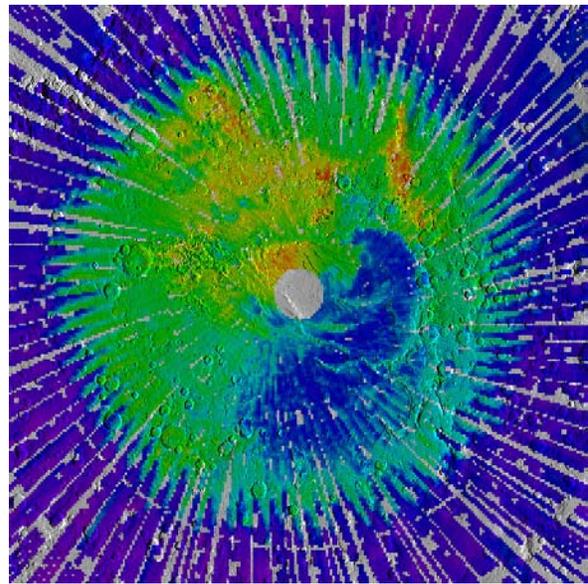


Figure 1 South pole springtime albedo map derived from the TES and overlain on MOLA topography. High albedos are indicated by warm colors (red shading) and low albedos are indicated by cool colors (blue shading). At the time of these observations the seasonal polar cap, composed primarily of CO₂ ice, extends from the pole to approximately 60° S. Zero longitude is straight up.

values of the grain size index include the SPRC and the Mountains of Mitchell. It has been suggested that high grain size indexes are the result of small ice grains in the atmosphere or freshly precipitated to the surface. MOLA detected cloud echoes within the polar night that have been attributed to the presence of CO₂ clouds [3]. The greatest rates of occurrence are within the western hemisphere. In the eastern hemisphere there are fewer cloud echoes, with a minimum poleward of Hellas basin [4].

Also correlating with surface albedos are temperatures derived from TES and RS. Frequently the atmosphere within the polar night chills to below the condensation temperature of CO₂ ice and becomes supersaturated. The greatest and most persistent supersaturation, $\delta T_{\text{sat}} = (T_{\text{sat}} - T)$, occurs in the Western hemisphere and in the longitude corridor of the SPRC. Atmospheric temperatures are significantly colder in the western hemisphere compared to the eastern hemisphere.

GCM Simulations: To further understand the southern winter dynamics and its association with the

SPRC and Cryptic region, several simulations were conducted with the NASA Ames Mars General Circulation Model (MGCM). The version of the MGCM used here includes a sophisticated CO₂ cloud scheme that predicts cloud formation and precipitation. Simulations were conducted for a variety of topographic permutations in which the southern extent of Tharsis, Hellas and Argyre were included or removed.

In the simulation with true (i.e. current MOLA observed) topography (Figure 2), temperatures predicted by the model closely match those observed and, in particular, the coldest temperatures are observed in the western hemisphere and encompass the SPRC. Predicted CO₂ cloud cover, precipitation and δT_{sat} agree well with the observations described so far. During the formation of the seasonal cap, cloud cover and precipitation are greatest in a longitude corridor that aligns with the SPRC and are almost completely absent over the Cryptic region. A strong wave-1 system dominates late autumn through mid-winter and establishes a pattern of low and high surface pressures that are consistent with the observations.

When the topography is altered, the regional circulation and, hence, atmospheric temperatures are changed. If the Hellas and Argyre impact basins are removed, the wavenumber one circulation pattern no longer dominates and cold temperatures occur with much greater symmetry about the pole. A very symmetrical pattern of circulation and cold temperatures results if all topography is removed.

Deposition Style: The two climates established by the topographically forced circulation produce differences in the nature of the surface ice deposits. From the MGCM simulations, the relative amounts of CO₂ ice that is deposited by precipitation and by direct deposition can be compared. The deposition ratio is defined as the amount of atmospheric precipitation (kg m⁻² sec⁻¹) divided by the amount of direct surface deposition of CO₂ ice. The deposition ratio is area weighted so that longitude corridors of differing extent can be compared. On average, across the entire polar cap, the deposition ratio is approximately 0.1. However, in some regions the deposition ratio can be as high as 0.9. The greatest deposition ratios occur in the western hemisphere. In the “true topography” case of the MGCM, the deposition ratio between the longitudes of -135 W and 45 W is 1.56 times as large as the deposition ratio in the opposite hemisphere. If the western edge of this corridor is extended to -180 W, so that the western corridor now extends from -180 W to 45 W, and the eastern hemisphere corridor is confined to just the longitude extent of the Cryptic region, the deposition ratio is 22.4 times as large.

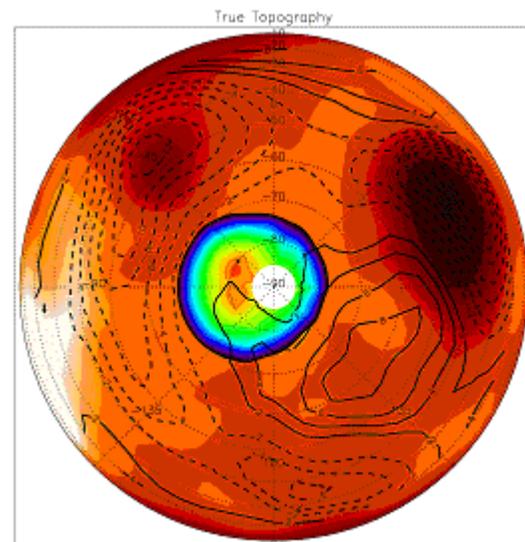


Figure 2 GCM results showing the dependence of the climate asymmetry on mid-latitude topography. Shown are NASA / Ames MGCM simulation results for column integrated δT_{sat} (color shading) at $L_s = 60$. Black contours indicate the time average (20 sols) temperature deviations from the zonal mean at the 3.5 mbar pressure level, with solid contours indicating temperatures higher than the zonal mean (high pressure region) and dashed contours indicating temperatures lower than the zonal mean (low pressure regions). Model topography is indicated with the red-white background shading.

Conclusions: The albedo of the south polar ice cap is primarily controlled by the frost grain size. Frost grain size is determined by the style of frost deposition. Smaller grains form when there is atmospheric precipitation to the surface and larger grains form when frost is directly deposited to the surface. Locations which favor one style of frost emplacement over the other are primarily determined by the regional circulation and resulting thermal state. Thus, topography through its influence on the circulation is ultimately responsible for the nature and location of the SPRC and Cryptic regions on Mars.

References: [1] Kieffer, H.H., et al. (2000) *JGR*, 105, 9653-9700. [2] Titus, T.N et al. (2000) *JGR.*, 106, 23181-23196. [3] Pettengill, G. H. and P. G. Ford (2001) *GRL*, 27, 609-613. [4] Colaprete, A. et al. (2003) *JGR*, 107, pp. 17-1, doi 10.1029/2003JE002053.