THE THERMAL PROPERTIES OF MARTIAN SURFACE MATERIALS AT HIGH LATITUDES: POSSIBLE EVIDENCE FOR PERMAFROST

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Thermal models for the distribution of martian permafrost indicate that subsurface water ice could presently be stable throughout the year at depths ranging from 10 to 100 cm at latitudes poleward of $\pm 40°$ (1). Proof for the existence of such deposits would have important implications for our understanding of the initial volatile inventory, atmospheric evolution, geology, and climate of Mars. Presented here are results of preliminary efforts to map the spatial distribution of surface and subsurface permafrost at high latitudes by using Viking IRTM surface temperature observations in conjunction with diurnal and seasonal thermal model calculations.

Solid water ice or hard-frozen ground can be distinguished from fine, unconsolidated surface materials on the basis of thermal inertia. Solid water ice has a thermal inertia of $I=50 \times 10^{-3}$ cal cm^{-2} sec $^{-1/2}$, whereas mid-latitude martian surface materials have thermal inertias ranging from 1×10^{-3} to 15×10^{-3} cal cm^{-2} sec $^{-1/2}$ (2). Thermal inertia can be inferred from remote sensing observations because it has a major influence on the amplitudes of diurnal and seasonal surface temperature variations. Since martian diurnal temperature waves penetrate a few centimeters into the surface, and seasonal temperature waves penetrate to at least a meter, surface temperature observations can be used to infer the presence of permafrost.

Figure 1 shows the boundaries of three relatively homogeneous regions in the north polar area that were selected for intensive study. They are all 2° in latitude by 30° in longitude. Region 1 lies within the north permanent water ice cap. Region 2 lies within the dark circumpolar sand sea. Region 3 lies within the north circumpolar planes. All highest quality IRTM observations that fell within these regions were selected. Emission angles for the observations were constrained to be less than 70°. The observations were binned by season at a resolution of 10 days and by Mars local time at a resolution of one hour.

Figures 2, 3 and 4 show the available measured IRTM 20μ channel brightness temperatures for these regions during one half of a Mars year. Seasonal and hourly temperature variations are multiplexed on the same plot. Each point consists typically of 1 to 20 separate observations, with standard deviations of less than 2K. During spring, all three regions are covered by seasonal CO_2 frost, which has a temperature of $\approx$ 148K. Measured brightness temperatures are generally higher than 148K during this season because of emission due to warmer dust and water ice clouds in the overlying atmosphere (3,4). During summer, when the seasonal CO_2 frost has disappeared, measured 20μ brightness temperatures are considered to be good approximations to actual surface temperatures because significant spectral contrasts between the four IRTM surface sensing channels are not observed during this season.

Also shown in Figs. 2, 3 and 4 are calculated diurnal surface temperature variations using the Viking Thermal Model (5). The model assumes constant thermal properties with depth and constant surface albedo with time. Atmospheric effects are ignored except for a small correction for the emissivity of the atmosphere at 15μ. The model also allows for the condensation and sublimation of CO_2 frost when appropriate. Assumed CO_2 frost albedos were adjusted so that the dates at which seasonal CO_2 frost disappeared at each location were in accord with the observations. In each case, the model was run for four Mars years to achieve stability over the annual cycle. Model-calculated diurnal surface temperature variations are plotted at 10 day intervals and can be compared directly with the available IRTM observations during the summer season.

For Region 1, it was possible to fit both the observed diurnal and seasonal temperature variations with a surface albedo of $A_s=0.43$ and a thermal inertia $I=40 \times 10^{-3}$. The derived thermal inertia is in good agreement north polar cap thermal inertias derived from heat balance considerations (3,4). This result implies that the bright regions of the north permanent polar cap consist primarily of dense water ice from the surface to great depths. The amount of dust and rock that may be imbedded within the ice cannot be determined from these observations.

For Region 2, it was not possible to satisfactorily fit both the observed diurnal and seasonal temperature variations with a single set of model input parameters. $A_s=0.22$ and $I=6.5 \times 10^{-3}$ gives a reasonable fit to the general seasonal temperature variations, but the amplitudes of diurnal surface temperature variations during early summer are underestimated. Despite this discrepancy, it can be argued that $I=6.5 \times 10^{-3}$ represents an upper limit for the thermal inertia of the uppermost few centimeters of the sand dune deposits. This surprisingly low value implies that the dunes are not frozen solid, and lends support to the the notion that they could presently be active (6).

For Region 3, it was again not possible to satisfactorily fit both the observed diurnal and seasonal temperature variations with a single set of model input parameters. $A_s=0.30$ and $I=15 \times 10^{-3}$ gives a reasonable fit to the general seasonal temperature variations, but again, the amplitudes of diurnal surface temperature variations during early summer are underestimated. Differences between observed and model calculated surface temperatures at midnight diminish as the summer season progresses, giving good agreement at the end of the season. Attempts to fit the early summer observations with lower thermal inertias yielded calculated late summer surface temperatures that were much lower than observed.

Two distinct arguments can be made for the existence of martian permafrost on the basis of these observations. The first is that annual average temperatures of regions 2 and 3 are ≈165K and ≈168K respectively. This means that temperatures at great depths are well below required permafrost temperatures of ≈198K (1).

The second is that the observed thermal behavior of Region 3 implies the existence of high thermal inertia material below the surface. If $I=15 \times 10^{-3}$ is an overestimate for thermal inertias at diurnal skin depths, then $I=15 \times 10^{-3}$ is an underestimate for for thermal inertias at seasonal skin depths. This reasoning can be tested quantitatively by developing a more flexible thermal model that can treat non-constant thermal properties with depth.

Although permafrost is not the only plausible martian surface material with high thermal inertia, polar thermal mapping may turn out to be a powerful tool for determining the distribution of permafrost deposits and understanding their behavior. At this point, the circumstantial case for permafrost deposits in the north polar region of Mars is very strong indeed.

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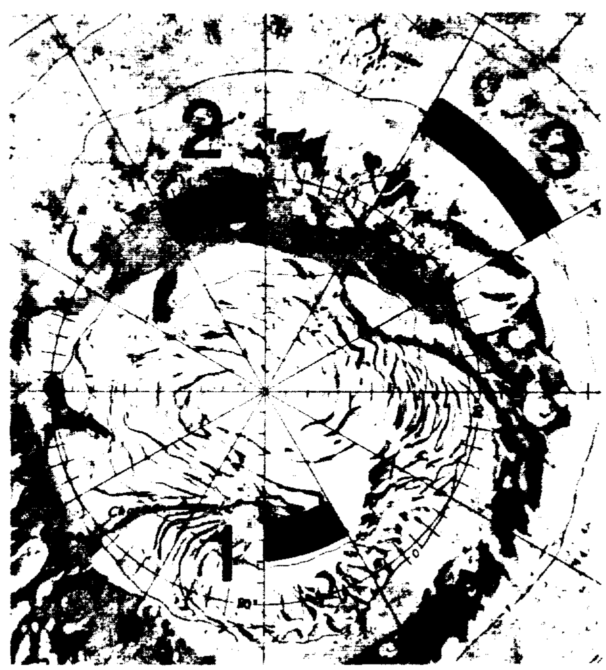
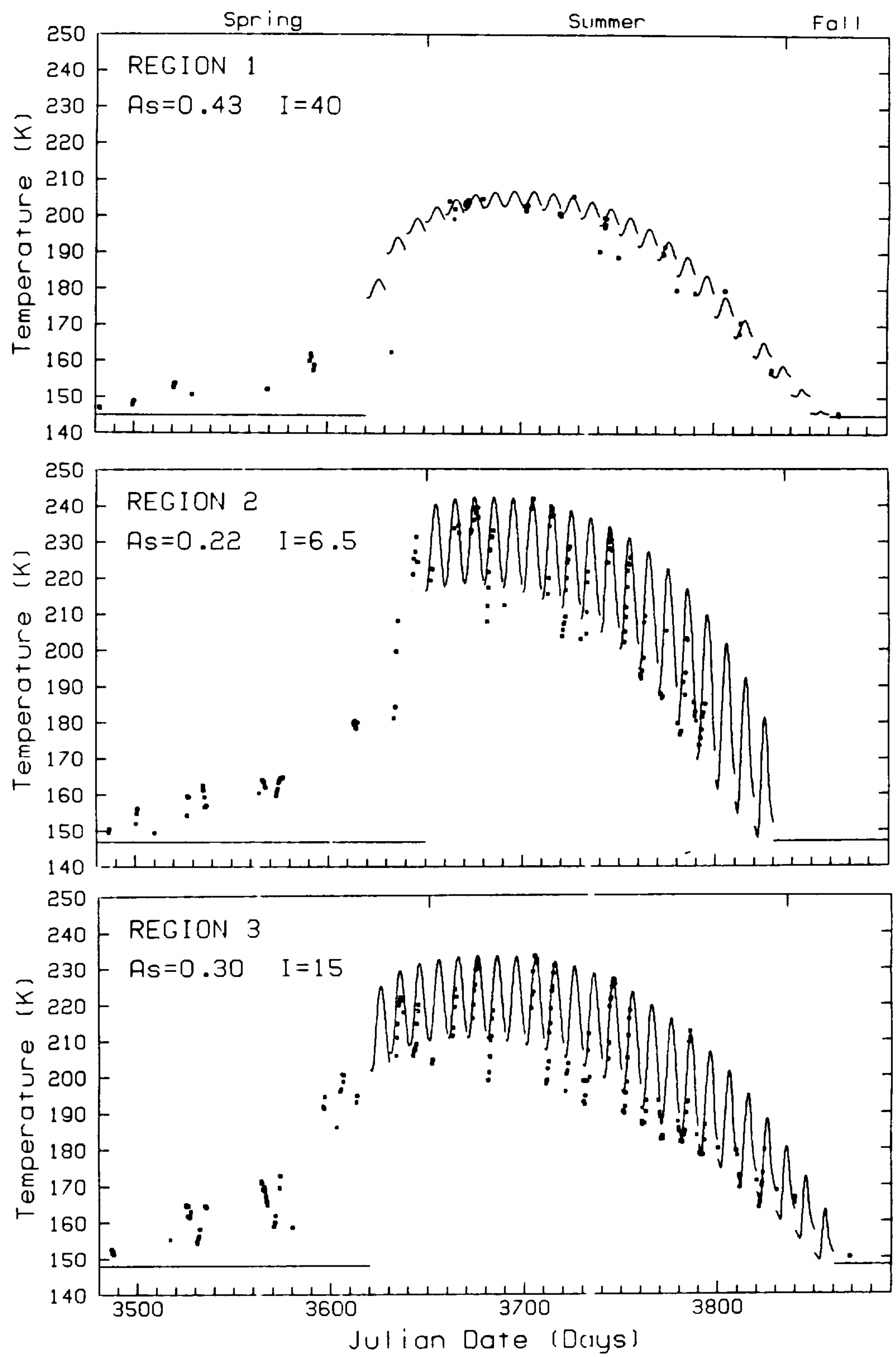


Figure 1. Three regions in the north polar area.



Figures 2, 3 and 4 Ten-day averaged diurnal surface temperature variations for three regions in the north polar area. (Dots) IRTM 20μ channel observations. (Lines) Thermal model calculations.