ACCOUNTING FOR CLOUD RADIATIVE EFFECTS IN THERMAL MODELING OF MARTIAN TROPICAL AND EQUATORIAL SURFACES AND SUBSURFACES.

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Overview: Remote nighttime temperature observations acquired across multiple seasons have the potential to be used to characterize the near-surface (upper ~0.5 m) regolith structure and vertical heterogeneities in thermophysical properties [e.g., 5]. However, seasonal variations in atmospheric conditions must be accounted for in order to accurately model observed surface temperatures. In particular, the significant radiative warming from seasonal equatorial clouds [11] is presently not well-accounted for in existing thermal models, hampering analyses of equatorial subsurface heterogeneity. In this work, we explore the possibility of extracting the radiative contribution of clouds from seasonal temperature records from Mars Global Surveyor Thermal Emission Spectrometer (TES) data to enable improved thermophysical analyses in equatorial and tropical regions of Mars.

Motivation: Buried water ice on Mars has the potential to unlock the planet's past given that water can serve as a climatic marker for previous eras. Water ice could also be used as In-Situ Resource Utilization (ISRU) [1] for future crewed exploration and settlement on Mars. Thus, determining the depth to buried water ice is of significant interest. Shallow water ice is known to be present in the midlatitudes and polar regions [e.g., 2,3,4,5], but whether it is present at lower latitudes is uncertain [6][7][8][9][10]. Gamma ray and neutron spectroscopy measurements indicate excess hydrogen is present at the equator, and has been attributed to either hydrated minerals or subsurface water ice in the upper ~1 m [6][7]. Both explanations remain plausible, however it has been noted that equatorial subsurface water ice would be in disequilibrium unless fully closed off from exchange with the atmosphere [e.g., 7].

While the depth to polar and mid-latitude water ice have been successfully mapped [e.g., 2,3,4,5], efforts to map any potential buried water ice at lower latitudes are hampered by a weak seasonal temperature signal compounded by unaccounted radiative influence from nighttime water ice clouds that produce significant surface warming [11]. During solar longitudes (L_s) 60°-150°, radiative effects from the Aphelion Cloud Belt (ACB)[12] (**Fig.1**) mask the seasonal temperatures needed to map sub-surface water ice [5]. This in turn impedes accurate calculation of thermal properties for surfaces and sub-surfaces in the -30° to 30° latitudes for Mars.

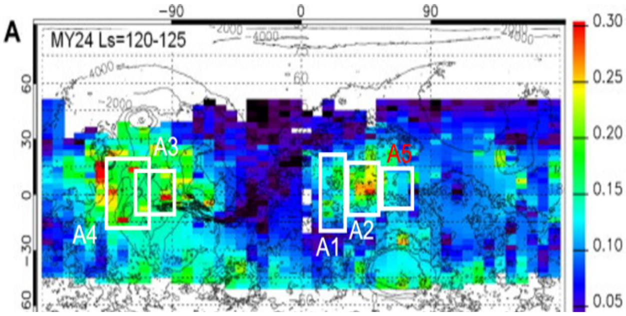

Figure 1: Water ice opacity map during Mars Year 24, Ls 120-125° [12] with delineated regions of interest (white polygons) for this study.

Approach: *Overview.* We used an empirical approach to estimate cloud radiative flux as a function of latitude by comparing modeled nighttime temperatures (without cloud flux) to measured TES nighttime temperatures across multiple L_s and latitudes within five narrow longitude bands (**Fig. 1**). Temperature offsets during the ACB were assumed to be due to radiative warming from clouds. The amount of radiative flux (W/m^2) needed to match measured temperatures was then calculated using the KRC thermal model. We preliminarily assume that radiative flux should be invariant with longitude and aim to create zonal mean look up tables of cloud radiative flux contributions as a function of latitude and L_s to serve as inputs for future thermal models of sites of interest.

Study locations. We selected 5 different locations in the Martian equatorial and tropical regions (**Fig. 1**) that are likely to be thermophysically homogeneous (e.g., dust deposits), to avoid complexity in seasonal temperatures that arise from vertical or lateral heterogeneity; we also included one region in Syrtis Major to determine if cloud-related temperature offsets could also be observed over a more complex surface. We selected 68 1x1 degree bins contained in these regions of interest (between 7 and 22 bins at each region) that had similar longitudes but varying latitudes.

Details. We used the KRC thermal model [13] to calculate surface temperatures and radiative fluxes [13]. KRC has a built-in function that calculates user-specified visible and thermal flux contributions from nearby orbiting bodies such as moons or asteroids on the surfaces of the locations being analyzed [13]. We

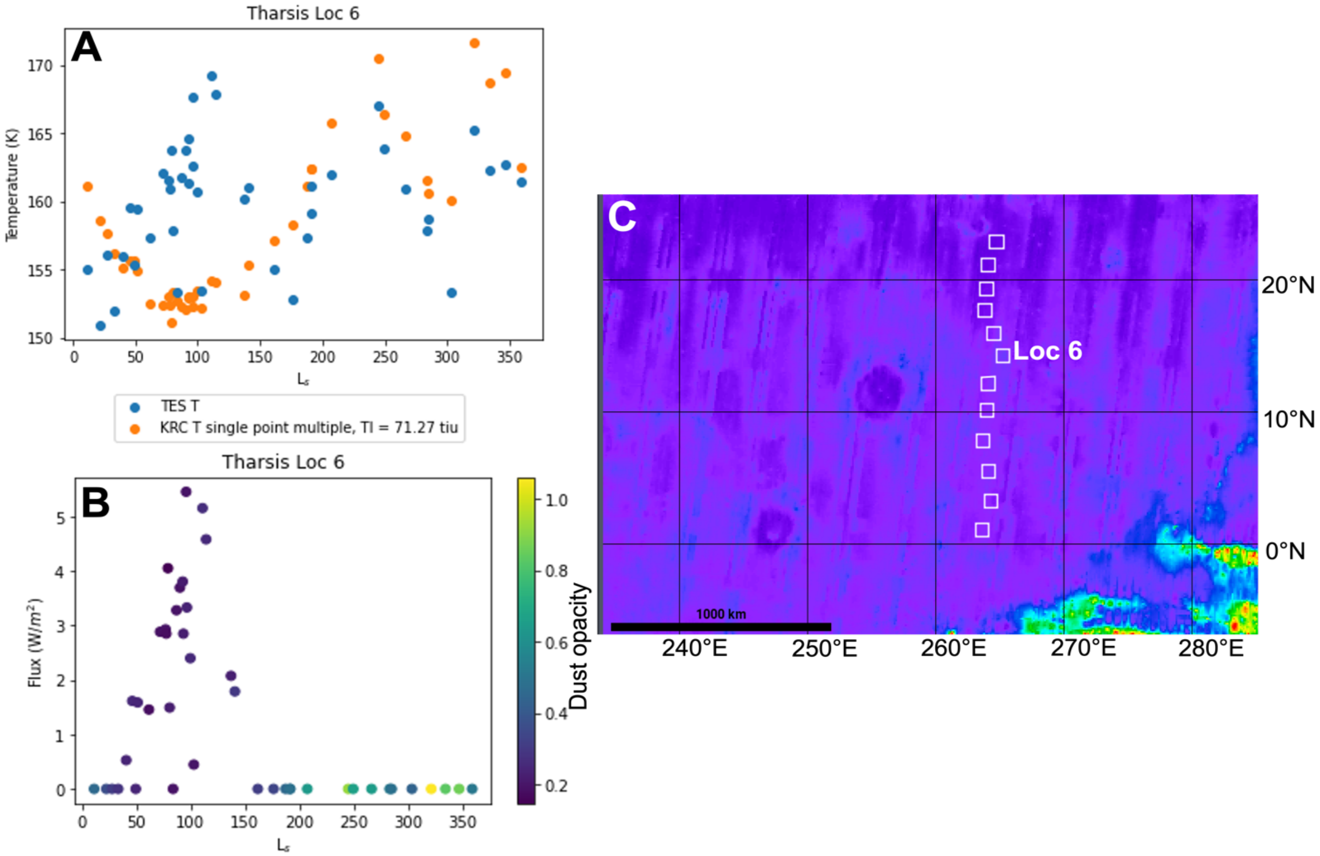

Figure 2: Analysis for one of the 1x1 degree bins in location A4 in figure 1. A) Temperature curves for KRC calculated temperatures (orange points) and TES temperatures (blue points) B) Calculated cloud flux versus time (L_s) C) TES TI [15] map showing locations where analysis was conducted (white polygons).

adapted this function into an algorithm to iteratively calculate cloud flux [W/m^2] contributions on Mars as a function of ΔT between measured and modeled temperatures and then interpolated to find the cloud flux for each measured temperature.

Results: Fig. 2 shows an example result for one of study areas in Tharsis. KRC temperatures are significantly lower than TES temperatures during the L_s range that corresponds to the ACB event (**Fig. 2A**). Calculated fluxes peak during Martian Aphelion with values around ~5 W/m^2 (**Fig.2B**). While promising, we did find that some of our locations did not show temperature offsets when expected. Further refinements by adjusting the assumed thermal inertia of surface materials may help to better determine the fluxes for all locations. Additional refinements are also needed to better account for the radiative contributions of dust in the latter parts of the year [14].

Conclusion: We have created an algorithm that estimates radiative flux contributions from clouds by comparing thermal model-calculated temperatures to remotely-sensed temperatures and assuming offsets during Ls 60-150° are due to clouds. Further refinement of the algorithm is needed. We aim to apply this methodology at tropical and equatorial regions of Mars to characterize their surface and subsurface material compositions.

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References: [1] Beaty et al., (2016) *Sixth International Conference on Mars Polar Science and Exploration* (pp. 6059), [2] Boynton et al., (2002), *Science, 297-5578, 81-85.* [3] Feldman et al., (2002), *Science, 297-5578, 75-78.* [4] Bandfield (2007), *Nature, 447, 64-67* [5] Piqueux et al., (2019) *GRL, 46,14209-14298*, [6] Feldman et al., (2004), *JGR Planets, 109-E9,* [7] Jakosky et al., (2005), *Icarus, 175-1, 58-67,* [8] Vicendon et al., (2010), *JGR Planets, 115-E10,* [9] Feldman et al., (2011), *JGR Planets, 116-E11* [10] Wilson et al., (2018), *Icarus, 299, 148-160* ,[11] Wilson and Guzewich, (2014), *GRL, 41,3375-3381,* [12] Pankine et al., (2013), *Icarus, 226-1, 708-722,* [13] Kieffer , (2013), *JGR Planets, 118-3, 451-470,* [14] Montabone et al., (2015), *Icarus, 251,65-95*, [15] Putzig and Mellon (2007) *Icarus, 191-1,* 68-94.