Using Emirates Mars Infrared Spectrometer (EMIRS) Science Observations to Analyze Diurnal Temperatures and Characterize Thermophysical Properties

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Introduction:

The Emirates Mars Mission (EMM), launched on July 20, 2020, is the United Arab Emirates' (UAE) first mission to Mars and the Arab World's first mission to another planet. EMM is designed to study the dynamics of the Martian atmosphere on a global, diurnal, and seasonal timescales using three instruments onboard a spacecraft named the Hope Probe. Two of EMM's instruments, the Emirates eXploration Imager (EXI) **[Jones et al. 2021]** and Emirates Mars InfraRed Spectrometer (EMIRS) [**Edwards et al. 2021]**, focus on the lower atmosphere. The third instrument, Emirates Mars Ultraviolet Spectrometer (EMUS) **[Holsclaw et al. 2021],** focuses on studying the Martian thermosphere and exosphere. The combination of instruments and the temporal and spatial sampling of the mission will be suited to perform studies to better understand the relationship between the atmosphere and surface. The science phase of the mission commenced on May 23rd, 2021, and the data of the three instruments became publicly available on October 1st, 2021**[Amiri et al. 2022]**. The Martian surface is known to display a high degree of variability in thermophysical properties between different regions as different types of surfaces and mixed materials respond differently to heating and cooling depending on their thermal inertia **[Jakosky et al. 2000]**. Thermal inertia is a thermophysical property of a material that represents the measure of material responses to changes in temperature. In addition, oscillations in the Martian surface temperature are primarily determined by its thermal inertia. The thermal inertia of the Martian surface depends on its particle size and degree of compaction/cementation within the topmost part of the surface, and it is independent of local time, latitude, and season **[Fergason et al. 2006]**. The work presented here using EMIRS data is a continuation of previous work **[Yousuf et al. 2021]** done using Mars Global Surveyor's (MGS) instrument Thermal Emission Spectrometer (TES) Aerobraking data which provided nearly complete diurnal coverages near the poles. For EMIRS data, currently, the majority of the diurnal coverage within a 5 by 5 degrees grid is found closer to the equator.

Research Objective:

Here we present a preliminary study on the best-fit estimates of thermal inertia derived using the KRC Thermal Model **[Kieffer 2013]** for observed diurnal temperatures taken by EMIRS instrument during the Science Phase. The ultimate goal will eventually be to compare the results of this study with previously undertaken work using TES Aerobraking data **[Yousuf et al. 2021]**.

Data and Tools:

EMIRS is an interferometric thermal infrared spectrometer that characterizes the lower atmosphere of Mars by taking measurements of infrared radiance and determining the distribution of lower atmospheric constituents such as dust, water ice, and water vapor optical depths, in addition to Mars surface and atmospheric temperature profiles up to 50 km from the surface with a vertical resolution of ~10 km. EMIRS operates in the 6-40+ μm range with 5 cm-1 and 10 cm-1 spectral sampling **[Edwards et al. 2021]**. JMARS software is used to query the hosted EMIRS science observation, investigate the general geologic characteristics of the selected regions of interest, as well as access the KRC numerical thermal model for thermal inertia analysis. KRC has the ability to compute the temperature of the surface as a function of time-of-day, latitude, season, and a multitude of physical parameters **[Kieffer, 2013]**. JMARS is a java-based package developed by Arizona State University that provides a layered system, whereby data from different sources and missions can be extracted, colorized, scaled, blended, merged, and superimposed on one another **[Dickenshied et al. 2014]**.

Methodology:

The methodology followed in this study is analogous to our previous work **[Yousuf et al. 2021]**. Using EMIRS data, several geographic locations displaying reasonable diurnal coverage and homogeneous surface properties within a 5 by 5 degree grid were chosen on Mars. This is important as there is important thermophysical information that is discernible using the full diurnal curve (e.g., different types of surfaces and mixed materials respond differently to heating and cooling depending on their thermal inertia). Using THEMIS nighttime and daytime infrared data, morphological and thermophysical properties of the selected ROIs were closely examined. Next, the average brightness temperatures of the selected ROIs were computed using two portions of the spectrum;

- short wavenumbers (i.e., 1290 - 1311 cm^{-1}), near this wavenumber, the atmosphere of Mars is almost transparent, i.e., the radiance is not absorbed by atmospheric gasses and aerosols. Thus, the surface temperature is represented by obtaining the brightness temperature at that wavenumber following the methods from **[Edwards et al. 2021]**; and
- long wavenumbers (i.e., 306.83 – 497.27 cm^{-1}) following the work of [**Kieffer et al. 2000], and** [**Kieffer et al. 2001]**, for cold surfaces, near this wavenumber region gives the most consistent surface kinetic temperature estimate as it is least affected by dust and CO_2 properties.

Using KRC Thermal Model (JMARS) **[Christensen et al. 2009]** and **[Kieffer 2013]**, best-fitting thermal inertia with EMIRS observed temperatures at all times of the day were derived, where thermal inertia was set in the range 50 - 600 J·m-2·K-1·s-½ at equally spaced steps of 50 J·m-2·K-1·s-½. Other parameters, such as Geographic Coordinates, Solar Longitude, and Albedo were the average of the points corresponding in each ROI. Based on the fit noticed between EMIRS observed (both calculated over short and long wavenumber) to the modeled temperatures, a hybrid version of the EMIRS temperatures having a combination of temperatures from short and long wavenumbers at a specific time cut-off was constructed taking into consideration the following: for hours before 6 am and after 6 pm were seen to be best fitted by long wavenumber, while hours between 6 am and 6 pm were best fitted by short wavenumber. To determine which thermal inertia output of the KRC Model best fits all the temperatures observed by EMIRS (the non-hybrid and hybrid versions) at all different local times, comparison plots were produced, statistical analyses of the Chi-squared test were performed using the modeled and observed data, and the results were compared to the measurements reported previously by the other missions.

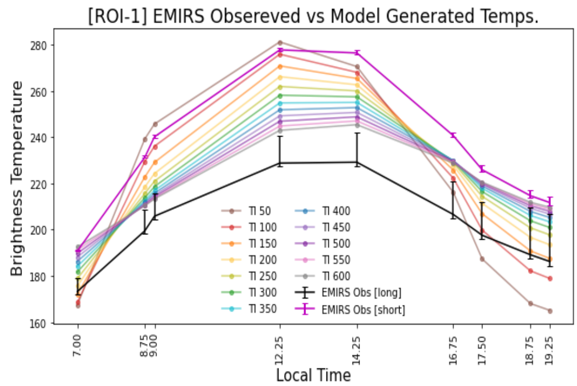
Preliminary Results:

By comparing the Hybrid version of EMIRS observed temperatures modeled using the KRC Thermal Model to find the best estimates of thermal inertia, it has been noticed that in some ROIs, we see a fit happening at all local times with a value of thermal inertia that is analogous to some degree to what has been reported by previous instruments. While other ROIs do not entirely have all local times fitted, this is often accompanied by a different value of thermal inertia, contrary to what has been reported previously by other studies using different instruments **(Figure 1, and Table 1)**.

The inconsistent results seen in **Figure 1** might be due to the following:

1. assuming the ROI is homogeneous and that all the points within the same ROI have the same geology, when in reality, the points may not be of the same geologic material.
2. errors in equating different atmospheric factors while deriving the temperatures using the KRC Thermal Model. Which may suggest the utility of a hybrid model with temperature cut-off instead.

Diurnal coverage allows one to investigate the heterogeneity of a geographic surface, indicating that some temperatures may come from different surface types within the ROI, as seen in **Figure 1**. This suggests that we need to consider the implications of different surfaces within an EMIRS pixel (i.e., it has the smallest instantaneous field of view 5.5 mrad, enabling small footprints from large distances **[Edwards et al. 2021]**).



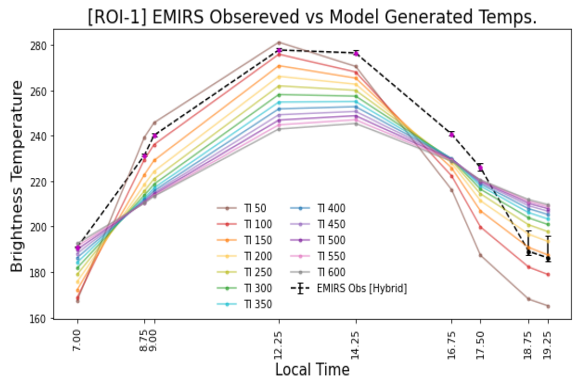


Figure 1. The line graphs on ***Top*** compare model-simulated temperatures using the KRC Thermal Model (multi-colored lines, each line depicting temperature variation of a specific value of thermal inertia incremented from 50 to 600 J·m-2·K-1·s-1⁄2 at equally spaced steps of 50 J·m-2·K-1·s-1⁄2) against EMIRS temperature observations calculated over short (magenta line) and long (black line) wavenumber separately, at different times of the day (x-axis) at a selected study region. Plot on the ***Bottom*** show model-simulated temperatures (multi-colored lines) plotted against the result of the hybrid version of the EMIRS temperature observations (black dashed line) constructed using a combination of short (magenta circles) and long (black circles) wavenumber temperatures based on time of the day cut-offs.

ROI-1		
Estimated TI using Chi² Test	Long Wavenumber	150
	Short Wavenumber	100
	Hybrid Wavenumber	100
Reported TI measurements	TES TI by Christensen	190
	TES Nightside TI by Putzig and Mellon	167
	TES Dayside TI by Putzig and Mellon	147
	THEMIS TI	190

Table 1 shows chi-squared results for a best-fit estimate of thermal inertia for all the three different scenarios (i.e., short wavenumber, long wavenumber, and the hybrid version), along with measurements reported by other studies using different instruments. The suggested thermal inertia from two out of three scenarios was found to be the same across ROI-1 at 100 tiu **(Figure 1)**, and comparing this to what previously has been reported in TES and THEMIS thermal inertia maps available in JMARS, TES daytime measurement is considered the closest with thermal inertia of 147 tiu. Surface materials exhibiting low values of thermal inertia are classified under 'fine grained and loosely packed'.

Future Work:

We will present the initial results and discuss the findings of various ROIs in our study for finding the best fit estimates using EMIRS diurnal observations and showcase the utility of a hybrid model. We currently use a time-of-day cut-off to construct the hybrid version of EMIRS temperature observations and we plan to change it to a temperature cut-off instead.

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