INTEGRATING IN-SITU, SATELLITE, AND REANALYSIS DATASETS TO ASSESS TEMPERATURE PROFILES IN THE MARTIAN TROPICS

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Introduction:

At the end of the night on much of Mars, particularly between days with high insolation, near-surface inversions are commonplace. The low thermal inertia of Martian soil enables the surface to cool more rapidly at night by radiation than the atmosphere above. Observations by Mars Science Laboratory in Gale Crater (Figure 1) and by Mini-TES in Gusev Crater and near Endeavour Crater show that inversions occur on the vast majority of nights in the Martian tropics [1–3]. However, observations from the Mars Environmental Dynamics Analyzer (MEDA) (Figure 2) aboard Perseverance show inversions on about half of nights in Jezero Crater from Ls 0° to Ls 160° (first 299 sols of the Mars 2020 mission). Furthermore, some inversions at Jezero occur at the beginning of the night rather than at the end. The reasons for the difference in inversions at Jezero compared to elsewhere in the Martian tropics is unclear and is the subject of this investigation. We aim to construct and understand the vertical profile of temperature at Jezero Crater, and more generally in the Martian tropics, from the surface to the base of the free atmosphere, through a depth of approximately 5 km.

Datasets:

M2020/MEDA: The Mars Environmental Dynamics Analyzer (MEDA) provides temperature observations in-situ at Jezero Crater that are key for this investigation [4–6]. The Thermal Infrared Sensor (TIRS) measures the ground temperature as well as the temperature at approximately 40 meters above the surface. The Air Temperature Sensor (ATS) provides temperature observations at approximately 1.4 meters above the surface. Other sensors included in MEDA allow us to correlate a wide range of other variables with the presence of an inversion, including downwelling shortwave and longwave fluxes, column optical depth, wind direction, and thermal inertia of the soil.

A longer record of in-situ data is provided by the Rover Environmental Monitoring System (REMS) aboard the Curiosity rover in Gale Crater. REMS has ground and air temperature (1.5 m above ground) sensors with five Martian years of measurements, starting in MY 31 [2]. The long record of REMS facilitates comparisons with other datasets.

MER/Mini-TES: Near-surface vertical temperature profiles from the Miniature Thermal Emission Spectrometers (Mini-TES) provide unparalleled resolution below 2 km, covering much of the Martian boundary layer [1,3]. The Spirit (in Gusev Crater) and Opportunity (near Endeavour Crater) rovers both included Mini-TES as part of their science payload.

MRO/MCS: The Mars Climate Sounder (MCS) aboard the Mars Reconnaissance Orbiter is a Sun-synchronous radiometer [7]. It observes the limb of Mars and retrieves vertical profiles of temperature, dust, and water ice at approximately 3 AM and 3 PM local time, with global coverage. Fields are reported at 105 standard pressure levels approximately 1 km apart, and MCS has a vertical resolution of about 5 km. Due at least in part to the observing geometry of MCS, near-surface observations, particularly within 10 km of the Martian surface, are of limited availability in the MCS dataset.

EMARS: The Ensemble Mars Atmosphere Reanalysis System (EMARS) combines the Geophysical Fluid Dynamics Laboratory Mars Global Climate Model (MGCM) with observations from TES and MCS using the local ensemble transform Kalman filter (LETKF), a data assimilation scheme [8]. As a reanalysis, it combines the full horizontal, vertical, and temporal coverage of a MGCM with a grounding in the real state of the Martian atmosphere because of TES and MCS observations. EMARS data is available for the entire period when TES was operational (MY 24-27) as well as the first five Martian years of the MCS observation period (MY 28-33). The grid spacing is approximately 150 km in the horizontal, with 28 vertical levels from the surface to approximately 100 km in the vertical, 13 of which are in the lowest scale height (about 12 km). Due to the lack of observations near the Martian surface in the MCS dataset as well as the coarse grid spacing of EMARS, EMARS does not necessarily reflect near-surface behavior well. This study offers an opportunity to quantify the performance of EMARS near the Martian surface and possibly shed light on spatiotemporal differences in inversions across the Martian tropics.

SCM: The University of Helsinki/Finnish Meteorological Institute adsorptive subsurface–atmosphere column model (hereafter called SCM) simulates temperature profiles up to 40 km altitude, with increasing grid resolution towards the surface to better resolve the planetary boundary layer (PBL) [9]. Solar radiation is handled with a fast broadband modified two-stream scheme, while the fast longwave emissivity scheme includes CO_2, H_2O and dust. SCM simulated profiles have been validates against MER Mini-TES observations [10]. We plan to use SCM to close the gap between MEDA and MCS observations.

Initial Results:

We have computed the difference between ground temperature and air temperature at approximately 1.5 meters above ground at Curiosity (Figure 1) and at Perseverance (Figure 2). Negative values are indicative of inversions, which are our primary focus. At Curiosity, the vast majority of nights have inversions. The temperature difference ranges from about 5 to 20 K, and there is little change in the temperature difference during the night between LMST 2100 and 0600. Furthermore, many of the nights lacking inversions, marked with green crosses, were during the global dust storm of MY 34 (2018) [11].

At Perseverance, the situation is quite different. The temperature difference ranges from about +10 to -10 K over the span of the night. Curiously, at LMST 1800, the temperature difference ranges from only about +5 to -10 K, with the maximum in temperature difference increasing as the night progresses. It is the difference between Figure 1, which is representative of the conventional understanding of near-surface temperature behavior on Mars, and Figure 2, observations from Perseverance, that we aim to understand.

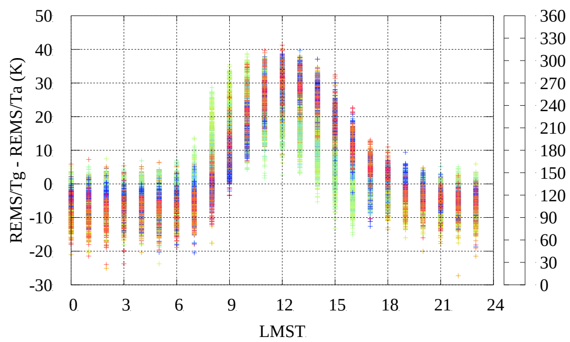

Figure 1. Ground temperature minus air temperature at 1.5 m as measured by REMS aboard Curiosity as a function of local mean solar time (LMST) and solar longitude (color bar).

One might expect the temperature difference to correlate with some of the variables mentioned at the end of the first paragraph of the Datasets section. Figure 3 shows the thermal inertia of the soil versus the difference between ground and air temperature as measured by REMS aboard Curiosity and MEDA aboard Perseverance. There is a clear correlation between thermal inertia and the difference in ground and air temperature. All other factors being equal, we would expect terrain with smaller thermal inertia to cool faster by radiation to space than terrain with

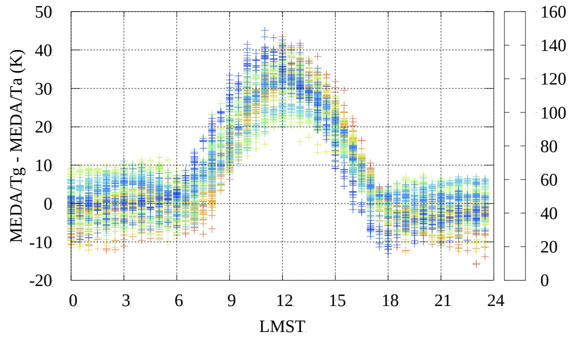

Figure 2. Ground temperature minus air temperature at 1.4 m as measured by MEDA aboard Perseverance as a function of local mean solar time (LMST) and solar longitude (color bar).

greater thermal inertia. However, while Figure 3 does show that thermal inertia is related to the difference in ground temperature, it does not prove that high thermal inertia terrain is responsible for suppressing inversions, and it also shows that there are other factors controlling the difference between ground and air temperature. For instance, in Jezero Crater, inversions typically do not occur when the thermal inertia of the terrain is greater than 350, but in Gale Crater, the thermal inertia typically must be greater than about 450 for inversions to occur. Furthermore, the correlation between thermal inertia and difference between ground and air temperature is less in Gale Crater than in Jezero Crater. While high thermal inertia may in fact suppress inversions, it is evidently not the only factor.

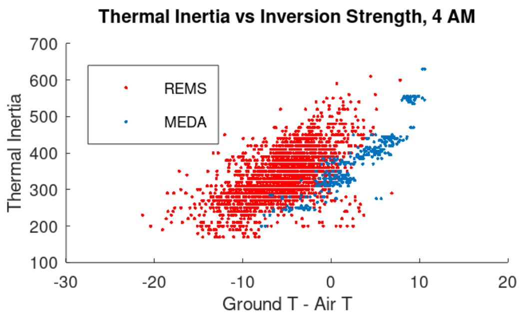

Figure 3. Correlation between difference in ground and air temperature at Perseverance (blue) and at Curiosity (red) with the thermal inertia of the soil between LMST 0330 and 0430.

Research Plan:

Because much of this research is yet to be completed, this section primarily details the pathway to the results that will be presented at MAMO 2022. For each in-situ observation site, we aim to construct vertical profiles of temperature with as many data points as possible. In addition to the in-situ observations, where possible, MCS observations will be added to these vertical profiles, allowing the profiles to extend through the Martian PBL to the free atmosphere.

There are a variety of ways to construct these profiles to consider in addition to simple linear interpolation between the points. For daytime profiles, an interesting assumption to make to connect in-situ profiles to MCS profiles is to assume that the lapse rate from the bottommost two observations in MCS continues downward from the bottommost MCS observation and the air temperature decreases at the dry adiabatic lapse rate from the 40 m TIRS observation upward until the two meet. This allows a crude estimate of the PBL depth. For nighttime profiles, the same assumption can be made from the MCS side, but from the in-situ side, the lapse rate should be calculated from available observations. The utility of such profiles is less clear at present, though it could potentially permit estimates of the depth of inversions.

The SCM, being a 1D model focused on the Martian boundary layer, can fill the gap between MEDA and MCS observations. We intend to tune the SCM using available MEDA and MCS observations to bound the vertical profile in the boundary layer from above and below with temperature observations. The profile can additionally be constrained through additional tuning using observed dust and water ice opacities. We can then determine the planetary boundary layer height during the day as well as the depth of inversions at night, and we can assess how the planetary boundary layer evolves over the diurnal cycle. Additionally, we can determine how good the linear extrapolation assumption (from the previous paragraph) is for the boundary layer.

The EMARS dataset, with its global coverage and ample number of model levels in the boundary layer, allows us to investigate whether or not the difference in inversion behavior between Gale and Jezero Craters is included in present-day reanalyses, and hence might be understood by analyzing reanalysis output. EMARS temperature profiles in the Martian tropics will be assessed at Jezero Crater, Gale Crater, and other assorted tropical locations on Mars. Using the EMARS profiles and dataset, we can assess how common and deep inversions are in general in the Martian tropics as well as how inversions at Jezero Crater compare to the rest of the Martian tropics. We can also assess the performance of EMARS at its lowest model level, which is 40 meters above ground, using the 40 meter temperature observations from TIRS at Jezero Crater.

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