Linking Thermal Properties of Terrestrial Sedimentary Environments to Mars

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Abstract

Despite nearly complete coverage of the Martian surface with thermal infrared datasets, uncertainty remains over a wide range of observed thermal trends. Combinations of grain sizes, packing geometry, cementation, volatile abundances, subsurface heterogeneity, and sub-pixel horizontal mixing lead to multiple scenarios that would produce a given thermal response at the surface. Sedimentary environments on Earth provide a useful natural laboratory for studying how the interplay of these traits control diurnal temperature curves and identifying the depositional contexts those traits appear in, which can be difficult to model or simulate indoors. However, thermophysical studies at Mars-analog sites are challenged by distinct controls present on Earth, such as soil moisture and atmospheric density. In this work, as part of a broader thermophysical analog study, we developed a model for determining thermal properties of in-place sediments on Earth from thermal imagery that considers those additional controls. The model uses Monte Carlo simulations to fit calibrated surface temperatures and identify the most probable dry thermal conductivity as well as any potential subsurface layering. The program iterates through a one-dimensional surface energy balance on the upper boundary of a soil column and calculates subsurface heat transfer with temperature-dependent parameters. The greatest sources of uncertainty stem from the complexity of how thermal conductivity scales with water abundance and from surface-atmosphere heat exchange, or sensible heat. Using data from a 72-hr campaign at a basaltic eolian site in the San Francisco Volcanic Field, we tested multiple models for how dry soil components and water contribute to thermal conductivity and multiple approaches to estimating sensible heat from field measurements. Field measurements include: upwelling and downwelling radiation, air temperature, relative humidity, wind speed, and soil moisture, all collected from a ground station, as well as UAV-derived surface geometries. By mitigating Earth-specific uncertainty and isolating the controls that are most relevant to Martian sediments, we can then validate those controls with in situ thermophysical probe measurements and ultimately improve interpretations of thermal data for the Martian surface.

LINKING THERMAL PROPERTIES OF TERRESTRIAL SEDIMENTARY ENVIRONMENTS TO MARS

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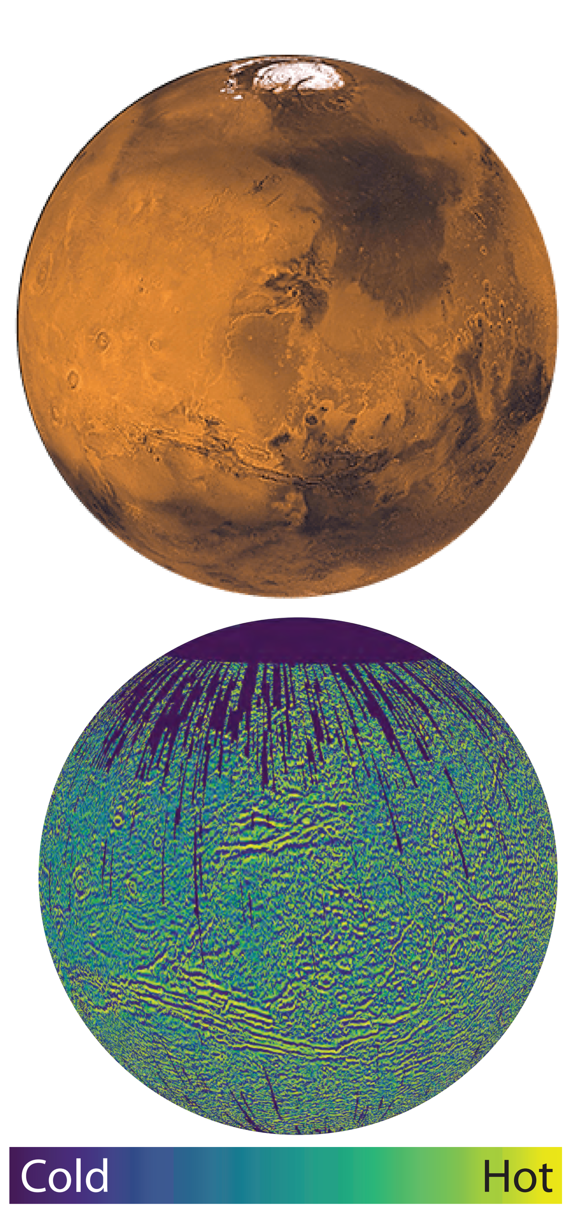
BACKGROUND

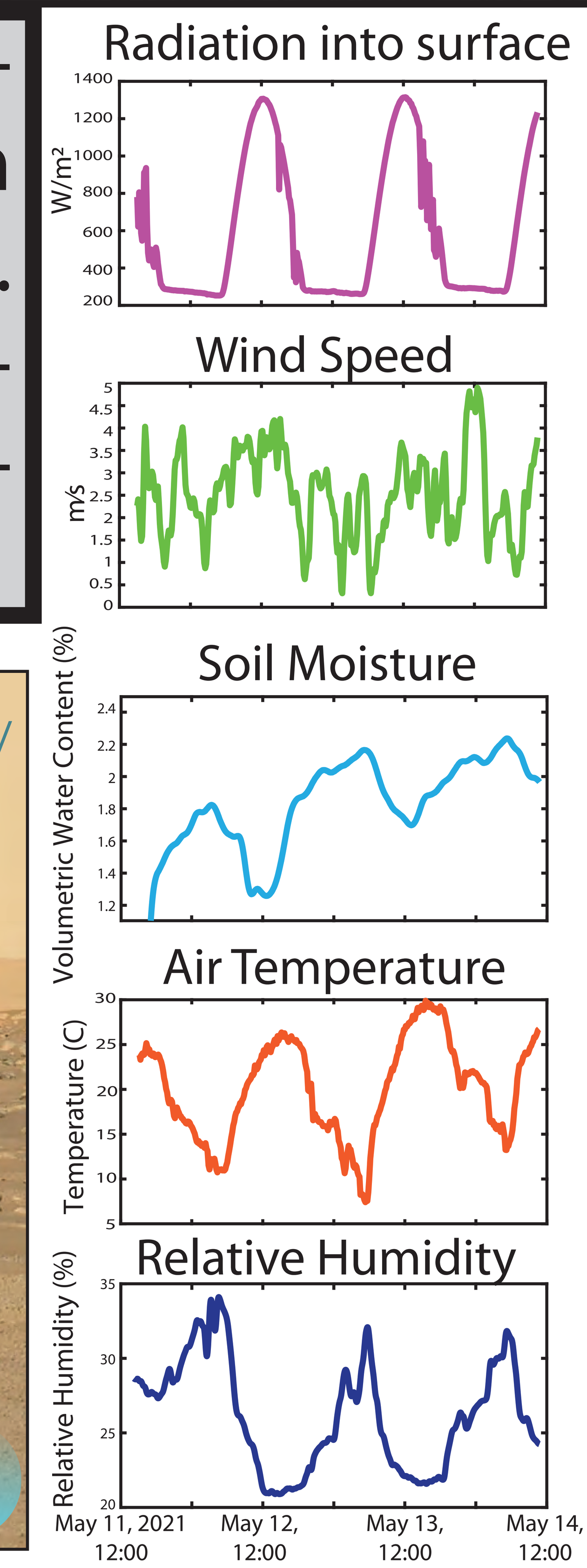
Infrared imagers orbiting Mars have collected an astoundingly complete record of surface temperatures spanning over five decades. Because the physical nature of different rocks and sediment affect how quickly they can heat up or cool down, temperature measurements provide us with a valuable tool for studying geology in areas where ground measurements are limited or absent. We can use inferred sedimentary features to help interpret past environmental processes.

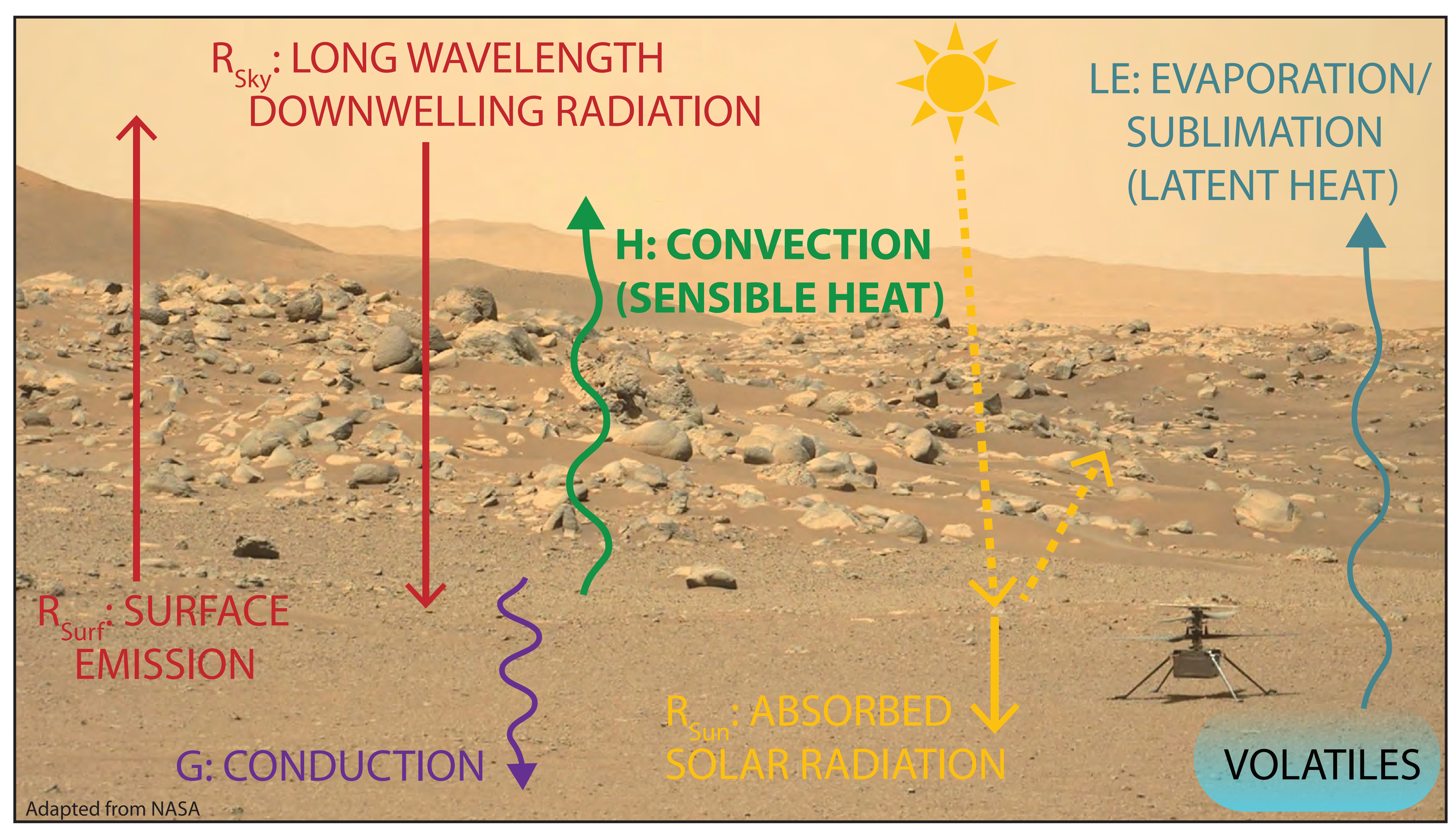


Mars visible and THEMIS Night-time Surface Temperature data

However, directly quantifying how a given temperature response aligns with a sediment type is difficult without at least initial validation from direct observations on the ground. To aid our understanding of materials on Mars' surface, we are studying thermal responses at sedimentary field analog sites, each representing a different depositional environment. Shown here are results from a 72-hr observation of a basaltic eolian dune site near Sunset Crater, AZ. We collected weather data from a tower and used UAVs to map surface temperatures, replicating satellite viewing angles. We use a surface energy balance model to derive thermal inertia, allowing us to ultimately relate thermophysical controls between the two worlds.

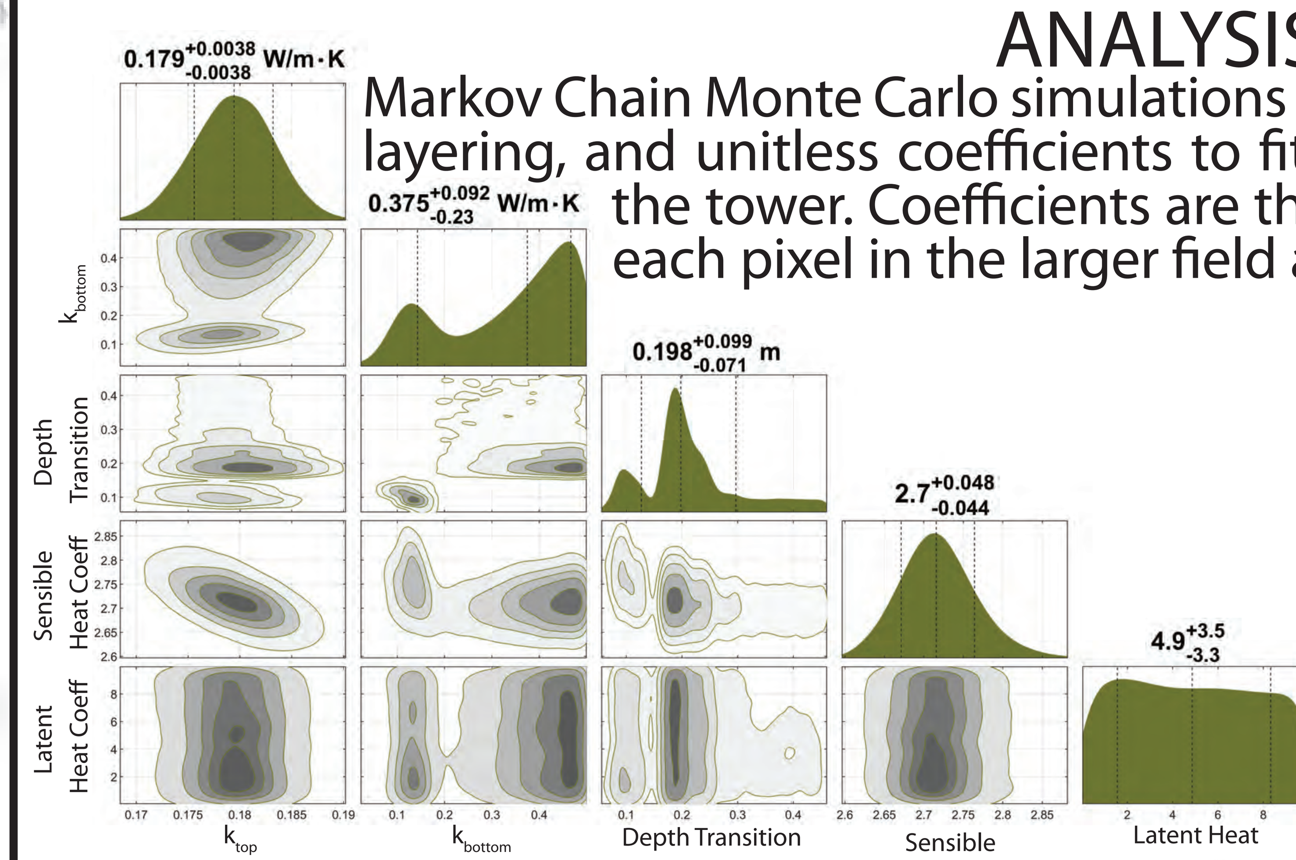
We developed an approach to deriving thermal inertia in undisturbed sediments on Earth using UAS and weather station data. The method allows for relating thermophysical controls observed on Earth to environments captured in satellite data from Mars.

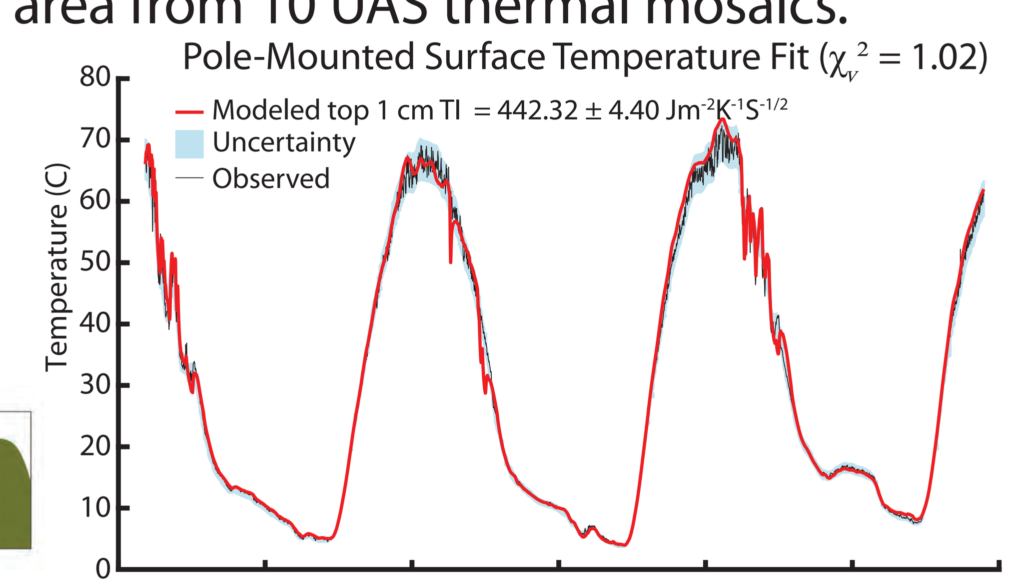


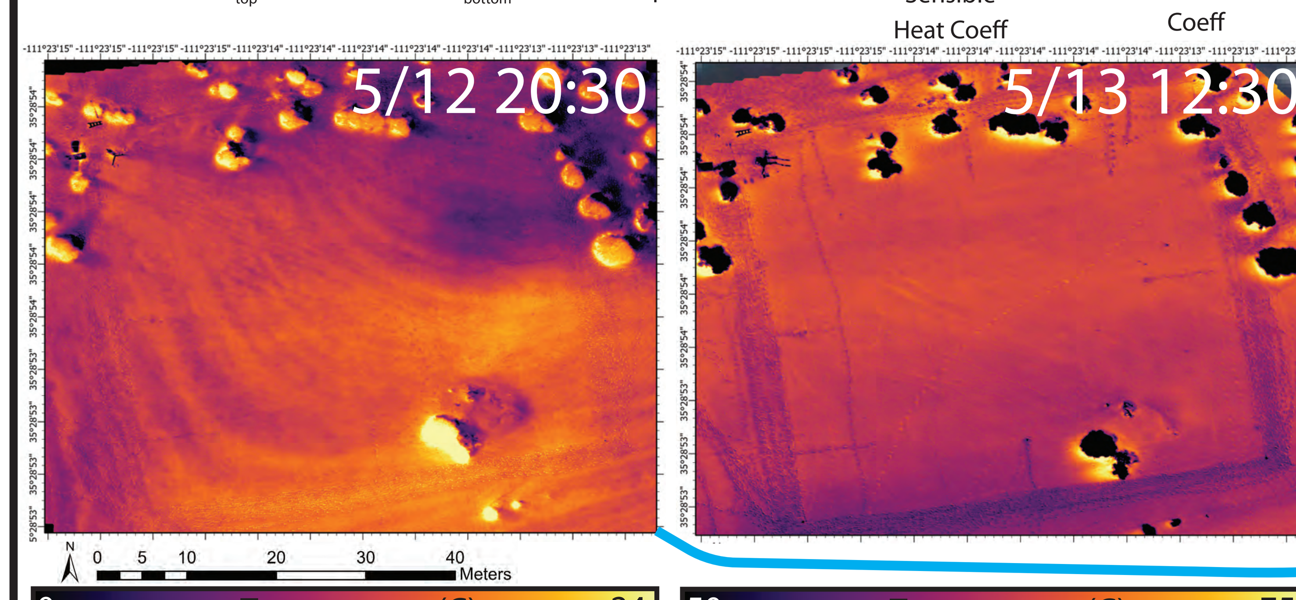


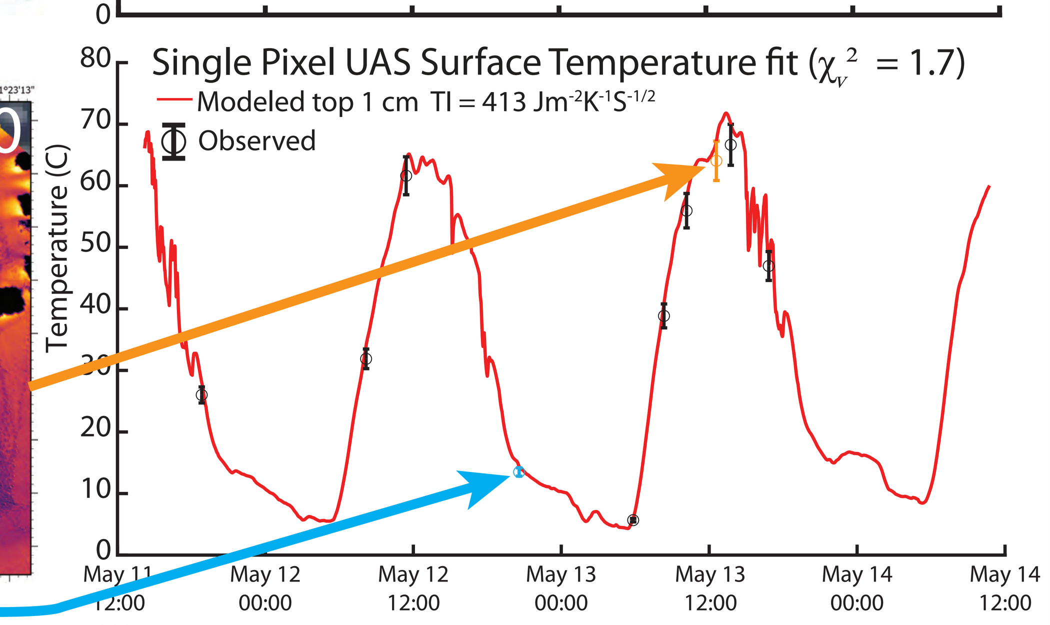
ANALYSIS

Markov Chain Monte Carlo simulations optimize thermal conductivity, subsurface layering, and unitless coefficients to fit observed surface temperatures beneath the tower. Coefficients are then recycled to fit thermal conductivity for each pixel in the larger field area from 10 UAS thermal mosaics.

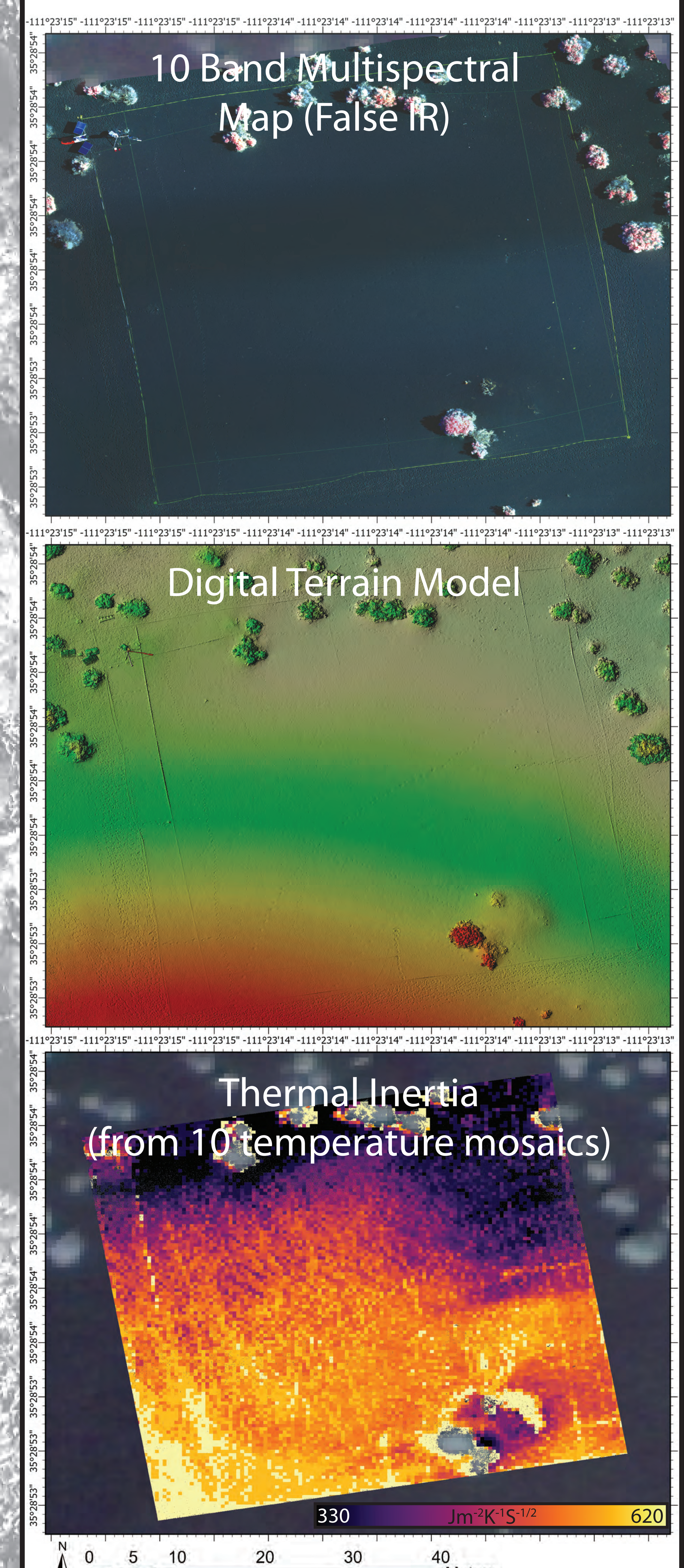








RESULTS



Thermal inertia is derived from the modeled thermal conductivity for each pixel. The ultimate goal will be to quantify how thermal inertia is correlated with measured sediment properties that include: soil moisture, grain size and shape, subsurface stratigraphy, mineralogy, and cementation in the context of each field site (eolian, fluvial, alluvial, glacial, pyroclastic).

Sources: Rogers et al. (2018) *GRL*; Cadieux & Kah(2015) *Icarus*; Kieffer (2013) *JGR*; Christensen et al. (2004) *SSR*; Farrand & Singer (1992) *JGR*; Navarre-Sitchler & Brantley (2007) *EPSL*; Schiffman et al. (2000) *GGG*; Seelos et al. (2010) *JGR*; Piqueux & Christensen (2009a) *JGR*; Piqueux & Christensen (2009b) *JGR*; Presley & Christensen (1997) *JGR*; Vasavada et al. (2017) *Icarus*; Edwards et al. (2018) JGR; Morgan et al. (2018) *SSR*.

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