TRACKING SURFACE ENERGY FLUX AT ANALOG FIELD SITES FOR THERMOPHYSICAL MODELING OF MARTIAN SEDIMENTS

A. Koeppel[1] (akoeppel@nau.edu), C. S. Edwards[1], L.A. Edgar[2], S. Nowicki[4], K.A. Bennett[2], B. Carr[2], A. Gullikson[2], S. Piqueux[3], H. Eifert[1], A.D. Rogers[5]. [1]Northern Arizona University, Dept. of Astronomy and Planetary Science, [2]U.S. Geological Survey, [3]Jet Propulsion Laboratory, [4]University of New Mexico, [5]Stony Brook University

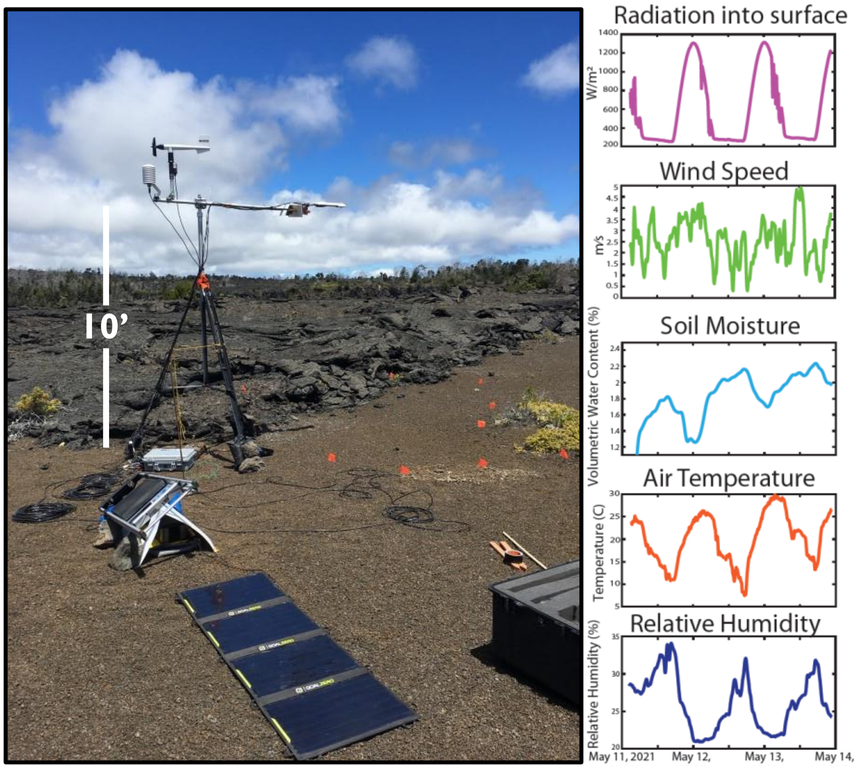

***Figure 1**. Left: Weather station setup at Kilauea Volcano, HI. Right: Subset of data collected over three days at the Sunset Aeolian Site, AZ.*

Introduction: Despite nearly complete coverage of the Martian surface with thermal infrared datasets (e.g., THEMIS, TES, IRTM), uncertainty remains over what a wide range of observed thermal trends indicate about surface geology [1,2]. Combinations of grain sizes, packing geometry, cementation, volatile abundances, subsurface heterogeneity, and sub-pixel mixing lead to multiple scenarios that would produce a given thermal response at the surface [3]. We use analog sedimentary environments on Earth, which show similar forms and compositions to many deposits on Mars, as natural laboratories for studying how the interplay of these traits control diurnal temperature curves. Using a weather station and UAS that captures visible and thermal infrared imagery, we are able to track surface energy flux and model thermal conductivity in undisturbed sediments in a manner similar to capabilities of satellites and rovers. Our ultimate goal is to identify how combinations of key thermophysical controls, including soil moisture, grain size and shape, cementation, and composition, dictate the thermal response in different environmental contexts, which can be difficult to model or simulate indoors. In doing so, this study relates features that can be diagnostic of specific weathering and alteration regimes to properties that can be measured from orbit, thereby improving the capabilities of thermal infrared remote sensing data in uncovering past environmental settings.

Methods: *Field Sites:* Data has been collected at five field sites thus far: ▪Roosevelt Hot Spring, Utah (April, 2021) contains hydrothermally-cemented detrital sediments ▪Sunset Crater, Arizona (May, 2021) hosts predominantly wind-reworked basaltic sediments in a warm and dry setting ▪Keanakakoi Crater on Kilauea Volcano in Hawai'i (August, 2021) contains both young basaltic tephra near its source and recently emplaced lavas (1970s), representing two relatively unaltered endmembers in a warm and wet setting ▪Pahrump Playa, California (October 2021) is an example of a dry basin-fill deposit in a warm and dry setting ▪Sperry Wash, California (October, 2021) is an ephemerally active fluvial wash in a warm and dry setting (a possible analog for Recurring Slope Lineae). Future data will also be collected at Kilbourne Hole, New Mexico in April, 2022 as an example of a cemented mafic pyroclastic deposit, and in May, 2022 at a glacially reworked basaltic deposit at Breiðamerkurjökull, Iceland.

Field/Lab Measurements: Field measurements include: upwelling and downwelling radiation, air temperature, relative humidity, air pressure, wind speed, and soil moisture, all collected from a ground station, as well as UAV-derived visible, near-infrared, and thermal infrared imagery. Samples from each site are measured in the field using Thermtest thermal conductivity and effusivity probes and a soil penetrometer. Samples returned to the lab are dried, sieved, and weighed to determine water content and grain size distributions. Thermal emission spectra are measured using an FTIR spectrometer.

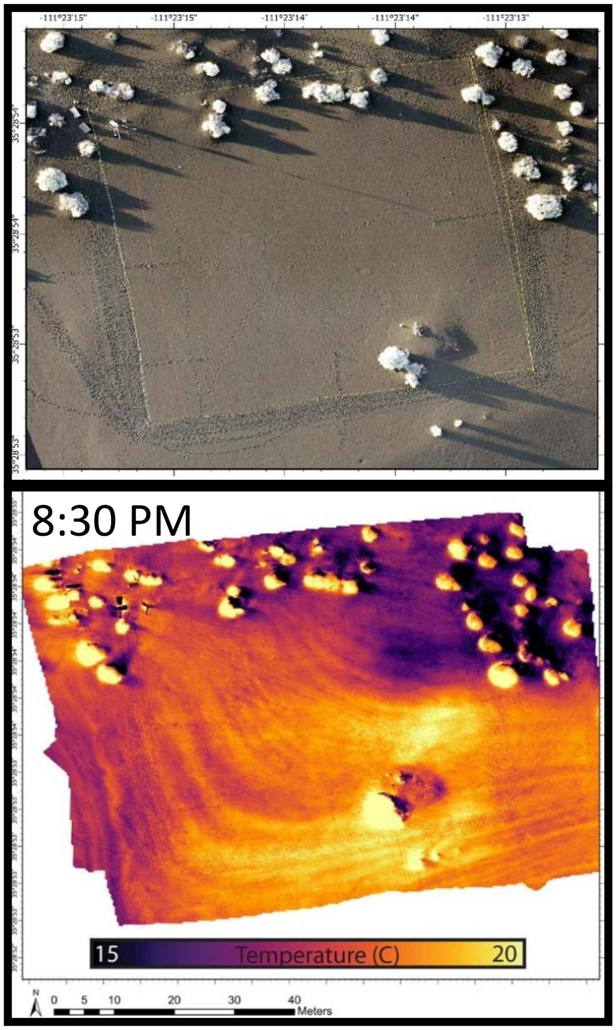

Figure 2. *True color multispectral (top) and 7.5-13.5 μm thermal (bottom) UAV-derived mosaics of Sunset Aeolian Site from May 12, 2021.*

Energy Flux Models: We developed a model that mitigates Earth-specific uncertainty and isolates the controls that are most relevant to Martian sediments. The model uses measured parameters to estimate sensible [4], latent [5,6], radiant, and ground fluxes [7] and fits the most probable dry thermal conductivity to calibrated surface temperatures. The program equilibrates subsurface temperatures and then iterates through a one-dimensional surface energy balance on the upper boundary of a soil column, calculating subsurface heat transfer with temperature-dependent parameters. By isolating the effects of liquid water on heat transfer we mitigate the major Earth-specific controls and identify the remaining controls most relevant to Martian sediments. We then validate those controls with the *in situ* thermophysical probe measurements.

Thermal Conductivity Model: Lab studies show that intergrain cements and liquids play an important but nonlinear role in controlling bulk thermal conductivity [8–10]. We tested multiple mixing models [9,10] and modes of temperature-dependency [11] for the effect of water and pore geometries on thermal conductivity. The effect of interstitial gas composition is treated analytically [12].

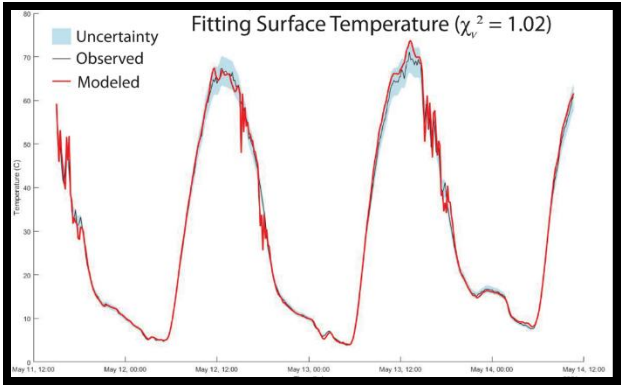

Figure 3. *Example surface temperature fits from model for minutely tower-mounted IR data.*

Results and Discussion: Model testing has revealed that the greatest sources of uncertainty stem from the complexity of how thermal conductivity scales with water abundance and from variable rates of evaporation for different soil structures. We find a robust approach to modelling sensible and latent heat is to use free coefficients fit using tower station IR data and then applied to the rest of the field area observed in UAV data. The most generally-applicable mixing model for our test environments was to use geometric means of components with empirical coefficients from [13]. The resulting thermal inertia maps reveal trends that appear most correlated with grain size, composition, and compaction.

Future Work: In addition to the two future field campaigns, we also plan to conduct microscopy, XRD, and EMPA on subset samples of all surface types. Ultimately, when the dataset is complete, we will develop a statistics-driven predictive model that uses satellite observations to evaluate sedimentary environments on the Martian surface.

Acknowledgements:

Funding for different pieces of this works comes from the NASA FINESST (19-PLANET20-0138) and PSTAR (17-PSTAR17_2-0044) programs.

References: [1] Edwards, C.S. *et al.* (2011) *JGR* 116 [2] Fergason, R.L. *et al.* (2006) *JGR* 111[3] Sabol, D.E. *et al.* (2006) *Recent Adv. Quant. Remote Sens.* [4] Cellier, P. *et al.* (1996) *Agric. For. Meteorol.* 82 [5] Price, J.C. (1985) *Remote Sens. Environ.* 18 [6] Kondo, J. *et al.* (1990) *J. Appl. Meteorol.* 29 [7] Kieffer, H.H. (2013) *JGR* 118 [8] Piqueux, S. & Christensen, P.R. (2009) *JGR* 114 [9] Zhang, N. & Wang, Z. (2017) *Int. J. Therm. Sci.* 117 [10] Dong, Y. *et al.* (2015) *Geotech. Geol. Eng.* 33 [11] Morgan, P. *et al.* (2018). SSR 214 [12] Piqueux, S. & Christensen, P.R. (2009) *JGR* 114 [13] Lu, S. *et al.* (2007) *Soil Sci. Soc. Am. J.* 71