CONSTRAINING THE POTENTIAL LIQUID WATER ENVIRONMENT AT GALE CRATER, MARS THROUGHOUT MSL'S TRAVERSE. E. G. Rivera-Valentín[1], R. V. Gough[2,3], V. F. Chevrier[4], K. M. Primm[2,3], G. M. Martínez[5], and M. Tolbert[2,3]; [1]Lunar and Planetary Institute and Arecibo Observatory, Universities Space Research Association, Houston, TX (ervalentin@usra.edu); [2]Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO; [3]Department of Chemistry and Biochemistry, University of Colorado, Boulder, CO; [4]Arkansas Center for Space and Planetary Sciences, University of Arkansas, Fayetteville, AR; [5]Department of Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, MI.

Introduction: The Mars Science Laboratory (MSL) Rover Environmental Monitoring Station (REMS) has now made continuous in-situ meteorological measurements for almost 3 martian years at Gale crater. Of importance in the search for liquid formation are REMS' measurements of air relative humidity, and air and ground temperature [1]. REMS measures relative humidity with respect to ice (RH_i) at a height of 1.6 m while experiments and thermodynamic models on the stability of potential brines have presented diagrams in relative humidity with respect to liquid (RH_l) [2-4]. Indeed, previous studies searching for liquid formation at Gale crater suggested surface and shallow subsurface $Ca(ClO_4)_2$ brines may be possible [5]; however, REMS data have undergone several calibrations since, the latest on June 2015 lead to drier conditions, but more importantly, previous studies have compared REMS RH_i to a phase space in RH_l [5-9].

Furthermore, MSL has traversed various terrain types, with a range of thermal properties, specifically thermal inertia of $170 \leq \Gamma \leq 600$ (mKs units) and albedo of $0.1 \leq A \leq 0.3$ [10]. In order to understand the potential liquid water environment at Gale crater, we analyze REMS data with consistent relative humidity comparisons. We specifically study calcium perchlorate, the Mars-relevant salt with the lowest eutectic temperature (198 K) [4,11]. Additionally, we simulate the subsurface environment to provide insights to future operation strategies.

Data Analysis: MSL's REMS is a suite of sensors recording daily air temperature, relativity humidity, wind speed and direction at 1.6 m, along with the ground temperature, pressure, and ultraviolet radiation of the martian surface at Gale crater [1]. Corrections to the data are applied to eliminate the rover's influence as well as other factors that may be altering the measurement accuracy. Here, we used REMS measured air relative humidity w.r.t. ice (RH_{ia}) and air temperature (T_a) at 1.6 m as well as the ground surface temperature (T_g) through sol 1648. Ground relative humidity was inferred assuming water vapor pressure is constant through the 1.6 m air column. T_g has a typical systematic error of ±1 K during daytime measurements, up to ±10 K at nighttime, while uncertainty in RH_{ia} is ±10% for 203 K ≤ T_a ≤ 243 K and ±20% for T_a < 203 K [8]. Propagating error, we found that most low RH_{ia} have large errors that do not preclude the possibility of RH_{ia} < 0%; therefore, this data was not included.

Data were compared to the phase diagram of $Ca(ClO_4)_2$ in search of favorable conditions for liquid formation. Furthermore, we infer the enthalpy of all active near-surface processes by constructing vapor pressure curves.

Results: In Fig. 1, we show the REMS data in RH_l with the $Ca(ClO_4)_2$ phase diagram. Accounting for updated REMS data calibrations and comparing relative humidity values in consistent phase space, we found that no measured environmental condition favor deliquescence of calcium perchlorate at the surface. Accounting for error, we found that to the 1-σ level deliquescence is still unfavored; however, to the 2-σ level in T_g there are two points on sols 1232 and 1311, Ls 99° and Ls 137° respectively, that could be within the liquid phase. These values, delineated in Fig. 1, occurred while the rover was near active sand dunes [10] during the early morning and late evening.

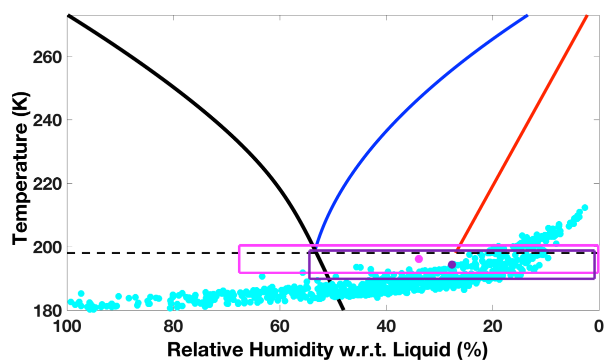

Fig. 1: MSL REMS measured ground temperature and inferred ground relative humidity in RH_l on the phase diagram of $Ca(ClO_4)_2$. The blue and red lines are DRH and ERH respectively while data is in cyan circles. The black dashed line is the eutectic temperature of calcium perchlorate brine while the black solid line is the ice line, where RH_i = 100% in RH_l phase space. Boxes indicate 2-sigma error for points where liquid formation is possible.

To derive enthalpic changes, we constructed vapor pressure curves by binning data over five sols. We found only four statistically significant (*i.e.,* non-zero) enthalpic changes, all of which occurred during the early morning on Ls 74°, 106°, 110°, and 139°. Cumulatively, the derived values have a weighted average of $\Delta H = 35 \pm 21$ kJ/mol. A non-zero derived enthalpy on Ls 139° could support liquid formation on sol 1311 for the potential 2-σ signature; however, no corresponding significant ΔH was found for sol 1232.

Modeling: Via a fully coupled heat and mass transfer model, we searched for potential subsurface liquid formation throughout one martian year for a variety of regolith thermal property combinations (Γ and *A*) in order to better inform future MSL operational strategies. Subsurface temperatures were simulated by solving the 1-D thermal diffusion equation via a finite element procedure [4,12] with a vertical resolution of 0.01 m. The time step required for stable solutions is dependent on the thermal properties of the regolith column; values used here ranged from 180 s to 370 s. The surface boundary condition is radiative and includes direct illumination, along with scattering and thermal emission atmospheric components.

Water vapor diffusion through regolith was simulated by solving the 1-D mass transfer equation. The diffusivity of water vapor through CO_2 gas was modeled as temperature dependent with nominal values on the order of 10^{-4} m^2/s [13]. At the surface-atmosphere interface, fits to REMS derived water vapor pressure are applied as a boundary condition. Perturbative processes to simple diffusion were not included.

Results: In Fig. 2, the total percent of the year calcium perchlorate brines are possible within the subsurface (down to 1 m) is plotted with respect to Γ and *A*. Simulations were run from 150 ≤ Γ ≤ 300 in increments of Γ=25, and for albedo from 0.1 ≤ *A* ≤ 0.3 in increments of *A*=0.05.

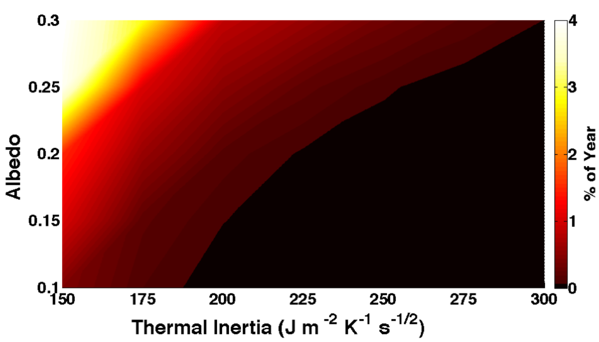

Fig. 2: The total percent of the year a $Ca(ClO_4)_2$ brine may be possible within the subsurface (summed over 1 m) as a function of thermal inertia and albedo. In the color map, 0% is designated as black. Color map shading is interpolated between studied cases.

For Γ > 300, we find that liquid formation in the subsurface is not favored. On the other hand, for Γ ≤ 300 liquid formation is possible depending on *A* while for Γ ≤ 185 liquid formation is possible regardless of *A*. Furthermore, results suggest that terrains with Γ ≤ 175 and A ≥ 0.25 are the most apt for brine formation. When subsurface brines are possible, the ambient conditions would permit a solution with a water activity of up to a_w ≈ 0.55, assuming equilibrium where a_w=(RH_l/100). The temperature during the presence of brines is at most 205 K. Although potential brines could meet the a_w criteria for Uncertain Regions [10], they do not simultaneously meet the temperature requirement (>250 K). Moreover, following reported perchlorate concentrations at Gale crater [14], the resulting liquid abundance in the regolith is 0.08 wt%. Therefore, even when liquids are potentially available, they are only present in small amounts.

Conclusions: Our results show that the surface environmental conditions in the first 1648 sols are not favorable to liquid formation through deliquescence of calcium perchlorate, the Mars relevant salt with the lowest known eutectic temperature. Accounting for error, this remains true at the 1-σ level, but not at the 2-σ level where at two times the surface conditions may have permitted liquid formation for up to an hour each day. These points occurred in active sand dunes on sols 1232 and 1311. Derived enthalpic changes may support liquid formation on sol 1311, but not necessarily sol 1232.

On the other hand, simulations of subsurface conditions would suggest that low thermal inertia units (Γ ≤ 300) could be occasionally favorable to brine production. Such simulations could support brine formation on sols 1232 and 1311. Furthermore, results suggest the potential for brine formation is best for terrains with Γ ≤ 175 and *A* ≥ 0.25. Potential brines would have water activities of up to a_w ~ 0.55 and experience temperatures at most of 205 K; as such these liquids would not meet the Special nor Uncertain Regions requirements [6]. Assuming typical perchlorate salt concentrations, liquid abundance in the regolith is also expected to be low, ~0.08 wt%.

Though thus far (up to sol 1648), the MSL environment did not favor brine formation through deliquescence at the surface, our results provide guidance to sites where the rover may best find liquids in the subsurface. At these sites, the REMS extended mode for sampling should be employed as well as for the DAN (Dynamic Albedo of Neutrons) instrument.

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