IF WET, HOW WET? INTRODUCING A SURFACE ALBEDO-BASED APPROACH FOR ESTIMATING THE VOLUMETRIC WATER CONTENT OF MARTIAN RECURRING SLOPE LINEAE (RSL). M. R. Salvatore[1], J. S. Levy[2], and L. E. Fackrell[1]. [1]Northern Arizona University, Flagstaff, AZ, mark.salvatore@nau.edu. [2]Colgate University, Hamilton, NY.

Introduction: Recurring slope lineae (RSL) are dark linear features that show annual patterns of downslope growth (during warm seasons) and subsequent fading (during cold seasons) [1]. Several potential formation mechanisms exist that can be categorized as "wet" or "dry." Wet RSL origins require a source of liquid water, a seasonal trigger, and a mode of recharge, so formation mechanisms typically include subsurface aquifers [2] or atmospheric recharge through deliquescence [3]. Dry RSL origins also require seasonal triggers that have been hypothesized to include wind [4] and the (de-)hydration of geologic materials causing surface destabilization [5].

Previous studies have estimated the potential water contents of RSL using various remote sensing datasets, including visible/near-infrared (VNIR) reflectance spectroscopy [6] and mid-infrared (MIR) thermography [7]. We introduce a new method for estimating the volumetric water content (VWC) of RSL by quantitatively relating the relative darkening of the surface with darkening observed in both natural landscapes and in laboratory analyses. These efforts assume that the darkening observed in RSL is due to increased surface water content (i.e., a "wet origin"). Our methods were originally developed for estimating VWC of soils in the McMurdo Dry Valleys (MDV) of Antarctica using high-resolution multispectral VNIR satellite data. Based on these relationships as well as the relative surface albedo characteristics of RSL in Tivat crater, Mars, described by [8,9], we estimate that the maximum VWC of RSL in Tivat crater is on the order of ~10%. This value is consistent with previous maximum estimates of VWC in RSL and is consistent with measured VWC of Antarctic water tracks.

Methods: Using changes in normalized surface albedo to estimate VWC has been a standard technique in remote sensing studies since the mid-1970s [10]. However, this technique has been traditionally challenging to apply to satellite images of natural landscapes because even the most subtle topography can cause variations in solar illumination which, in turn, can result in apparent surface darkening or brightening. The availability of high-resolution topographic data on Earth (via lidar and structure from motion) has allowed direct modeling of surface illumination of terrain at fine spatial scales, allowing topographic corrections to satellite data to derive more accurate estimates of surface albedo and reflectance properties without significant contributions from differential surface illumination. For example, for Antarctic water tracks, after generating a median surface albedo product using more than 50 individual and topographically corrected surface albedo images, we were then able to compare each individual image to this median albedo product to determine if observed spatial patterns of brightening/darkening could be due to variations in surface VWC.

Finally, we performed a series of lab experiments using Antarctic surface sediments to quantify the relationship between surface albedo and VWC. This relationship can be dependent on several factors, including particle size, porosity, and surface composition (including the presence of salts or swelling clays, for example), all of which are captured in the range of sediments used in these lab studies. Fortunately, our experiments demonstrate that the vast majority of MDV soils behave similarly with regards to the relationship between relative surface albedo and calculated VWC.

While challenging due to the presence of steep slopes, complex shadows, and the limited availability of high-resolution imagery and digital elevation models for most of Mars, [8] performed a similar topographic correction technique to martian images to quantify the amount of darkening in RSLs across Mars. The normalized surface albedo products generated by [8] were used in our investigation to estimate VWC from changes in surface albedo.

Results: Our lab experiments demonstrate a linear relationship (r^2 = 0.988) between VWC and relative surface albedo up to ~25% VWC when the samples become saturated (**Fig. 1**). Model uncertainty is still being quantitatively investigated, but initial work suggests that our VWC estimates are accurate to within ± 3%. We are continuing to refine these error estimates through the use of cross validation model evaluations.

We applied this linear relationship to data from eighteen High Resolution Imaging Science Experiment (HiRISE) images for two observed RSL locations and one non-RSL location (**Fig. 2**). HiRISE DN values were normalized to an invariant control region to generate the relative albedo data [8]. Brightness in the non-RSL location varied between 0% and 10% (equivalent to ~0% to ~5% VWC using the Antarctic relationship), while the two RSL location share a similar temporal pattern and overall brightness-derived VWC between ~0% and ~12% (**Fig. 2**).

Discussion and Future Work: These data place important constraints on the typical range of brightness changes that occur seasonally in RSL that could potentially be caused by changes in VWC within RSL.

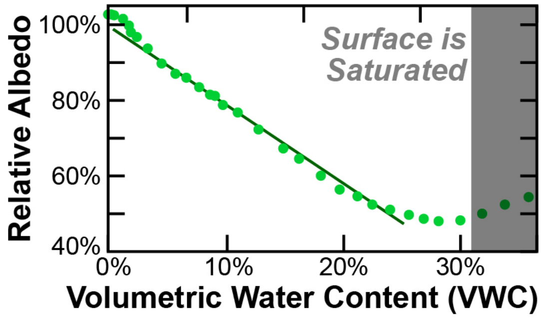

Figure 1. A linear relationship between volumetric water content (VWC) and relative surface albedo. This relationship is nearly linear (r^2 = 0.988) between surface albedos of 0% and ~25%.

These values are generally consistent with other means of estimating water abundance in these features, including the use of Thermal Emission Imaging System (THEMIS) data and heat transfer modeling that were used to derive an upper limit of 3% VWC in martian RSL [7]. [7] discussed how the 3% VWC for RSL might be a significant underestimate of water content, as HiRISE data were acquired during the warmest times of day (mid-afternoon) while THEMIS data were acquired during some of the coldest overnight times of day. Diurnal changes in soil moisture and brightness in MDV soils can be large (a few vol. % to 5-10% VWC) and result from changes in atmospheric relative humidity [11] and can change over minutes to hours. These differences in the timing of observations might help to reconcile the discrepancy between HiRISE VWC estimates and those made using THEMIS surface temperature data [8].

Our ability to translate remotely derived relative surface albedo measurements to VWC estimates is rooted in the assumption that the darkening of RSL is due to increases in near-surface soil moisture. When applied to the MDV of Antarctica, where relative darkening of surfaces is known to be exclusively due to increases in soil moisture, initial results suggest our technique is accurate to within ± 3% VWC and is consistent with previous studies [12]. Importantly, the soils of the MDV host complex microorganism and microinvertebrate ecosystems that are uniquely adapted to the harsh cold and dry environmental conditions [13,14]. These ecosystems have adapted to the harsh conditions, including the ability to survive hard freezes, indefinite desiccation, and high levels of ultraviolet radiation, and have long been considered analogs for potential martian life [15]. Typical VWC of soils in the MDV are on the order of ~3% (right at our technique's detection limit) [12] and suggest that the ~10% VWC estimated here for martian RSL would be capable of supporting hearty ecosystems like those found in the MDV.

Future work will focus on validating the HiRISE topographic correction pipeline and image georeferencing efforts, building upon the work of [8]. The availability of numerous HiRISE images over many of the well-studied locations with RSL as well as the ability to derive digital elevation models (DEMs) through stereo-photogrammetry [16] enables us to continue these studies of normalized relative albedo variations and the estimation of VWC in RSL. Continuing these efforts will help the scientific community to understand the ecological potential of RSL if they are indeed "wet" features.

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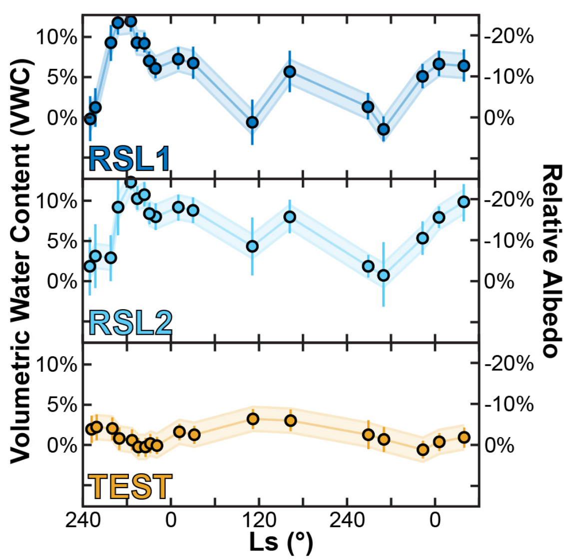

Figure 2. Volumetric water content (VWC) estimates for two RSL in Tivat crater, Mars, as well as a control "test" site. VWC estimates were derived from relative surface albedo measurements made by [8] and original locations were identified and characterized by [9]. Error bars represent 1σ uncertainties in relative albedo measurements while the shaded halo represents our initial ± 3% error approximation for VWC.