DRONE-BASED MEASUREMENTS OF SOIL WATER CONTENT IN POTENTIAL RSL ANALOGS: HYPERSPECTRAL MOISTURE MAPPING OF HYDROTHERMAL SPRING DISCHARGE IN THE ALVORD DESERT, OREGON.

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Introduction and Motivation: Determining whether liquid water or brines are present in near-surface soils and regolith in planetary settings is a major goal for the evaluation of planetary habitability [1]. Possible detection of hydrated mineral phases in the vicinity of recurring slope lineae (RSL) [2] raised the possibility that aqueous solutions may play an important role in RSL formation and evolution, despite seasonal thermal obstacles to the preservation of near-surface water ice in RSL environments [3]. However, re-analysis of RSL spectroscopic measurements suggests that some hydrated mineral detections associated with RSL may be spurious based on processing artifacts associated with 1.9 and 2.1 µm absorption features [4]. The challenges associated with moisture detection and quantification in these high-priority astrobiological targets suggests a need to develop remote-sensing workflows for remote soil moisture analysis in well-constrained terrestrial settings. While previous field analyses of seasonal, linear soil moisture features have focused largely on analysis of image data [5] or ground-based spectroscopic measurements [6], here we report on new efforts to quantify soil moisture in a hydrothermal spring discharge plume in the Alvord Desert of eastern Oregon (Fig. 1), using drone-based hyperspectral measurements in the vicinity of 1.4 µm, combined with ground-based measurements of soil composition and physical properties (clay content and grain size distribution, salinity, and soil moisture).

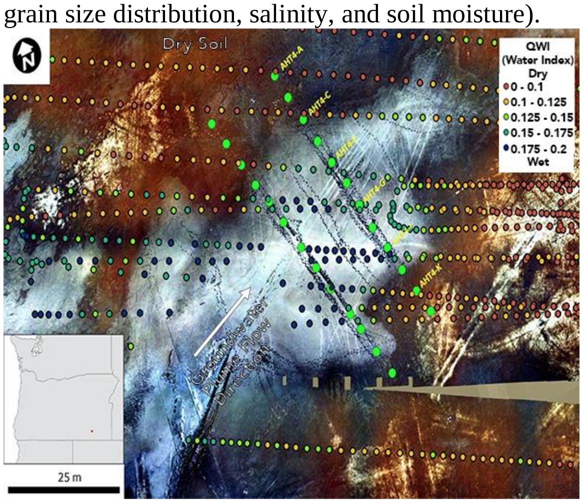

Fig. 1. Site and sample locations in the Alvord Desert. Wet soil hydrothermal plume is gray/white in this orthoimage; dry playa sediments are brown, white, and black. Green indicates sampling site. Color-coded points show average airborne spectra collection locations and soil moisture index valyes. Transect 4 is labeled in yellow.

Methods: *Sample Collection*. Sediment samples for two ground truth-transects were collected in the Alvord Desert, located near the Steens Mountains in Southeastern Oregon, USA. The target location was a visibly wetted area where spring discharge flowed out in digitate groundwater plumes into the Alvord Lake playa. Sediments were collected in August, 2019, at 5 m intervals crossing the groundwater plume and were stored in sealed Whirl-Pak bags. Soil volumetric water content (VWC), temperature, and electrical conductivity were measured at sampling points using a Decagon Devices 5TE probe.

UAV-borne Reflectance Spectroscopy. Point spectra were collected from 15 m elevation using a Matrice 210-RTK UAV (drone) carrying an Ocean Optics FLAME-NIR spectrometer. Measurements were collected at ~10 Hz from 900-1600 nm over 128 spectral channels, and were averaged at 1 Hz to increase S/N. A quick water index (QWI) adapted from [6] was used to assess band depth in the vicinity of the 1.4 µm water absorption feature shoulder by ratioing the mean spectrum within ~5 nm of 1500 to valuessurrounding 1600 nm: QWI = 1-(mean of 1495 – 1507 nm / mean of 1595-1607 nm).

Sample Preparation. Soil samples were dried to determine gravimetric water content (GWC) via weighing. VWC for each sample was calculated using the raw 5TE voltage data and the Topp equation. A similar process was used for calculating the electrical conductivity (converted from mV to dS/cm). A METER Pario automated settling column system was used to determine sample particle size.

Results and Discussion: *Soil Properties.* As shown in Fig. 1-2, soil moisture peaks in the middle of the cross-track transects, while the amount of clay reaches a minimum just off from the center of the plume. Intriguingly, dielectric-derived VWC also decreases at the plume center. This suggests that the dielectric properties of clay rich soils may hamper accurate soil moisture content measurement by electrical methods, necessitating spectroscopic measurements of soil moisture that are calibrated by gravimetric soil moisture determinations. Clay has a high field capacity and low hydraulic conductivity, which means that clay-rich plume margins may help both store water in these marginal soils, increasing the width of the wetted zone, while also channelizing flow in the plumes, extending their length from the discharge spring.

Water absorption feature indices. The 1.4 µm shoulder feature was present in all samples. Figure 3. shows reduced reflectance at 1.4 µm (higher QWI) in wetter soils. High QWI is strongly correlated with soils within the groundwater plume (blue dots in Fig. 1).

Conclusions: Characteristic water absorption bands near 1.4 µm varied linearly with GWC in spectra collected from ground and airborne sensors. This raises the possibility that reflectance spectroscopy in this spectral range can be used to quantify the mixing ratio of water in desert RSL-analog soils, provided soil-specific calibrations can be determined. Unlike dielectric methods, water absorption indices appear to be minimally affected by changes in solution salinity or clay abundance at this site.

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References: [1] Rummel, J. D. *et al.* (2014) *Astrobiology* **14,** 887–968 (2014). [2] Ojha, L. *et al.* (2015). *Nat. Geoscience* (2015). doi:10.1038/ngeo2546 [3] Schorghofer, N., *et al.* (2019) *JGR-Planets* **124,** 2852–2862. [4] Leask, E. K., *et al.* (2018) *GRL* **45,** 151–10. [5] Bhardwaj, A., *et al.* (2019) *Remote Sensing* **11,** 2104–32. [6] Levy, J., *et al.* (2014) *Antarctic Science* **26,** 565–572.

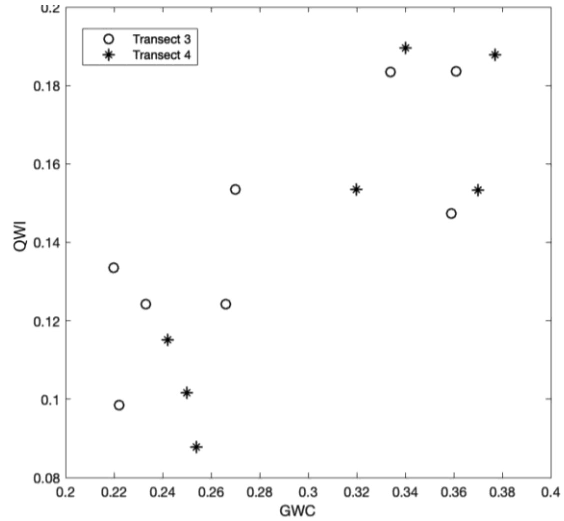

Fig. 3. Water-related absorption quick water indices (QWI) versus gravimetric water content (GWC) soil moisture by mass for all samples.

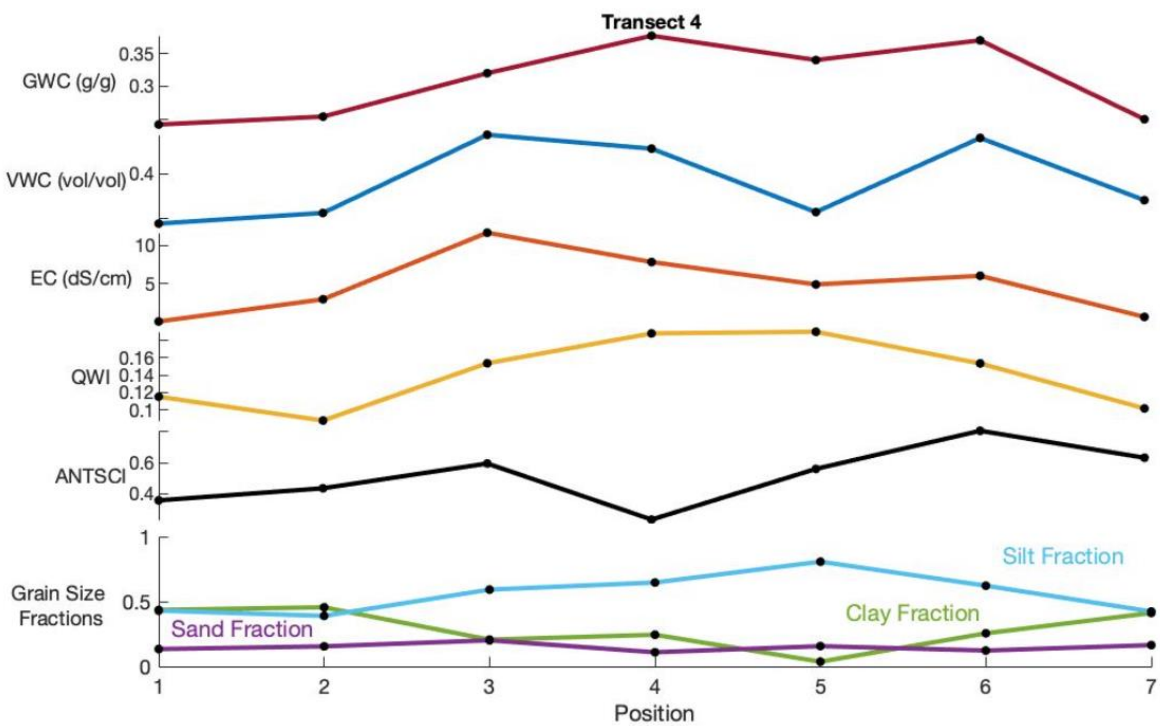

Fig. 2. Example ground truth and remote sensing data for AHT4: A-M showing gravimetric water content (GWC), volumetric water content (VWC), electrical conductivity (EC), quick water index (QWI), full water index from [6] (ANTSCI), and soil clay and silt, fractions. Positions 1-7 are AHT4-A, C, E, G, I, K, and M, respectively, from dry soil to dry soil across the plume.