A SIMPLE LABORATORY CALIBRATION METHOD FOR MITIGATING SEAWATER EFFECTS ON SOIL MOISTURE SENSORS

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INTODUCTION

The importance of moisture content for sediment dynamics in coastal environments is well documented, particularly in reference to aeolian sediment transport (Davidson-Arnott, 2005). Tidally-induced changes in moisture content in partially saturated environments, such as beaches, cause significant changes in surface shear strength through the development of suction stresses, which can affect erodibility (Sassa and Watabe, 2007). Thus, the accurate measurement of moisture content in these environments is important for determination of strength properties and for predicting sediment transport. Most moisture sensors work by measuring dielectric permittivity, the ability to carry electric charge, of the substrate, which is proportional to the moisture content. However, most moisture sensors are not calibrated for seawater, which has a higher dielectric permittivity than freshwater, causing overestimation of the moisture content. Therefore, the goal of this study is to develop and demonstrate a laboratory calibration scheme to account for this overestimation, and thus to allow for more accurate measurements of moisture content in coastal environments.

METHODS

To keep density constant a fixed amount of sediment was mixed with the desired volume of water to reach the target water content for each test. The sediment was compacted into a plastic container of known volume, burying the sensor and packing completely around it. Sensor readings were taken to give the measured moisture content. Afterwards, the full sample was weighed and dried to obtain the true moisture content. The tests were repeated by varying the moisture content from 0%-35%, with 35% moisture by volume being experimentally determined as fully saturated. Each of the 4 full sets of tests was run at a constant salinity and changing the salinity between sets of tests from fresh (0 PSS) to 30 PSS in increments of 10 PSS.

LABORATORY RESULTS

The true freshwater moisture content was represented best by a linear fit to the measured water content (blue line in Figure 1). Salinities in the 10-20 PSS range behaved similarly as freshwater up until approximately 15% true moisture content by volume, beyond which the moisture content was overestimated by the sensor, and thus a bilinear fit gave the best results (green and yellow curves in Figure 1). At a salinity of 30 PSS, the moisture contents consistently were overestimated by the sensor, and a polynomial fit was selected to represent the calibration (red curve in Figure 1).

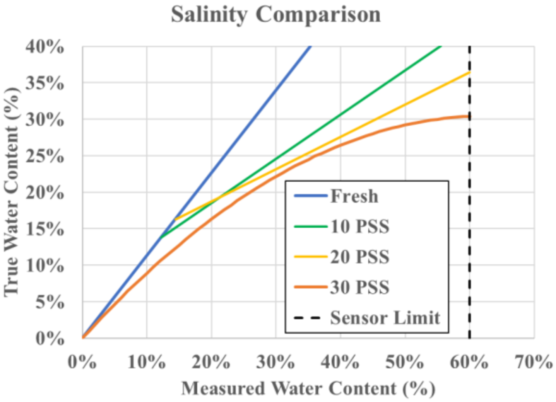

Figure 1 -True water content versus measured water content for different salinities (listed in the legend).

FIELD RESULTS

In addition to the laboratory calibration, a field data set was collected in December 2020 in Duck, NC. A vertical array of four sensors was buried in the beach over a 2-day period to observe the tidally induced change in groundwater level.

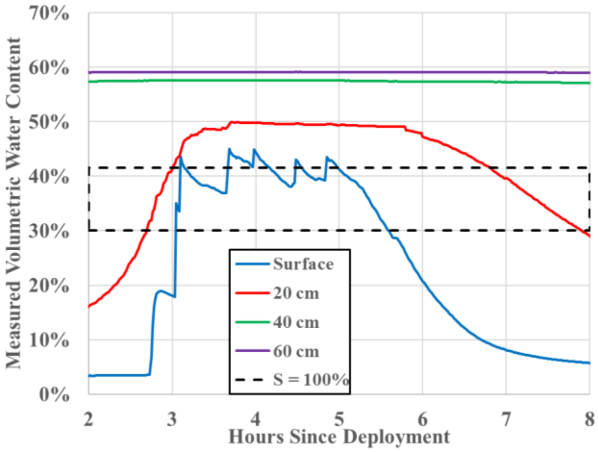

Figure 2 -Measured volumetric water content for a vertical array of buried moisture sensors versus time.

For a 6-hour time series of data over one tidal cycle.

the surface sensor (Figure 2, blue curve) measured a series of wave runup events at high tide, and the sensor at 20 cm depth (Figure 2, red curve) also measured the tidally induced groundwater fluctuations. The two deepest sensors at 40 and 60 cm were relatively constant (green and black curves, Figure 2), implying that they were permanently below the water table and fully saturated. However, based on the soil properties the theoretical range of water contents at which the soil is fully saturated (the dashed area in Figure 2). shows the overestimation of water content caused by seawater.

These values were determined using the theoretical minimum and maximum void ratios for the sand found at the site, having been determined via ASTM D4253 and ASTM D4254. With the range of possible void ratios, minimum and maximum gravimetric water content at saturation was computed via:

$$w = \frac{Se}{G_s} \tag{1}$$

where w is the gravimetric water content, S is the degree of saturation (assumed equal to 1 for full saturation), e is the void ratio, and G_s is the specific gravity of the sediment, taken as 2.65 for the quartz sand found at the site. Gravimetric water content differs from volumetric water content (measured by the sensor) in that it represents the water content as the weight of water for a given weight of sediment, rather than using the volume of water in a given volume of sediment, air, and water. The two types of water content are related by:

$$\theta = \frac{w\rho_b}{\rho_w} \tag{2}$$

where θ is the volumetric water content, ρ_b is the bulk density of the sediment, obtained using the measured void ratios, and ρ_w is the density of water. Using this analysis, the minimum volumetric water content for saturation was found to be $\theta = 30\%$, and the maximum was found to be $\theta = 41.5\%$. The upper bound value of θ also can be thought of as the maximum water content the soil theoretically can sustain (maximum possible pore volume).

The knowledge of the range of possible water contents for full saturation highlights the main problem with overestimation of water contents due to seawater. A majority of the measurements lie above the upper bound (dashed line in Figure 2), suggesting that the in-situ water content is higher than the maximum possible water content, which is not realistic. Without proper calibration, these data do not depict a physically possible scenario, and are therefore of little use. The same timeseries of data, with the calibration from Figure 1 applied. (Figure 3) provides a more realistic depiction of the in-situ water contents. The surface and 20 cm depth sensors are below the lower bound dashed line, suggesting that they are not fully saturated and are measuring tidal and wave-induced fluctuations in water level (Figure 3, red and blue curves). Additionally, the 40 and 60 cm depth sensors (Figure 3, green and purple curves), which were believed to be below the permanent water table due to being constant value over the tidal cycle, now fall within the range of possible water contents for full saturation (above lower bound dashed line). This example using a field data set highlights the necessity and usefulness of calibrating moisture sensors for the effects of seawater. The calibration scheme was successful in mitigating the overestimation of moisture content in field observations in a saline environment.

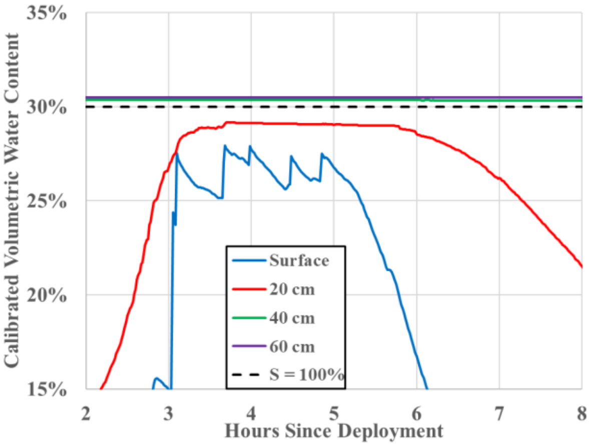

Figure 3 -Calibrated volumetric water content for a vertical array of buried moisture sensors versus time.

CONCLUSIONS

A calibration scheme that mitigates the overestimation of moisture content in the presence of saline water was developed in the laboratory and used with field data. The results suggest it is possible to collect accurate moisture content in coastal environments. Future work will use this calibration scheme to gain a better understanding of geomorphodynamics in beach environments by studying the relationship between moisture content, other sediment strength properties, and hydrodynamically-induced bed-level change.

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