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as of 21-Aug-2019

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Submitted By: William Philpot

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Major Goals: The goal of this project was to develop a physically-based model describing reflectance of radiation from 350-2500 nm from dry, moist, and saturated soil. The intent was to account for the optical and structural soil characteristics – including moisture content – that contribute to the observed reflectance in order to functionally describe the effect of wetting on the spectral and directional reflectance of soil. The underlying scientific interest was to understand how wetting and drying alters the observable optical character of the soil as exhibited in the reflectance spectra.

The initial intent was to build on existing models; however, existing models proved to be a poor match to the task of characterizing reflectance from moist, but not saturated soils. In particular, existing models fail to account for the distinction between pore water and adsorbed water, and ignore the effect of water on the directional reflectance. Another difficulty was that current models do not explicitly account for scattering within soil particles, a process which would tend to increase the strength of absorption by the particles. Given the poor fit of the existing models for dealing with wet soils, the effort shifted to exploring the details of how water altered the directional reflectance of soils, with the goal of defining the requirements for an effective radiative transfer model.

The experimental effort was already a part of the research plan, given the limited number of observations of sufficient detail to support and verify model predictions. That was particularly true for moist soils; the preponderance of the existing spectral observations are for dry soils. Even then, there were very few directional observations that considered directional illumination and viewing. Thus, the revised goal was to make a series of spectral-directional reflectance observations of soils at all drying stages from air-dry to saturated.

Accomplishments: The substance of the accomplishments are a series of laboratory measurements designed to identify the optical properties and soil characteristics essential to an effective model of wet soil. Initial experiments called into question some basic assumptions of existing models, and led to further experiments which helped to define constraints on an effective model. Results also suggested both limits and possibilities for the use of spectral reflectance in characterizing soil properties under a range of moisture conditions. Simple models were introduced to explore specific aspects of relationships between soil properties, wetting characteristics, and directional reflectance, but no general model was developed. While we were not able to assemble a final, complete model, we were able to establish important constraints for a functional model. Most importantly, we determined that it should be possible to construct an effective model by merging a surface reflectance model and a volume reflectance model. This would likely be simpler than a continuous model, and could be more computationally manageable. A model is envisioned that would consist of the following parts:

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1. Surface reflectance model.

The directional character of reflectance is primarily controlled by the surface morphology, and an effective model will need to capture the general shape characteristics. The extent of shadows for a given illumination/viewing geometry appears to be particularly critical. Addition of water to the surface is an important complicating factor, because water adsorbed to the particle surfaces redistributes the incoming light (most likely by multiple internal reflection), making illumination of the soil surface more uniform, and reducing – or even eliminating – the directional aspect of reflectance. Water also alters the spectral character of the reflectance, most significantly in the shortwave infrared (SWIR), defined here as the range from 1350-2500 nm. This lower limit of this range is the point at which water absorption becomes a dominant factor in the spectral reflectance. Water absorption is negligible in the visible-near infrared (VNIR), which for the current purpose is taken to be 350-1350 nm. Thus, in the VNIR water enhances the transmission of light into the soil, and absorption by the soil, but does not noticeably affect the spectral reflectance. In the SWIR, water absorption dominates the spectral reflectance, masking (rather than enhancing) reflectance from particles.

2. Volume reflectance model

Volume reflectance is any light not reflected at the upper surface of the soil sample. This radiation appears to be essentially diffuse, i.e., there was very little experimental indication of a directional preference. On the other hand, the magnitude of the reflectance was very sensitive to the amount of water filling the pore spaces. Water enhances transmission into the soil in the VNIR by reducing the relative index of refraction at the particle surface. This increases the opportunity for absorption by soil particles. We also found experimental evidence for small-particle (Rayleigh-like) scattering that we attributed to scattering within the particles. This would further increase the optical path of the light, and thus the opportunity for absorption.

3. Matched boundary conditions

The surface and volume reflectance models will be fundamentally different. The surface model must be expressed in terms of radiance in order to account for direction illumination and reflectance from a complex geometry. It must also incorporate a representation of the soil surface that captures the shape, orientation, and shadowing at the soil surface. The volume reflectance model is envisioned as a layer model, with the subsurface material being horizontally homogeneous. Volume reflectance can be expressed as a two-flow irradiance model. Matching the boundary conditions at the interface of the two models regimes will be a crucially important step in the process.

Summary of the most important results

1. An effective model must discriminate between adsorbed water and pore water.

Given the very distinctive characteristics of the water absorption spectrum, we explored the possibility of using strong water absorption bands as direct indicators of soil water content. No obvious effects, other than general darkening, were apparent in the VNIR (350-1300 nm), where the attenuation length for water ranges from centimeters to meters. In the SWIR (1350-2500 nm), where the attenuation length of water drops to millimeters or less, direct absorption by water was apparent in the reflectance spectra, but the changes in the absorption bands could only be explained by considering the relative importance of pore water vs. the water adsorbed to the particle surface (Philpot & Tian, 2016a; Tian & Philpot, 2015a, 2015b).

2. There are two distinct regimes, VNIR and SWIR, for reflectance from moist soils.

Wet soil – even slightly damp soil – is darker than dry soil, yet the attenuation of water in the VNIR (350-1350 nm), which ranges from over 100 m in the blue to about 1 cm at 1300 nm is negligible on the scale of soil penetration depth. Thus, rather than absorbing light directly, water enhances the absorption by the soil in the VNIR. The situation is very different in the SWIR, where the water attenuation length due to absorption ranges from a few millimeters at 1350 nm to about 100 μ m at 2500 nm; water absorption tends to dominate in this spectral range. This strong contrast provides an opportunity to extract very different information from the two spectral regions, but also provides a challenge for modeling. (Philpot & Tian, 2016b; Tian & Philpot, 2017)

3. Directional reflectance is dominated by 1st or 2nd order scattering from the surface; volume reflectance (reflectance from just below the surface) is effectively diffuse.

An experiment observing the directional reflectance of soils when illuminated at zenith angles ranging from near-normal (10°) to glancing incidence (70°) showed strong direction sensitivity for dry soils, comparable to that seen in other experiments when the soil was dry (Bachmann, Philpot, Abelev, & Korwan, 2014). However, the directional character of the reflectance essentially disappeared for wet soil (Tian & Philpot, 2018). In a separate experiment, we examined the attenuation of light in the soil when the soil surface was illuminated from a wide range of angles (Tian & Philpot, 2017), and found that the attenuation rate was insensitive to the illumination angle. Together,

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these experiments suggest that the directional character of reflectance is almost entirely due to the first surface interaction, and that the volume reflectance is essentially diffuse.

4. Spectral transmission of wet soil suggests that multiple scattering within soil particles is partially responsible for attenuation in the visible.

The attenuation of wet soil in the visible demonstrates what appears to be a wavelength-dependent character that is characteristic of small particle scattering. A simple power law dependence on wavelength provides a reasonable description of the loss (Philpot & Tian, 2017). Given the penetration depth of a few millimeters, such a wavelength dependence cannot be explained by multiple passes through the pore spaces. The alternative is that light penetrating the particles is multiply scattered within the particles, leading to enhanced absorption by the soil material. Since the effective path length increases with as the wavelength decreases, the effective absorption increases. (Philpot & Tian, 2017)

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PARTICIPANTS:

Participant Type: Graduate Student (research assistant)

Participant: Jia Tian

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Authors: Jia Tian, William Philpot

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Abstract: The spectral reflectance of three soil samples – selected to represent a range of particle size distribution, texture, and drying characteristics – was monitored as the samples progressed from fully saturated to air dry. Band depths of prominent water absorption features in the near and shortwave infrared, centered at 970 nm, 1160 nm, 1440 nm, and 1930 nm, were then compared to the surface water content, with the expectation that this metric would be characteristic of the soil moisture content and be largely independent of soil properties. As expected, the band depths at 970 nm and 1160 nm decreased monotonically as the water content decreased. Unfortunately, these bands were only detectable in the sample consisting of large, reflective particles and large pore spaces (quartz sand). That they were not apparent in the darker soils with smaller particles and pore spaces suggests that these water absorption bands will not be generally useful for observing surface soil moisture. In cont

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