INFLUENCE OF SURFACE SOIL MOISTURE ON SPECTRAL REFLECTANCE OF BARE SOIL IN THE 0.4 – 15 μM DOMAIN

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ABSTRACT:

The purpose of this paper is to analyse the impact of surface soil moisture on spectral reflectance in the optical domain [0.4 – 15 µm]. This work is based on lab spectral reflectance measurements of many bare soils at different moisture contents. Firstly, a classification of bare soil samples is performed according to their spectral signatures: five classes are then defined. Secondly, the soil moisture content impact on spectral signatures is analysed. In the [0.4 – 15 µm] domain, measurements exhibit, for all the samples, a decreasing of the reflectance level with an increasing of moisture content. These measurements give information on absorption peaks related to soil mineral components like hydroxyl, carbonate, and quartz. Thus, analysis of our lab measurements indicates that soil moisture impact on spectral reflectance depends of studied spectral domain. These measurements may improve existing data bases, and will be used in a processing chain to estimate the soil moisture content (cases of bare soil and/or sparse vegetation) in the optical domain [0.4 – 12 µm] by using airborne hyperspectral imaging.

1. INTRODUCTION

Knowledge of soil moisture content (SMC) is significant for many applications like trafficability after flood, ground – atmosphere exchanges and plant good health,... Remote sensing data (optical to radar) have several advantages in comparison to in situ methods for monitoring SMC, like better temporal and spatial coverages. Moreover, hyperspectral data composed by numerous and contiguous spectral bands provide the most detailed information. Thus, the opportunity of using such technique to retrieve the SMC is investigated.

Soil optical properties, spectral reflectance and emissivity, are usually studied in the solar [0.4 – 2.5 µm] and thermal [3 – 15 µm] domain, and SMC characterisation from optical properties is more studied in the solar domain. In the [0.4 – 15 µm], mainly of approaches have been validated by lab measurements.

First works (Angström, 1925) have been performed in 1925 with lab measurements of spectral reflectance of bare soils at different moisture contents in the [0.4 – 2.5 µm]. This study showed a decreasing of reflectance level with an increasing of SMC due to a darkening of soil color. Later, other lab measurements of bare soils (Liu et al. 2002) have confirmed this result, and have been mainly used to develop soil moisture estimation's approaches from spectral reflectance (Lobell et al., 2002; Liu et al., 2003; Whiting et al., 2003; Khanna et al., 2007; Haubrock et al., 2008).

In the infrared thermal domain [3 – 15 µm], few works have been realised from optical properties (Salisbury et al., 1992 ; Salisbury et al., 1994) and soil moisture impact have been studied only in the long wavelength infrared (LWIR) [8 – 15 µm] domain (Mira et al., 2007) with spectral emissivity.

Consequently, there are not enough information in the thermal domain, and no measurement covering at once solar and thermal domains. So, we propose to build a database of spectral reflectance of bare soils in [0.4 – 15 µm] depending on SMC. This is the reason for having purchased lab measurements.

In this paper, the details of the experiment setup both for spectral reflectance and moisture content measurements are explained in section 2. The measurements are presented and analyzed in section 3. Finally, conclusions are given in section 4.

2. METHODS AND MEASUREMENTS

Lab measurements of spectral reflectance of bare soils at different moisture contents have been purchased in August 2008 at ONERA Toulouse (France). About thirty natural soil samples, covering different ranges of composition (clay, limestone, sandy) and coloration, have been collected over eight locations in France (Figure 1).
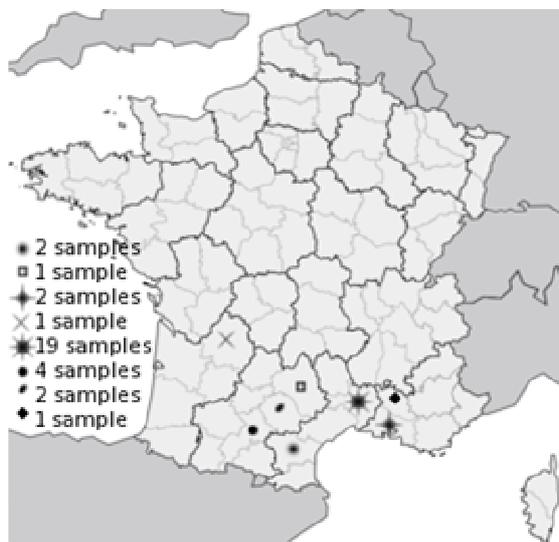

Figure 1. Bare soils samples location

2.1. Measurement of moisture content sample

Soil samples are put in petri-dishes and humidified until saturation. Drying process is obtained by in lab oven dry. Samples are dried to obtain five or six levels of moisture contents, which are estimated with the gravimetric method (Haubrock et al., 2008). Soil moisture content SMC (%) is computed according to the following relation:

$$ SMC = \frac{m_W - m_D}{m_W} \times 100 \qquad (1) $$

where m_W = weight of the wet sample
m_D = weight of the dry sample
m_D is estimated from the weight of the sample after a 24 hours drying period in oven at 60°C, assuming that the residual soil moisture content was 2 % (Peters, 2000).

2.2. Measurement of spectral reflectances

Concerning reflectance measurements, respectively bi-conical and directional hemispherical spectral reflectance data over [0.4 – 2.5 µm] and [3 – 15 µm] wavelength region are acquired using ASD (Analytical Spectral Device) Fieldspec Pro with an accuracy of $\Delta\lambda \pm 1$ nm, and Bruker Equinox 55 spectroradiometer with an error inferior at 3 %. So, kind of measurement is different following the waveband. We could not use an integral sphere on soil sample with the ASD.

In solar domain [0.4 – 2.5 µm], ASD with about 10 nm spectral resolution is installed in a dark room laboratory. The soil samples are uniformly illuminated by a solar lamp with 15° incidence, which spectral behavior is close to the spectral sun shape in the reflective domain. The measurements are performed at Nadir, and the 10° field of view spectroradiometer is positioned vertically at a distance such that the observed surface is in agreement with the one of the Bruker spectrometer. Instrument calibration is

performed with a spectralon lambertian references.

In thermal domain [3 – 15 µm], spectral reflectances are directly measured with a Fourier Transform InfraRed (FTIR) instrument (Bruker). An Infragold integral sphere is used from 2 µm to 15 µm with a spectral resolution better than 0.5 cm^{-1}. Instrument calibration is achieved using an Infragold diffuse reference twice per day.

3.   RESULTS

The spectral reflectances of bare soil's samples are measured at different moisture contents (about 50% to 2%). Therefore, more than three hundred spectral signatures are measured and analysed from the visible (VIS) [0.4 – 0.8 µm], near and shortwave infrared (NSWIR) [0.8 – 2.5 µm], medium wavelength infrared (MWIR) [3 – 5 µm], and to the long wavelength infrared (LWIR) [8 – 15 µm] domains. We suggest first an analysis of dry samples spectra to determine a soil classification from spectra behaviour, and then a study of soil moisture content impact on spectra.

3.1.   Soil classification

In VIS domain, three reflectance spectra classes are determined from previous works (Courault et al., 1988): spectra weakly concave with low-level (T1V); spectra that is not particularly convex with high level (T2V); and spectra concave then convex with predominant level that is not particularly high (T3V). Spectra's T1V indicates that soil is composed by predominant organic matter, whereas T2V is typical of fullness's soil in lime but weak in iron oxide, then T3V appears for fullness's soil in iron oxide.

In NSWIR domain, presence of absorption peaks of hydroxyl (OH^-) at 1.4 µm, 1.9 µm and 2.2 µm is the principal common characteristic for all the samples. And so we consider that there is only one type of spectra behaviour (TNS) for all the samples in NSWIR domain.

In MWIR domain, we are considering two types of spectra in this waveband: spectra bell-shaped (T1M) and spectra with two lobes (T2M).

In LWIR domain, most of minerals have typical minimum of emissivity. This minimum (or maximum of reflectance) is known like Reststrahlen band (Salisbury et al., 1992). Presence of quartz (S_iO_2) in soils, shows on reflectance spectra a strong Reststrahlen band between 8 µm and 10 µm, whose the true location depends on amount of silica, and a weak Reststrahlen band between 12.2 µm and 13 µm. Carbonates (CO_3^{2-}) are usually Reststrahlen bands between 6 µm and 8 µm. However, secondary bands can exist, as an other band of carbonates at 11.3 µm. Finally, for our soil classification we are considering three types of spectra in LWIR: spectra with strong and weak Reststrahlen bands of quartz (T1L); T1L plus spectra with weak secondary Reststrahlen bands of carbonates (T2L); and spectra with strong secondary Reststrahlen bands of carbonates (T3L).

Finally, an illustration of two soils classes is given in Figure 2. For these samples, the spectra behaviour is mainly different in VIS and LWIR domain. The first soil (Figure 2,up) has strong sandy characteristics, with T3V, T2M and T2L behaviour whereas the second soil (Figure 2, down) has rather calcareous features, with T2V, T2M and T3L spectra.

A first validation is performed according to soil coloration. Indeed, soil coloration is mainly due to mineral composition. For examples, a fullness's soil in iron oxide provides a soil coloration which tend toward red, whereas a white soil has as mainly component calcareous (carbonates). Soils classified by groups are compared to hue values of soils coloration by using Munsell color system (*http://www.applepainter.com/*). We observe a coherence between groups and hue values. In the next, it will be interesting to validate our classification by means of chemical analysis.
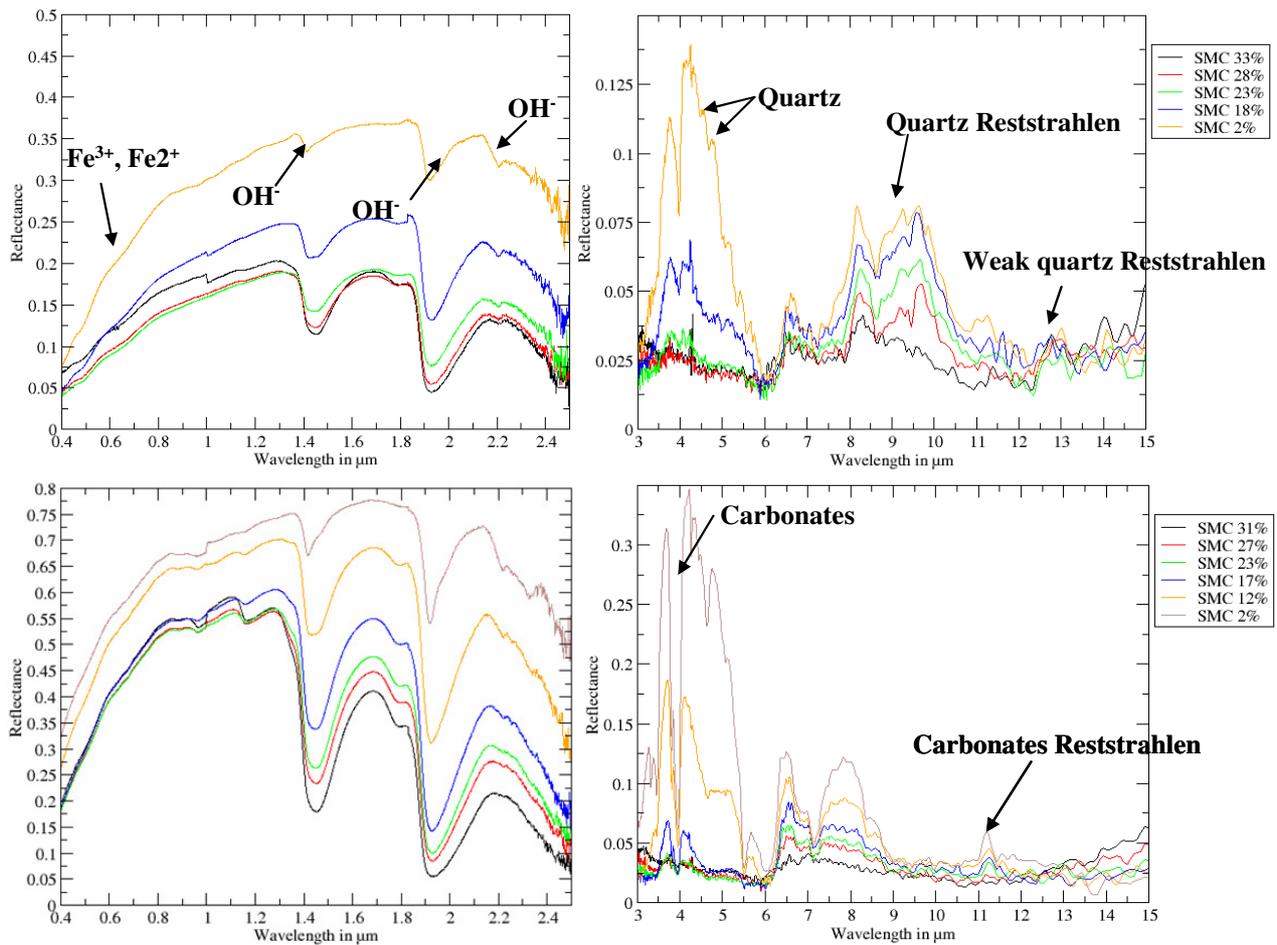
Figure 2. Spectra measurements of two samples (up, down) in the solar (left) and thermal (right) domain

3.2. Impact of soil moisture content

From this classification, impact of soil moisture on spectral reflectance is studied. An example for T3V, TNS, T2M and T1L is given in Figure 3.

In VIS, level of reflectance decreases when SMC increases for all types of soil (T1V, T2V and T3V) and spectra level deviation between dry and saturated sample is inferior to 0.13 for all the samples. Furthermore, absorption peaks of iron (Fe^{2+}) existing in spectra T3V, not seem sensitive to moisture content (Figure 3, up and left).

In NSWIR, as demonstrated by previous works (Angström, 1925; Liu et al., 2003; Haubrock et al., 2008), level of reflectance reduces (inferior to 0.3), and depth of absorption peaks of hydroxyl (OH^-), at 1.4 µm and   1.9 µm, increase and widen with

SMC (Figure 3, up and right). On the other hand, we noted loss of absorption peaks of the hydroxyl (OH^-) at 2.2 µm, because this peak is not linked to water but to other minerals.

In thermal domain [3 – 15 µm], as solar domain, increase of SMC involves decrease of reflectance level as described by Mira et al. (2007) for emissivity, and furthermore, absorption peaks detection is almost impossible if SMC is upper 20 % (Figure 3, down). In MWIR, carbonates and silicates (quartz) absorption peaks are lowered when SMC increases. This observation is better underlined in the spectra type T2M than T1M. In LWIR, SMC impact on Reststrahlen bands of quartz and carbonates (Figure 3). Spectra level deviation is higher in MWIR (inferior at 0.17) than in LWIR domain (inferior at 0.05), and so it's more difficult to study impact of soil moisture content in LWIR domain.
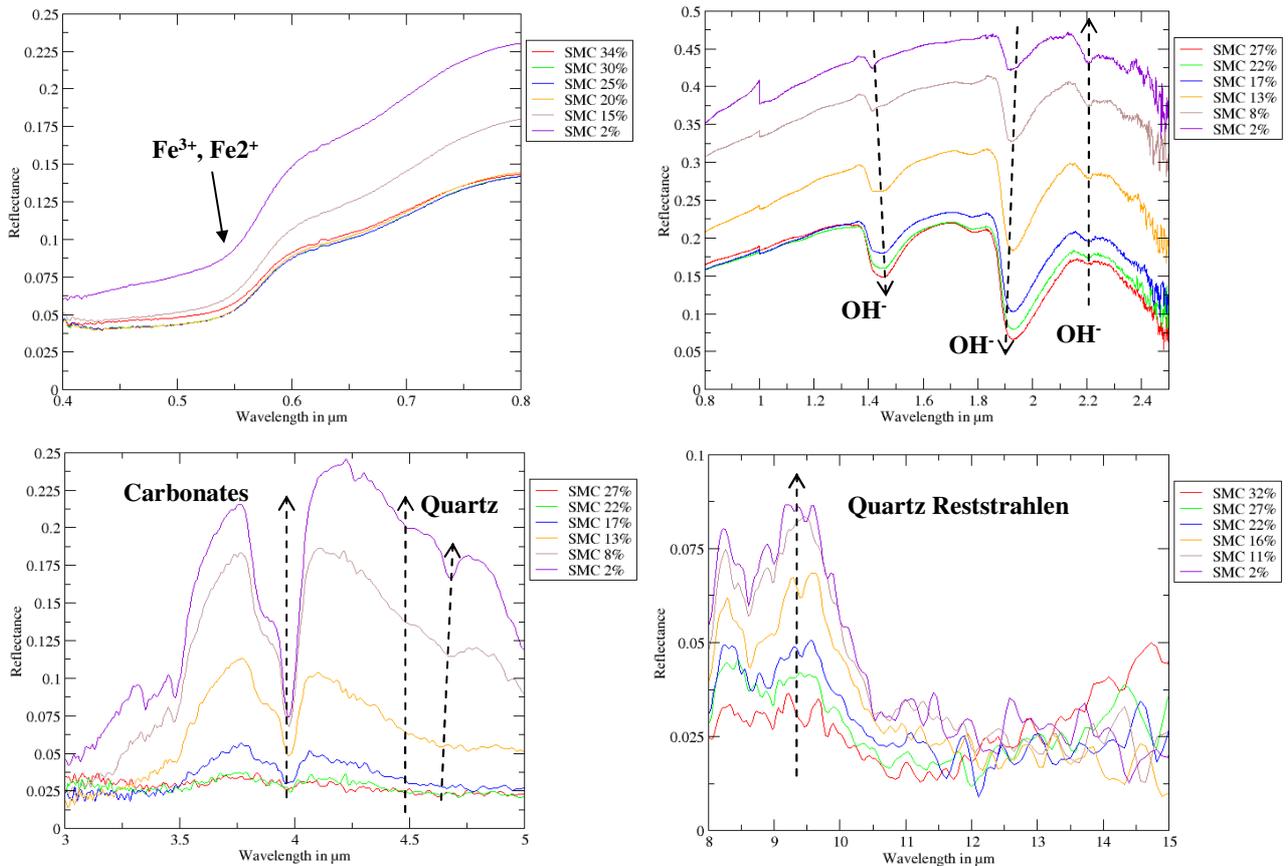
Figure 3. Impact of SMC in T3V (up, left), TNS (up, right), T2M (down, left) and T1L (down, right) reflectance spectra measurements

4. CONCLUSIONS

We dispose of a new database, composed of spectral reflectance of bare soils related to SMC in [0.4 – 15 µm].

Therefore, laboratory measurements of bare soils show that an increase of SMC involves: a reduction of reflectance level in optical domain (mean of maximum reflectance deviation inferior to 0.3); a growth of depth and spreading absorption peaks of hydroxyl (OH^-), linked to water (H_2O), at 1.4 µm and 1.9 µm; a diminution of depth absorption peaks of minerals in NSWIR and MWIR wavebands; and a decrease of Reststrahlen bands of quartz and carbonates in LWIR.

This work has permitted us to better understand the soil moisture impact, and measurements will be used in a processing chain to estimate the SMC in the optical domain [0.4 – 15 µm], and to develop an empirical model of spectral reflectance of bare soil at different moisture contents.

5. REFERENCES

Angström, A. (1925). The albedo of various surfaces of ground. *Geografiska Annali*, 7, pp. 323-327

Clark, R. N. (1995). Reflectance spectra. *American Geophysical Union*, pp. 178-188

Courault, D., Girard, M.C., & Escadafal, R. (1988). Modélisation de la couleur des sols par télédetection. *Actes du 4e Coll. Int. Signatures spectrales d'objets en télédétection*, Aussois, 357-362

Haubrock, S., Chabrillat, S., Lemmnitz, C., & Kaufmann, H. (2008). Surface soil moisture

quantification models from reflectance data under field conditions. *International Journal of Remote Sensing*, Vol. 29, 1, pp. 3-29

Khanna, S., Palacios-Orueta, A., Whiting, M.L., Ustin, S.L., Riaño, D., & Litago, J. (2007). Development of Angle Indexes for Soil Moisture Estimation, Dry Matter Detection and Land-cover Discrimination. *Remote Sensing of Environment*, 109, pp. 154-165

Liu, W., Baret, F., Gu, X.F., Tong, Q., Zheng, L., & Zhang, B. (2002). Relating soil surface moisture to reflectance. *Remote Sensing of Environment*, vol. 81, pp. 238-246

Liu, W., Baret, F., Gu, X., Tong, Q., Zheng, L., & Zhang, B. (2003). Evaluation of methods for soil surface moisture estimation from reflectance data. *International Journal of Remote Sensing*, 24, pp. 2069-2083

Lobell, D., & Asner, G. (2002). Moisture Effects on Soil Reflectance. *Soil Sciences American Journal*, 66, pp. 722-727

Mira, M., Valor, E., Boluda, R., Caselles, V., & Coll, C. (2007). Influence of soil water content on the thermal infrared emissivity of bare soils : implication for land surface temperature determination. *Journal of Geophysical Research*, Vol. 112, F04003

Peters, J. (2000). On-Farm Moisture Testing of Corn Silage. *Focus on Forage*, vol 2, n°6

Salisbury, J.W., & D'aria, D.M. (1992). Emissivity of terrestrial materials in the 8 - 14 µm atmospheric window. *Remote Sensing of Environment*, vol. 42, pp. 83-106

Salisbury, J.W., & D'aria, D.M. (1994). Emissivity of terrestrial materials in the 3 - 5 µm atmospheric window. *Remote Sensing of Environment*, vol. 47, pp. 345-361

Whiting, M.L., Li, L., & Ustin, S.L. (2003). Predicting water content using Gaussian model on soil spectra. *Remote Sensing of Environment*, vol. 89, pp. 535-552

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