ESTIMATION OF SOIL MOISTURE CONTENT OF BARE SOILS FROM THEIR SPECTRAL OPTICAL PROPERTIES IN THE 0.4 – 12.0 µM SPECTRAL DOMAIN

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1. INTRODUCTION

The purpose of this paper is the capacity of spectral reflectance, in the full optical domain 0.4 – 12.0 µm, to retrieve the Soil Moisture Content (SMC) of bare soils. Indeed, the knowledge of surface soil moisture is a key point for many applications like trafficability after flood, ground – atmosphere exchanges and plant good health. Hyperspectral image acquisitions (narrow spectral bands and high spectral resolution) provide the most detailed information. Thus, the opportunity of using such measurements to retrieve the soil moisture of bare soils is exploited.

Using the opportunity accessing to the spectral reflectance of bare soil as a function of several SMC on the entire optical domain, this paper aims to compare the SMC estimation as a function of existing SMC formulations and of the spectral domain. To this end, an end to end simulator is used to simulate the incident signal, acquired by an optical sensor over a given homogeneous landscape characterised by its spectral optical properties, followed by a retrieval method to estimate the on ground spectral reflectance and then its corresponding SMC. The results are compared to SMC methods directly applied on spectra measured in laboratory [5].

2. PROBLEM STATEMENT

Until now, separate approaches to estimate SMC from spectra exist in solar and thermal domains.

In the solar domain, methods, based on spectral reflectance, may be classified in two main approaches: analytical method and spectral model. Analytical methods based on spectral bands processing [1], and spectral index [2], show that the short wavelength infrared (SWIR, 1.4 – 2.5 µm) domain is the best appropriate spectral range to estimate the SMC. Further, spectral models, like inverse Gaussian model (SMGM) [3], show that the area of the fitted continuum in the 1.2 – 2.5 µm, is highly correlated with the SMC.

In the infrared thermal domain, few works have been conducted and soil moisture impact have only been studied in the long wavelength infrared (LWIR, 8 – 15 µm) domain [4], from the spectral emissivity. Mira et al. [4] show the spectral ratio seems to be a good indicator of SMC in the LWIR.

From this state of art, several criterion of SMC estimation are retained: spectral index, correlation matrix method, and a convex hull model. Robustness of these approaches is then tested taking into account the atmosphere.

3. METHODOLOGY

3.1. Criterion of SMC estimation

The SMC estimation used different methods existing in the literature: spectral index, correlation matrix method which permit to characterize the most wavelengths sensitive to SMC and deduce new spectral index, and convex hull method (Figure 1). This last is based on the model of SMGM [3], and its principle is to determine the convex hull (continuum) of spectra on the entire optical domain (Figure 1, left). Then, the determination of the area contained between the convex hull and the spectra is linked to the SMC (Figure 1, right). All these methods have been developed and grouped in a tool box, named Analysis Tools of Spectra (ATS) which allow identifying wavelengths and criterion sensitive to SMC in the entire optical domain.

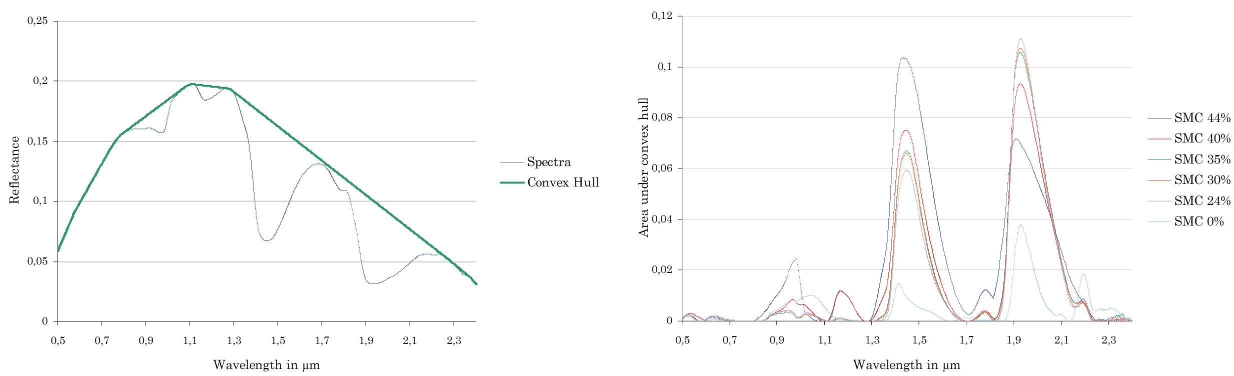

Figure 1 – Convex hull method (left), Difference between the convex hull of bare soil's spectra for several SMC (right).

3.2. Applications of the several SMC retrieval methods

A first evaluation of the SMC methods performances is purchased with spectra of lab measurement. This step permits to give some results for ideal cases (that means free oneself from external disturbing parameters related for example to atmosphere) and to specify an empirical soil reflectance model. This last synthetic model allows us to simulate spectral reflectance at every SMC.

In real conditions, the scene is viewed by an airborne or space borne sensor and a retrieval method is necessary to estimate the resulting reflectance. To cover the entire optical domain, a complete simulation chain is required, and based on our end-to-end simulator. This last is composed of the direct model to simulate the at sensor radiance and the inverse procedure, named ALOHA, Algorithm for soiL mOistrure estimation from Hyperspectral datA, to retrieve the spectral reflectance after an atmosphere compensation.

The direct chain (Figure 2, up) allows obtaining synthetic at sensor radiance for several SMC. Inputs are the atmosphere and viewing conditions and the spectral reflectances of bare soils for several SMC. The reflectance data set come from either laboratory measurements purchased in 2008 [5] or the empirical soil model fitted over these measurements.. The radiative effect of the atmosphere to simulate at sensor radiance is achieved using the MODerate resolution atmospheric TRANsmission code [6]. A sensor module including spectral response and instrumental noise is integrated. The inverse code (Figure 2, down), ALOHA, provides two kind of outputs: ground soil reflectance retrieval from at sensor radiance, and estimation of the SMC. The atmospheric compensation is done in the solar (0.4 – 2.5 µm) domain using the code COCHISE [7], and in the thermal domain (3 – 12 µm), an ASTER [8] based algorithm.

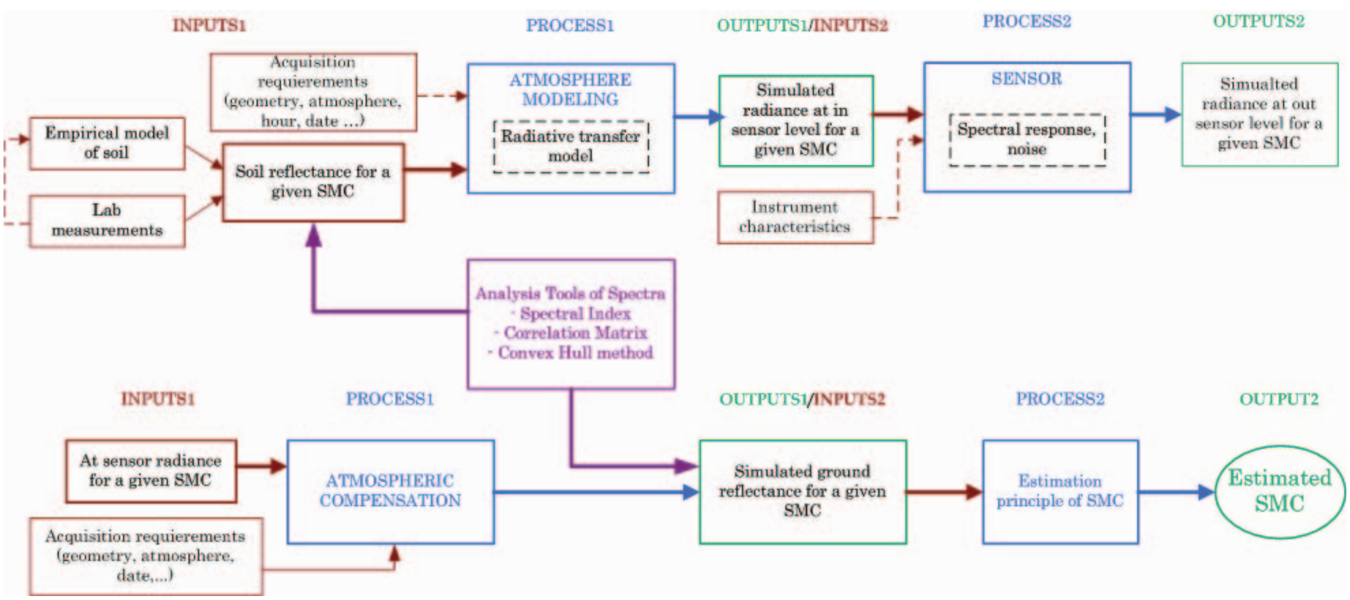

Figure 2 – End-to-End simulator: direct (up) and inverse (down) chain.

4. RESULTS

Spectral index from literature have been tested on our lab measurements, and confirmed literature results. Currently, they are evaluated after atmospheric compensation. The convex hull method (Figure 1), which determines the spectra continuum and the area includes between spectra and its convex hull, indicates that area is well sensitive to SMC with a $R^2 > 0.8$ for our lab measurements, especially in solar domain. Currently, robustness of the convex hull method is studying with the end-to-end simulator according to water vapour content related to the atmospheric profile.

5. CONCLUSIONS

Several criterions for the SMC retrieval from the spectral reflectance were determined. The ATS have been applied on spectra of lab measurements and spectra obtained with the end-to-end simulator. Currently, analysis of atmosphere impact on the different method is purchased. So, when the processing chain and simulations will be completed, we could develop a robust method to SMC retrieval from spectral reflectance (from hyperspectral imaging).

6. REFERENCES

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

[2] S. Haubrock, S. Chabrillat, C. Lemmnitz, and H. Kaufmann, "Surface soil moisture quantification models from reflectance data under field conditions", *International Journal of Remote Sensing*, vol. 29, 1, pp. 3-29, 2008.

[3] M.L.Whiting, L. Li, and S.L. Ustin, "Predicting water content using Gaussian model on soil spectra", *Remote Sensing of Environment*, vol. 89, pp. 535-552, 2003.

[4] M. Mira, E. Valor, R. Boluda, V. Caselles, and C. Coll, "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, 2007.

[5] Lesaignoux A., Fabre S., Briottet X., Olioso A., "Soil moisture impact on lab measured reflectance of bare soils in the optical domain 0.4 – 15 µm", *Proceedings IGARSS'09 workshop*, Capetown, South Africa, 12-17 July 2009.

[6] A. Berk, G.P.Anderson, P.K Acharya, J.H. Chetwynd, L.S. Bernstein, E.P. Shettle, M.W. Matthew, and S.M. Adler-Golden, "MODTRAN4 USER'S MANUAL", Air Force Research Laboratory, 1999.

[7] C. Miesch, L. Poutier, V. Achard, X. Briottet, X. Lenot, and Y. Boucher, "Direct and inverse radiative transfer solutions for visible and near infrared hyperspectral imagery", *IEEE Transactions on Geosciences and Remote Sensing*, Vol. 43, no 7, 2005.

[8] ASTER : http://www.science.aster.ersdac.or.jp/en/documnts/atbd.html