PhD position

Clay hazard mapping by intelligent spectral-spatial mixing of hyperspectral images acquired by drone

Keywords: hyperspectral, multi-temporal, clay discrimination, demixing, spectro-spatial methods

Start: end of November 2020

Profile: optical or physical engineering schools, remote sensing, physical geography, signal / image processing, radiative transfer, scientific programming

Context and problematic: Soils represent a complex environment, dynamic in time and space, in their structure as in their composition [1]. They provide essential services to humanity such as water storage and filtration, aid to precision farming, carbon sequestration to regulate the climate and physical support for buildings. In particular, knowledge of the composition of the soil in clay minerals and its mapping are necessary for the assessment of the “shrinkage-swelling” risk that affects buildings, or the taking into account of the effects of runoff / infiltration during floods. The identification of soils impacted by these phenomena is currently based on the recognition of specific minerals either by spot measurements for example by using X-ray diffraction (XRD) on samples or using hazard maps (1: 50,000) produced from geological data to identify these clay formations. Such maps cannot take into account local spatial heterogeneities (1 to 100 m) [2]. Another solution lies in the use of in situ and / or proximal sensors. Several authors have successfully quantified mineralogical clays in soils [3-5] by field and laboratory spectroscopy. In these studies, the measurements were generally carried out on dry soils in order to overcome the impact of humidity on the measured spectral reflectance, and under ideal lighting conditions. But such a technique does not cover a large area. Airborne hyperspectral imagery removes this limitation and has been used successfully to detect and quantify clays [6-8], despite low spatial resolution and a low signal-to-noise ratio in the spectral range of clays (1000-2500 nm). Recent advances in drone-type platforms with hyperspectral imagery are expected to eliminate some of these limitations through better spatial processing of acquired images. In addition, they would open up possibilities for revisiting for different environmental conditions thanks to a more agile mobilization of the sensors. Thus, multiple acquisitions on a well-informed site, particularly on its surface and in-depth lithological and geotechnical characteristics, would make it possible to establish the relationships between the volume characteristics of the soil and the hyperspectral surface acquisitions. It would then be possible to construct a map of clay hazards consistent between surface observations and geotechnical measurements. These advances must offer more pure pixels and therefore improve the quantification of clay minerals. But quantifying the mineralogical clays by taking into account the mixture of the spectral signatures of the minerals requires to verify the hypotheses of a linear spectral response of the mixture or the need to take into account a non-linearity of this response [9] using methods of " mixture ". Finally, given the accumulation of various types of available data (spectroscopic, morphological, geological, pedological, environmental, etc.), multi-source processing methods using exogenous data can also help to develop strategies to better conclude as for the abundances of clay minerals on plots of bare soil and visible in airborne remote sensing. The work of Ducasse (2019) carried out as part of a BRGM-ONERA thesis showed that it was possible to quantify the abundance of montmorillonite compared to other mineralogical clays (kaolinite and illite) and others minerals (calcite and quartz) in the laboratory but also in the field by hyperspectral spectroscopy for spatial resolutions of the order of cm and assuming known a priori the pure poles of mixtures ("endmembers"). The performances are highly dependent on the origin of the endmembers (databases), the type of pre-treatment applied to the reflectance spectra before mixing and the choice of the mixing model (linear or non-linear). One of the limitations of this work was the soil moisture.

Objective of the thesis: The objective of this new thesis aims to improve, validate and extend our methodology in order to build a clay hazard map based on hyperspectral airborne acquisitions on an ULM light carrier or drone. To this end, work will focus on an assessment and improvement of the methods of mixing change of scale (change from cm to dm, role of local shadows and sparse vegetation), development of a new research strategy for mixing poles using all of the area covered by an aircraft (contribution of machine learning), evaluation of the contribution of exogenous data (1: 50,000 soil mapping) and / or multi-time acquisitions to improve our estimates, in order to take better account of soil moisture.

Several stages are thus identified:

1. Carrying out light carrier acquisition campaigns on different types of terrain. The doctoral student will have several datasets. A first dataset has already been acquired as part of the Ducasse's thesis using hyperspectral cameras placed at the top of a nacelle (12 m) and it will be used to carry out the first developments and comparison of methods of discrimination of clays. A second data set will be acquired during this thesis from cameras on board a light aircraft in two areas (an instrumented reference area and a second area for applying and validate the methods). This dataset will consist of several acquisition campaigns during of the year which can correspond to different humidity states.
2. Evaluation of the methods developed within the framework of Ducasse's thesis at the resolution scale spatial acquisition on light aircraft (typically tens of centimeters) on different types of soil having different clay contents taking into account multitemporal data. Indeed, the taking several shots into account during the year should make it possible to better assess the behavior of these methods in natural environments. Particular attention will be paid to the analysis of the influence of grain size and surface moisture of soils on performance.
3. Evaluation of the impact of the chosen endmembers (USGS database, ground truth, spectra of synthetic blends, etc.) and the type of blending model for optimal convergence of algorithms. In this context, two paths will be analyzed. The first will be based on the use of exogenous data from geological, soil, mineralogical maps, etc. will be analyzed in order to better constrain our algorithms. The second way will be based on the exploitation of all the pixels in a hyperspectral image (other than the mean and standard deviation of the spectra, traditionally used) in order to remove classification rules which will make it possible to identify "Clusters" of homogeneous behavior, then to extract the group considered as the best candidate as an endmember to the blending algorithms. This will allow, among other things, to compare the performance between pixel and object approaches, as well as a combination of criteria spatial and spectral. Finally these different methods will be compared in order to define the best procedure for obtaining a mineralogical clay abundance map.
4. Production of a hazard map useful for the assessment of the "shrinkage-swelling" risk. It will be about being able cross hyperspectral information (clay abundance map) and lithological data, soil, mineralogical… The selection of sites by their characteristics will be a major criterion to investigate in this thesis in order to offer an exemplary character to establish a hazard map. So questions such as the choice of natural, agricultural or anthropogenic areas (constructions) should be approached in particular from the angles of contributions and limitations for the investigation multidisciplinary envisaged.
5.

The candidate will draw on the skills of 3 laboratories BRGM, LPG and ONERA. The doctoral student will share its time between BRGM-Orléans (50%) and ONERA-Toulouse (50%).

[1] Carmon N, Ben-Dor E. An advanced analytical approach for spectral based modelling of soil properties. International Journal of Emerging Technology and Advanced Engineering. 2017; 7(3):90-97

[2] Bouchut J, Giot D. Cartographie de l'aléa retrait-gonflement des argiles dans le département du Loiret. Rapport technique RP-53316-FR, BRGM. 2004. Available from: http://infoterre.brgm.fr/rapports/RP- 53316-FR.pdf
[3] Dufréchou V, Grandjean G, Bourguignon A. Geometrical analysis of laboratory soil spectra in the shortwave infrared domain: Clay composition and estimation of the swelling potential. Geoderma. 2015; 243-44(2015):92-107
[4] Mulder VL, Plötze M, de Bruin S, Schaepman ME, Mavris C, Kokaly RF, et al. Quantifying mineral abundances of complex mixtures by coupling spectral deconvolution of SWIR spectra (2.1-2.4 mm) and regression tree analysis. Geoderma. 2013; 207-208:279-290
[5] Viscarra Rossel RA, McGlynn RN, McBratney AB. Determining the composition of mineral-organic mixes using UV-vis-NIR diffuse reflectance spectroscopy. Geoderma. 2006; 137(1-2):70-82
[6] Bedini E, van der Meer F, van Ruitenbeek F. Use of HyMap imaging spectrometer data to map mineralogy in the Rodalquilar caldera, Southeast Spain. International Journal of Remote Sensing. 2009; 30(2): 327- GEN-F160-9 (GEN-SCI-029) 348
[7] Chabrillat S, Goetz AFH, Krosley L, Wolsen H. Use of hyperspectral images in the identification and mapping of expansive clay soils and the role of spatial resolution. Remote Sensing of Environment. 2002; 82(2-3): 431-445
[8] Kruze FA, Boardman JW, Huntington JF. Comparison of airborne hyperspectral data and EO-1 Hyperion for mineral mapping. IEEE Transactions on Geoscience and Remote Sensing. 2003;41(6): 1388-1400 [9] Ducasse, E., 2019. Cartographie fine de l'argile minéralogique par démélange d'images hyperspectrales à très haute résolution spatiale. Thèse 3eme cycle, ISAE, Toulouse.

Supervisors : ONERA (X. Briotet, K. Adeline), BRGM (G. Grandjean, Anne Bourguignon, Audrey Hohmann), LPG (Véronique Carrère)

Contacts : xavier.briottet@onera.fr, g.grandjean@brgm.fr