Thesis proposal EcoSys-SAS

Hyperspectral spatio-temporal monitoring of soil properties and management practices in Northwestern France

Thèse de doctorat spécialisé : soil, remote sensing, environment.
Hosting labs : UMR SAS, 65 rue de Saint-Brieuc, 35042 cedex Rennes/UMR EcoSys, équipe Sol&Tox, 22 Place de l'Agronomie 91120 Palaiseau.
Thesis director : Emmanuelle Vaudour (emmanuelle.vaudour@inrae.fr), UMR EcoSys.

Co-supervisors: Didier Michot (didier.michot@ agrocampus-ouest.fr), Youssef Fouad (youssef.fouad@agrocampus-ouest.fr), UMR SAS.

Key-words : soil properties, soil organic carbon, soil moisture, soil roughness, soil management practices, hyperspectral time series, drones, satellite time series, digital soil mapping

Date : 36 months from November 2023.

Context of the thesis proposal

One of the key objectives of agroecology and agroforestry is to promote carbon storage in soils and to develop the type of practices to achieve this, see initiative 4/1000 (INRAE, 2019; Pellerin et al., 2021) . This thesis proposal will contribute to the flagship MELICERTES project, which aims to integrate data from multiple heterogenous sources to develop satellite and data-driven spectral and spatial models of soil organic carbon content and stocks and develop satellite-based diagnoses of agricultural practices that maximize soil carbon storage.

There is a growing need to spatially estimate and monitor many soil properties, at different spatial and temporal scales, to support and guide soil and land management as well as decision- and policymakers. Among these soil properties, the soil organic carbon (SOC) content is of particular importance, evolving over medium (5-10 y) time periods at least. However, until now, there is no efficient and straightforward way of monitoring topsoil organic C (SOC) content at such scales, and even less SOC stock, being the carbon mass per unit area for a given depth, ie the product of SOC content by considered depth, soil bulk density, and the percent volume of soil out of rock fragments. Over the last two decades, digital soil mapping (DSM) has gained more and more recognition and application linking field, laboratory, proximal and remote soil observations and patterns with quantitative spatial and geostatistical methods to infer spatial patterns of soils (Grunwald et al., 2010). The GlobalSoilMap program which aims to provide a fine resolution global grid of soil functional properties has specified international standards for output maps (Arrouays et al., 2014, 2018), including the requirement of estimates of their associated uncertainties (Malone et al., 2011, 2017; Vaysse and Lagacherie, 2017; Zaouche et al., 2017) and these are used in various global products (Global Soil Partnership, 2017; Hengl et al., 2017). However, the update of digital soil maps is time consuming and labour intensive for proximal approaches, while in the majority of approaches, satellite data are only used as pattern information or as ancillary information. Remotely sensed images, either acquired from airborne or satellite sensors, may enable to acquire exhaustive datasets that could serve to predict soil properties, either directly as primary predictors, or indirectly as ancillary covariates as is often the case now.

Thesis objectives

The thesis proposal is focused on the development, calibration and validation of models for i) SOC content prediction and detection ; ii) soil management works, from spectral data at local farm or catchment scales. The models will be based mainly on hyperspectral airborne data in conjunction with Sentinel-2 data, radar (e.g., Sentinel-1) or and hyperspectral satellite data (e.g., PRISMA, EnMap) and/or thermal infrared images (Landsat-8, Sentinel-3, CCI products) to have information on the surface temperature.

Q1 – Do hyperspectral images from drone or satellite favor a performance gain for predicting surficial SOC contents ?

To date, no hyperspectral drone image has been used for the purpose of SOC content prediction. Very few papers have used single-date hyperspectral satellite images at local scale : Hyperion in Australia (Gomez et al., 2008), PRISMA in Italy (Casa et al., 2013 ; Mzid et al., 2021). The accuracy that can be reached from such data source is to be known.

Q2 – Do hyperspectral time series from drone or satellite enable to retrieve disturbing factors for the SOC prediction, such as soil moisture and soil roughness ?

Our recently published study demonstrated the benefits of incorporating soil moisture information through a Sentinel2 and 1 time series, and of the use of deep learning for the purpose of SOC content prediction from such series (Zayani et al., 2023). This thesis will elaborate more on this feasibility and on its performance evaluation considering algorithms, data sources and sites, and also soil roughness measurement and impact.

Q3 - Do hyperspectral time series from drone or satellite enable to monitor ploughing ?

Very few papers have used remote sensing images, even more hyperspectral images, for the purpose of characterizing soil management. Referring to the mapping of agricultural practices, our previous studies demonstrated not only the feasibility of crop detection at early crop stages using very high resolution Pléiades images (Vaudour et al., 2015), but also the feasibility of discriminating between non reworked winter plough and spring tillage operations using an optical/radar pair (SPOT/ASAR ENVISAT) (Vaudour et al., 2014), and the feasibility of spectrally retracing of organic amendment practices (Dodin et al., 2023).

This thesis will relate the soil roughness and soil moisture measurements from varied sources to the ploughing events through several time series. It will carry out time analysis and benefit data fusion or data disaggregation (Rivas et al., 2021) at daily scale. The processing of an earth observation data cube obtained from the fusion of several sensor data, including radar S1, or daily Sentinel-3, or even Landsat8 thermal data, across a very large temporal series covering 3-5 y or more (Lewis et al., 2017; Giuliani et al., 2019) will be sought in order to improve both spectral richness and temporal resolution (daily) of the time series.

Organisation and methodology

The thesis will be cosupervised by INRAE Ecosys (E. Vaudour) and Institut Agro Rennes Angers (Didier Michot, Youssef Fouad) with specific collaboration with INRIA (Nicolas Brodu). It will rely on long term experiment facilities, such as the Nouzilly farm and the Naizin catchment, on which airborne and EnMap acquisitions and field campaigns will be scheduled. It will benefit from the soil data and the datasets already gathered and under collection in the framework of the ongoing projects POLYPHEME and STEROPES. The processing approaches will benefit the backing from INRIA.
Several measurement campaigns will be scheduled over the two first years of the thesis. The second and third years will be focused on data processing and on paper and manuscript redaction.

Working environment

The PhD student will be hired by AgroParisTech, EcoSys in the framework of MELICERTES (PEPR « Agroécologie et numérique, France 2030 program). He will be mainly based in the UMR SAS in Rennes. He will register to the doctoral school ABIES.

Funding : PhD salary (2023-2025) of ~1950 euros net of taxes/month.

Requested profile

- Master diploma in soil science, agronomy, rural or physical geography, remote sensing/geomatics ;
- Good knowledge and practice of geomatics, stats ;
- Skills and knowledge in remote sensing, stats with R and/or Python are a plus ;
- Good oral and written skills, in French and in English ;
- Driving licence, and taste for field observations.

Procedure for candidating

Candidates must send a motivation letter and a CV , copies of academic transcripts and the names of two referring persons (traininship supervisor or teachers) to emmanuelle.vaudour@inrae.fr, didier.michot@ agrocampus-ouest.fr, youssef.fouad@agrocampus-ouest.fr. Oral selection will be proposed to a number of candidates upon their written documents.

Thesis shall start on November 3rd for a 3-years duration.

Bibliographie

1. Arrouays, D., Grundy, M.G., Hartemink, A.E., Hempel, J.W., Heuvelink, G.B.M., Hong, S.Y., Lagacherie, P., Lelyk, G., McBratney, A.B., McKenzie, N.J., et al., 2014. GlobalSoilMap. In Advances in Agronomy; Elsevier, Vol. 125, pp. 93–134 ISBN 978-0-12-800137-0.
2. Arrouays, D., Richer de Forges, A., McBratney, A. B., Hartemink, A. E., Minasny, B., Savin, I., Grundy, M., Leenaars, J. G. B., L. Poggio, Roudier, P., Libohova, Z., McKenzie, N. J., van den Bosch, H., B. Kempen, Mulder, V. L., Lacoste, M., Chen, S., Saby, N., Martin, M., Roman Dobarco, M., Cousin, I., Loiseau, T., Lehmann, S., Caubet, M., Lemercier, B., Walter, C., Vaudour, E., Gomez, C., Martelet, G., Krasilnikov, P., Lagacherie, P., 2018. The globalsoilmap project; past, present, future, and national examples from France. Bulletin of Dokutchaev Soil Science Institute, 95, 22 p. DOI : 10.19047/0136-1694-2018-95-3-23.
3. Casa, R., Castaldi, F., Pascucci, S., Basso, B., Pignatti, S., 2013. Geophysical and Hyperspectral Data Fusion Techniques for In-Field Estimation of Soil Properties. Vadose Zone Journal 12, 0. https://doi.org/10.2136/vzj2012.0201
4. Dodin, M., Levavasseur, F., Savoie, A., Martin, L., Foulon, J., Vaudour, E., 2023. Sentinel-2 satellite images for monitoring cattle slurry and digestate spreading on emerging wheat crop: a field spectroscopy experiment. Geocarto International 38, 2245371. https://doi.org/10.1080/10106049.2023.2245371
5. Giuliani, G., Camara, G., Killough, B., Minchin, S., 2019. Earth Observation Open Science: Enhancing Reproducible Science Using Data Cubes. Data 4, 147. https://doi.org/10.3390/data4040147
6. Gomez, C., Viscarra Rossel, R.A., McBratney, A.B., 2008. Soil organic carbon prediction by hyperspectral remote sensing and field vis-NIR spectroscopy: an Australian case study. Geoderma 146, 403–411.
7. Grunwald, S. 2010. Current State of Digital Soil Mapping and What Is Next. In Digital Soil Mapping; Boettinger, J.L., Hengl, T., Mendes de Jesus, J., Heuvelink, G.B.M., Ruiperez Gonzalez, M., Kilibarda, M., Blagotić, A., Shangguan, W., Wright, M.N., Geng, X., Bauer-Marschallinger, B., Guevara, M.A., Vargas, R., MacMillan, R.A., Batjes, N.H., Leenaars, J.G.B., Ribeiro, E., Wheeler, I., Mantel, S., Kempen, B., 2017. SoilGrids250m: Global gridded soil information based on machine learning. PLOS ONE 12, e0169748. https://doi.org/10.1371/journal.pone.0169748
8. Howell, D.W., Moore, A.C., Hartemink, A.E., Kienast-Brown, S., Eds.; Springer Netherlands: Dordrecht; pp. 3–12 ISBN 978-90-481-8862-8.
9. INRAE - Étude de faisabilité de « 4 pour 1000 » en France : préserver et augmenter les stocks de carbone dans le sol - Juin 2019
10. Lewis, A., Oliver, S., Lymburner, L., Evans, B., Wyborn, L., Mueller, N., Raevksi, G., Hooke, J., Woodcock, R., Sixsmith, J., Wu, W., Tan, P., Li, F., Killough, B., Minchin, S., Roberts, D., Ayers, D., Bala, B., Dwyer, J., Dekker, A., Dhu, T., Hicks, A., Ip, A., Purss, M., Richards, C., Sagar, S., Trenham, C., Wang, P., Wang, L.-W., 2017. The Australian Geoscience Data Cube — Foundations and lessons learned. Remote Sensing of Environment 202, 276–292. https://doi.org/10.1016/j.rse.2017.03.015

11. Malone, B.P., de Gruijter, J.J., McBratney, A.B., Minasny, B., Brus, D.J., 2011. Using Additional Criteria for Measuring the Quality of Predictions and Their Uncertainties in a Digital Soil Mapping Framework. Soil Science Society of America Journal 75, 1032. https://doi.org/10.2136/sssaj2010.0280
12. Malone, B.P., Minasny, B., McBratney, A.B., 2017. Some methods for the quantification of prediction uncertainties for digital soil mapping. In Malone et al. (Eds), Using R for digital soil mapping, chapter 7, Springer, 169-218.
13. Mzid, N., Castaldi, F., Tolomio, M., Pascucci, S., Casa, R., Pignatti, S., 2022. Evaluation of Agricultural Bare Soil Properties Retrieval from Landsat 8, Sentinel-2 and PRISMA Satellite Data. Remote Sensing 14, 714. https://doi.org/10.3390/rs14030714
14. Pellerin, S., Bamière, L., Savini, I., Réchauchère, O., 2021. Stocker du carbone dans les sols français; éditions Quae, 2021; ISBN 978-2-7592-3149-2.
15. Rivas, H., Delbart, N., Ottlé, C., Maignan, F., Vaudour, E., 2021. Disaggregated PROBA-V data allows monitoring individual crop phenology at a higher observation frequency than Sentinel-2. International Journal of Applied Earth Observation and Geoinformation, 104, 102569, doi:10.1016/j.jag.2021.102569.
16. Vaudour, E., Baghdadi, N., Gilliot, J.M., 2014. Mapping tillage operations over a peri-urban region using combined SPOT4 and ASAR/ENVISAT images. International Journal of Applied Earth Observation and Geoinformation, 28, 43-59. DOI:10.1016/j.jag.2013.11.005
17. Vaudour, E., Noirot-Cosson, P.E., Membrive, O., 2015. Early-season mapping of crops and cultural operations using very high spatial resolution Pléiades images. International Journal of Applied Earth Observation and Geoinformation 42, 128–141. https://doi.org/10.1016/j.jag.2015.06.003
18. Vaysse, K., Lagacherie, P., 2017. Using quantile regression forest to estimate uncertainty of Digital Soil Mapping products. Geoderma, 291, 55–64, doi:10.1016/j.geoderma.2016.12.017.
19. Zaouche, M., Bel, L., Vaudour, E., 2017. Geostatistical mapping of topsoil organic carbon and uncertainty assessment in Western Paris croplands (France). Geoderma Regional 10, 126-137.
20. Zayani, H., Fouad, Y., Michot, D., Kassouk, Z., Baghdadi, N., Vaudour, E., Lili-Chabaane, Z., Walter, C., 2023. Using Machine-Learning Algorithms to Predict Soil Organic Carbon Content from Combined Remote Sensing Imagery and Laboratory Vis-NIR Spectral Datasets. Remote Sensing 15, 4264. https://doi.org/10.3390/rs15174264