MONITORING SOIL PROPERTIES USING ENMAP SPACEBORNE IMAGING SPECTROSCOPY MISSION

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ABSTRACT

The Environmental Mapping and Analysis Program (EnMAP) is a new spaceborne German hyperspectral satellite mission, whose primary goal is to generate accurate information on the state and evolution of the Earth´s ecosystems. The core themes of EnMAP are monitoring environmental changes, ecosystem responses to human activities, and management of natural resources such as soils and minerals. EnMAP started on 1st April 2022 and is now in operational phase since over six months, with strong expectations regarding data quality and impact on soil research. In this paper, we aim to demonstrate in a few case studies the observed current capabilities for EnMAP with regard to soil mapping based on different test sites and methodologies. Key soil properties could be derived and spatially mapped in agricultural test sites in semi-arid and temperate zones such as Soil Organic Carbon (SOC) content important for soil health and carbon sequestration, texture (clay content) important for soil fertility, and carbonate content. Additionally, we test different standard and state-of-the art methodologies, including new scenarios for time-series of hyperspectral remote sensing data for improved soil products.

Index Terms— spaceborne imaging spectroscopy, EnMAP, soil resources, digital soil mapping

1. INTRODUCTION

Soils are recognized as an essential provider of foods and services, and for their role as carbon storage with 30% of global terrestrial carbon stored in soils. The mapping and monitoring of soil properties as indicators of soil quality and soil health is an important pre-requisite and requested to support several actions and policies such as the European Soil Protection Directive. Preserving our soil and its health will support e.g. the European Green Deal, international initiatives such as the 4 per 1000 Initiative, and policies for reducing greenhouse gas emissions.

Spectroscopy of soils (point and imaging) in the VNIR-SWIR spectral range (400-2500 nm) has demonstrated a strong potential for the accurate determination of soil properties in the laboratory, field, and from airborne data with a resolution of a few meters. Accordingly, there is a high expectation from adopting the current and upcoming VNIR-SWIR imaging spectroscopy spaceborne sensors to monitor soils [1], e.g. using PRISMA (ASI, launch 2019), EnMAP (DLR, launch 2022), and EMIT (NASA/JPL, launch 2022). Nevertheless, a comprehensive demonstration and thorough testing of their capabilities and limitations for the global mapping and monitoring of soil properties from space at varying resolution (spatial, spectral and temporal) is still necessary.

EnMAP orbital sensor is based on a push-broom type sensor concept [2] and operates in a polar, sun-synchronous, low orbit around Earth at 652 km height. EnMAP's core parameters are a regional coverage at global scale (target mission), 30 m pixel size, tile size 30 km x 30 km, 242 spectral channels (currently 224 bands are delivered to the users), revisit of 27 days at nadir and 4 days with off-nadir tilting (+-30º). The project management of the EnMAP mission is with the DLR Space Agency in Bonn, Germany. The sensor was built by OHB System AG, the Ground

Segment is led by DLR in Oberpfaffenhofen, and the Science Activities led by GFZ Potsdam with the support of the EnMAP Science Advisory Group (EnSAG) and the EnMAP science project teams. After six months of commissioning phase related to calibration and validation activities [3], the EnMAP mission opened for routine operations on November 2022. The EnMAP archives and requests for new observations can be accessed through the EnMAP portal at https://planning.enmap.org/. EnMAP offers a free and open data policy.

In the frame of the EnMAP science program related to soil science applications, main research objectives are the demonstration of its potential for the provision of new and accurate soil products, and the developments of operational retrieval of soil properties with processing chains and algorithms for the scientific and operational exploitation of EnMAP data (L3 soil products), and future CHIME data. In our study, we are working at the calibration and validation of soil products from spaceborne imaging spectroscopy data based on available in-situ soil data and global soil spectral libraries, and on testing the EnMAP performances for soil properties modeling in different environments and climatic zones, using different regression methods.

2. EXAMPLE USE CASES

2.1. SOC, clay, and carbonate mapping (Aminteio, Greece)

The study area is located near the village of Amyntaio in the region of West Macedonia in northern Greece. It is characterized with a Mediterranean climate, rain-fed agriculture, and it is mostly covered with grain crops and sunflower. The area is bordered in the north by a mountain range and in the south by a lignite open-pit mine. Overall, the test site is characterized by a significant variety in the terrain of the surrounding area, which explains the wide range of soil properties in terms of carbonate and organic matter content, and makes it an ideal case to test different methodologies and prediction performances.

The area was covered by two EnMAP scenes (60 km x 30 km) acquired on 7th October 2022. The L2A product orthorectified Bottom-of-Atmosphere reflectance was ordered and downloaded from the archive. The atmospheric wavelengths were removed and the apparent reflectance spectra were smoothed using Savitzky-Golay method. For the derivation of soil maps, all pixels that were not dry and bare soil (associated with water, green vegetation, non-photosynthetic vegetation) were first masked based on spectral indices and thresholds developed within the framework of the HYSOMA/ENSOMAP development [4]. Then a Partial Least Square Regression (PLSR) model was performed on the bare soil pixels using ground truth data from soil sampling campaigns conducted in 2018 and 2019.

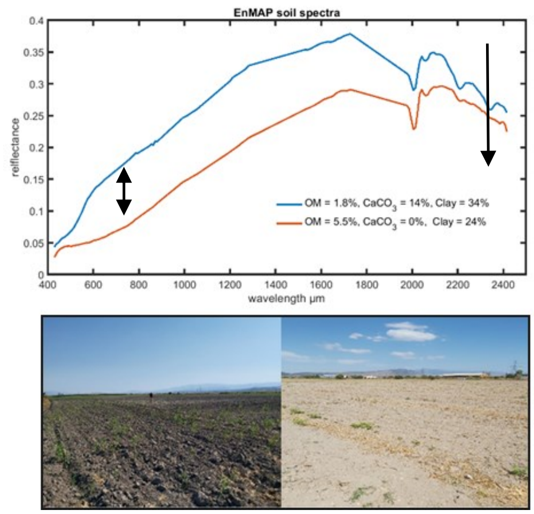

Fig 1. EnMAP soil spectra of organic matter rich area (left picture, red spectrum) vs. a carbonate and clay rich area (right picture, blue spectrum).

A total of 64 soil sampling points were collected during this period, which were subsequently narrowed down to 17 locations representing bare soils in 2022.

Figure 1 shows typical high signal-to-noise ratio EnMAP spectra. Spectral signature was able to indicate differences on its morphology due to organic matter contents. In the higher organic matter sample with 5.5% OM, we can clearly see the spectral concave shape from 500 to 1000 nm, and the opposite at the one with 1.8% OM. The absorption feature of CaCO3 is also strong and clear. These results supports the statistical results (Figure 2).

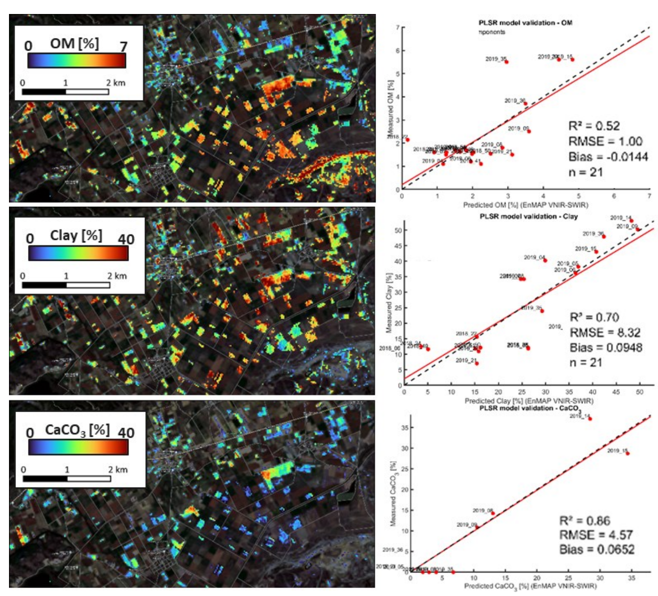

Fig 2. Quantitative maps of soil properties (left) based on EnMAP satellite data; Performance of the spectral modeling with leave-one-out cross validation (right).

Figure 2 shows the results for soil properties mapping. We can observe areas with very high carbonate contents in the north-east and very high organic matter contents in the south-west. The spatial mapping is coherent with previous studies in the region [5], and prediction accuracies are reasonable compared to similar studies in European test sites [6] with R^2 from ~0.5 to 0.8.

2.2. Clay, iron oxide and carbonate mapping (Camarena, Spain)

The study area Camarena is located in the centre of Spain, in the north-west sector of the Autonomous Community of Castilla-La Mancha, Province of Toledo, approximately 50 km SW from Madrid. This area joins characteristics of special interest such as Mediterranean climate, extended agricultural rain-fed uses, mostly evolved soils, and erosion features associated to contrasting soil horizons. The sustained agricultural practices have caused soils to be degraded by erosion and the result is a transformation of the soil as different surface or subsurface horizons have been exposed. It is therefore of interest to identify and determine the distribution of different soil properties associated to the soil degradation where underlying soil horizons are exposed or the eroded material is displaced and accumulated downslope [7]. This causes the soils to reduce their capacity to function adequately and therefore are less fertile which affects the final crop production [8].

Figure 3 shows semi-quantitative soil property maps based on an EnMAP summer acquisition of 3d August 2022. The areas high in iron-oxide and clay mineral content are examples of moderately eroded field plots with exposed weathering horizon (Bt), whereas the stripe of high carbonate content highlights a strongly eroded region with exposed calcite rich bedrock layer (Ck). At 30 m spatial scale resolution, the contrasted Camarena small-scale surface features can still be detected and show coherent differences with the field and previous observations.

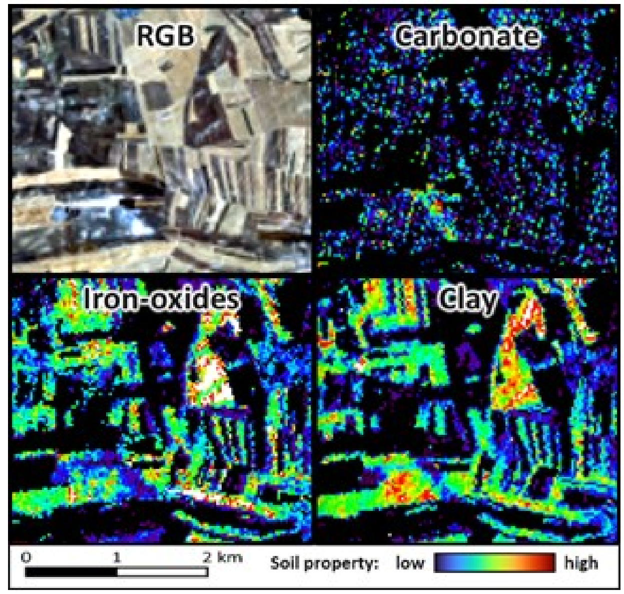

Fig 3. Semi-quantitative maps of clay, iron oxide and carbonate content based on EnMAP satellite data.

2.3. SOC mapping (Demmin, Germany)

The study site is located in an agricultural area in the North-East of Germany within the long-term observatory of TERENO-NE and near the village of Demmin. An important soil property to observe is the content of soil organic carbon (SOC) as it provides important ecosystem services and plays an essential role in the context of climate change and food security. In order to improve its quantification and monitoring we applied state of the art methods of imaging spectroscopy to estimate and map the SOC content in the uppermost soil layer. Additionally, here we are testing new scenarios to involve time-series hyperspectral for an improved spatial mapping of bare soils that can be seen as methodological precursors for CHIME and SBG missions. For this, as EnMAP is a new mission, we used for this work four PRISMA scenes that have been recorded over two years.

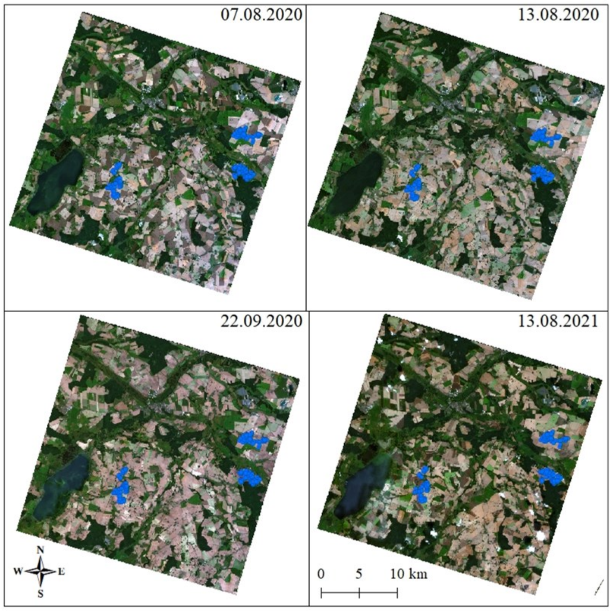

Fig 4. Multitemporal hyperspectral spaceborne acquisitions over Demmin soil test site.

A ground truth dataset of about 180 soil samples is used, for which SOC content was analyzed. For the SOC spectral prediction in each image, besides using current state-of-the-art regression techniques linked with local soil data, we used large-scale soil spectral library (European wide LUCAS Soil database) in an approach called two-step local PLSR [6]. This approach replaces the wet-chemistry analyses by estimating the SOC content of the local samples from the study site based on their laboratory reflectance and models calibrated from the LUCAS database using spectral similarities. Additionally, we investigated different approaches to combine the four images into one multitemporal composite SOC map. Depending on the compositing approach and on the regression methods, R^2 from 0.5 to 0.83 were achieved. The best performing model was applied to all bare soil pixels to produce SOC content maps within all PRISMA scenes, resulting on a seamingless soil product.

3. CONCLUSIONS

This paper demonstrates what the new era of spectroscopy from space can bring to the soil discipline. The high quality of EnMAP data allows to derive and map several key topsoil properties in bare and semi-bare areas with high accuracy. Future work focuses on improving spectral and modeling techniques for an improved determination of thresholds for semi-bare pixels and improving the soil properties determination over mixed soil-vegetation scenarios. An additional focus is on the development of global soil spectral libraries with standards and protocols. Also, this paper shows for the first time how future scenarios of hyperspectral spaceborne time-series may be used to develop the full potential of imaging spectroscopy from space and will benefit global soil mapping and monitoring.

4. ACKNOWLEDGMENTS

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