



CUP4SOIL

Soil organic carbon stocks of agricultural fields in Brandenburg – CUP4SOIL showcase documentation

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1. Purpose and structure of the document

One of the objectives of the CUP4SOIL project is to prepare and develop a user community that tests and validates data products suitable for soil health/quality assessment. One of the pillars of this objective is the development of showcases. This document contains one of the conducted showcases, describes the aim, partner, methodology and results. It is expected to gain important and user-based information for the usefulness of the generated EO-based information products as well as a more detailed view into the purpose, for which the information products might be used in the future.

2. CUP4SOIL project overview

The CUP4SOIL project aims to contribute to a downstream EO-based service to support national and European agencies in reporting on soil health/quality and thus, contribute to Land Degradation Monitoring (LDN) and Sustainable Development Goal (SDG 15.3.1) reporting. The products can potentially also be used for other than national uses, such as for more local and/or commercial applications. It underpins the pre-operational Soil Monitoring System currently being developed within the ESA WorldSoils project with the potential to serve as a component of the Copernicus Land Monitoring Service. The synergies between the ESA WorldSoils project and the CUP4SOIL activities investigating soil health mapping will streamline the activities and boost user uptake. The 2-year CUP4SOIL project comprises the following objectives:

- Suggest soil data products as new products for the Copernicus Land Monitoring Service to support national and European agencies for reporting on soil health/quality.
- Generate European-wide example data products characterising soil health/quality
- Develop a user community that tests and validates data products for soil health/quality information
- Ensure close cooperation with the ESA WorldSoils project activities and other related projects/initiatives

Initiatives and literature: In the first step, CUP4SOIL explores the different literature and project resources to get an update about the current discussion of essential soil health indicators. This is collected in a first version of a User Requirement Document (URD) that CUP4SOIL presents, discussed and adapted with a larger community during the first User Requirement virtual meeting. For this purpose, a specific online user survey is developed based on the framework of the Copernicus user requirements. The survey is planned to be repeated at the end of the project.

Soil data products: In the next step, CUP4SOIL generates European-wide soil information products based on Sentinel-1 and Sentinel-2 data. For this purpose, DLR and ISRIC join their large-scale processing expertise and facilities. DLR is creating several soil-related input products such as soil reflectance composites, information about the cover frequency of soils and the vegetation dynamic on a high spatial resolution (20 m). These data products flow into the high-performance computing environment of ISRIC that generates information about soil organic carbon content, texture pH values, etc. using digital soil mapping approaches. The resulting output data will be made publicly available. Selected key users are involved to evaluate the usability of the proposed soil information products. It is also planned to compare the CUP4SOIL products with other existing European-wide soil products from running projects and initiatives. The results will be presented and discussed at the final workshop.

Showcases: Based on this user exchange and feedback, the Copernicus URD is updated and required changes are integrated into the soil information processors of DLR and ISRIC to improve the soil product portfolio. In this phase, showcases are developed together with local municipalities, national institutes and European agencies. The showcases use the suggested Copernicus soil input data to derive higher-value information about soil quality and health for specific regions to demonstrate the usability and applicability of the soil product portfolio for Copernicus users. The results and evaluation of these showcase developments will be presented and discussed for a larger user community at the final CUP4SOIL workshop.

3. Showcase – Soil organic carbon stocks of agricultural fields in Brandenburg

The objective of this project is to predict the spatial distribution of soil organic carbon stocks in agricultural fields of the Federal State of Brandenburg. The project is a contribution to the climate strategy of Brandenburg which aims to reduce the net greenhouse gas emissions to zero by the end of 2045. The results will enable federal authorities to assist farmers in their activities to reduce loss of soil organic carbon and increase soil fertility.

3.1 Partner description

The State Office for Mining, Geology and Raw Materials of Brandenburg (Landesamt für Bergbau, Geologie und Rohstoffe; LBGR) is the Federal Geological Service of Brandenburg, an agency that provides information on the properties and the spatial distribution of soils (e.g. soil maps) to federal and national agencies, scientific institutions and the public. Traditionally, soil maps have been created manually based on expert knowledge by assessment of data from soil sampling campaigns and of environmental data such as maps of geology, geomorphology and land use. More recently, these traditional techniques are complemented by data-driven methods such as machine learning. These models allow to represent more complex interactions and include a far higher set of input variables, such as image data. This showcase is one of the first projects of the LBGR where these techniques have been applied.

3.2 Involved data

Data (acronym)	Data name	Area	Time period	Used (checkbox)
SCMaP Soil Suite				
SRC-MEAN	Bare Surface Reflectance Composite (Mean)	Federal State of Brandenburg	2018-2022	x
SRC-STD	Bare Surface Reflectance Composite (Standard deviation)			
SRC-CI95	Bare Surface Reflectance Composite (95% Confidence)			
MASK	Bare Soil Mask			
BSF	Bare Soil Frequency			
BSC	Bare Soil Count			
VPC	Valid Pixel Count			
MREF-MEAN	Reflectance Composite (Mean)			
MREF-STD	Reflectance Composite (Standard deviation)			

Table 3-1: CUP4SOIL data list

Other data involved:

- digital elevation model and derived morphometric variables
- geological maps

- soil maps
- land use maps
- crop (rotation) maps

3.3 Task for this showcase

The goal of the project is the estimation and prediction of the organic carbon stock of mineral soils for agricultural fields (cropland, grassland) in Brandenburg. This is the first attempt of the LBGR for a state-wide estimation of carbon stocks on agricultural mineral soils with no comparable prior project. Agriculturally used peatlands were not considered, because a map of the organic carbon stocks for peatlands has already been published (Fell et al. 2015).

For the project 650 sites were selected for sampling (Figure 1). At each site, 5 soil pits combined with drilling up to a depth of one meter were conducted. Soil horizons with an organic carbon content above 0.3 % were sampled and analysed for bulk density, pH, organic and inorganic carbon content. The carbon stock of each site was then derived in four depth intervals (0-10 cm, 0-30 cm, 0-50 cm and 0-100 cm). The spatial distribution of carbon stocks was modelled with random forest for each depth interval independently, resulting in four trained separate models and four carbon stock maps. The covariates used for model fitting and prediction involve the digital elevation model and derived morphometric variables (e.g. slope, topographic wetness index), SRC, geological maps, soil maps, land use maps (i.e. cropland vs. grassland) and annual maps of crop types that were combined to yield proxy variables of crop rotation. The same set of covariates was used for each of the four models.

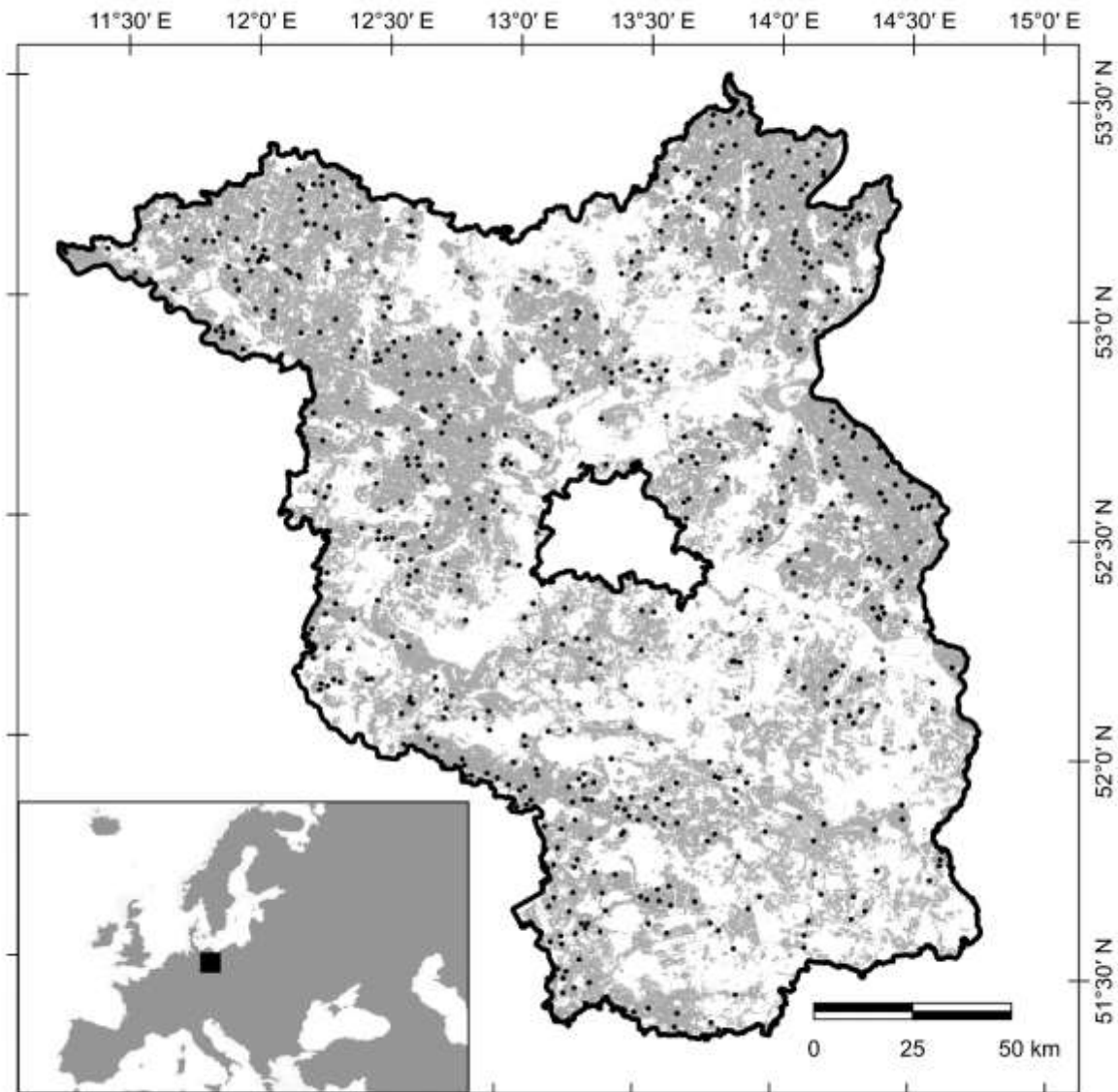


Figure 1: Map of the locations of the 650 sampling sites (black dots) and the agricultural area (grey shading) in the Federal State of Brandenburg. Inset: Location of the detailed map pane (black rectangle) in Europe (grey shading). Additional map data (state borders, agricultural area) from OpenStreetMap 2025 and GeoBasis-DE/LGB 2024 & 2025. Coordinates are in coordinate reference system with EPSG code 4326.

The preliminary results show that carbon stocks in the depth interval 0-10 cm and 0-100 cm are on average 2.0 and 6.5 kg m⁻² and range between 0.7-8.7 and 1.4-27.3 kg m⁻², respectively. This is lower than the average carbon stock of agricultural mineral soils for entire Germany. However, for Brandenburg it is in line with previous studies (Jacobs et al. 2018). Sites with higher carbon stocks are grasslands, hydromorphic soils and (poldered) floodplains such as the Oderbruch whereas low carbon stocks are croplands located on till plateaus (Figure 2). The regional pattern of carbon stock distribution corresponds to a small scale (1:300,000) map of carbon stocks in Brandenburg that has been published previously (Kühn et al. 2015).

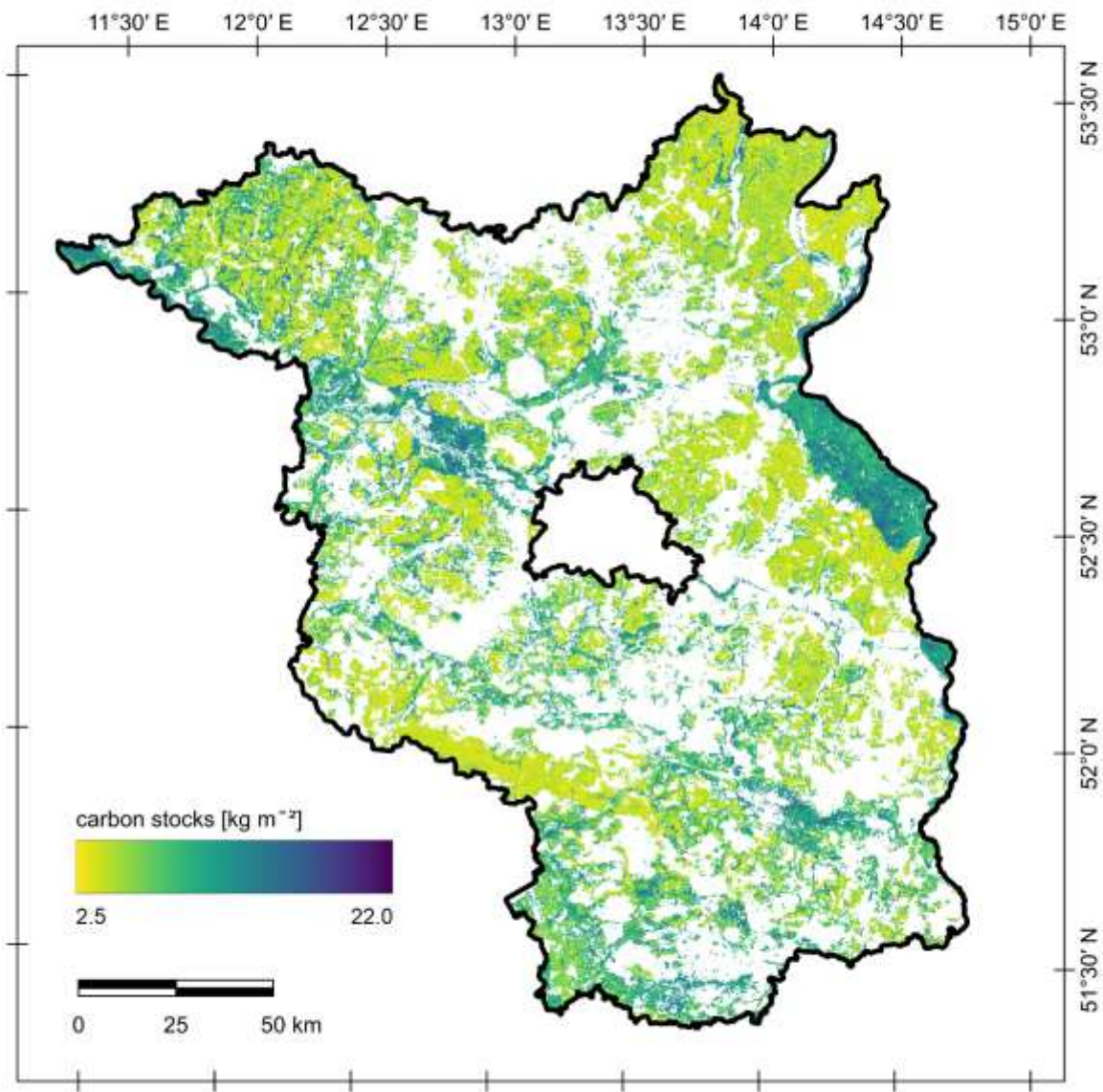


Figure 2: Spatial distribution of organic carbon stocks in the depth interval 0-100 cm of mineral soils for agricultural fields in the Federal State of Brandenburg. Additional map data (state border) from GeoBasis-DE/LGB 2025. Coordinates are in coordinate reference system with EPSG code 4326.

Each model was validated by the out-of-bag data giving a root mean square error and a Pseudo- R^2 of, for instance, 0.7 kg m^{-2} and 0.69 for the depth interval 0-10 cm and 3.0 kg m^{-2} and 0.53 for the depth interval 0-100 cm, respectively. The variable importance indicates that land use type, soil type, geological material and SRC are the most relevant predictor variables for all models.

3.4 Summary / evaluation of the CUP4SOIL data used

For our showcase, the SRC product proved to be a valuable contribution. As outlined above, SRC ranked among the most relevant covariates in terms of variable importance for all four models of soil carbon stock spatial distribution. The LBGR has currently not the expertise and the computing infrastructure to process satellite image data such as the SRC and thus depends on external providers to create high-quality soil

maps. Comparative tests of model performance with and without SRC as covariate showed a distinct improvement of performance when SRC was included. Based on our assessment of model quality we will include the SRC product in our set of predictors for our final publication of the carbon stock map of Brandenburg. In addition, we will test the applicability of SRC and similar CUP4SOIL products for prospective soil maps of Brandenburg.

The data format of the CUP4SOIL image data could be easily integrated in our data modelling pipeline. A feature that could simplify our future work would be the provision of image data in a custom coordinate projection system (e.g. the Universal Transverse Mercator projection combined with the European Terrestrial Reference System 1989) and resolution. As reprojection requires the application of an adequate resampling technique, we would benefit from recommendations of the data provider. This could be solved by either providing the image data with custom coordinate reference systems or providing guidelines on how to resample the data products.

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