The DLR SoilSuite and Beyond

AG Boden Meeting

10.04.2025

On behalf of the
CUP4SOIL Team (DLR and ISRIC)
Terrestrial Remote Sensing Team (DLR)

Content

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Copernicus
Framework Partnership Agreement for Copernicus User Uptake

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CUP4SOIL: High-resolution soil property service development for National and European soil carbon reporting

Survey on requirements and wishes for future soil products provided by the Copernicus Land Monitoring Service (CLMS).

Deutsches Zentrum für Luft- und Raumfahrt
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Implementing Partner: DLR
Implementing Country: Germany
Primary Topic: Land
Primary Target Users: Public Sector, Research Sector
Primary Target Region: Europe
Type of Action: Developing and piloting downstream applications and services
Action No.: 2020-2-14
Duration: Apr 2022 - Apr 2025 Last Update: 20 Oct 2023

This action aims at a downstream service to support national and European agencies for reporting on soil health/quality and thus, contribute to the Land Degradation Monitoring (LDN) and Sustainable Development Goal (SDG 15.3.1) reporting. It further 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. Using synergies between this action and the ESA WorldSoils project will streamline the activities and boost the user uptake. The 2-year CUP4SOIL project comprises the following objectives:

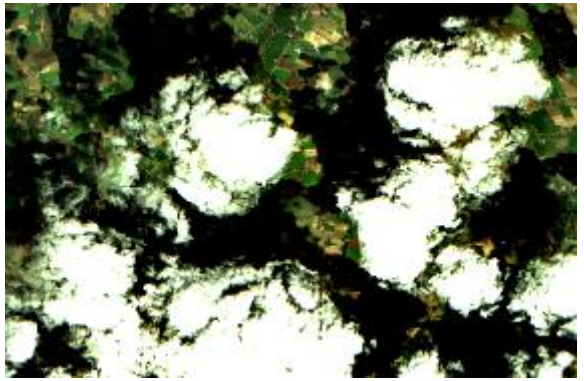
- Develop a potential Copernicus downstream service to support national and European agencies for reporting on **soil health/quality**.
- Generate **European-wide data products** and indicators characterising soil health/quality
- Prepare and **develop a user community** that tests and validates data products for soil health/quality information
- Ensure close **cooperation** with the ESA WorldSoils project activities and other related projects/initiatives such as the EJP soil project STEREOPES, SERENA, etc.

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 will be collected in a first version of a User Requirement Document (URD) that CUP4SOIL presents, discuss and adapt with a larger community during the first User Requirement virtual meeting. For this purpose, a specific online user survey will be developed based on the framework of the FPCUP requirements. The survey is

SOILSUITE FOR EUROPE

EO for soils

Clouds / Cloudshadow / …



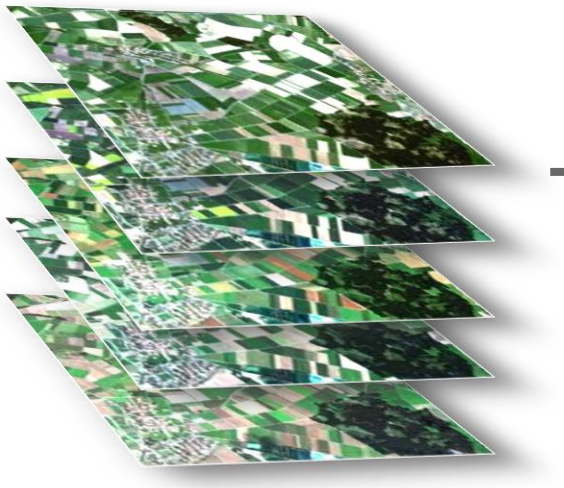
Detecting bare soil

Disturbances:
Green and dry vegetation, stubbles, moisture, structure

SoilSuite for Europe

Basic Idea

Single date images



Spectral index threshold

Single date bare soil masks

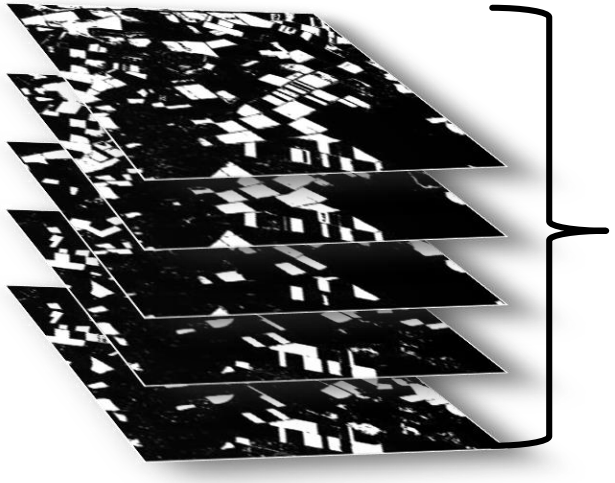
April 20.5%

May 17.5%

July 13.8%

Aug 26.8%

Sept 25.8%



Temporal Composite bare soil mask

Expanding data base

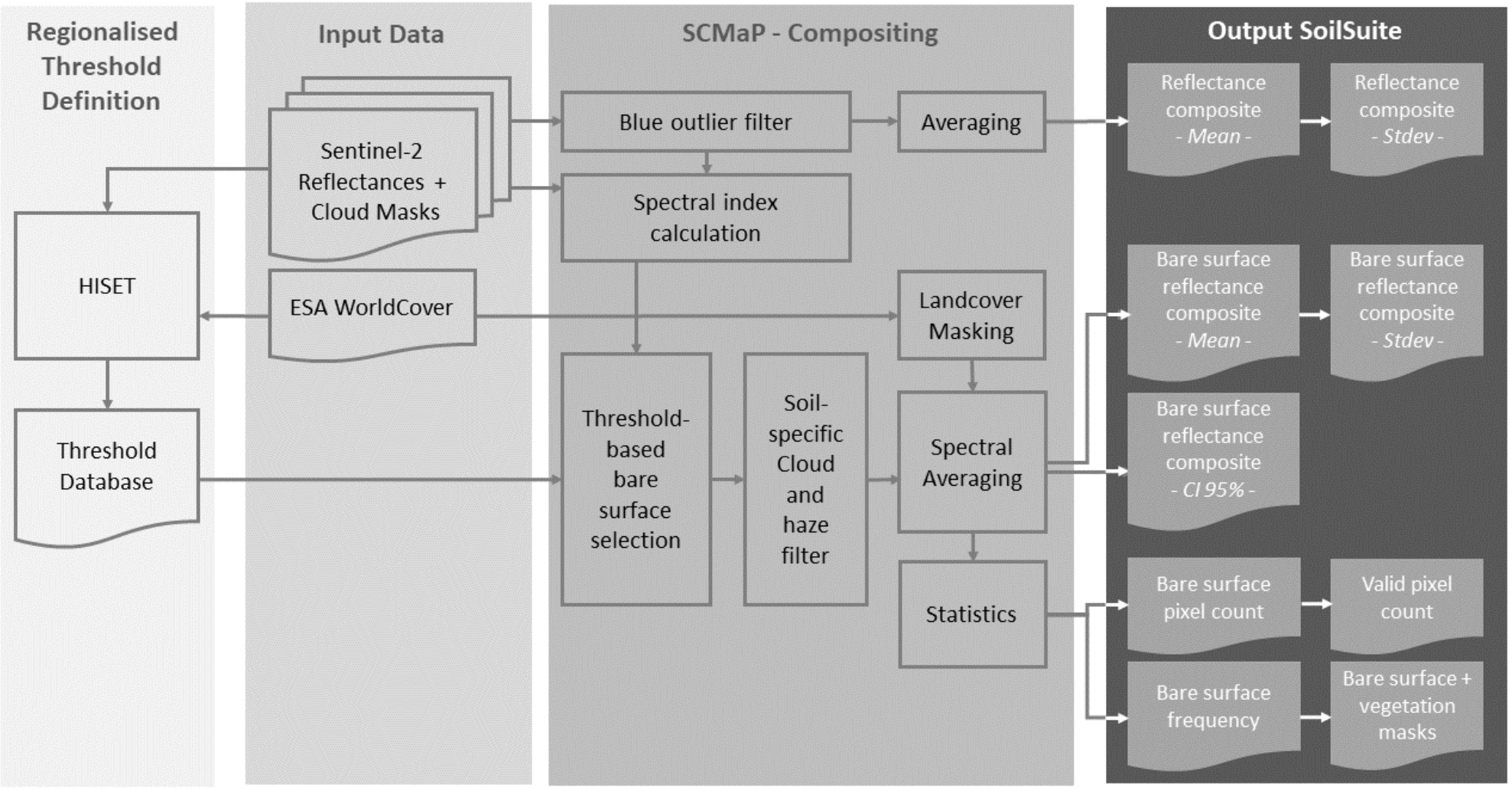
Bare Soil Exposure = 47.9 %

References

- Diek, S.; Fornallaz, F.; Schaepman, M.E.; De Jong, R. Barest Pixel Composite for Agricultural Areas Using Landsat Time Series. Remote Sens. 2017, 9, 1245.
- Rogge, D. et al. (2018). Building an exposed soil composite processor (SCMaP) for mapping spatial and temporal characteristics of soils with Landsat imagery (1984–2014), RSE, 205, 1-17.
- Demattê, J.A.M.; Fongaro, C.T.; Rizzo, R.; Safanelli, J.L. (2018). Geospatial Soil Sensing System (GEOS3): A powerful data mining procedure to retrieve soil spectral reflectance from satellite images. RSE, 212, 161–175.
- Heiden, U.; d'Angelo, P.; Schwind, P.; Karlshöfer, P.; Müller, R.; Zepp, S.; Wiesmeier, M.; Reinartz, P. Soil Reflectance Composites—Improved Thresholding and Performance Evaluation. Remote Sens. 2022, 14, 4526. https://doi.org/10.3390/rs14184526

SoilSuite for Europe

Soil Composite Mapping Processor (SCMAP)



Deployed at terrabyte – DLR's HPDA platform

Karlshöfer et al. (submitted)

Heiden et al., 2025: Tech report. https://doi.org/10.15489/qkud8cudg596

Heiden, U. et al.,2022: https://doi.org/10.3390/rs14184526

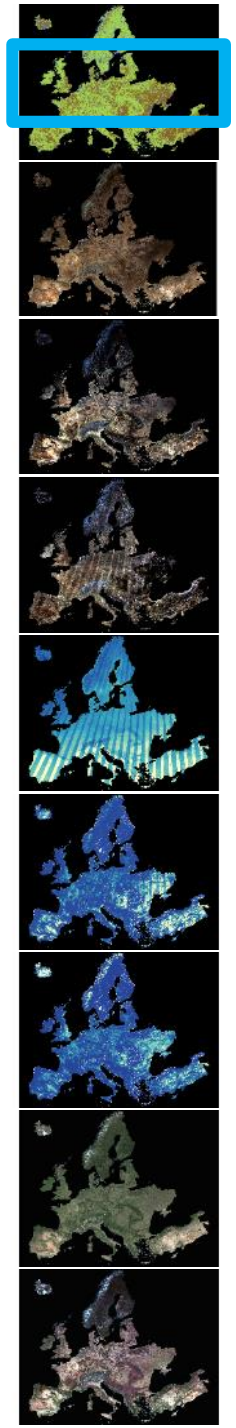
Rogge et al., 2018: https://doi.org/10.1016/j.rse.2017.11.004

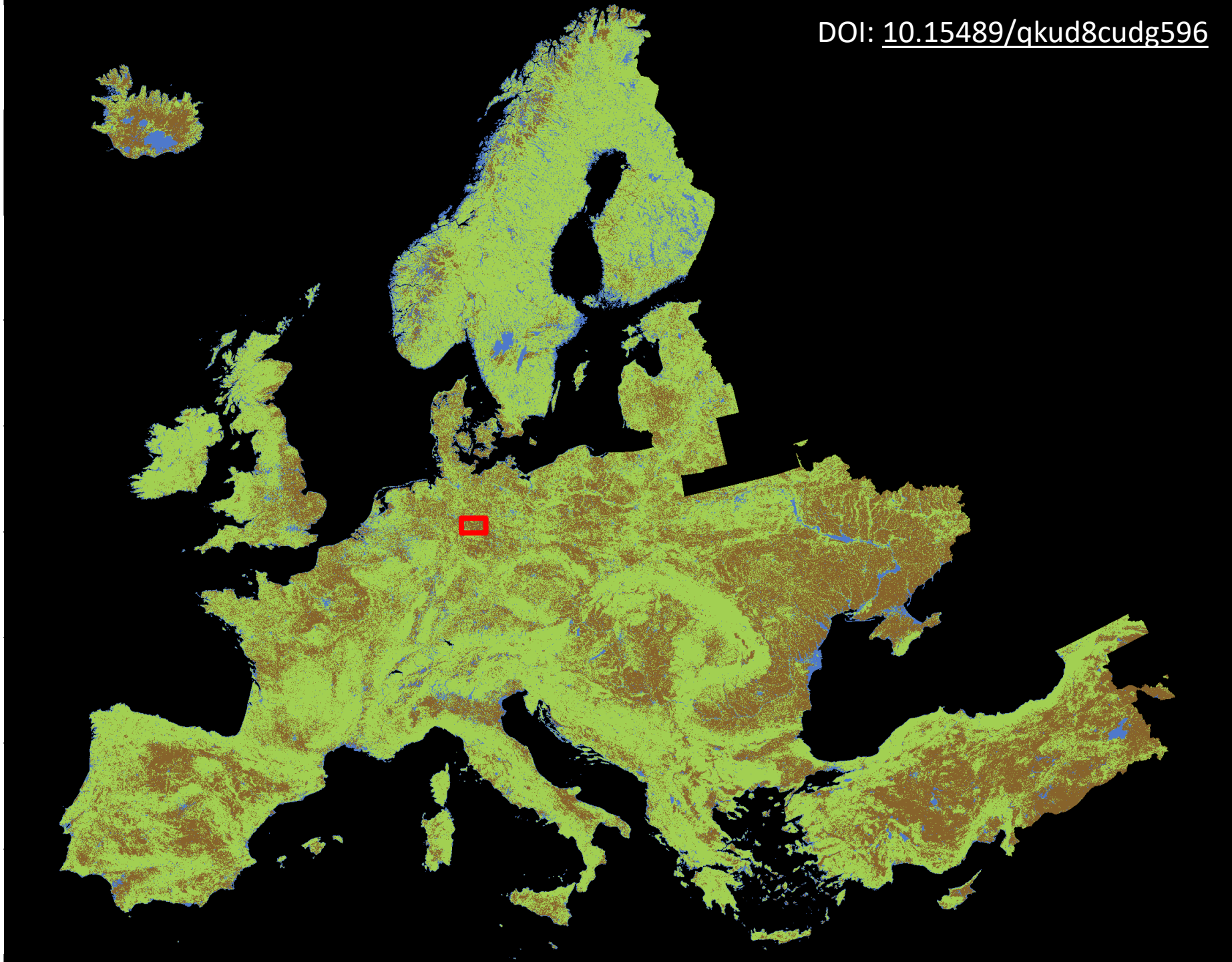
SoilSuite 2018 – 2022

- Sentinel-2
- 2018 – 2022
- < 80 % cloud cover
- > 20° sun elevation
- 20 m pixel size
- 3 bands

Bare Surface Mask

- Bare surface occurrence
- Permanent vegetation
- Other surfaces





DOI: 10.15489/qkud8cudg596

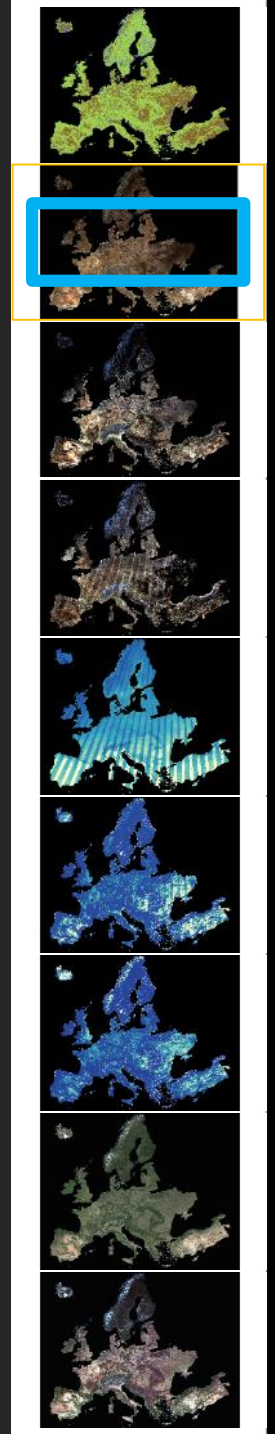
DLR

SoilSuite 2018 – 2022

- Sentinel-2
- 2018 – 2022
- < 80 % cloud cover
- > 20° sun elevation
- 20 m pixel size
- 10 bands

Bare Surface Reflectance Composite

– Mean



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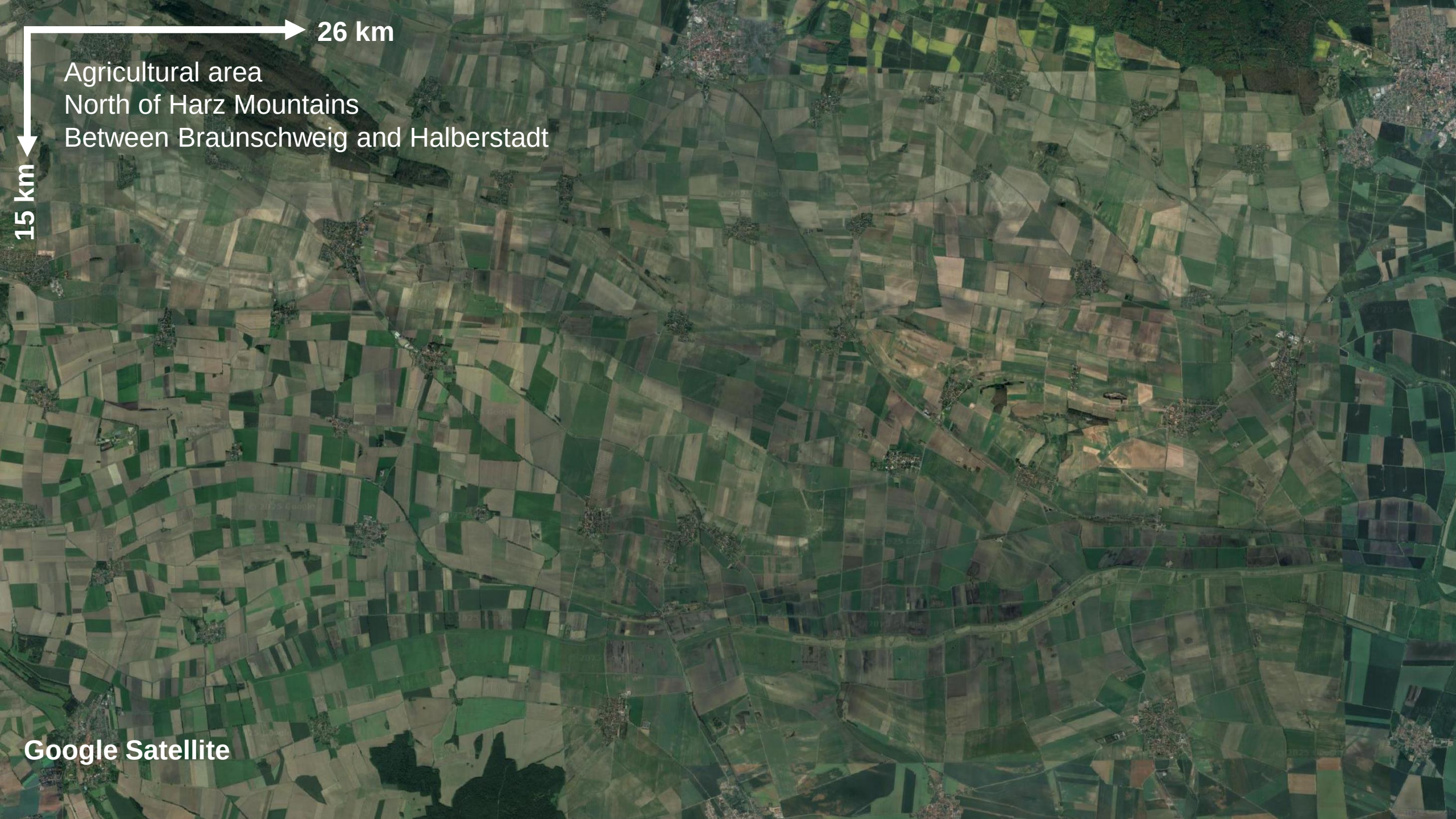
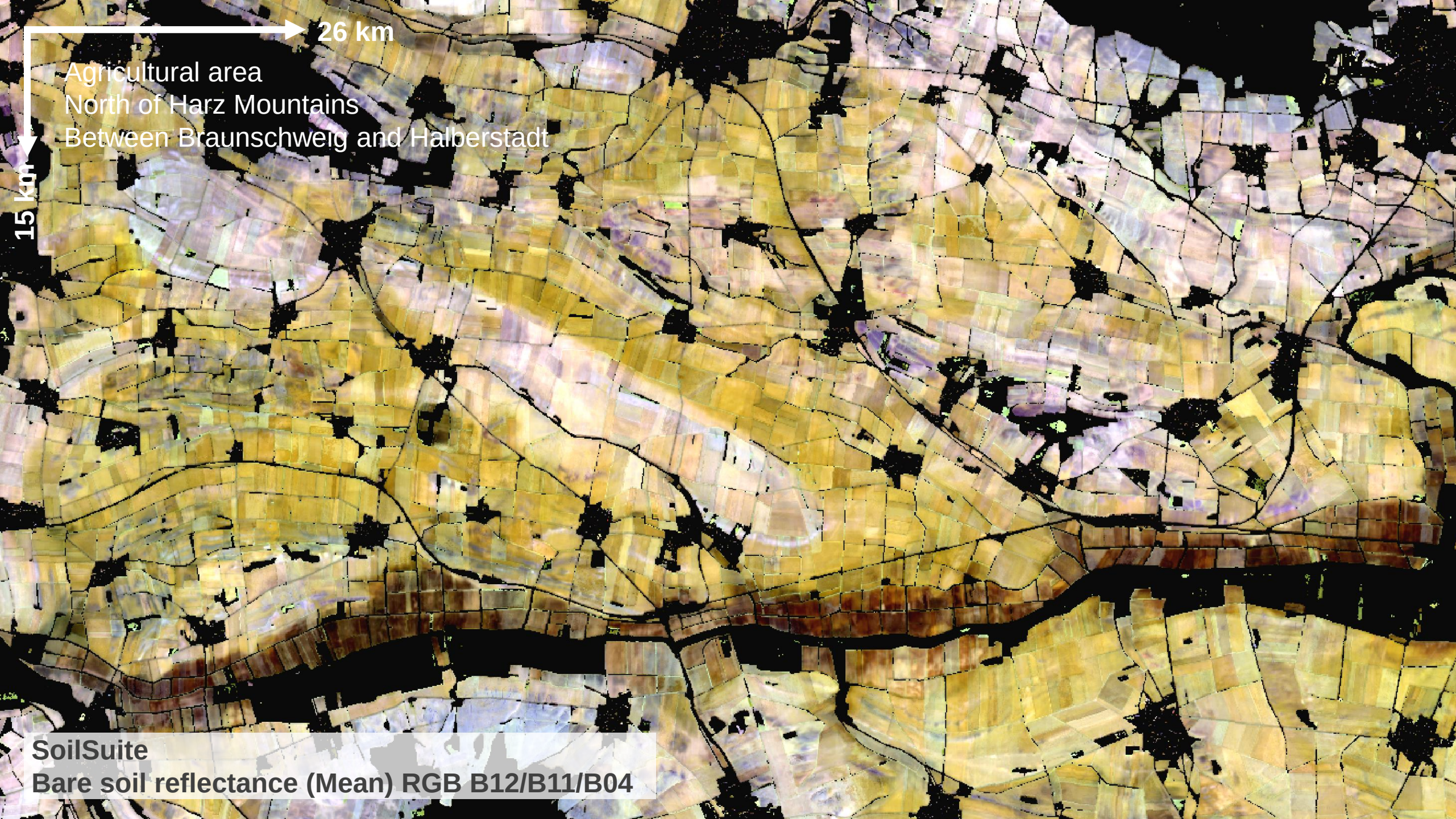

26 km
15 km
Agricultural area
North of Harz Mountains
Between Braunschweig and Halberstadt
Google Satellite

26 km
15 km
Agricultural area
North of Harz Mountains
Between Braunschweig and Halberstadt
SoilSuite
Reflectance (Mean) RGB B04/B03/B02

SoilSuite
Reflectance (Stdev) RGB B04/B03/B02


26 km
15 km
Agricultural area
North of Harz Mountains
Between Braunschweig and Halberstadt
SoilSuite
Bare soil reflectance (Mean) RGB B12/B11/B04

26 km
15 km
Agricultural area
North of Harz Mountains
Between Braunschweig and Halberstadt
40 %
0 %
SoilSuite
Bare soil frequency

26 km
15 km
Agricultural area
North of Harz Mountains
Between Braunschweig and Halberstadt
Bare surface occurrence
Permanent vegetation
Other surfaces
SoilSuite
Mask

SoilSuite for Europe

Spectral and statistical information of bare soils

Home / Datasets / SoilSuite / SoilSuite – Sentinel-2 – Europe, 5 year composite (2018-2022)

SoilSuite – Sentinel-2 – Europe, 5 year composite (2018-2022)

Map | Download | STAC Collection | CSW Record

All Themes | Pedosphere

DOI: 10.15489/qkud8cudg596

DLR EOC Land SCMaP Soil Sentinel-2 Temporal Composites Soil Coverage Soil Composite Mapping Processor Reflectance Composite Surface Reflectance Composite Bare Soil Coverage Bare Soil Frequency

The SoilSuite contains a collection of different image data products that provide information about the spectral and statistical properties of European soils and other bare surfaces such as rocks. It is created using DLR's Soil Composite Mapping Processor (ScMAP), which utilises the Sentinel-2 data archive.

SCMaP is a specialised processing chain for detecting and analysing bare soils/surfaces on a large (continental) scale. Bare surface and soil pixels are selected using a combined NDVI and NBR index (PVIR2) that optimises the exclusion of photosynthetically active and non-active vegetation. The index is calculated and applied for each individual pixel. All SoilSuite products are calculated based on the available Sentinel-2 scenes recorded between January 2018 and December 2022 in Europe. The data package excludes all scenes with a cloud cover of > 80 % and a sun elevation of < 20 degrees. The spectral composite products are calculated from the mean value after extensive removal of clouds, haze and snow effects at both scene and pixel level. The spectral data products are available at a pixel size of 20 m and contain 10 Sentinel-2 bands (B02, B03, B04, B05, B06, B07, B08, B08a, B11, B12).

Contacts:

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- Pablo d'Angelo (Producer, Processor) DLR/EOC Photogrammetry and Image Analysis
- Paul Karlshöfer (Producer, Processor) DLR/EOC Imaging Spectroscopy
- EOC Geoservice (Host) DLR/EOC

SOIL PROPERTY MAPPING

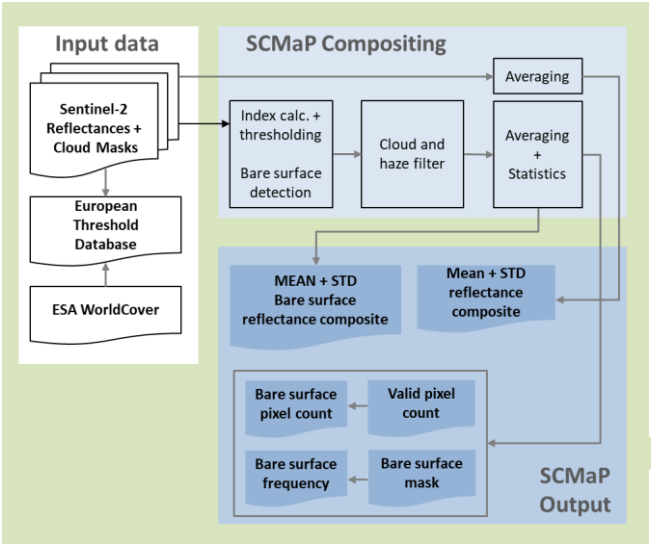
Soil property mapping

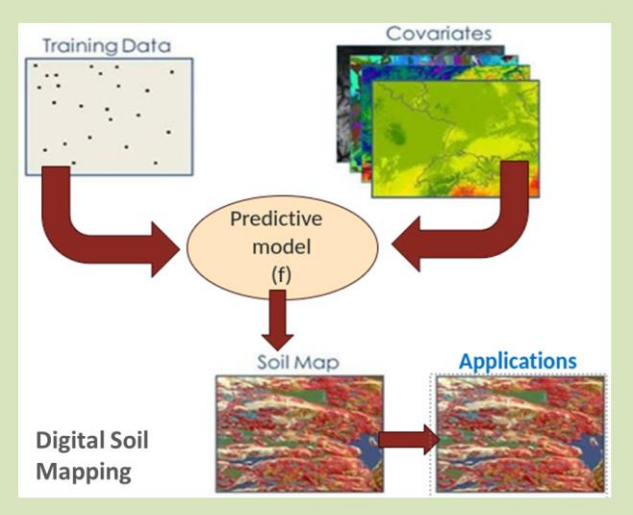
List of soil properties

Property	Description	Depths	Units
soc	Soil organic carbon content	topsoil - 0-30cm	g/kg
phh2o	pH in water	topsoil - 0-30cm	pH
nitrogen	Total nitrogen	topsoil - 0-30cm	g/kg
bdod	Bulk density, oven dry	topsoil - 0-30cm	kg/dm3
cfvo	Coarse fragments, volumetric	topsoil - 0-30cm	cm3/100cm3
sic	Soil inorganic carbon content	topsoil - 0-30cm	g/kg
sand	Sand	topsoil - 0-30cm	g/100g
silt	Silt	topsoil - 0-30cm	g/100g
clay	Clay	topsoil - 0-30cm	g/100g
ocstk	Soil organic carbon stocks	topsoil - 0-30cm	kg/m2
icstk	Soil inorganic carbon stocks	topsoil - 0-30cm	kg/m2
nistk	Soil nitrogen stocks	topsoil - 0-30cm	kg/m2

Uncertainty was calculated as:

$$uncertainty = \frac{(Q0.95 - Q0.05)}{Q0.50} * 10$$

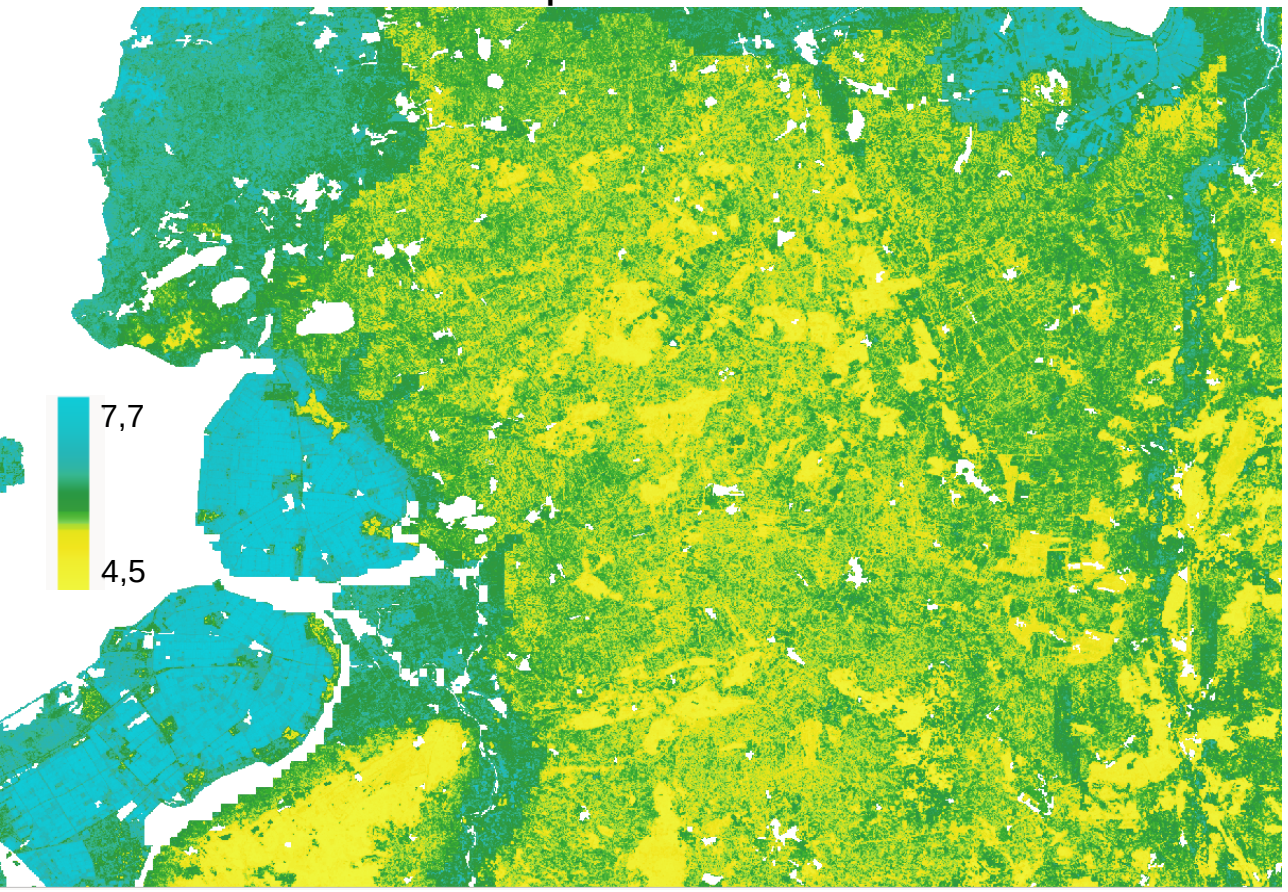




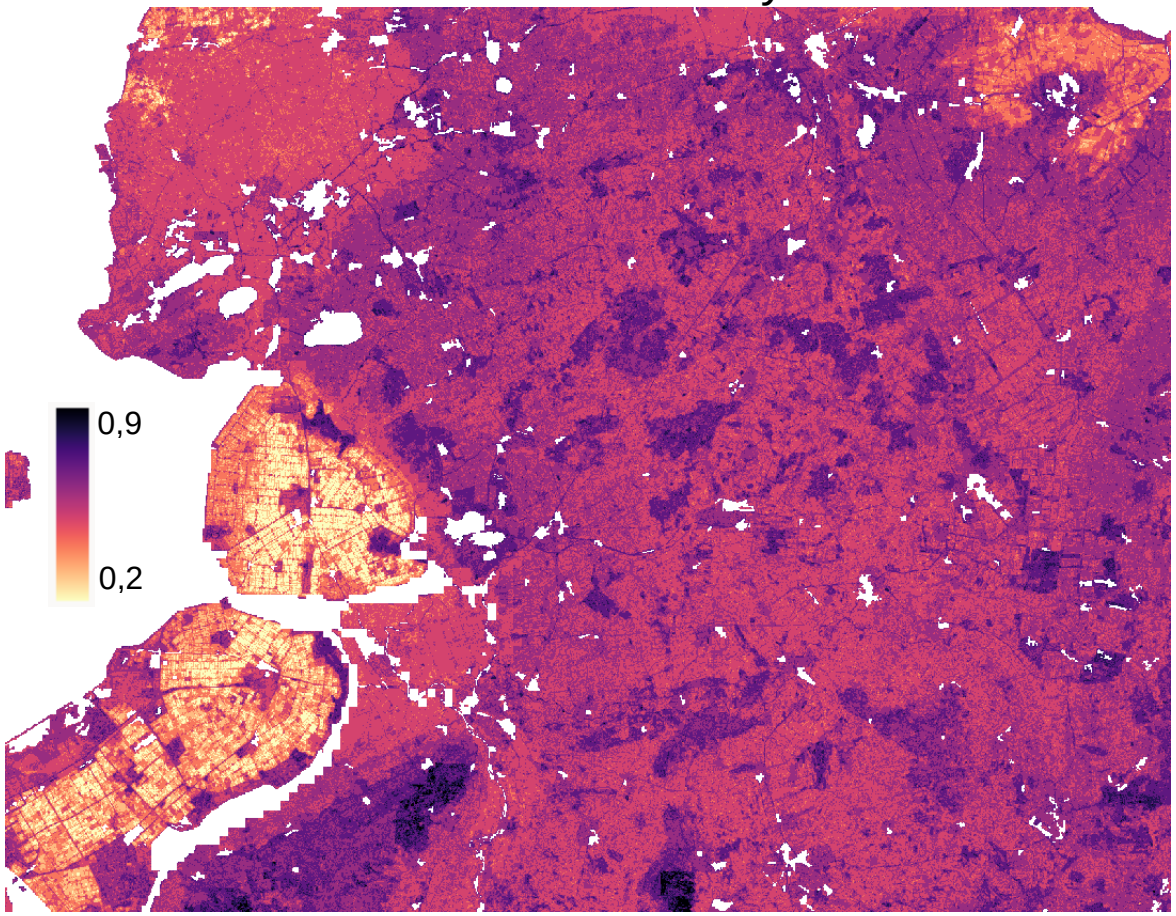
Soil property mapping – preliminary results for Northern Netherland

pH value and uncertainty

pH value



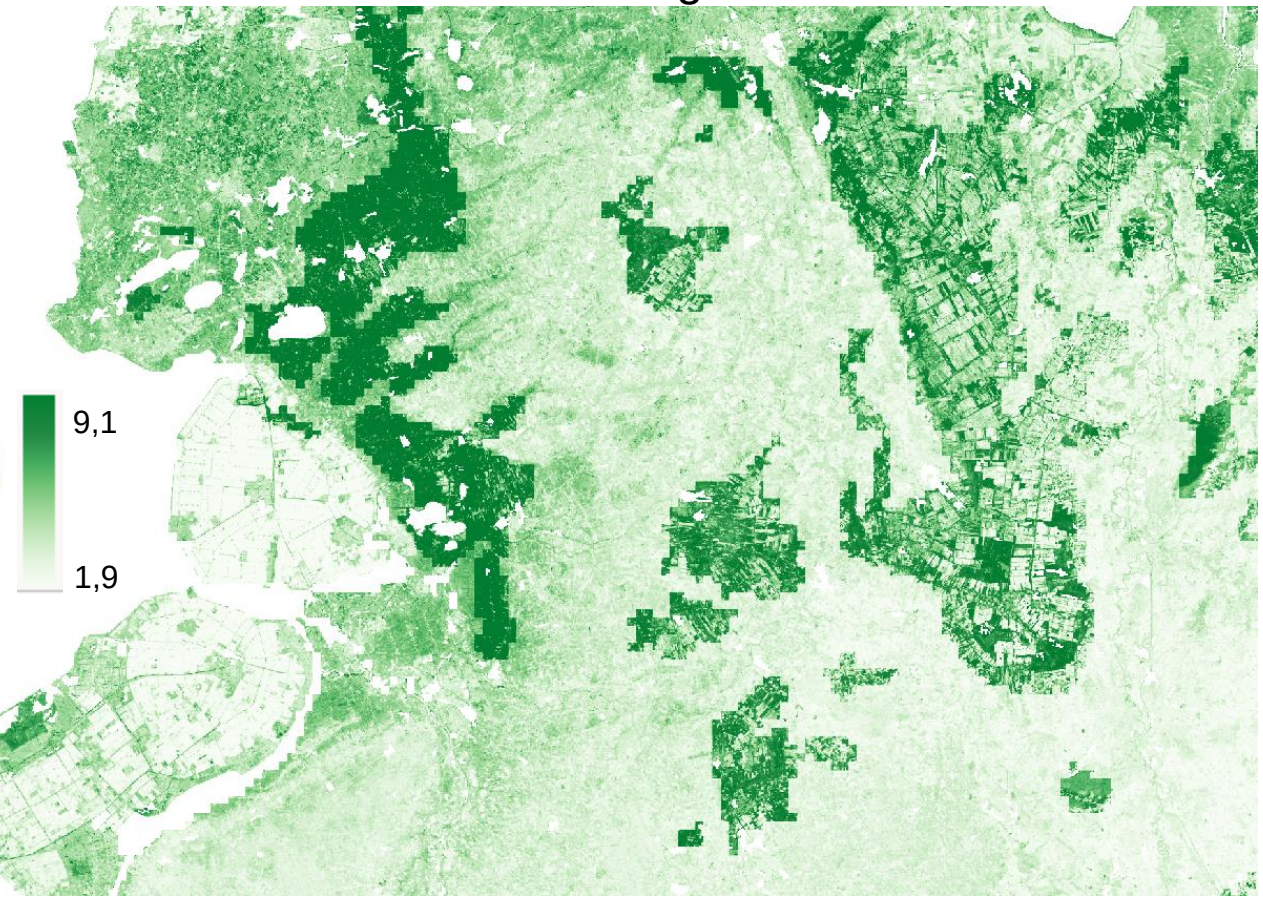
Uncertainty



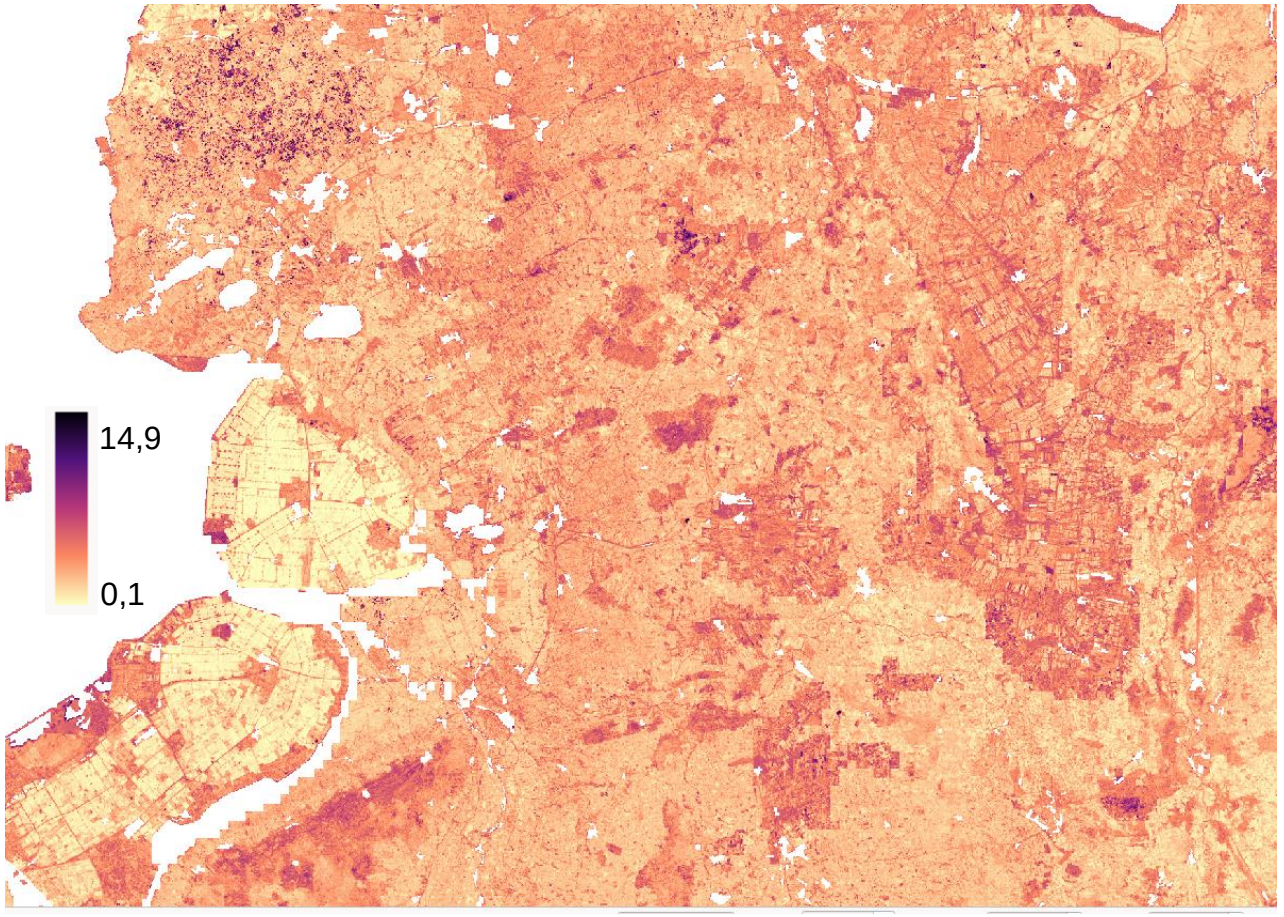
Soil property mapping – preliminary results for Northern Netherland

Total nitrogen and uncertainty

Total nitrogen



Uncertainty



PROJECTS, SHOW CASES, FEEDBACK

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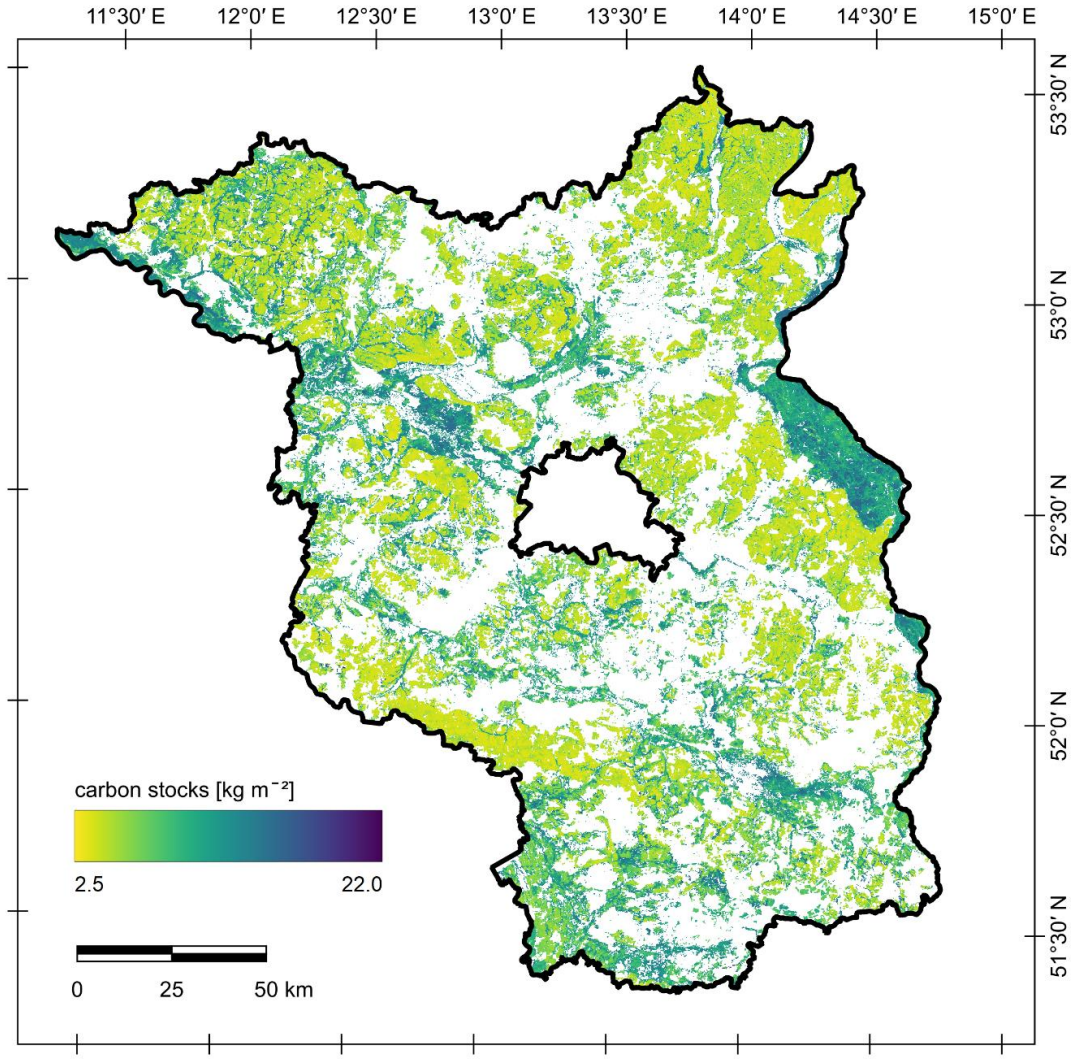
List of showcases so far

Case #	Partner	Scale	Title
1	Landesamt für Natur, Umwelt und Verbraucherschutz NRW	Germany	Use of SCMaP MASK product to monitor grassland activity (CropGRÜN project)
2	**Landesamt für Bergbau, Geologie und Rohstoffe Brandenburg (LBGR)**	**Federal State Brandenburg in Germany**	**Using SRC for soil carbon stocks mapping of agricultural fields in Brandenburg**
3	Bayerische Landesanstalt für Landwirtschaft (LFL)		Test various SCMaP products for soil erosion monitoring
4	**SoilCapital**	**France, Belgium**	**Test bare soil frequency (BSF) for agricultural monitoring, particularly in the context of regenerative agriculture**
5	MRV4SOC project	Test sites across Europe	Using SRC-MEAN and SRC-STDEV for soil parameter mapping (texture, SOC, pH, …) and BSF for modelling carbon

Showcase – LBGR Cottbus, Germany

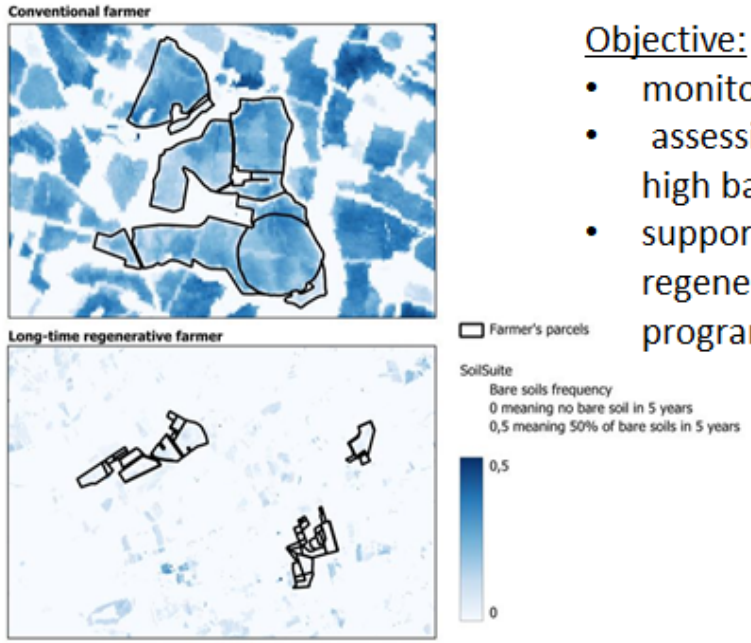


<u>Used data:</u>
<u>Soil reflectance com</u>posite
digital elevation model and derived morphometric variables
geological maps
soil maps
land use maps
crop (rotation) maps

<u>Validation (out-of-bag):</u>
RMSE: 0.7 kg m-2, Pseudo-R^2: 0.69 (0-10 cm)
RMSE: 3.0 kg m-2, Pseudo-R^2: 0.53 (0-100 cm)

Feedback:
- SRC ranked among the most relevant covariates
- LBGR will include SRC in set of predictors for carbon stock map of Brandenburg
- Data format transformation + resampling guidelines would be beneficial

Showcase – SoilCapital, BE|NL|FR



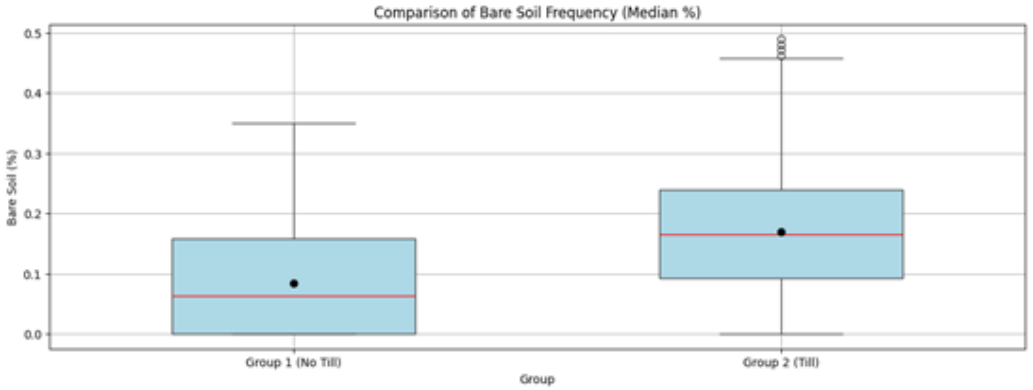


Figure 3: Box plot comparing the median frequency of bare soil between the two groups of agricultural practices.

Objective:

- monitoring of regenerative agriculture
- assessing long-term changes in areas with high bare soil frequency
- supporting the validation of continued regenerative agriculture practices post-program implementation

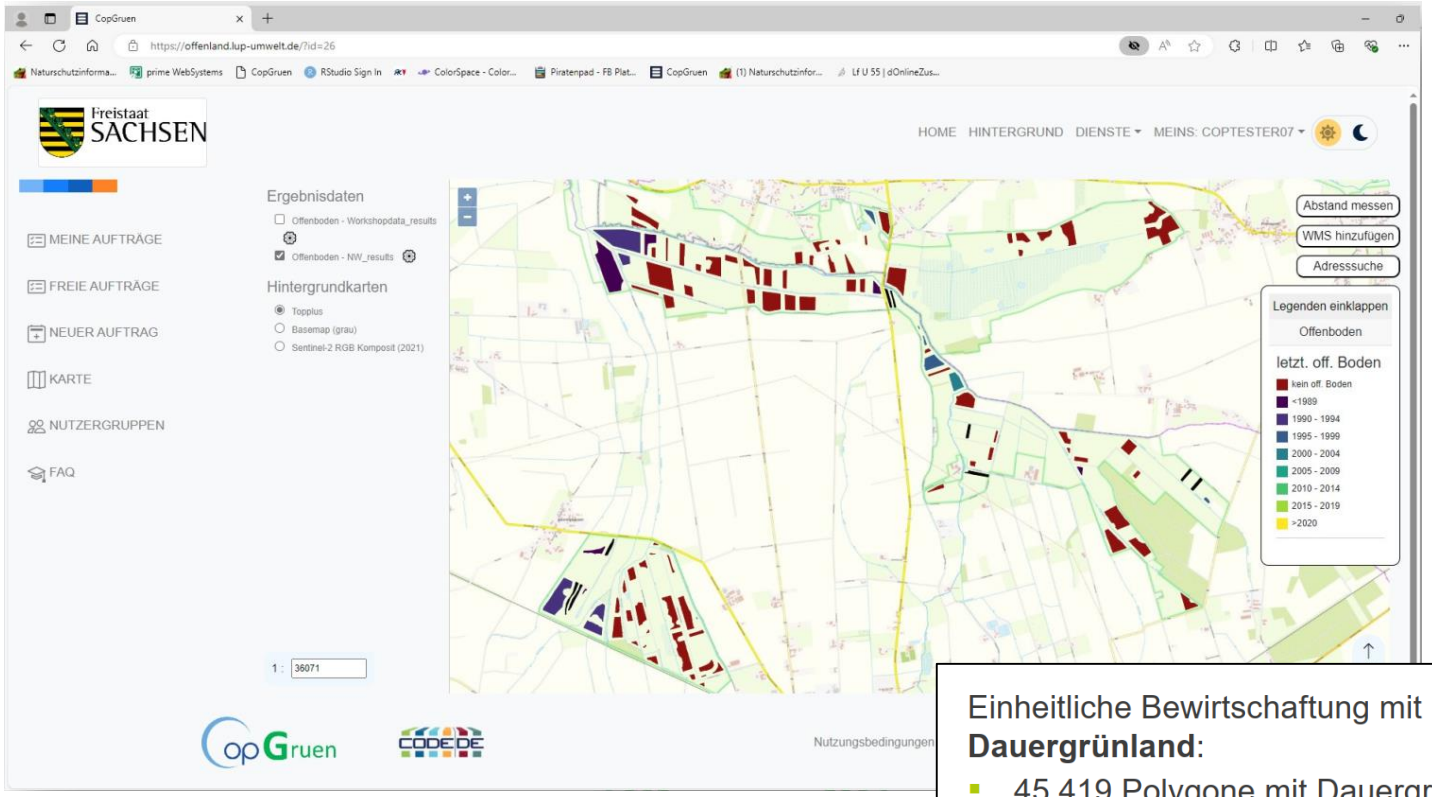
Results:

- CUP4SOIL strong potential for assessing the adoption of regenerative agriculture and distinguishing between permanent and cultivated fields
- bare surface frequency indicator and the 3-class mask (bare surface, permanent vegetation, other) are highly relevant for our use cases.
- dataset is valuable for monitoring persistent changes
- High data volume
- Soil Suite appears to systematically overestimate bare soil frequency when compared to commercial datasets. This discrepancy could stem from underreporting by commercial providers or methodological differences.

Suggestions:

- Enhancing temporal granularity (e.g. yearly)

Showcase – CopGrün project



- „Offenbodendienst“ available for local/regional authorities
- Informs about tillage / no-tillage per year
- Statistics derived (5-year rule)

- Validation (example NRW using open.Geodata portal):

Input:
SoilSuite product „MASK“ calculated per year (2019 – 2022)

Einheitliche Bewirtschaftung mit **Dauergrünland**:

- 45.419 Polygone mit Dauergrünland

Detektierter offener Boden:

- 2019: 533 Polygone (1,72%)
- 2020:704 Polygone (1,56%)
- 2021: 90 Polygone (0,25%)
- 2022: 1.243 Polygone (2,74%)

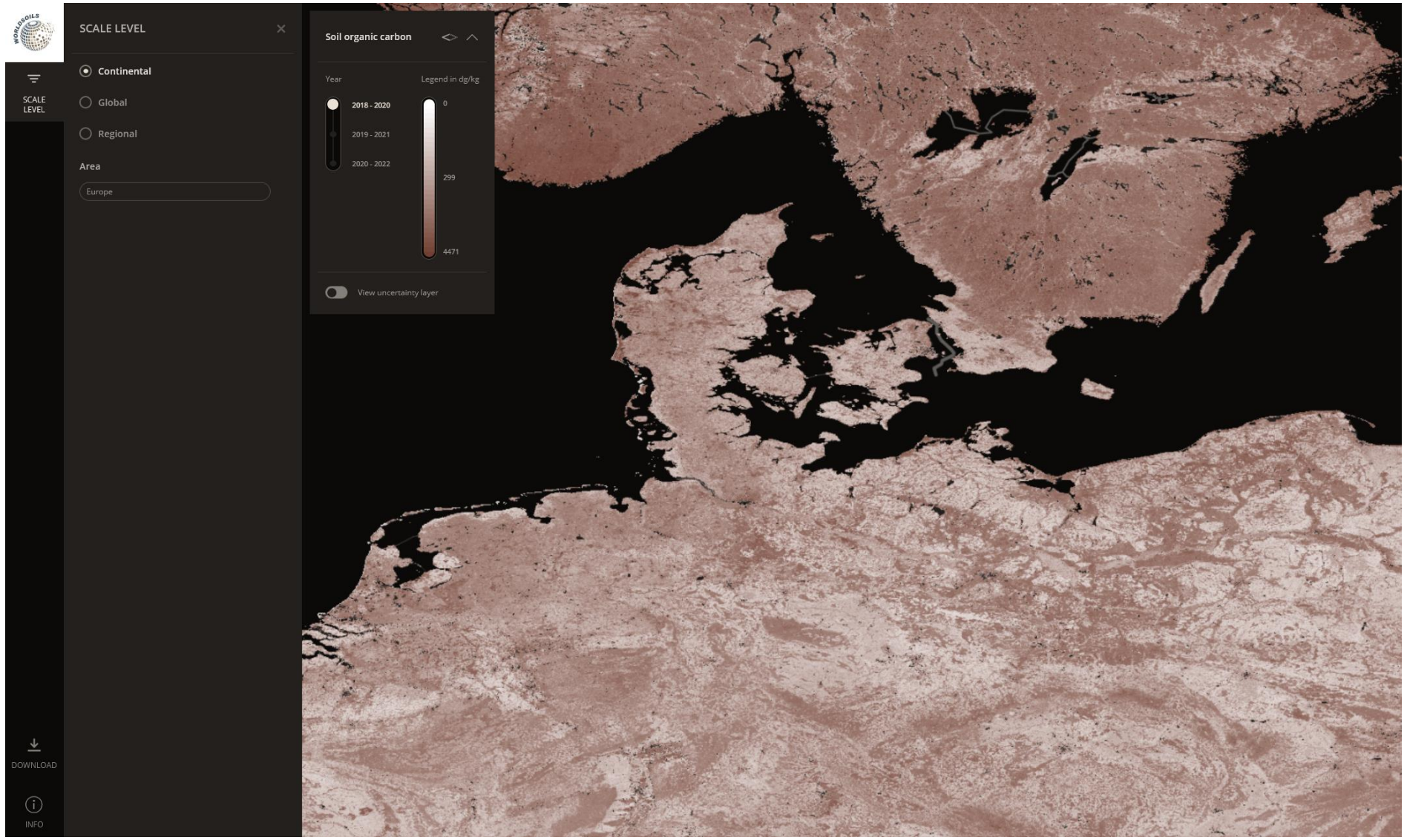
Einheitliche Nutzung als **Ackerflächen** (als Kontrolle):

- 7.817 Polygone mit selektierter Ackernutzung

Detektierter offener Boden:

- 2019: 7.647 Polygone (98,14%)
- 2020: 7.638 Polygone (97,90%)
- 2021: 7.272 Polygone (96,22%)
- 2022: 7.685 Polygone (98,37%)

Showcase – ESA WorldSoils I and II



- Preoperational system for the monitoring of soil organic carbon in top soils
- 50 m (regional)
- 100 m (global)

Variability of the SoilSuite based project outputs

	WorldSoils (ESA)	CUP4SOIL (EU - FPCUP)	ML4Earth - TP Boden (DLR)
Leitung	GMV	DLR	TU München
Ziel	Entwicklung eines pre-operationellen Systems zum Monitoring von organischen Kohlenstoff im Oberboden (SOC)	Vorbereitung von EO-basierten Bodenprodukten im Rahmen des Copernicus Land Monitoring Service (CLMS)	Vorbereitung von EO-basierten Bodenprodukten im Rahmen des Copernicus Land Monitoring Service (CLMS)
Projektdauer	09/2020 – 03/2024	01/2023 – 12/2024	07/2022 – 06/2025
Bodenparameter	Organischer Kohlenstoffgehalt im Oberboden	Organischer Kohlenstoffgehalt im Oberboden, pH-Wert, Kationen-Austauschkapazität, Textur, Lagerungsdichte, …	Organischer Kohlenstoffgehalt im Oberboden, evtl. mehr, wenn Daten da sind …
Modellierung	Spektrale Bodenmodellierung (für unbedeckte Böden) Digitale Bodenmodellierung (für vegetationsbestandene Böden)	Digitale Bodenmodellierung (für alle Böden)	Digitale/Spektrale Bodenmodellierung (Fokus Methodik)
Räumliche (Pixel)Auflösung	50 m (Europa) 100 m (Global)	20 m (Europa)	30 m (Bayern)
Inputdaten	Sentinel-2, Sen2Cor (ESA)	Sentinel-2, MAJA (DLR)	DESIS, PACO (DLR)
Prozessierungs-plattform	Open Telekom Cloud	• LRZ – HPDA Plattform terrabyte • ISRIC intern	• LRZ – HPDA Plattform terrabyte

FURTHER PLANNED TASKS

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Further planned tasks

Comparison of SoilSuite products

ESA-WorldSoils	100m (50m)	All soils	Integration of bare soil modelling with spectral signature and DSM for permanently vegetated soils	DLR compositing products
JRC-LUCAS	100m	All soils	DSM	
Holisoils	100m	Forest soils	DSM	EEA seasonality covariates
EJP SOIL	100m	All soils	DSM (combination/comparison of continental models vs stitching of national models)	
CUP4SOIL	20m	All soils	DSM	DLR compositing products + Standard deviation EEA seasonality covariates
SoilGrids - ISRIC	250m	All soils	DSM	Global model
FAO-GSP GloSIS	1000m	All soils	DSM (combination of SoilGrids and national models)	

Further planned tasks

New products etc.

- Products:
  - Yearly statistical products (bare soil frequency)
  - Bare soil dates
  - Tillage events
  - Input products for soil erosion modeliing and mapping

- Publication:
  - Product comparison – output of different projects
  - Data publication

- CUP4SOIL final workshop:
  - In September 2025
  - Virtual workshop for 1 day or 2 half days
  - Topics:
    - CUP4SOIL achievements (User requirements, data products, documentation, …)
    - Showcases
    - Data accessibility
    - Discussion

Vielen Dank für Ihre Aufmerksamkeit!

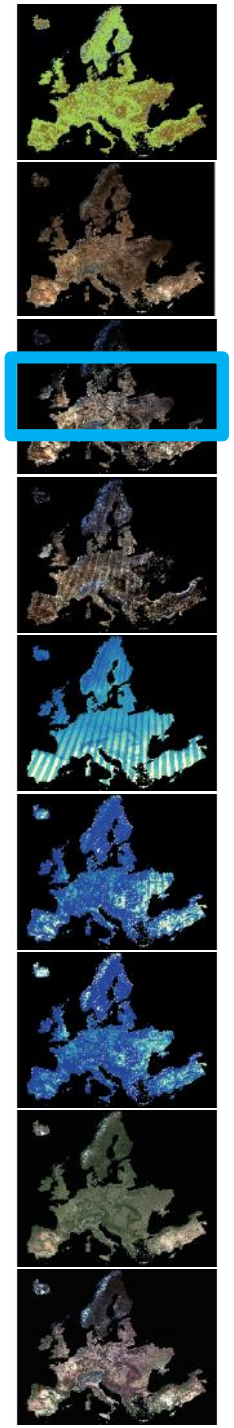
Kontakt: uta.heiden@dlr.de

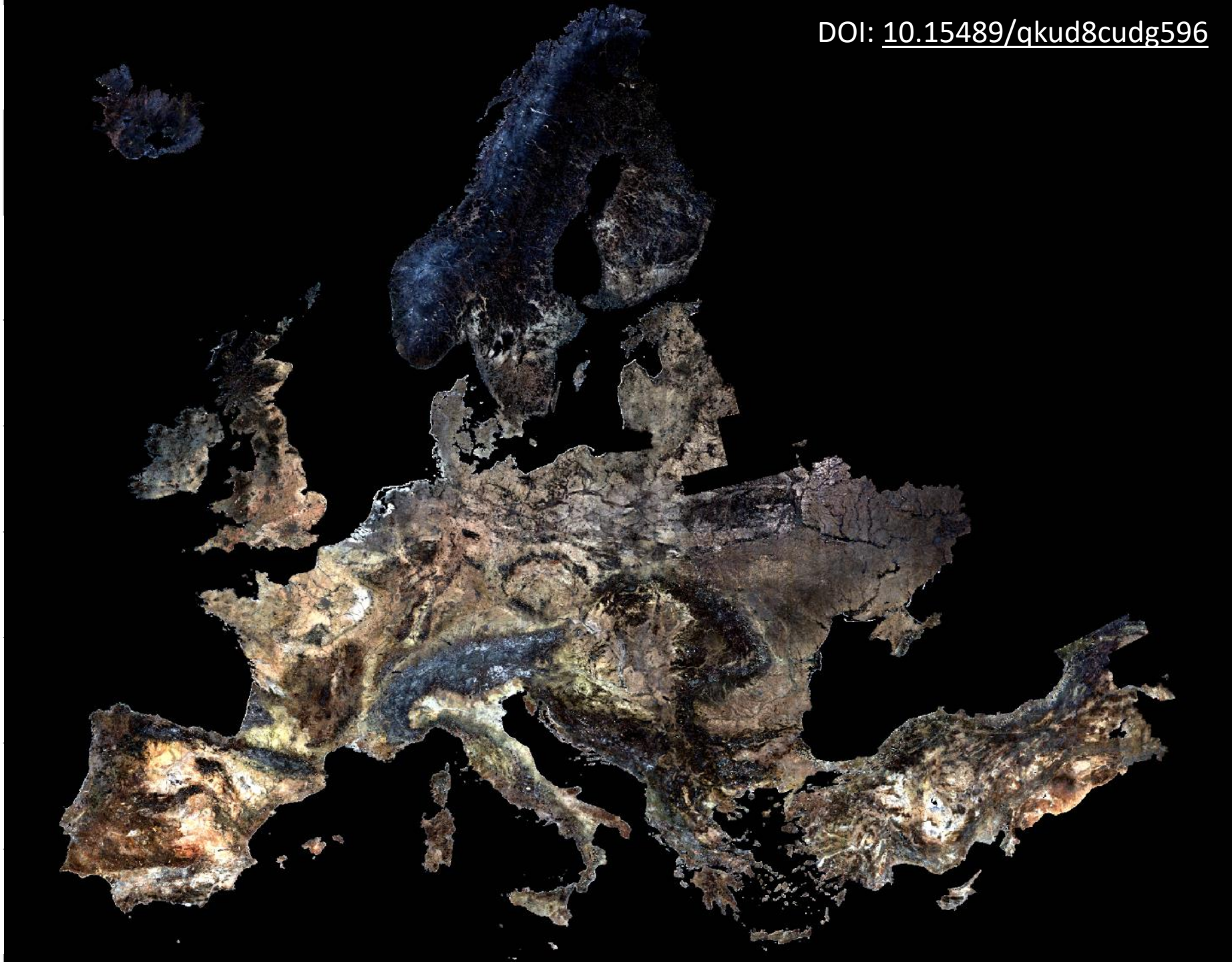
SoilSuite 2018 – 2022

- Sentinel-2
- 2018 – 2022
- < 80 % cloud cover
- > 20° sun elevation
- 20 m pixel size
- 10 bands

Bare Surface Reflectance Composite

– Standard deviation





DOI: 10.15489/qkud8cudg596

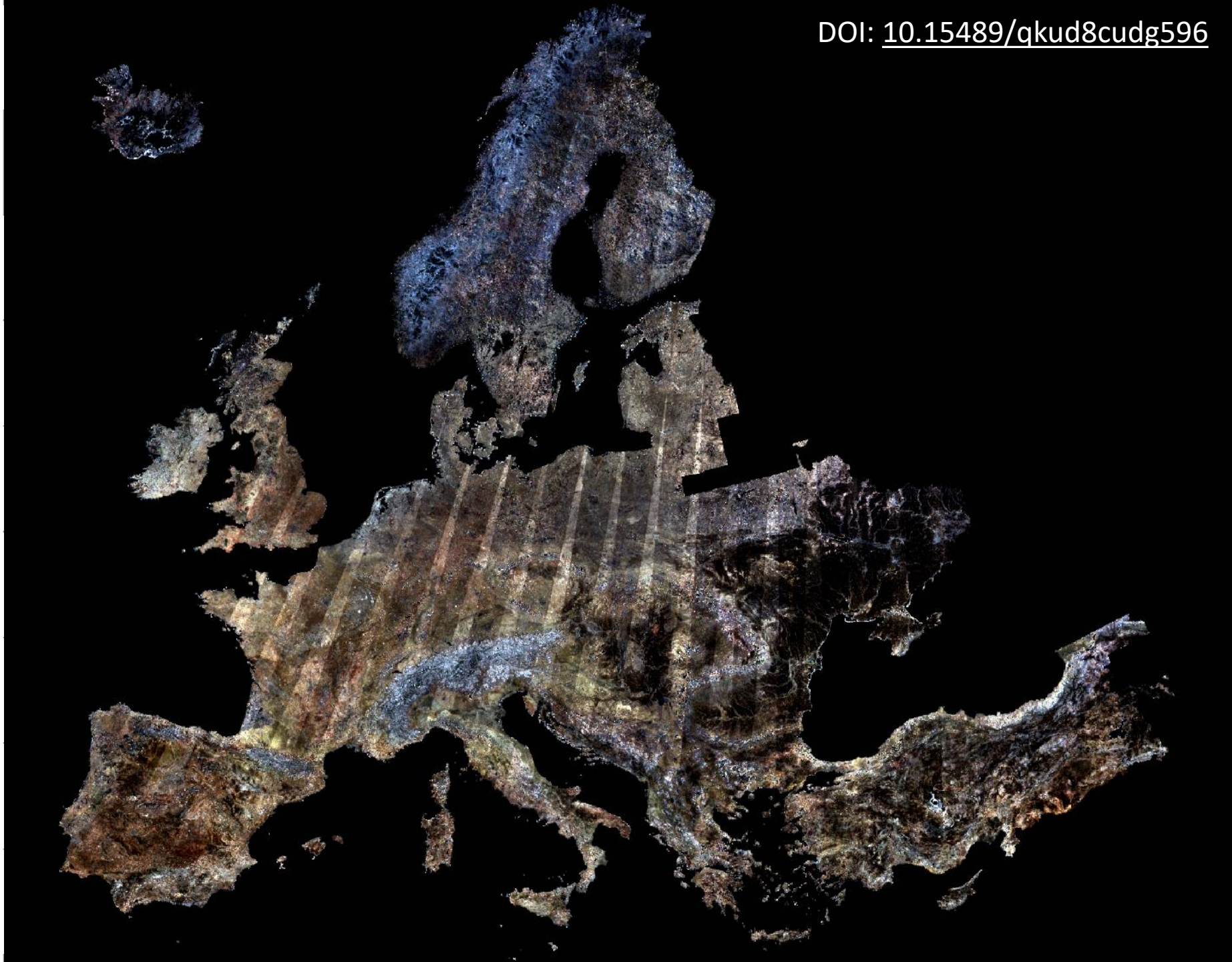
DLR

SoilSuite 2018 – 2022

- Sentinel-2
- 2018 – 2022
- < 80 % cloud cover
- > 20° sun elevation
- 20 m pixel size
- 10 bands

Bare Surface Reflectance Composite

– Confidence 95%



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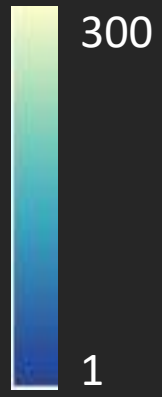
DLR

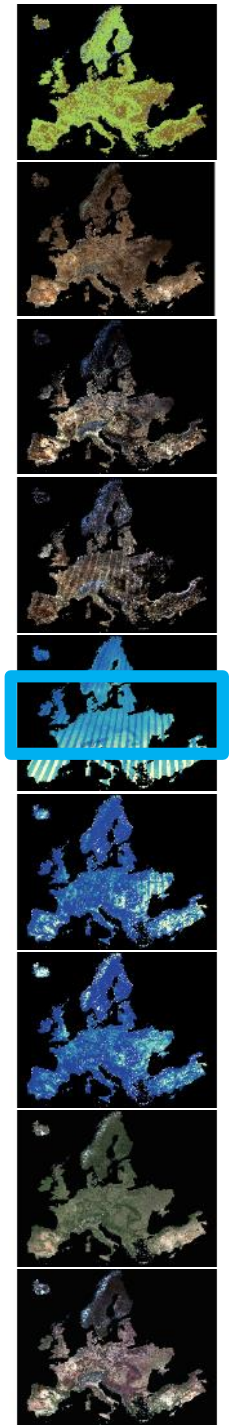
SoilSuite 2018 – 2022

- Sentinel-2
- 2018 – 2022
- < 80 % cloud cover
- > 20° sun elevation
- 20 m pixel size
- 1 band

Bare Surface Statistics

- Valid observations (number of scenes)





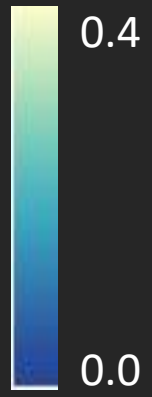
DOI: 10.15489/qkud8cudg596

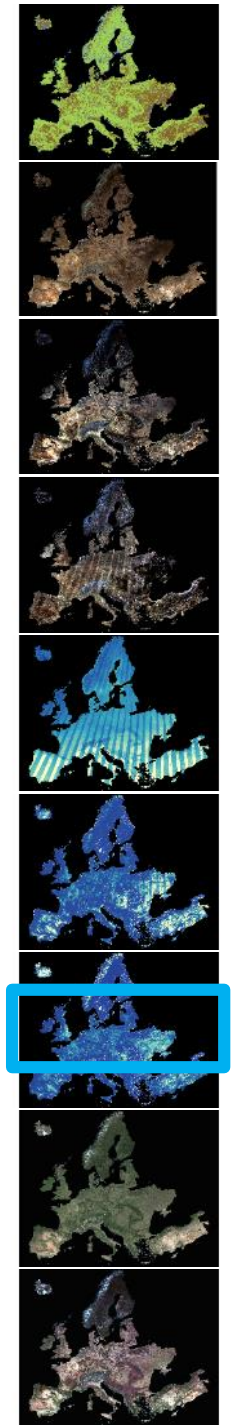
SoilSuite 2018 – 2022

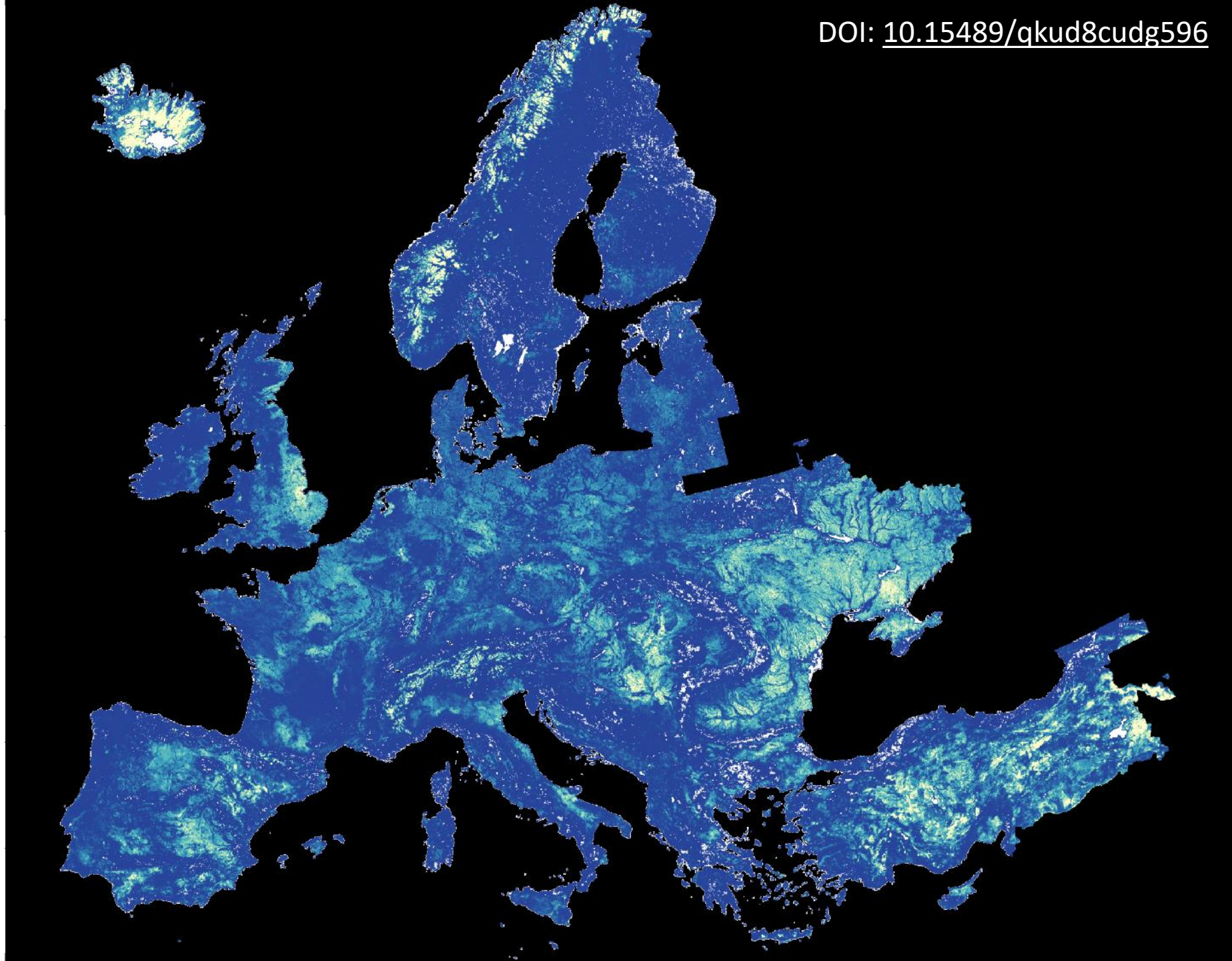
- Sentinel-2
- 2018 – 2022
- < 80 % cloud cover
- > 20° sun elevation
- 20 m pixel size
- 1 band

<u>Bare Surface Statistics</u>

- Bare Soil Frequency [%]





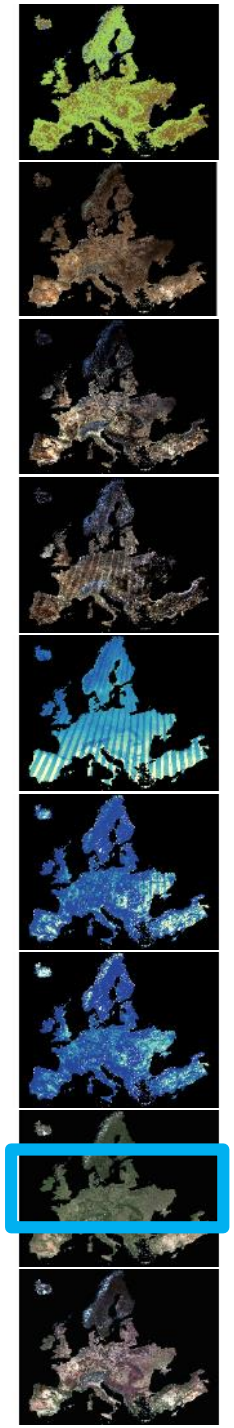


DOI: 10.15489/qkud8cudg596

SoilSuite 2018 – 2022

- Sentinel-2
- 2018 – 2022
- < 80 % cloud cover
- > 20° sun elevation
- 20 m pixel size
- 10 bands

Reflectance Composite
– Mean



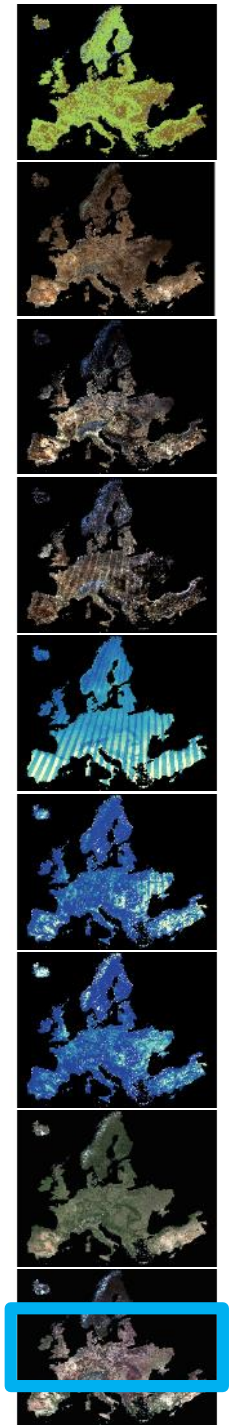
DOI: 10.15489/qkud8cudg596

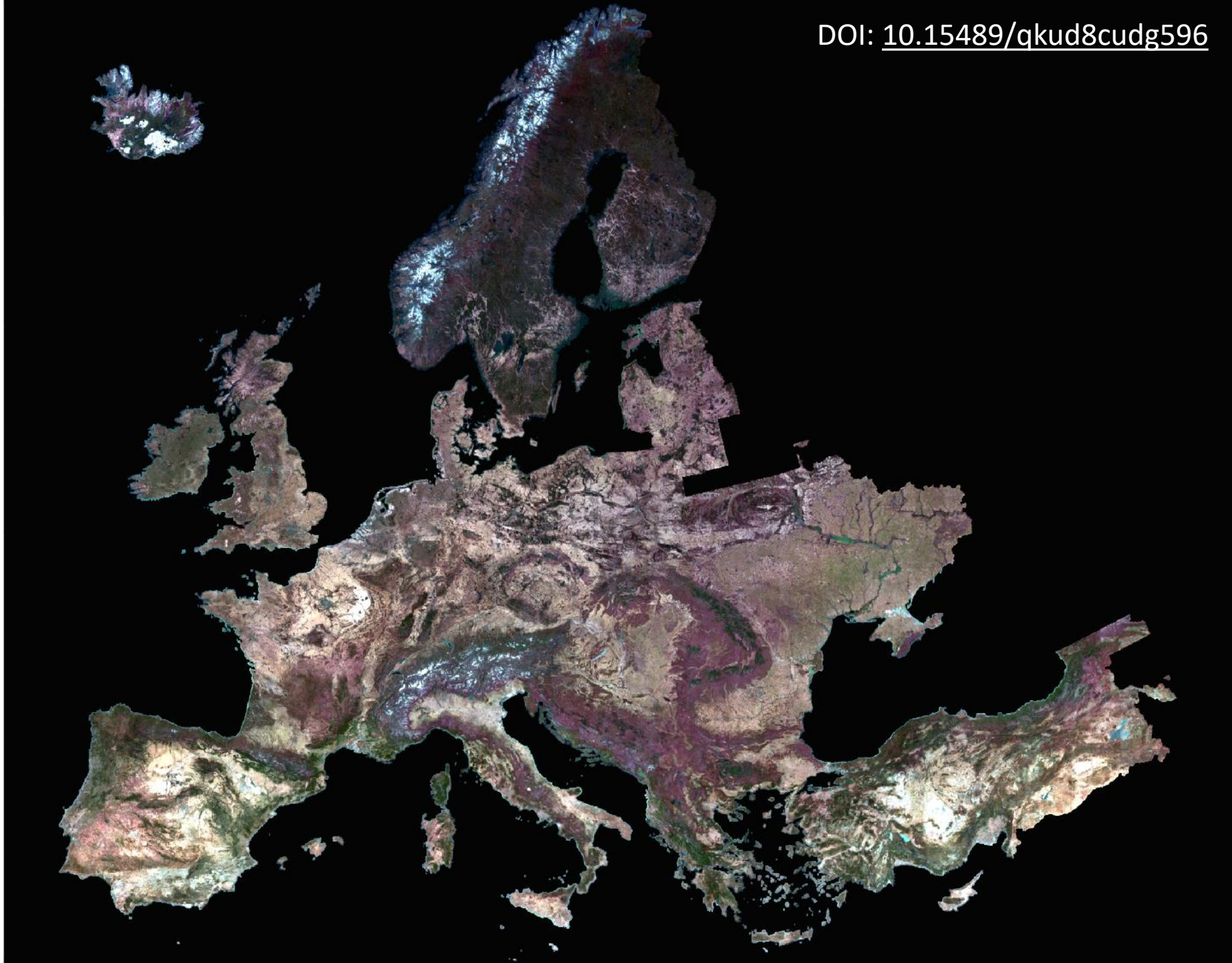
DLR

SoilSuite 2018 – 2022

- Sentinel-2
- 2018 – 2022
- < 80 % cloud cover
- > 20° sun elevation
- 20 m pixel size
- 10 bands

Reflectance Composite
– Standard Deviation





DOI: 10.15489/qkud8cudg596

DLR