MULTI- UND HYPERSPEKTRALEN INFORMATIONEN FÜR BÖDEN UND BODENBEDECKUNG

Uta Heiden, Paul Karlshöfer, Kevin Kühl, Pablo d‘Angelo, Peter Schwindt, David Marshall, Martin Bachmann

Potential of Optical EO Data

Revised Universal Soil Loss Equation (RUSLE)

SoilSuite

(SCMAP)

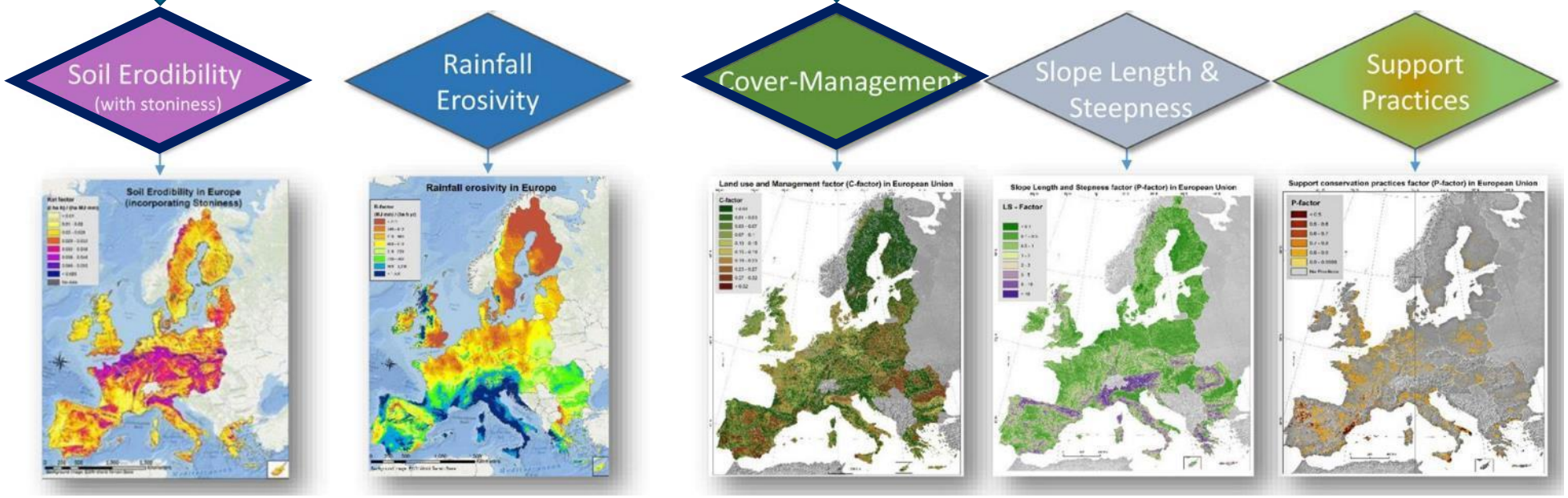
- Soil organic carbon
- Mineralogy
- pH
- Coarse fragments
- Nutrients
- …

Bare soil occurance
- Where, When
- Frequency

Soil coverage
- Vegetation density
- Dry vegetation cover

fCover

(FRANCA, DL)



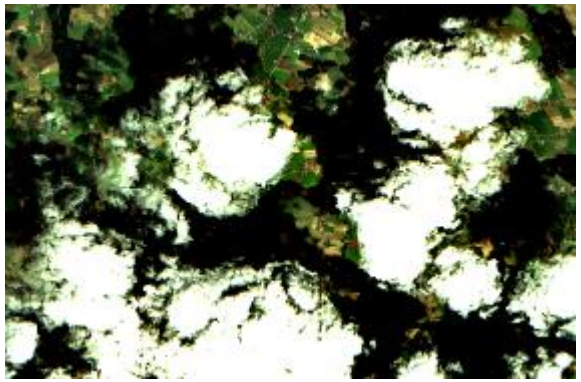
Modified from EEA, 2016*.

* https://www.eea.europa.eu/data-and-maps/figures/rusle-soil-erosion-model-structure/rusle-soil-erosion-model-structure

Temporal compositing for soil property mapping

Observing soils from optical satellite platforms

Clouds / Cloudshadow / …

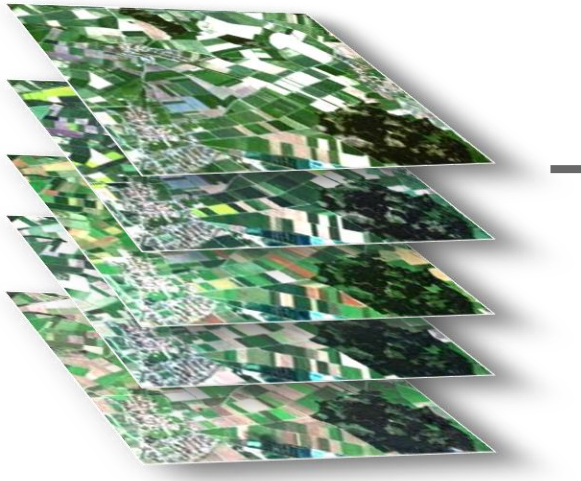


Detecting bare soil

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

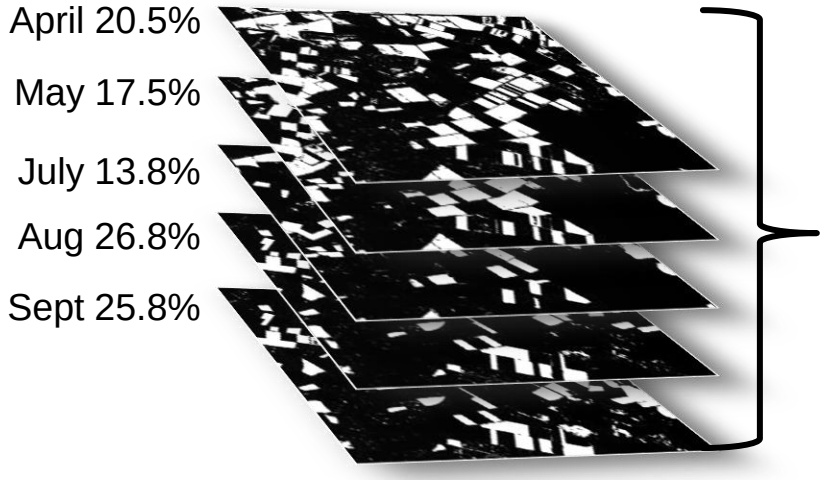
Basic idea – temporal compositing of bare soils

Temporal stack
Reflectance images



Spectral index
threshold

Temporal stack
Bare soil masks



Temporal Composite
Bare soil mask

Expanding data base
Bare Soil Exposure = 47.9 %

References (selection)

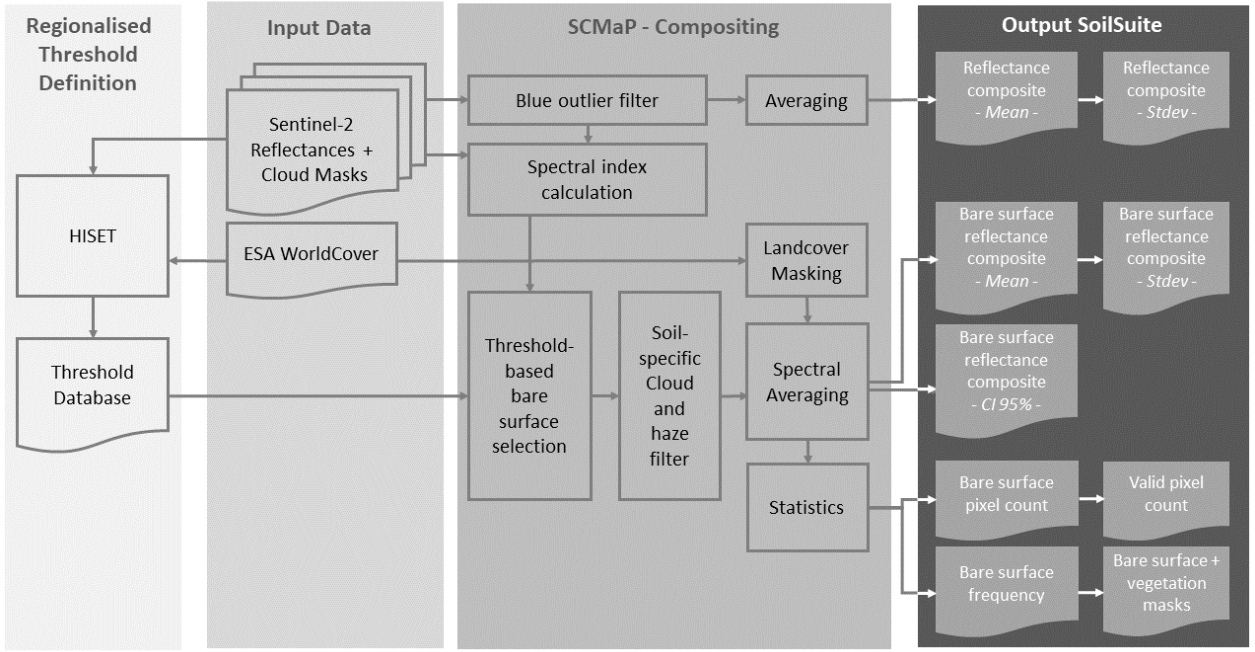
- Diek, S. et al. (2017). Barest Pixel Composite for Agricultural Areas Using Landsat Time Series. Remote Sens. 2017, 9, 1245.
- Rogge, D. et al. (2018). Building an exposed soil composite processor (SCMaP) for mapping spatial and temporal characteristics of soils with Landsat imagery (1984–2014), RSE, 205, 1-17.
- Demattê, J.A.M. et al. (2018). Geospatial Soil Sensing System (GEOS3): A powerful data mining procedure to retrieve soil spectral reflectance from satellite images. RSE, 212, 161–175.
- Vadour, E., et al. (2021). Temporal mosaicking approaches of Sentinel-2 images for extending topsoil organic carbon content mapping in croplands, International Journal of Applied Earth Observation and Geoinformation, 96, 2021, 102277, DOI: 10.1016/j.jag.2020.102277.
- Dvorakova, K. et al. (2021). Sentinel-2 Exposed Soil Composite for Soil Organic Carbon Prediction. RS, 13 (9), 1-21. doi: 10.3390/rs13091791
- Heiden, U. et al. (2022). Soil Reflectance Composites - Improved Thresholding and Performance Evaluation. Remote Sensing, 14 (18), Seiten 1-26. doi: 10.3390/rs14184526.

SCMaP Overview

- Fully automated and operational processor generates product suite for:
  - Digital and spectral modelling and mapping of soil parameter
  - Statistics about soil use intensity
  - Evaluating the quality - spectral uncertainty (confidence interval)
- Temporal statistics of several spectral indices such as NDVI, NBR, NDWI, etc.
- Tested and validated for Europe, parts of Brazil, Westafrica, Canada, China
- Deployed e.g. at terrabyte – DLR‘s HPDA platform and Open Telekom Cloud:
  - For the 5-year compositing:
    - 445 806 individual Sentinel-2
    - 1145 UTM tiles

Publication:

- Karlshöfer et al. 2025, Geoderma, 10.1016/j.geoderma.2025.117340.
- Heiden et al., 2025: Tech report, 10.15489/qkud8cudg596
- Heiden, U. et al.,2022: RS, 10.3390/rs14184526
- Rogge et al., 2018: RSE, 10.1016/j.rse.2017.11.004



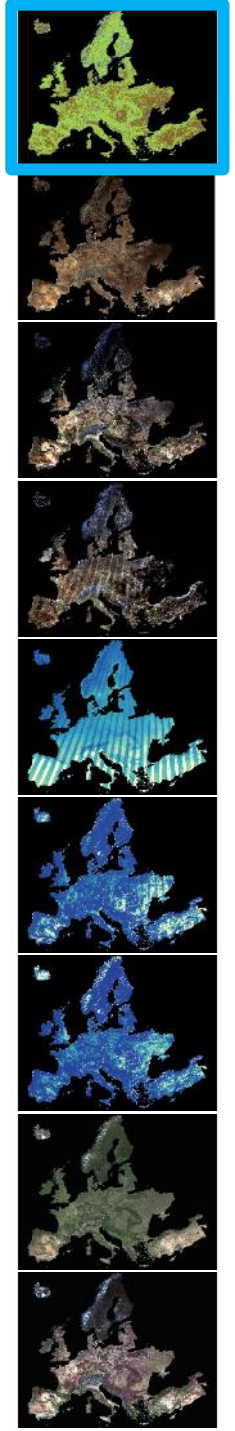
SOILSUITE FOR EUROPE

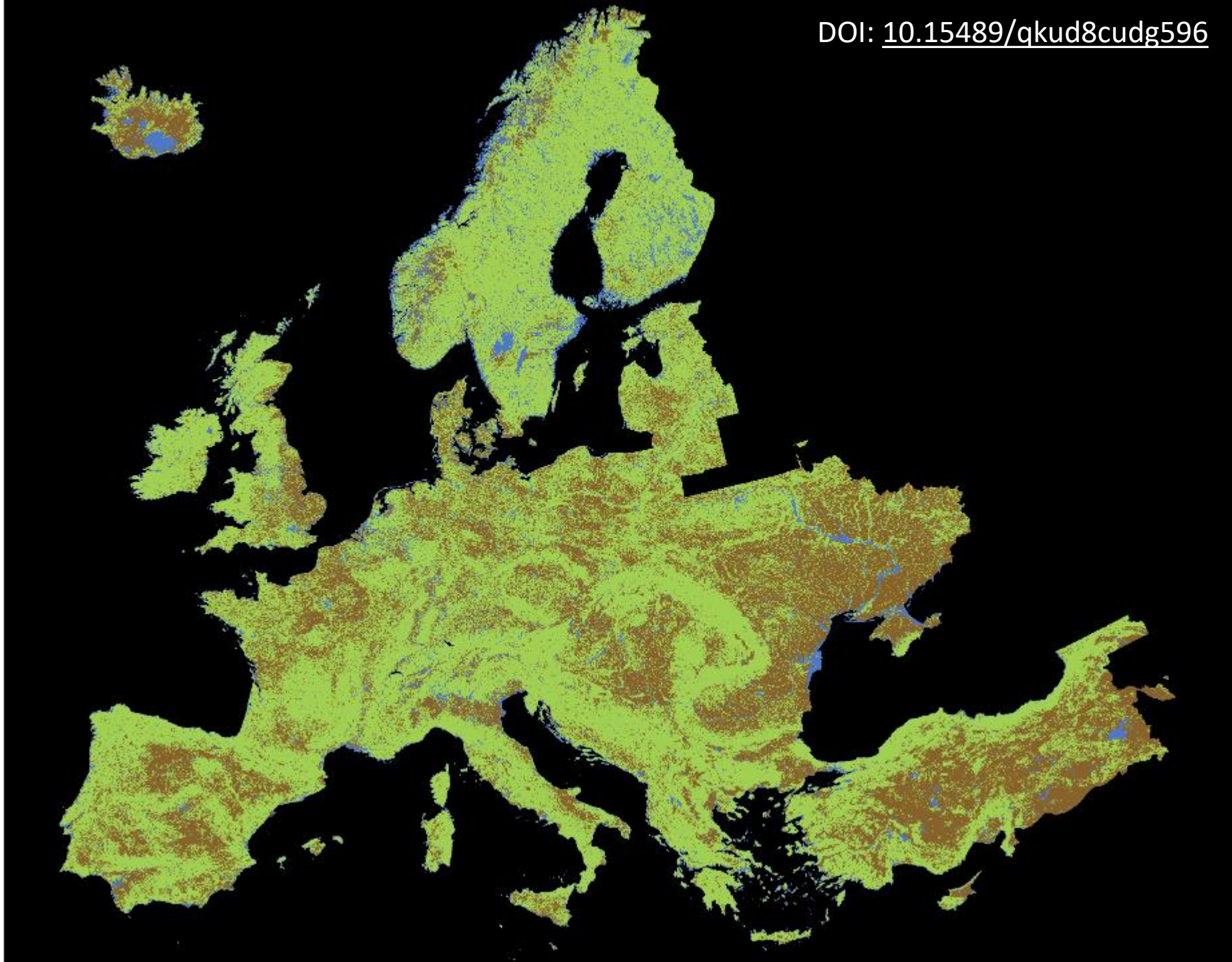
SoilSuite 2018 – 2022

- 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

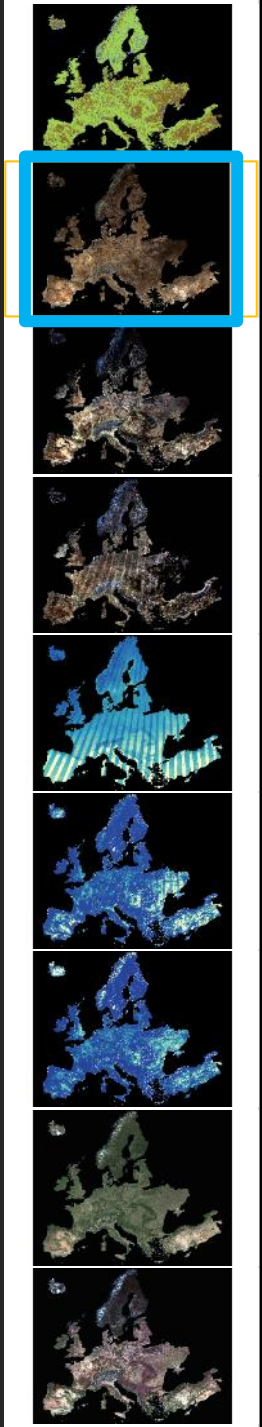
DLR

SoilSuite 2018 – 2022

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

Bare Surface Reflectance Composite

– Mean



Projects

- EU CUP4SOIL
- EU MRV4SOC
- ESA WorldSoils – SOC

Publications

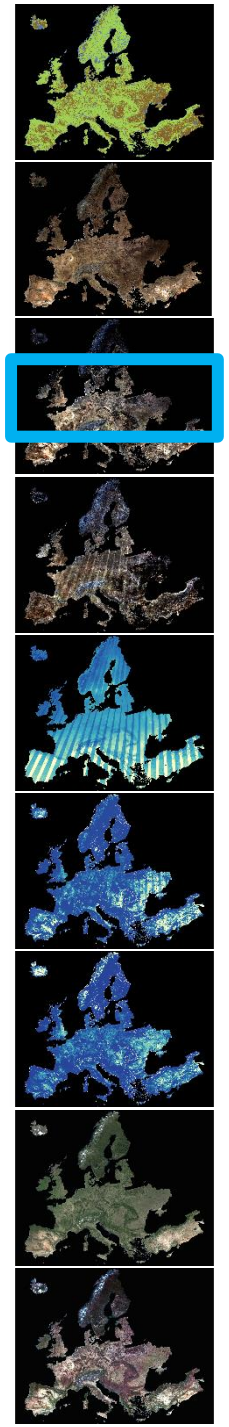
- doi: 10.1016/j.geoderma.2025.117340
- doi: 10.1016/j.jag.2025.104504
- doi: 10.1111/ejss.70071
- doi: 10.1016/j.geoderma.2024.117113
- doi: 10.3390/rs17010089
- doi: 10.1016/j.geoderma.2024.116867
- doi: 10.1109/IGARSS53475.2024.10642714
- doi: 10.1016/j.geoderma.2022.116128
- doi: 10.3390/rs13091791

SoilSuite 2018 – 2022

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

<u>Bare Surface Reflectance Composite</u>

– Standard deviation



<u>Projects</u>

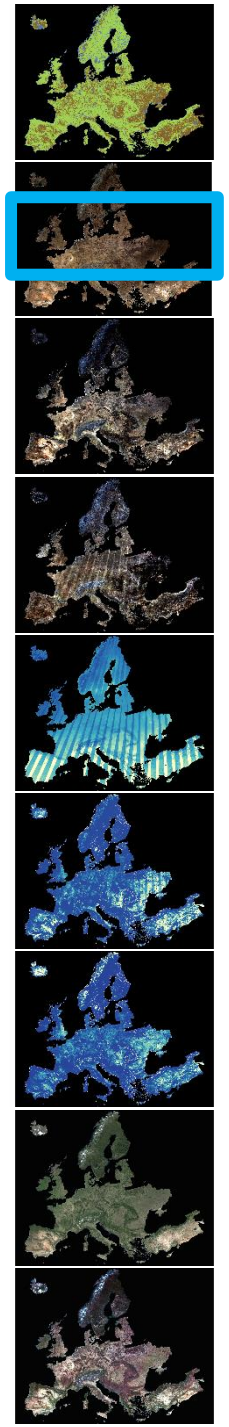
- EU MRV4SOC
- ESA WorldSoils II

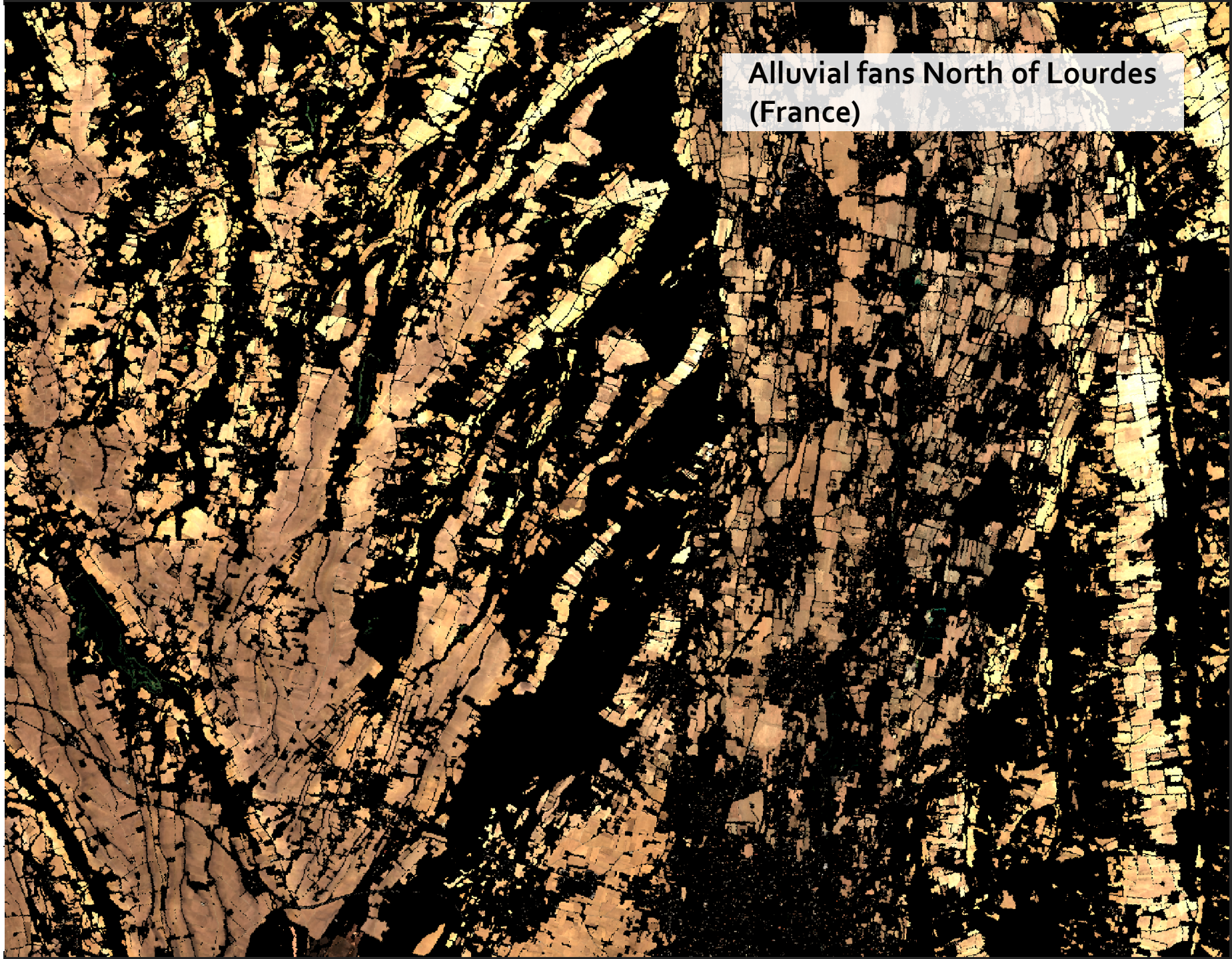
SoilSuite 2018 – 2022

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

<u>Bare Surface Reflectance Composite</u>

– Mean





SoilSuite 2018 – 2022

- Sentinel-2
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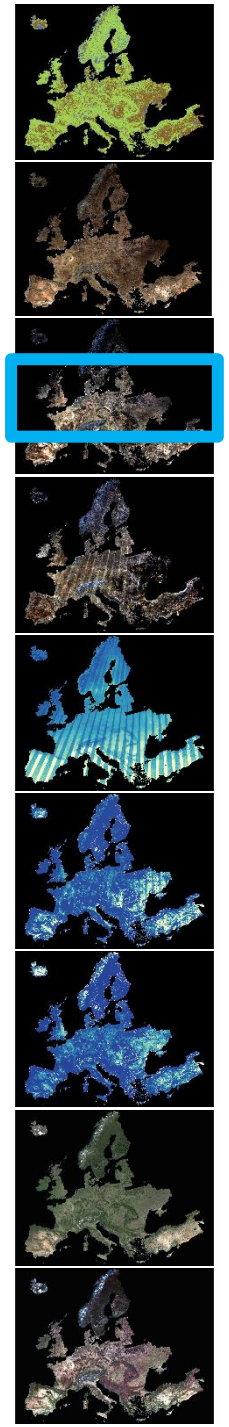
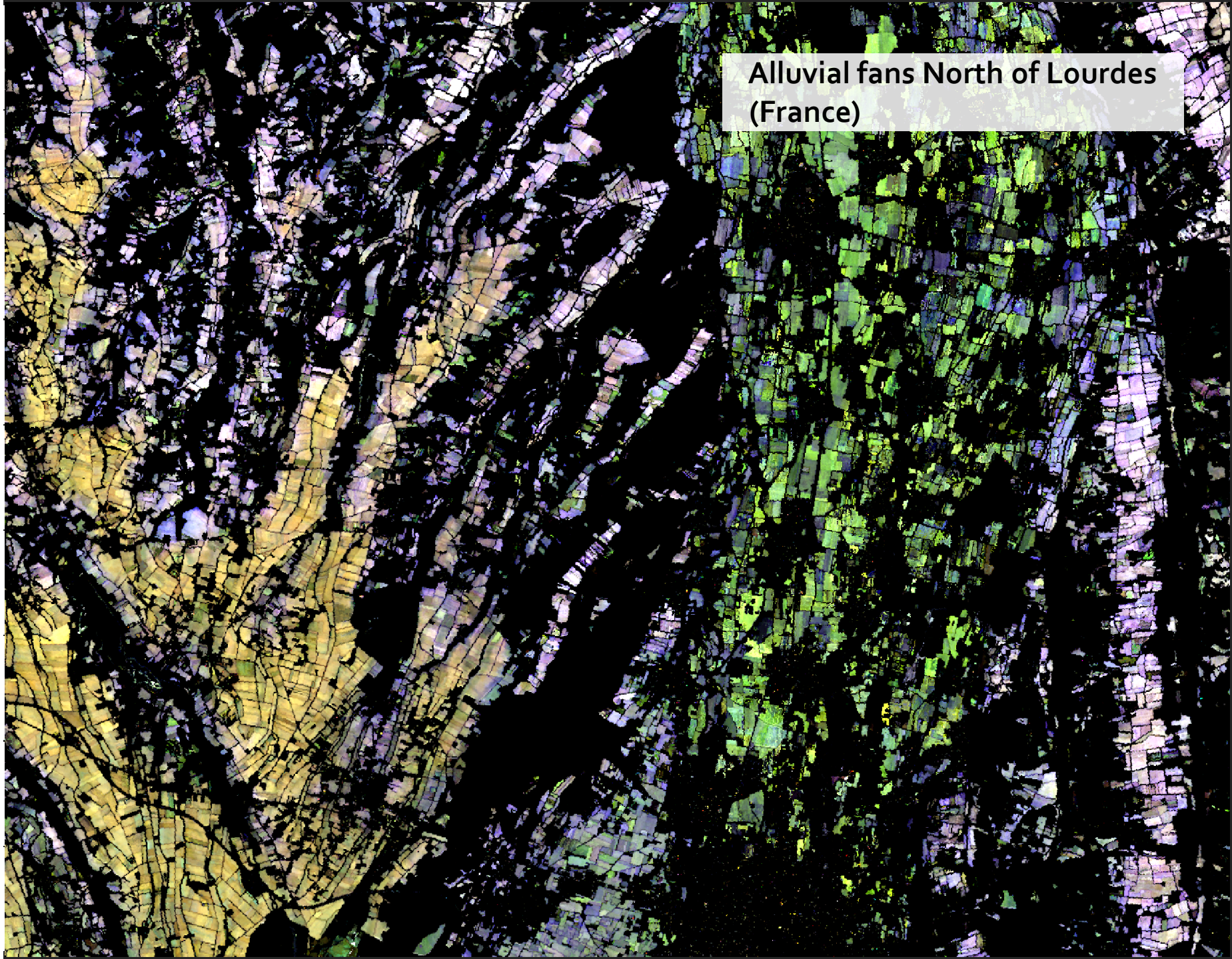




SOILSUITE FÜR BRANDENBURG

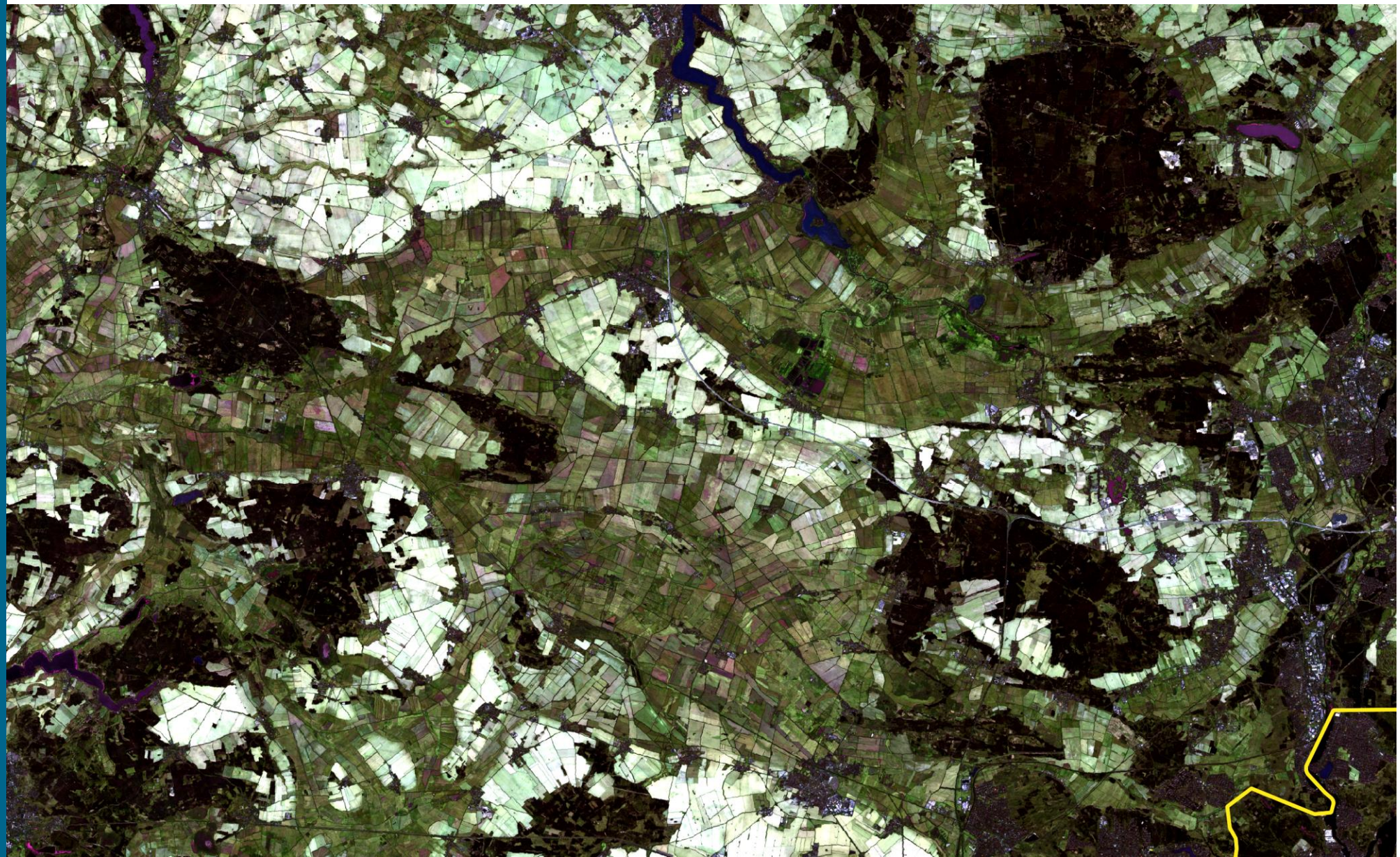
SCMaP Produkte für Brandeburg

- Agricultural area (Linumer Bruch) Northwest of Berlin
- Google Maps

SCMaP Produkte für Brandeburg

- Agricultural area (Linumer Bruch) Northwest of Berlin
- **Mean reflectance Composite (average)**
- RGB 4/3/2 (true color)
- Sentinel-2 data collected from 03/2018 – 12/2022
- Spectral differences between landcovers visible

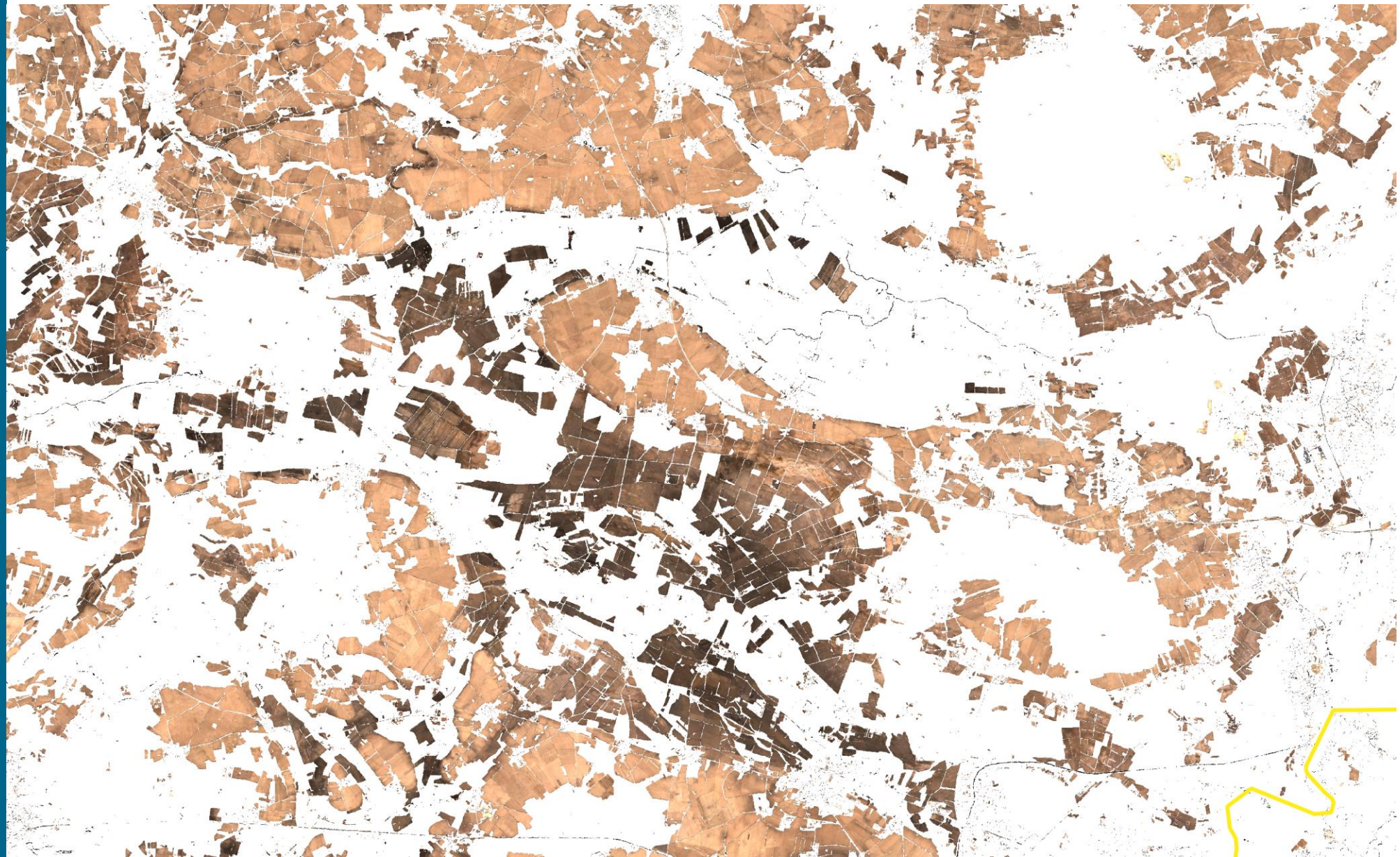
SCMaP Produkte für Brandeburg



- Agricultural area (Linumer Bruch) Northwest of Berlin
- **Mean reflectance Composite (standard dev.)**
- RGB 4/3/2 (true color)
- Sentinel-2 data collected from 03/2018 – 12/2022

- Spectral dynamics differ due to landuse, background soils, etc.

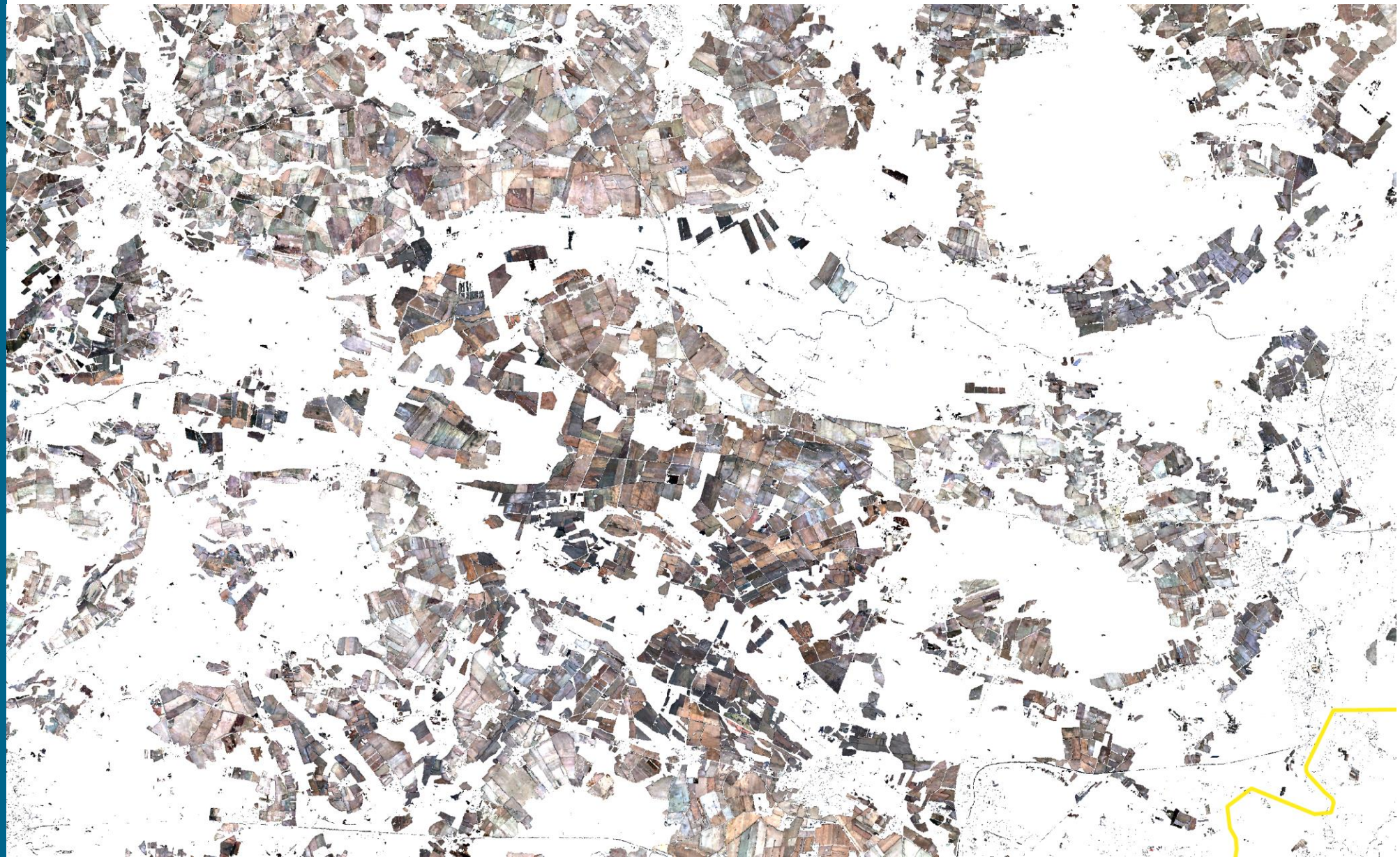
SCMaP Produkte für Brandeburg



- Agricultural area (Linumer Bruch) Northwest of Berlin
- **Soil Reflectance Composite (average)**
- RGB 4/3/2 (true color)
- Sentinel-2 data collected from 03/2018 – 12/2022

- Differences due to soil type, mineraology, soil moisture, SOC content

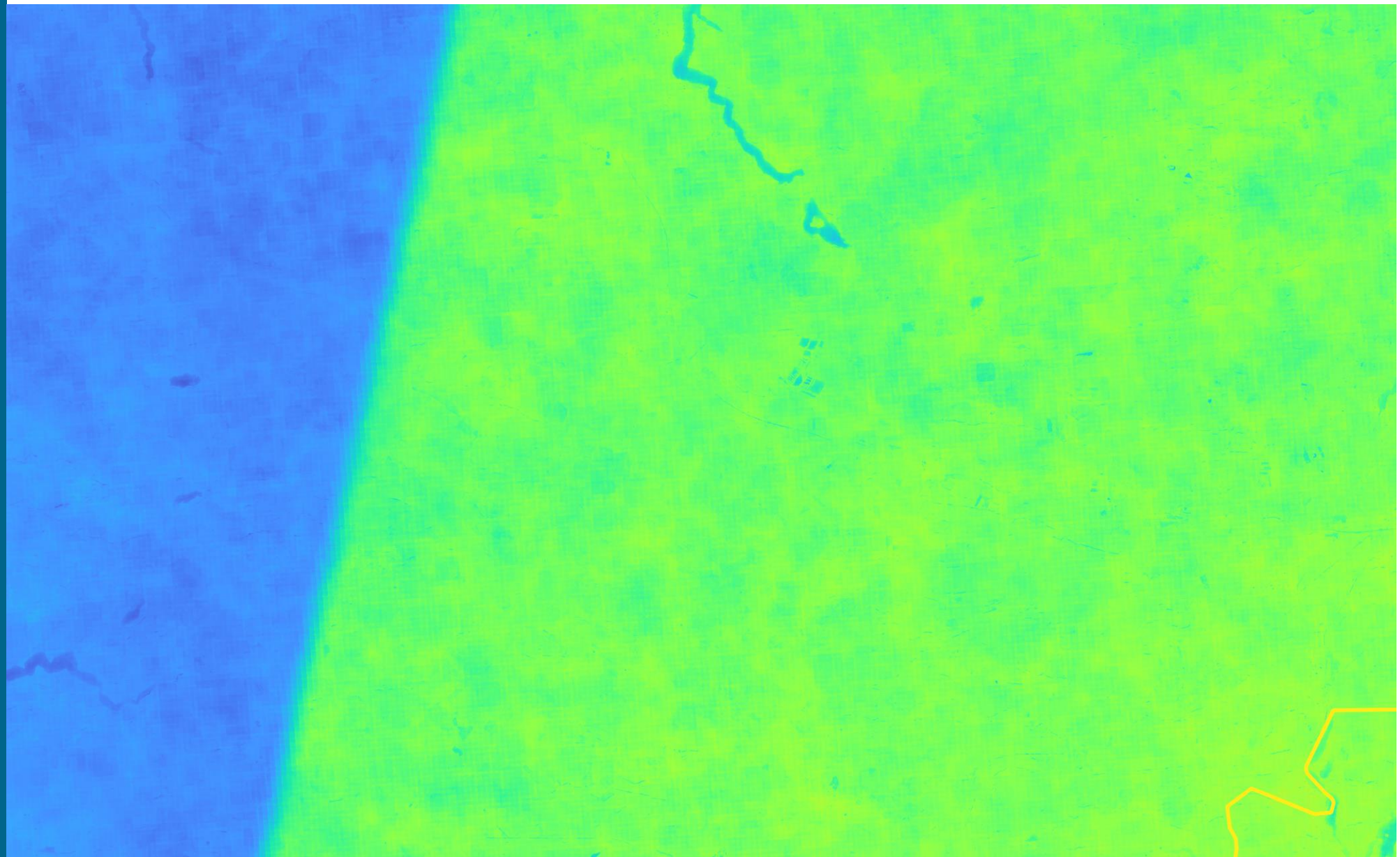
SCMaP Produkte für Brandeburg



- Agricultural area (Linumer Bruch) Northwest of Berlin
- **Soil Reflectance Composite (standard deviation)**
- RGB 4/3/2 (true color)
- Sentinel-2 data collected from 03/2018 – 12/2022

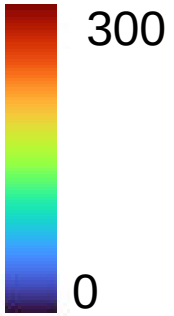
- Soils have different spectral dynamics due to their characteristics

SCMaP Produkte für Brandeburg

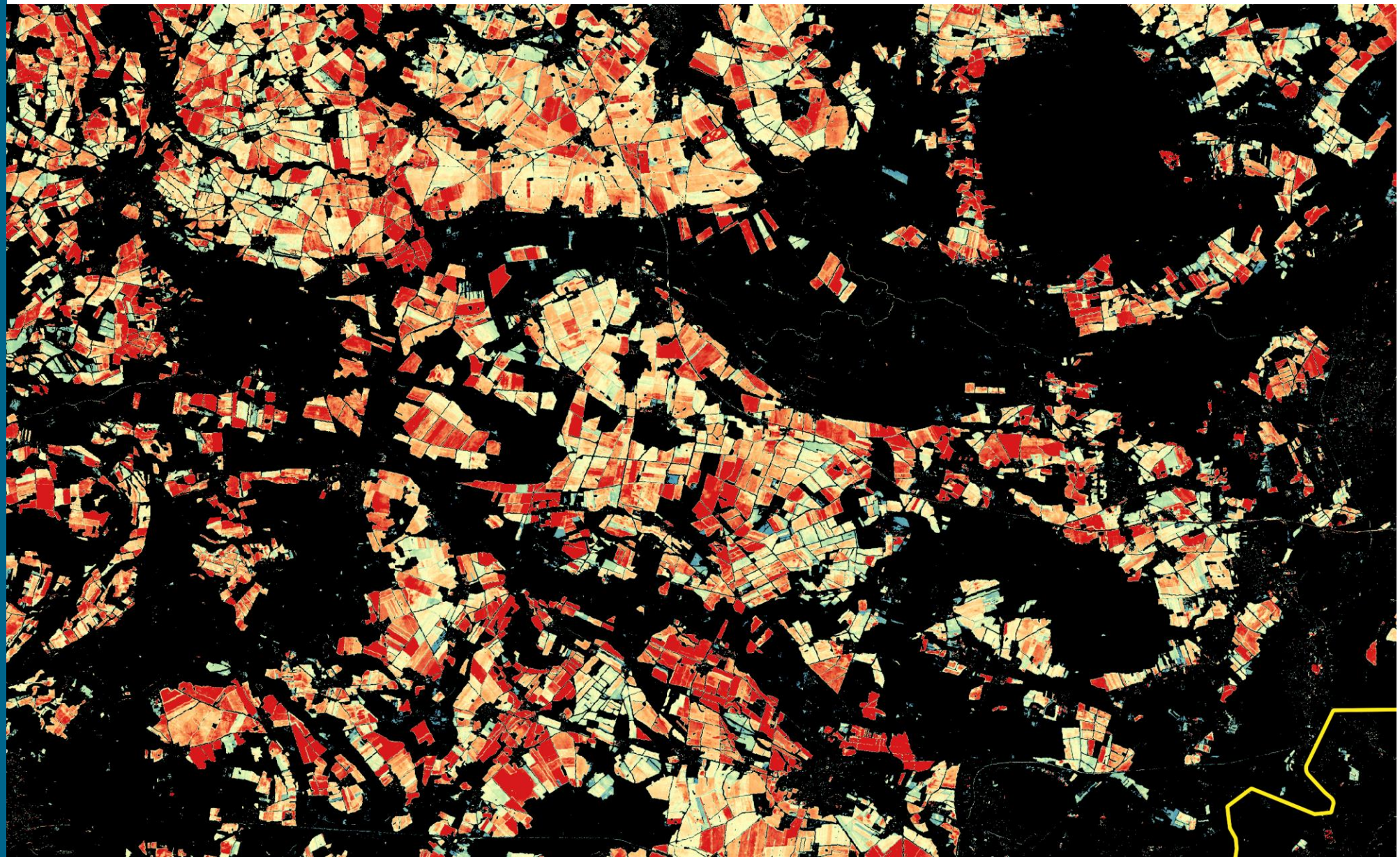


- Agricultural area (Linumer Bruch) Northwest of Berlin
- **Valid pixel count**
- Sentinel-2 data collected from 03/2018 – 12/2022

- How often do we have a cloudfree observation?



SCMaP Produkte für Brandeburg



- Agricultural area (Linumer Bruch) Northwest of Berlin
- **Bare soil frequency**
- Sentinel-2 data collected from 03/2018 – 12/2022

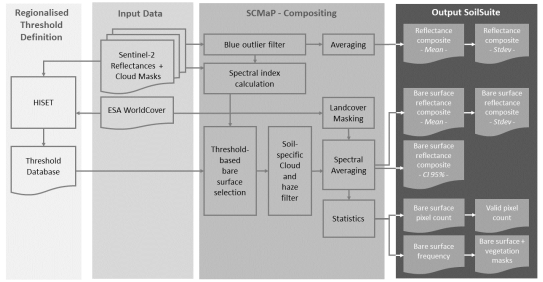
- Soil visibility in percent, interesting for erosion studies

34 %

0 %

Soil Composite Mapping Processor (SCMAP)

Project-specific configurations

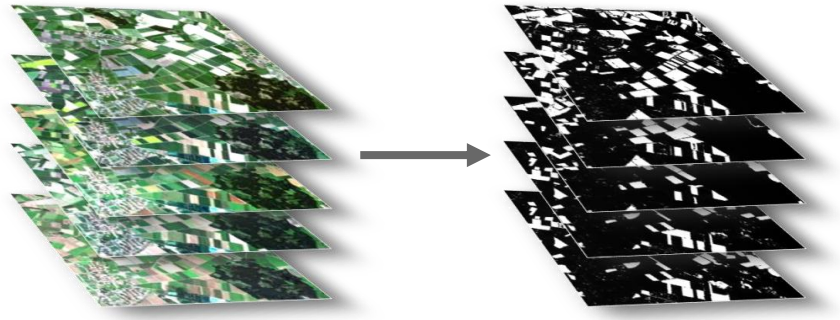


Selection of optical **sensors**

- Landsat: 1984 – today (max. 1 valid observation per month)
- **Sentinel-2: 2015 – today (2-4 valid observations per month)**

Temporal settings:

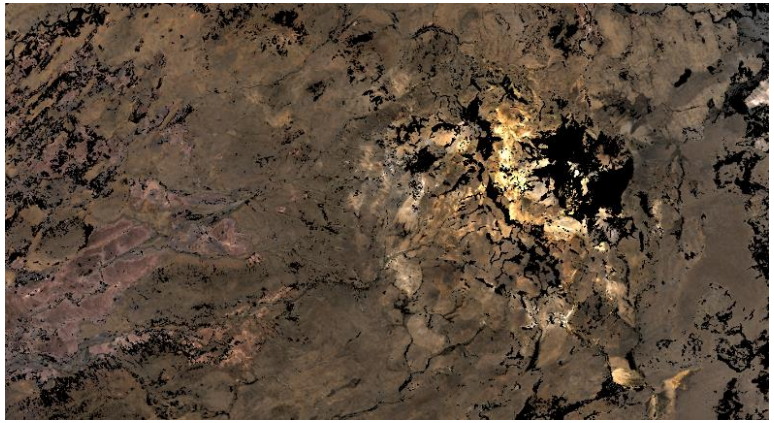
- Long time series for stable soil properties (eg. SOC): 01/2018 - 12/2022
- Monitoring of specific events or quickly changing properties
  - Monthly or quarterly products (single and multi year), eg. Q2: 04/2023 - 06/2023
  - Overlapping (2018-2020, 2019-2021, …)
  - Consecutive periods (2018-2020, 2021-2023, …)



- Min. **sun elevation** (for better spectral reliability) – can filter out images with low sun elevations (spectral images with low quality)

- Soil-specific **cloud screening**:
  - (B11-B8A)/(B11+B8A) > 0.02
  - $b \leq median(B) + 3\sigma$; σ=1.48 $median(|B - median(B)|)$

- **Various spectral indices** for selection of bare soil pixels



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

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:

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

SoilSuite for Europe

Spectral and statistical information of bare soils

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

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- EOC Geoservice (Host) DLR/EOC

Platform for derived soil properties:
https://cup4soil.isric.org/

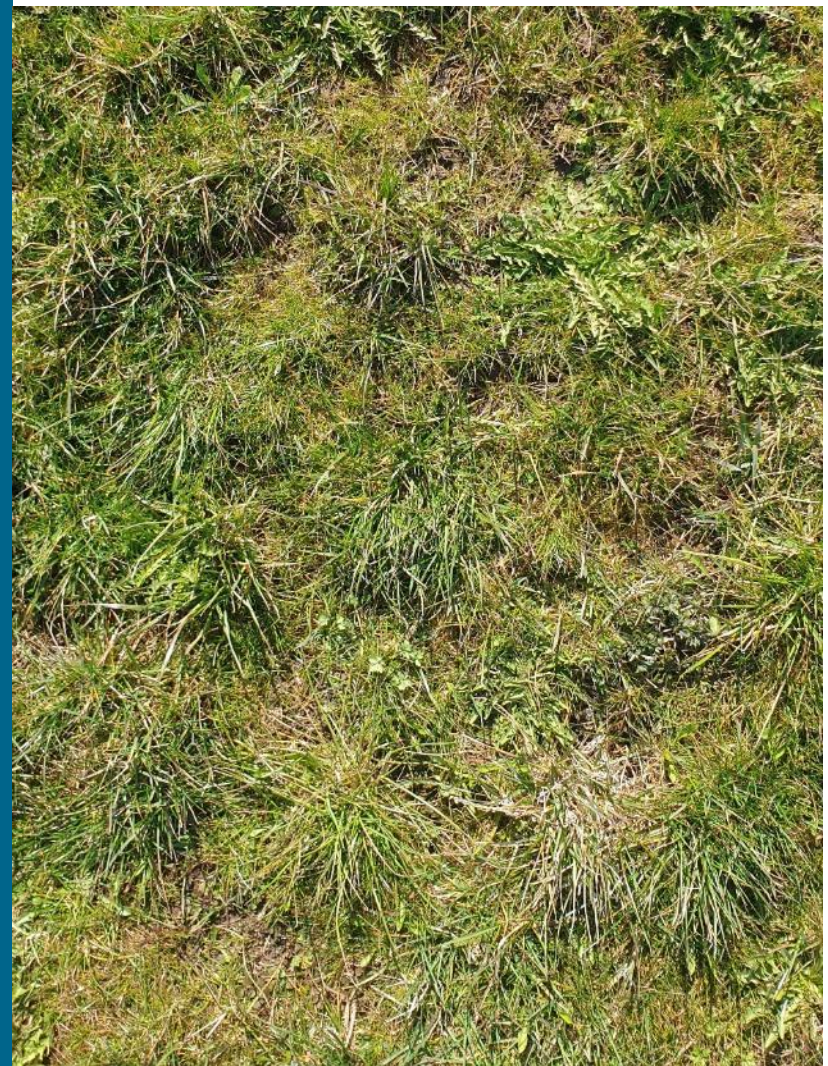
(ISRIC)

FRACTIONAL VEGETATION COVER - FCOVER

Fractional vegetation cover - fCover

Definition

Green vegetation



Dry vegetation

Bare soil

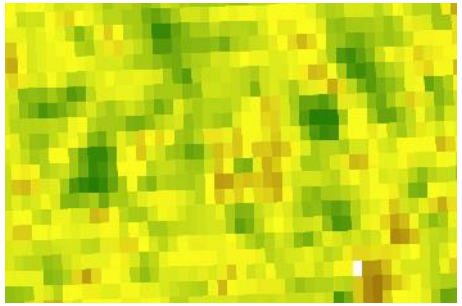
fCover products in comparison

Fraction of **green** vegetation
0% 100%

Fraction of **dry** vegetation
0% 100%

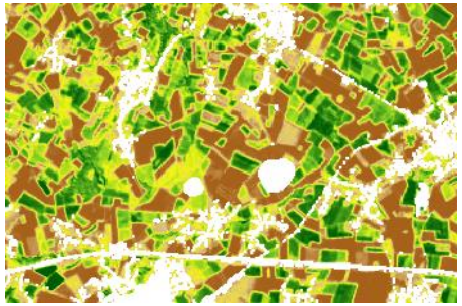
Fraction of **bare soil**
0% 100%

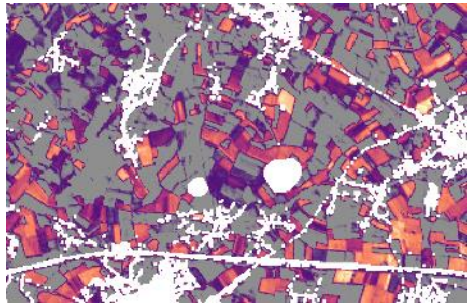
<u>Current Copernicus Product:</u>
Fraction of Green Vegetation Cover
300 m



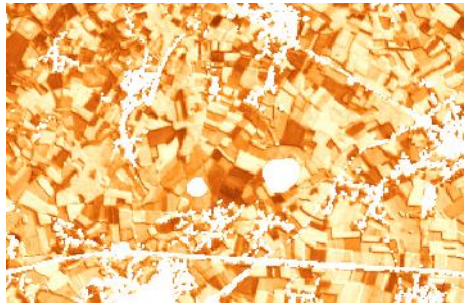
<u>Hyperspectral EnMAP</u>
Fraction of
- Green veg.
- Dry veg.
- Bare soil

30 m





- Crop residues
- Grassland dynamics



- Bare soil coverage
- Bare soil dates
- Tillage events per time period

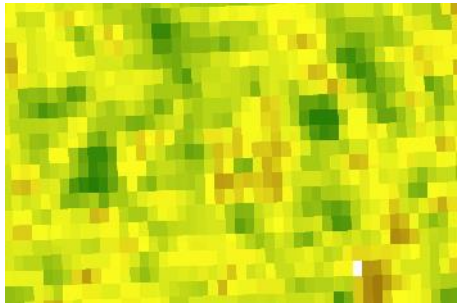
fCover products in comparison

Fraction of **green** vegetation 0% 100%

Fraction of **dry** vegetation 0% 100%

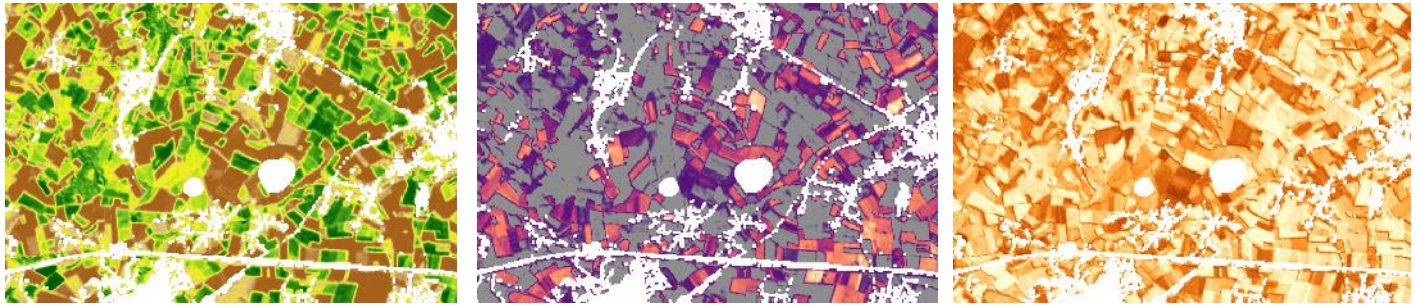
Fraction of **bare soil** 0% 100%

<u>Current Copernicus Product:</u>
Fraction of Green Vegetation Cover
300 m



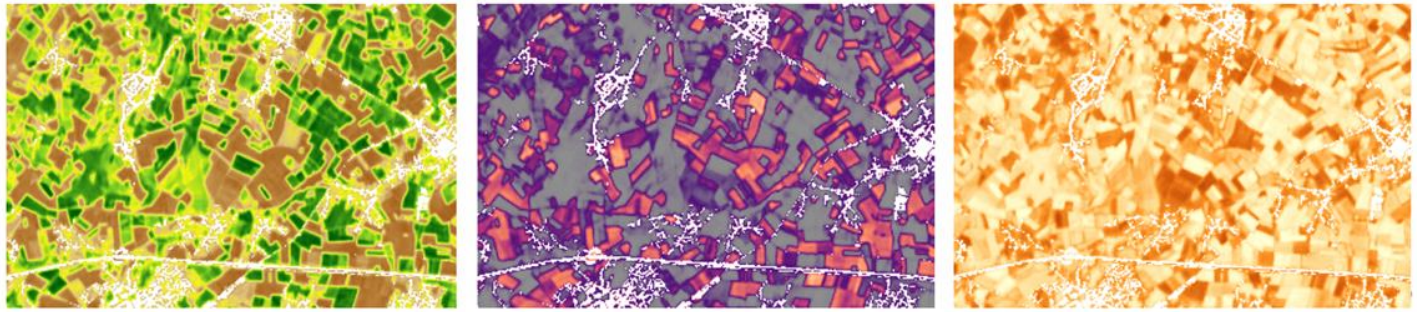
<u>Hyperspectral EnMAP</u>
Fraction of
- Green veg.
- Dry veg.
- Bare soil

30 m



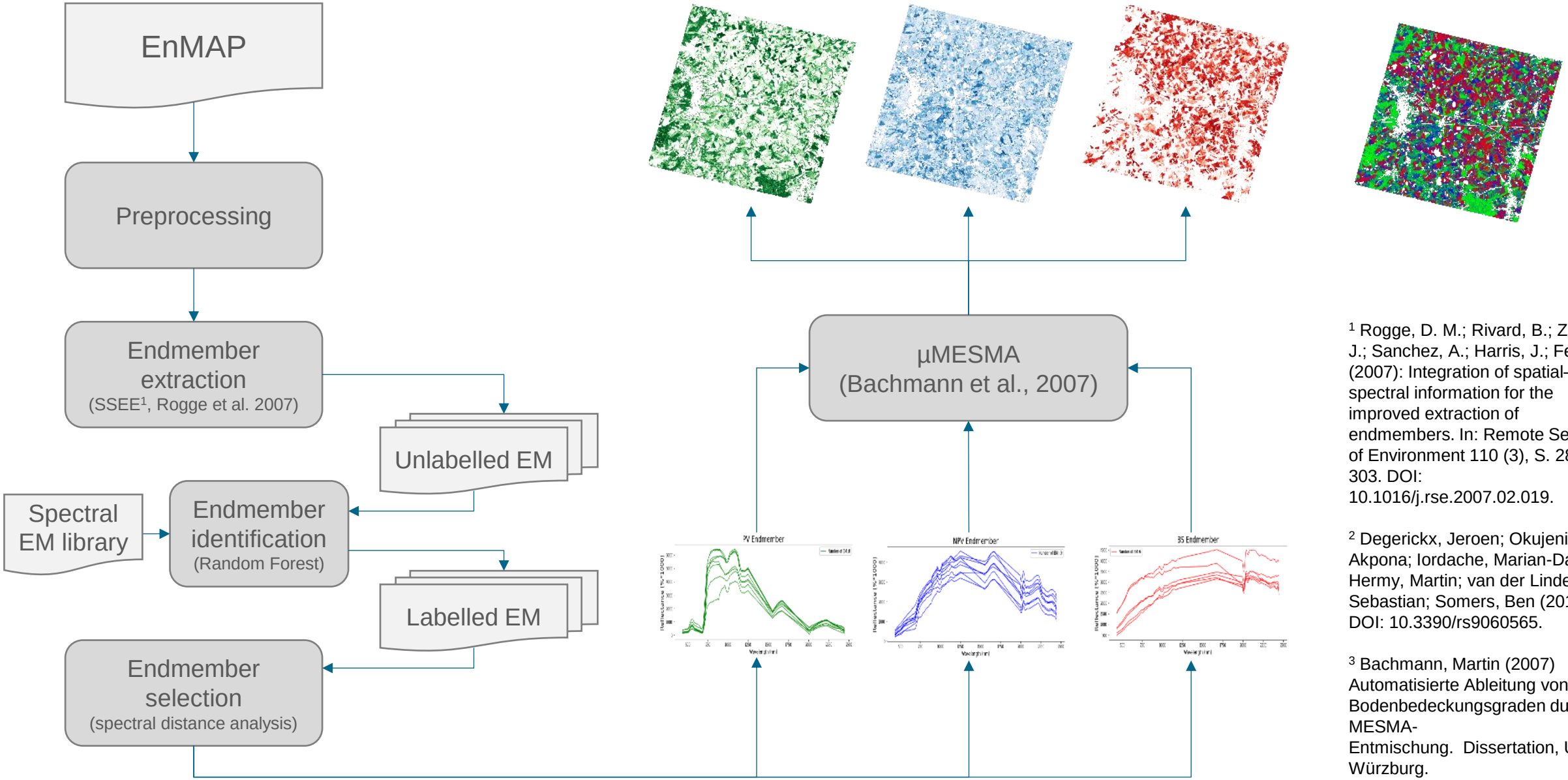
<u>Multispectral Sentinel-2</u>
Fraction of
- Green veg.
- Dry veg.
- Bare soil

20 m - 30 m



Fractional vegetation cover - fCover

FRActioNal Cover Analysis Processor (FRANCA)



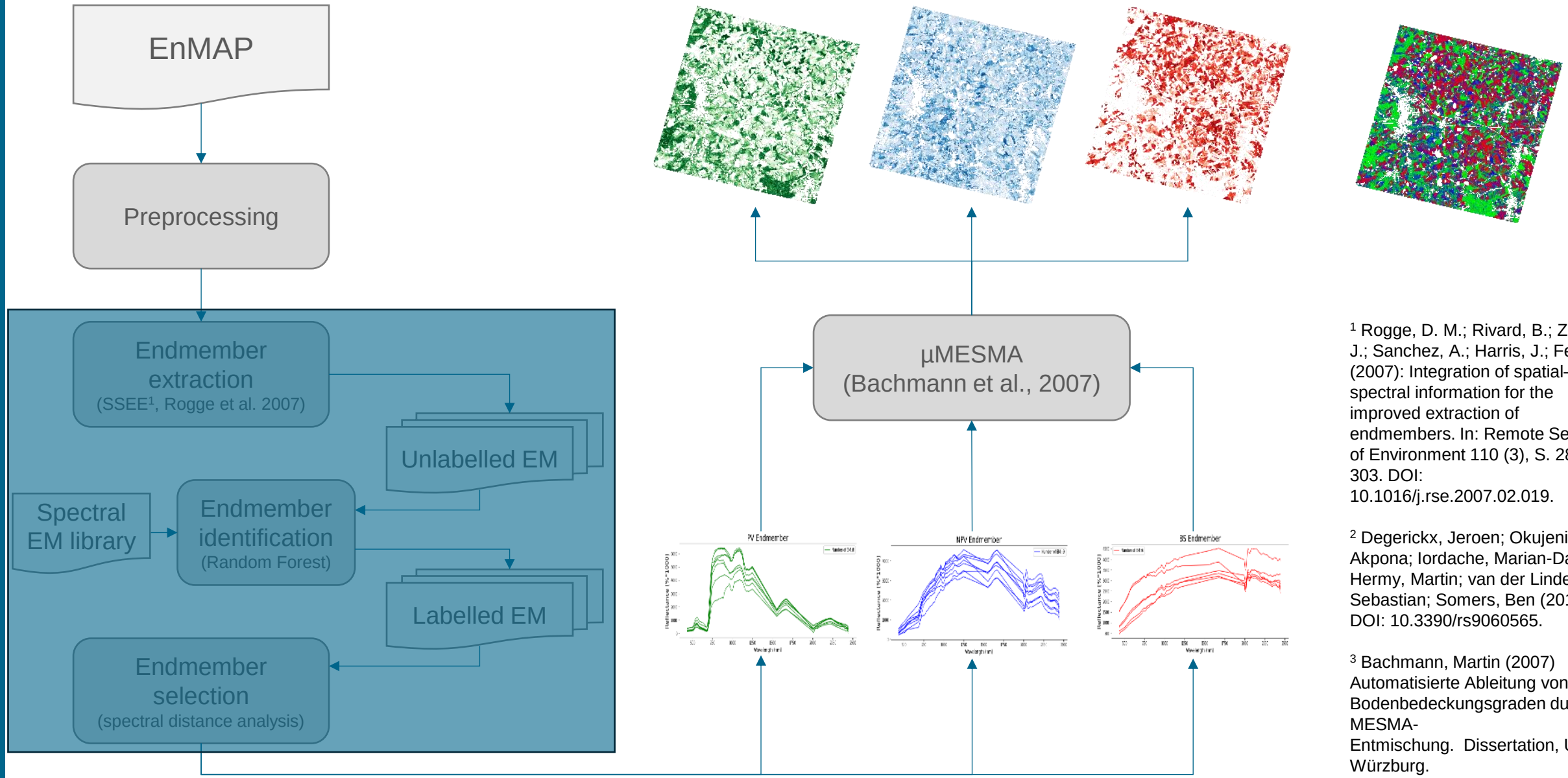
[1] Rogge, D. M.; Rivard, B.; Zhang, J.; Sanchez, A.; Harris, J.; Feng, J. (2007): Integration of spatial–spectral information for the improved extraction of endmembers. In: Remote Sensing of Environment 110 (3), S. 287–303. DOI: 10.1016/j.rse.2007.02.019.

[2] Degerickx, Jeroen; Okujeni, Akpona; Iordache, Marian-Daniel; Hermy, Martin; van der Linden, Sebastian; Somers, Ben (2017) DOI: 10.3390/rs9060565.

[3] Bachmann, Martin (2007) Automatisierte Ableitung von Bodenbedeckungsgraden durch MESMA-Entmischung. Dissertation, Uni Würzburg.

Fractional vegetation cover - fCover

FRActioNal Cover Analysis Processor (FRANCA)



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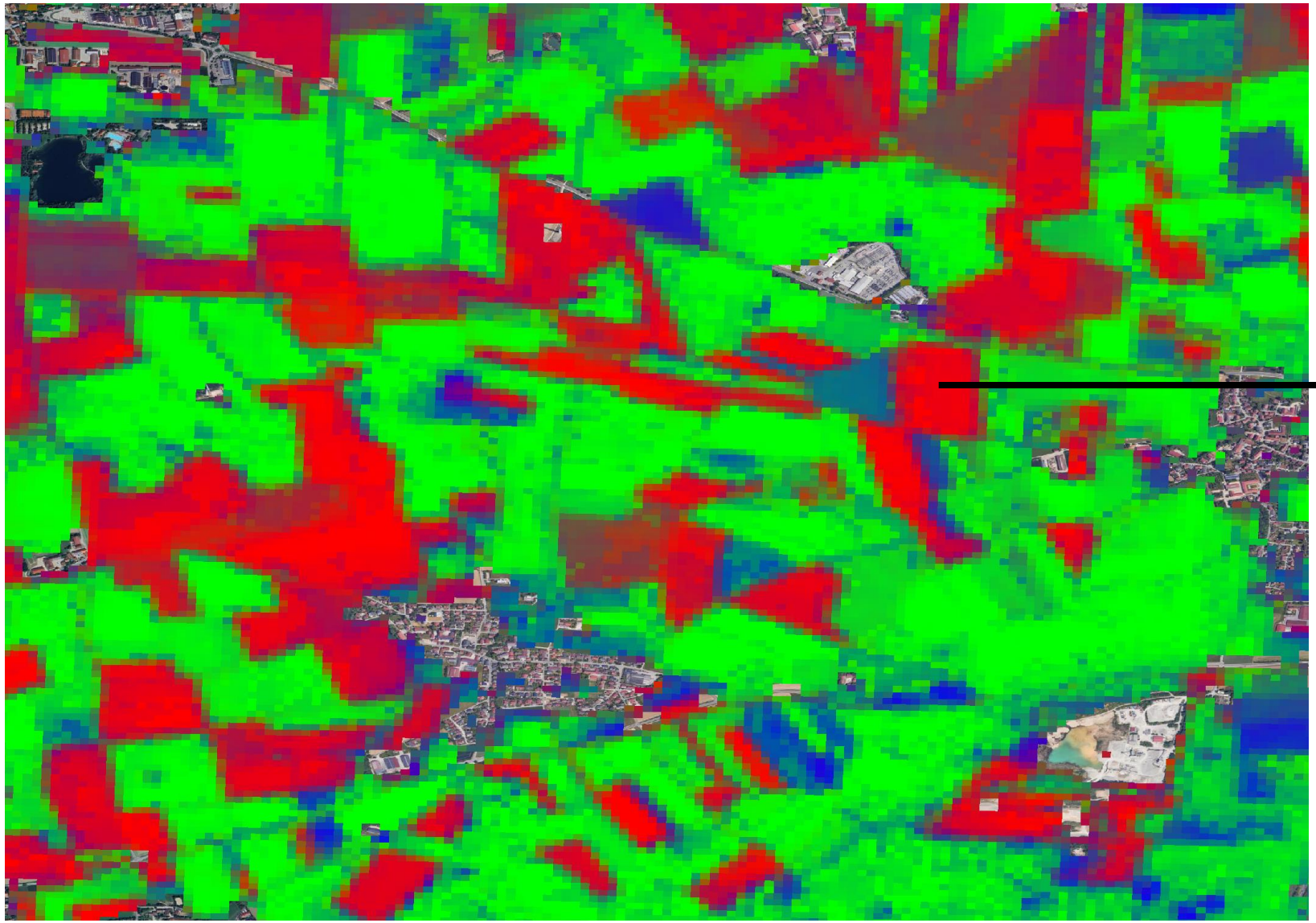
Fractional vegetation cover - fCover

FRActioNal Cover Analysis Processor (FRANCA)

- Google Maps
- Puch, Germany
- 3 km x 5 km

Fractional vegetation cover - fCover

FRActioNal Cover Analysis Processor (FRANCA)



- fCover (EnMAP)
- Puch, Germany
- 3 km x 5 km
- **31.05.2025**

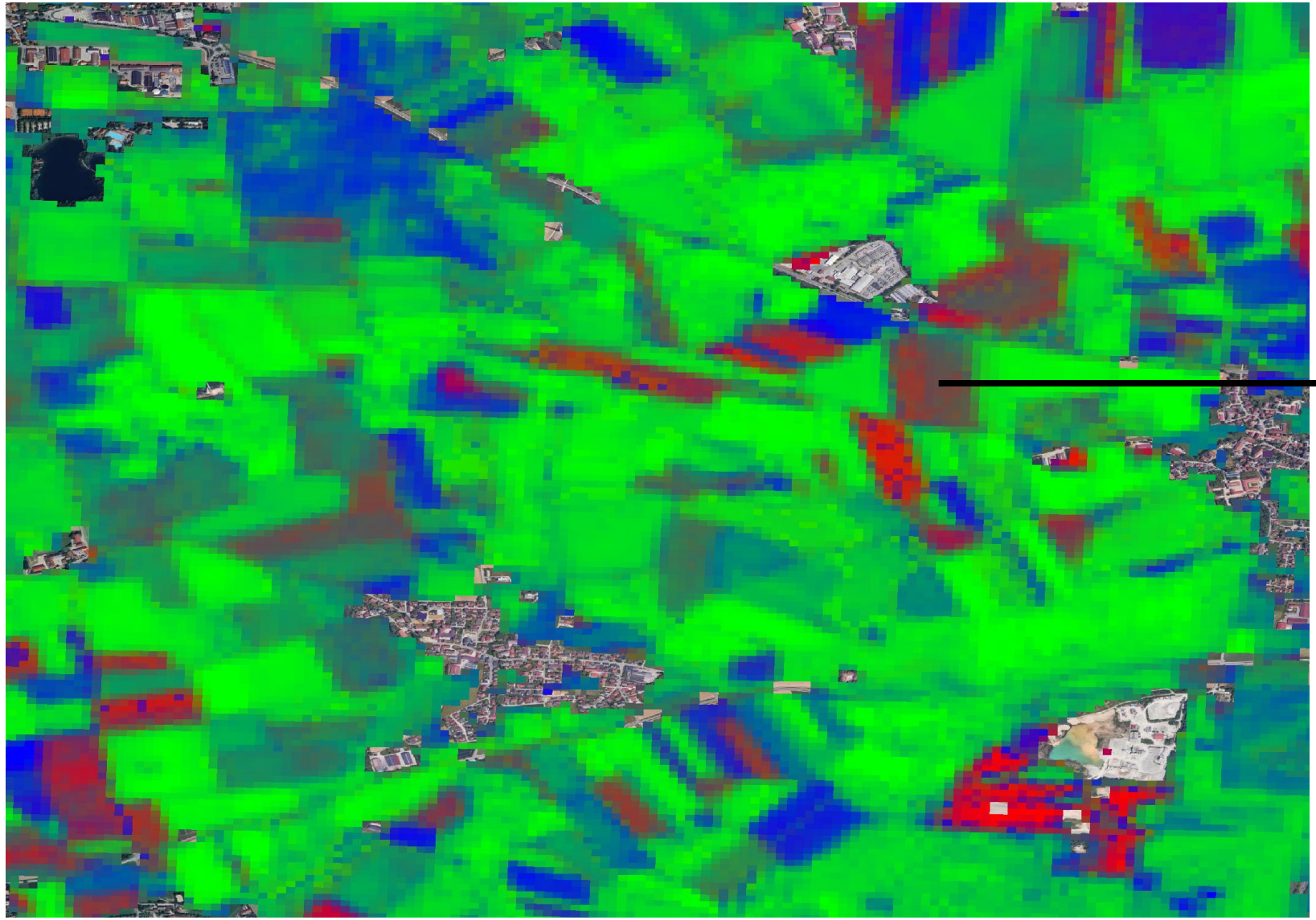
6 %
Trockene
Vegetation

94 %
Unbedeckter
Boden

0 %
Grüne
Vegetation

Fractional vegetation cover - fCover

FRActioNal Cover Analysis Processor (FRANCA)



- fCover (EnMAP)
- Puch, Germany
- 3 km x 5 km
- **22.06.2025**

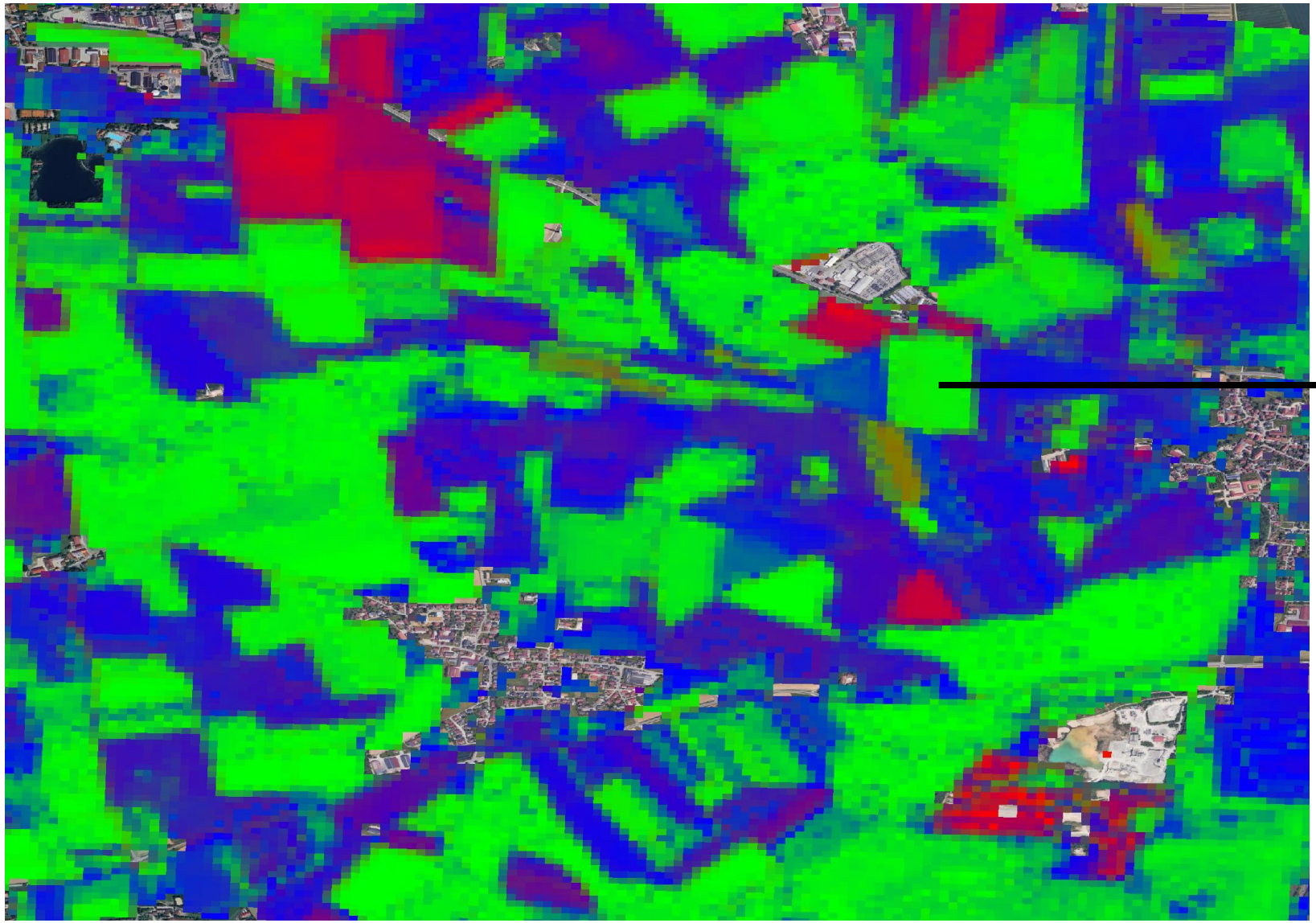
25 %
Trockene
Vegetation

46 %
Unbedeckter
Boden

29 %
Grüne
Vegetation

Fractional vegetation cover - fCover

FRActioNal Cover Analysis Processor (FRANCA)



- fCover (EnMAP)
- Puch, Germany
- 3 km x 5 km
- **20.07.2025**

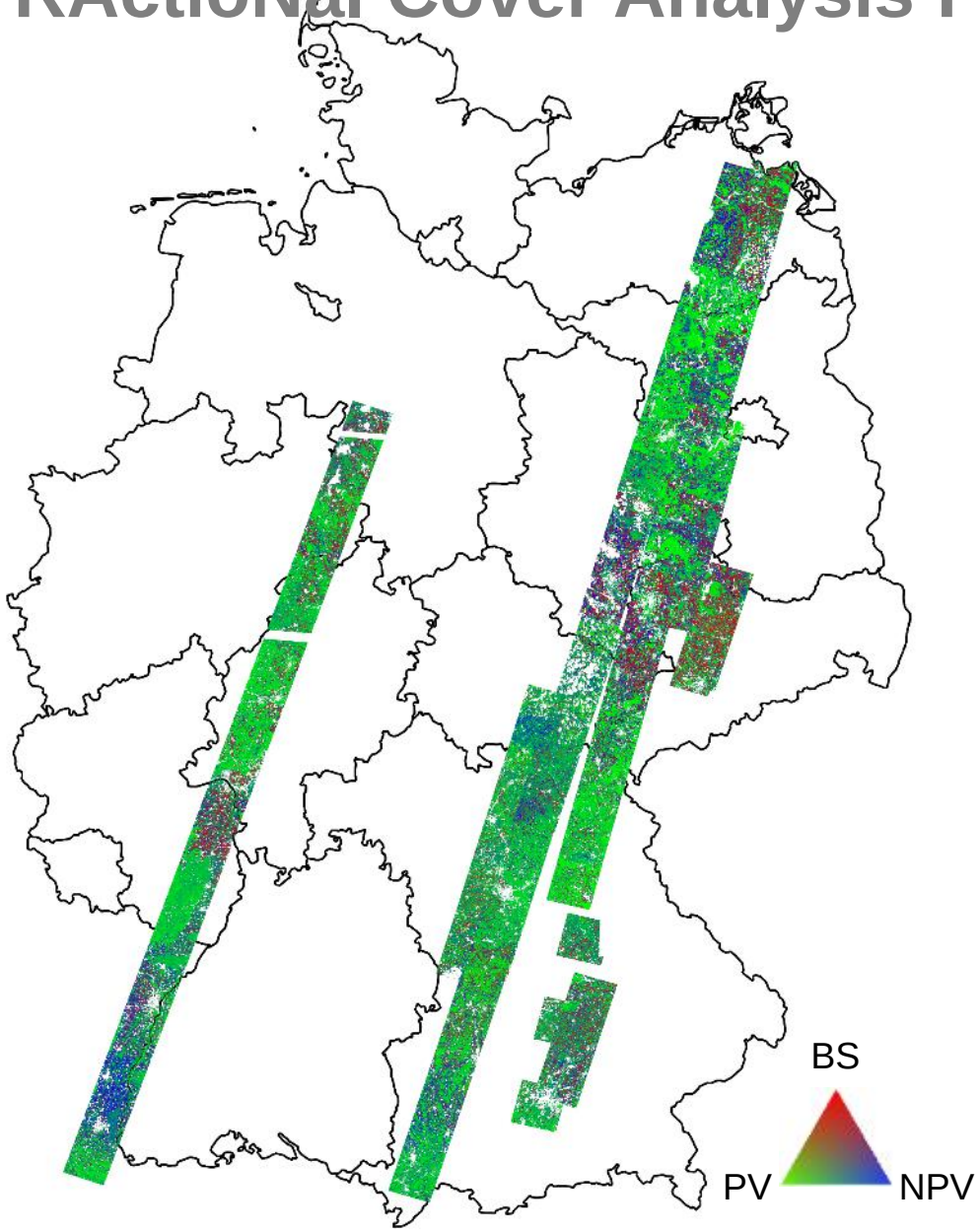
3 %
Trockene
Vegetation

3 %
Unbedeckter
Boden

94 %
Grüne
Vegetation

Fractional vegetation cover - fCover

FRActioNal Cover Analysis Processor (FRANCA)

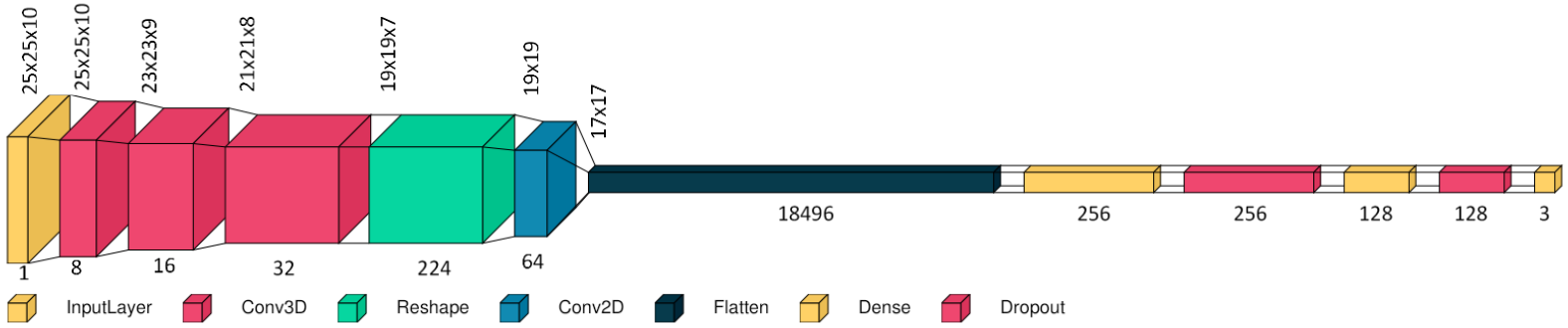


Summary:

- FRANCA: Preoperational processor so quantify abundances of green vegetation, dry vegetation and bare soil per pixel
- Based on spaceborne hyperspectral data (e.g. EnMAP) with pixel sizes of 30 m x 30 m
- Optimized for large data takes (seemless results)
- **Revision of EnMAP = 27 days**
- **Results in temporally and spatially fragmented information about soil coverage**

fCover using Deep Learning

- Modified HybridSN model - trained with Sentinel-2 L2A scenes paired with EnMAP-based abundance maps of BS, NPV and PV of the same day and area

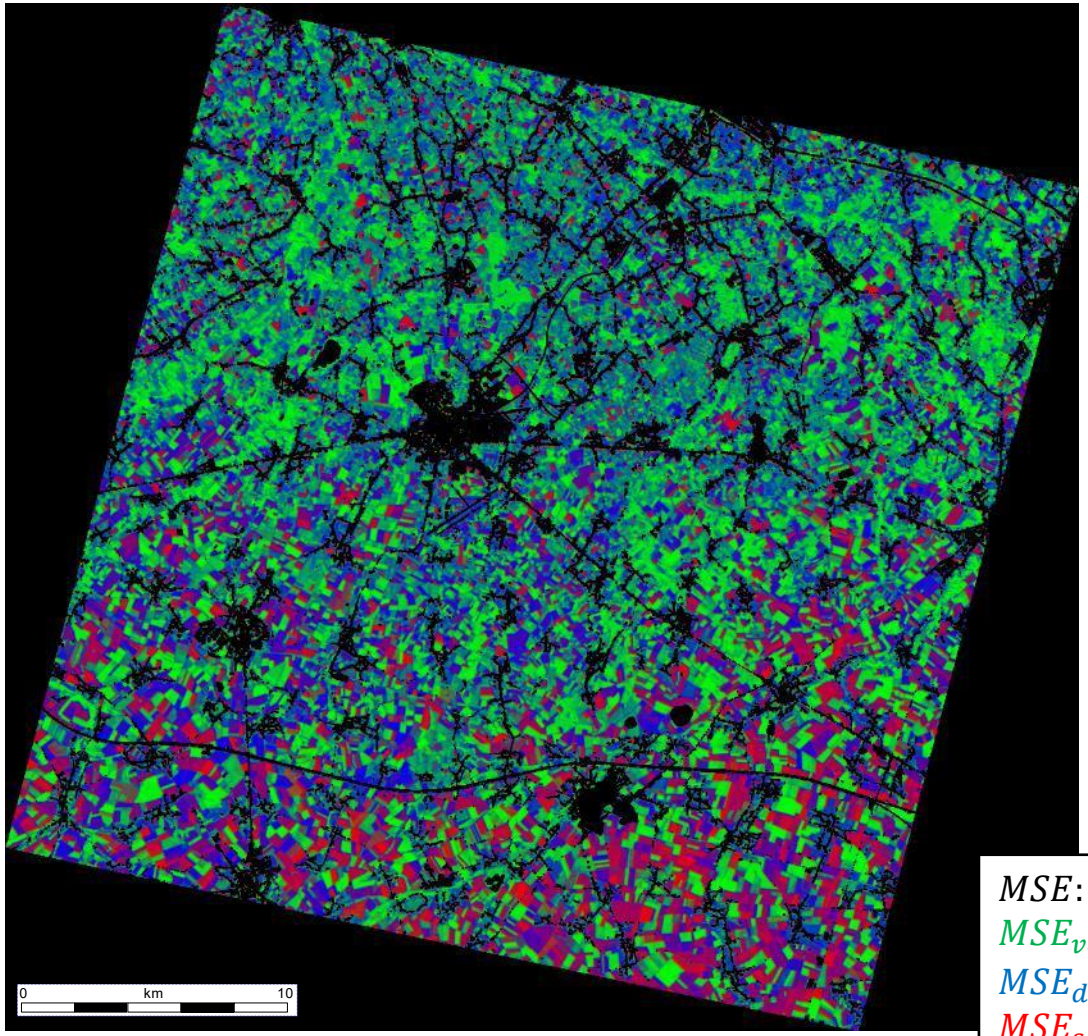


Idea: Leverage the archive of EnMAP to predict fCover (NPV) with Sentinel-2 data

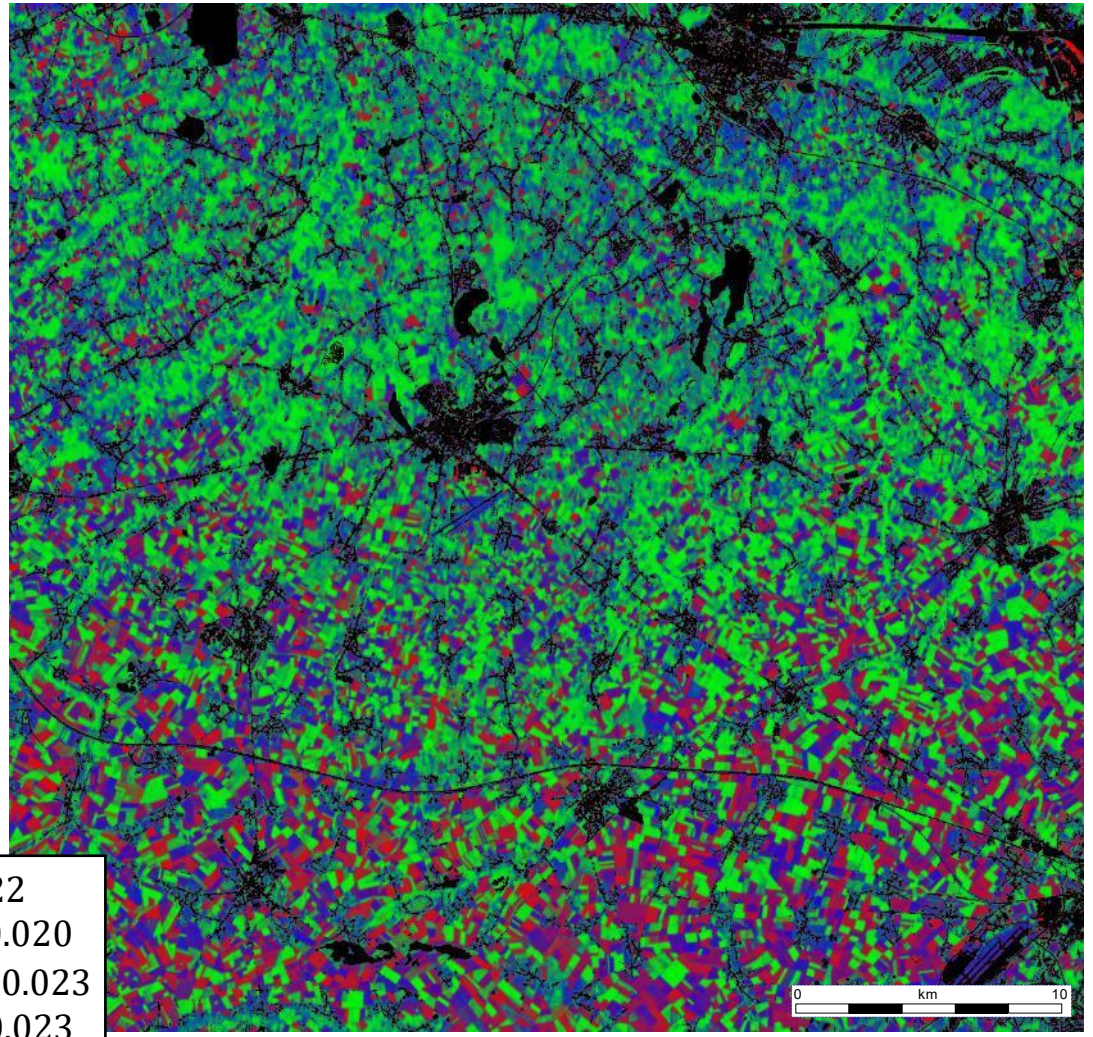
- Create fCover maps on hyperspectral data from EnMAP data (224 bands, 420-2450 nm)
- Find spectral imagery from Sentinel-2 for same areas/dates
- Train a DL network using S2 images as input and fCover maps as labels
- The trained model can be used to create fCover maps on S2 data (10 bands, 443-2202 nm)

fCover using Deep Learning: Belgium, Sint-Truiden

fCover from EnMAP (10.08.2022)



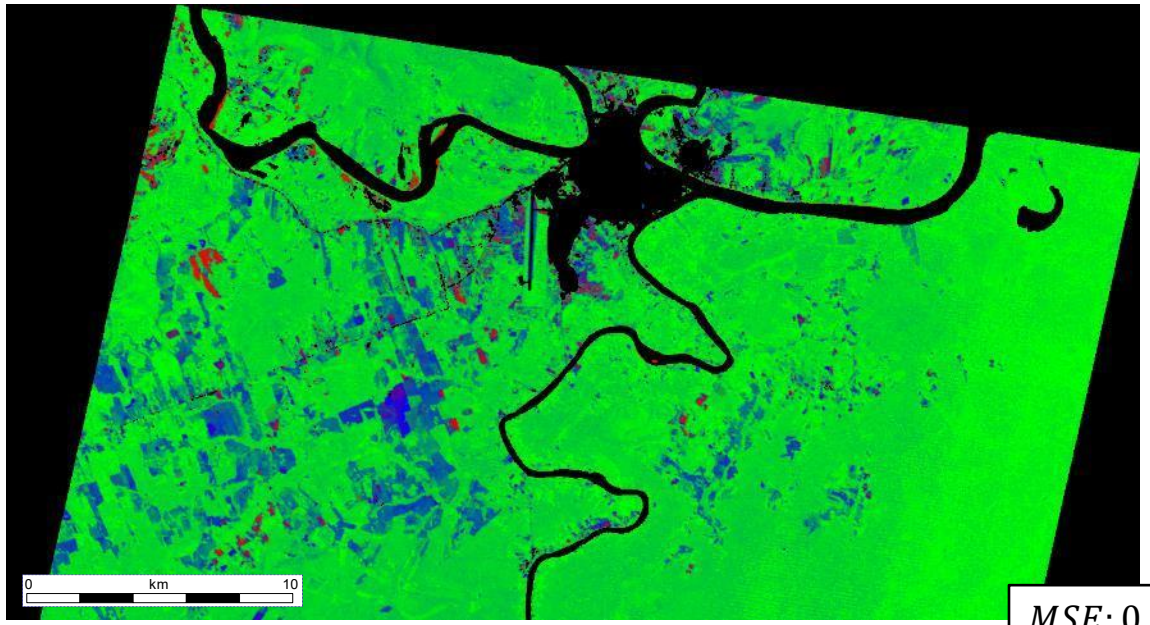
DL - fCover from S2 (10.08.2022)



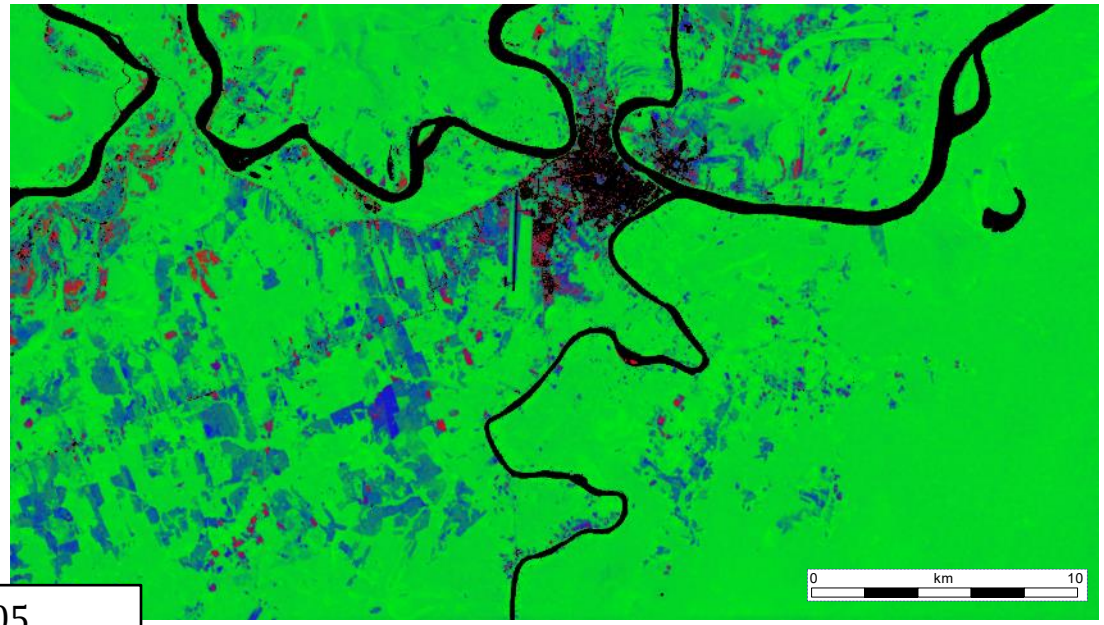
MSE: 0.022
MSE_{veg}: 0.020
MSE_{dead}: 0.023
MSE_{soil}: 0.023

fCover using Deep Learning: Peru, Puerto Maldonado

fCover from EnMAP (20.07.2023)



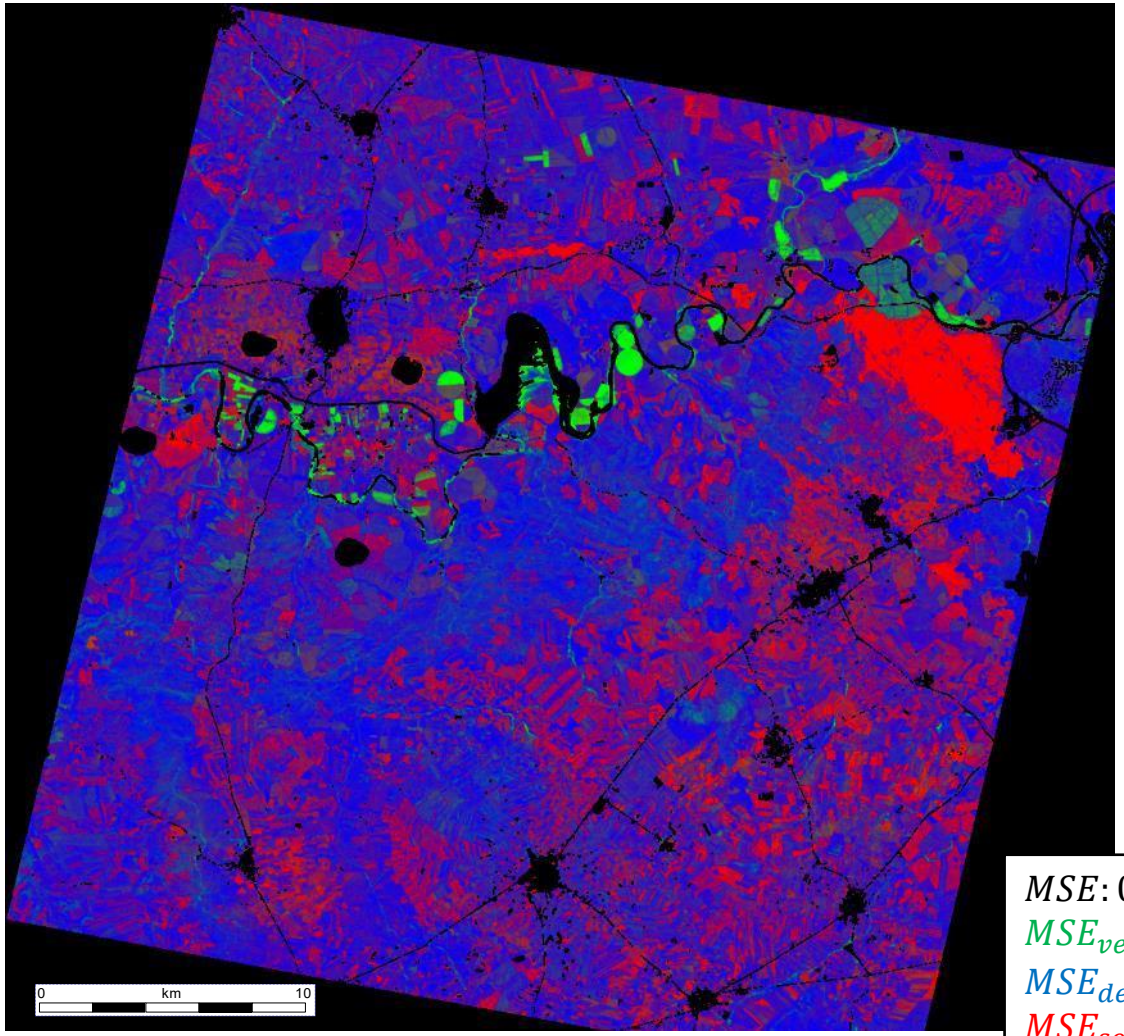
DL - fCover from S2 (20.07.2023)



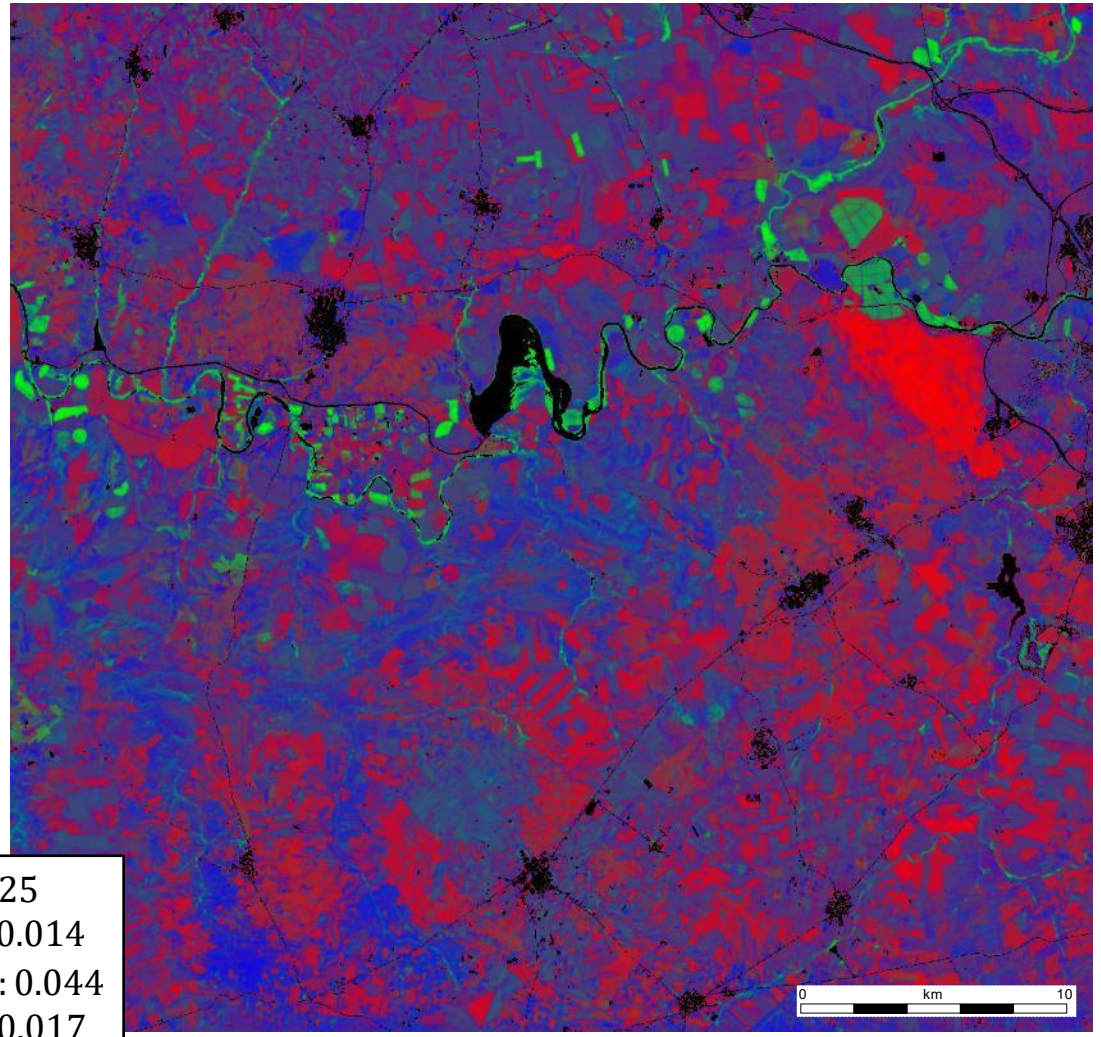
MSE: 0.005
MSE_{veg}: 0.008
MSE_{dead}: 0.007
MSE_{soil}: 0.002

fCover using Deep Learning: Spain, Toledo

fCover from EnMAP (26.07.2022)



DL - fCover from S2 (04.08.2022)



MSE: 0.025
MSE_{veg}: 0.014
MSE_{dead}: 0.044
MSE_{soil}: 0.017

FUTURE DEVELOPMENTS

Bildquelle hier angeben

Future developments

- Selective SoilSuite products on a yearly basis (e.g. bare soil frequency)
- New SoilSuite products such as bare soil dates, bare soil duration, …
- Fractional vegetation cover on a multitemporal basis using spaceborne hyperspectral data + Sentinel-2 data for e.g. soil erosion mapping, crop residues, regenerative agriculture
- New areas outside Europe

SoilSuite Africa

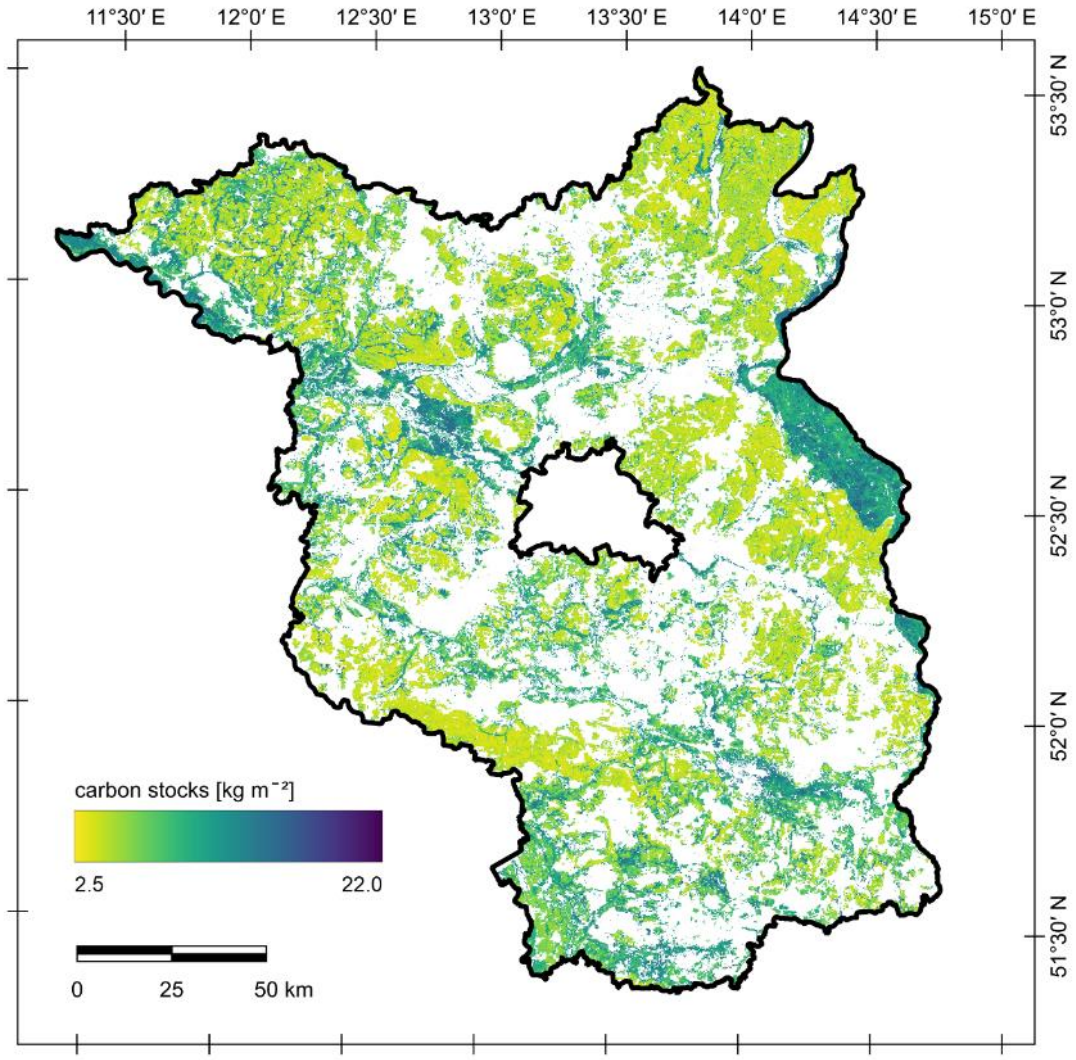
(Rwanda, Kenya, Ethopia)

https://doi.org/10.15489/xhihk9rkff04

Thank you very much for your attention!

Contact: Uta.Heiden@dlr.de

Showcase – LBGR Cottbus, Germany



Used data:

Soil reflectance composite

digital elevation model and derived morphometric variables

geological maps

soil maps

land use maps

crop (rotation) maps

Validation (out-of-bag):

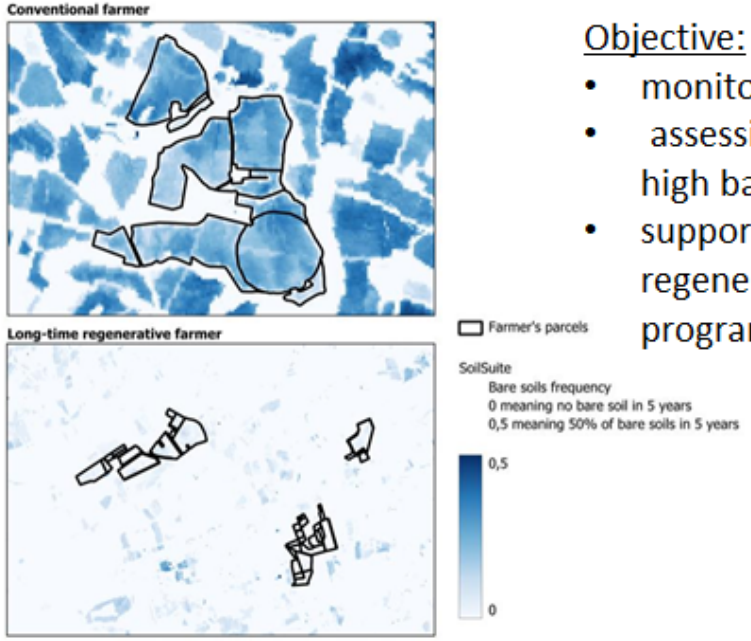
RMSE: 0.7 kg m-2, Pseudo-R^2: 0.69 (0-10 cm)

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



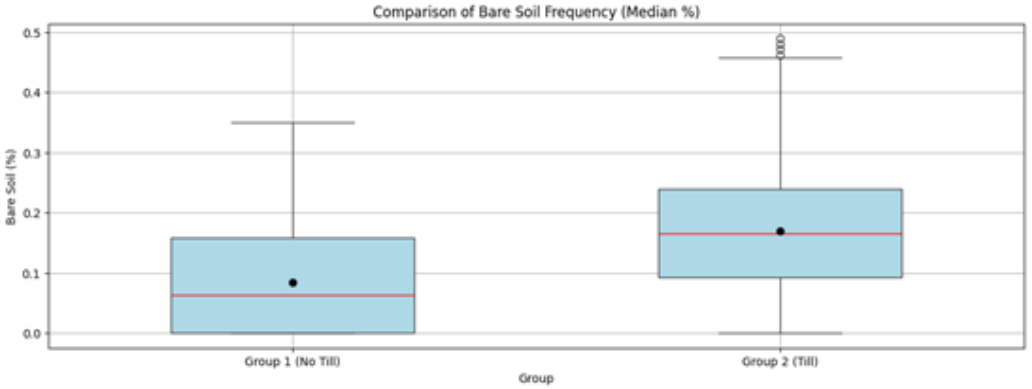


Figure 3: Box plot comparing the median frequency of bare soil between the two groups of agricultural practices.

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

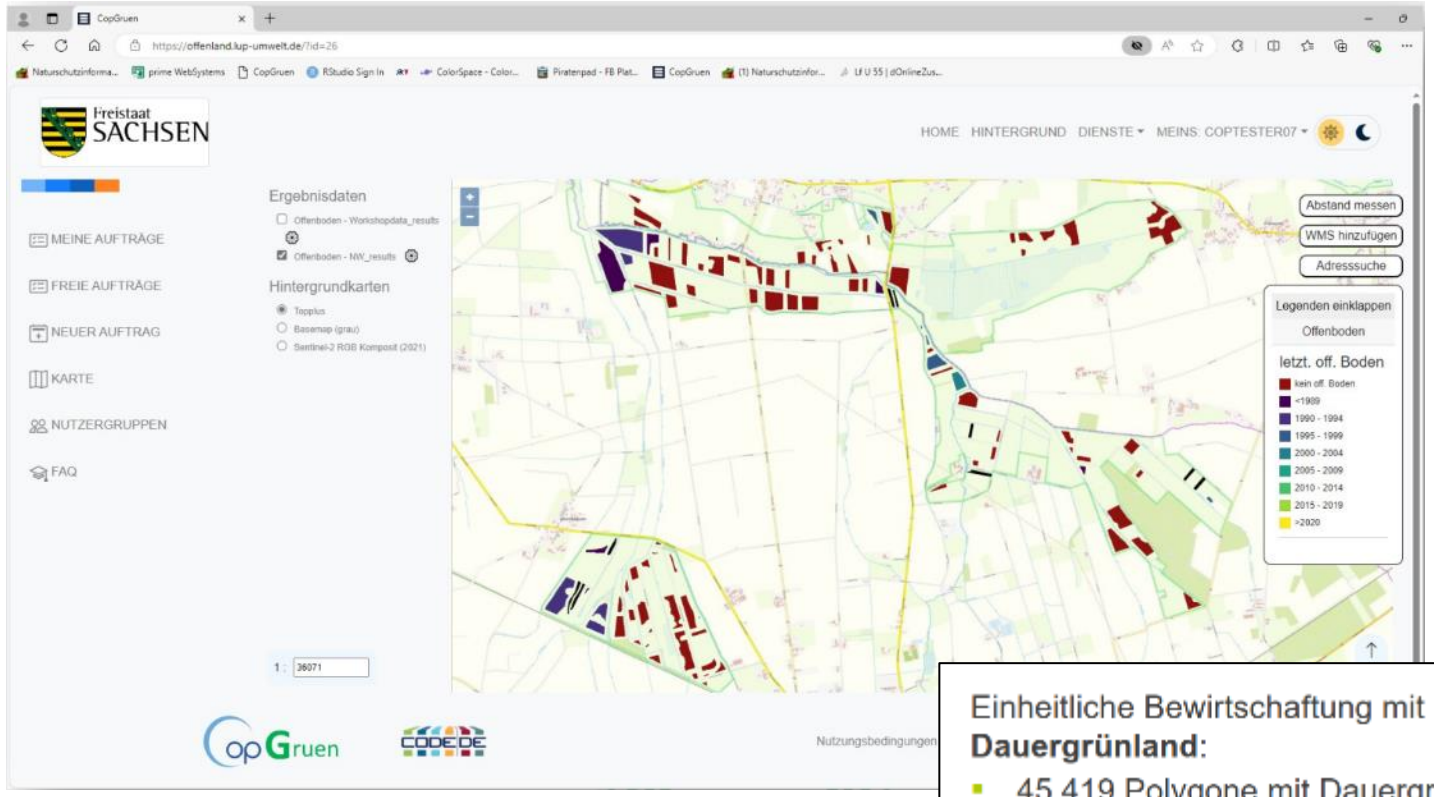
Results:

- 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%)

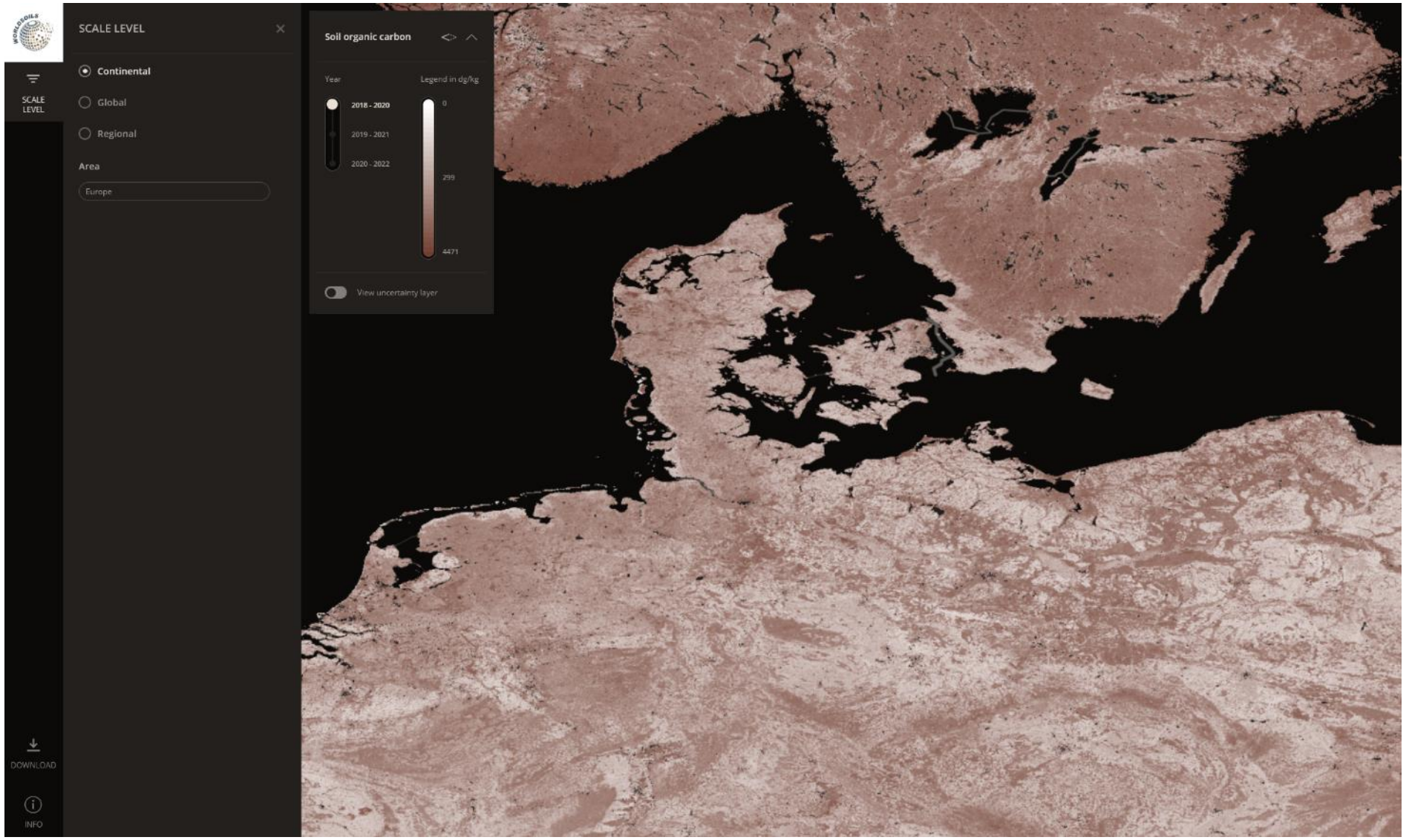
Einheitliche Nutzung als **Ackerflächen** (als Kontrolle):

- 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)