EARTH OBSERVATION FOR SOILS AND SOIL EROSION

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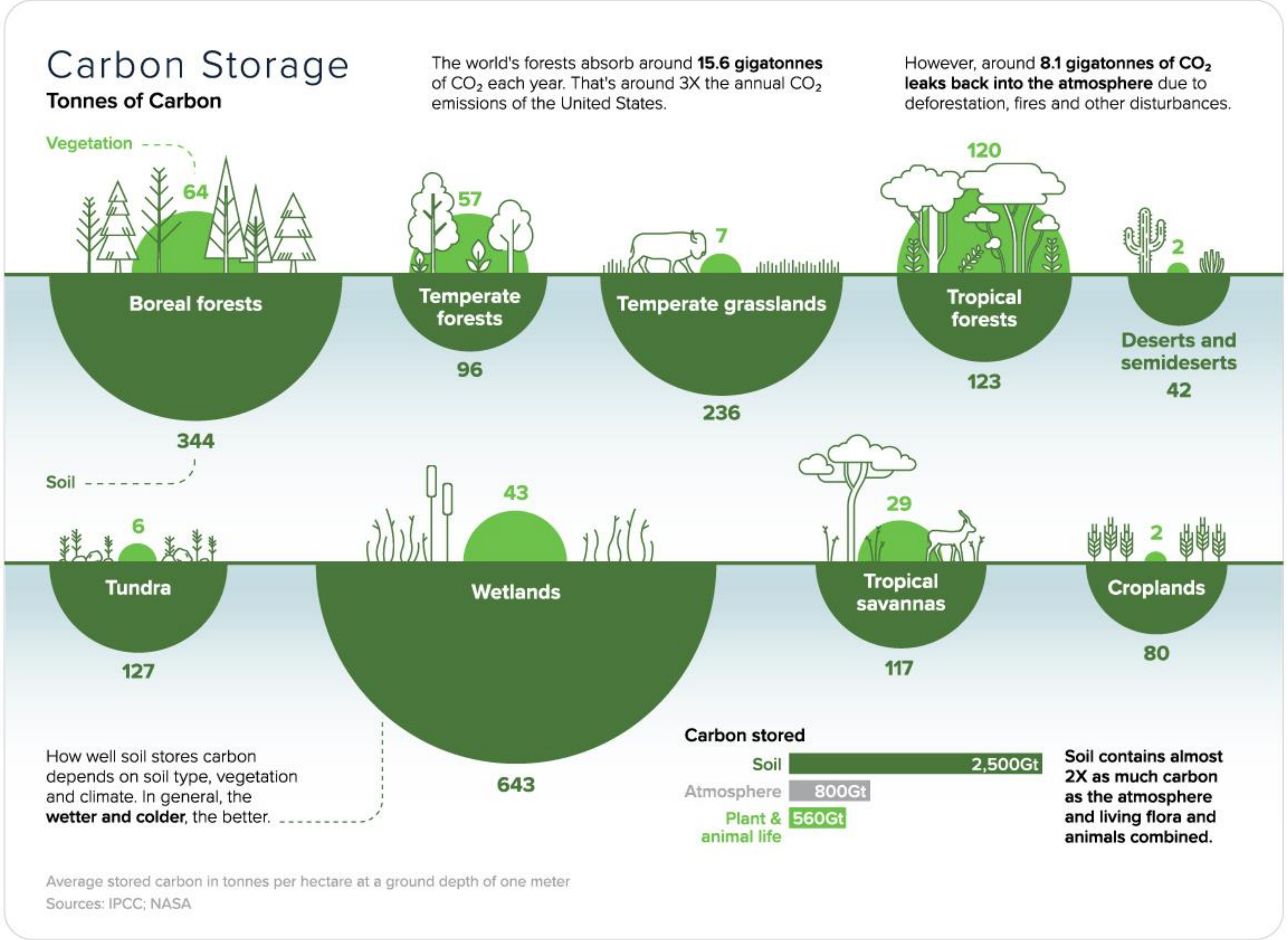
DLR

Content

- Potential of Optical Earth Observation (EO) data for soil erosion monitoring
- SoilSuite for Europe
- Fractional vegetation cover - fCover
  - Potential of optical remote sensing data
  - fCover based on hyperspectral data
  - fCover using Deep Learning
- Outlook to Map Soil Erosion
- Discussion

Significance of Soils



Soil functions:

- Vital soils ensure food security
- Soil biodiversity
- Water retention
- Filters out impurities
- …

- **Largest terrestrial carbon pool**

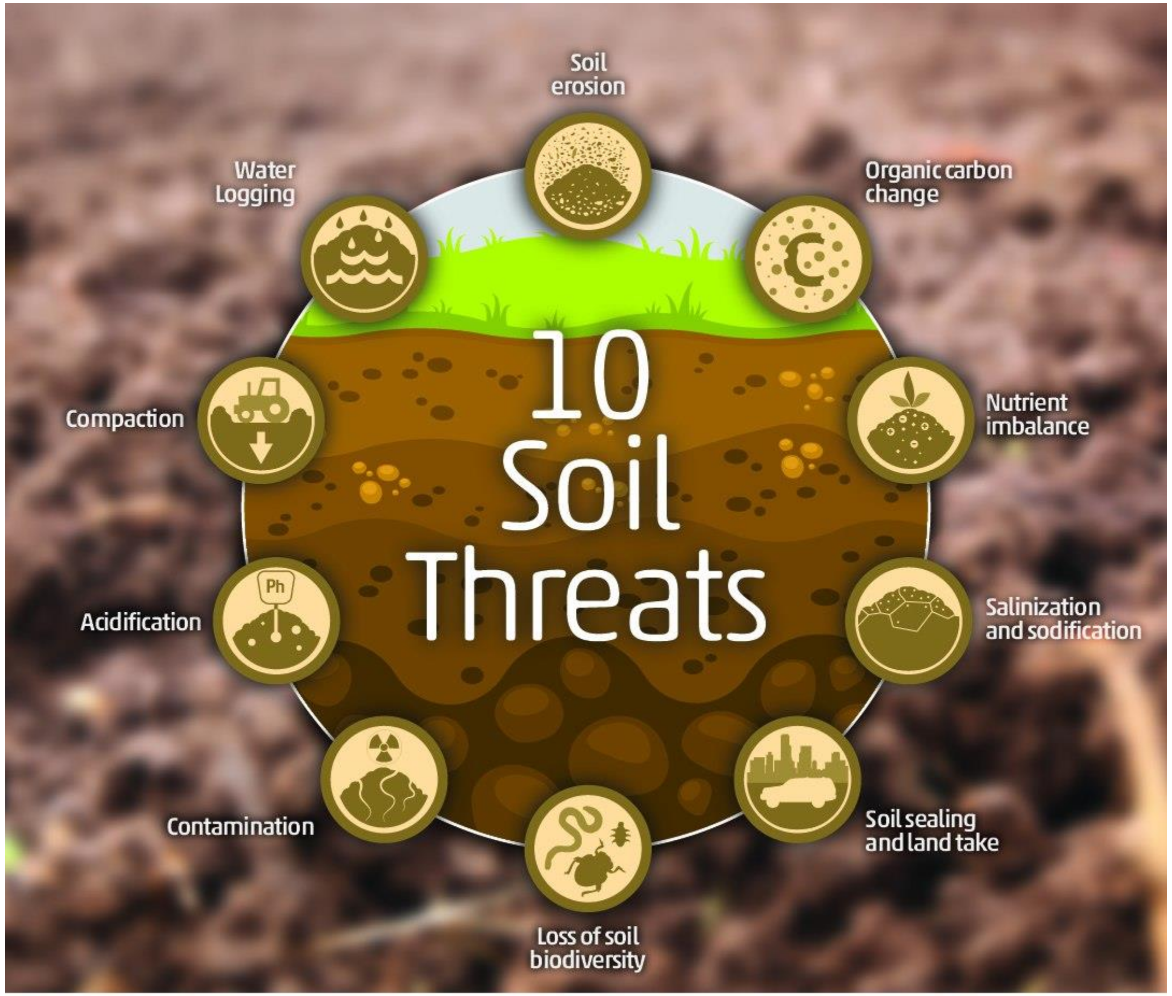
Soil Threats

Loss of A and B horizons due
to wind erosion in Spain

Water erosion due to bare soil and
compaction in Germany

Potential of Optical EO Data for Soil Erosion Monitoring

Soil Threats



Food and Agriculture Organization of the United Nations

GLOBAL SOIL PARTNERSHIP

Needs

- Monitoring
- In high spatial resolution
- Frequently

Earth Observation

Revised Universal Soil Loss Equation (RUSLE)

SoilSuite

(SCMAP)

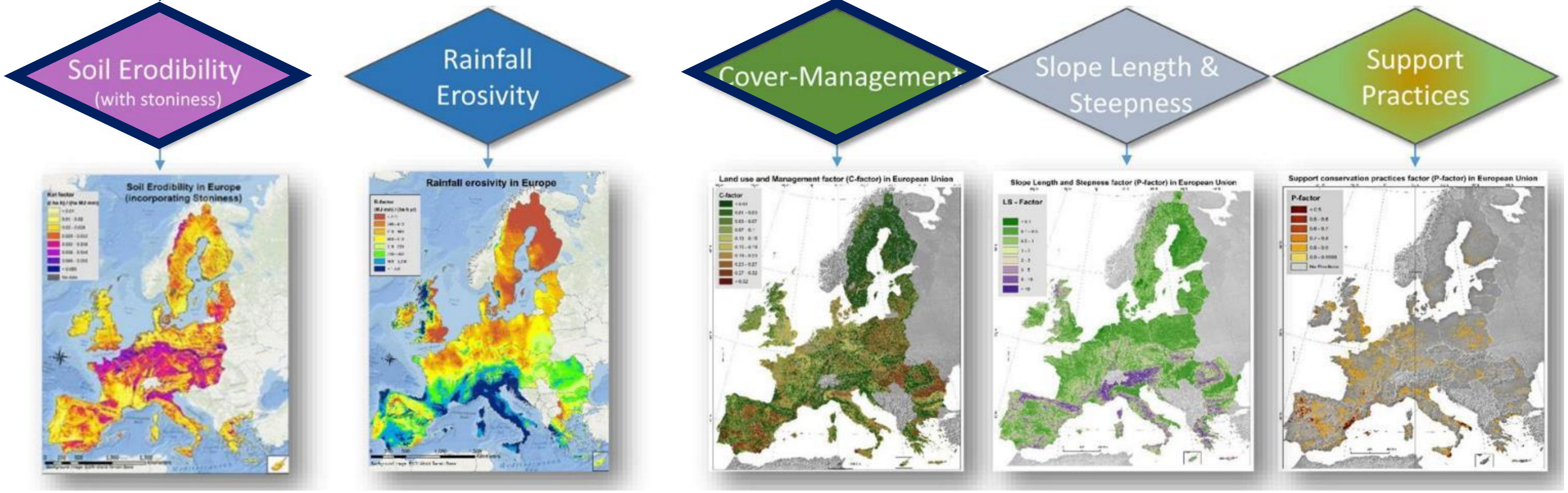
- Soil organic carbon
- Mineralogy
- pH
- Coarse fragments
- Nutrients
- …

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

SOILSUITE FOR EUROPE

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:

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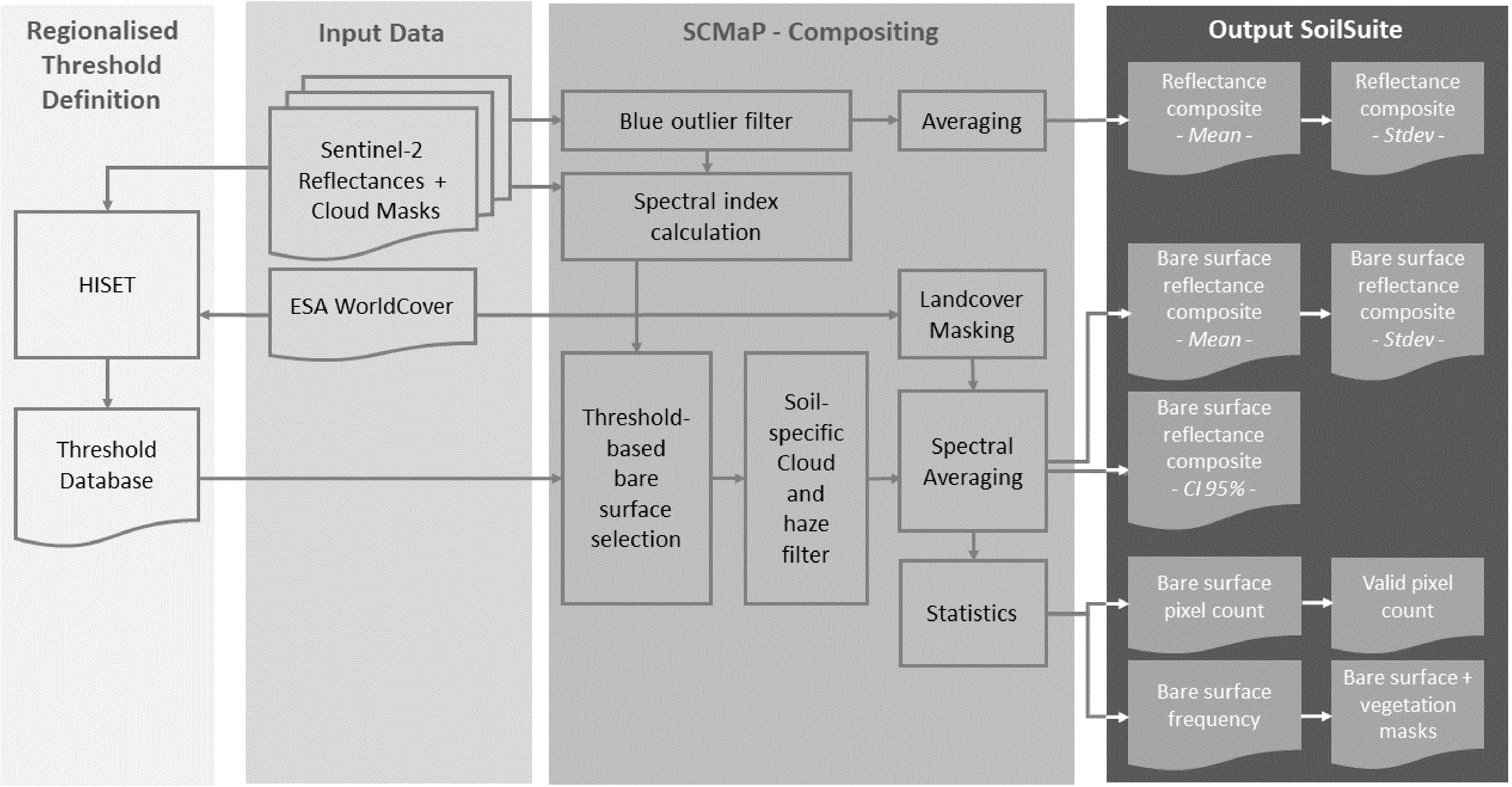
- Paul Karlshöfer (Producer, Processor) DLR/EOC Imaging Spectroscopy
- EOC Geoservice (Host) DLR/EOC

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.

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

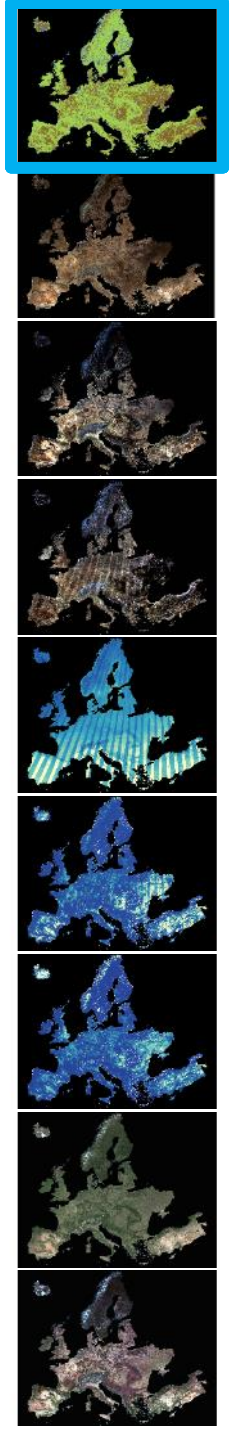
<u>Bare Surface Mask</u>

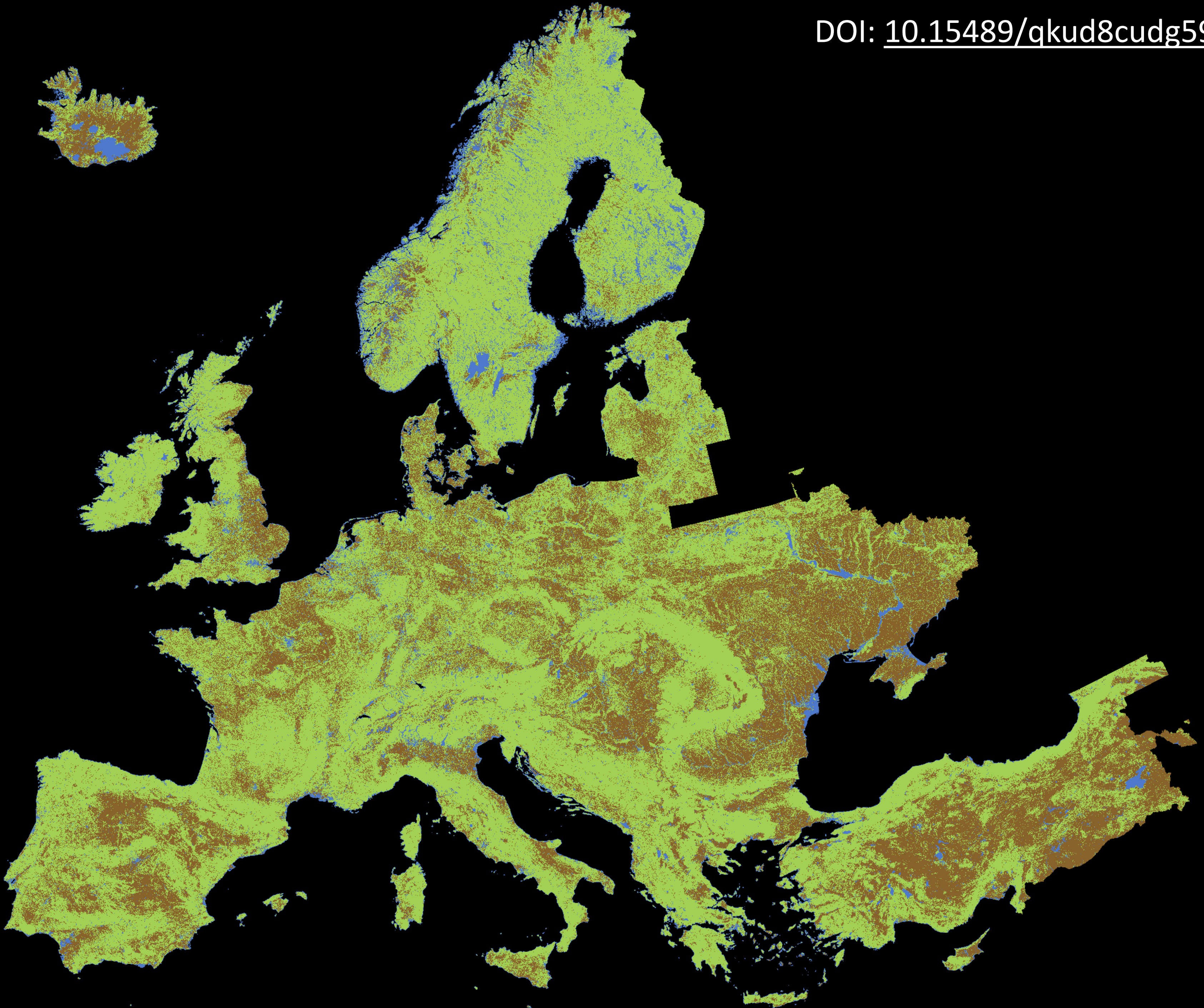
Bare surface occurrence

Permanent vegetation

Other surfaces

DLR





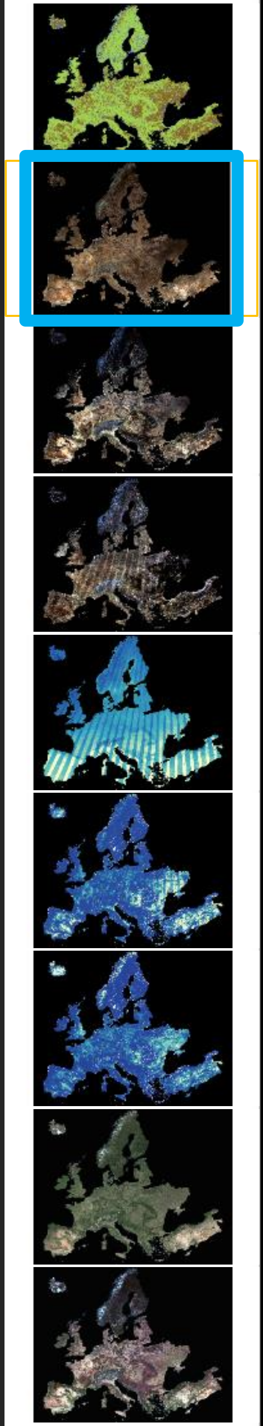
DOI: 10.15489/qkud8cudg596

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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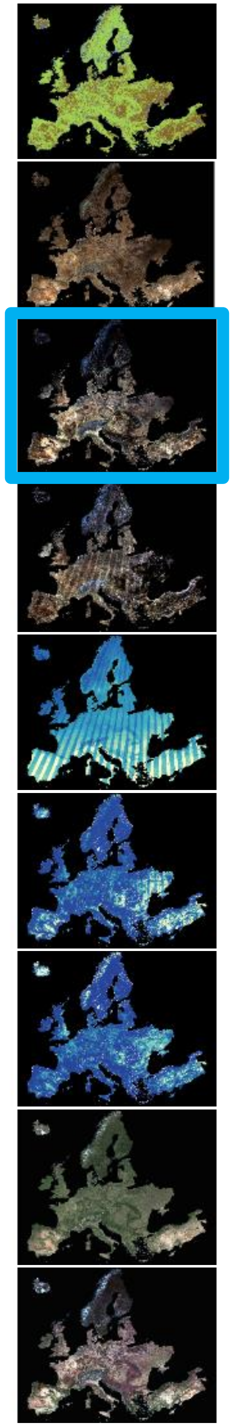
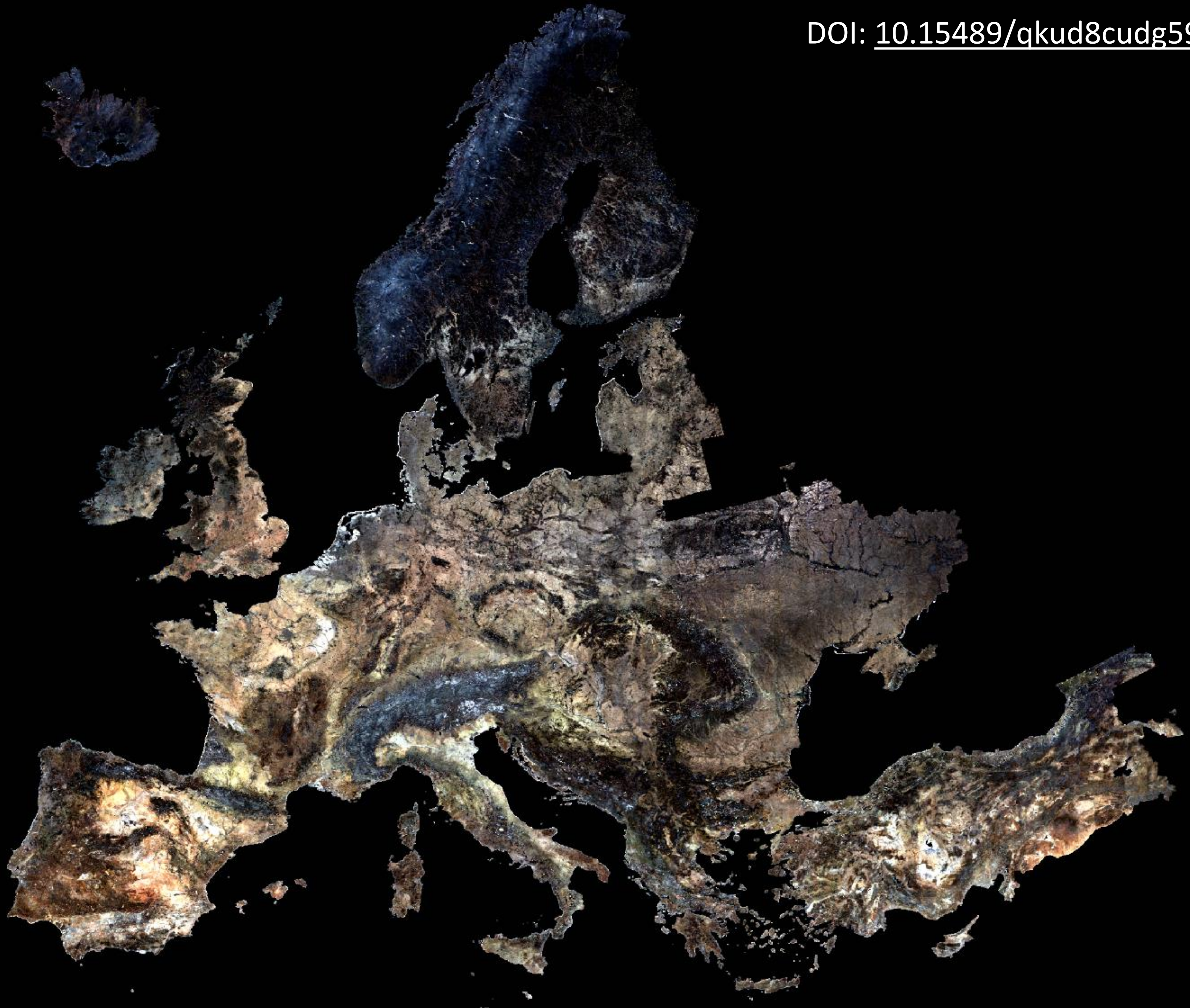
SoilSuite 2018 – 2022

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

Bare Surface Reflectance Composite

– Standard deviation





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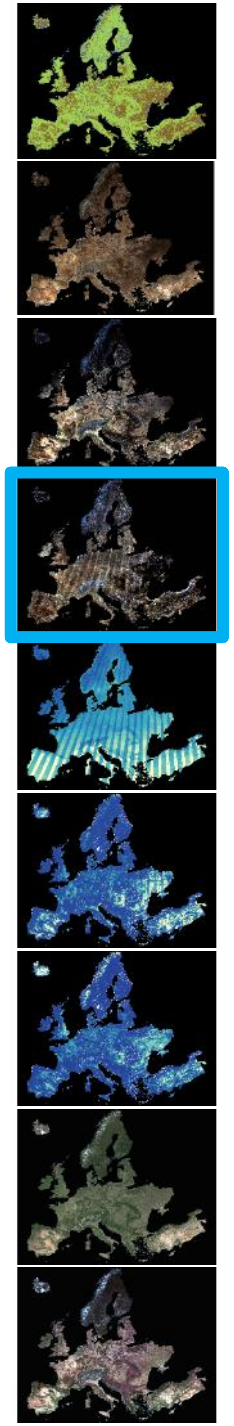
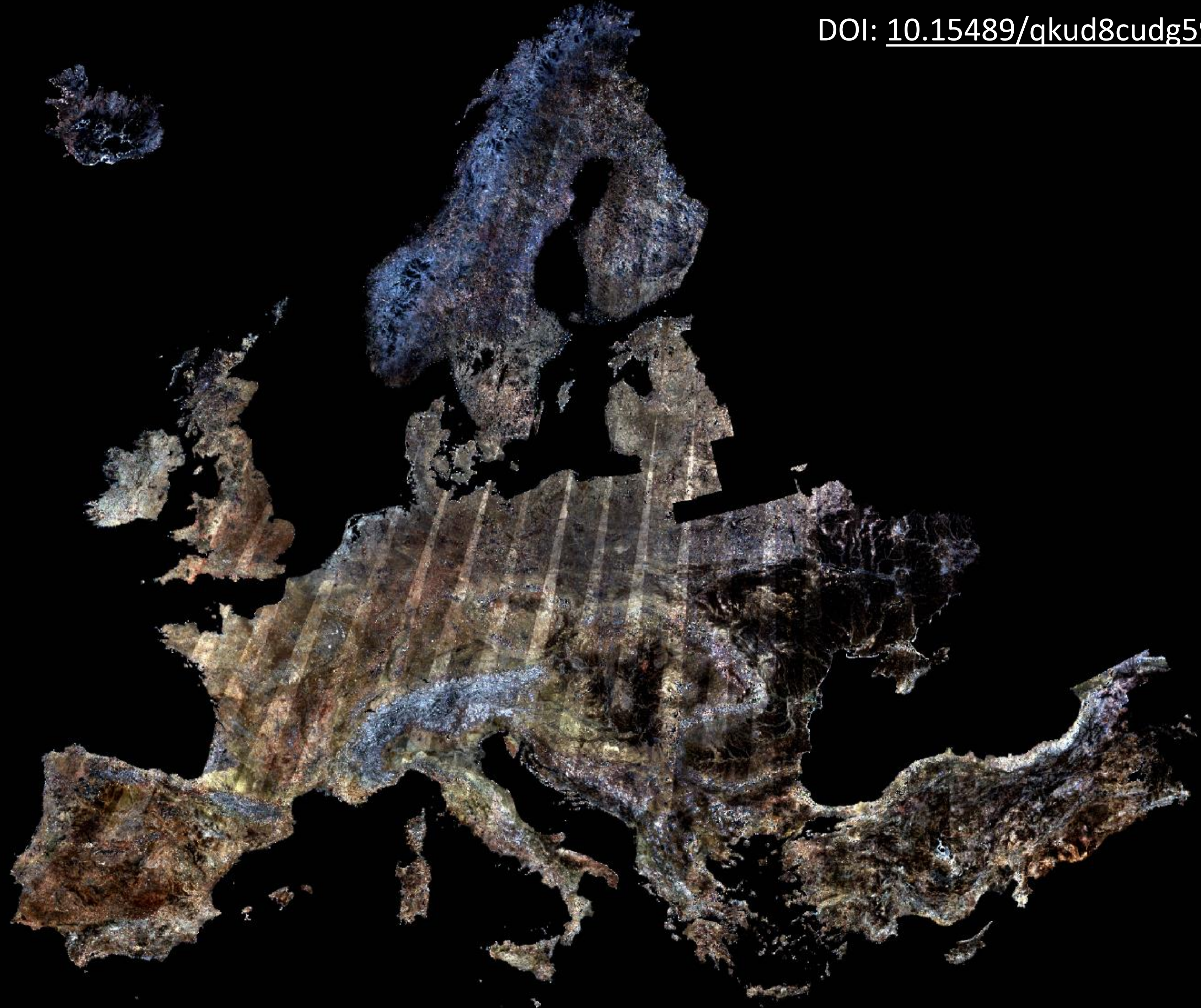
SoilSuite
2018 – 2022

- 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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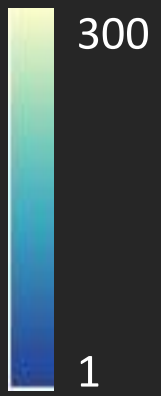
SoilSuite
2018 – 2022

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

<u>Bare Surface Statistics</u>

- Valid observations (number of scenes)



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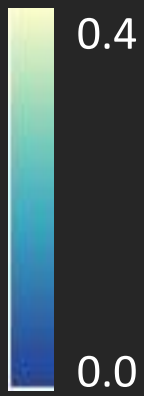
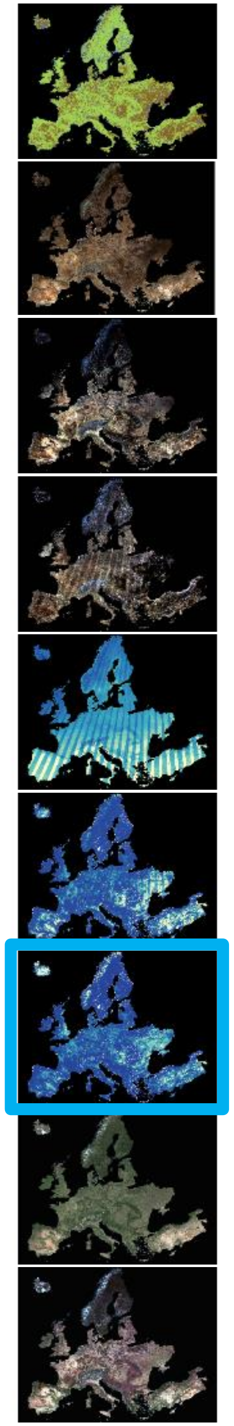
SoilSuite
2018 – 2022

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

Bare Surface Statistics

- Bare Soil Frequency [%]





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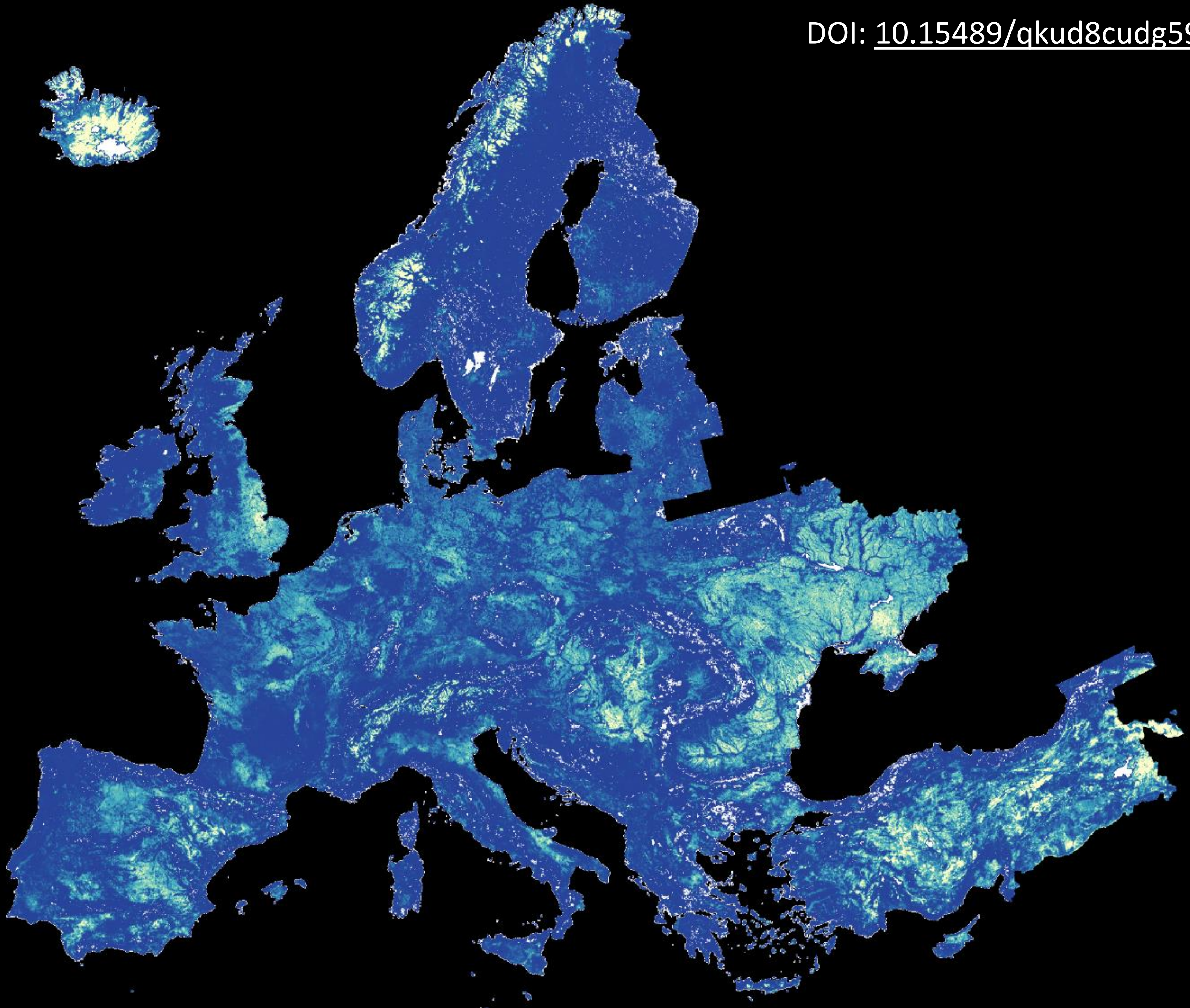
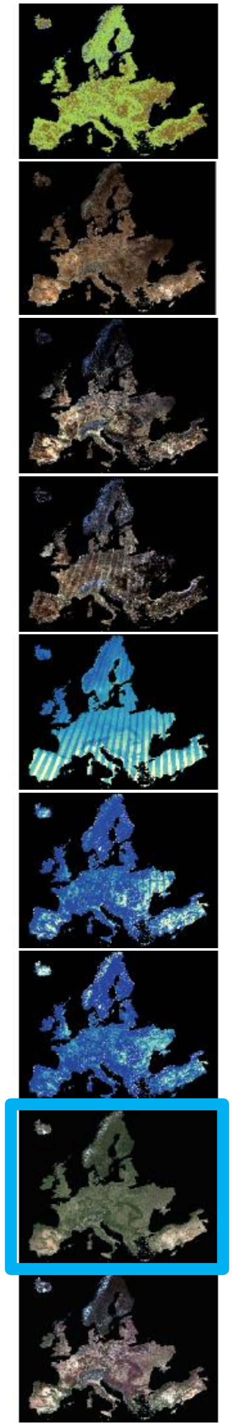


SoilSuite
2018 – 2022

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

Reflectance Composite – Mean



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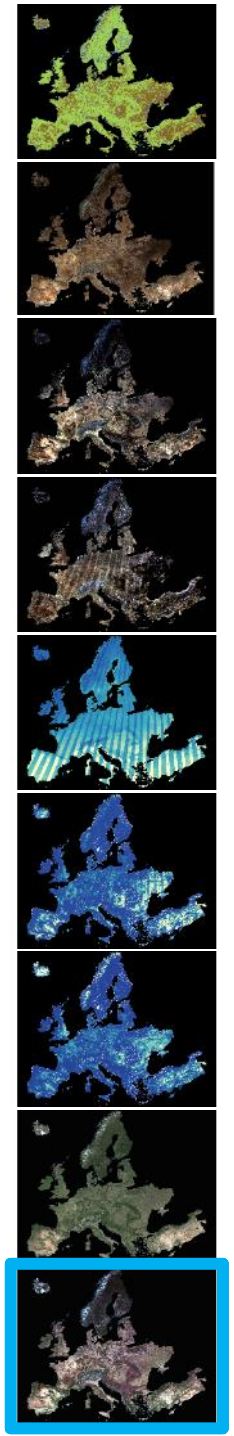
SoilSuite 2018 – 2022

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

Reflectance Composite
– Standard Deviation



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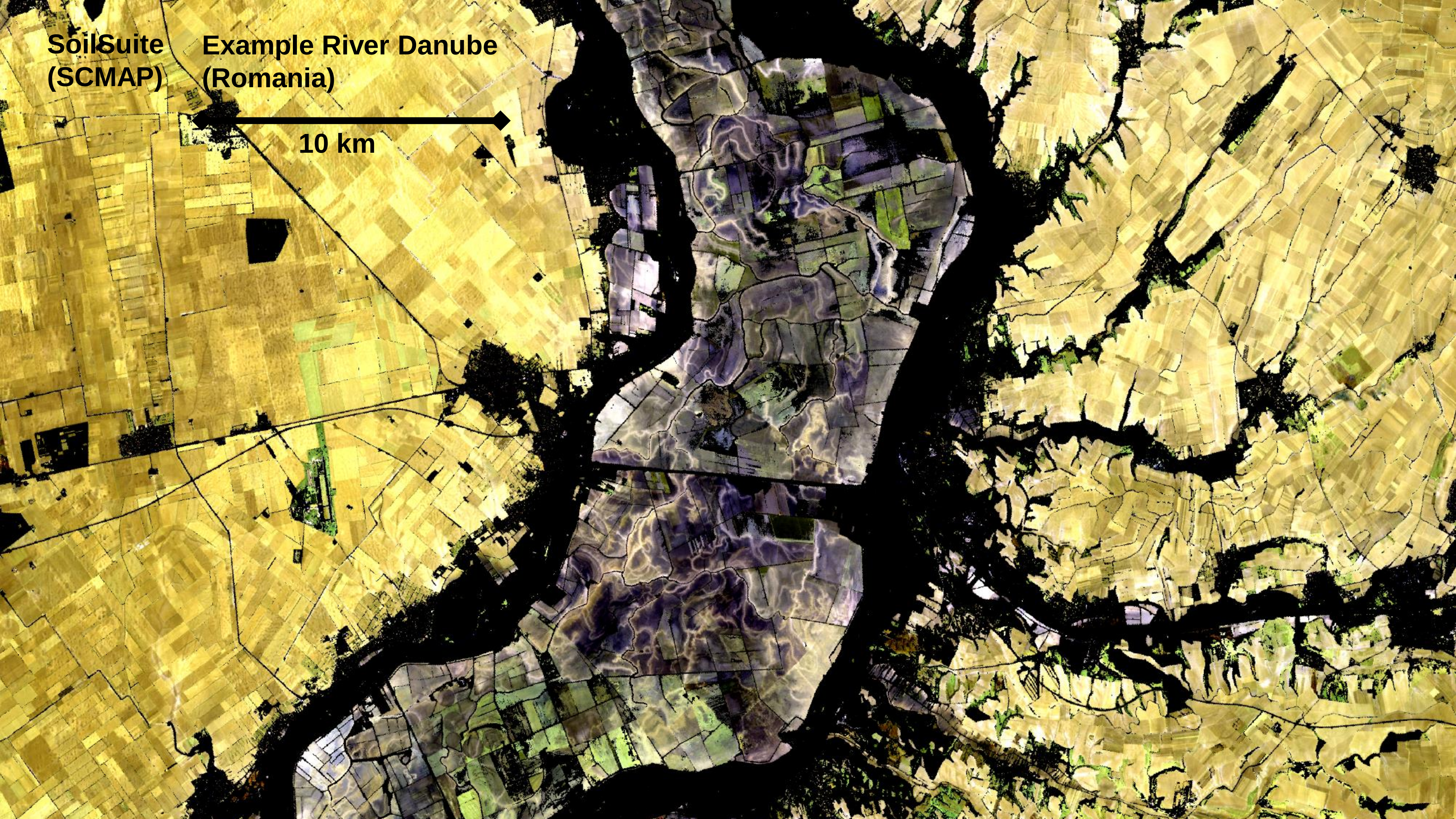
Google Maps
Example River Danube (Romania)
10 km
Topalu
Crucea
Donau
Lățești
Bordușani
Cegani
Gălbiori
Băltăgești
KREIS IALOMIȚA
KREIS CĂLĂRAȘI
Dunărea
Țepeș Vodă
DUCA
Perișoru
Ștefan cel Mare
Fetești-Gară
Stelnica
Siliștea
Seimeni
Seimenii Mici
Fetești
Buliga
Cernavodă
Tortoman
Țibrinu
Gherghina
Borcea, Călărași
Gâldău
Jegălia
Saligny
Mircea Vodă
Cochirleni
MIRCEA VODĂ GARĂ
Satu Nou
Unirea
KREIS CĂLĂRAȘI
3A
3B
E81
22C


SoilSuite
(SCMAP)
Example River Danube
(Romania)
10 km

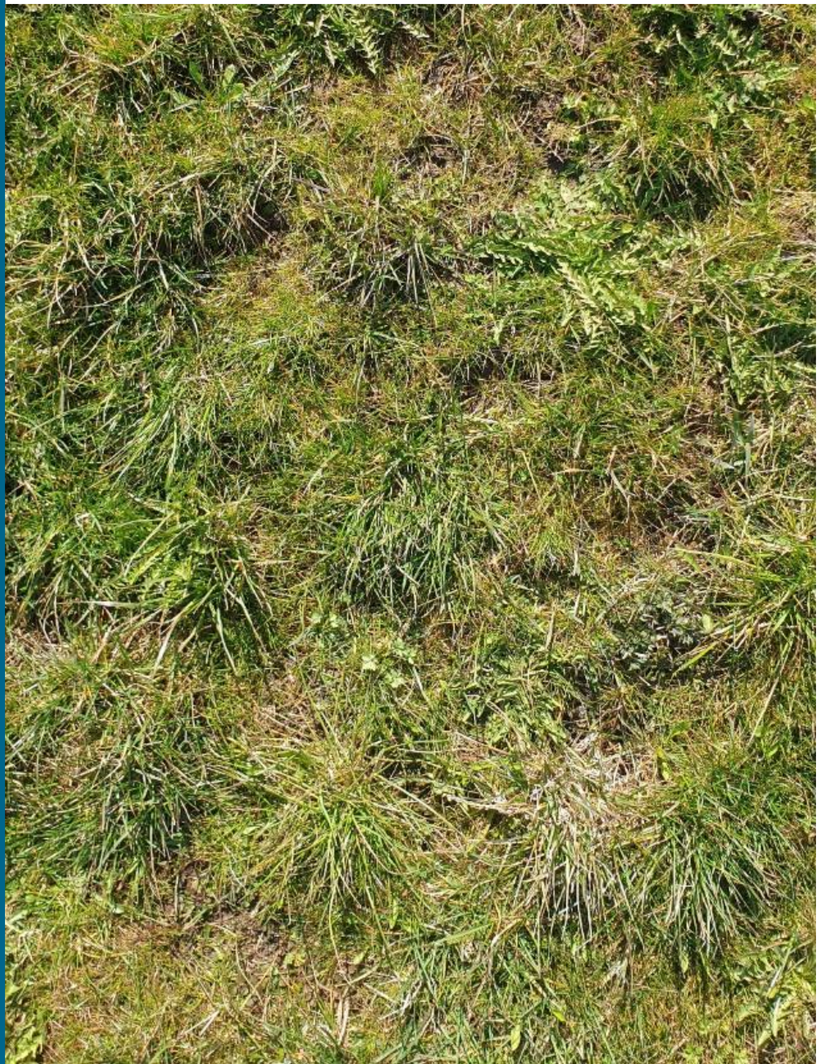
FRACTIONAL VEGETATION COVER - FCOVER

Bildquelle hier angeben

Fractional vegetation cover - fCover

Definition

Green vegetation



Dry vegetation

Bare soil

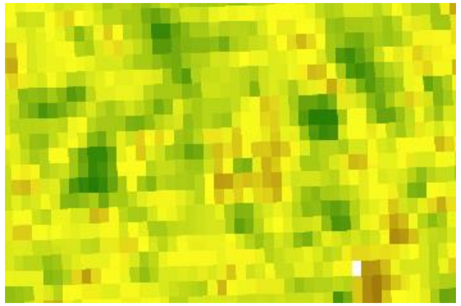
fCover products in comparison

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

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

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

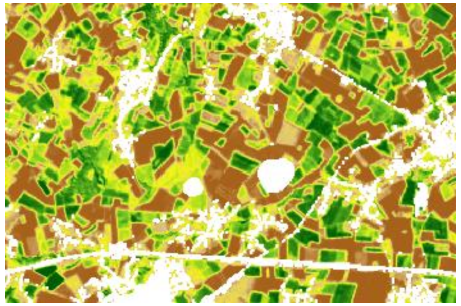
<u>Current Copernicus Product:</u>
Fraction of Green Vegetation Cover
300 m

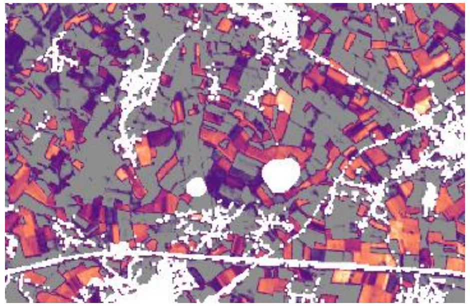


Temporal compositing of 10 days

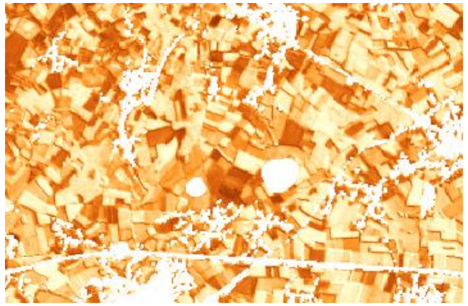
<u>Hyperspectral EnMAP</u>
Fraction of
- Green veg.
- Dry veg.
- Bare soil

30 m





- Crop residues
- Grassland dynamics

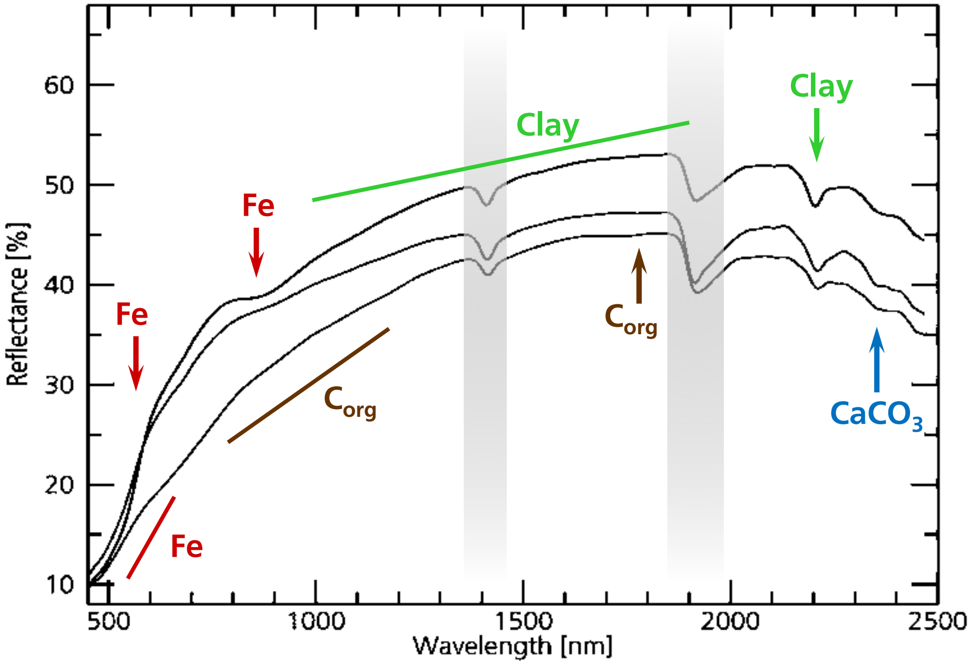


- Bare soil coverage
- Bare soil dates
- Tillage events per time period

Potential of hyperspectral EO data

Hyperspectral soil spectral reflectance

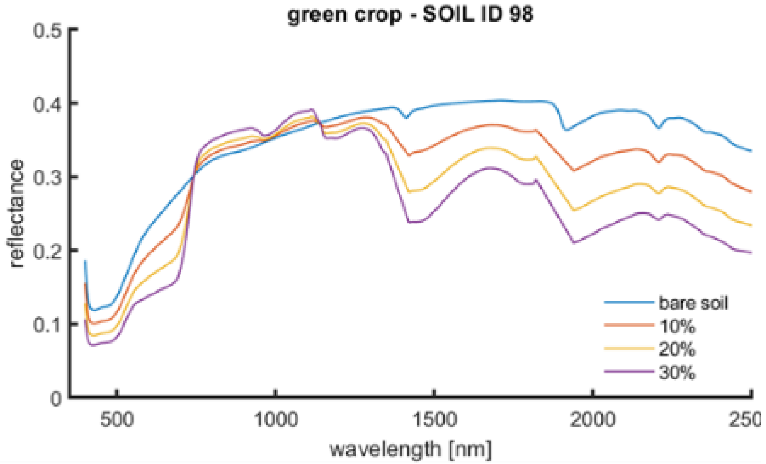
(Anita Bayer, Dissertation)

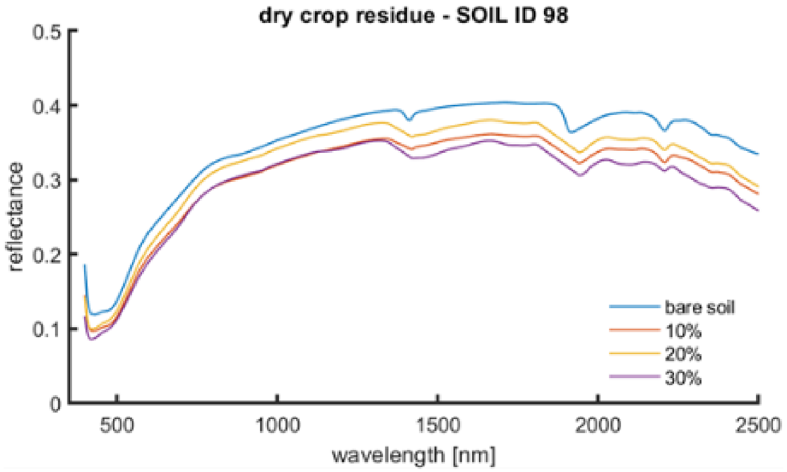


Soil Organic Carbon Absorptions

Influencing factors

(material provided by GFZ, Feasibility Assessment and Impact Report (FIAR) of the WORLDSOILS project)

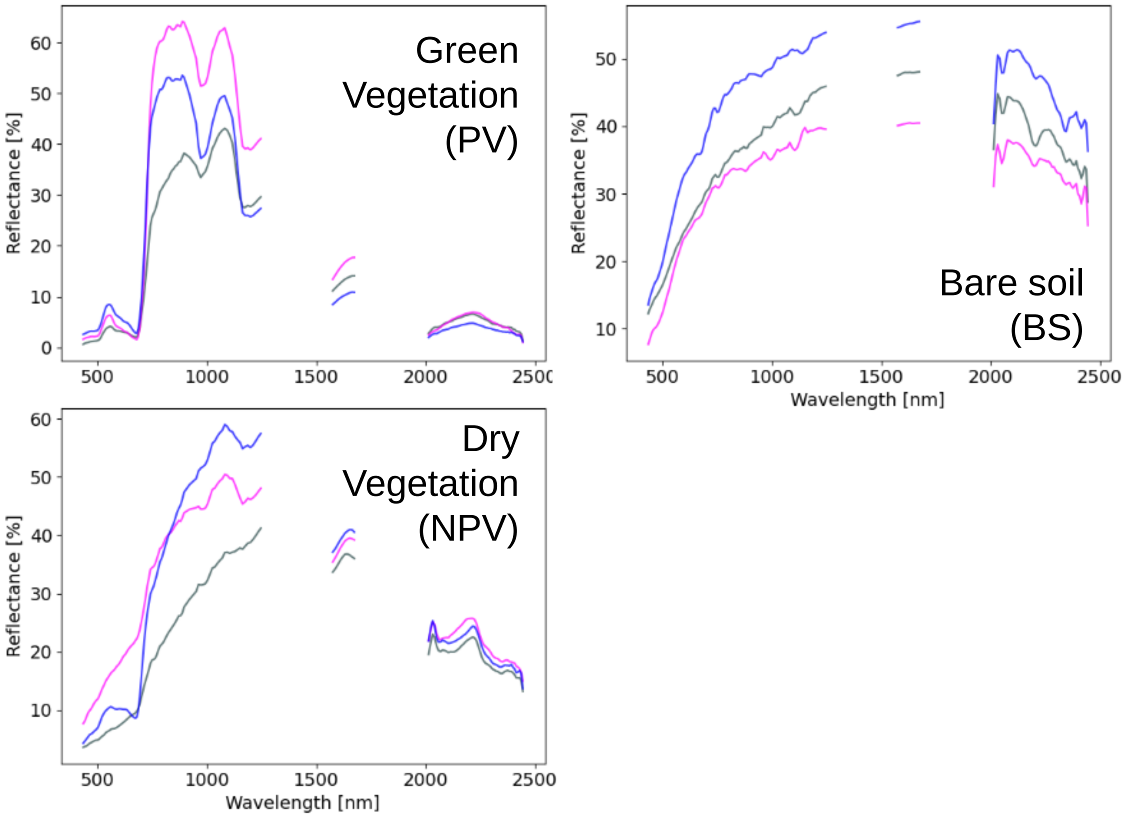




Potential of hyperspectral EO data

Spectral inner-class variability shown for:

- PV = Photosynthetically active vegetation
- NPV = Non-photosynthetically active vegetation
- BS = Bare soil



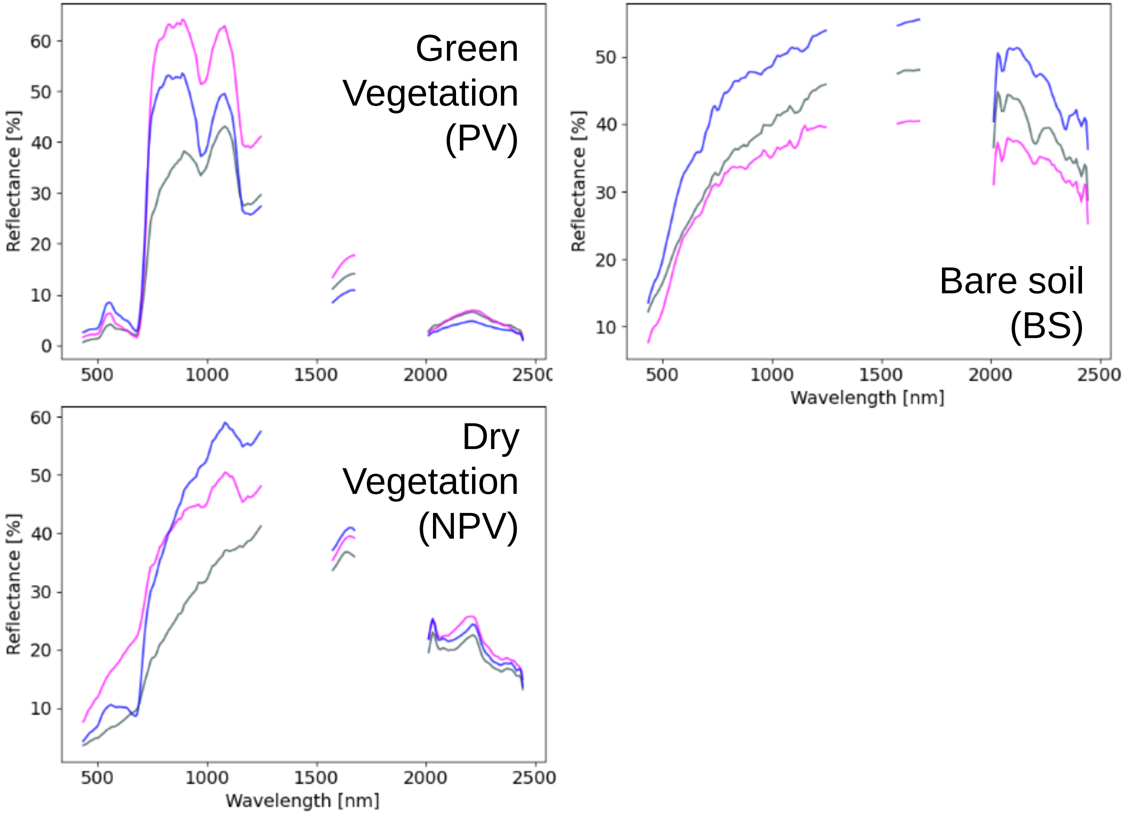
Fractional vegetation cover - fCover

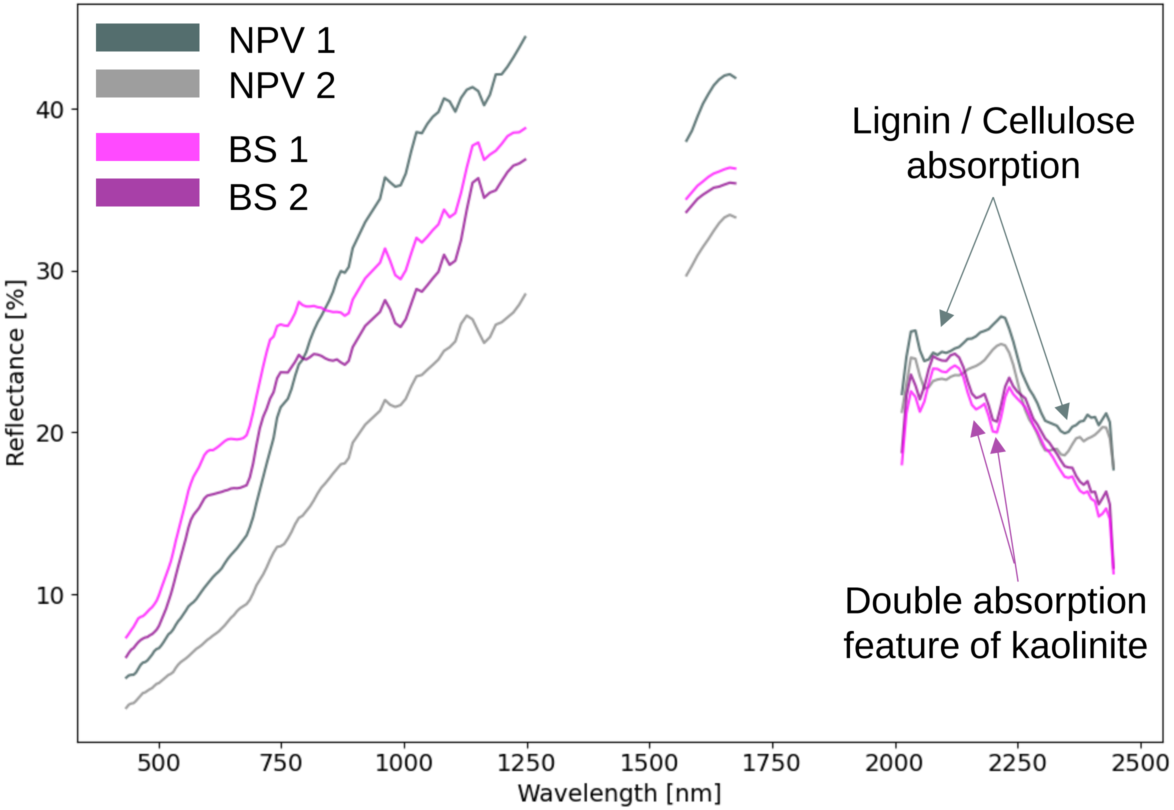
Potential of hyperspectral EO data

Spectral inner-class variability shown for:

- PV = Photosynthetically active vegetation
- NPV = Non-photosynthetically active vegetation
- BS = Bare soil

- Spectral similarity between NPV and BS except of narrow spectral absorption features in the SWIR



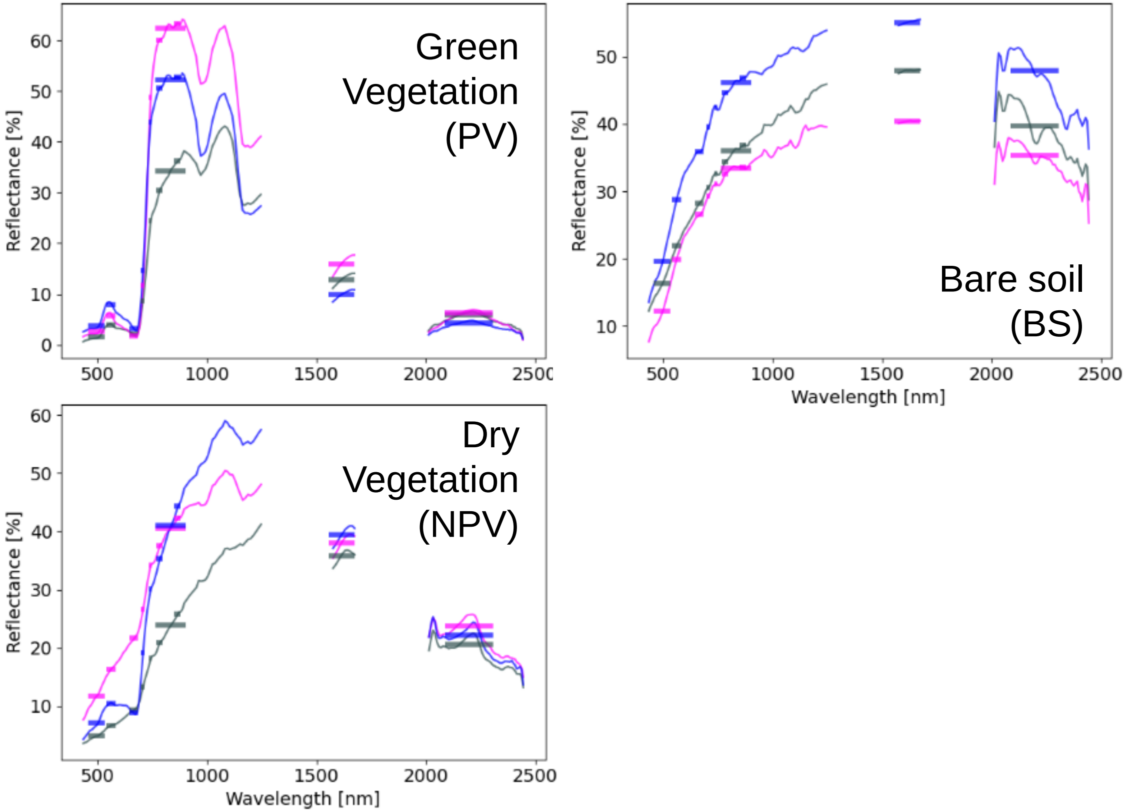


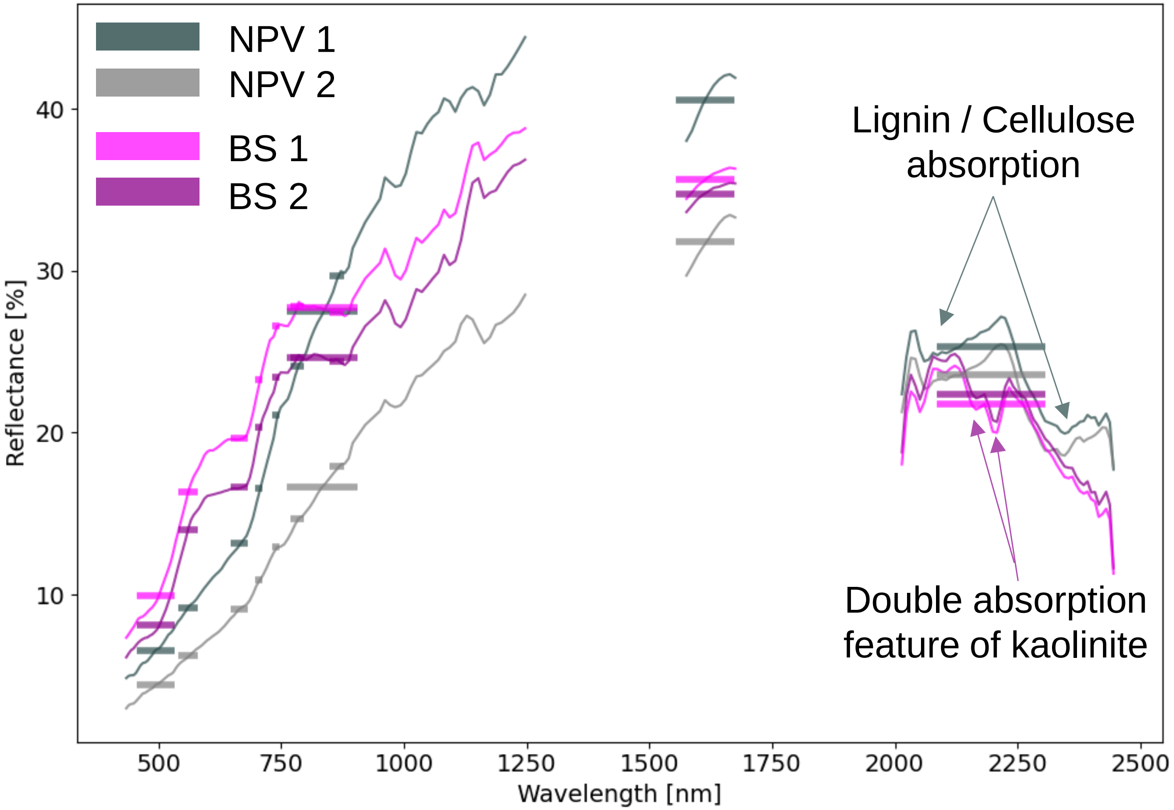
Potential of hyperspectral EO data

Spectral inner-class variability shown for:

- PV = Photosynthetically active vegetation
- NPV = Non-photosynthetically active vegetation
- BS = Bare soil

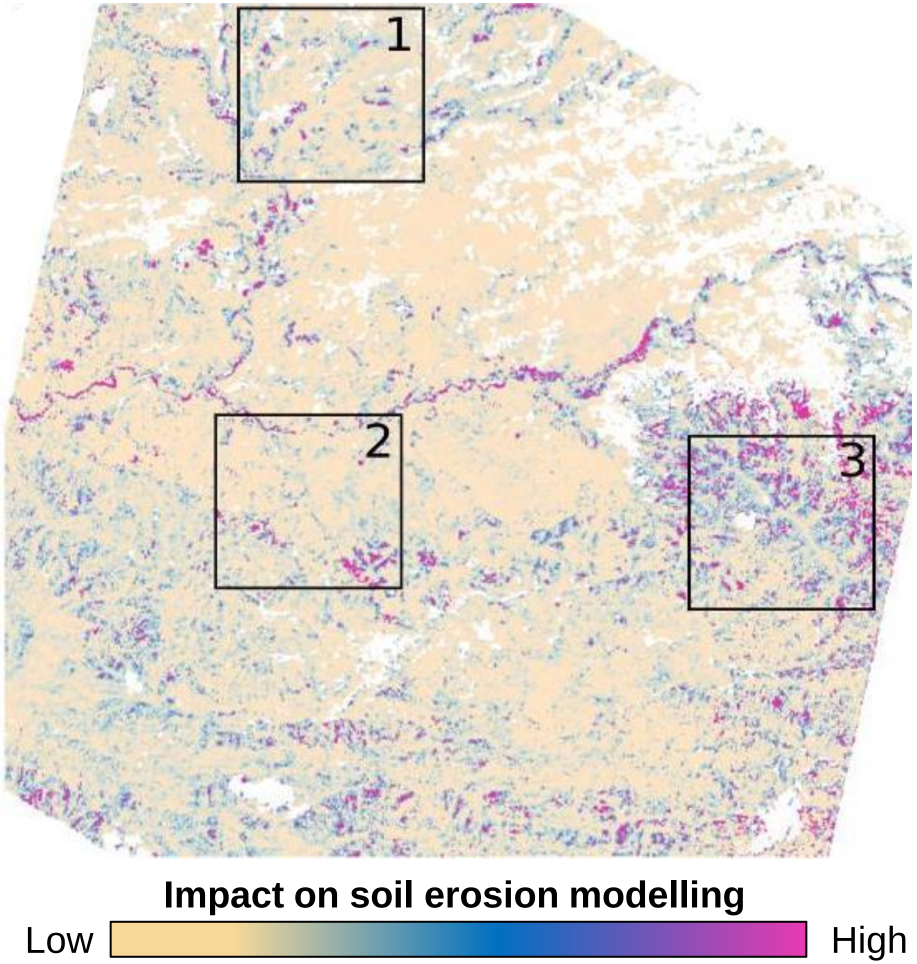
- Spectral similarity between NPV and BS except of narrow spectral absorption features in the SWIR
- disappears in the 10 broad-band measurements of Sentinel-2

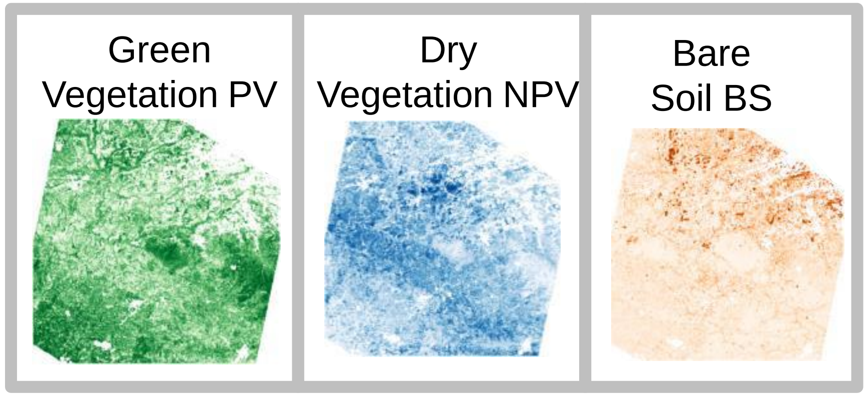




Fractional vegetation cover - fCover

Potential of hyperspectral EO data



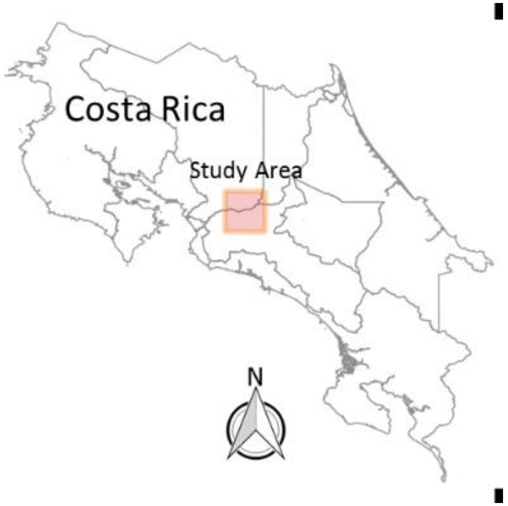


Combining

Cover Fraction (C)

Slope Length (L)

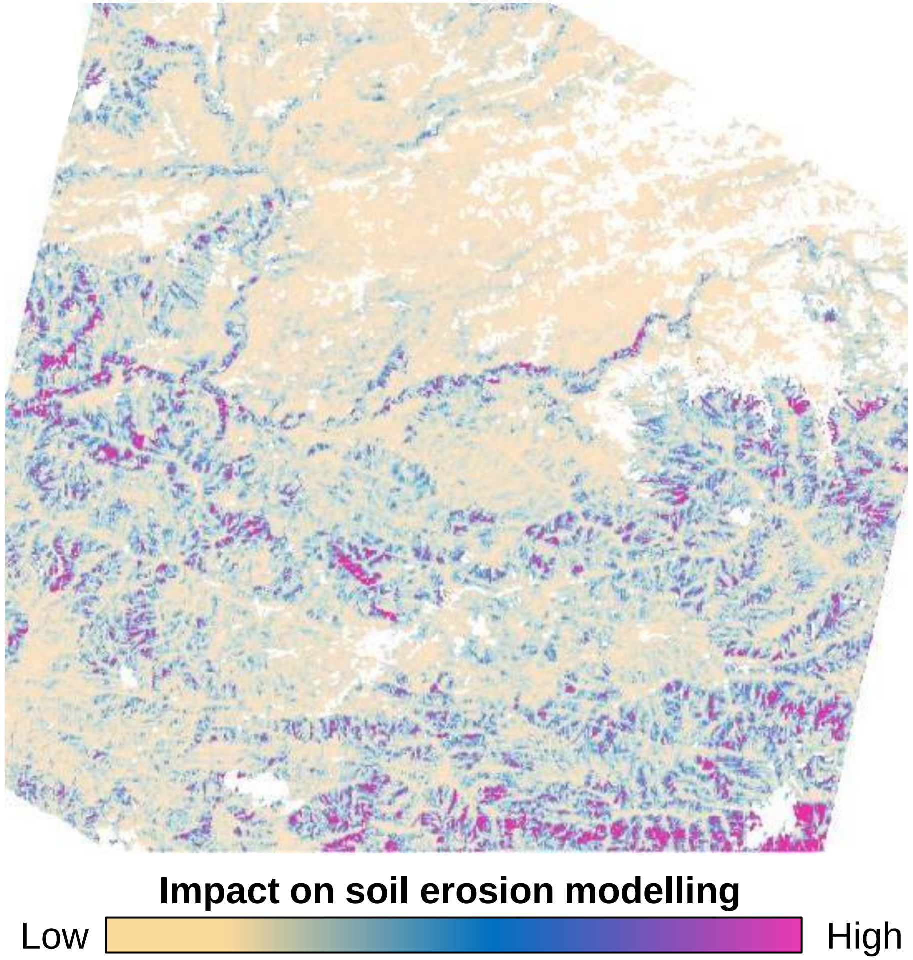
Slope Steepness (S)

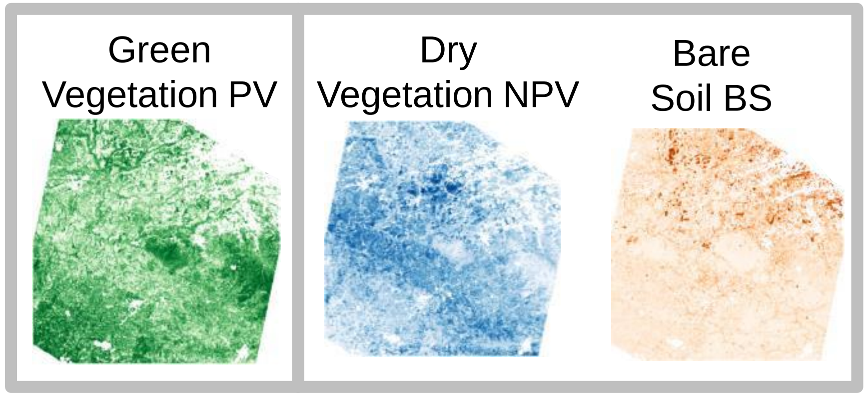


Malec, S.; Rogge, D.; Heiden, U.; Sanchez-Azofeifa, A.; Bachmann, M.; Wegmann, M. Capability of Spaceborne Hyperspectral EnMAP Mission for Mapping Fractional Cover for Soil Erosion Modeling. Remote Sens. 2015, 7, 11776-11800.

Fractional vegetation cover - fCover

Potential of hyperspectral EO data





Combining

Cover Fraction (C)

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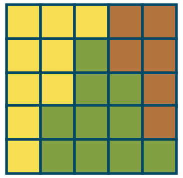
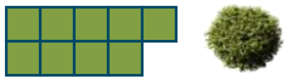
Malec, S.; Rogge, D.; Heiden, U.; Sanchez-Azofeifa, A.; Bachmann, M.; Wegmann, M. Capability of Spaceborne Hyperspectral EnMAP Mission for Mapping Fractional Cover for Soil Erosion Modeling. Remote Sens. 2015, 7, 11776-11800.

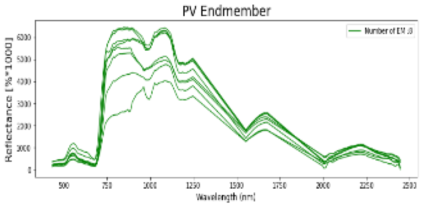
Principles of linear spectral unmixing

Mixed pixel

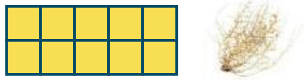


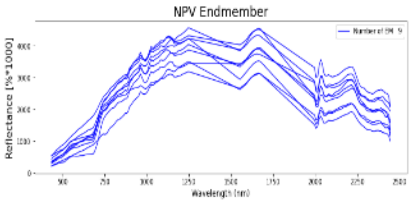
PV Endmember



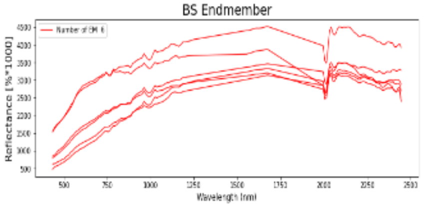


NPV Endmember





BS Endmember



- Linear Spectral Mixture Model

$$\begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{pmatrix} = \begin{pmatrix} b_1 \\ b_2 \\ \vdots \\ b_m \end{pmatrix}$$

$$Ax = b$$

Where

a_{mn}: reflectance of EM n in band m
b_m: measured reflectance in band m
x_m: abundance for EM n

A: m*n EM-matrix
x: abundance vector for n EM
b: measured spectrum in m bands

Overdetermined problem, solving by Least-Squares approximation, e.g. $x = A^{+}b$ where $A^{+} = (A^{T}A)^{-1}A^{T}$ plus constraints (sum-to-one, non-neg.)

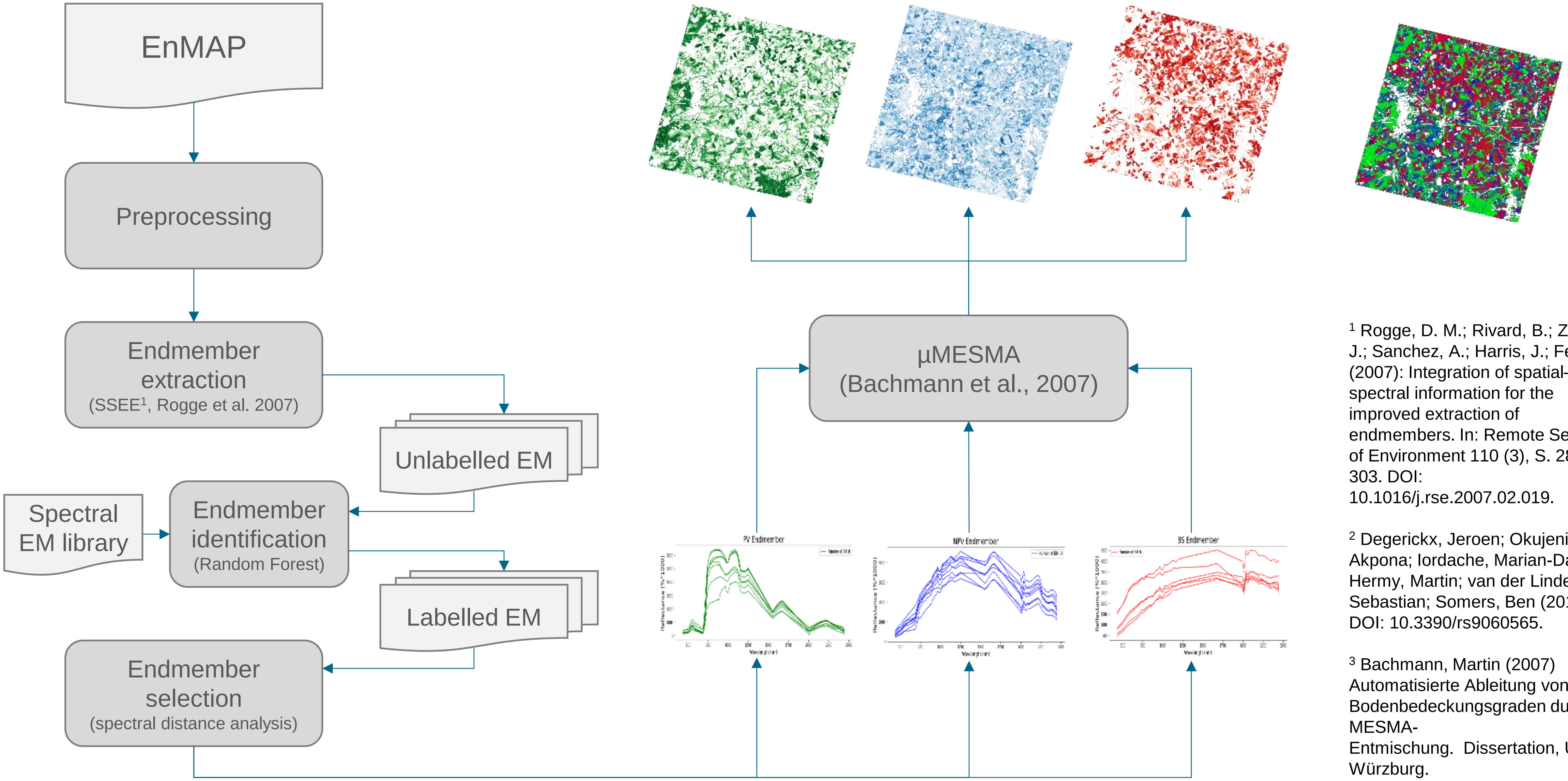
<u>Multiple EM Spectral Mixture Analysis (MESMA):</u>

- All EM are know
- EM reflect spectral variability in the scene
- Number of EM vary per pixel

<u>Essential!</u>
Quality of EM selection and identification

Fractional vegetation cover - fCover

FRActioNal Cover Analysis Processor (FRANCA)



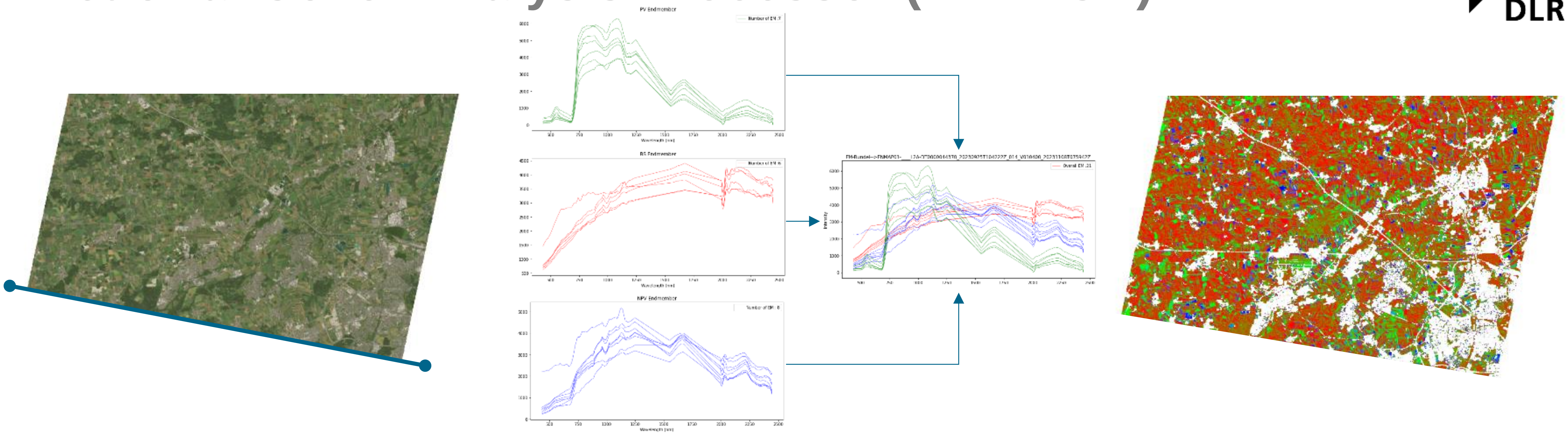
[1] Rogge, D. M.; Rivard, B.; Zhang, J.; Sanchez, A.; Harris, J.; Feng, J. (2007): Integration of spatial–spectral information for the improved extraction of endmembers. In: Remote Sensing of Environment 110 (3), S. 287–303. DOI: 10.1016/j.rse.2007.02.019.

[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.

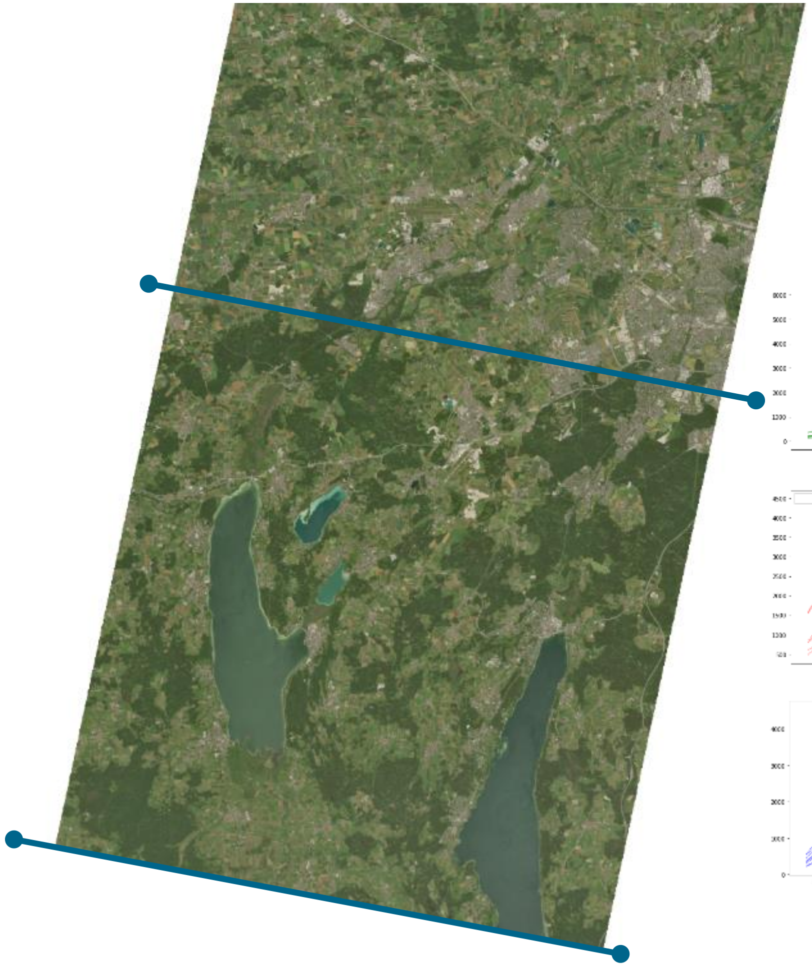
Fractional vegetation cover - fCover

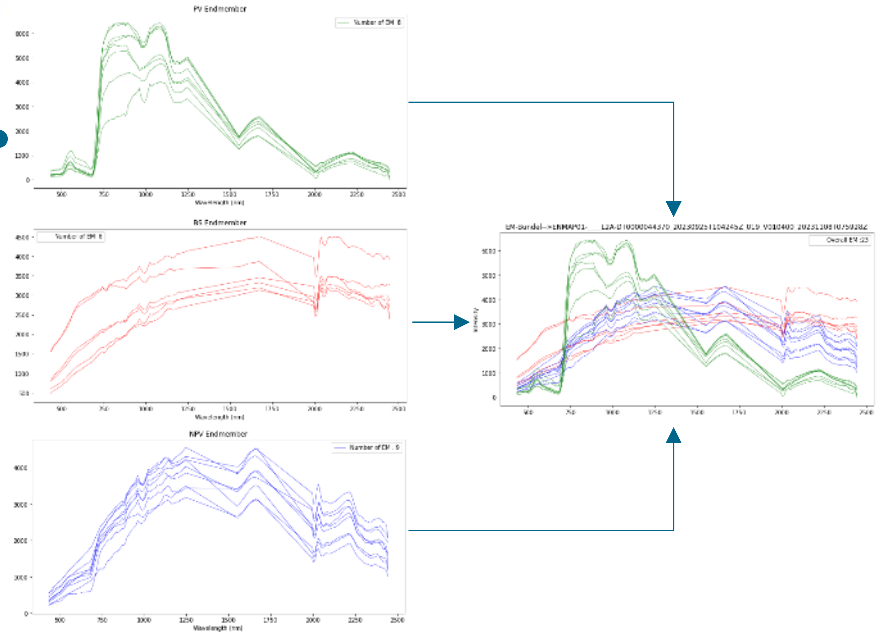
FRActioNaL Cover Analysis Processor (FRANCA)

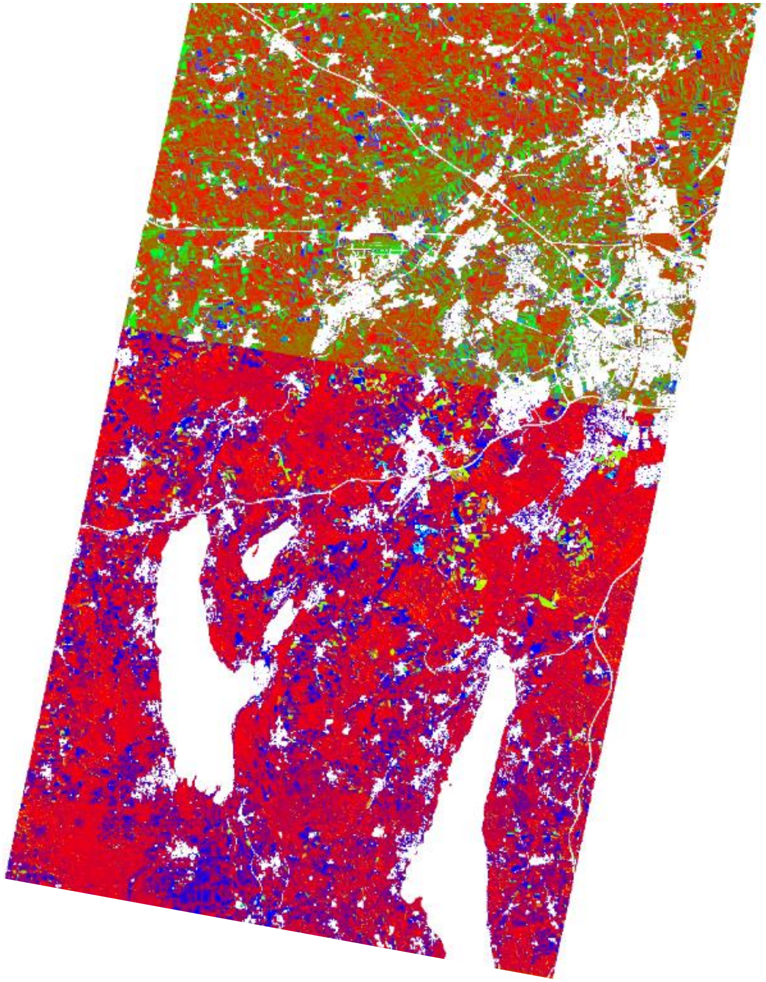


Fractional vegetation cover - fCover

FRActioNal Cover Analysis Processor (FRANCA)







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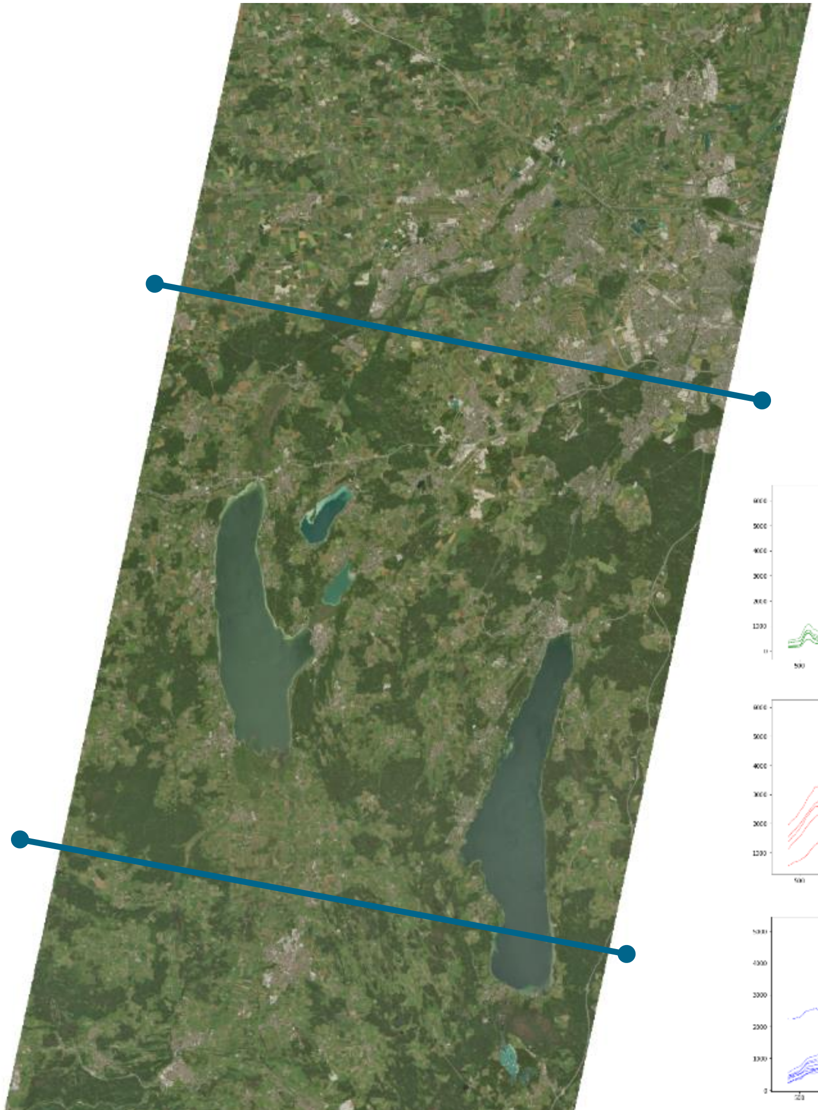

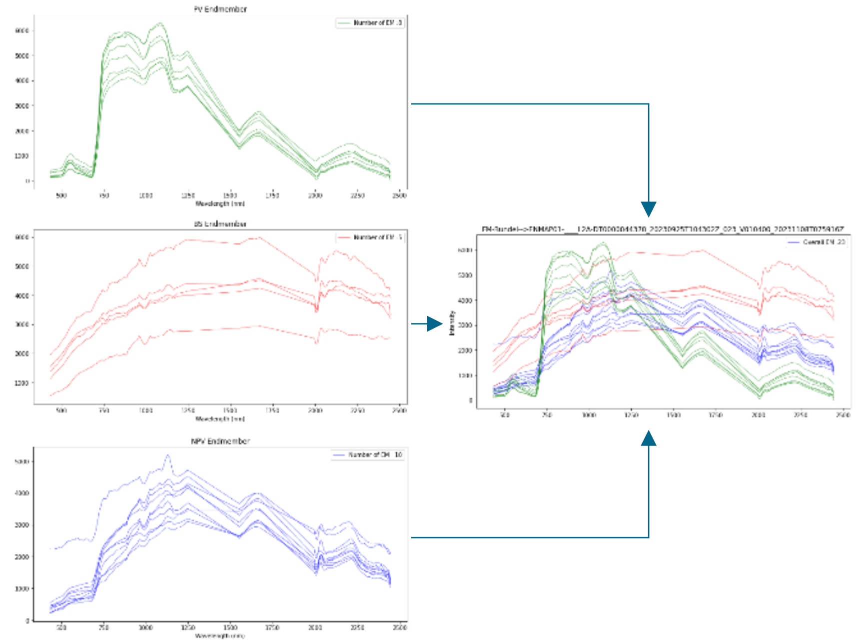

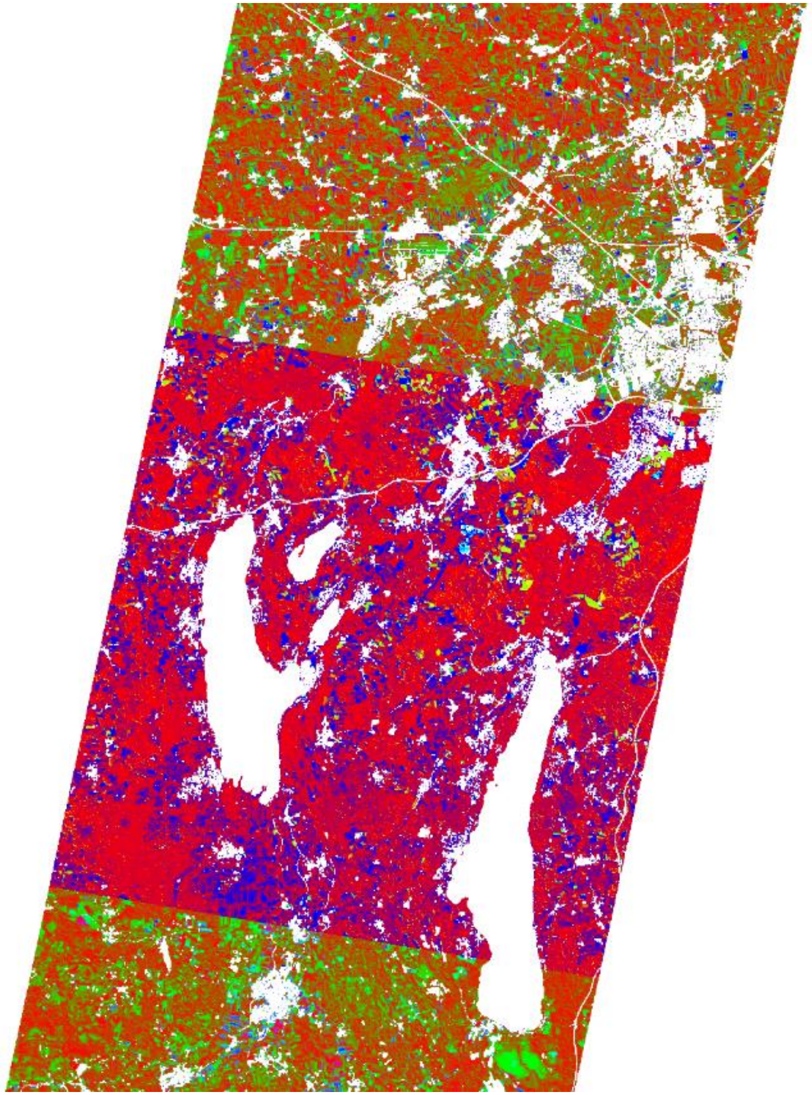

Fractional vegetation cover - fCover

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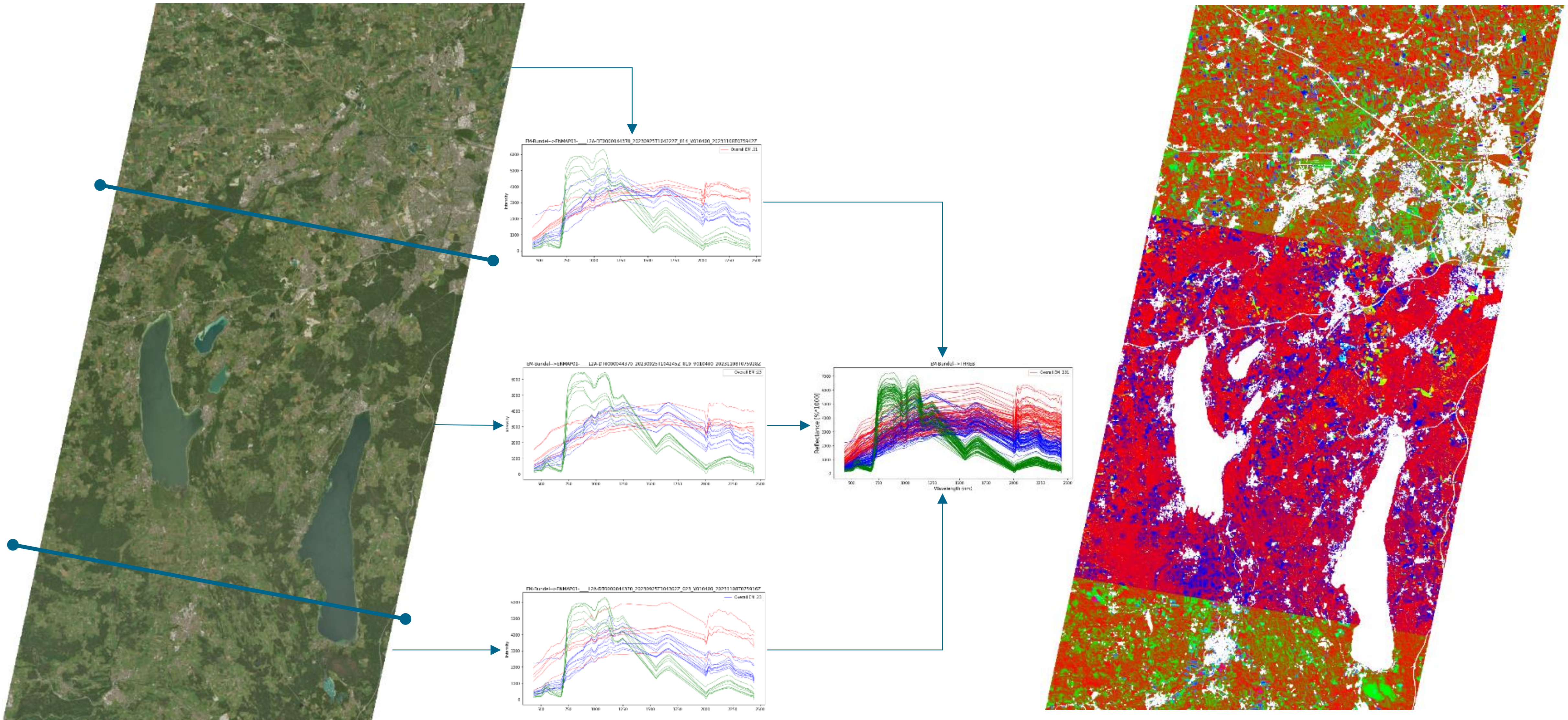

Fractional vegetation cover - fCover

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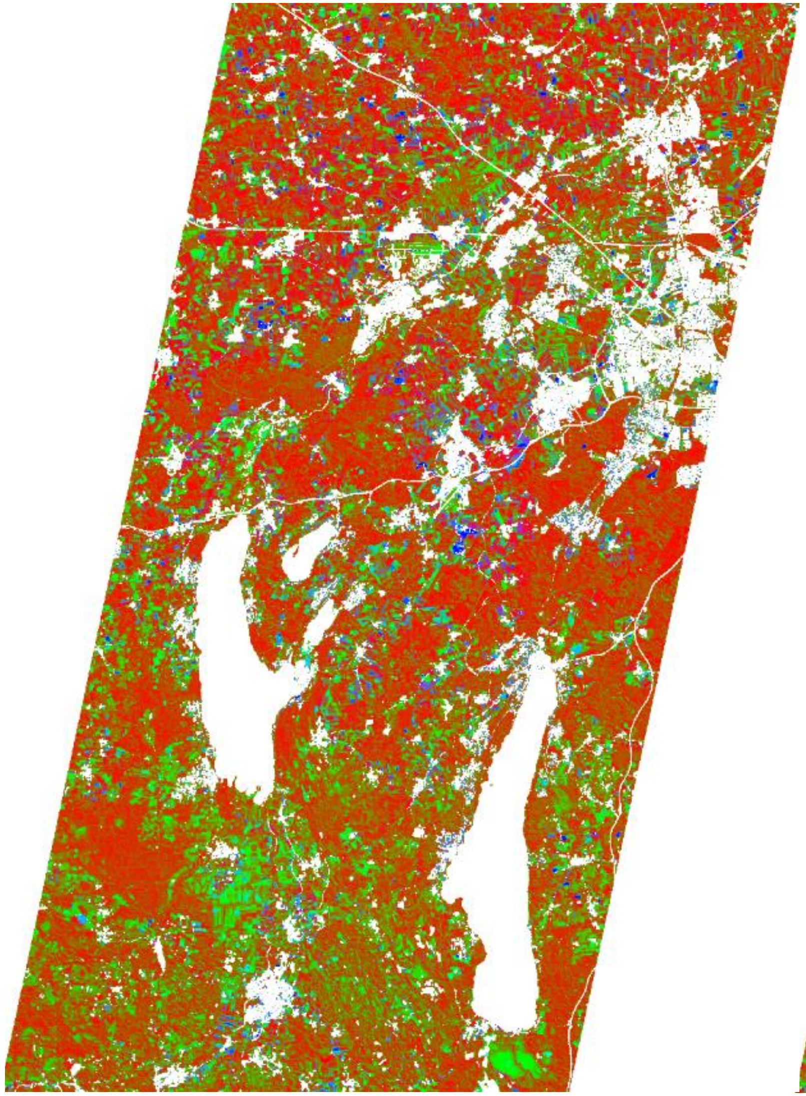

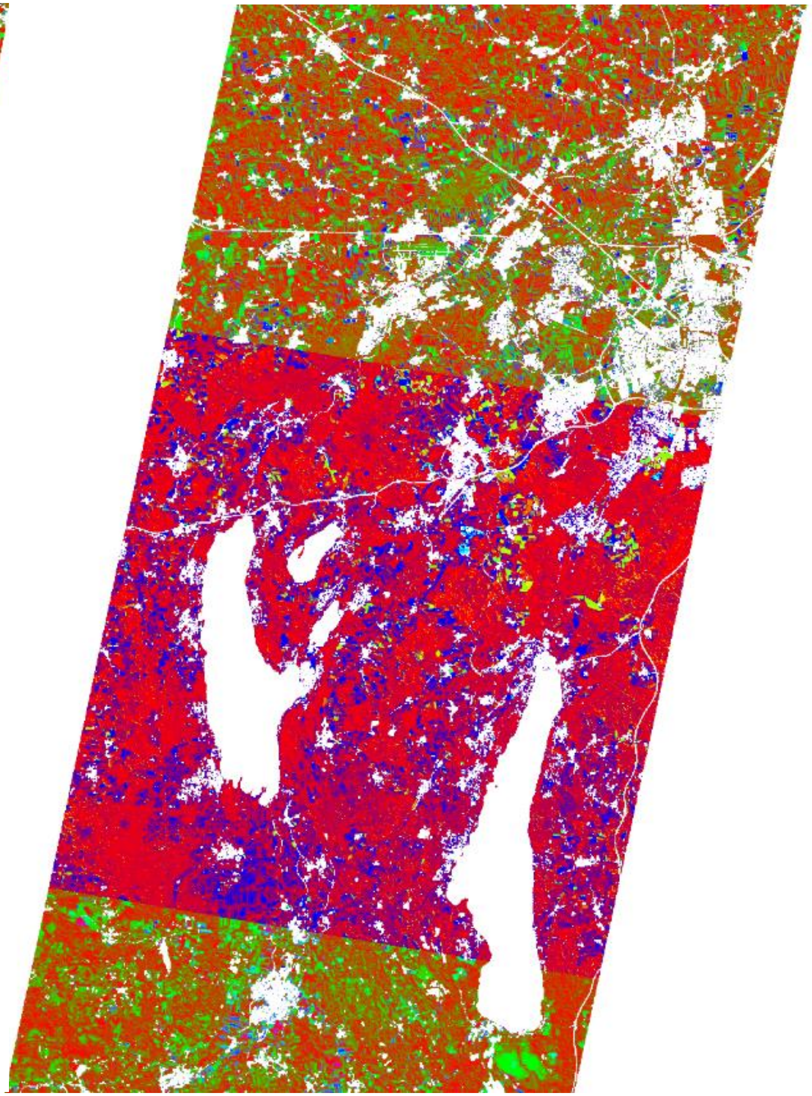

Fractional vegetation cover - fCover

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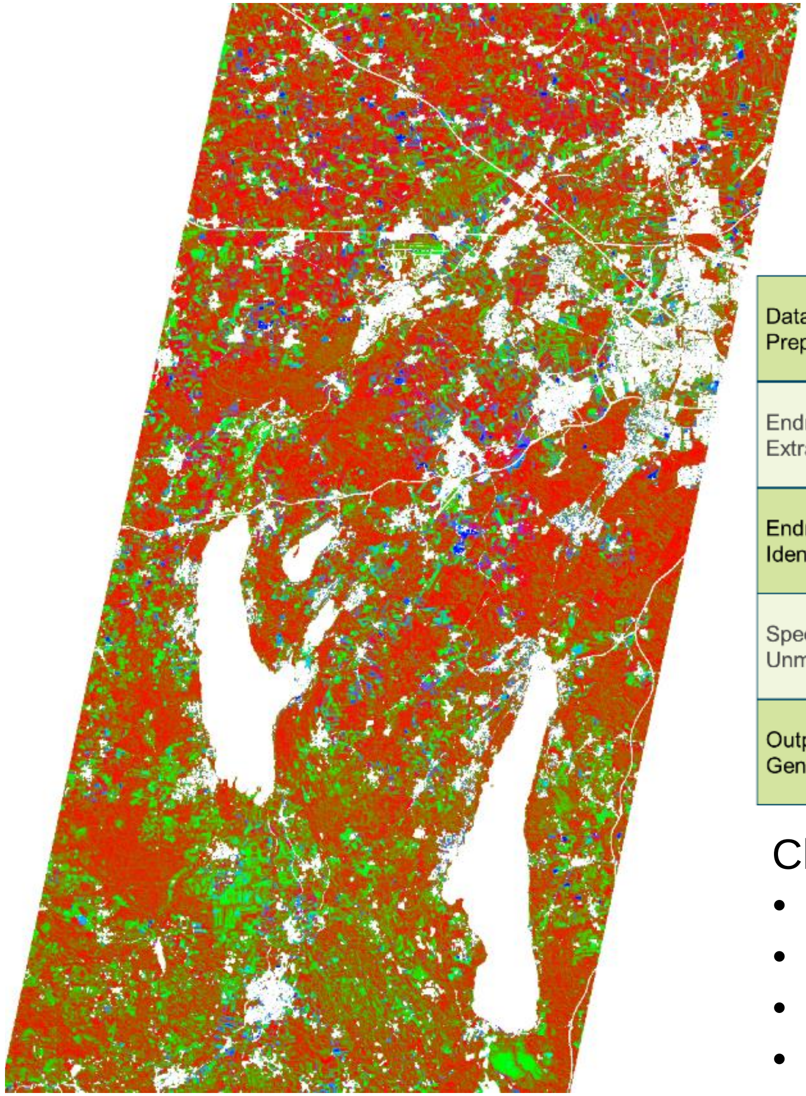
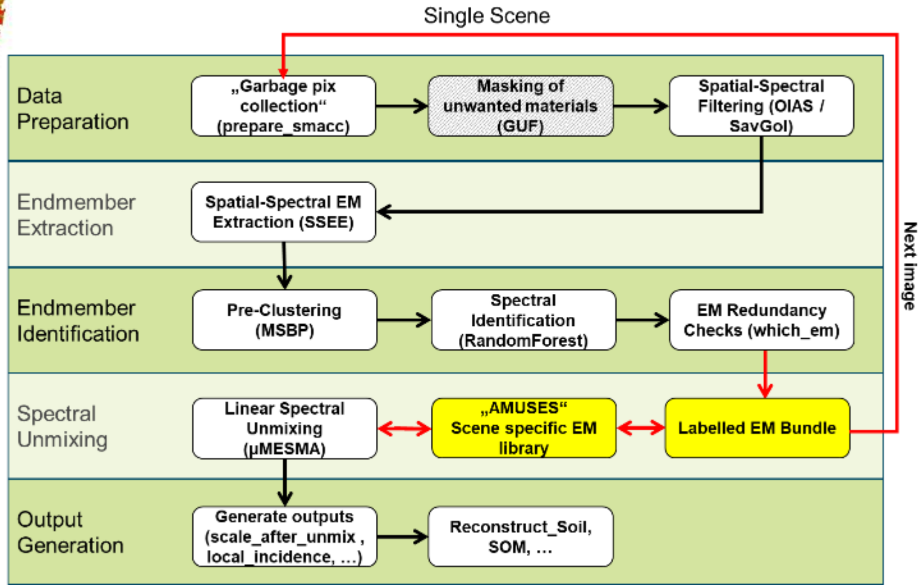


THREB

Temporal **H**yperspectral **R**egional

Endmember **B**undle

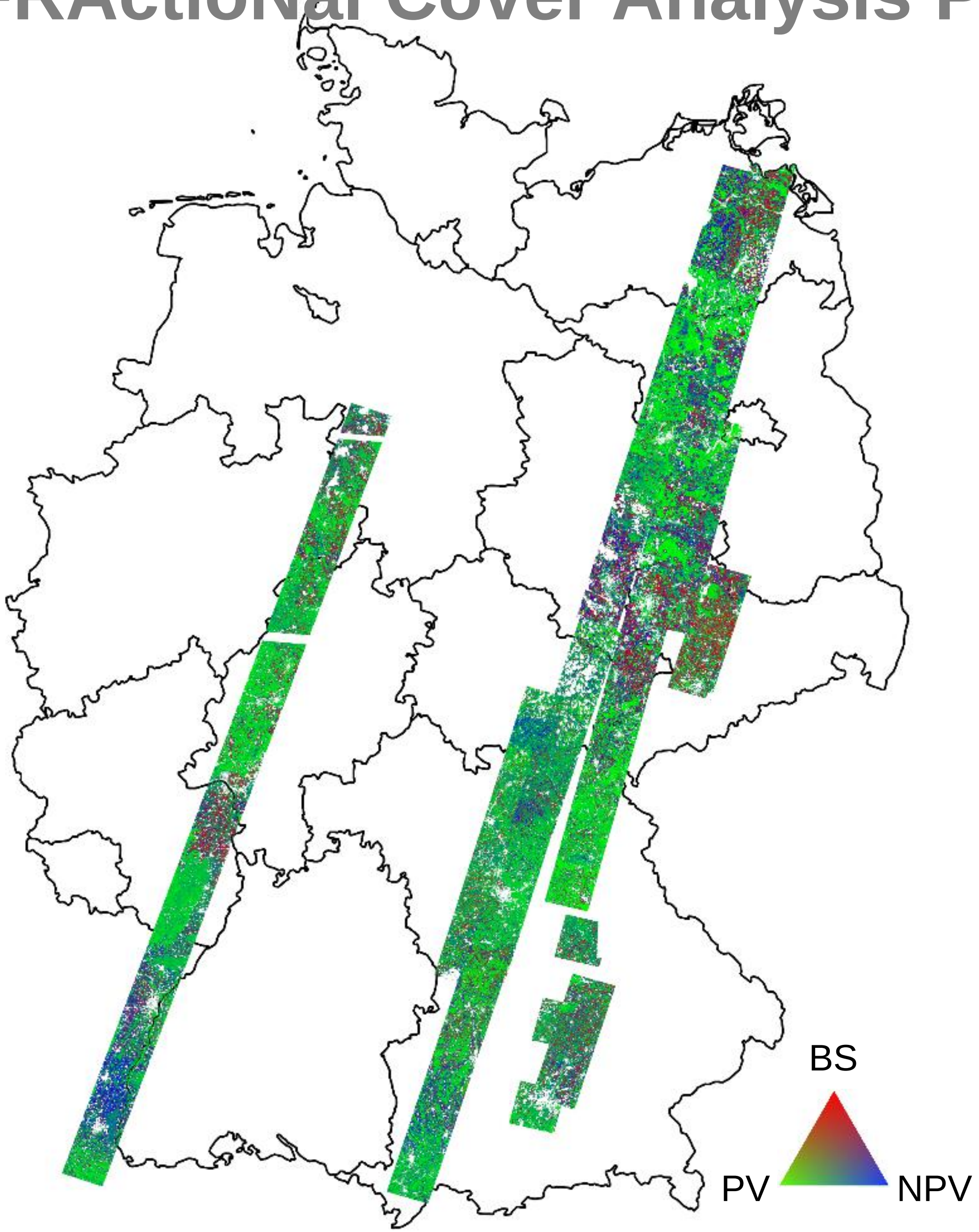


Challenge:

- Higher inner-class variability of EMs
- Reduction of the number of EMs
- Selection of optimal / relevant EMs
- Seamless quantitative fCover result

Fractional vegetation cover - fCover

FRActioNal Cover Analysis Processor (FRANCA)

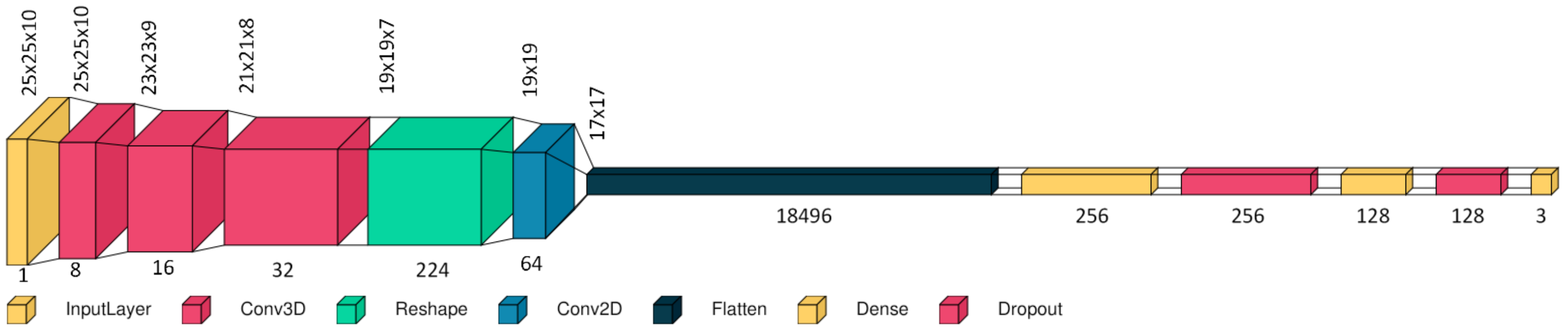


Summary:

- 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

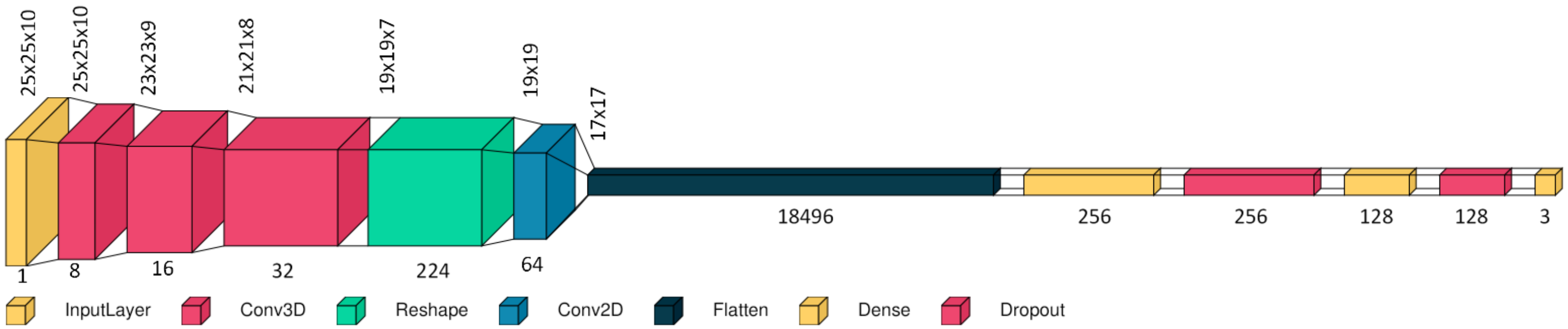


Idea: Leverage the archive of EnMAP to predict fCover (NPV) with Sentinel-2 data

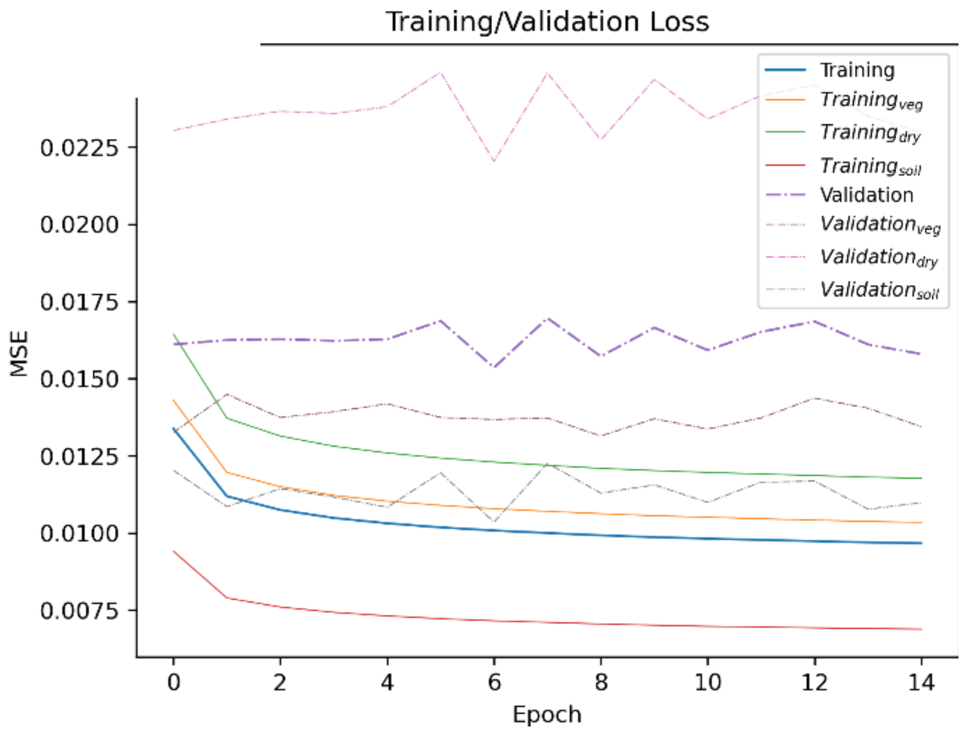
- Create fCover maps on hyperspectral data from EnMAP data (224 bands, 420-2450 nm)
- Find spectral imagery from Sentinel-2 for same areas/dates
- Train a DL network using S2 images as input and fCover maps as labels
- The trained model can be used to create fCover maps on S2 data (10 bands, 443-2202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

fCover using Deep Learning

- 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



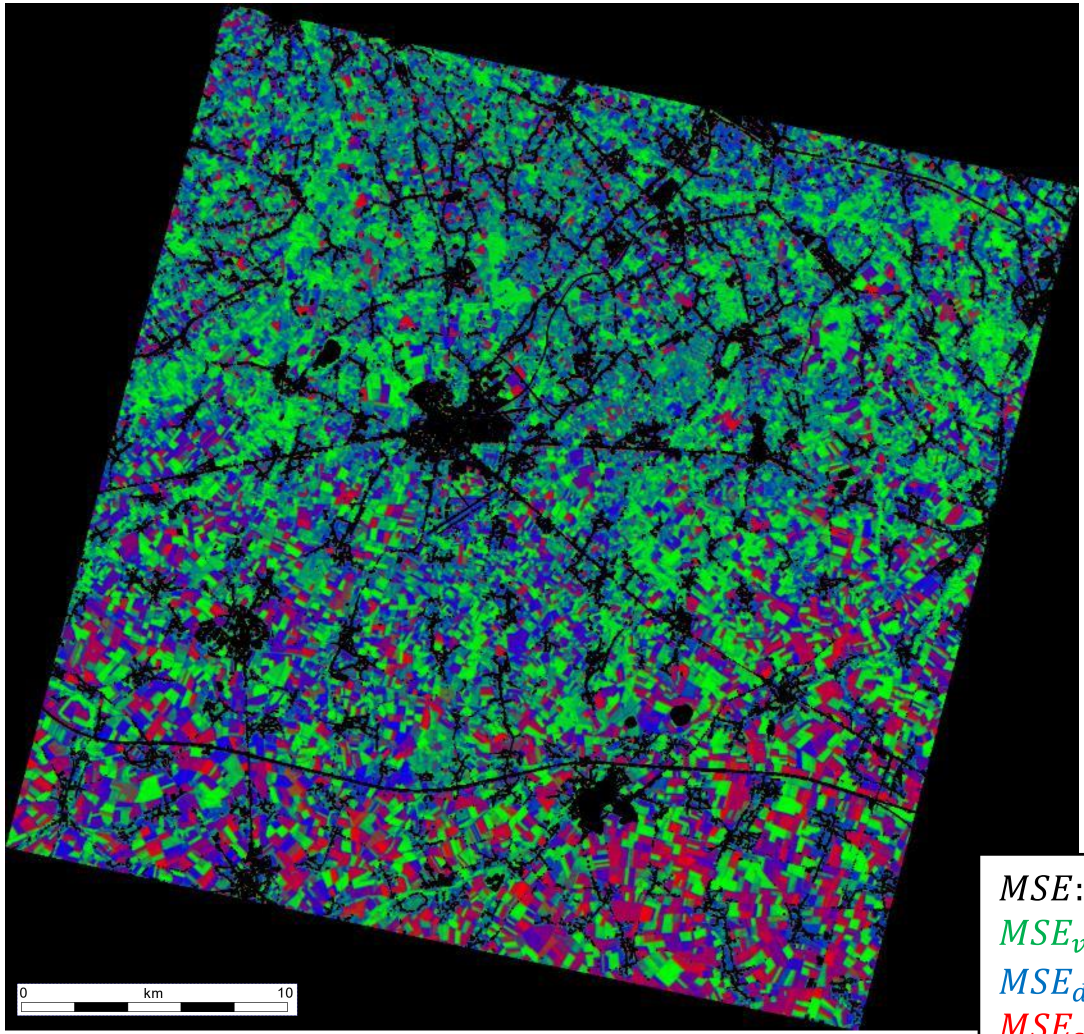
- The model is trained with 61 Sentinel-2 image/EnMAP fcover pairs. 55 pairs are used for training:
    - (30.579.104 patches with size 25x25x10; randomly flipping training patches in X/Y to prevent overfitting
    - Trained on single NVIDIA GeForce RTX 2080 Ti
    - Training for 15 epochs (1 epoch =157 minutes)
    - Min. validation loss achieved at epoch 7: 0.015 MSE
    - The mean squared error (MSE) for sample fCover predictions in mid Europe range from 0.025 – 0.022



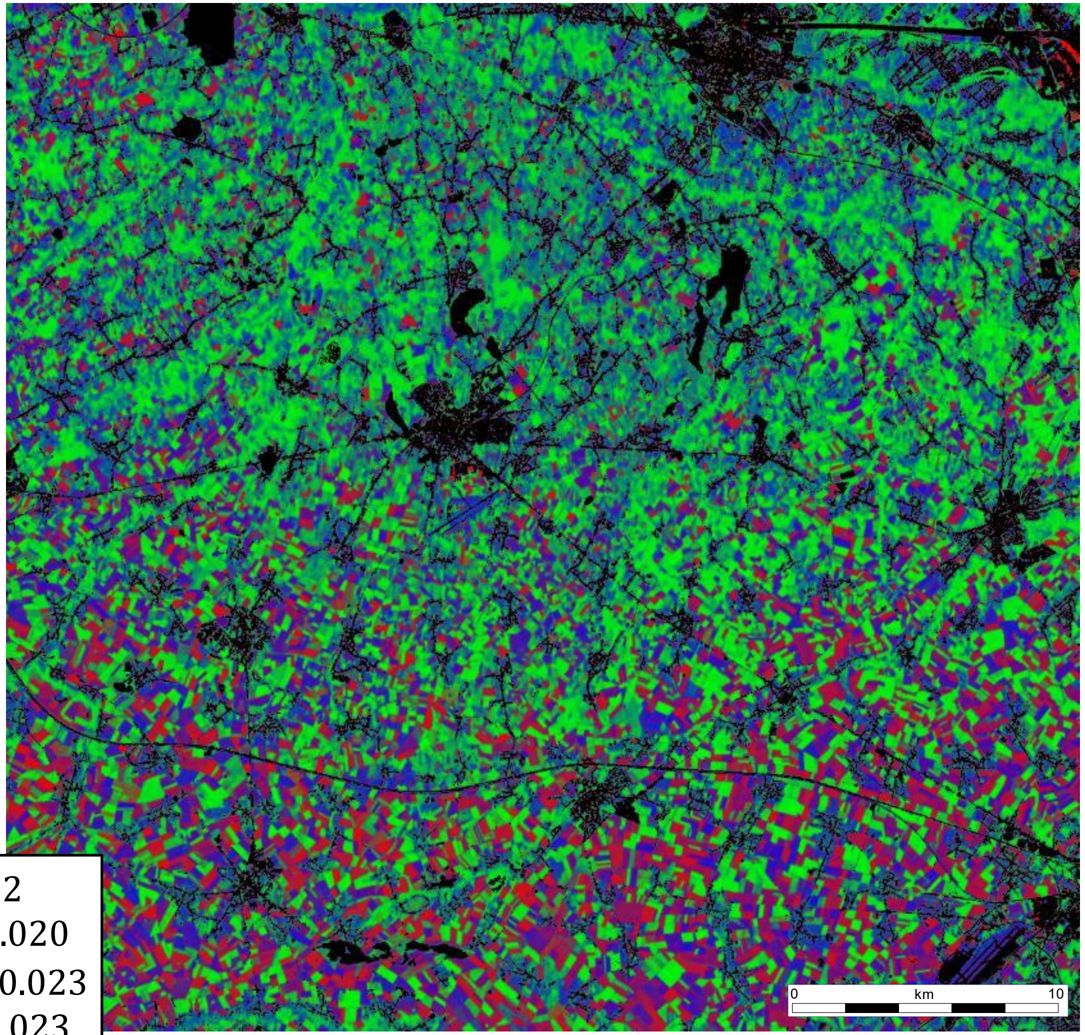
Fractional vegetation cover - fCover

fCover using Deep Learning: Belgium, Sint-Truiden

fCover from EnMAP (10.08.2022)



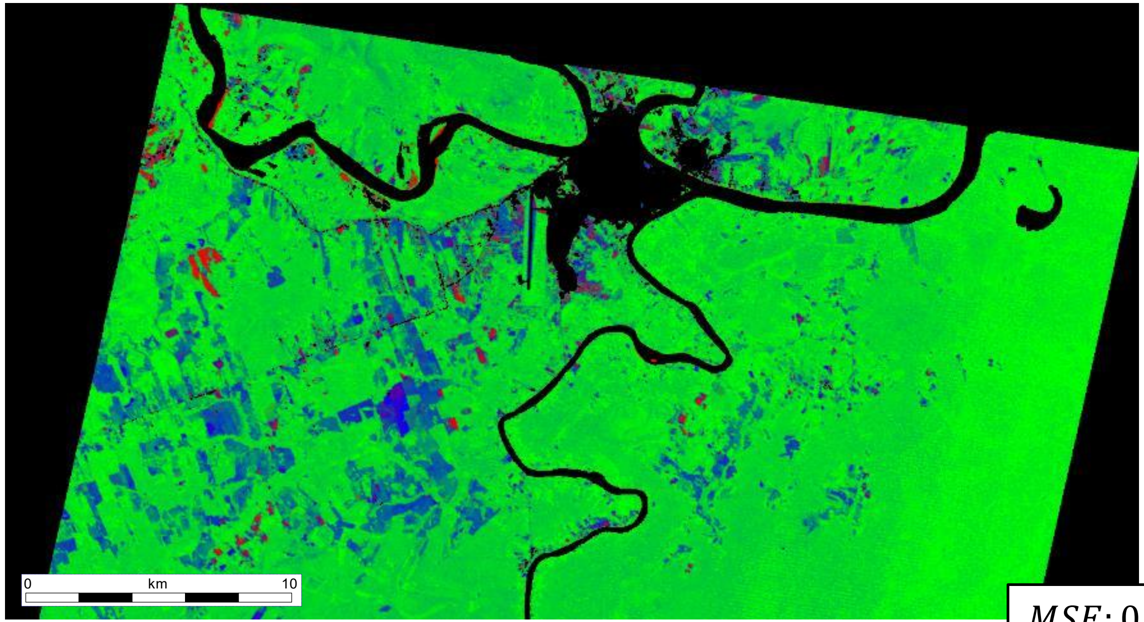
DL - fCover from S2 (10.08.2022)



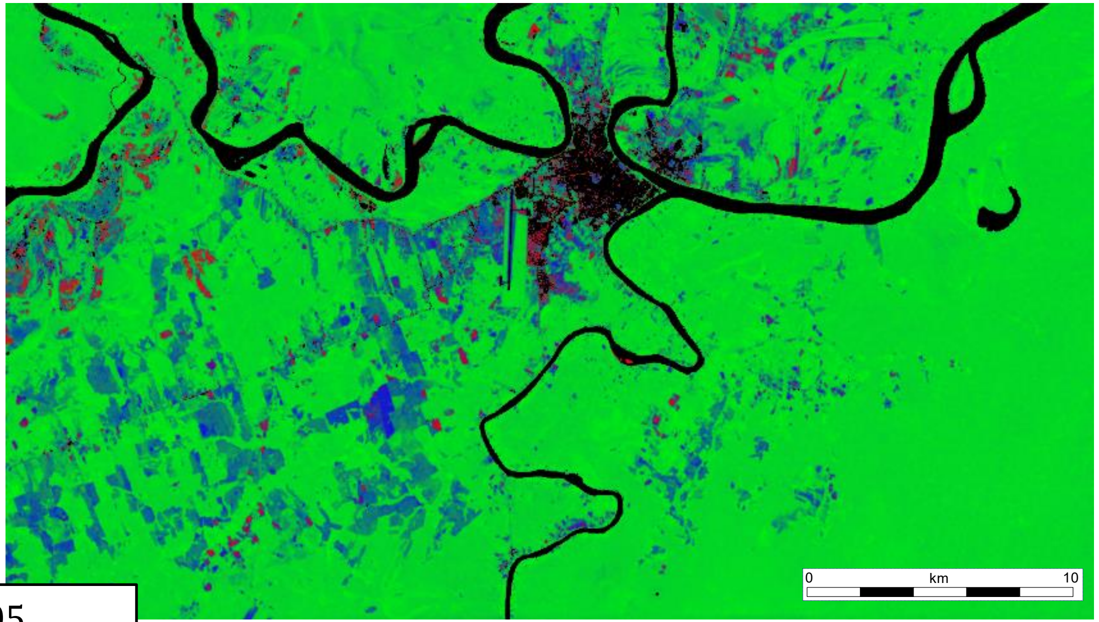
$MSE: 0.022$
$MSE_{veg}: 0.020$
$MSE_{dead}: 0.023$
$MSE_{soil}: 0.023$

fCover using Deep Learning: Peru, Puerto Maldonado

fCover from EnMAP (20.07.2023)



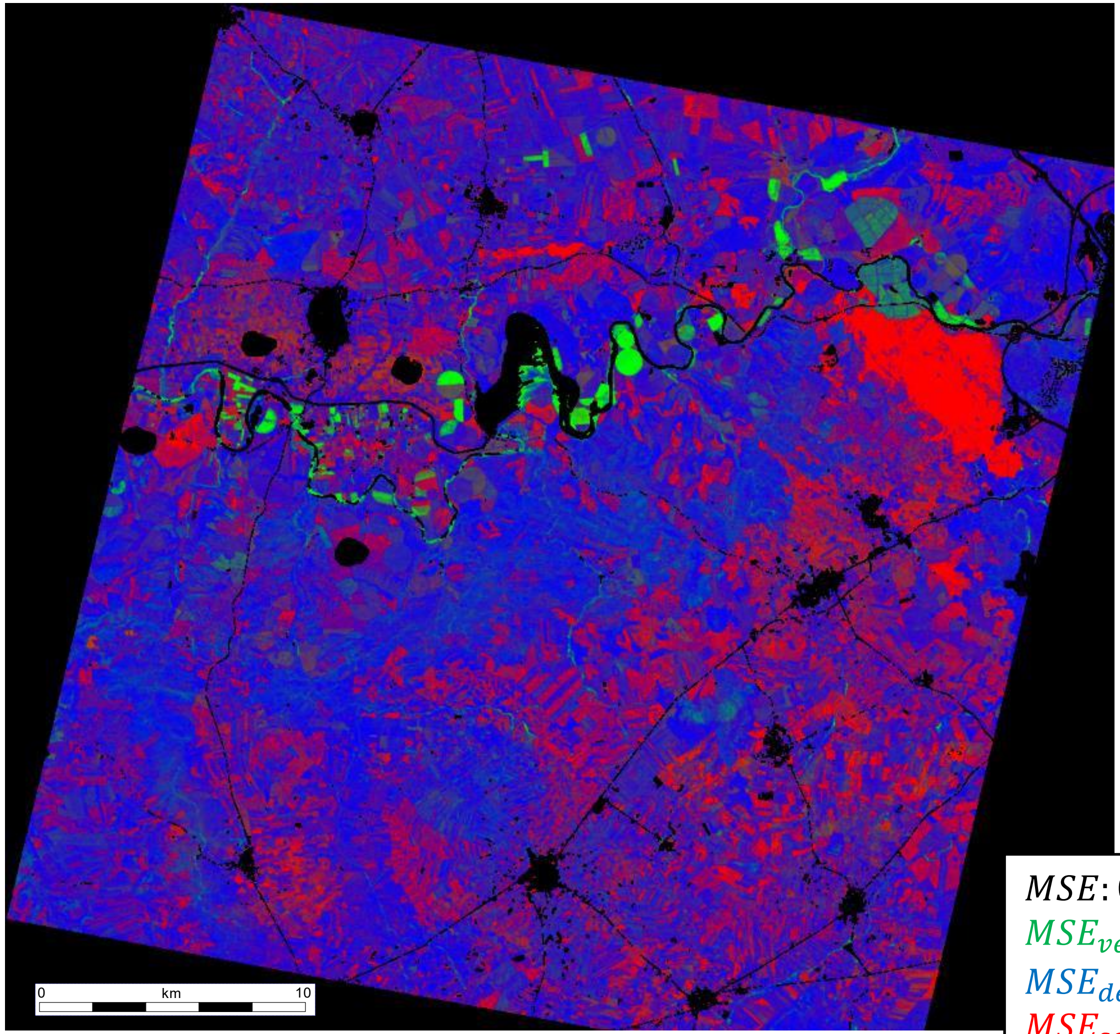
DL - fCover from S2 (20.07.2023)



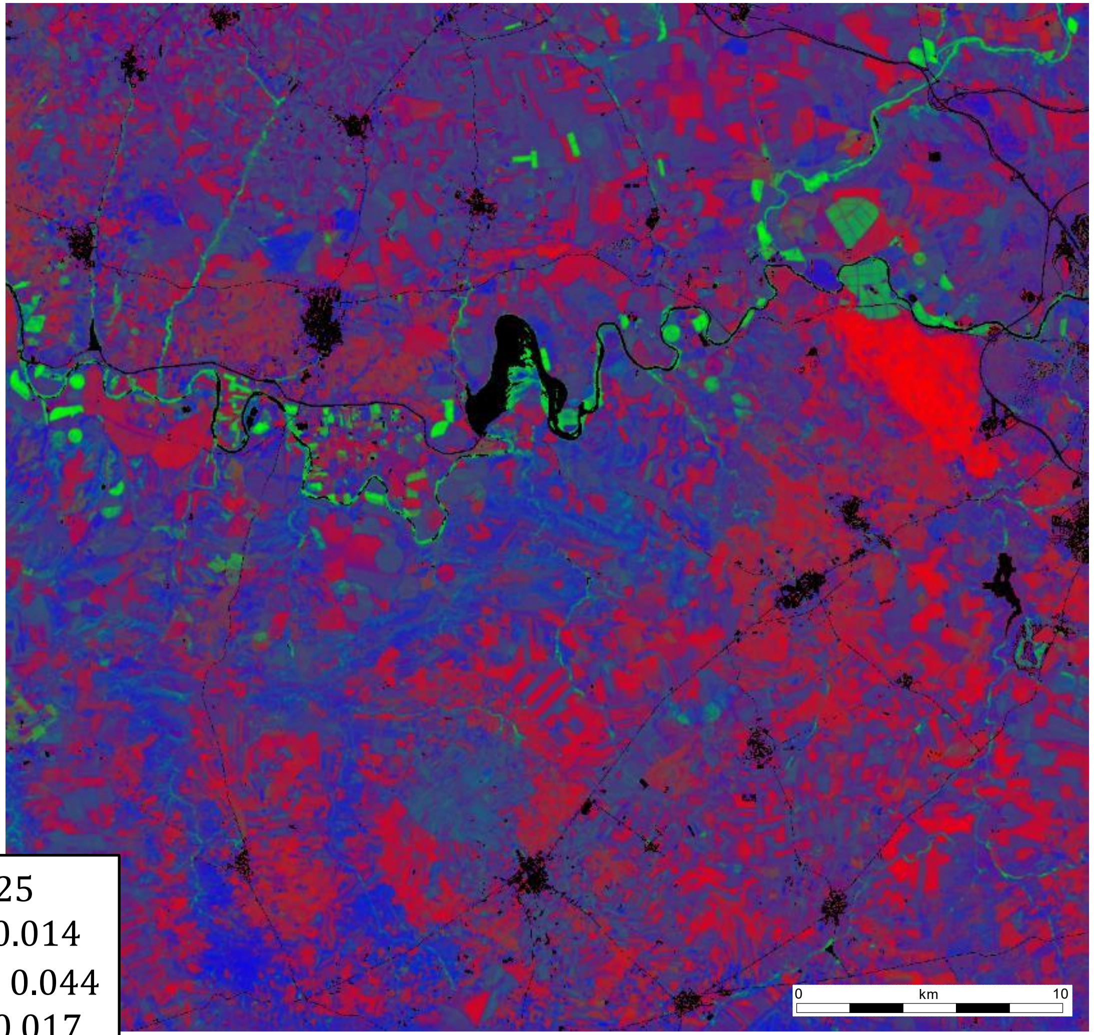
MSE: 0.005
MSE_{veg}: 0.008
MSE_{dead}: 0.007
MSE_{soil}: 0.002

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

Thank you very much for your attention!

Contact: Uta.Heiden@dlr.de, Paul.Karlshoefer@dlr.de