High resolution soil property maps and their uncertainty for Europe

SOIL

CUP4SOIL / ESA Living Planet Symposium 2025

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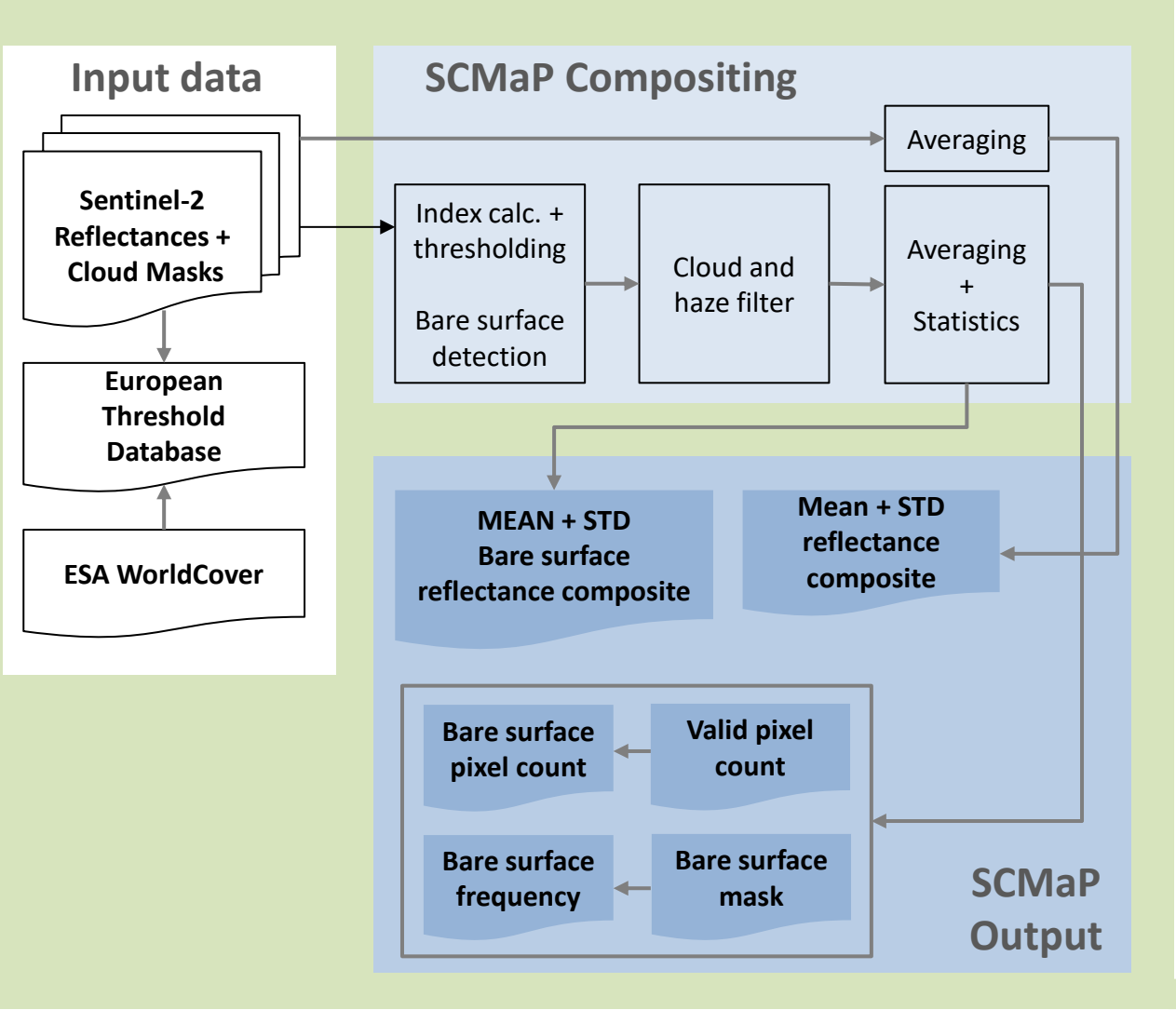
Paul Karlshoefer, Fenny van Egmond

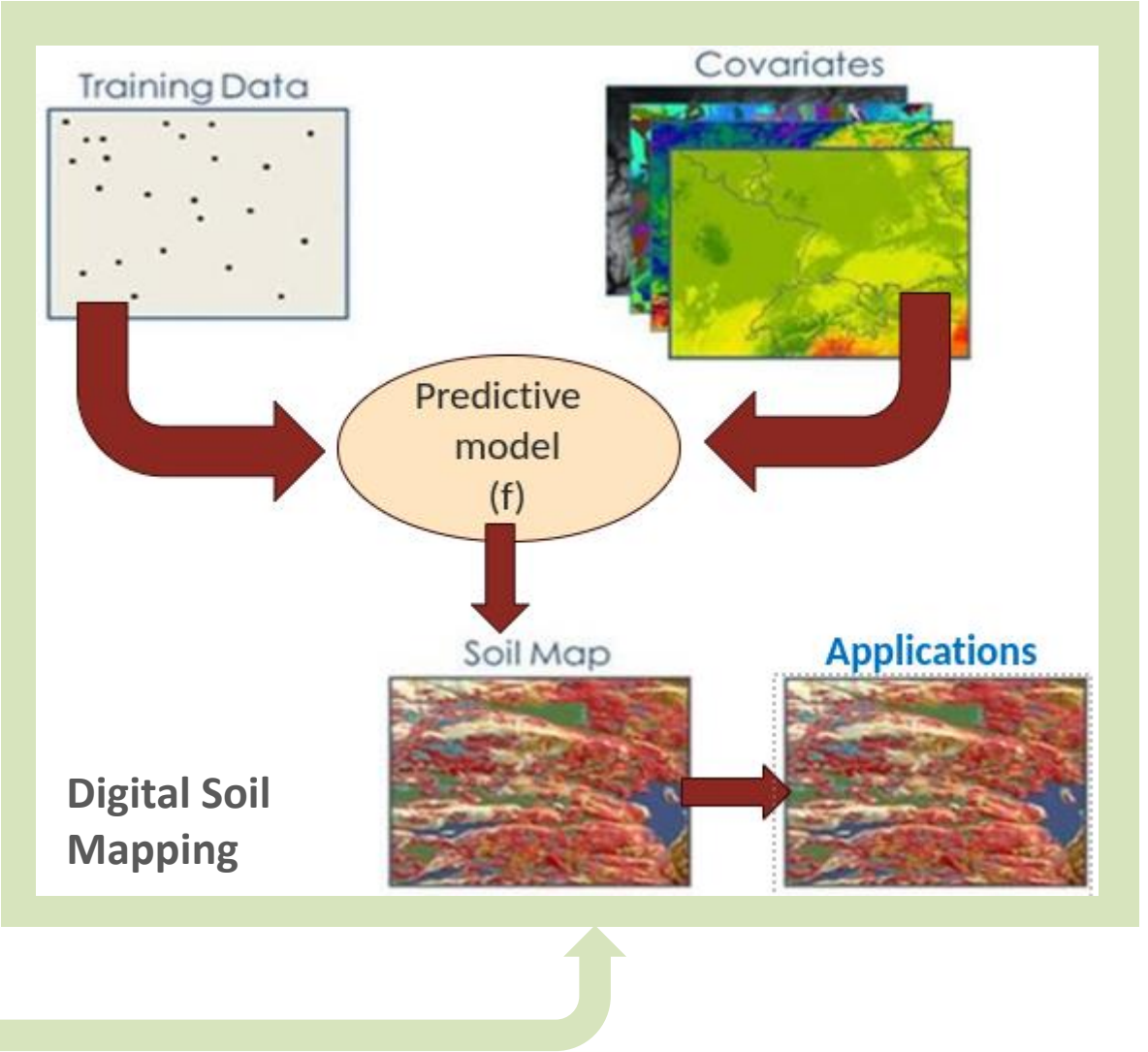
DLR

ISRIC
World Soil Information

Methodology

General overview



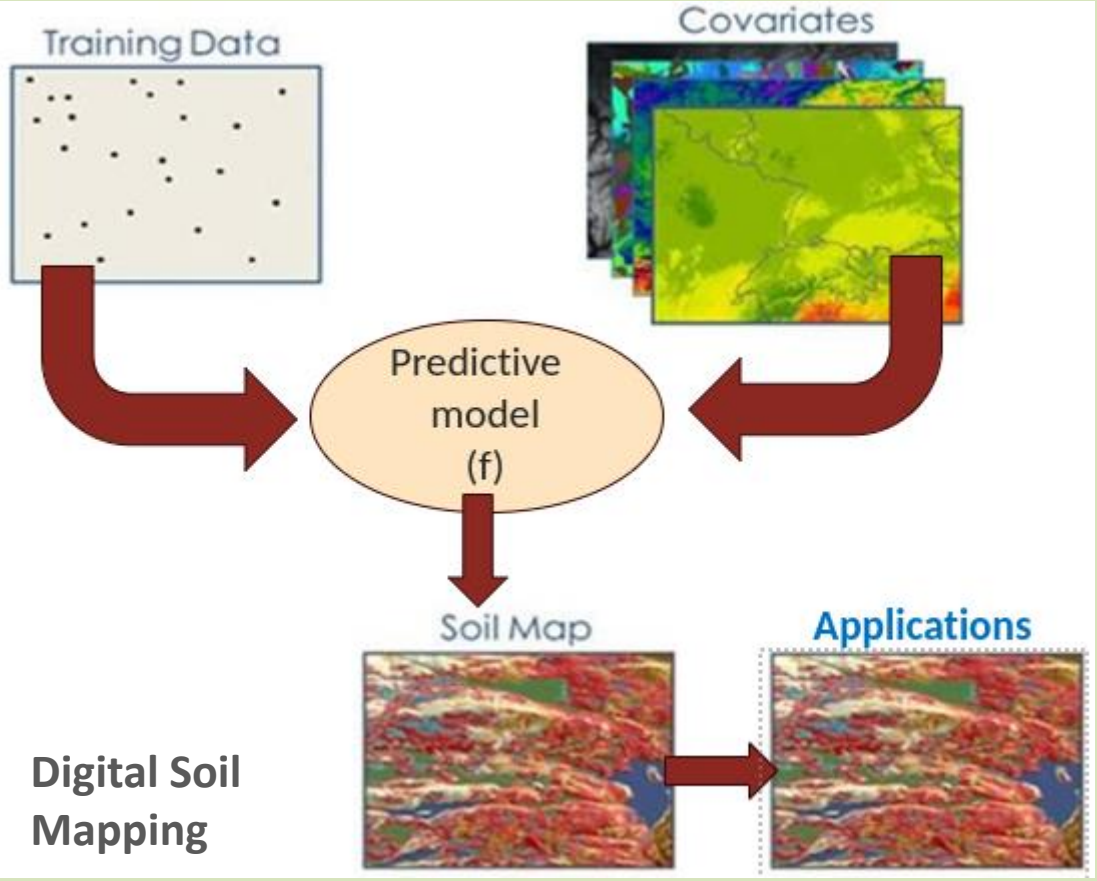


Methodology

Digital Soil Mapping – some notes

- Input data from LUCAS (and other sources in WoSIS if relevant)
- Covariates:
  - Data prepared by DLR
  - Data available from Copernicus (DEM, land cover)
  - Geology/parent material (JRC)
  - Simple radar products from Sentinel1

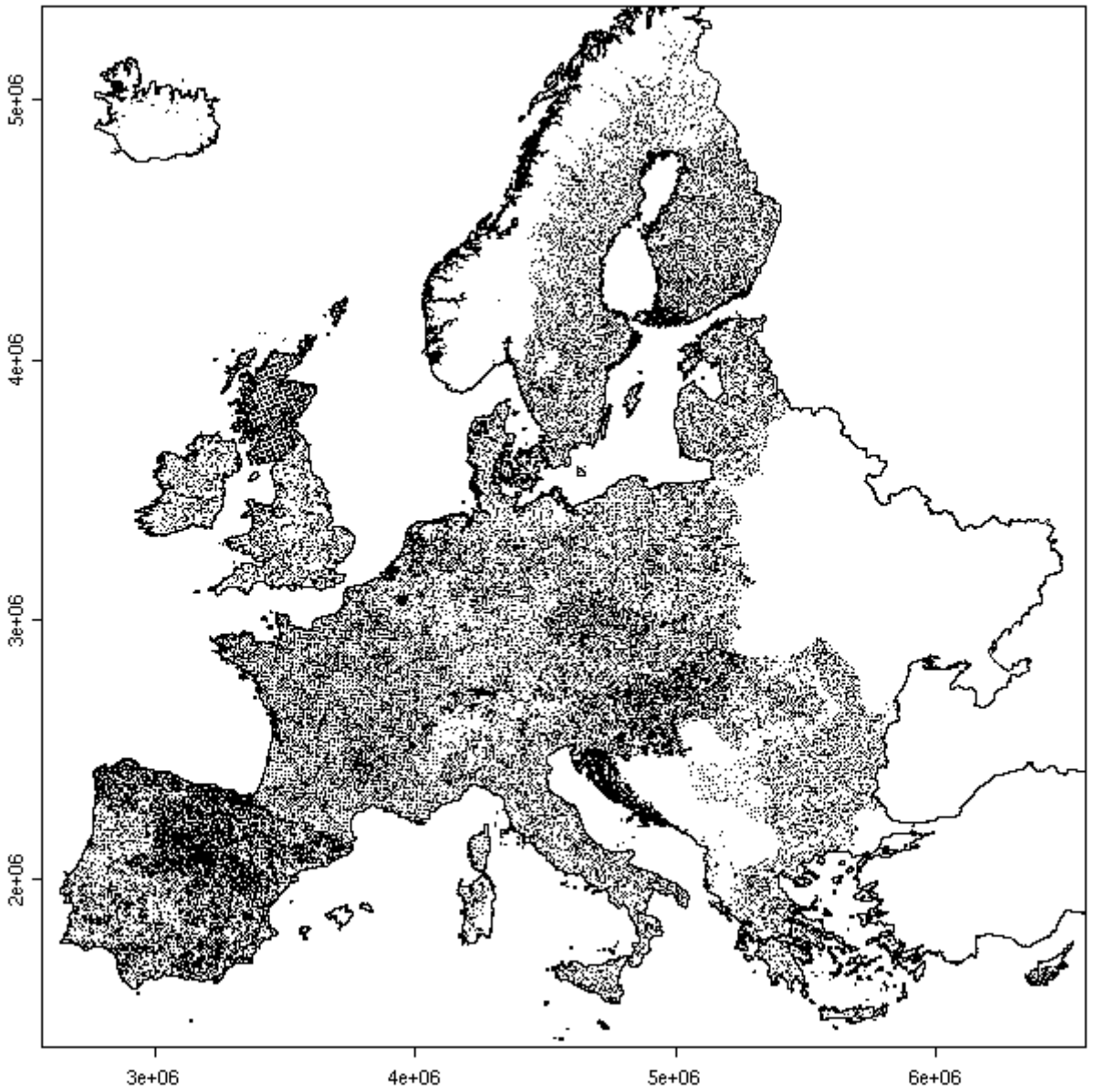
- Model: quantile random forest (robust approach allowing pixel-based uncertainty assessment)
- Outputs:
  - Primary soil properties
  - Uncertainty index
  - Other uncertainty measures (to be further developed)



CUP4SOIL – Soil properties mapping – Input data

About 94K input observations for various properties :

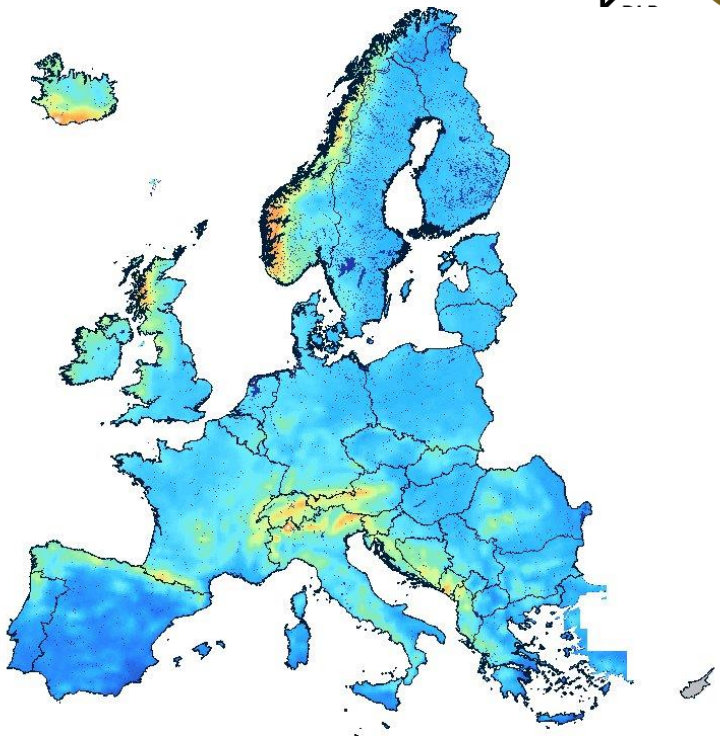
- SOC,
- SIC,
- pH (water),
- (total) nitrogen,
- sand/silt/clay (compositional data)
- bulk density (oven dry),
- coarse fragments

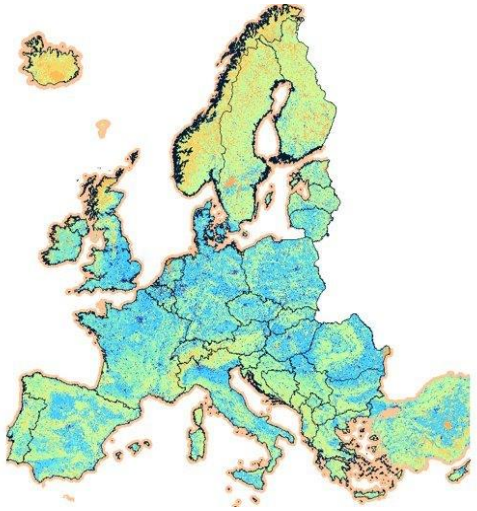


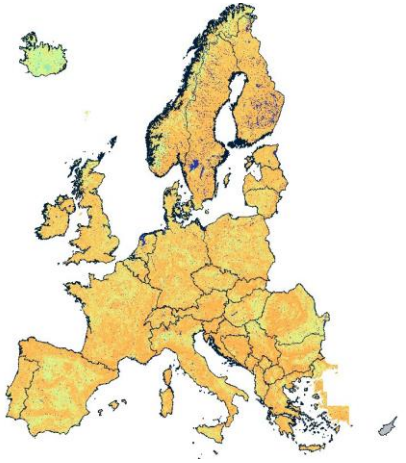
CUP4SOIL – Soil properties mapping – Covariates

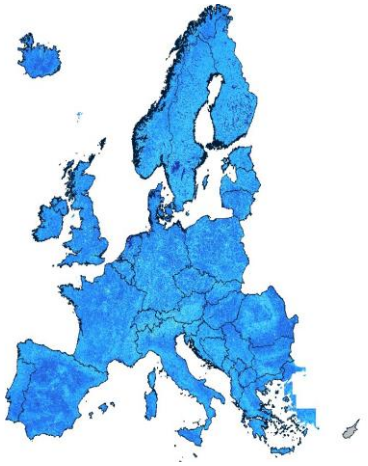
Soil forming factors :

- Climate
- Relief
- Organisms (vegetation, land cover):
- parent material
- Other: radar









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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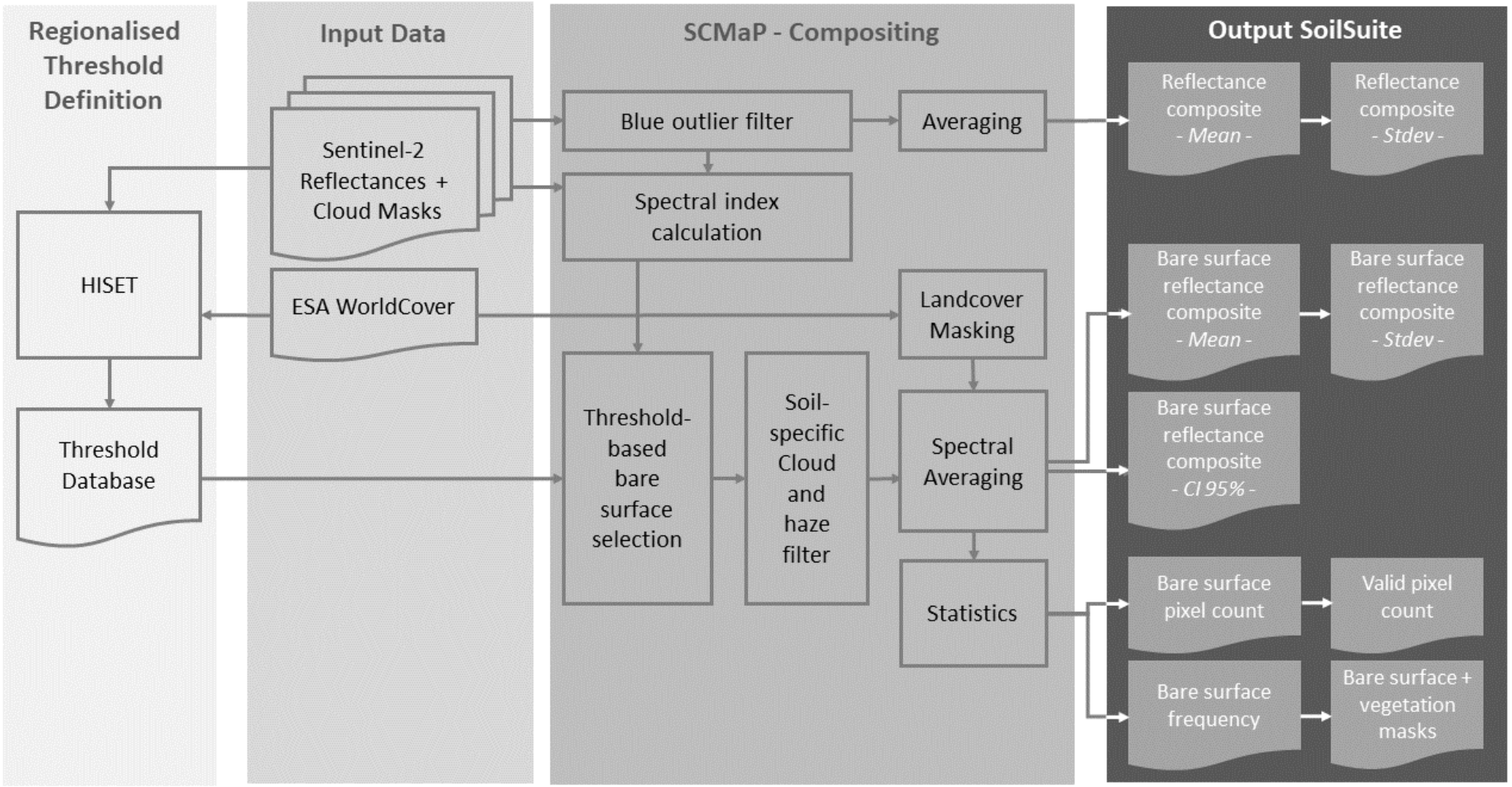
- EOC Geoservice (Host) DLR/EOC

SoilSuite for Europe

Soil Composite Mapping Processor (SCMAP)



Deployed at terrabyte – DLR‘s HPDA platform

Karlshöfer et al., 2025: Geoderma. https://doi.org/10.1016/j.geoderma.2025.117340

Heiden et al., 2025: Tech report.

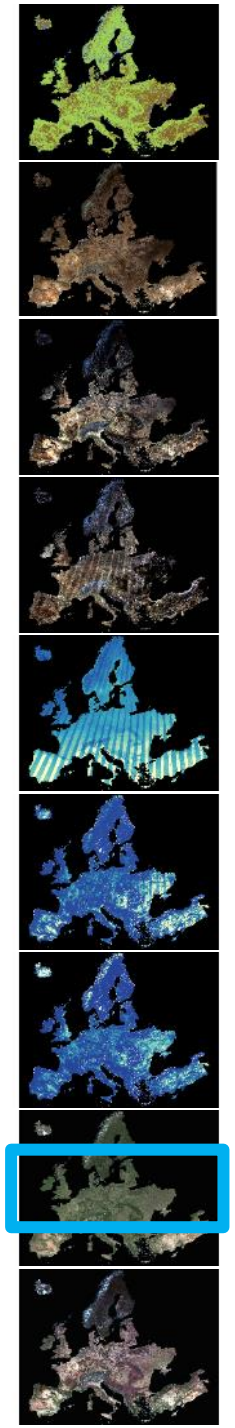
Heiden, U. et al.,2022: https://doi.org/10.3390/rs14184526

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
- 10 bands

Reflectance Composite
– Mean

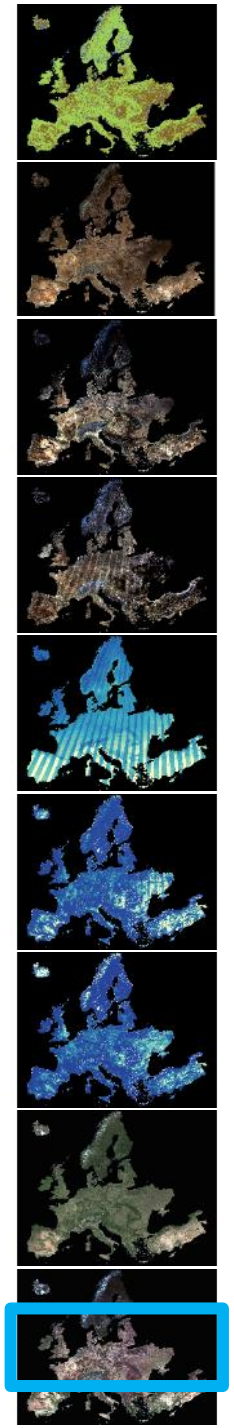


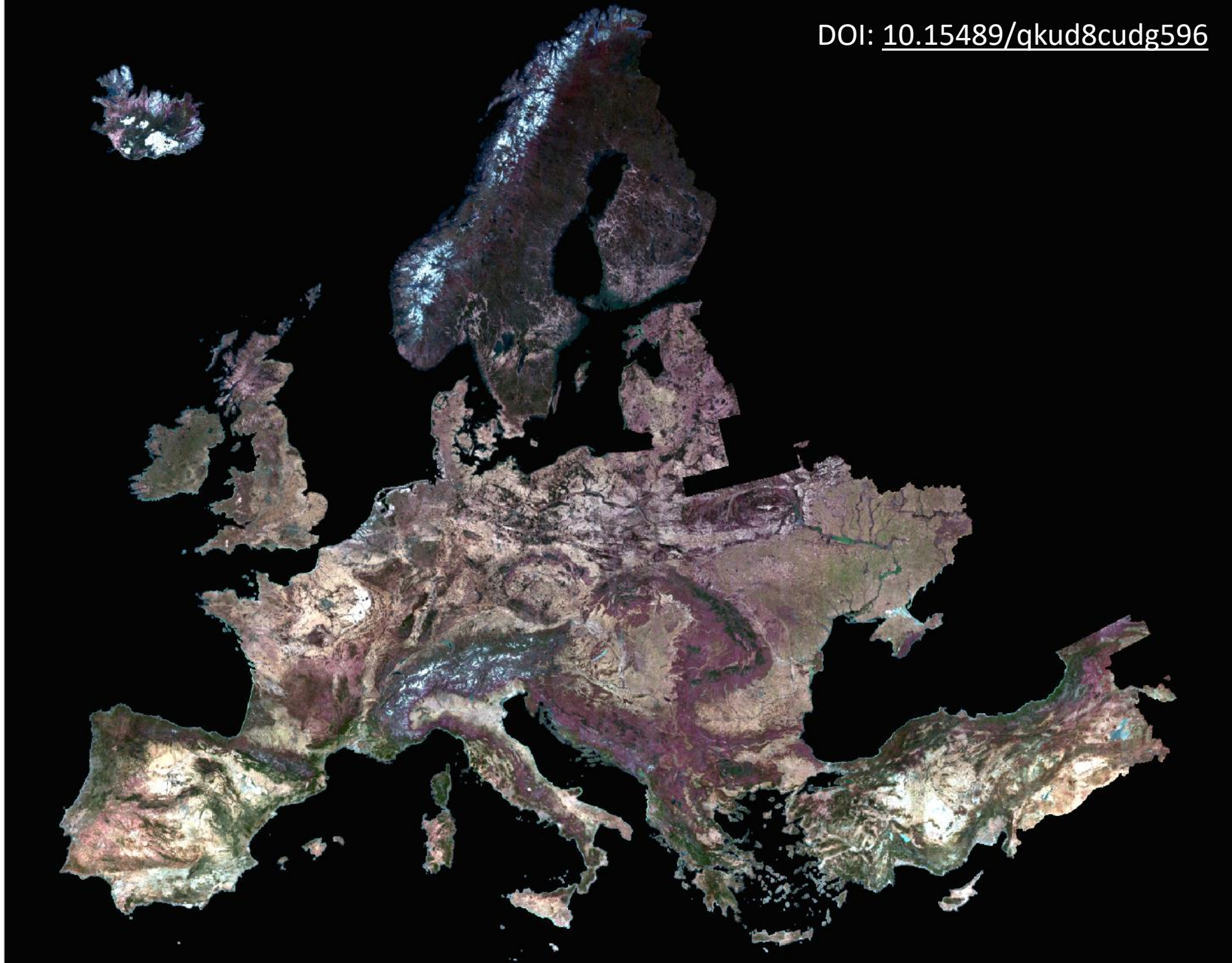
DOI: 10.15489/qkud8cudg596

SoilSuite 2018 – 2022

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

Reflectance Composite
– Standard Deviation





DOI: 10.15489/qkud8cudg596

DLR

SOIL PROPERTY MAPPING

CUP4SOIL

Soil Property Mapping

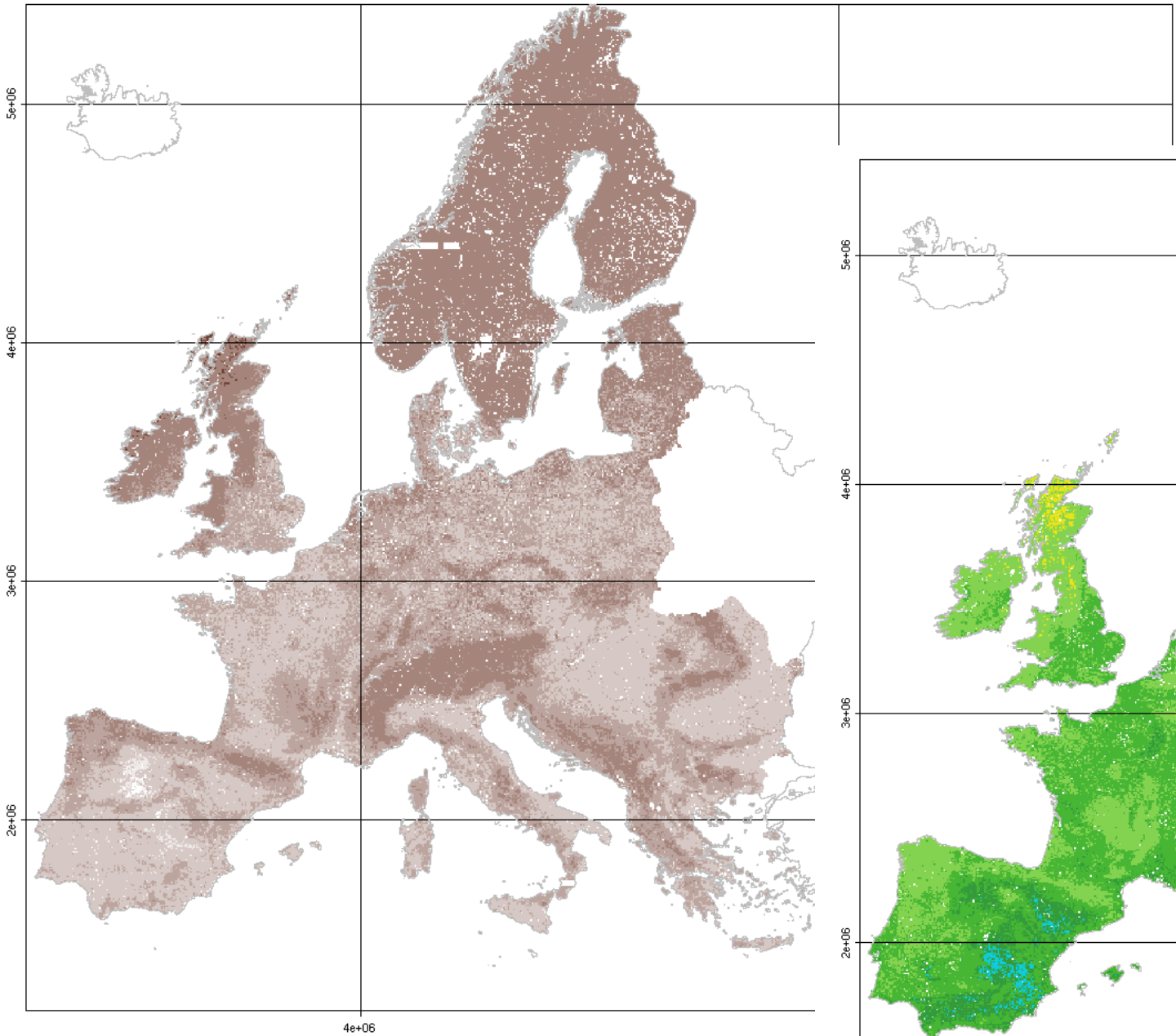
Property	Description	Depths	Units
soc	Soil organic carbon content	topsoil - 0-30cm	g/kg
phh2o	pH in water	topsoil - 0-30cm	pH
nitrogen	Total nitrogen	topsoil - 0-30cm	g/kg
bdod	Bulk density, oven dry	topsoil - 0-30cm	kg/dm3
cfvo	Coarse fragments, volumetric	topsoil - 0-30cm	cm3/100cm3
sic	Soil inorganic 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

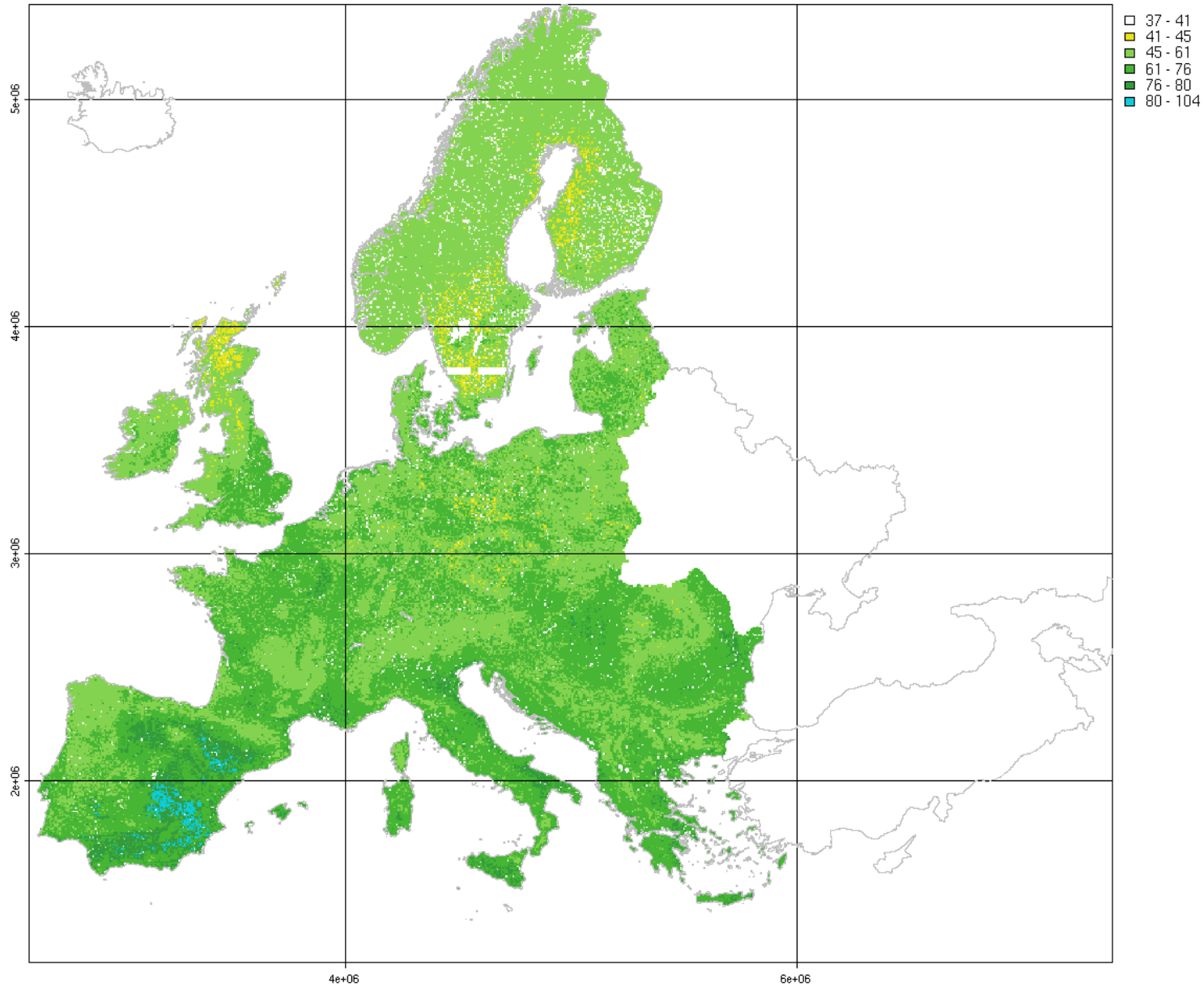
Uncertainty was calculated as:

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

Preliminary cross-validation

	Bulk density	Coarse fragment	Nitrogen	Organic carbon stocks (topsoil)	pH (water)	Soil inorganic carbon	Soil organic carbon
mae	0.20	8.97	1.79	3.76	0.65	5.25	33.91
mec	0.45	0.28	0.31	0.09	0.61	0.52	0.36
rmse	0.27	12.81	3.29	6.76	0.82	10.51	68.12


39 - 73
73 - 104
104 - 282
282 - 642
642 - 3800
3800 - 6660
5e+06
4e+06
3e+06
2e+06
4e+06


37 - 41
41 - 45
45 - 61
61 - 76
76 - 80
80 - 104
5e+06
4e+06
3e+06
2e+06
4e+06
6e+06

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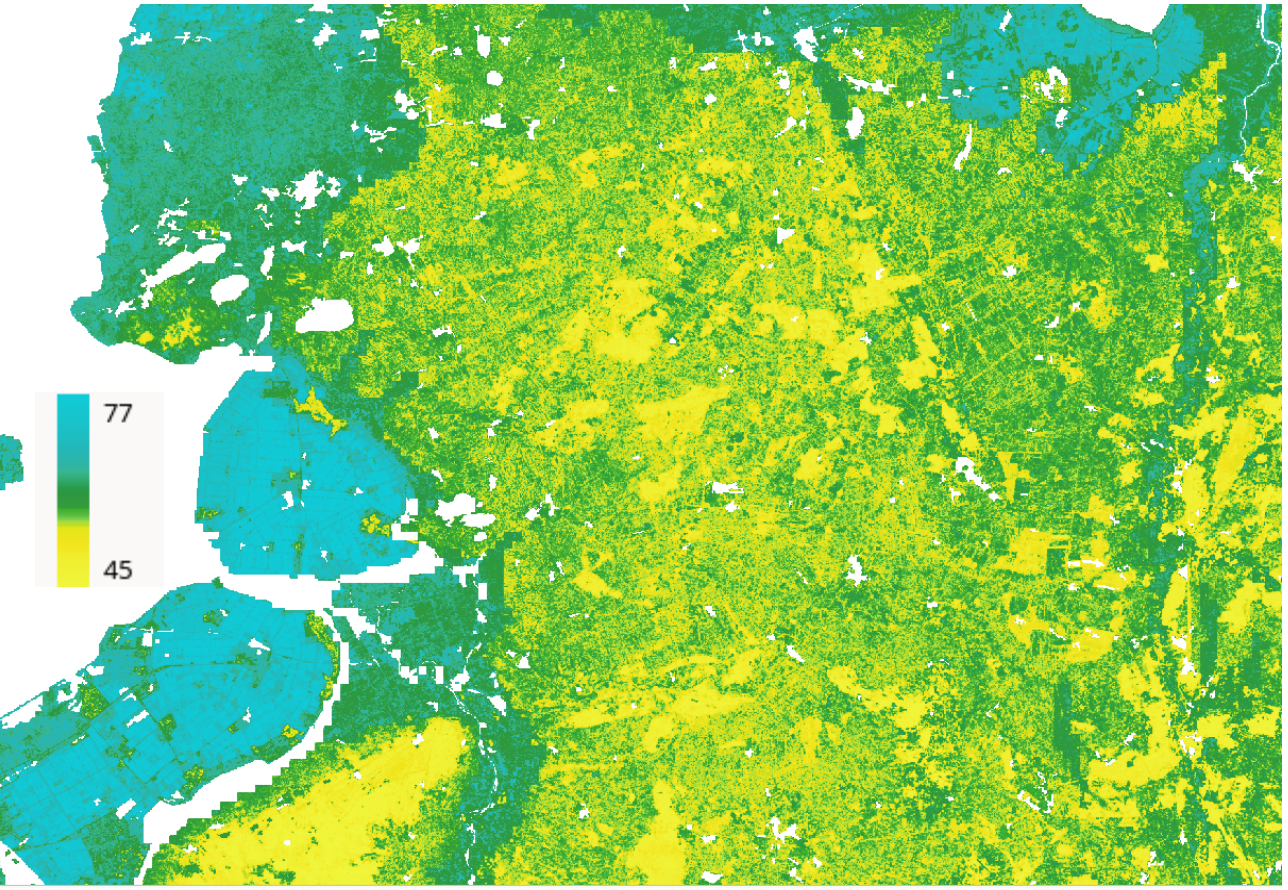
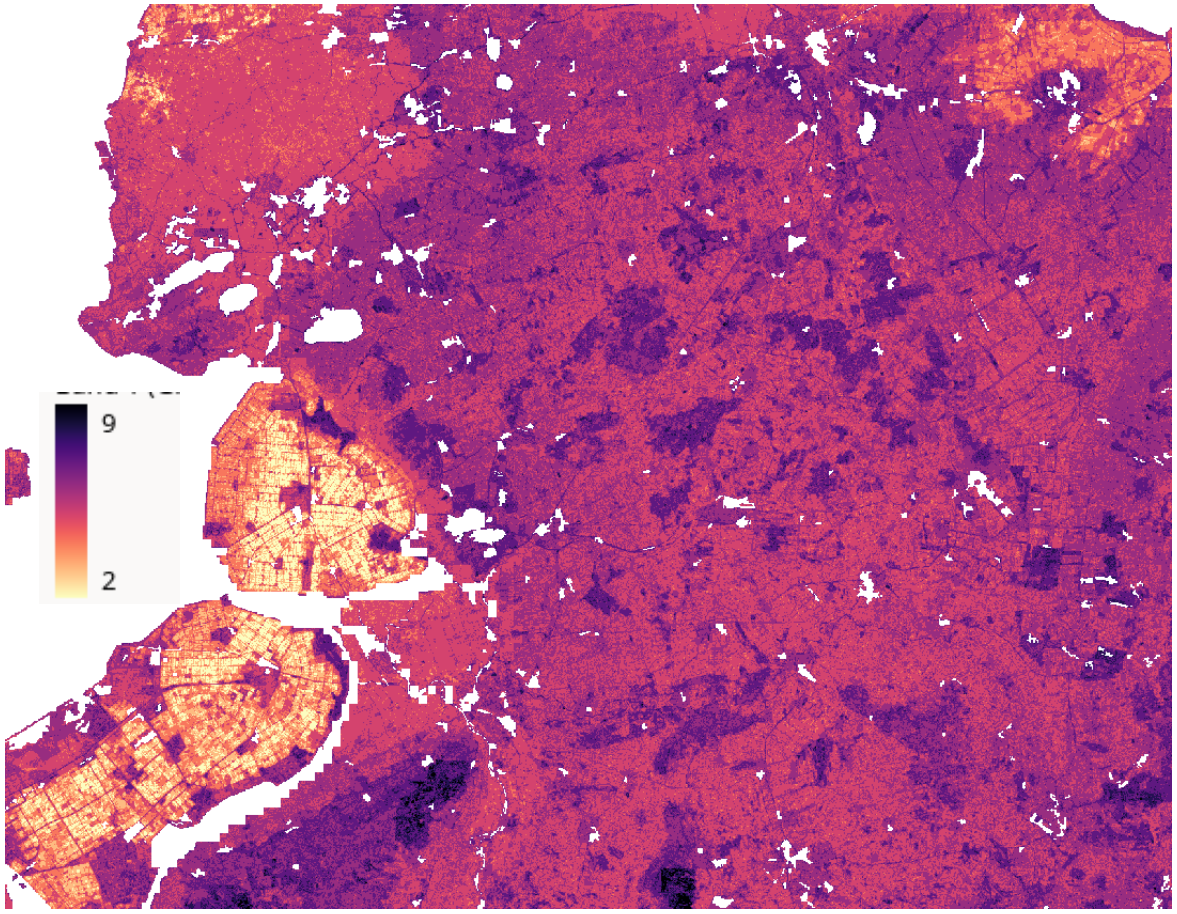
Soil Property Mapping – pH water and its uncertainty





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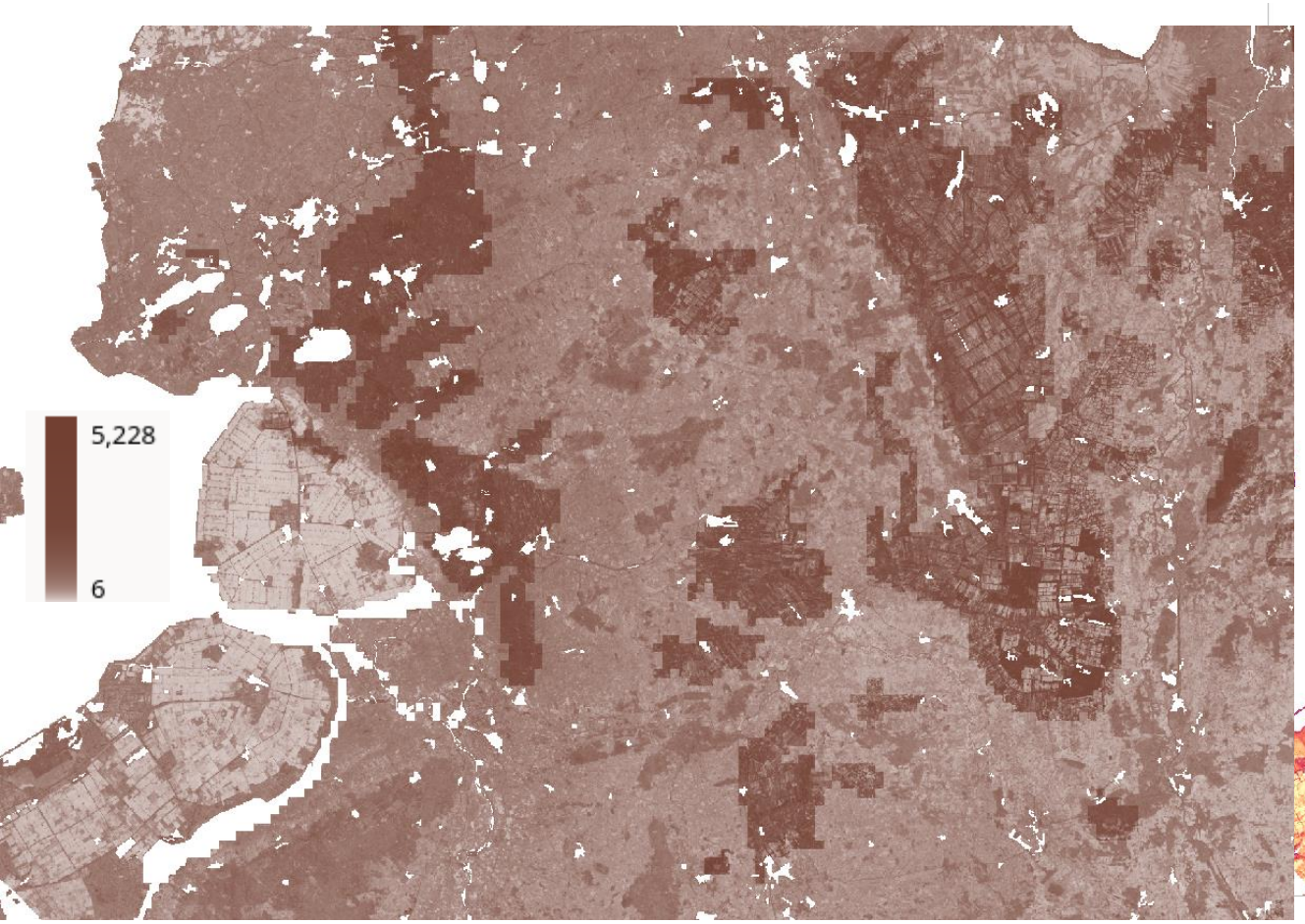
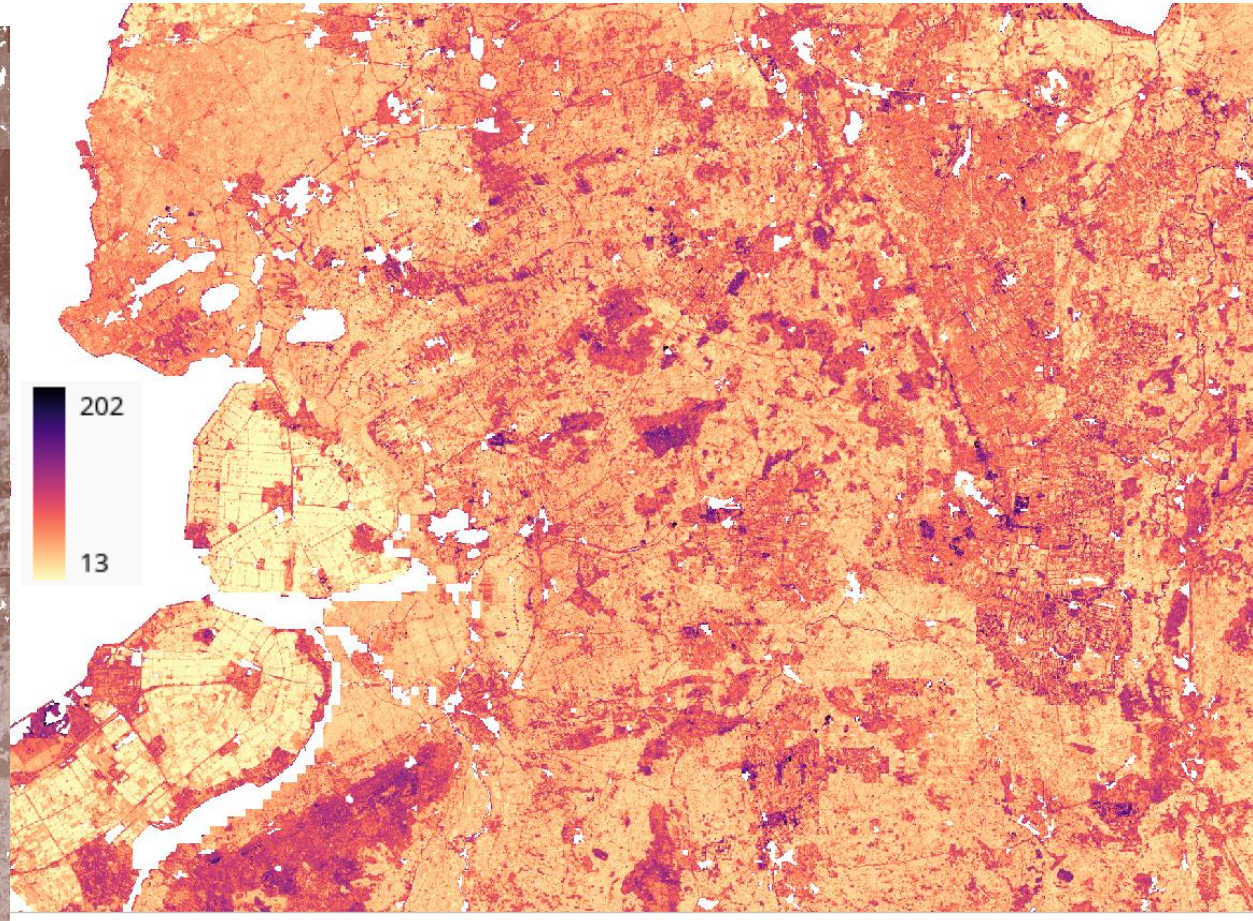
Soil Property Mapping – SOC and its uncertainty





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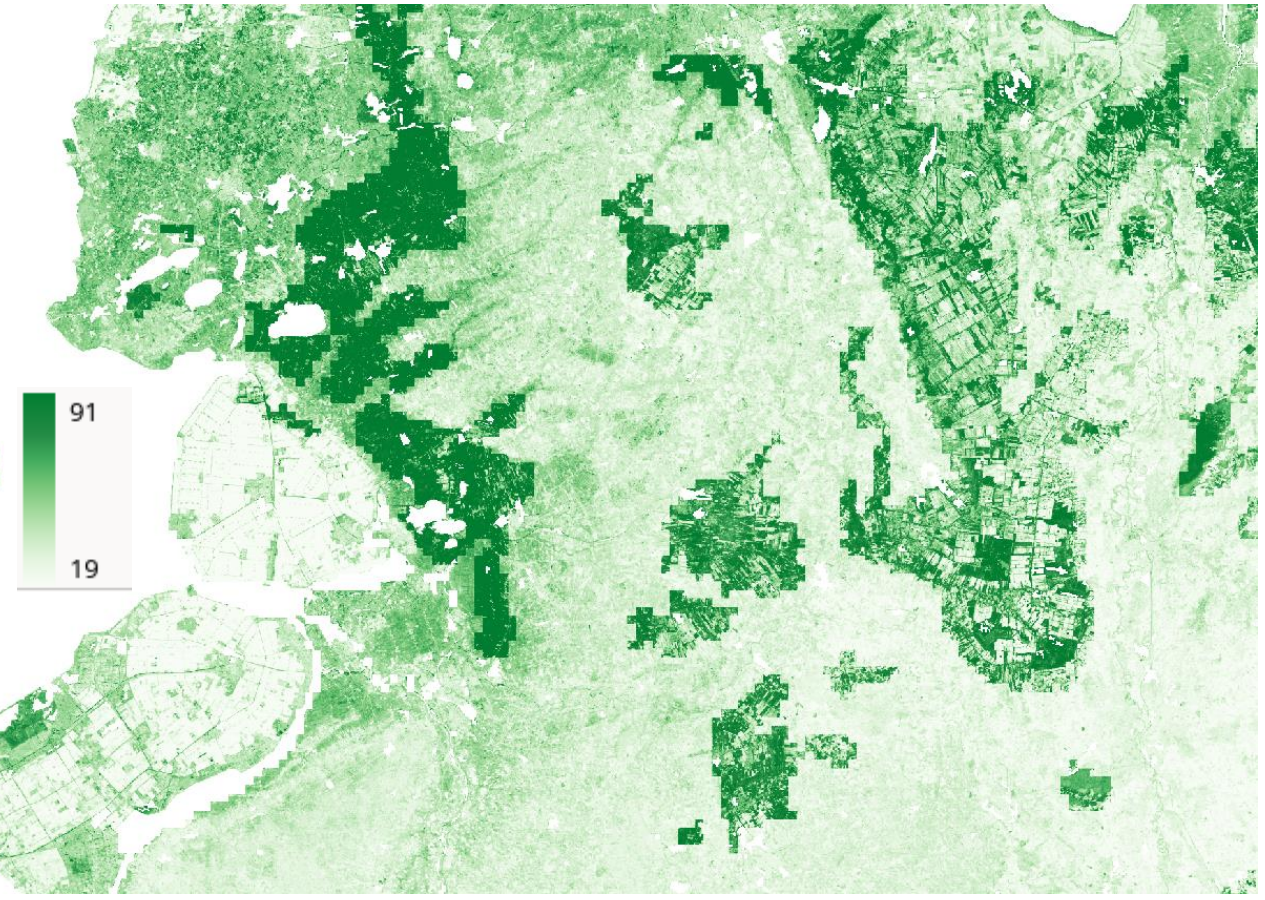
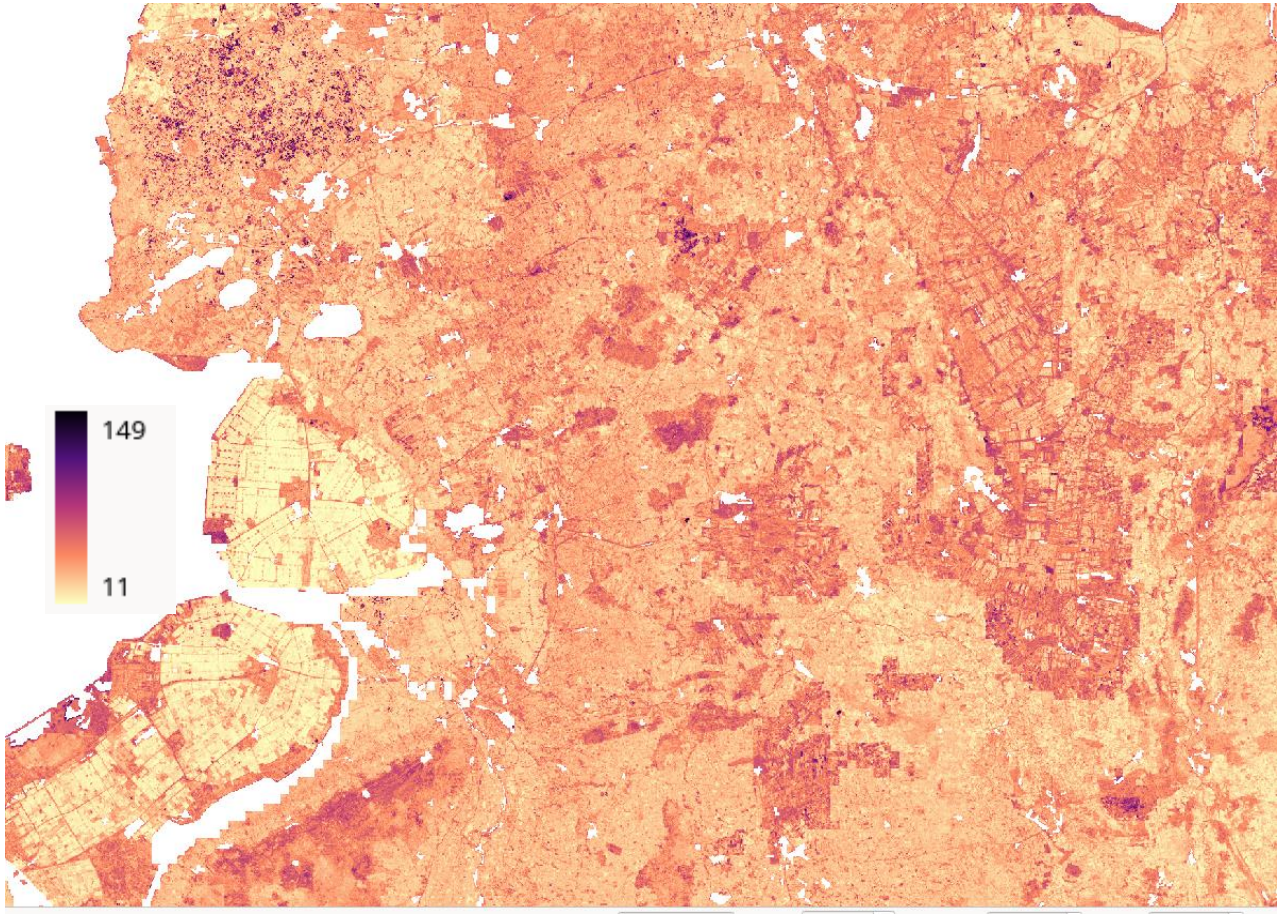
Soil Property Mapping – total nitrogen and its uncertainty





PRODUCTS COMPARISON

CUP4SOIL – Soil properties mapping – Comparison

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)	

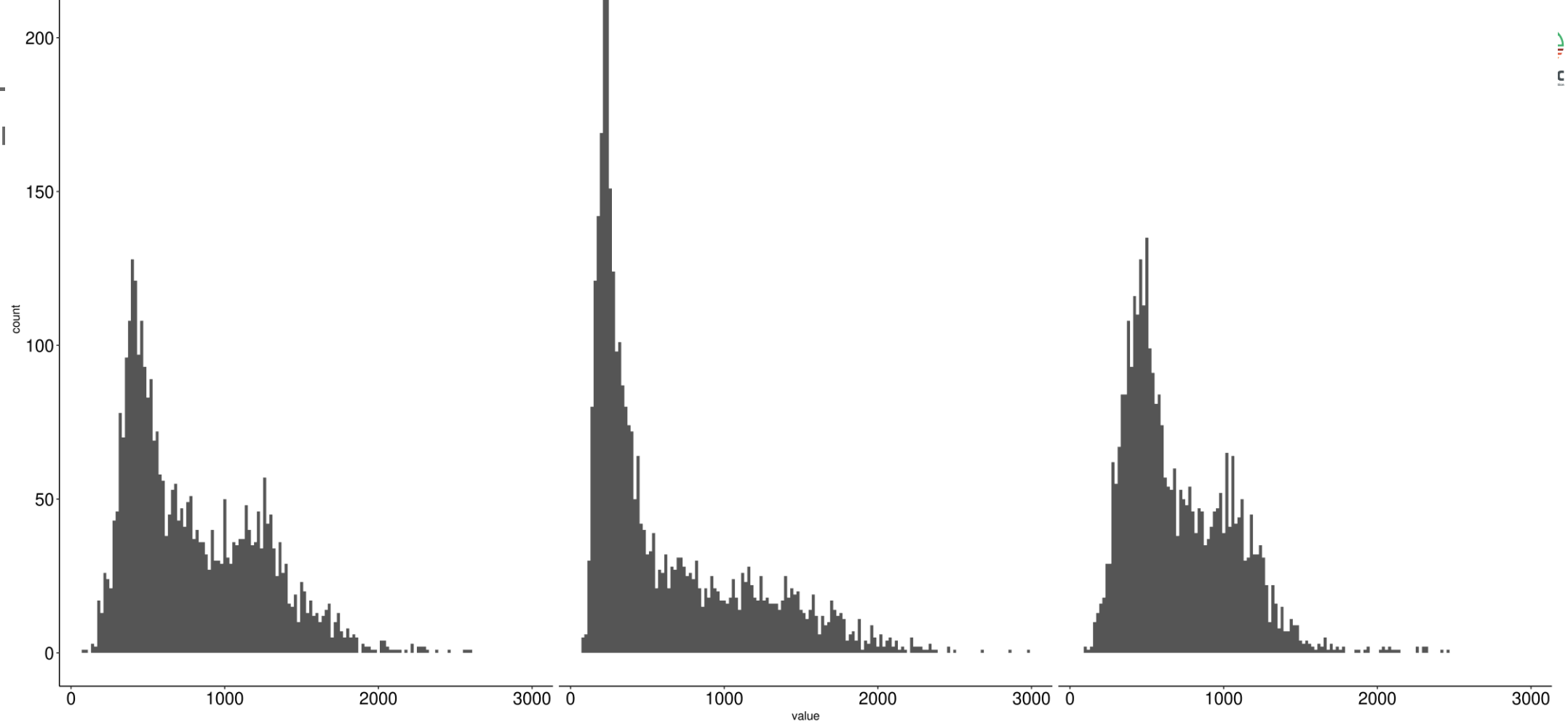
How to compare the products?

- validation statistics, point-wise usually by cross-validation.
  - We know how well DSM can reproduce these known points.
- map users are looking for areas in the soil landscape.
  - evaluate DSM products by their spatial patterns, i.e., how well they reproduce the soil landscape.

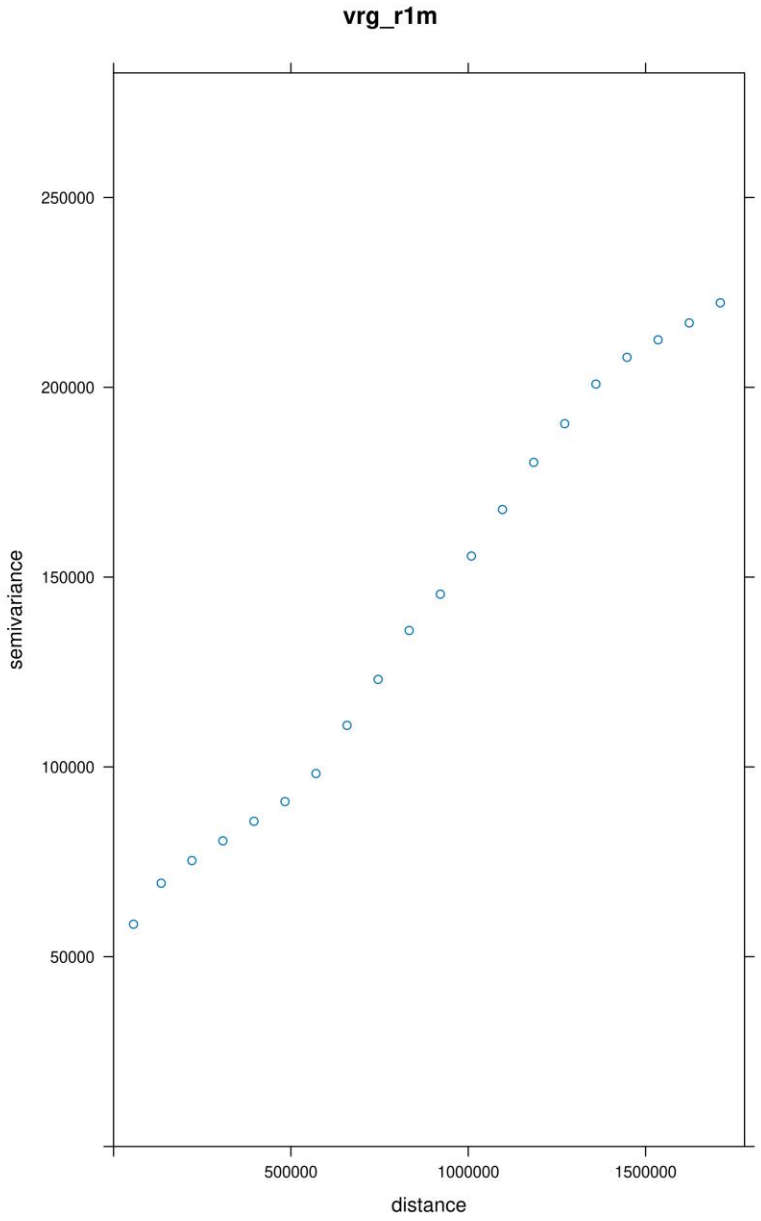
Which is the most suitable for the user case?

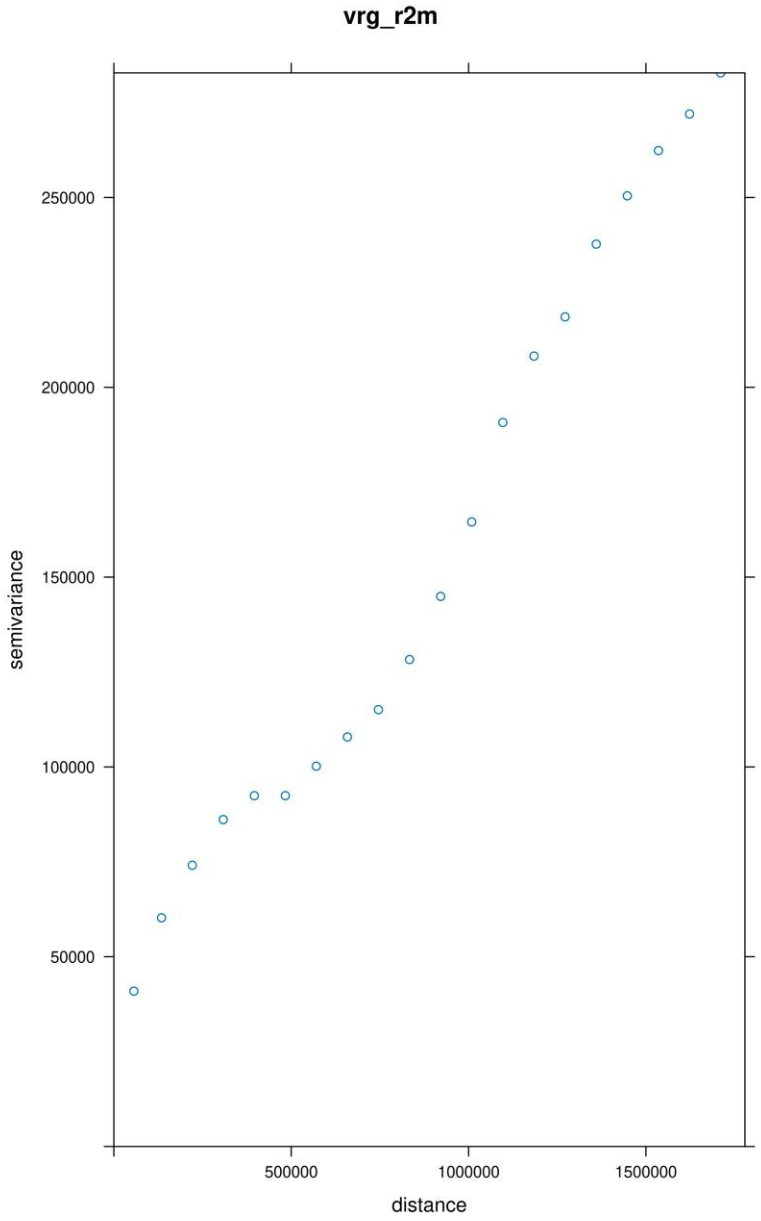
- does it reflect the information that is needed?
- the most accurate?
- the one with most reliable landscape pattern?
- the one created for the scale of the application?
- the most complex?

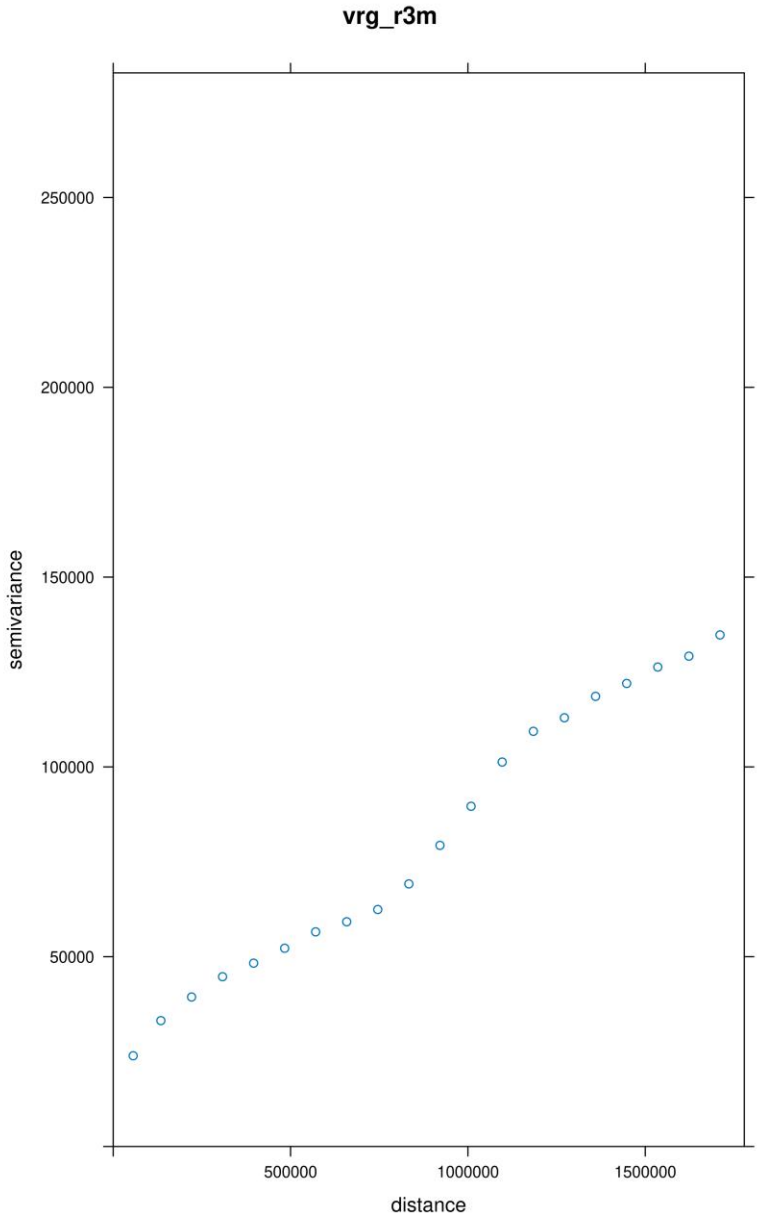
CUP4SOIL – three rando



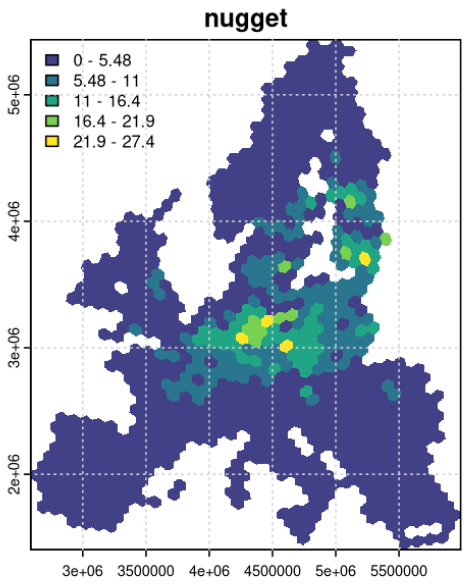
CUP4SOIL – Soil properties mapping – Comparison – three random products (same property)

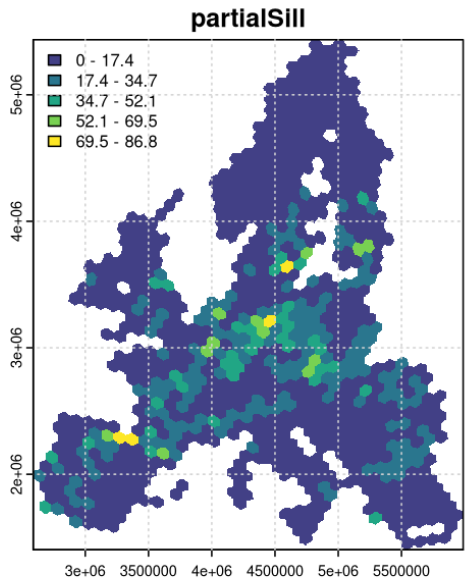


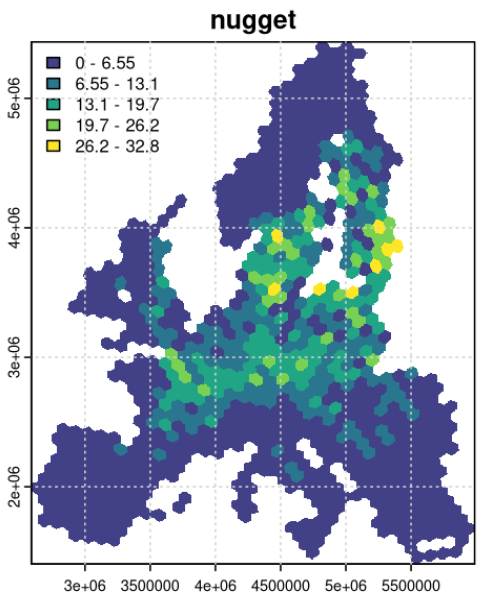


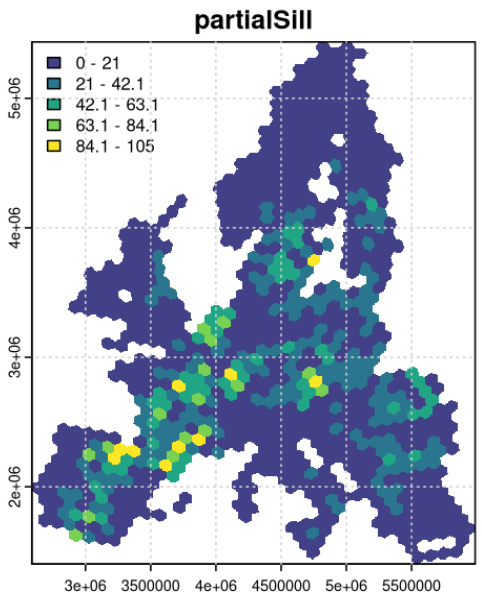


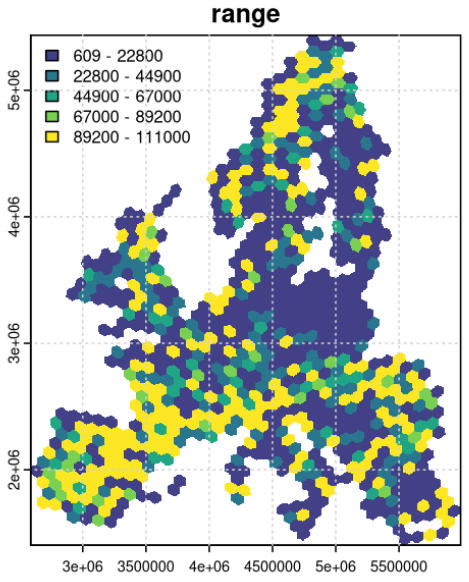
CUP4SOIL – Soil properties mapping – Comparison – two random products (same property)

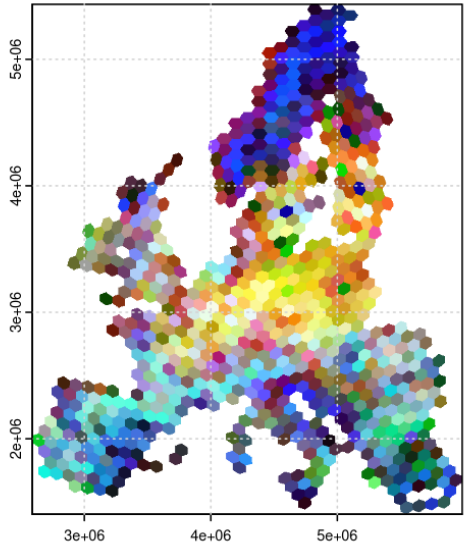


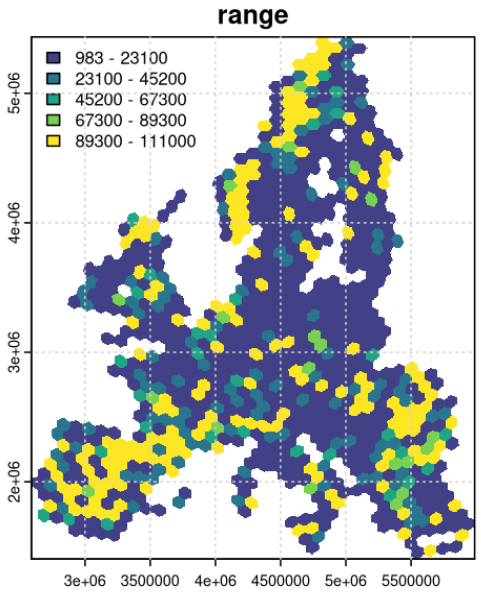


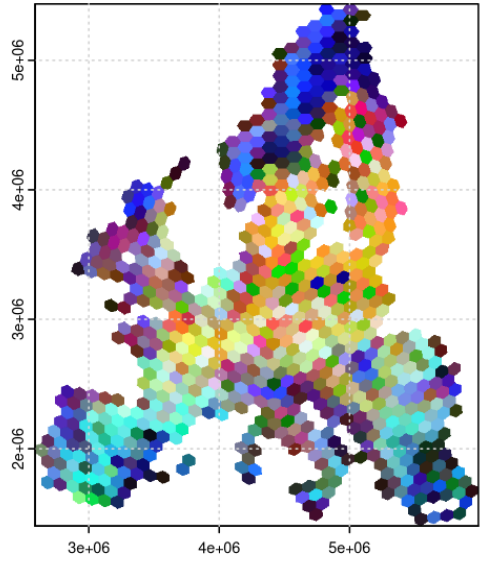






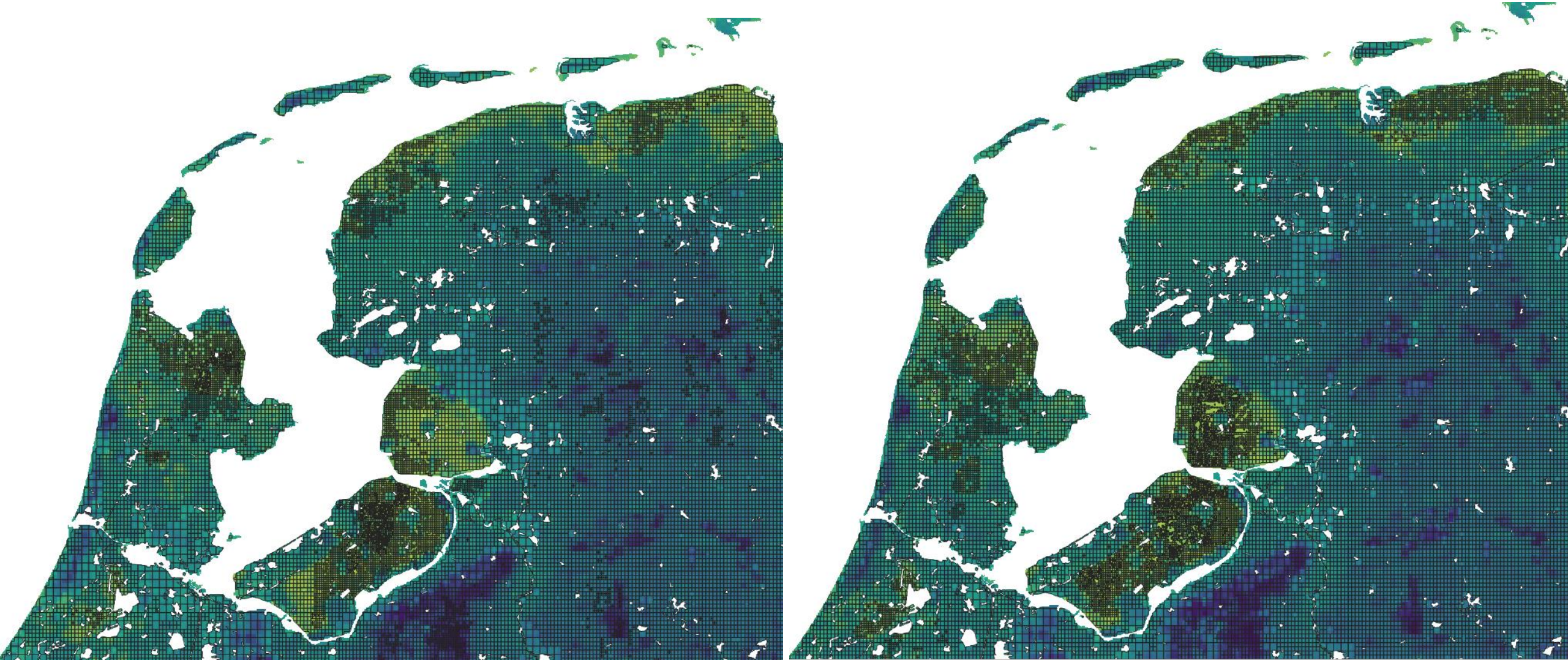






- Variable resolution maps to better represent spatial uncertainty (Padarian, McBratney, 2023)
- a method to create a single map with the uncertainty encoded as the pixel size.
- based on quadtree algorithm recursively partitioning the map into quadrants until the uncertainty criteria are fulfilled
- Using different uncertainty thresholds can yield dramatically different maps

CUP4SOIL – Soil properties mapping – Comparison – two random products (same property)



Summary and future developments

- Summary:
  - Innovative covariates produced from SCMaP intermediate products
  - Initial Soil parameters produced including the SCMaP covariates
  - Comparison of models with different advanced Remote sensing products as covariates

- Future developments:
  - Refinement of the uncertainty assessment for the soil properties
  - Further evaluation of the products „spatial pattern agreement“ („How well does digital soil mapping represent soil geography “)
  - Full comparison of cup4soil products with other products covering the same continental extent (Europe)