Nation-wide mapping of fractional land cover with regression-based unmixing and Sentinel-2 imagery

David Frantz, Franz Schug

EO-Lab, Humboldt-Universität zu Berlin

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Outline

1 Introduction Mat Stocks (DF)

2 Introduction Workflow (DF / I

3 Land Cover Mapping incl. OSI

4 Settlement Type Mapping (FS

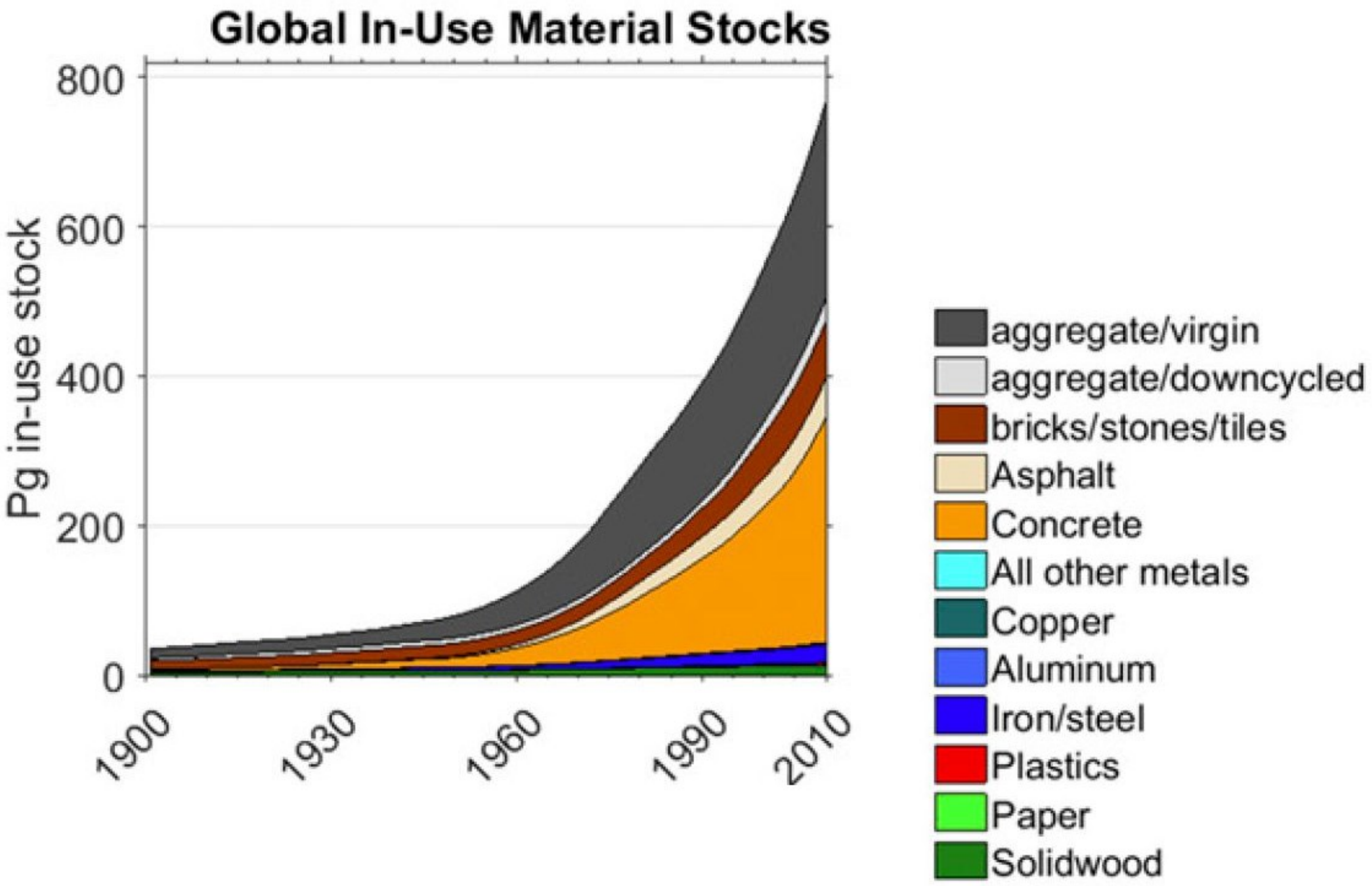
5 Height Mapping incl. Volume

6 Stocks Mapping (DF)

7 Other Countries (DF)

		FS	DF	Min	Min FS	Min
1	Intro		1	5	0	
2	Workflow		1	3	0	
3	Data & STMs		1	5	0	
4	Types	1		3	3	
5	LC incl. OSM	1		10	10	
6	Height		1	10	0	
7	Stocks		1	8	0	
8	Other	1		3	3	
9	Countries		1	3	0	
				50	16	

Background



Kraussmann et al. (2017), PNAS, 114

- Materials stocks are resources stored for **long term** periods
- **Construction materials** are the most used materials for stock accumulation.
- Global **material stock accumulation** since 1950 is important
- **Where** is the stock and how does it relate to **socio-economic factors**.
- Currently on a **nation-wide** level only.

Background

Inflow-driven approach

- **Deduces** stock estimation from (national) **statistics**.
- Can be easily applied to **large areas**.

e.g. Fishman et al. 2014, Wiedenhofer et al. 2015, Krausmann et al. 2017, …

Stock-driven approach

- **Induces** large area stock amounts from **single features**.
- Studies **small areas** and **aggregates** possible stock distribution.

e.g. Tanikawa et al. 2010, Kleemann et al. 2016, Kleemann et al. 2017,

Remote Sensing for material stocks mapping

Objectives and Workflow

- Three-step approach:

1. **Mapping human-made buildings and infrastructure**
2. Characterize human settlements
3. Approximate material stock patterns

Sentinel-2 MSI

Best temporal coverage: max 5/10 days since 2017

Spatial resolution: 10/20m

Spectral bands: 10 (13)

- **Research goal**: Map buildings and infrastructures through land cover detection and surface cover quantification
- **Key information**: Presence and density of artificial structures and human settlements as well as their physical surface composition.

Objectives and Workflow

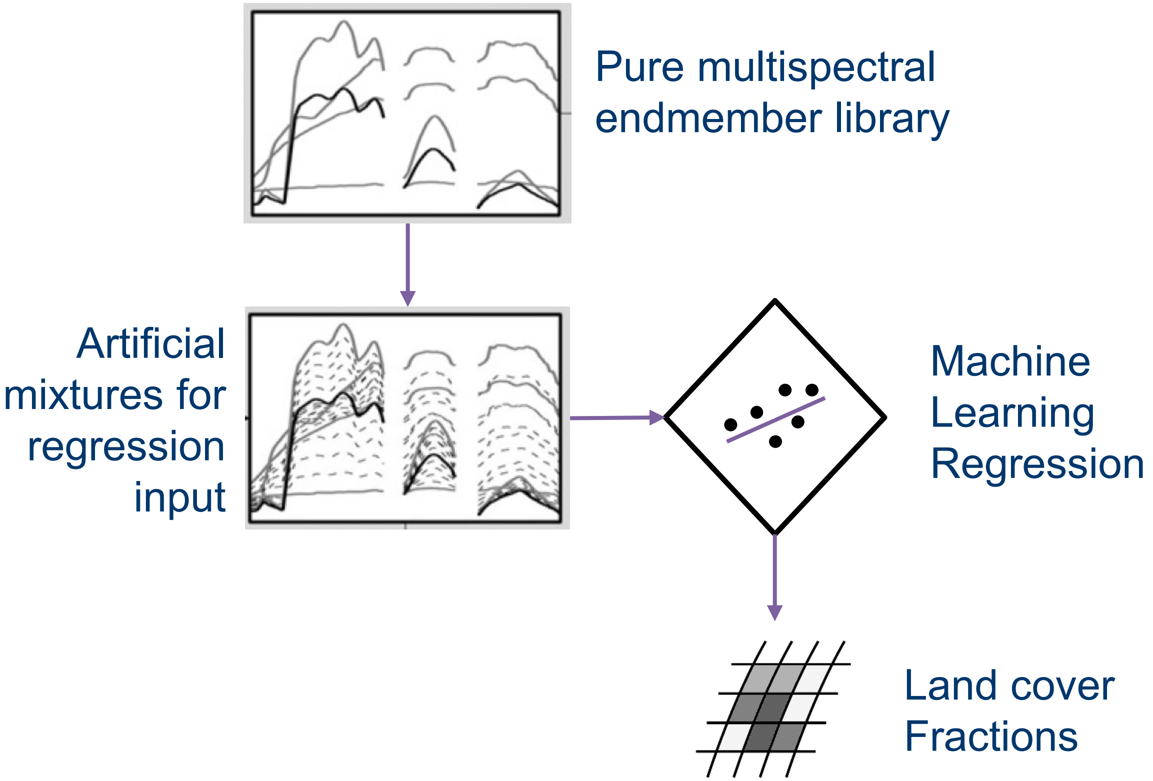
- → Quantify land cover over large areas
- → Preserve information on settlement gradients and gradual settlement characteristics
- → Use robust models with little seasonal impact (from, e.g., phenology)
  - → Seasonality is no indicator for stocks
  - → Seasonality is different across regions

Methods

‘Preserve gradual information‘

- Sub-pixel mapping: Regression-based unmixing with synthetically mixed endmember spectra

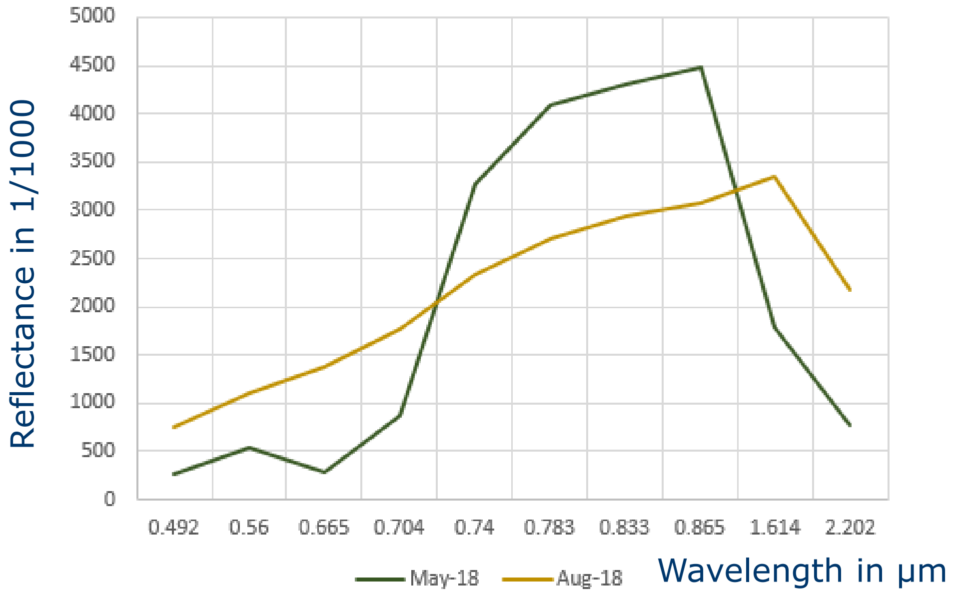
- Library: ca. 500 reference locations (Berlin/Brandenburg + selected sites) for 10 classes. Mapping is performed for 4 classes:
  - built-up surfaces and infrastructure
  - woody vegetation
  - non-woody vegetation
  - soil



Methods

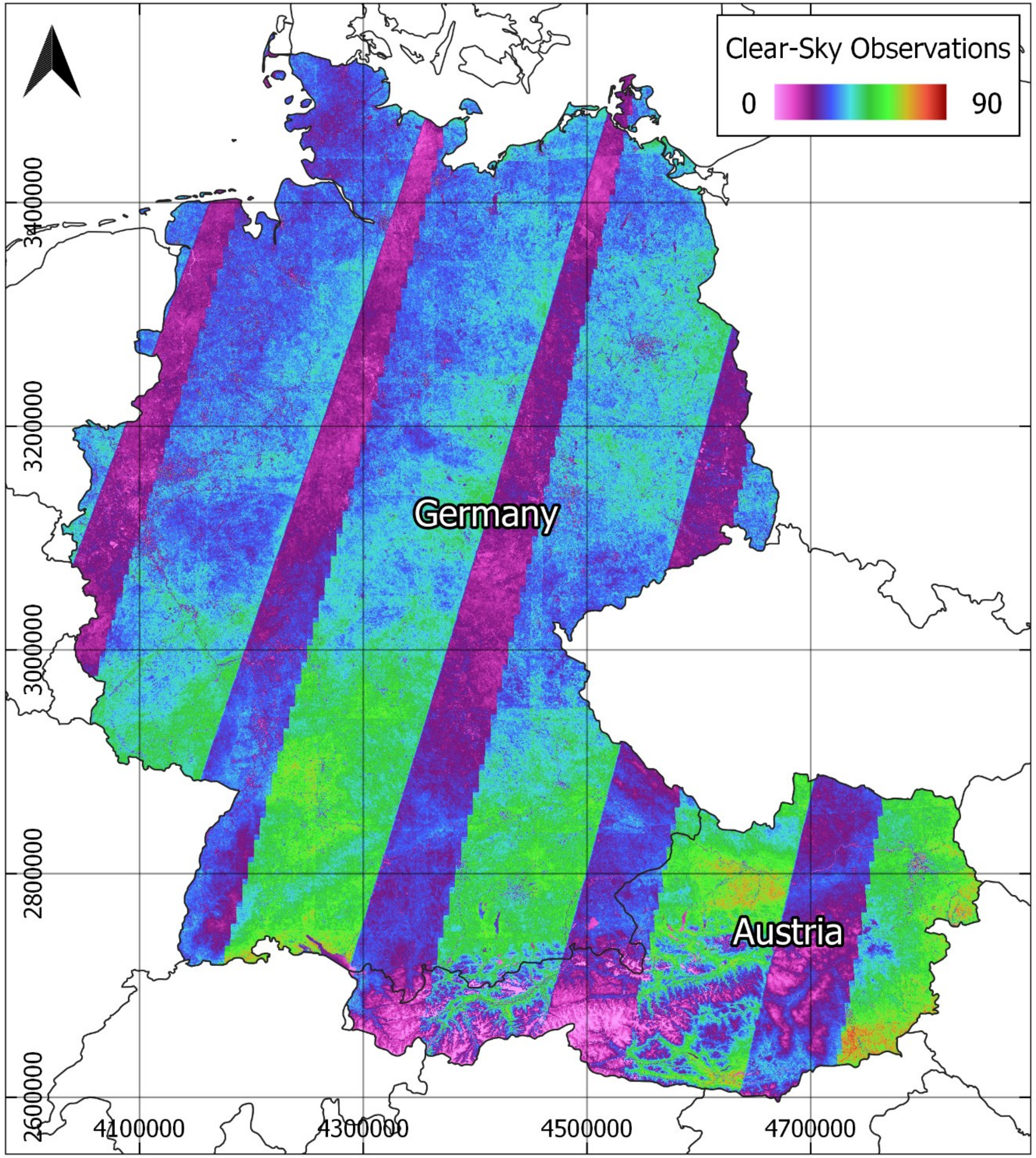
‚Robust models with little seasonal impact‘

- We use **intra-annual spectral-temporal metrics**
  - Spectral statistics, e.g. spectral mean / quartiles
  - No manual data selection process
  - Diminish seasonal effects, Decrease confusion of resembling surfaces



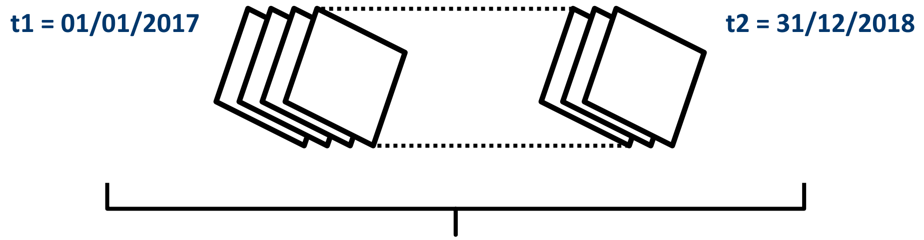
Methods

- Study area: Germany / Austria
- Data availability 20 to 60 observations per pixel



study area: clear-sky observations per pixel

Methods



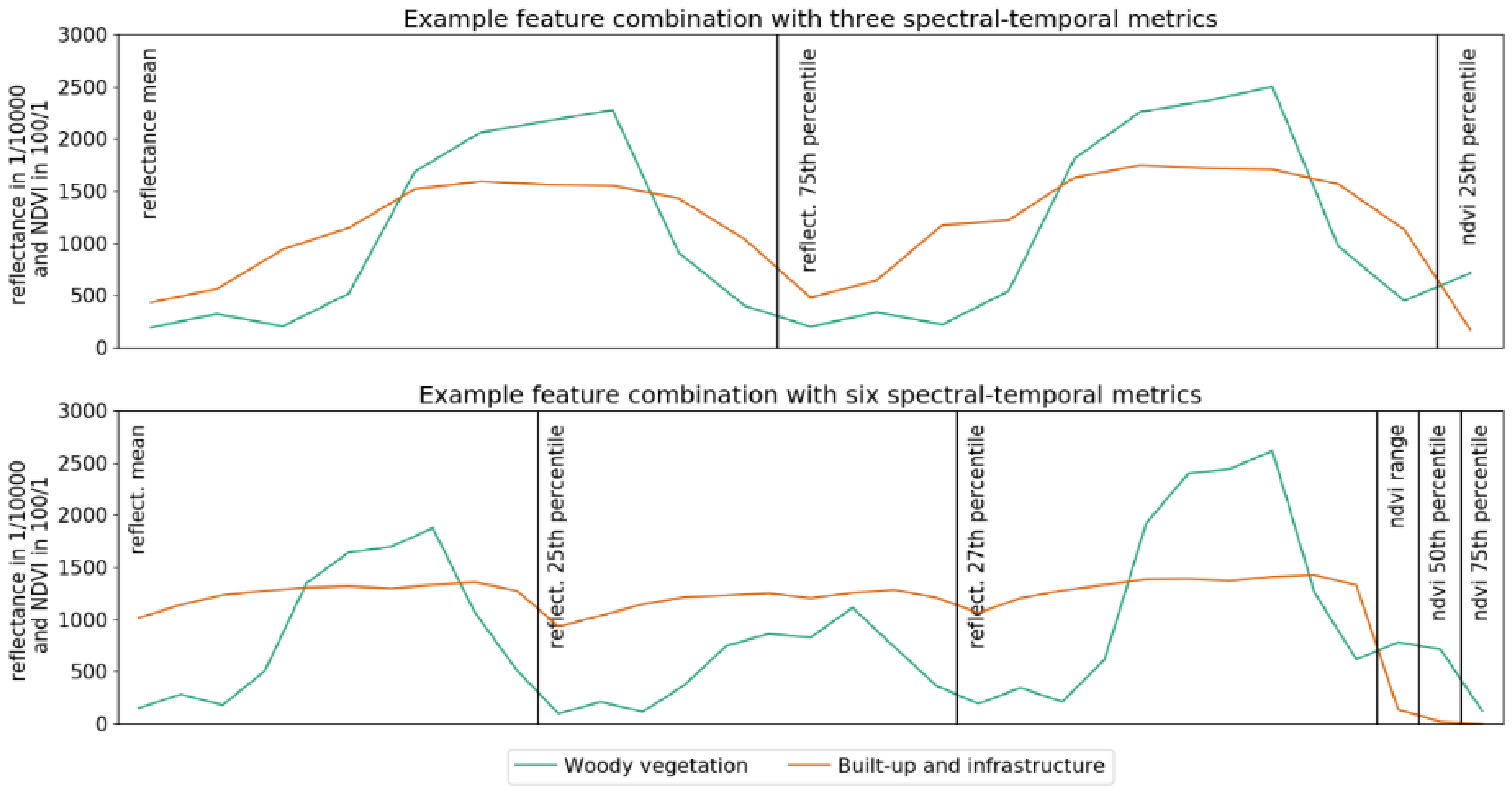
Spectral-temporal metrics:
Standard deviation
Inter-quartile range
Range
Mean
Median
Minimum
Maximum
25th percentile
75th percentile

NDVI:
Standard deviation
Inter-quartile range
Range
Mean
Median
Minimum
Maximum
25th percentile
75th percentile

All combinations of 18 elements = 262.143 models

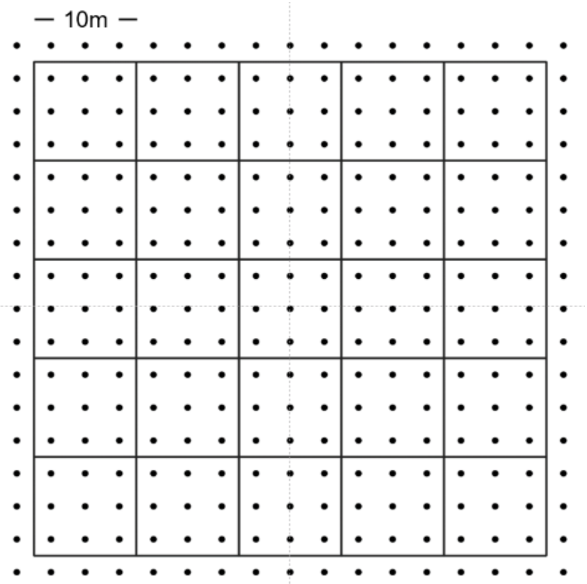
- Are there features or feature combinations particularly suitable as an input to regression-based modelling?
- Group and randomly select metrics as data input
- Compare a number of 1,275 models with different respective input data

Methods

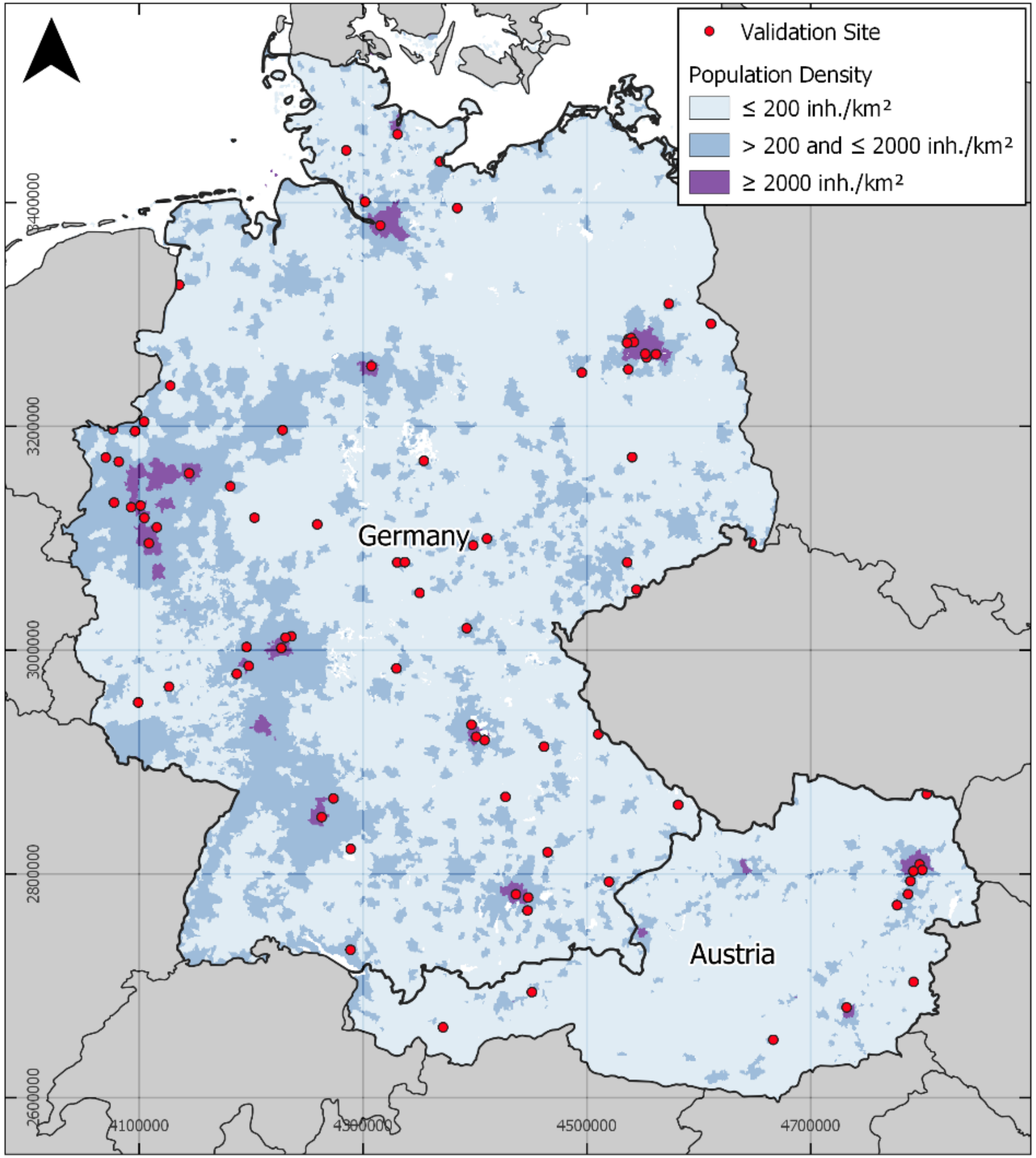

Example feature combination with three spectral-temporal metrics
reflectance in 1/10000 and NDVI in 100/1
3000
2500
2000
1500
1000
500
0
reflectance mean
reflect. 75th percentile
ndvi 25th percentile
Example feature combination with six spectral-temporal metrics
reflect. mean
reflect. 25th percentile
reflect. 27th percentile
ndvi range
ndvi 50th percentile
ndvi 75th percentile
Woody vegetation
Built-up and infrastructure

Methods

- Validation: 84 sites, stratified by population density (3 classes) AND Copernicus Imperviousness (0-0.25, 0.25-0.5, 0.5-0.75, 0.75-1)
- Validation grid at 10m, 20m and 50m spatial resolution
- 24,276 pts
- Fractions



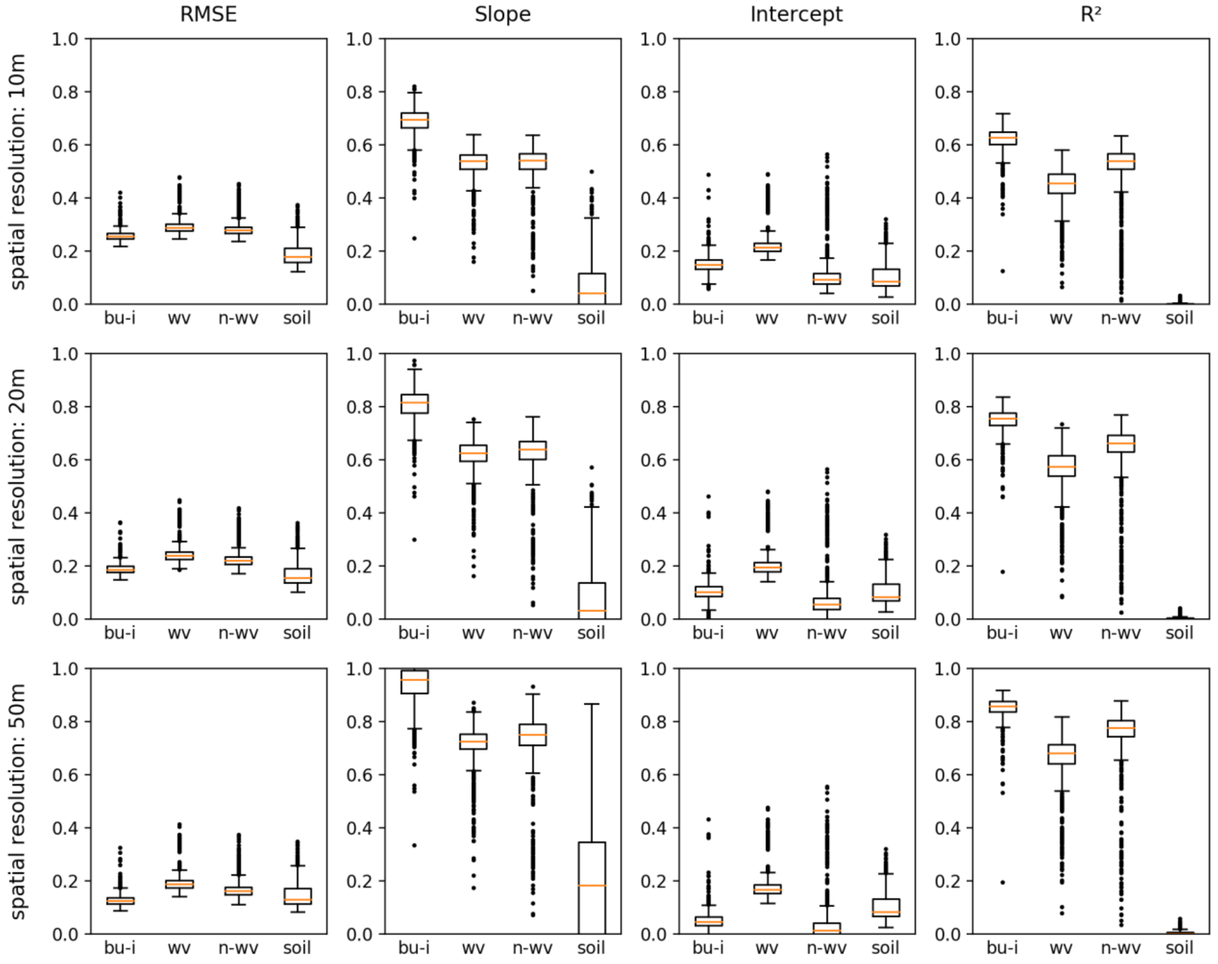
validation grid



validation Sites Density from SEDAC Gridded Population of the World POPGRID v4

Results

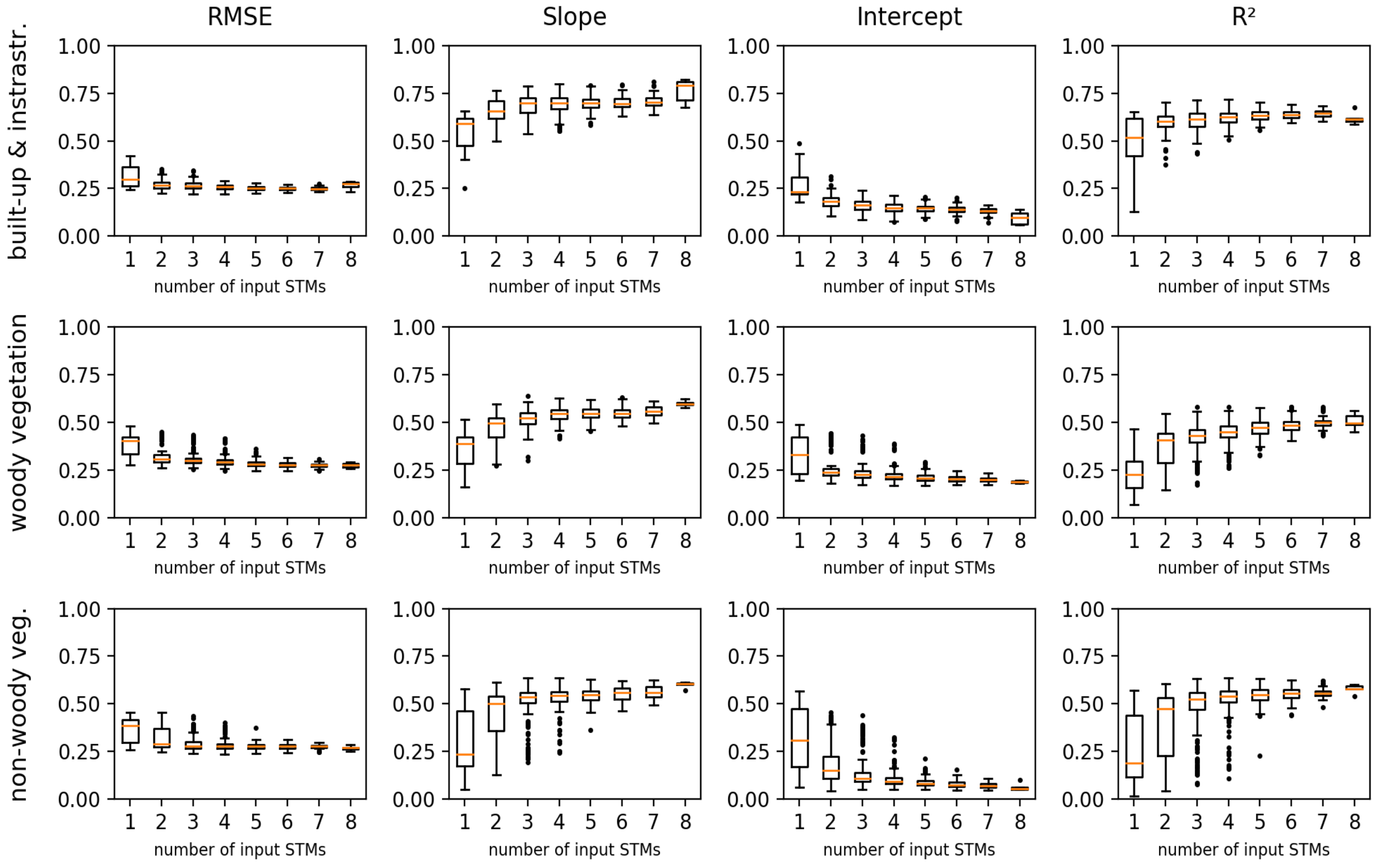
- Quality of 1,275 models by spatial resolution and class



- Distribution of RMSE is rather stable.
- Built-up and non-woody vegetation class reach better slopes and coefficients of determination.
- Quality increases with decreased resolution, patterns remain.

Results

- Quality of 1,275 models by number of input metrics

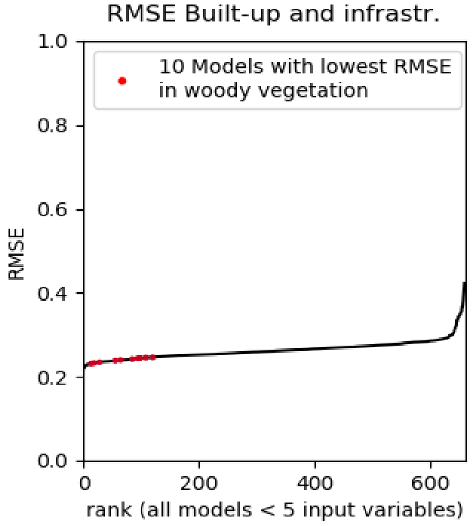


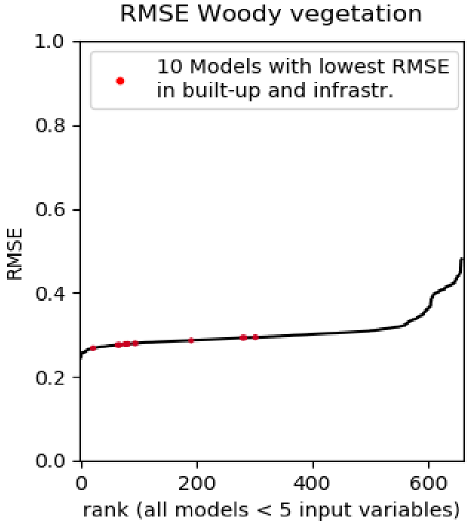
- A number of three to four input metrics is usually sufficient to reach best model quality.

STM:

Results

- Which input spectral-temporal metrics perform well in all classes and all quality metrics?



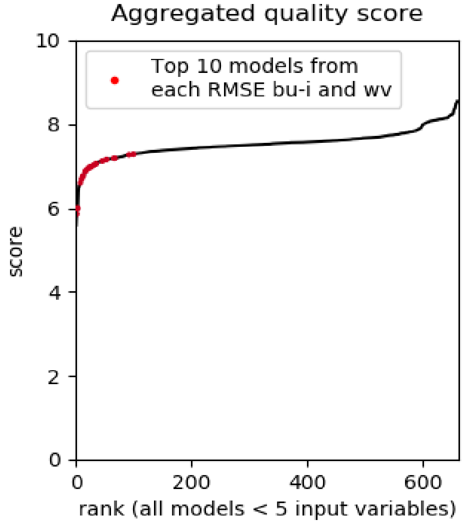


Transformation function that penalizes low performance:

$$f(x) = \frac{1}{4}\log_{10}(x + 0.001) + 1$$

with x as the normalized RMSE, $1/R^2$ and |(1 - Slope)| for each model.

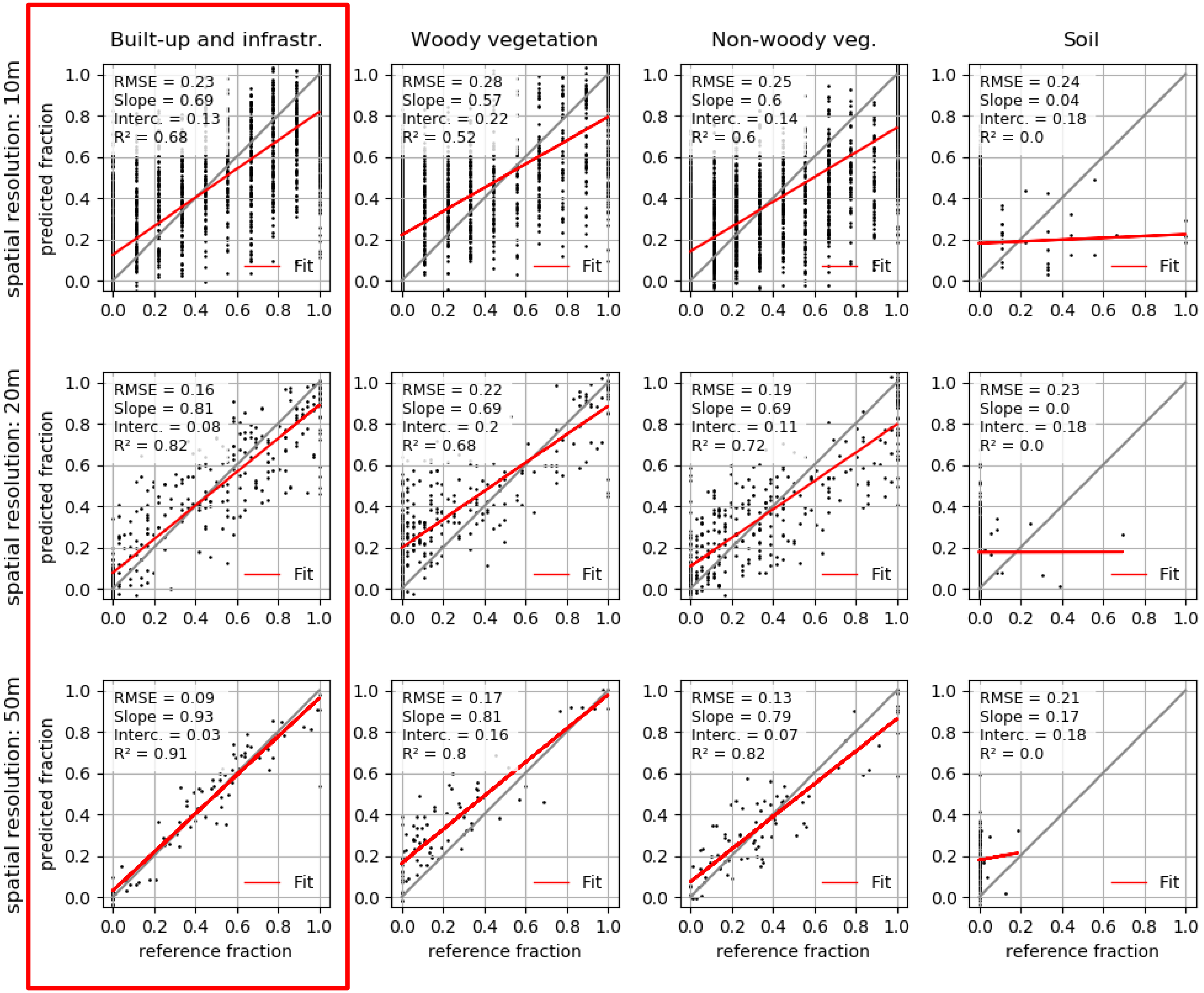
Sum of f(x) for three classes and three quality metrics = quality score.

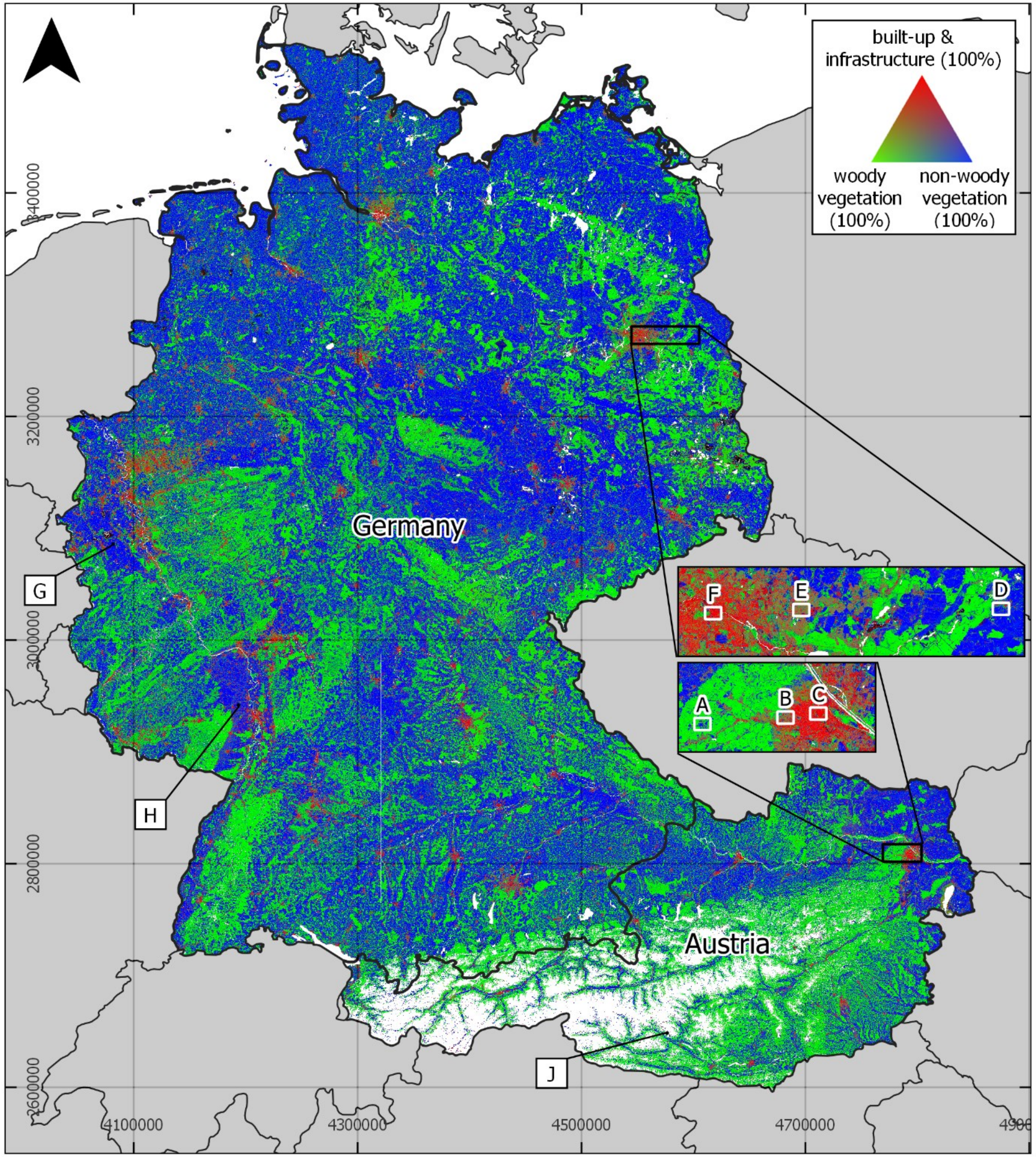


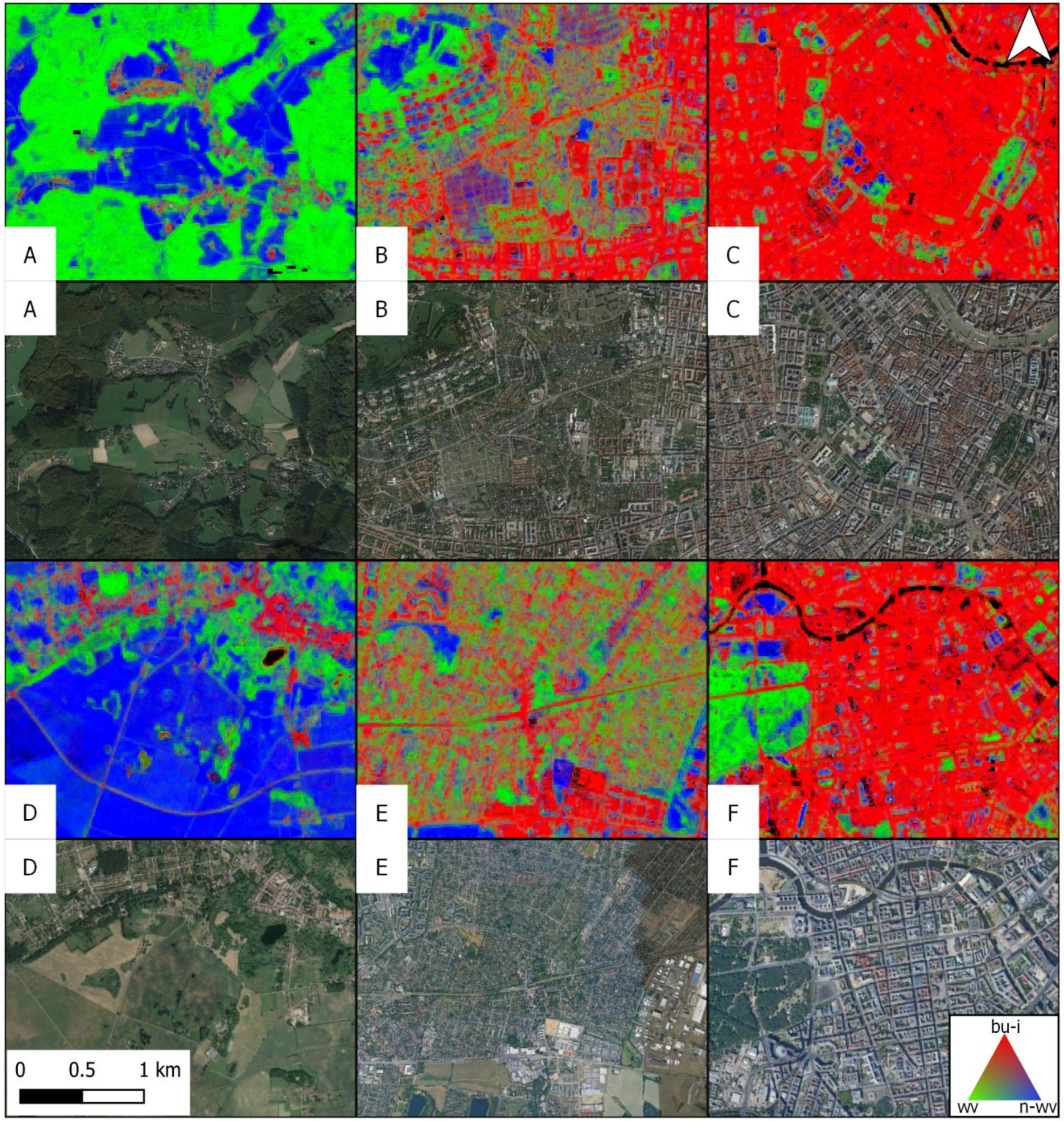
Based on the top-ranked models we chose a metrics combination for the large area mapping:
Median reflectance, 25th & 75the percentile of reflectance and max. NDVI

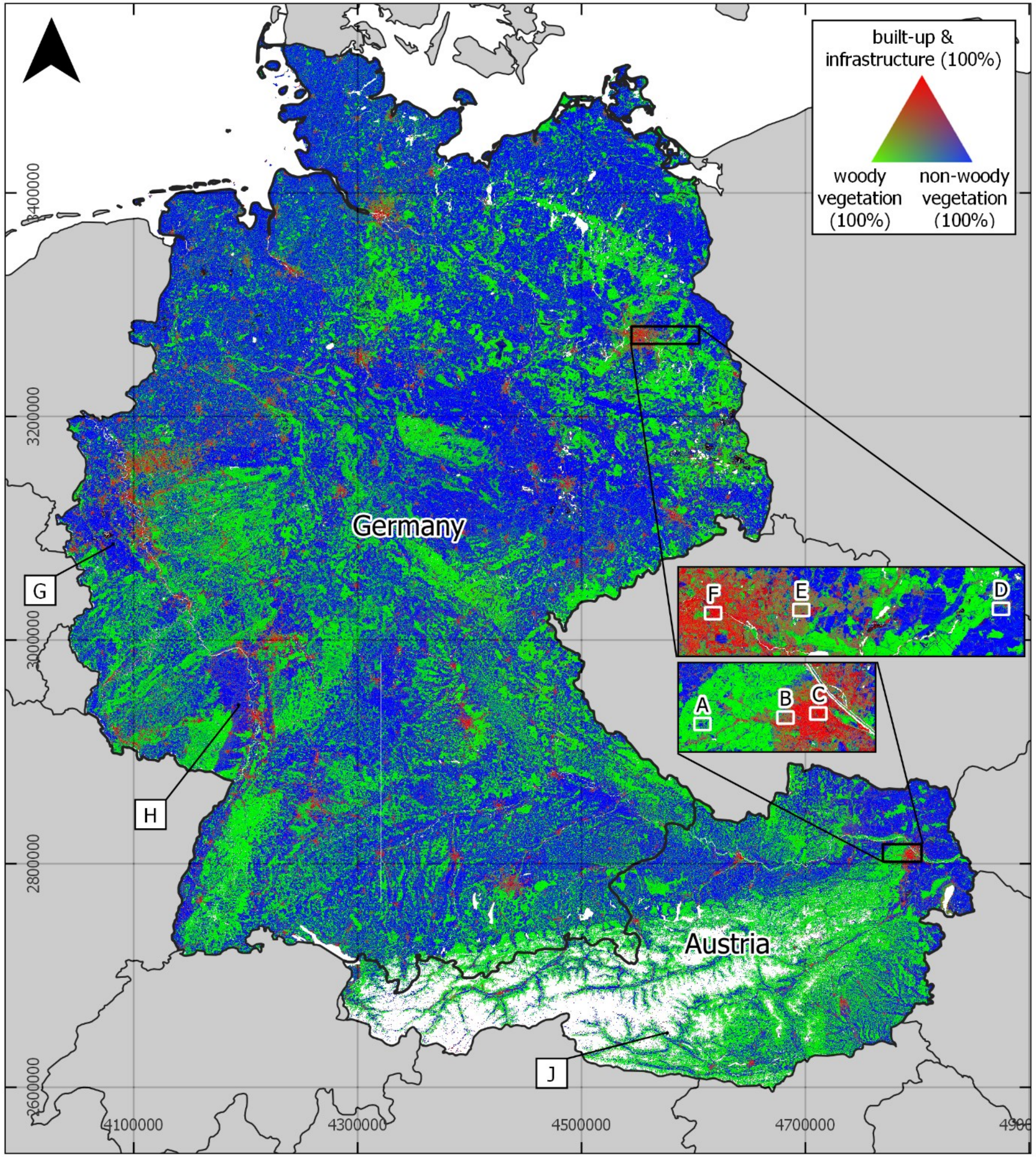
Results

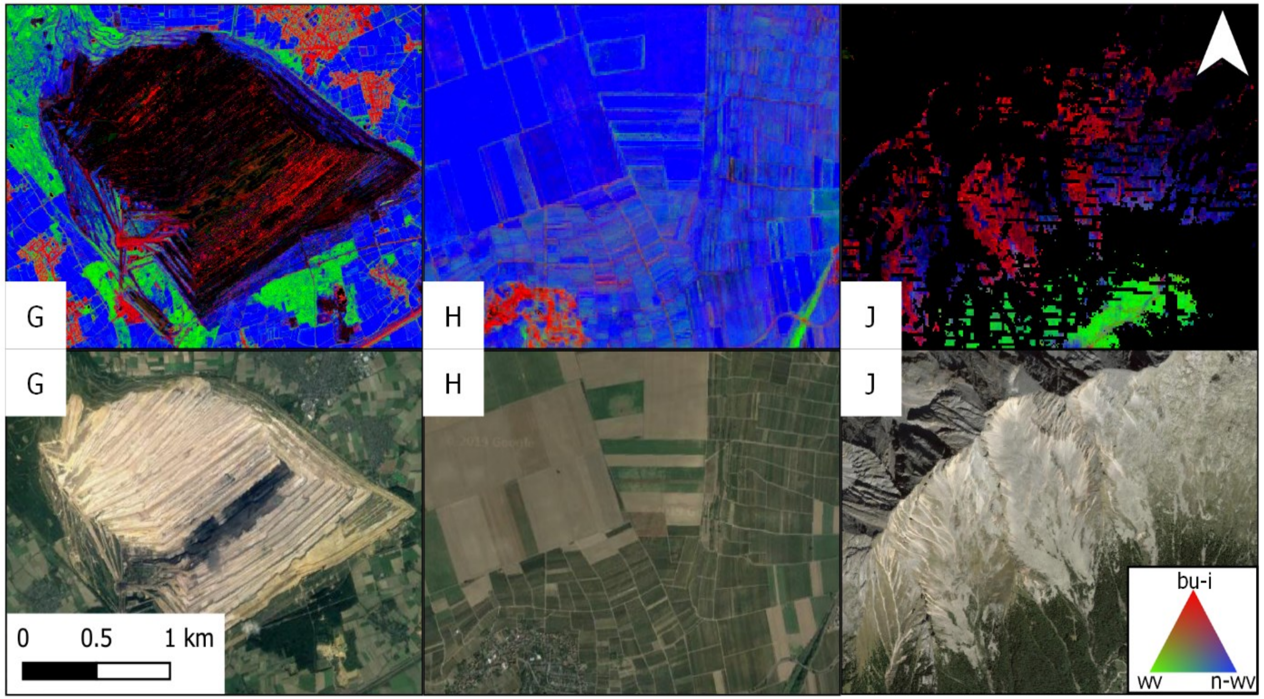
- Selected model quality:
  - Four classes
  - Three spatial resolutions
- Good model performance in three out of four classes




built-up & infrastructure (100%)
woody vegetation (100%)
non-woody vegetation (100%)
Germany
Austria
G
H
J
A
B
C
D
E
F
3400000
3200000
3000000
2800000
2600000
4100000
4300000
4500000
4700000

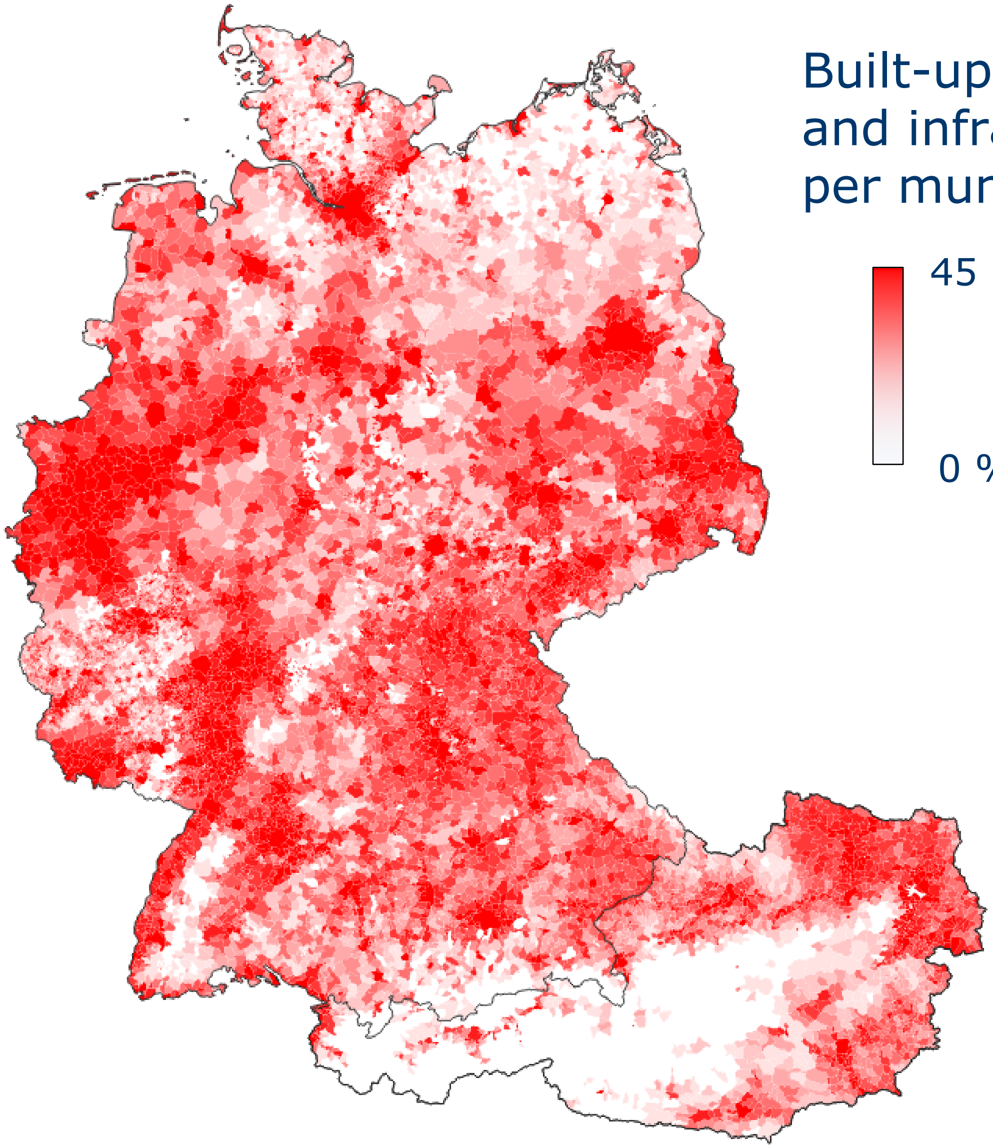

A
B
C
D
E
F
0 0.5 1 km
bu-i
wv
n-wv





- About 9.6 % of the overall area in Germany (6.7 % in Austria) is covered with built-up features and infrastructure.
- Copernicus Land Cover Product 2012, *artificial area*: Germany 9%, Austria 6%.

Results



Built-up surface and infrastructure per municipality

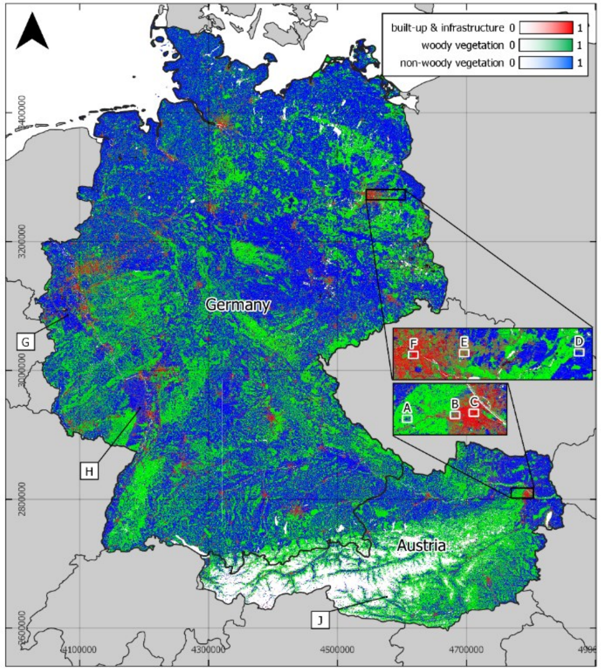
45 %

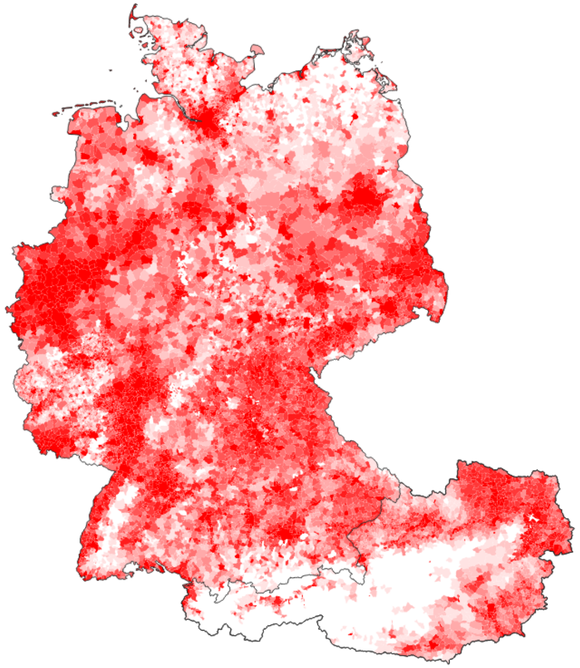
0 %

Municipality	Mean built-up in %
Ottobrunn b. München	48.29
Oberhausen	47.49
Weißenthurm/Rhein	46.76
Herne	46.52
Eichwalde	45.80
Ludwigshafen/Rhein	44.13
Nürnberg	43.47
Neulußheim (BW)	42.82
Gröbenzell b. München	41.83
München	41.25
Bischofsheim	41.18
Siershahn	40.88
Gelsenkichen	40.48
Mannheim	40.20
Asperg	40.12

Conclusion

- We can accurately map fractions of built-up surfaces and infrastructure, woody and non-woody vegetation with spectral-temporal metrics from Sentinel-2 time series
- Spectral-temporal metrics offer a very robust input to regression-based unmixing. No feature combination particularly stands out.
- We use a sub-pixel information, multi-class, high resolution, large area approach!
- Challenges exist in areas where surfaces appear like those used for built-up features
- Further research will be required on regional model transferability and library composition





Thank you

Franz Schug

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European Research Council
Established by the European Commission

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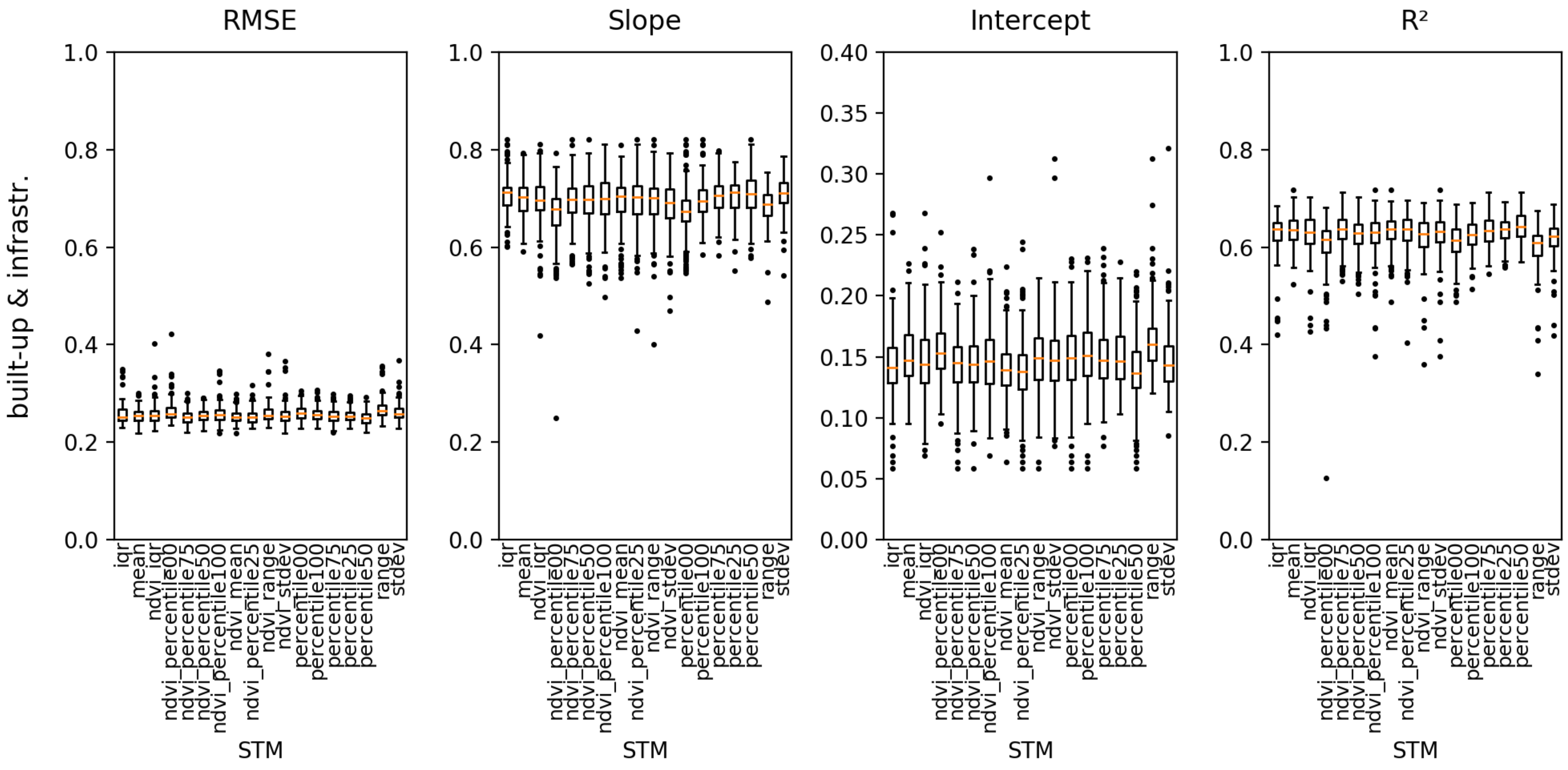
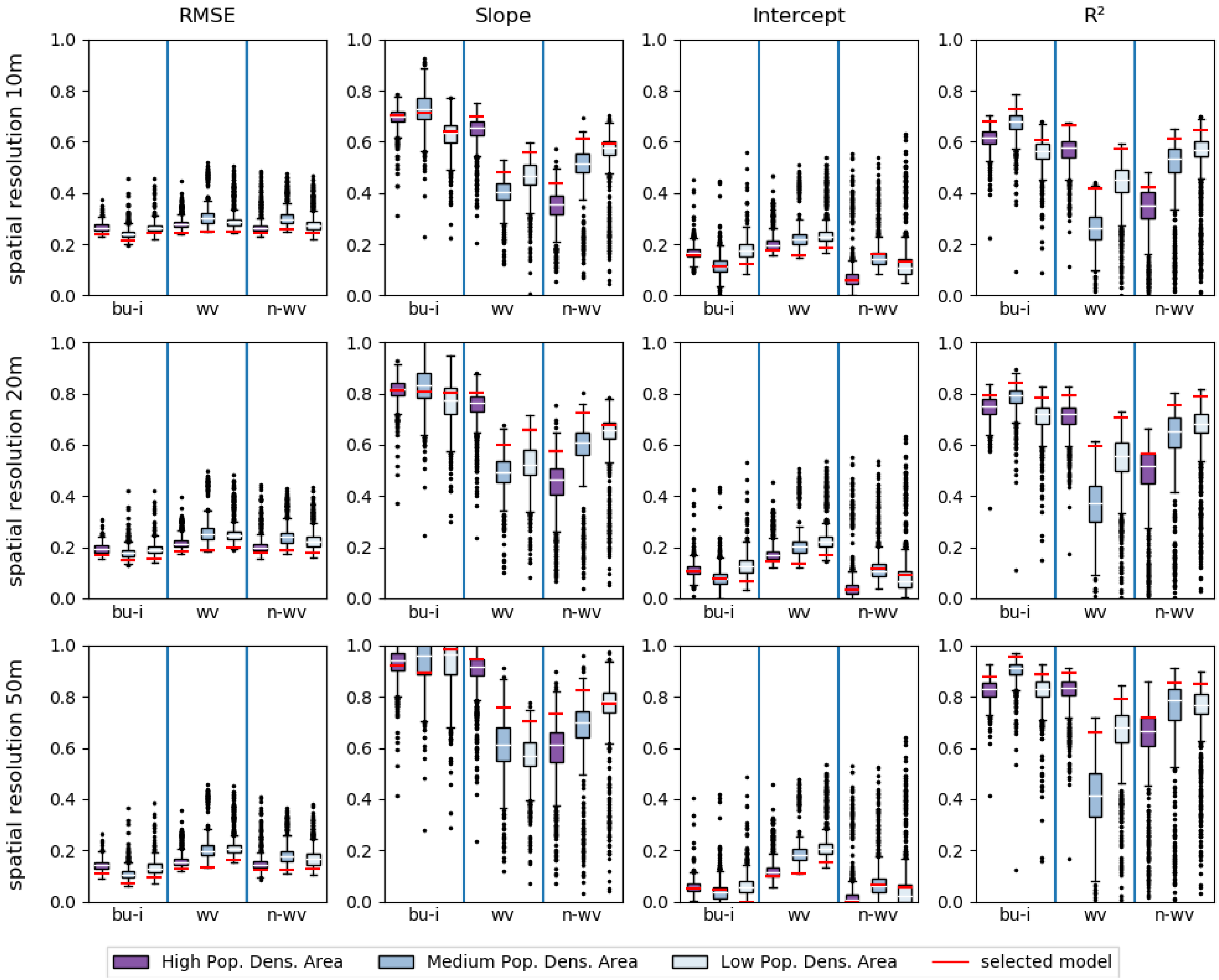

RMSE
Slope
Intercept
R²
built-up & infrastr.
STM
iqr
mean
ndvi_iqr
ndvi_percentile00
ndvi_percentile75
ndvi_percentile50
ndvi_percentile100
ndvi_mean
ndvi_percentile25
ndvi_range
ndvi_stdev
percentile00
percentile100
percentile75
percentile25
percentile50
range
stdev


RMSE
Slope
Intercept
R²
spatial resolution 10m
spatial resolution 20m
spatial resolution 50m
1.0
0.8
0.6
0.4
0.2
0.0
bu-i
wv
n-wv
High Pop. Dens. Area
Medium Pop. Dens. Area
Low Pop. Dens. Area
selected model