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Wald5Dplus / Forest5Dplus

An AI benchmark dataset for the combined spatial, spectral, polarimetric and temporal coverage of forest stands using Sentinel-1 & -2

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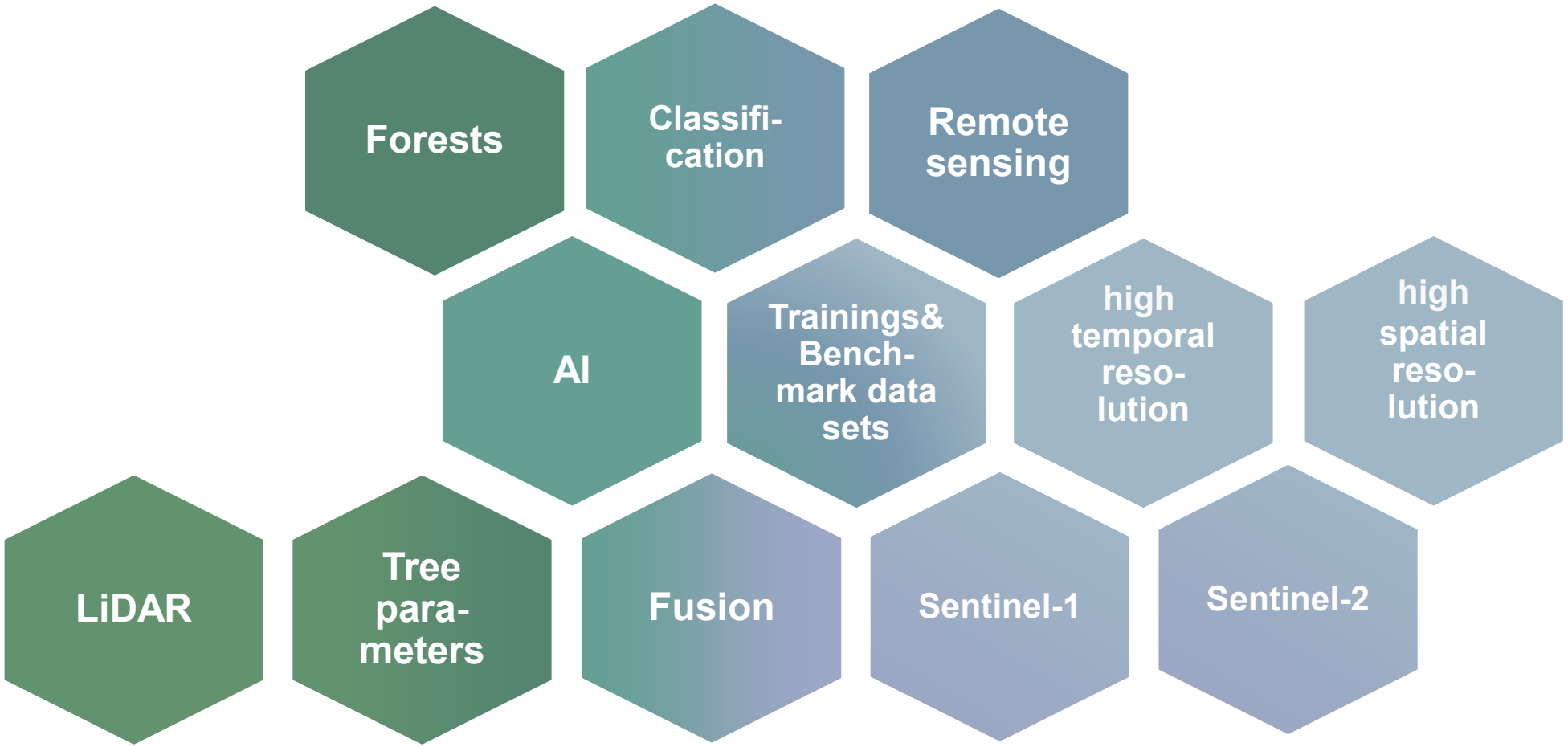
(IAMLIS, Institute for Applications of Machine Learning and Intelligent Systems)

Source: BayernAtlasPlus | Geo-basisdata: Bayerische Vermessungsverwaltung

HM

„Forest“

Forests & Remote sensing



Wald5Dplus

An AI benchmark dataset for the combined spatial, spectral, polarimetric and temporal coverage of forest stands using Sentinel-1 & -2

Single measurements over three selected forest areas are to be combined in the following five dimensions:

- north-south direction *(first dimension),*
- east-west direction *(second dimension)*,
- polarimetrically by Sentinel-1 *(third dimension),*
- spectrally by Sentinel-2 *(fourth dimension),*
- and over time *(fifth dimension)*

+ Labels

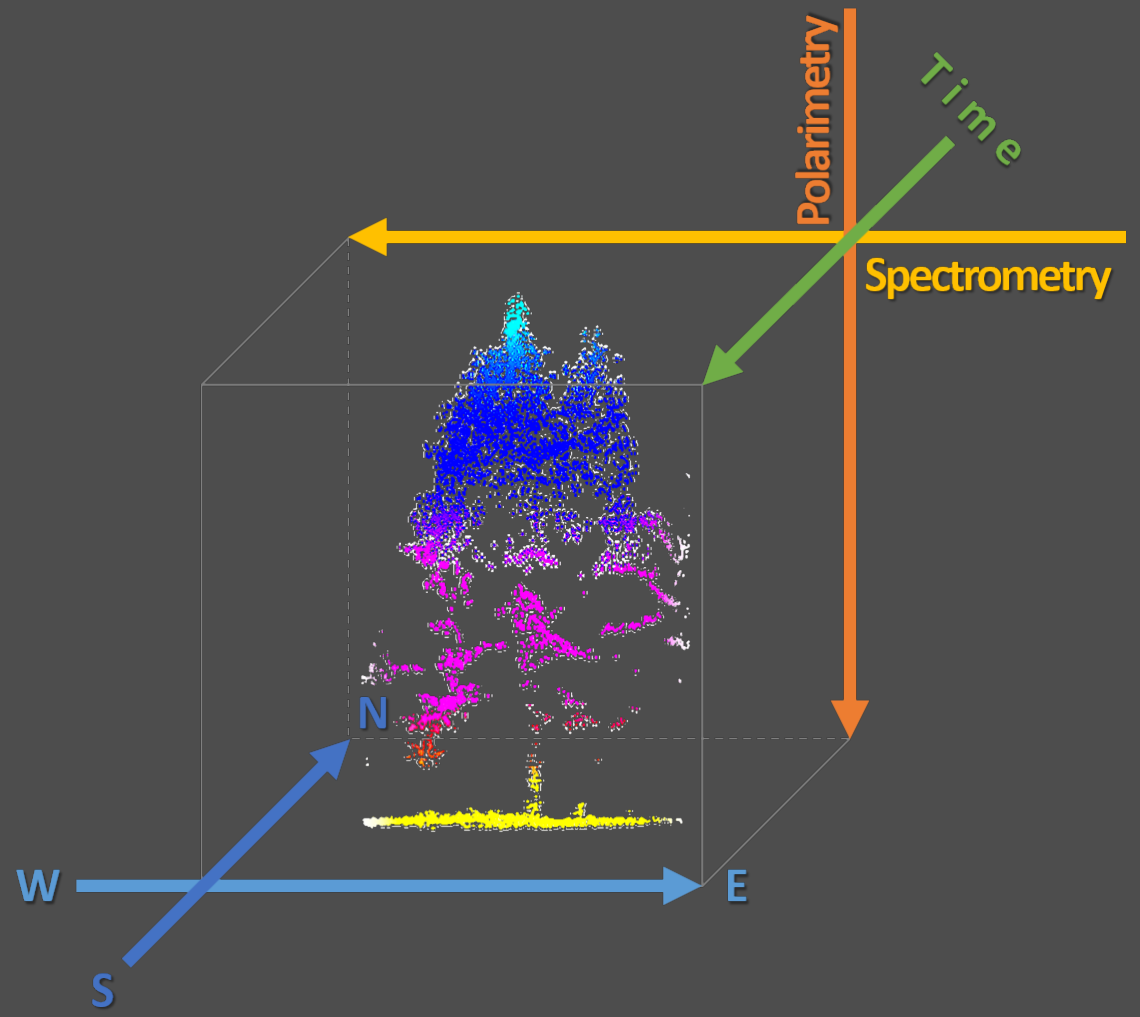


Fig. 1: *Five dimensions of Wald5Dplus*

Study Sites

1. **Bavarian Forest National Park**
   - 25,000 *ha*
   - Airborne LiDAR image including evaluation (2017)
2. **Kranzberger Forst near Freising**
   - 100 *ha* +
   - UAV LiDAR and multispectral data (2020) and preliminary study
   - UAV LiDAR and multispectral data (2023)
3. **Steigerwald**
   - 2,600 *ha*
   - Airborne LiDAR image including evaluation (2015)

Fig. 2: *Study sites*

Objectives

- Generation of a ‘labelled’ reference dataset for the use of AI methods in forest remote sensing
- Creation of a cross-domain test dataset for training and validation of AI algorithms
- Information gain through data fusion of open access multimodal earth observation data from the Sentinel-1 and Sentinel-2 sensors, heterogeneous data from different domains such as UAV surveys of forest areas, and the fusion of earth observation data with geodata from field surveys such as forest inventories
- Providing the labelled Sentinel-1 and -2 datasets as Analysis Ready Data Cubes, as well as the algorithms needed to create it and the pre-trained AI classifiers, free to the public

Project description

Work package 1: Data fusion Sentinel-1 and -2 [1-5] – ARD Cubes

- Based on orthogonal transformation of reflection channels of optical and SAR sensors on hypercomplex bases.
- Possibility of compressed data fusion of optical and SAR data features of both systems are used

  (the sharpness of optics and the texture of SAR)
- Product of the fusion are normalised Kennaugh elements
- Basic requirement: existence of a total intensity (best-available intensity image) and an orthogonal mapping of the remaining feature space.

Work package 2: Labelling from UAV

- Single tree detection method derives forest parameters such as tree types [7-10] from the point clouds, which are assigned as labels to the fused dataset.
- Aggregation of the vector information to the 10m grid of the data cube
- Creation of a benchmark dataset

Methods (I)

Hypercomplex bases

- Orthogonal transforms in 2^n dimensional spaces
- Complex $C = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$
- Quaternion $Q = \begin{bmatrix} C & C \\ C & -C \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix}$
- Octonion $O = \begin{bmatrix} Q & Q \\ Q & -Q \end{bmatrix} = \ldots$

Characteristics

- one total intensity
- several intensity differences
- fusible, normalizable, and compressable

Wald5Dplus approach

- 4 polarimetric Kennaugh elements from Sentinel-1
- 4 spectrometric Kennaugh-like elements from Sentinel-2
- 64 temporally fused Kennaugh-like elements over one year

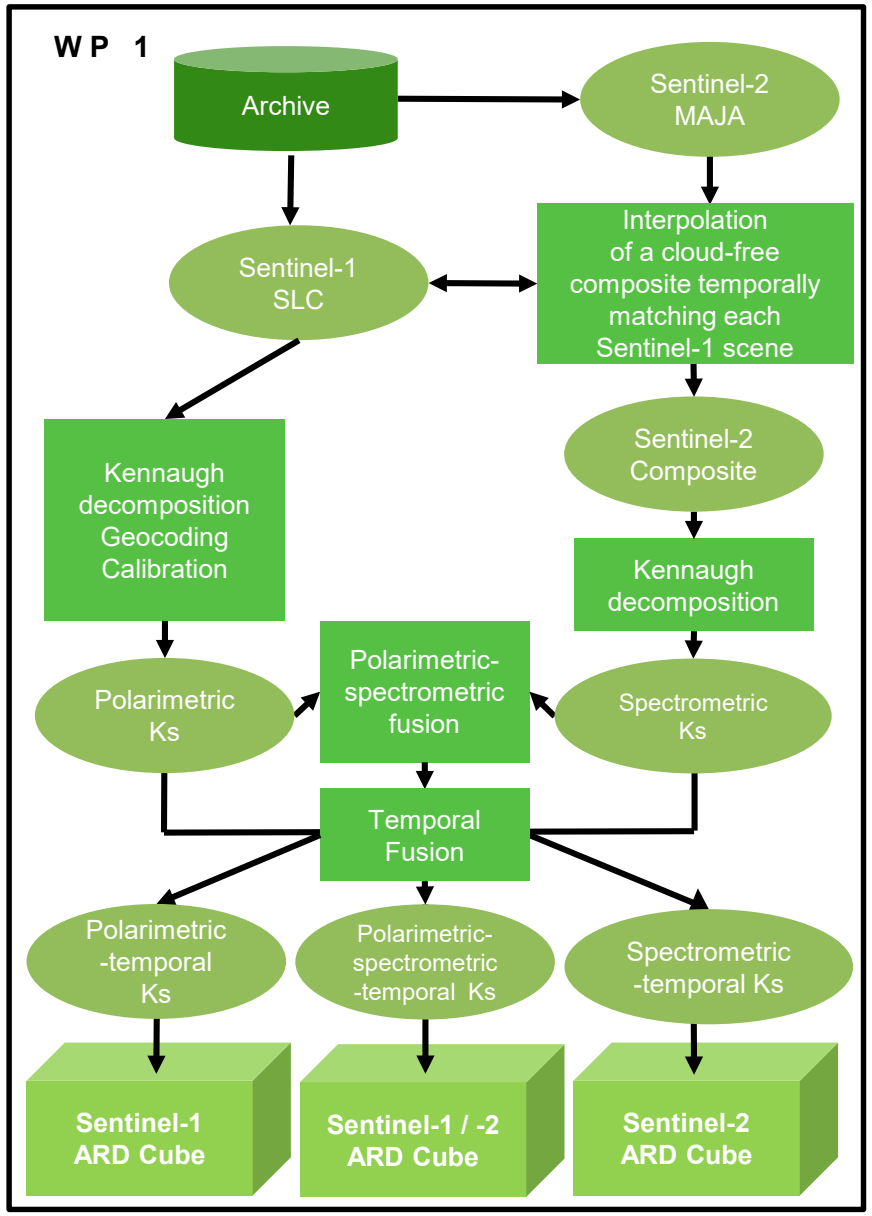


Fig. 3: *Workflow – WP 1*

Methods (II)

Labels

- airborne LiDAR and multispectral data
- single tree segmentation and classification
- single tree polygons with attributes
- forest parameters aggregated on a 10m x 10m grid

Add-on

- pre-trained classification algorithms

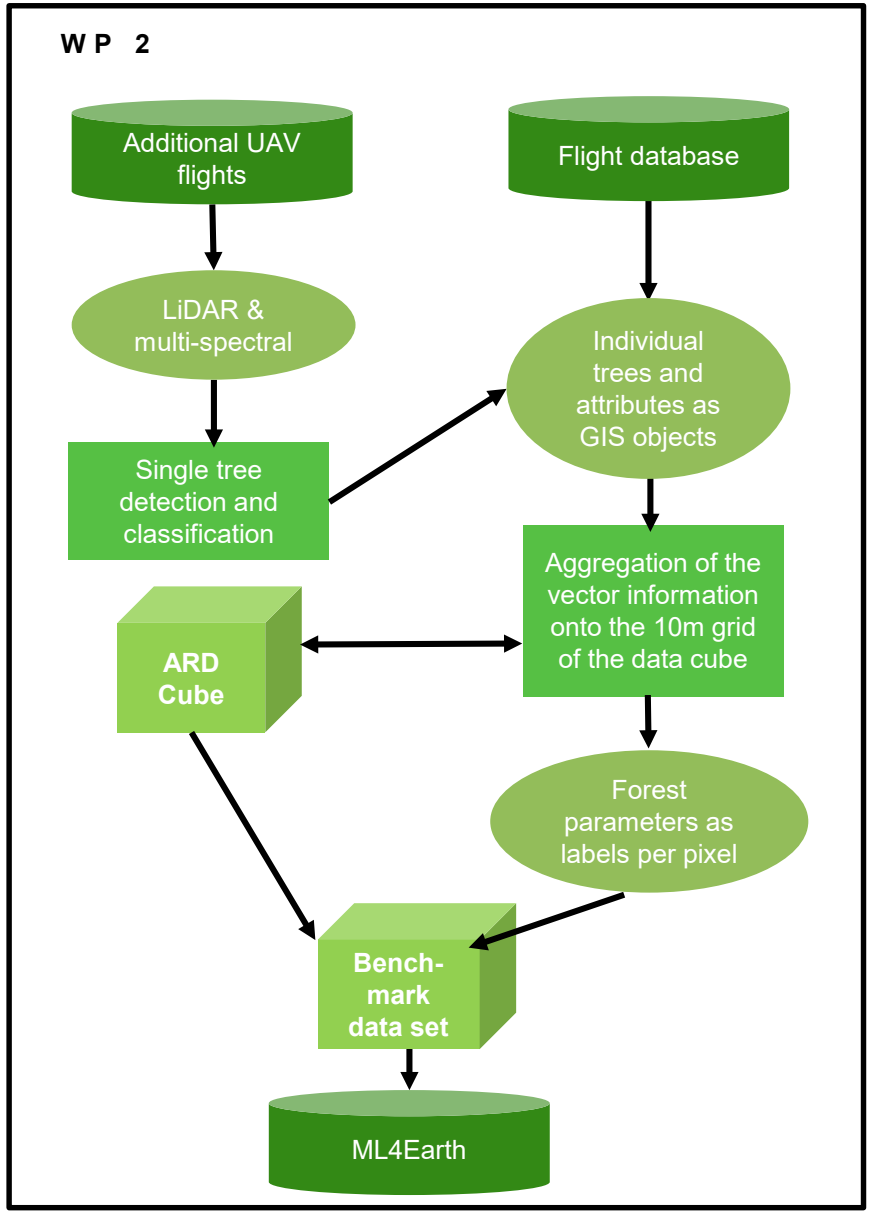


Fig. 4: *Workflow – WP 2*

Fusion – Visualization

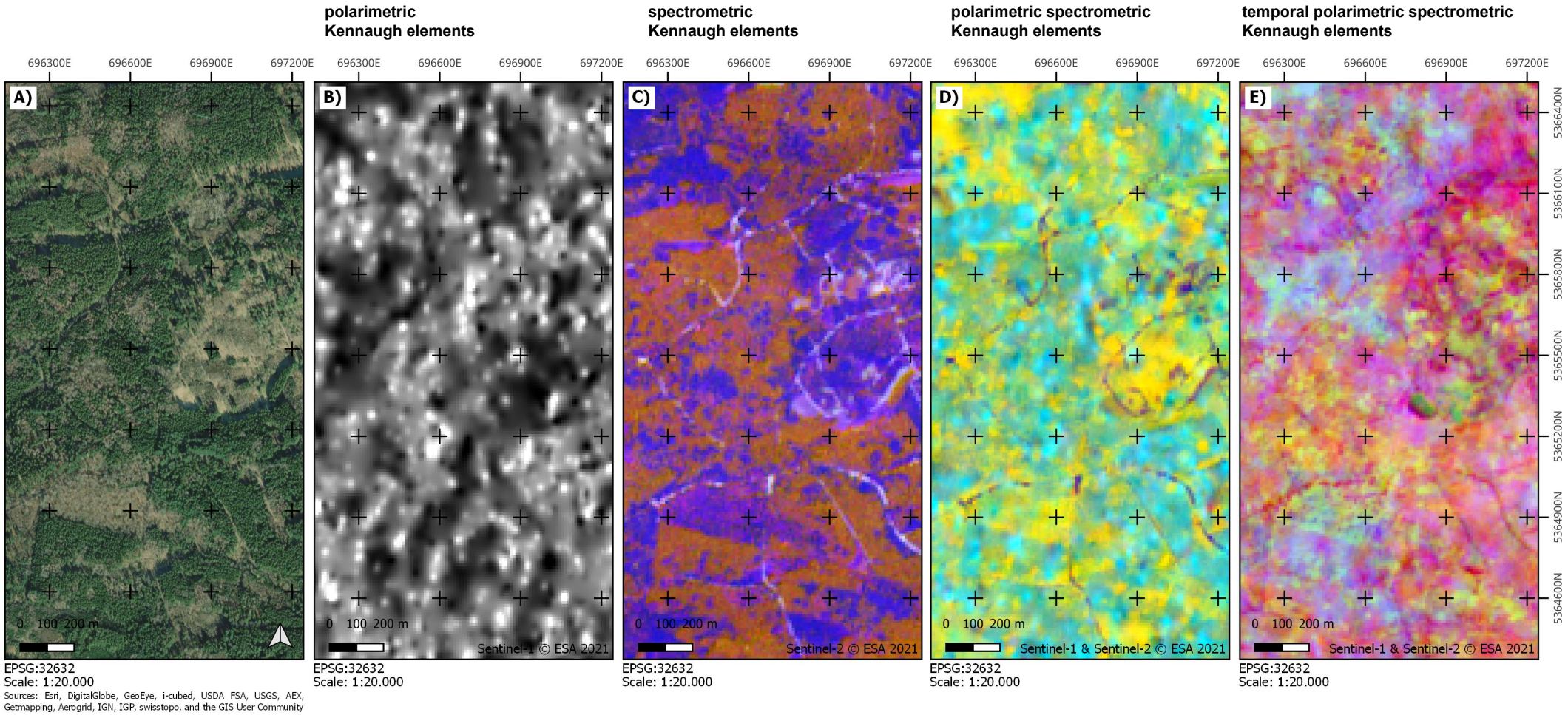


Fig. 5: *Composition displaying the step-wise evolution of the datasets in AOI 2, and for comparison purposes a satellite overview of the ground (A); Kennaugh element K0 of Sentinel-1 MultiSAR (2021-07-19) (B); Kennaugh elements of Sentinel-2 (2021-07-19) (C); Polarimetric and spectrometric fused dataset of Sentinel-1 & Sentinel-2 (2021-07-19) (D); and a polarimetric, spectrometric and temporally fused dataset over the whole period of 2021 (E) © ESA 2021.*

Fusion – Visualization

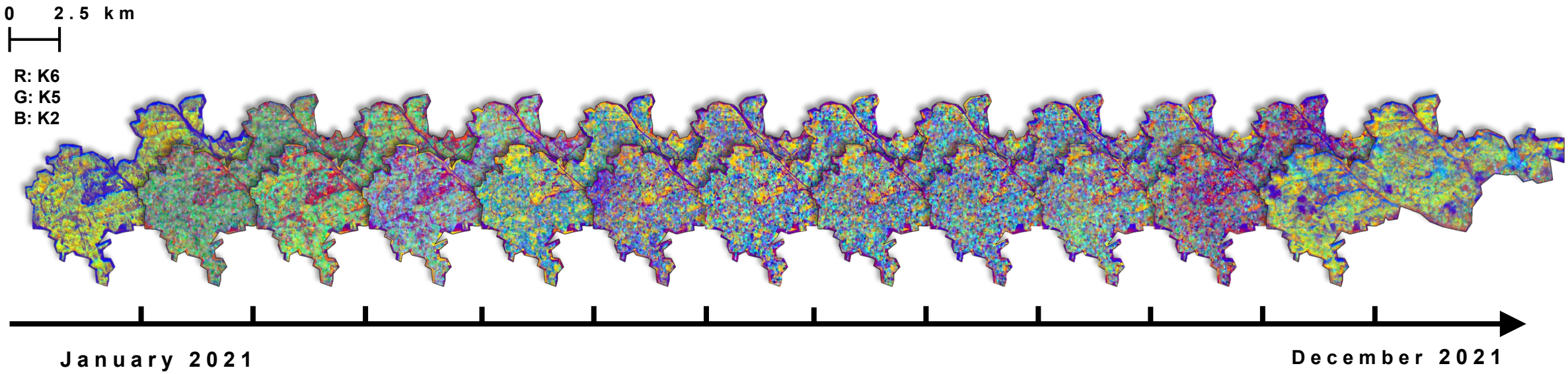
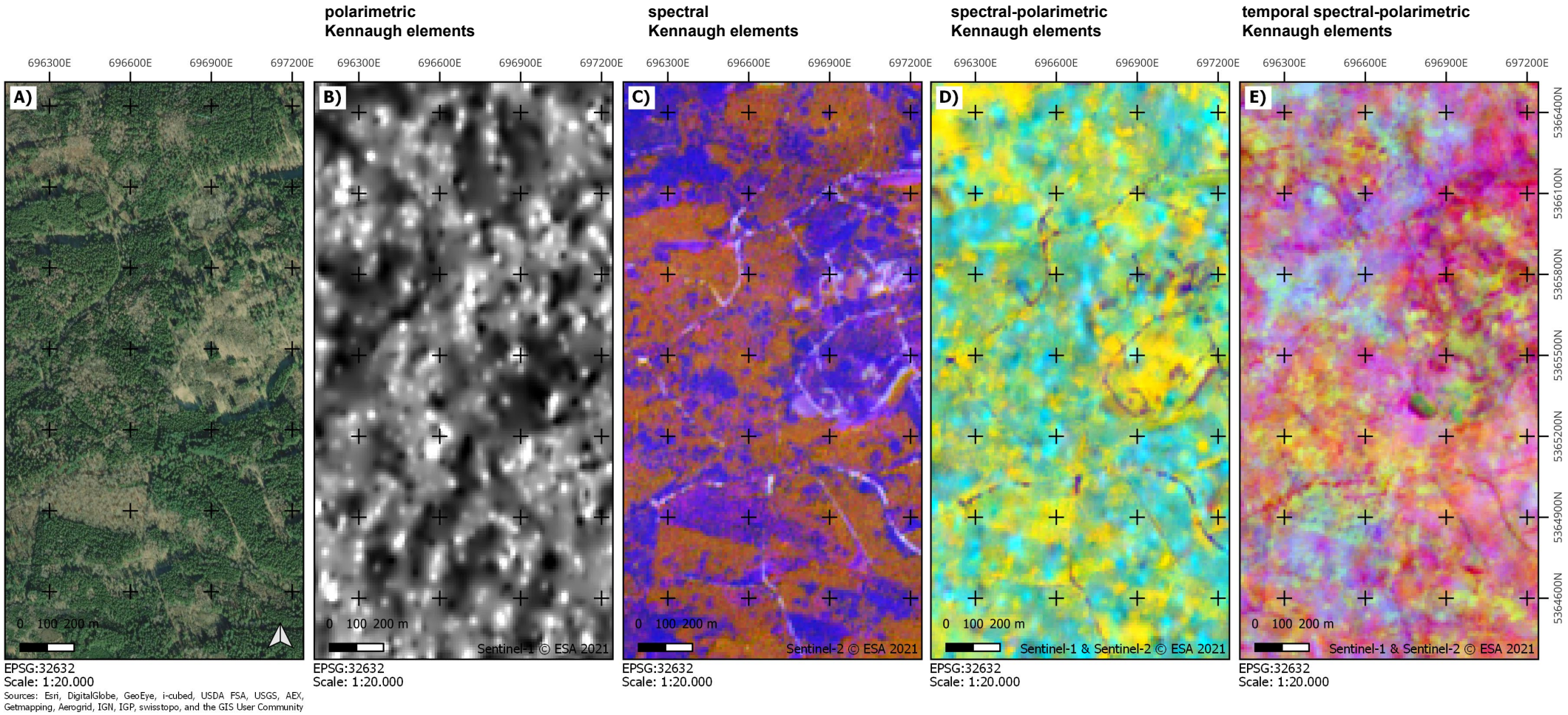


Fig. 6: *Hypercomplex data fusion of the Kranzberger Forst on a monthly basis over the period of 2021 based on Sentinel-1 and Sentinel-2 data © ESA 2021*

Fusion – Visualization



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Aggregation

- Aggregation of tree parameters onto the pixel grid of the fused satellite dataset
- using the average and percentage of the values, as demonstrated in Figure 7, with tree type and crown volume.

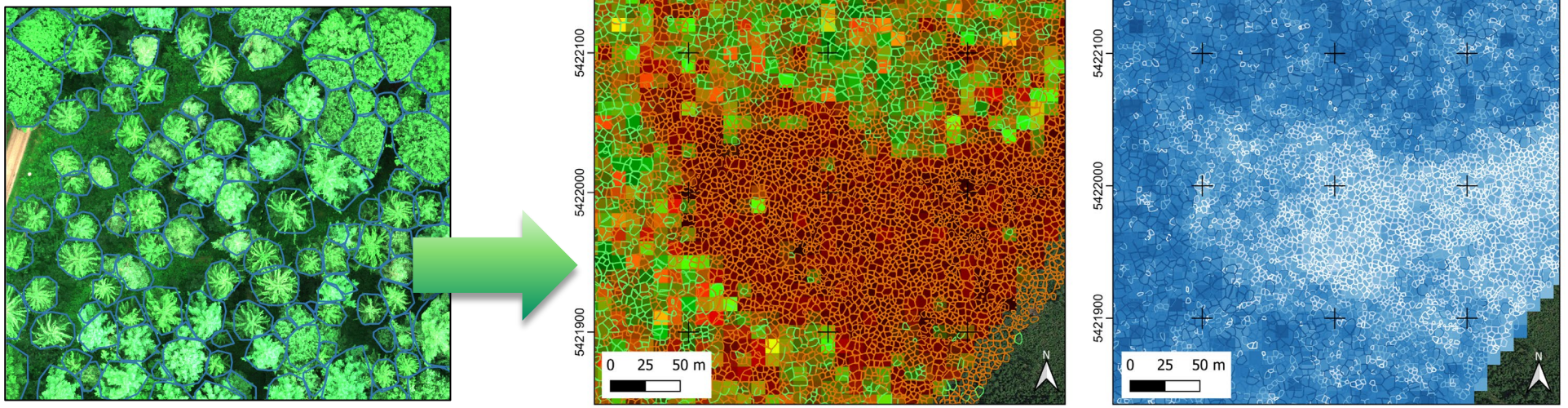

Fig. 7: *Exemplary aggreagtion results of the tree segments onto the 10m grid of the raster data, displaying the tree class (l.) and the crown volume (r.)*

Regression

Research question:
Is there a correlation between fused datasets from space and the forest parameters derived from airborne LiDAR?

Random Forest Regression

- Fused Sentinel-1 and Sentinel-2 datasets
- Labels based on the airborne LiDAR aquisitions (applied single tree segmentation and classification) [10]

- Tree parameters tested:
  - Tree type (coniferous, deciduous)
  - Crown volume
  - Crown base height
  - Tree Height

➢ **Correlation clearly detectable with an of R^2 0.80**

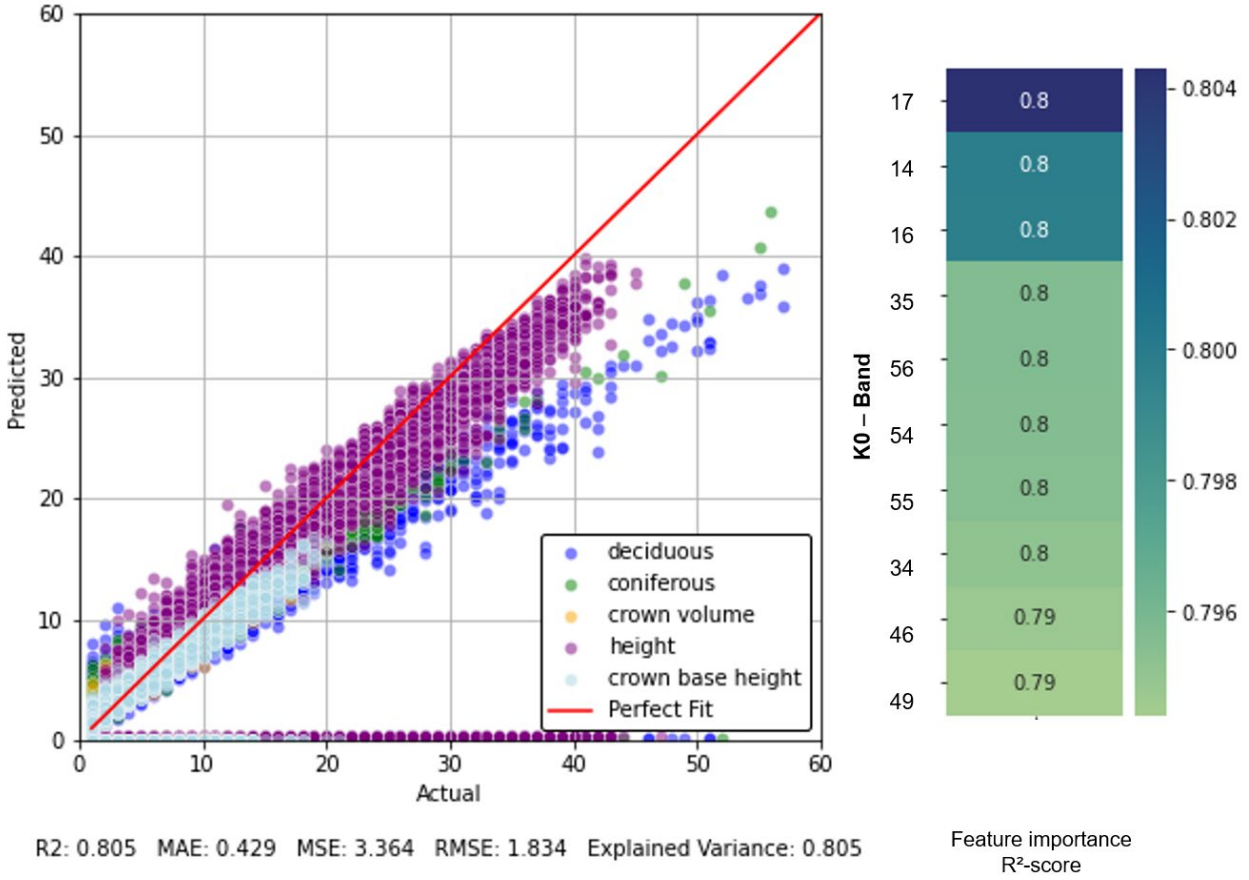

Fig. 8: *Scatterplot of the overall regression (l.) and the influence per band – feature importance ranking of the R^2 scores (r.)*

Prediction

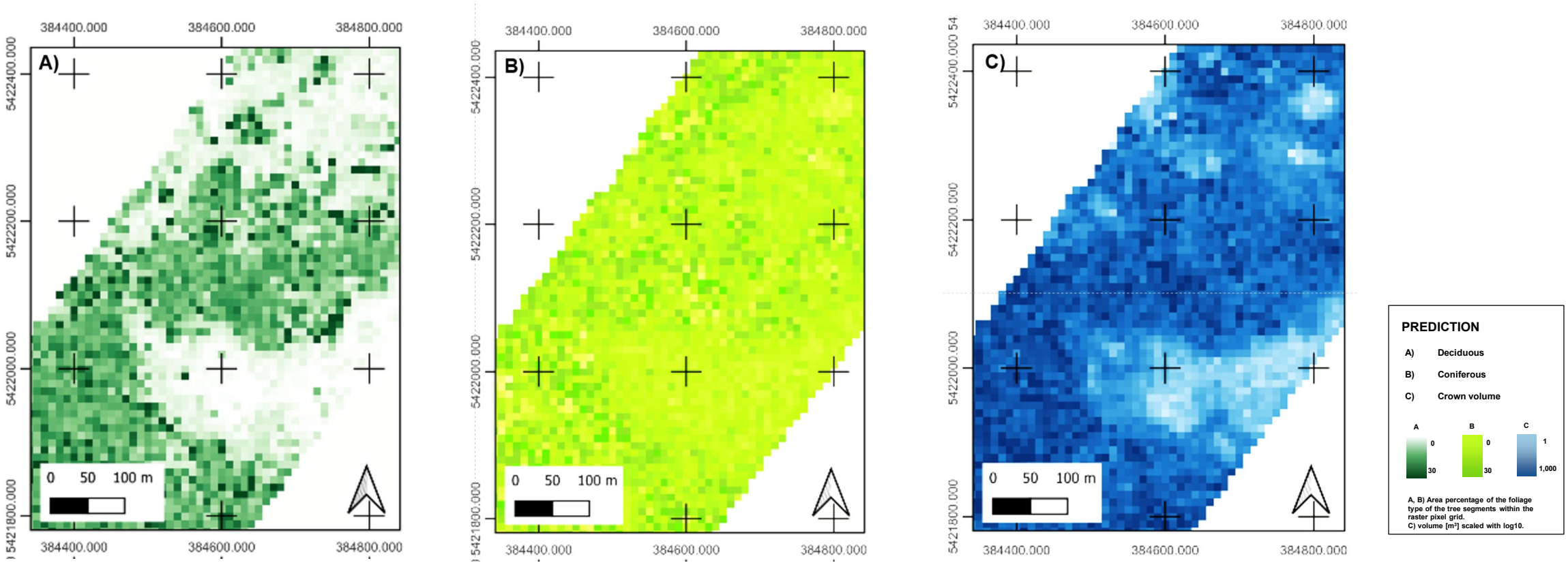

Fig. 9: *Prediction of forest/tree parameters using the RF model, displaying the tree type in A) deciduous and B) coniferous and the crown volume in C)*

Summary and prospects

Summary:

- Polarimetric, Spectrometric, and Temporal Kennaugh elements from merged Sentinel-1 and -2 data
- Single tree detection and classification from airborne LiDAR and multispectral cameras
- Prediction of forest prameters such as tree type, crown volume and crown base height while using our fused Sentinel-1 and -2 data based on Hypercomplex bases with a certainty of 80%
- Analysis Ready Data Cubes with forest parameters as labels
- Expected availability by the end of 2023
- Provision of the benchmark data set and the algorithms via the ML4Earth platform

Prospects:

- Multi-temporal regression
- Correlation of further tree-species
- Extension of the reference data set through new flights

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