Detecting tree species-specific forest health anomalies using Sentinel-2 time series

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6. October 2022 @Arbeitskreis Fernerkundung Halle/Saale

Motivation

Forest health research

- Increasing forest cover loss: drought, bark beetle, fire, windfall
- Increasing need for disturbance detection, vulnerability assessment and risk management
- Important input for ecological models: biomass, carbon flux etc.

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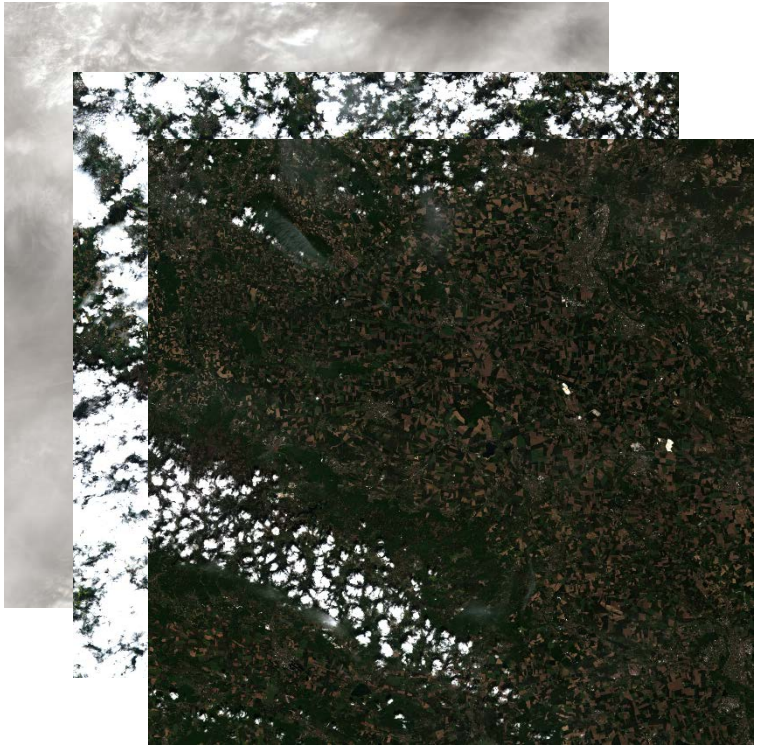
Data

Satellite data: Sentinel-2 A/B Level 2A

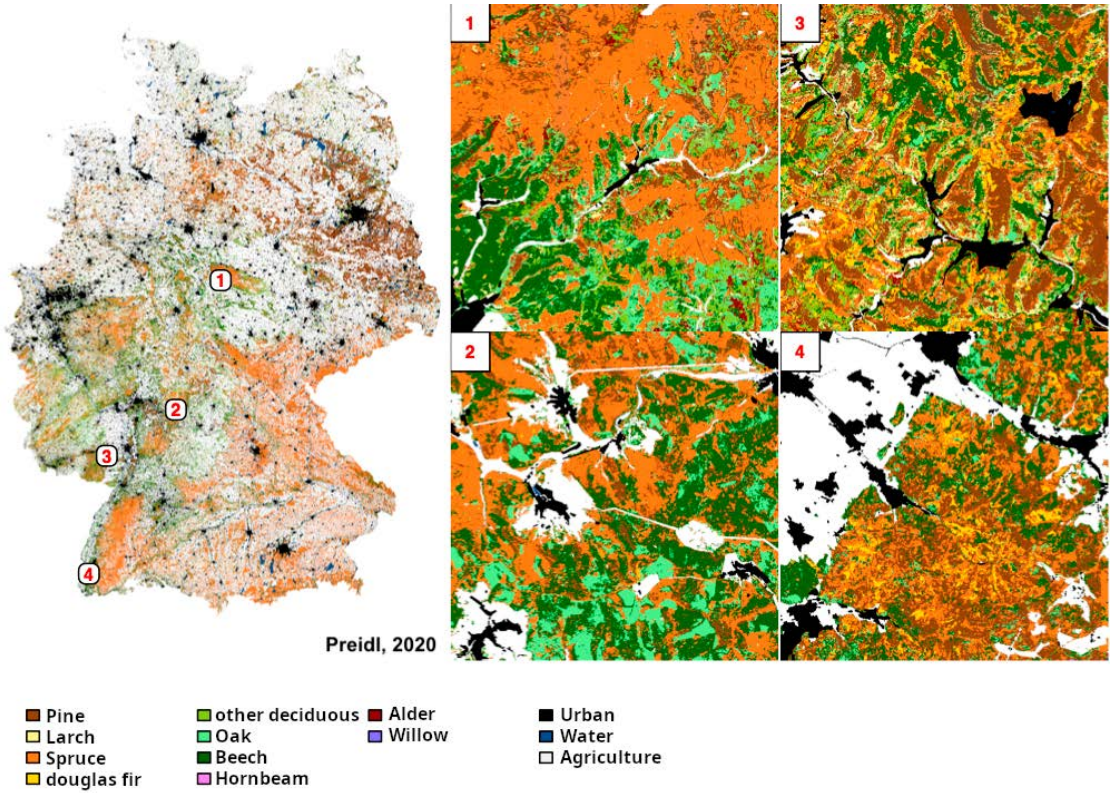
- Germany-wide, 2016 - 2021
- 20 *m* spatial resolution
- 3-5 *days* temporal resolution
- Level 2A: atmospherically, topographically and cirrus corrected
- Cloud masks from sen2cor scene classification



Data

Tree species classification

- Germany-wide, 2016
- 20 *m* spatial resolution
- Based on Sentinel-2 data and forest inventories
- 9 (main) tree species



Data

Regionalisation

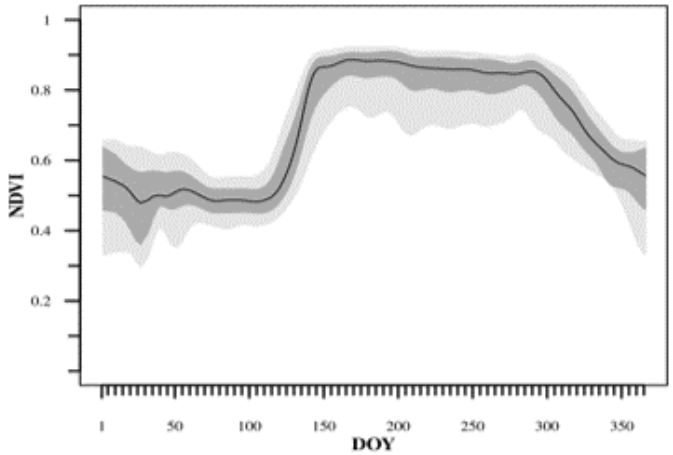
- 6 forestry regions across Germany („Forstliche Großlandschaften“)
- Difference in morphological, orographical and climatic conditions
- Forest health anomaly detection using reference time series for each **species and region**

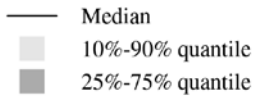
Procedure

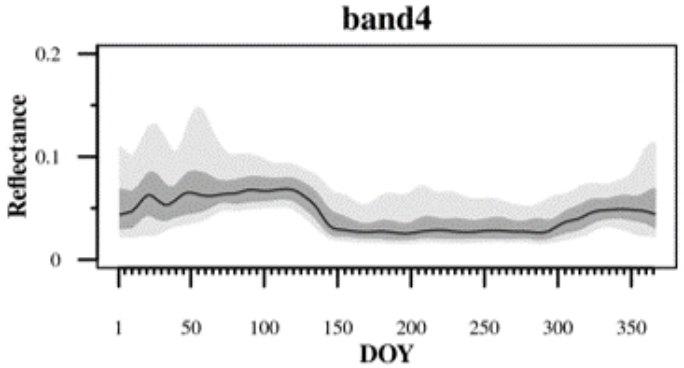
Step 1: Tree species specific feature spaces spanned by reflectance time series

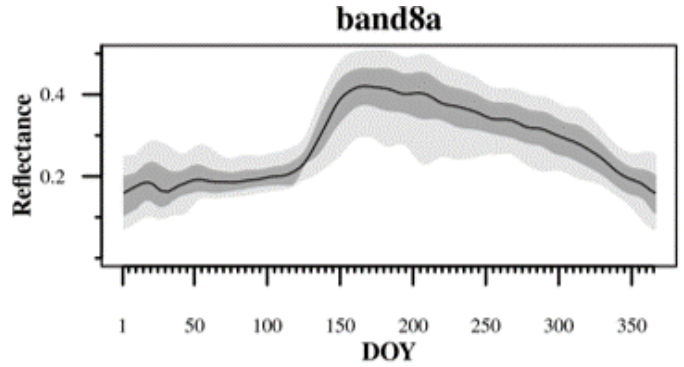
- Statistics of reflectance time series (all bands, n=9) of a species in a given region
- Outlier removal & smoothing

- Here: Oak, „Lösshügelländer“ (Germany)



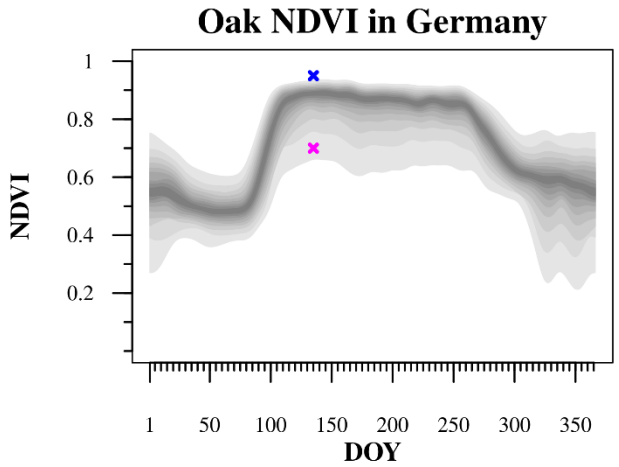


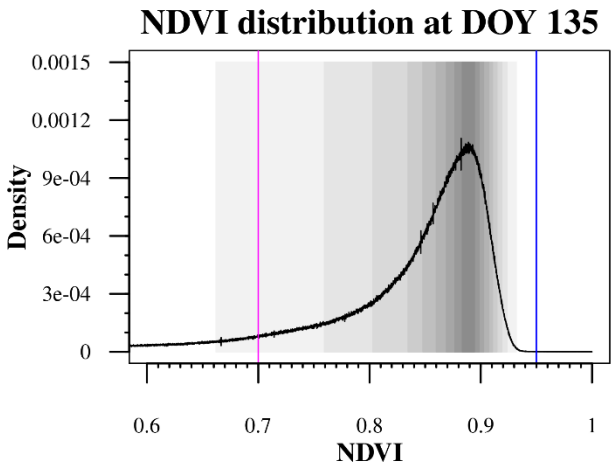




Procedure

Step 2: Calculate a (dis)similarity metric



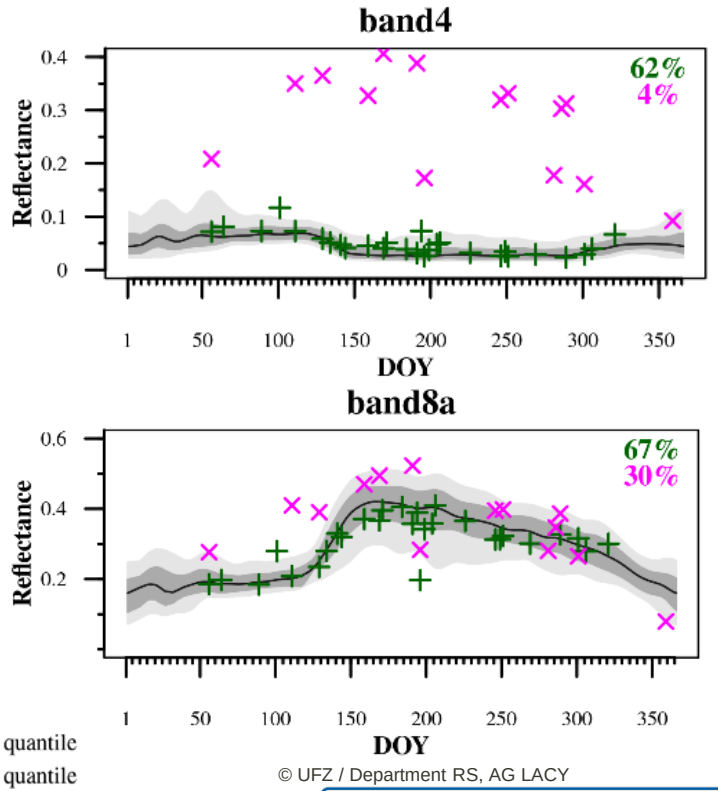


- Distribution-dependent distance to median (50%-percentile)
- Numeric approximation: number of percentiles between measurement and median

Procedure

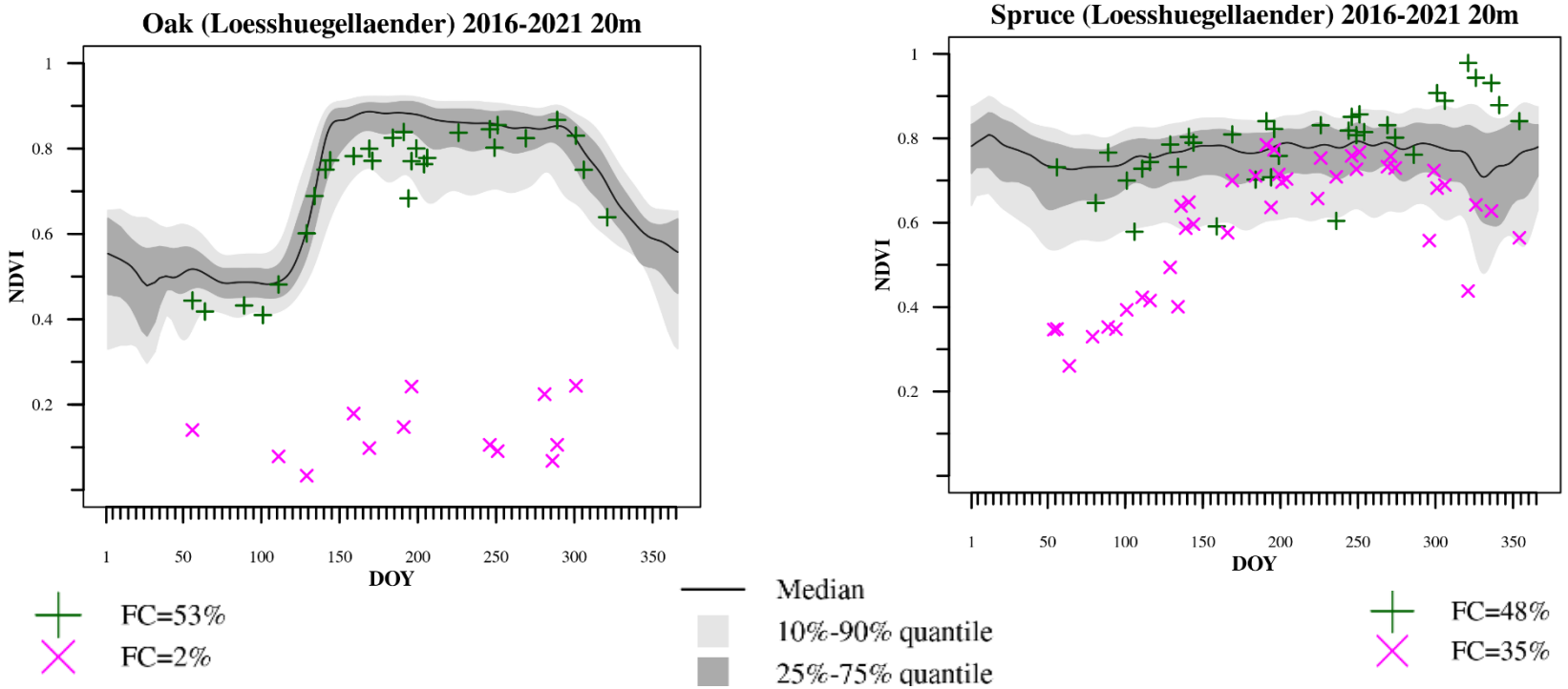
Step 3: Average (dis)similarity metrics for each pixel‘s time series

- Here: 2 pixels covering oak trees in „Hohes Holz“ (Germany)
- Comparison with statistics of oak reflectances in the „Lösshügelländer“ (Germany) 2016-2021
- (Weighted) mean of spectral dissimilarity values (bands, time):
  - Magenta: 0.11 or 11% (less similar)
  - Green: 0.65 or 65% (more similar)
- Simplification in future slides: Similarity values → „forest condition“ (FC)



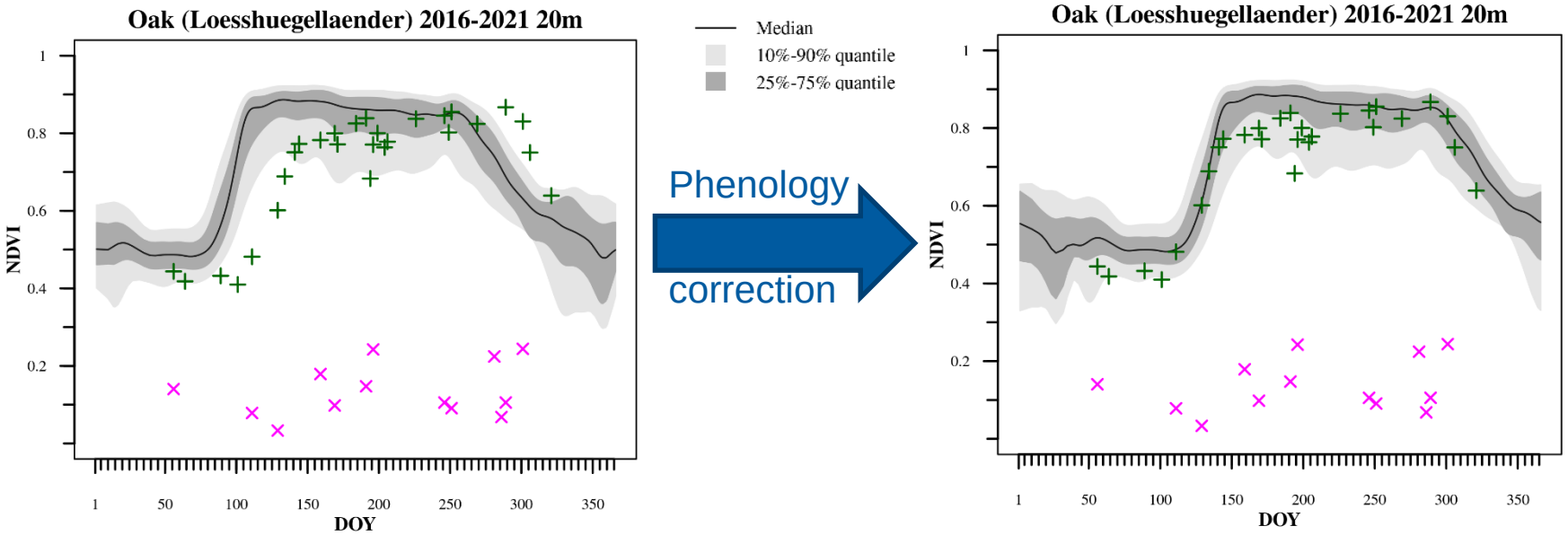
Procedure

Step 3: Average (dis)similarity metrics for each pixel‘s time series



- Example: Hohes Holz, central Germany, phenology correction

Procedure
Phenology Correction

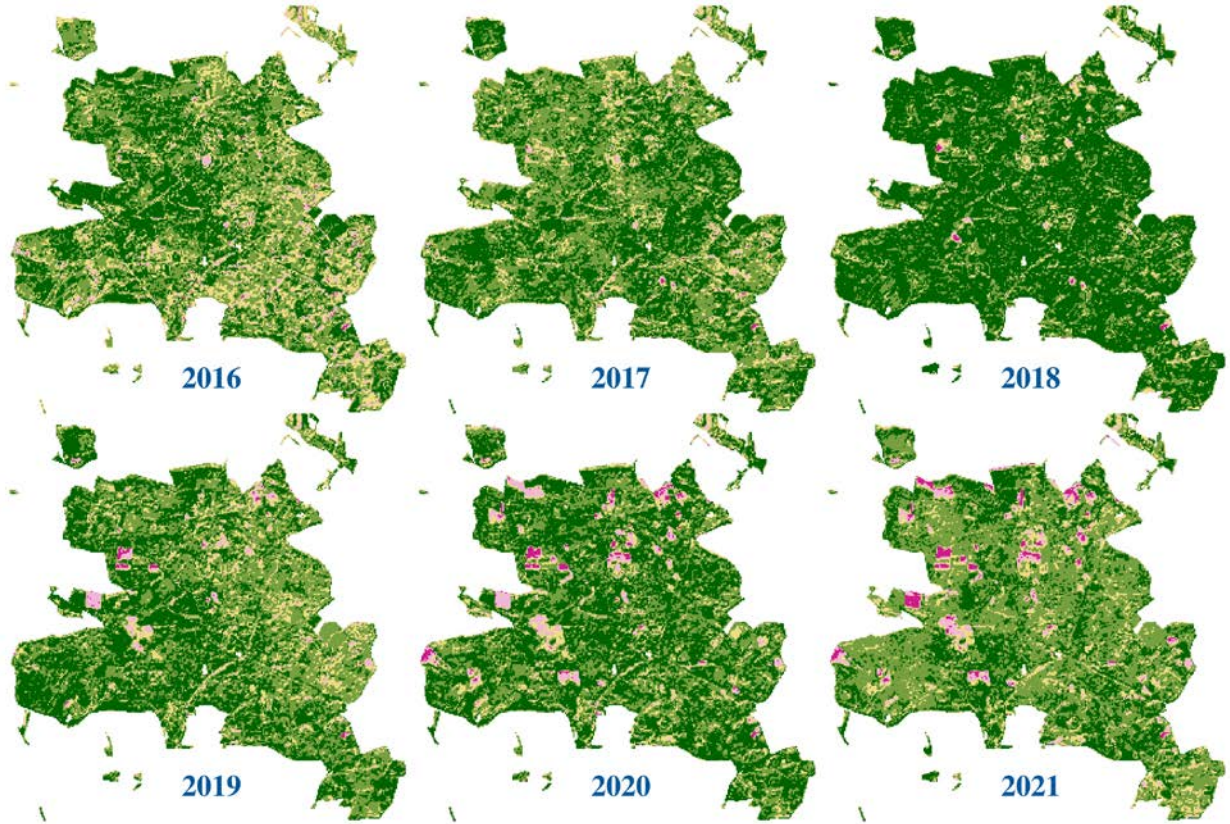


- Green-up estimation with R-package „phenex“*
- Shift of reference time series

* Lange M, Doktor D (2017) phenex: Auxiliary Functions for Phenological Data Analysis. R-package version 1.4-5, CRAN.R-project.org/package=phenex (last access 21th Jul 2022)

Example

Hohes Holz, central Germany, yearly time series



Examples

Fire in Frohnsdorf, District Potsdam-Mittelmark, 23th August 2018

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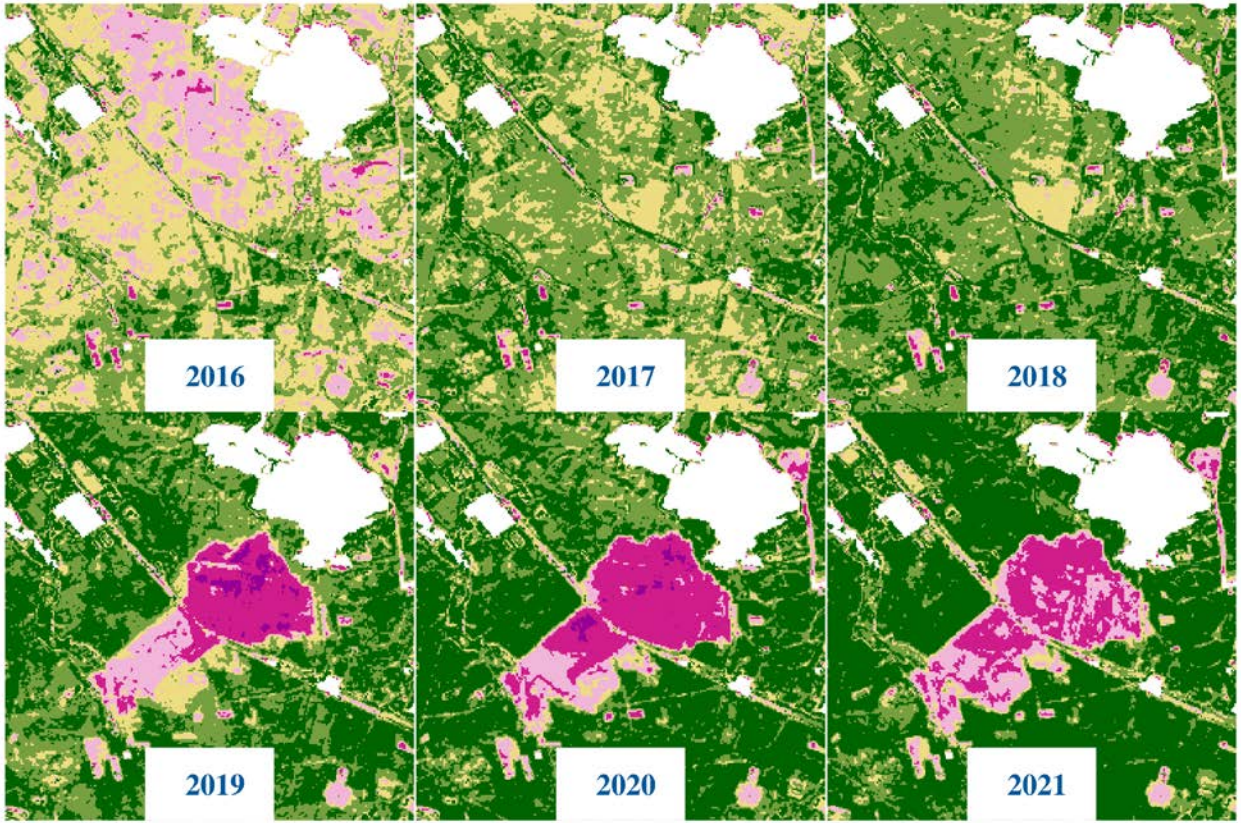
300 ha burnt area

Examples

Fire in Frohnsdorf, District Potsdam-Mittelmark, 23th August 2018

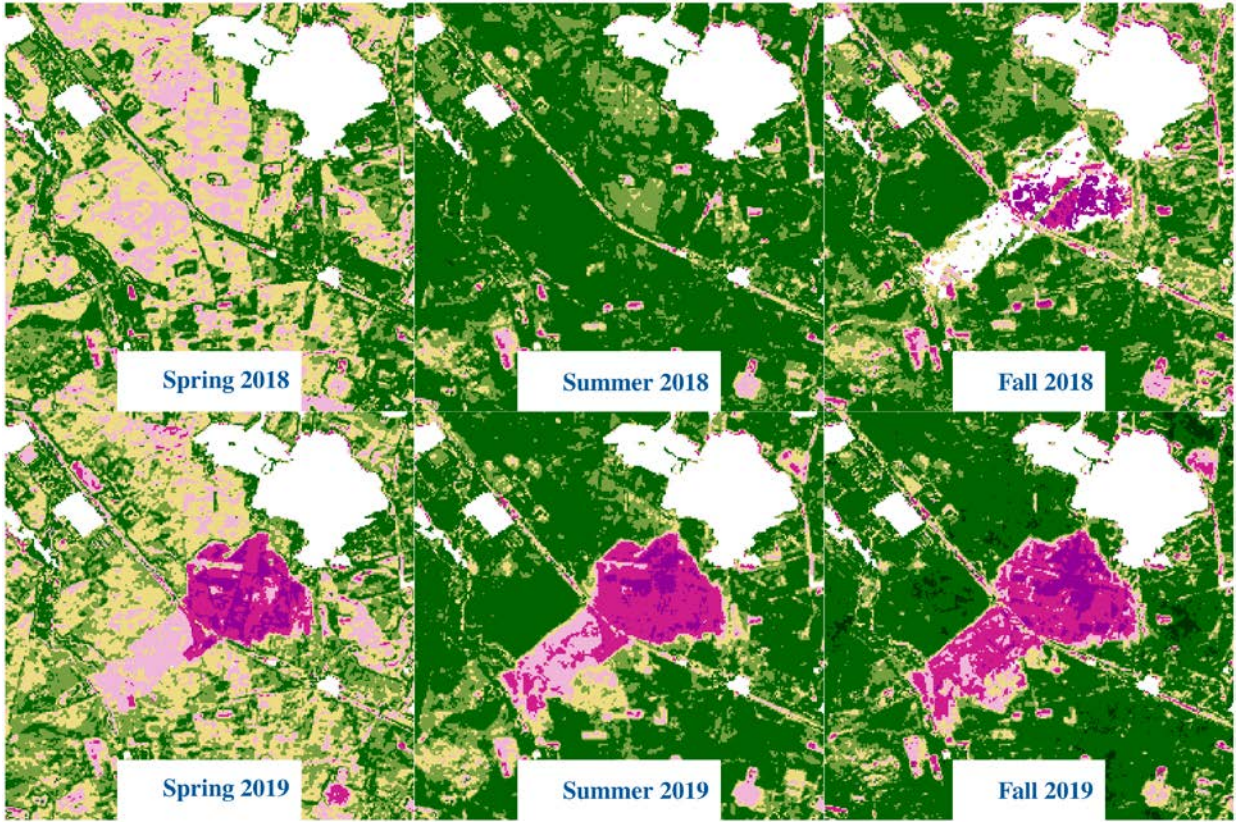


Forest condition estimate

- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.75
- > 0.75

Examples

Fire in Frohnsdorf, District Potsdam-Mittelmark, 23th August 2018



Examples

Bad Liebenstein, Wartburgkreis, central Germany, satellite images

Aug 2017

Jul 2018

Examples

Bad Liebenstein, Wartburgkreis, central Germany, Spruce, Windfall

© Google Earth

Sturm hinterlässt Schlachtfeld: hunderte Bäume niedergemäht

Thüringen

18.03.2018, 18:19

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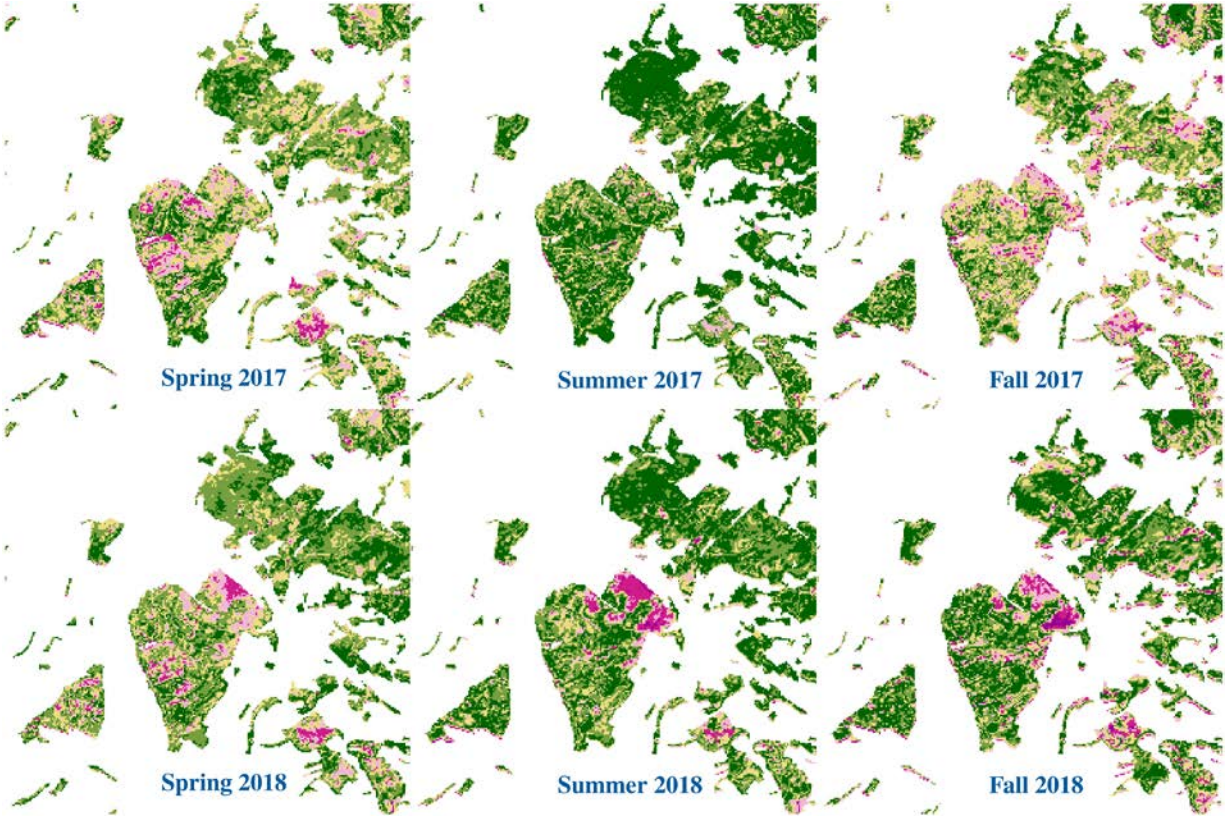
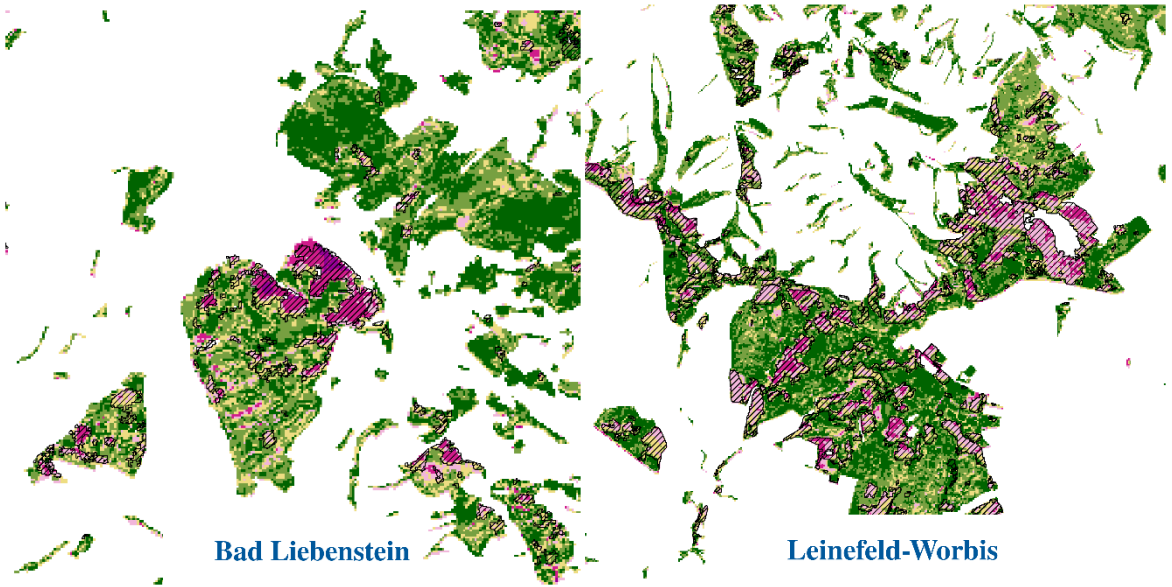
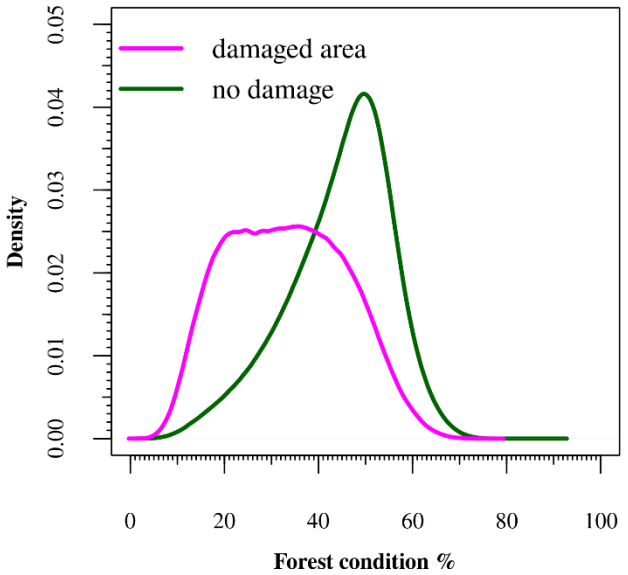
Example

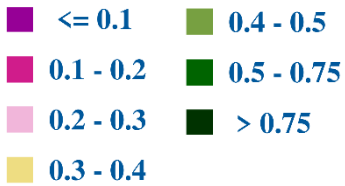
Bad Liebenstein, Wartburgkreis, central Germany, seasonal time series



Examples
Damaged areas in Thuringia



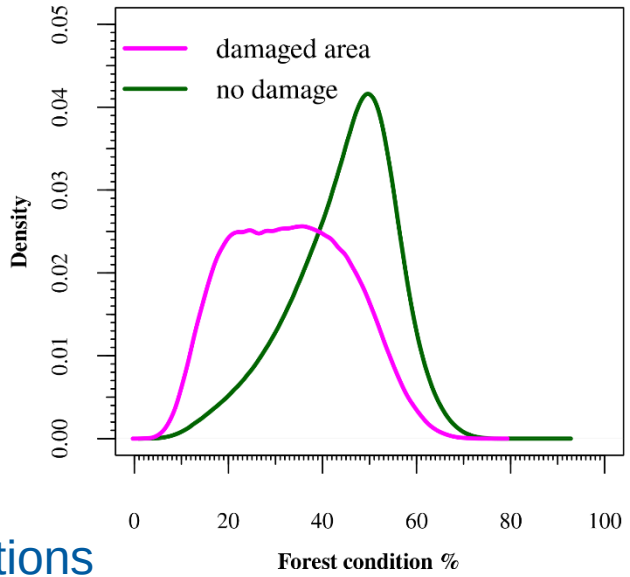




Damaged areas as reported by Thuringia

Examples
Damaged areas in Thuringia

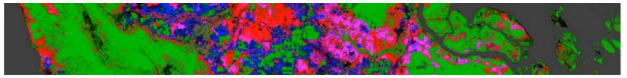
	0	1	total	Users‘s
FC > 40%	9,139,678	212,183	9,351,861	97.7%
FC < 40%	4,033,252	453,107	4,486,359	10.1%
total	13,172,930	665,290	13,838,220	
Producer‘s	69.3%	68.1%		**96.3%**



- Significant (p < 2.2e-16) differences of value distributions in areas reported as damaged vs. not damaged
- Threshold for spectral similarity values (FC=0.4)

Examples

Global Forest Change (Hansen et. al, 2013*)



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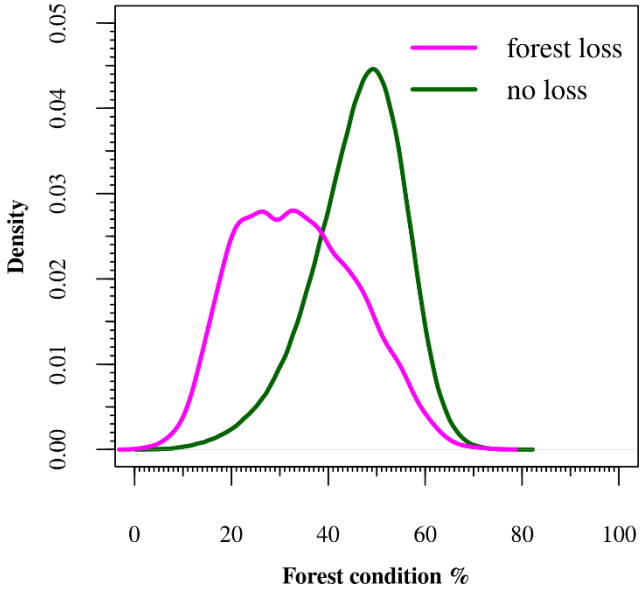
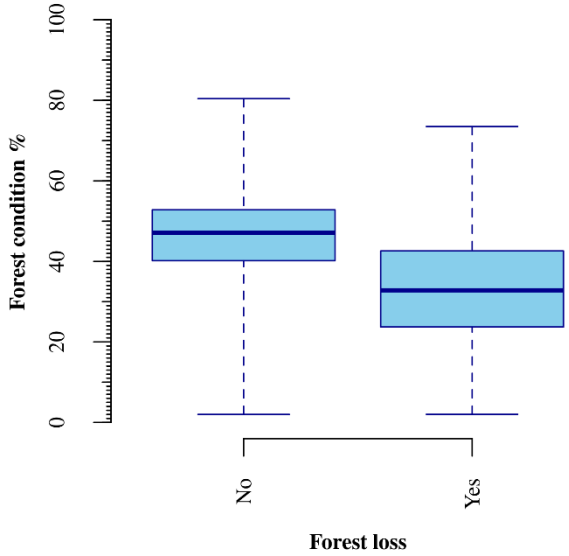
Global Forest Change 2000–2021





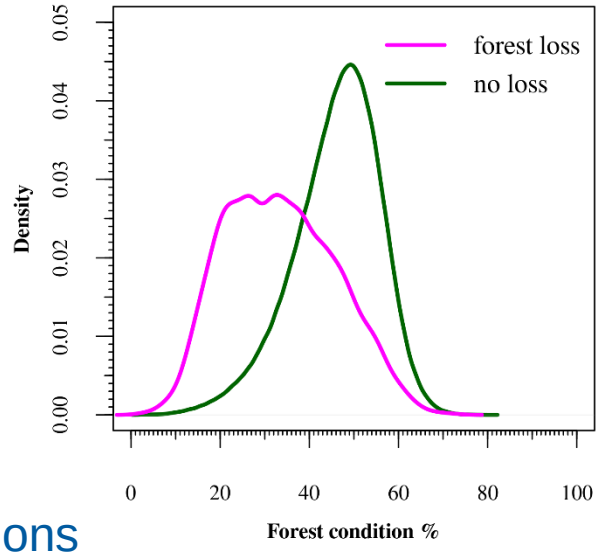
© Hansen/UMD/Google/USGS/NASA

- Comparison of 100,000 pixels in 6 years (2016-2021)

* Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. 2013. “High-Resolution Global Maps of 21st-Century Forest Cover Change.” Science 342 (15 November): 850–53. Data available on-line from: https://glad.earthengine.app/view/global-forest-change.

Examples
Global Forest Change (Hansen et. al 2013)

	0	1	total	Users‘s
FC > 40%	445,172	3,310	448,482	99,3%
FC < 40%	144,049	7,426	151,475	4.9%
total	589,221	10,736	599,957	
Producer‘s	75.5%	69.2%		**75.4%**



- Significant (p < 2.2e-16) differences of value distributions in areas with forest loss vs. no loss
- Threshold for spectral similarity values (FC=0.4)

Open Issues

Causal relationships, validation

- More **spectral anomalies** than reported forest cover loss
  - What are the causal relationships?
  - How to weight the different bands?

- Most products show discrete classes (loss vs. no loss, damage / undamaged)
  → a **continuous anomaly value** may be beneficial to depict gradual changes

- Validation is critical to assess **performance** and detected **patterns**
  - Data comparable to remote sensing data?
  - Data sources are scarce

Project
UFZ Forest Condition Monitor

- Aim: Knowledge transfer
- Establishment of a **web service**
- More **information & contacts** on project website*

Thank you for your attention!

SCAN ME

* https://www.ufz.de/index.php?en=48150

Concept

Forest condition monitoring based on spectral and temporal deviations from tree species specific feature spaces spanned by reflectance time series

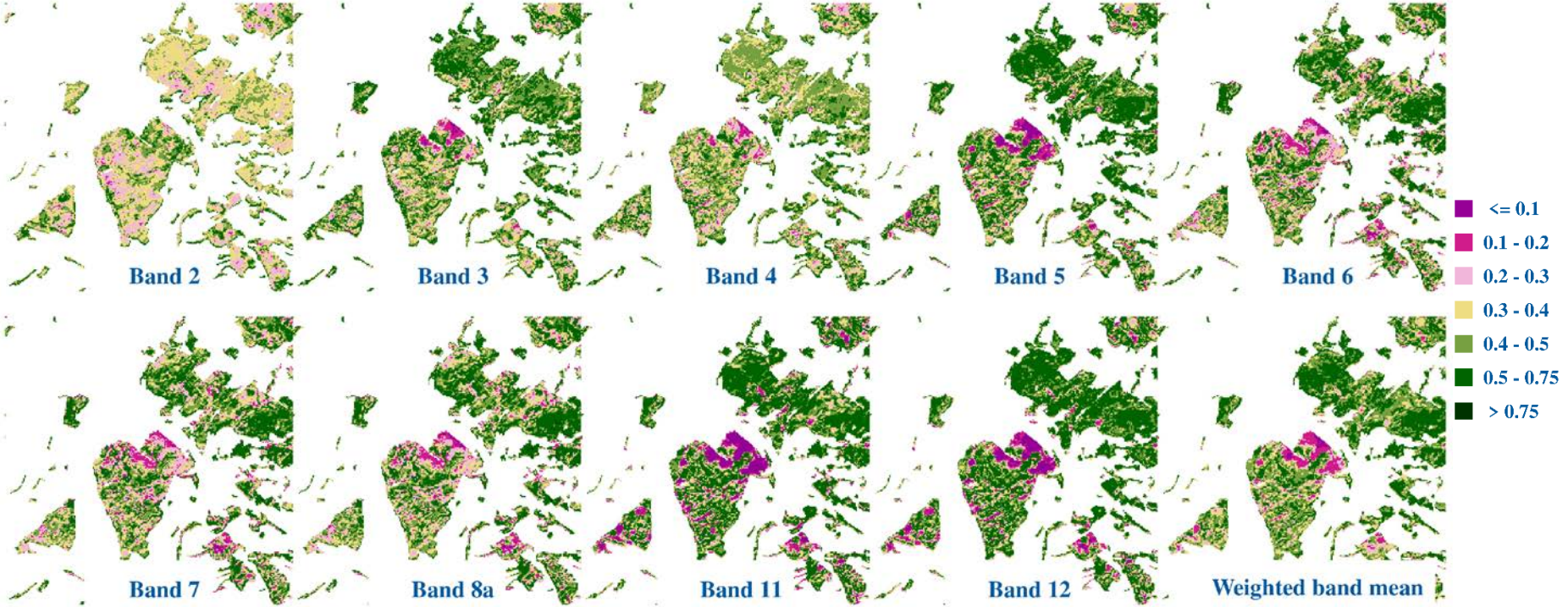
- Usage of **all available spectra of a tree species** within a given region
    - all pixels across Germany
    - all observations within a year
    - all available years (2016-2021)
    - all bands (n_{bands}=9)

- Estimation of an observation‘s distance to the median observation of a tree species considering its value distribution
    - Anomalous forest stands will show high distances over time

- **Aggregation of spectral and temporal dimension allows to detect pixels with an accumulation of such anomalies**

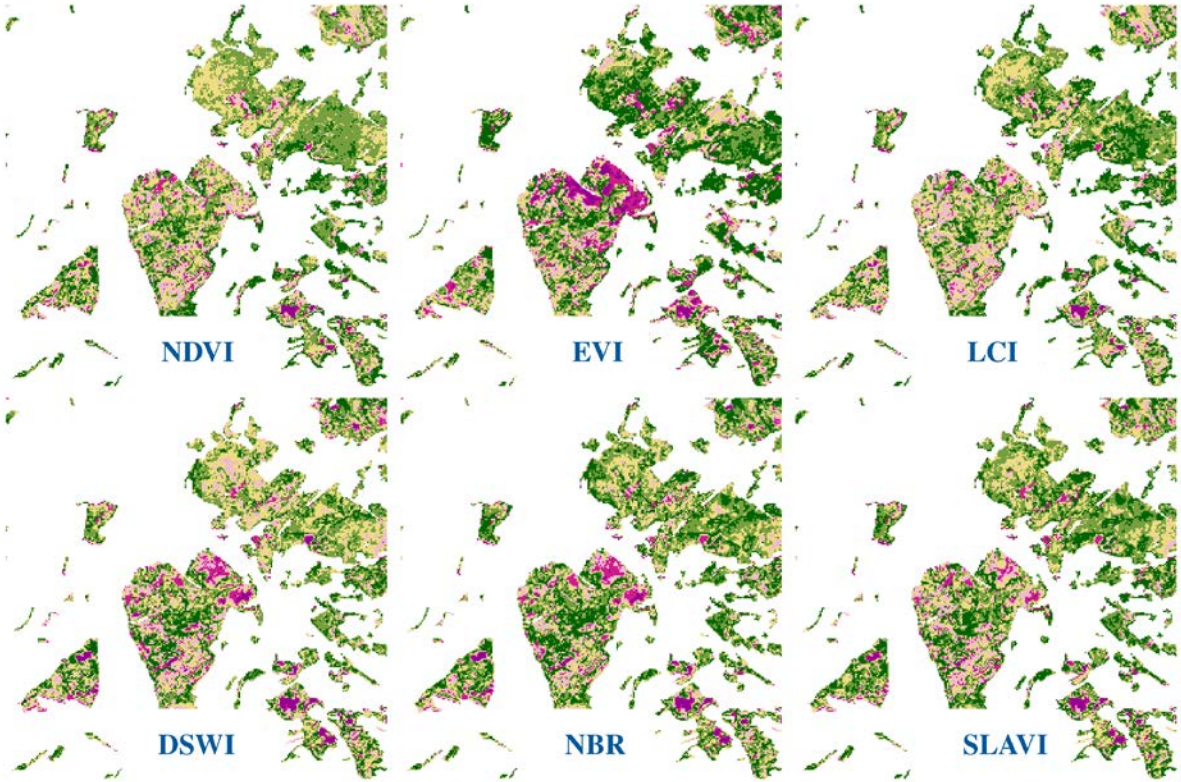
Example

Bad Liebenstein, Wartburgkreis, central Germany, Sentinel-2 Bands, 2021



Example

Bad Liebenstein, Wartburgkreis, central Germany, vegetation indices, 2021



NDVI = Normalised Difference Vegetation Index

EVI = Enhanced Vegetation Index

LCI = Leaf Chlorophyll Index

DSWI = Disease Water Stress Index

NBR = Normalised Burn Ratio

SLAVI = Specific Leaf Area Index