# LV 857.002
# Remote Sensing Time Series Analysis

**Exercise 3:**

**Single pixel time series II: Processing and analysis**

## Case study burned areas

Institute of Geomatics

# Goals

- Visually assess and discuss the time series of the different study sites
- Methods for processing of remote sensing time series
  - ✓ Make use of quality information and date of observation
  - ✓ Treat long periods of missing data (e.g., winter in northern latitudes)
  - ✓ Detection and removal of outliers
  - ✓ Non-parametric approaches for smoothing:
    Savitsky-Golay, Whittaker smoother
  - ✓ Parametric approaches for function fitting:
    Double logistic function, Asymmetric Gaussian function
- Methods for evaluating the effectiveness of fitting/smoothing
- Visualising and interpreting the time series data
- Analysing disturbed and undisturbed time series

# Recall:
# Case study burned areas

## Objective

Develop a methodology for detecting wildfires in natural vegetation, e.g. forests.

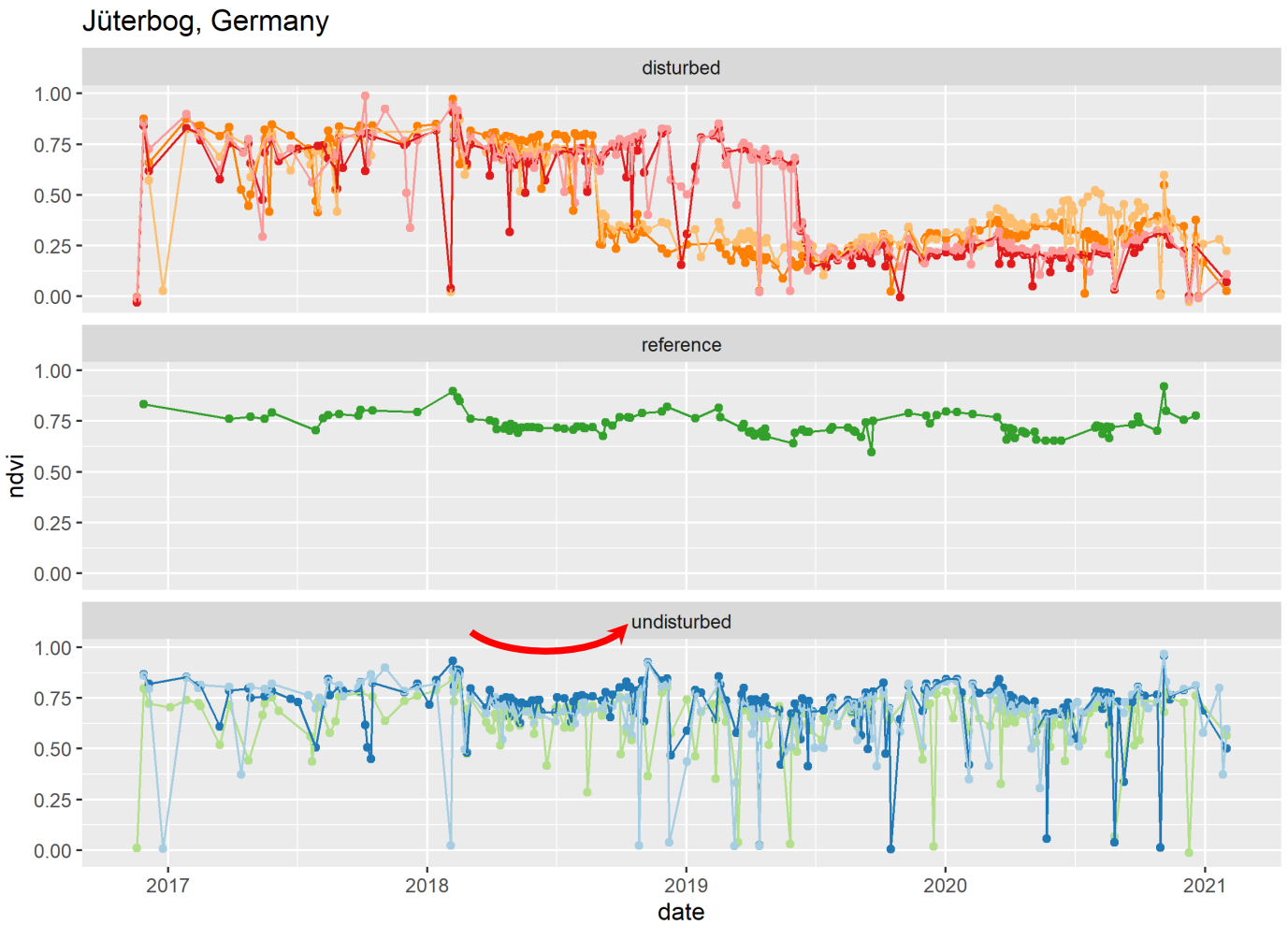
- ✓ Choose a study site/fire event
- ✓ Acquire suitable time series
- ✓ Sentinel-2 NDVI single pixel time series from Sentinel Hub EO Browser
- ✓ Import and visualise the time series in R



**Visually assess and discuss the time series - answer the following questions:**

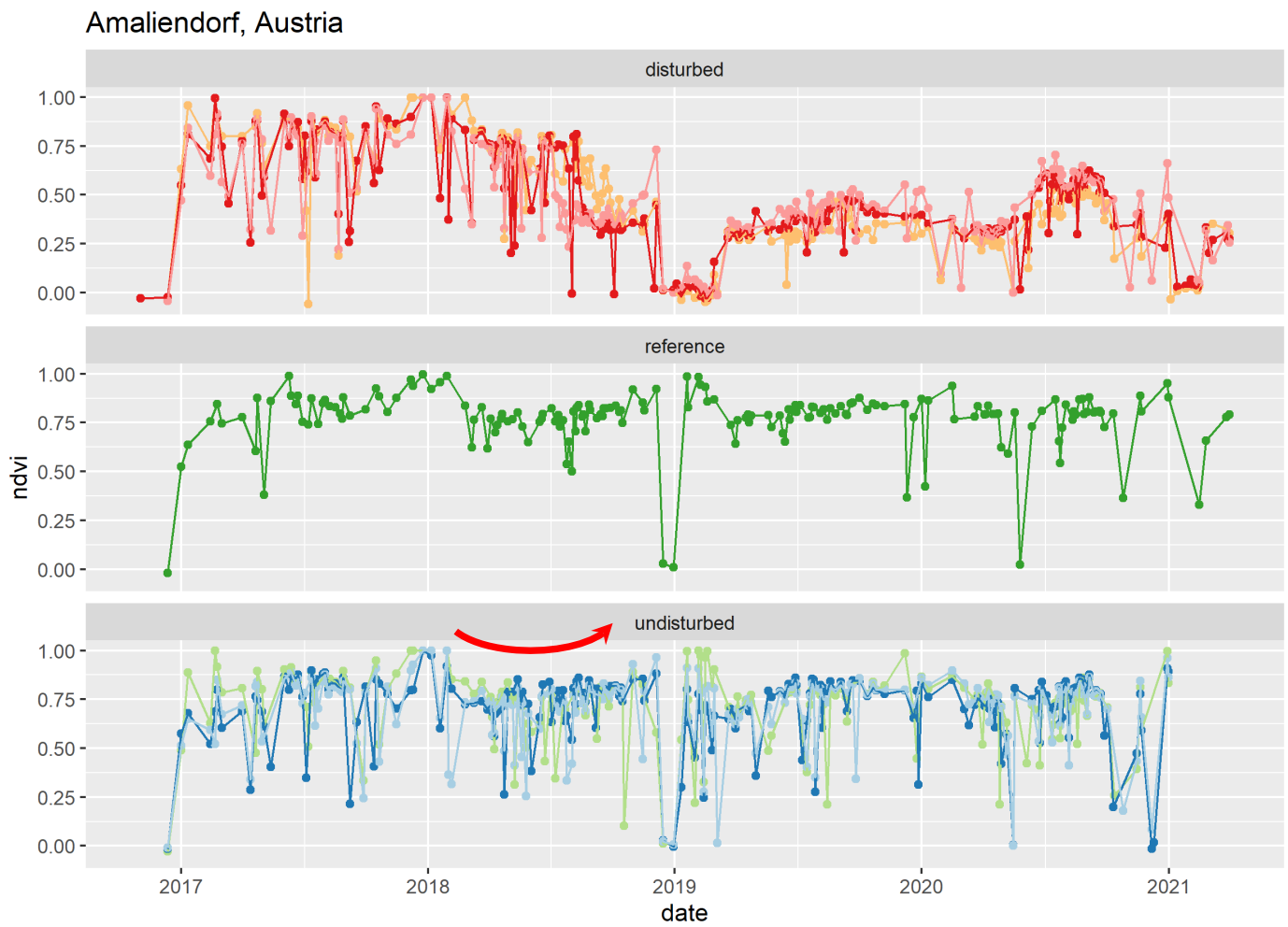
- **Q1:** What are the properties of the time series?
- **Q2:** What type of forest or other land cover is it?
- **Q3:** What do you see in terms of seasonality and trend?

# Recall: Single pixel time series Sentinel-2

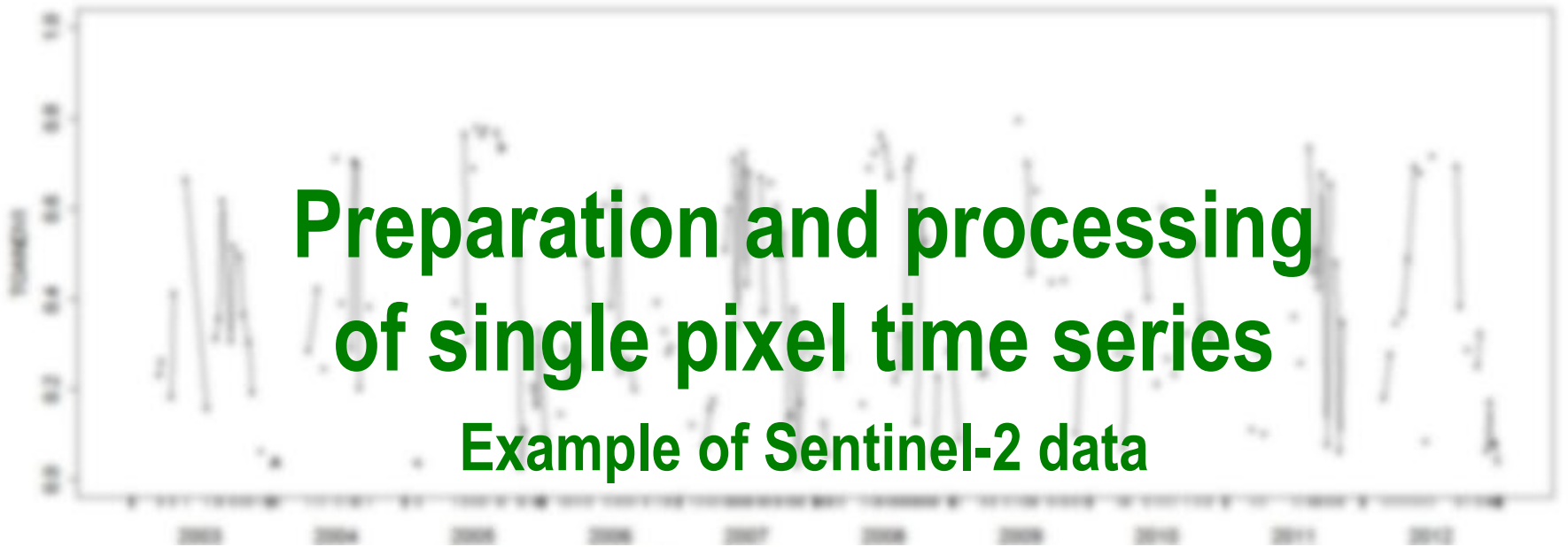



**Implausible phenology in L2A product:**
Problem in atmospheric correction of red band?

# Recall: Single pixel time series Sentinel-2




**Implausible phenology in L2A product:**
Problem in atmospheric correction of red band?



# Preparation and processing of single pixel time series

## Example of Sentinel-2 data

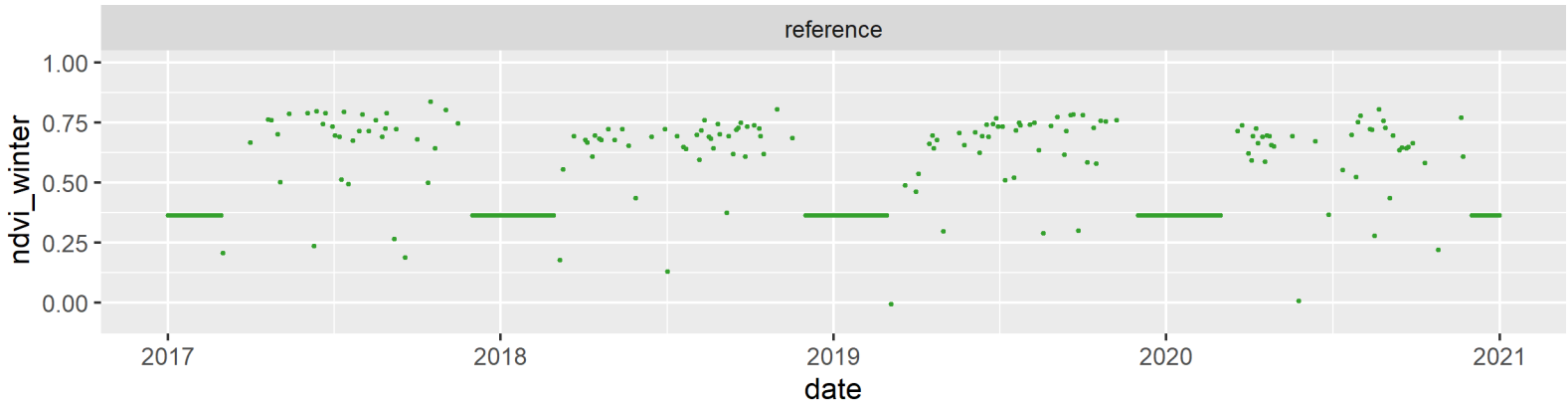
# Preparation of single pixel data

## before & after


**Apply winter NDVI**

→ period (which months or weeks)?

→ value (NDVI before or after growing period)



# Principle of Whittaker and adaptation to NDVI data

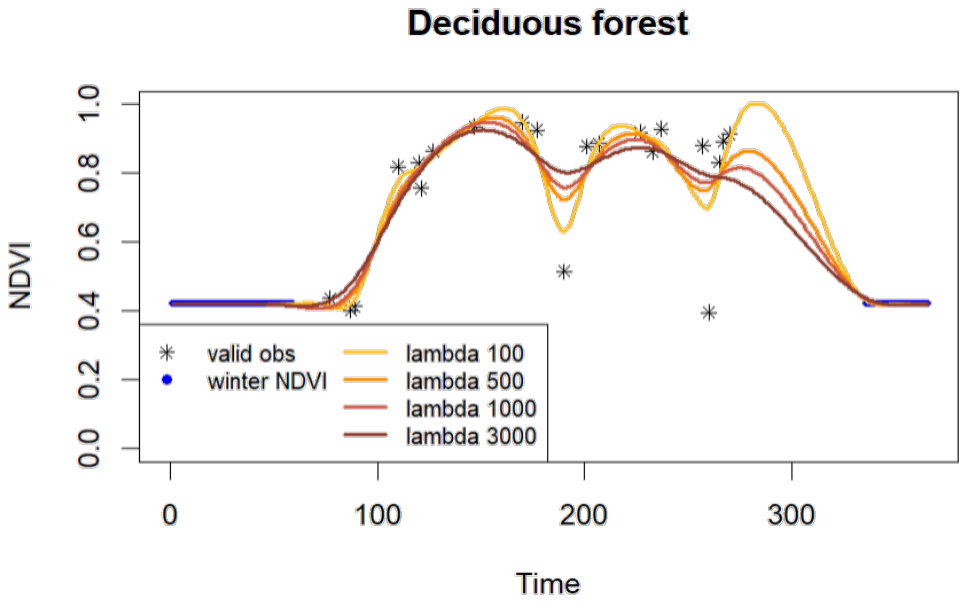
- Smoothing data by striking a balance between fidelity to the data and smoothness of the fitted curve:
- Fidelity of curve is measured by the sum of squares of deviations where $y_i$ = observed time series and $z_i$ = smoothed time series
- Roughness of data can be expressed with differences, e.g. 1st, 2nd, 3rd
- $\lambda$ (lambda) is a number chosen by the user
- Find $z_i$ (= smoothed time series) by minimising Q for a given lambda

$$Q = S + \lambda \cdot R$$

$$S = \sum_i (y_i - z_i)^2$$

$$R = \sum_i ((z_i - z_{i-1}) - (z_{i-1} - z_{i-2}))^2$$

- Effect of Lambda:
  - the larger $\lambda$
  - the stronger the influence of roughness R
  - the smoother z will be
  - at the cost of the fit of the data getting worse

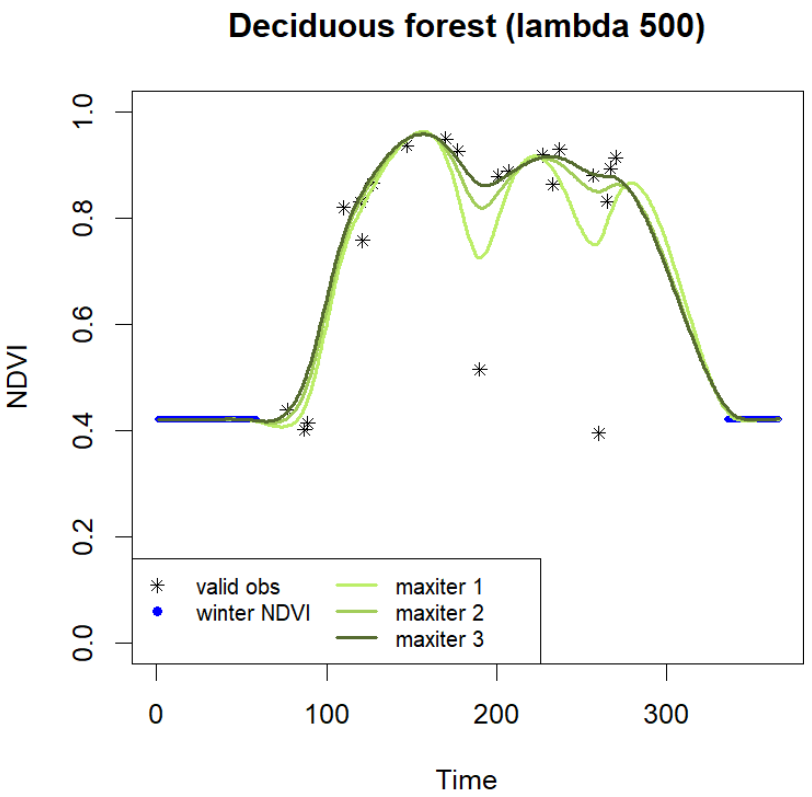


# Principle of Whittaker and adaptation to NDVI data cont.

## Apply Iterations

→ TIMESAT: adaptation to the upper envelope

- In most cases, vegetation indices generated from remotely sensed land data are negatively biased; if there are noisy observations, they most likely cause a decrease in NDVI
- The smoothing procedure often involves several steps including:
  - In the first run, the smoothing is based on the observations (if available weighted by ancillary quality data) → "maxiter 1"
  - Data values below the smoothed result are thought of as being less important. These data values are replaced by the smoothed values in the second run.
  - "maxiter 2": two runs
    "maxiter 3": three runs



# Process time series in R

Create a tibble with daily time steps (from 2017-01-01 to 31-12-2020)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | … | 1456 | 1457 | 1458 | 1459 | 1460 | 1461 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Column „date“** seq(ymd("2017-01-01"), ymd("2020-12-31"),by=1) | 2017-01-01 | 2017-01-02 | 2017-01-03 | 2017-01-04 | 2017-01-04 | 2017-01-05 | 2017-01-06 | … | 2020-12-26 | 2020-12-27 | 2020-12-28 | 2020-12-29 | 2020-12-30 | 2020-12-31 |

**Observations** (tibble with columns „date“ and „ndvi“)

| 2016-12-12 | 2017-01-04 | 2017-01-11 | … | 2020-11-14 | 2020-11-21 | 2020-12-26 |
|---|---|---|---|---|---|---|
| 0.08 | 0.25 | 0.17 | … | 0.31 | 0.15 | 0.38 |

| **Column „ndvi“: load obs with mutate join left_join(x,y,by="date")** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NA | NA | NA | obs | NA | obs | NA | … | obs | NA | NA | NA | NA | NA |

Jan-Feb Dec

| **Column „ndvi_winter“:** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | p10 | p10 | p10 | p10 | p10 | obs | NA | … | obs | NA | p10 | p10 | p10 | p10 |

mutate(month=month(date),
ndvi_winter = if_else(between(month,3,11), ndvi, winterNDVI))

| **Column „ndvi_smooth“:** smooth & interpolate | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | si | si | si | si | si | si | si | … | si | si | si | si | si | si |

mutate(ndvi_smoothed=whittaker(ndvi_winter, l=1000, minval=winterNDVI, maxval=1))

# Processing of Sentinel-2 data

## Single pixel time series

### Exercise 3-1a: Prepare and process the time series using R

As we need a temporally consistent NDVI time series for further analysis, the data will be processed with the Whittaker smoother that is available in the R library “ptw”.
Download the R scripts "whittaker.R" and “exerc3_processTS.R - template” (e.g. in ../RSTSA2021/Exerc3/).

- Install and load the libraries *"ptw" (and "nloptr"), "tidyverse", "lubridate"*
- Define and set working directory for Exercise 3
- Include the R script "whittaker.R" in your own script, e.g. *source()*
- Import data (Rdata file) from Exercise 2-2 in R using, e.g. *load()*
- Test the processing steps on one time series:
  - Filter one time series (e.g. undisturbed)
  - Create a tibble with the column “**date**” containing daily time steps (e.g. *lubridate::ymd()*)
  - Use mutate join to load ndvi observations (join by column “**date**”)
  - Calculate winter NDVI as 10th percentile of time series (e.g. *quantile()*)
  - Create column “NDVI_winter” with observations from March to November and winterNDVI from December to February
  - Create a column "ndvi_smooth" that contains the smoothed time series (e.g. lambda = 1000)
  - Prepare plot with observations and smoothed time series for different lambda (e.g. 1000,10000,50000,100000)

# Breakout Sessions

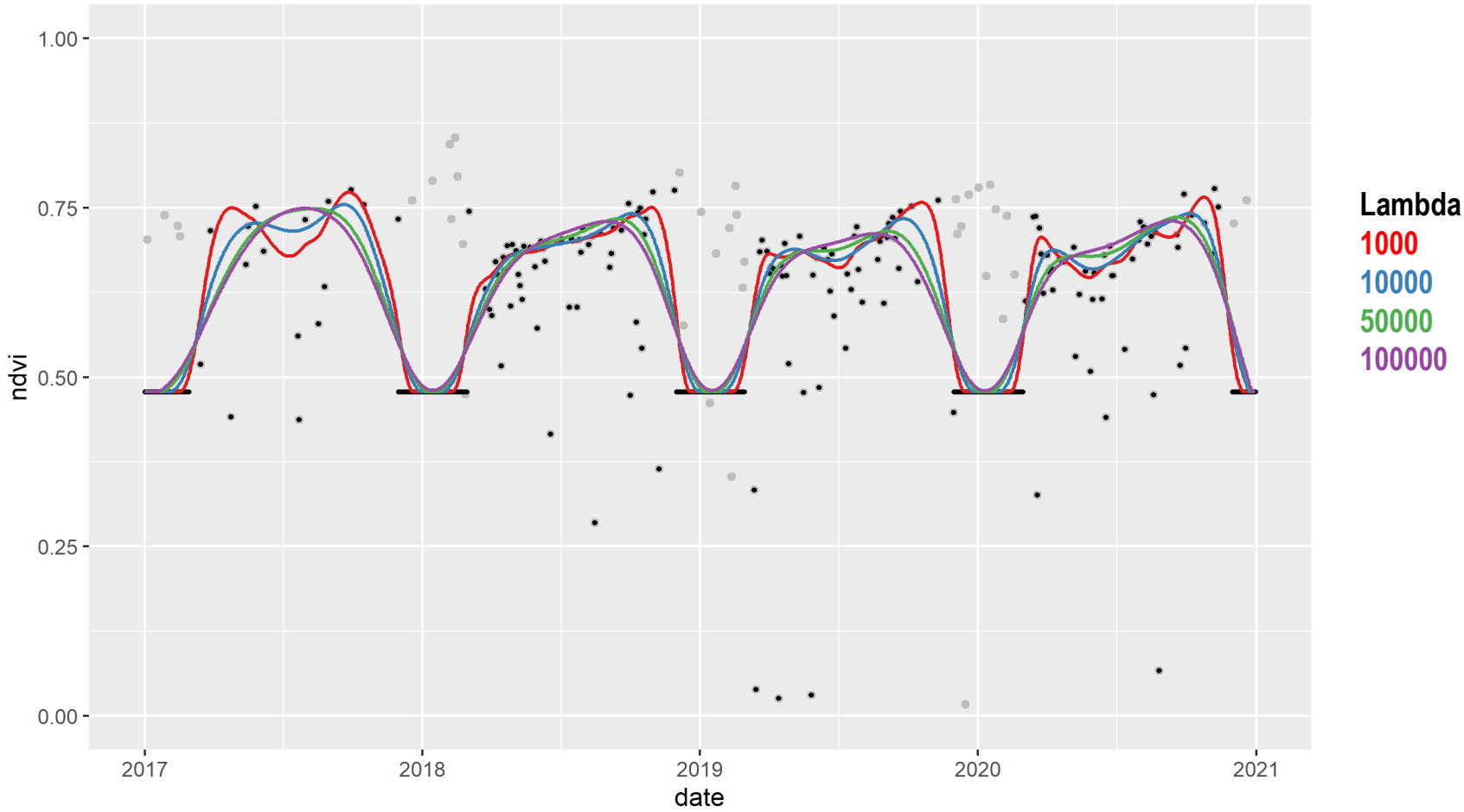
## What is the procedure?

- groups of three
- random assignment
- duration 45 min
- Task:
  Complete the code, share it and apply to your own data
  Select one study site of the group and discuss the result

## Afterwards in the main session:

- **Answer the question:** What was the most difficult thing or what was unclear?
- **Share the result of one study site in the group:** What lambda would you recommend and why?

# Result of Exercise 3-1a



# Processing of Sentinel-2 data

## Single pixel time series

**Exercise 3-1b:** Prepare and process the time series using R

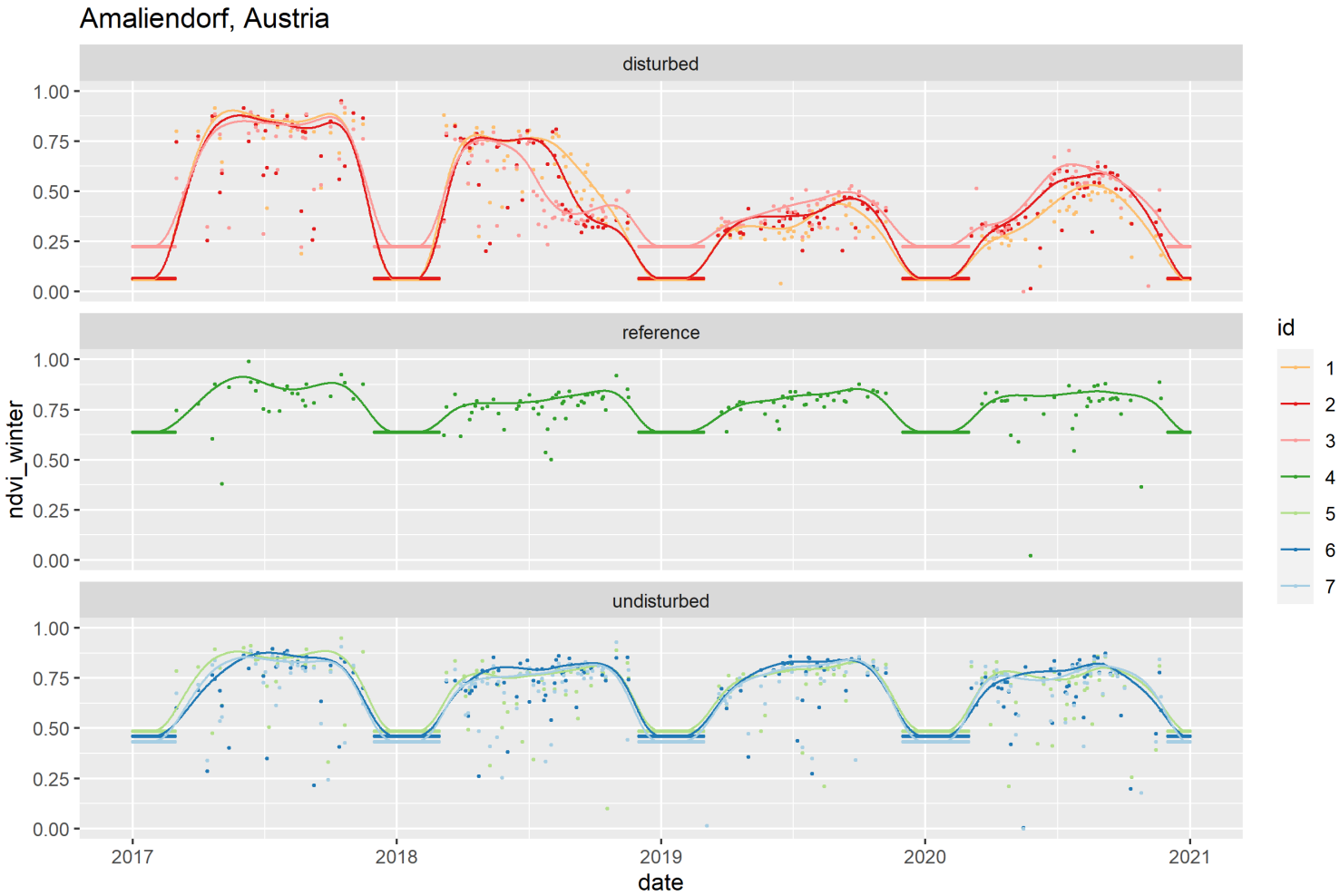
Individual work **~20 min**:

- Apply the processing steps to all time series
  - Go through the code lines and adjust to your objects, variables and lambda
- Prepare a plot similar to Exercise 2-2b with:
  - the observations including the winter NDVI as points
  - the smoothed times series as line
- Save the plot in the working directory
- Save the tibble with the smoothed NDVI data in the Rdata format using *save()*

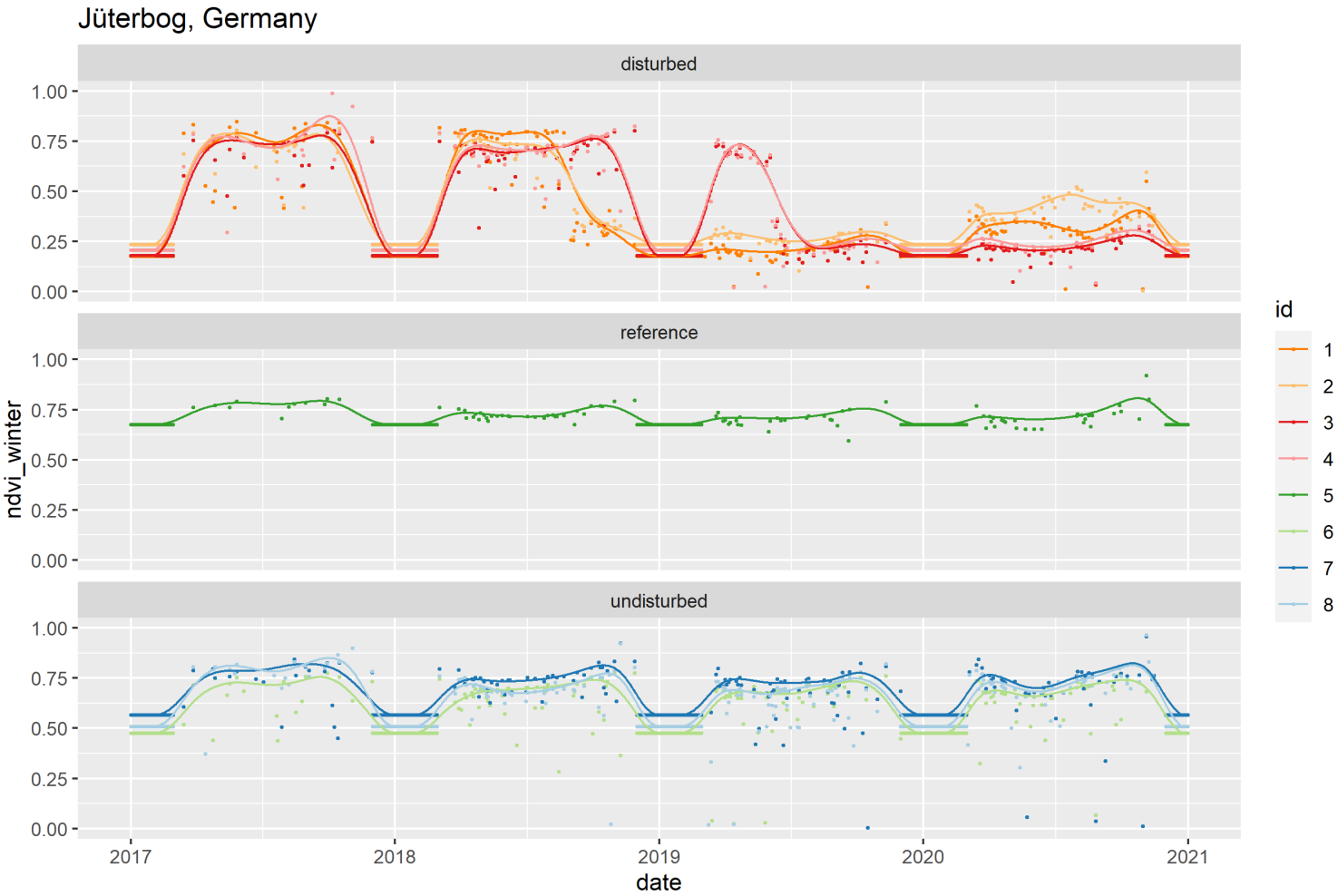
**Afterwards answer the following questions:**

- **Q1:** What was unclear?
- **Q2:** What would you have done differently?

# Results of Exercises so far …



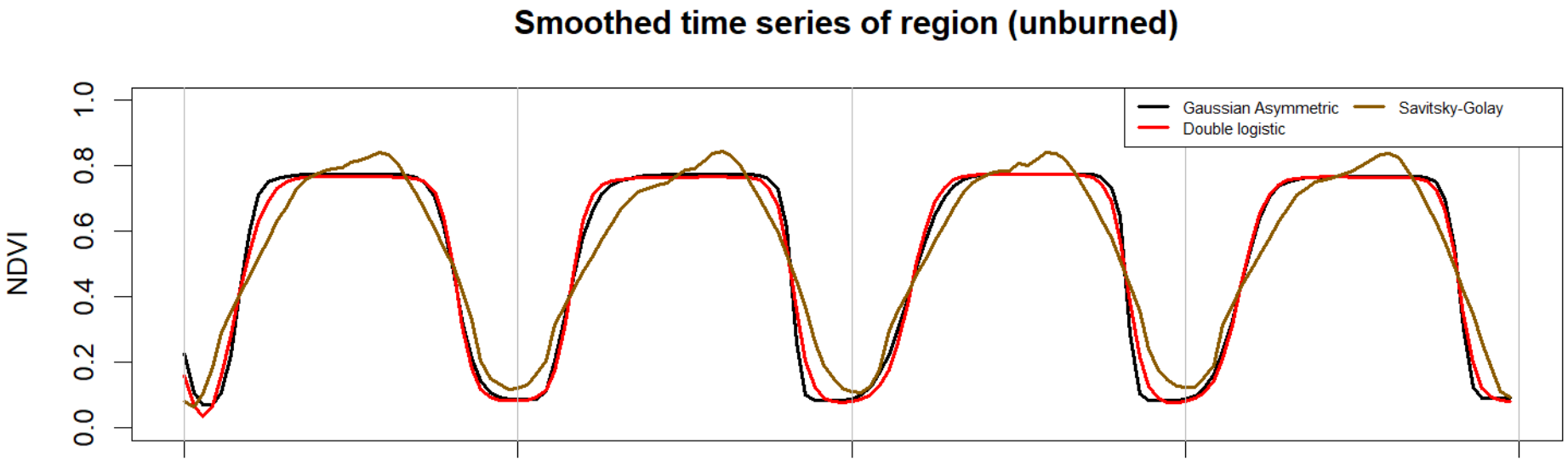
# Results of Exercises so far …



# Quality of fitting/smoothing

## How to evaluate the effectiveness or quality?

- Problem: difficult to obtain (ground-based) reference measurements for coarse resolution vegetation index time series
- Visual inspection of fitted time series or comparison against other fitting results
- Use of synthetic datasets
- Assessment of impact on further data analysis (e.g. classification, extraction of seasonality)
- …
- Plausibility checks e.g. gradual change of vegetation density → temporal persistency



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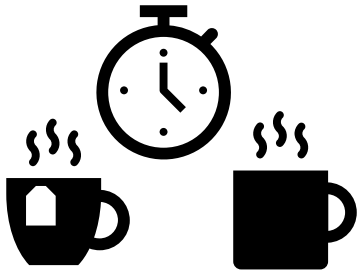
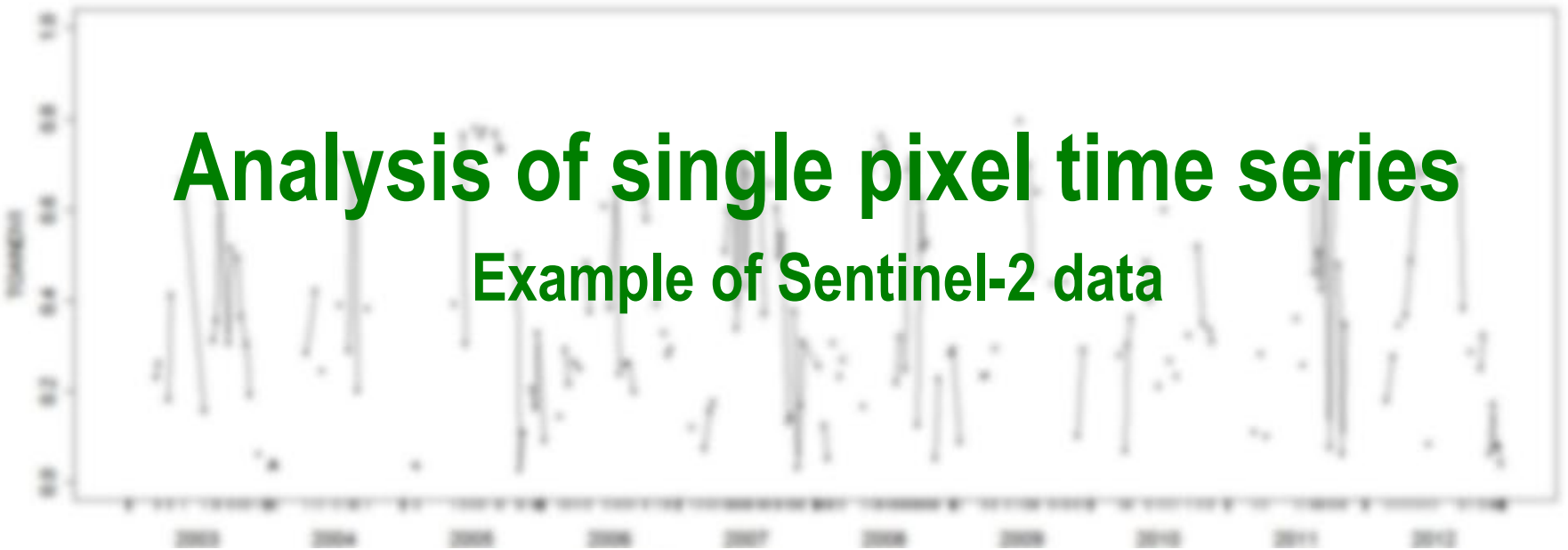
Remote Sensing Time Series Analysis

# Exercise 3: Single pixel time series II - processing and analysis



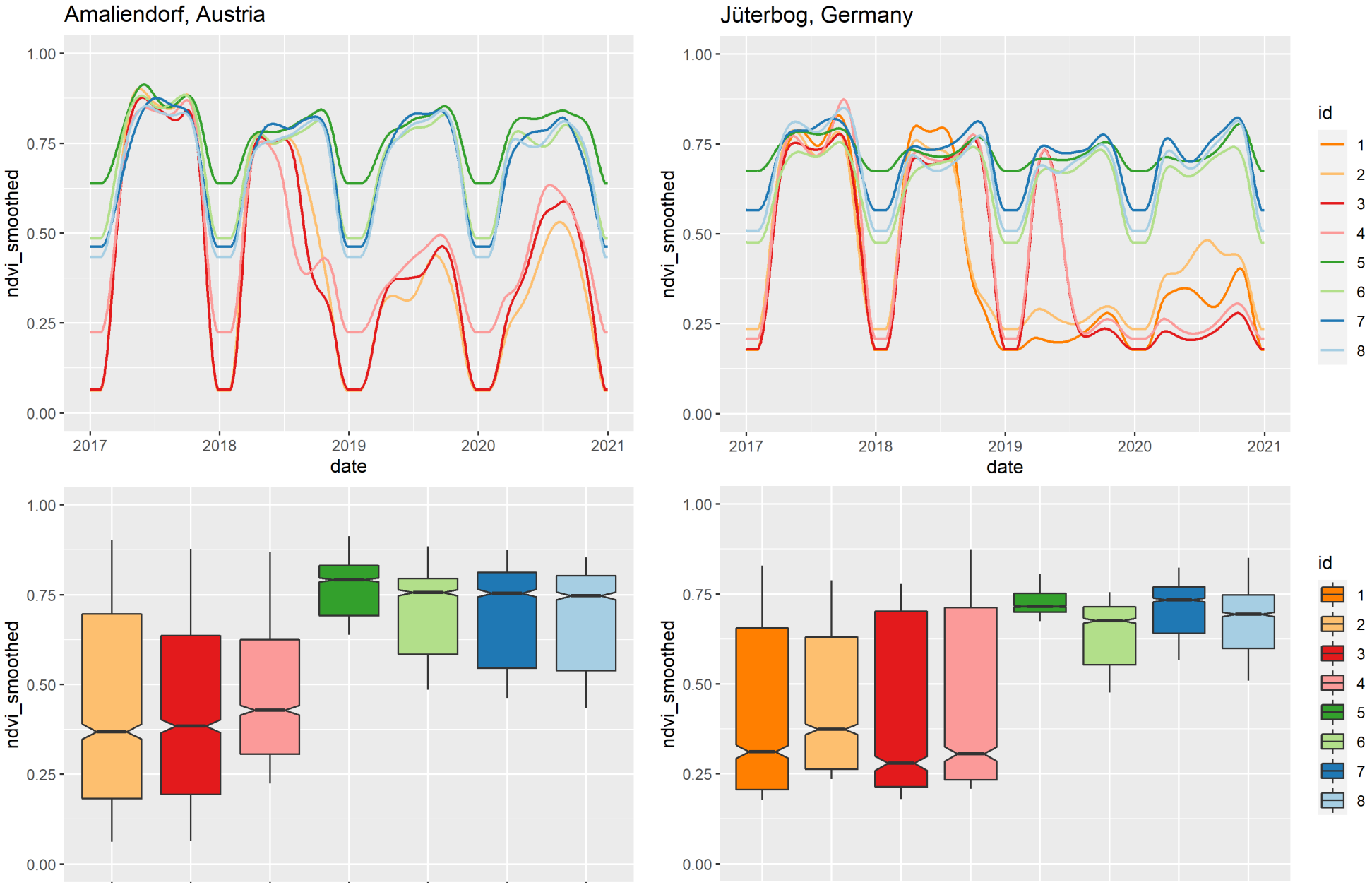
10 min



# Analysis of single pixel time series

## Example of Sentinel-2 data

# Analysis of single pixel time series

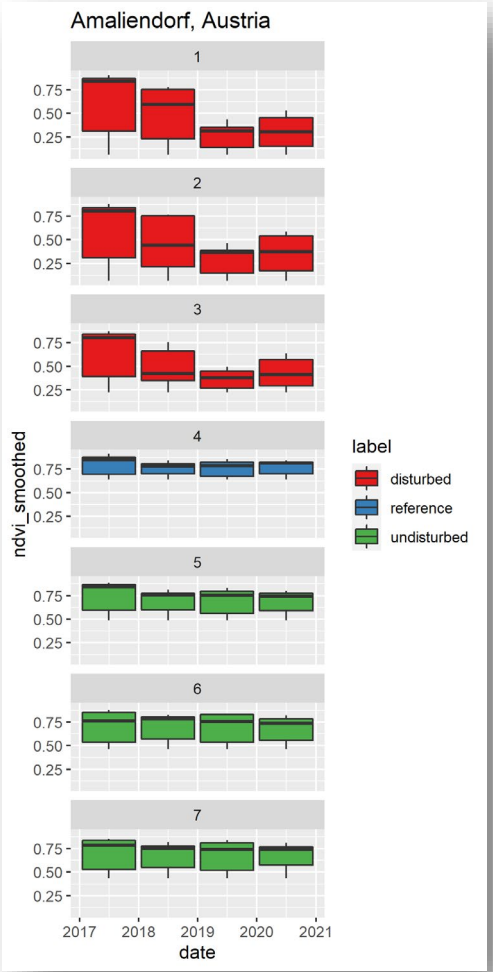


# Analysis of single pixel time series

## Exercise 3-2:

The Sentinel-2 time series have been processed with the Whittaker smoother. Use R to further explore these data with meaningful plots, e.g. display intra-annual and inter-annual variability with boxplots.

- Load the smoothed time series of Exercise 3-1 using *load()*
- Add columns with year, month, week derived from date using *lubridate* library
- Use the *ggplot2* package to prepare the boxplots; create a subplot for each id and fill boxes by label:
  - display **inter-annual variability**: create boxplots for each year over all days
  - Display **intra-annual variability**: create boxplots for each month OR week over all years
- Save the plots to png files



## Afterwards answer the questions in the main session:

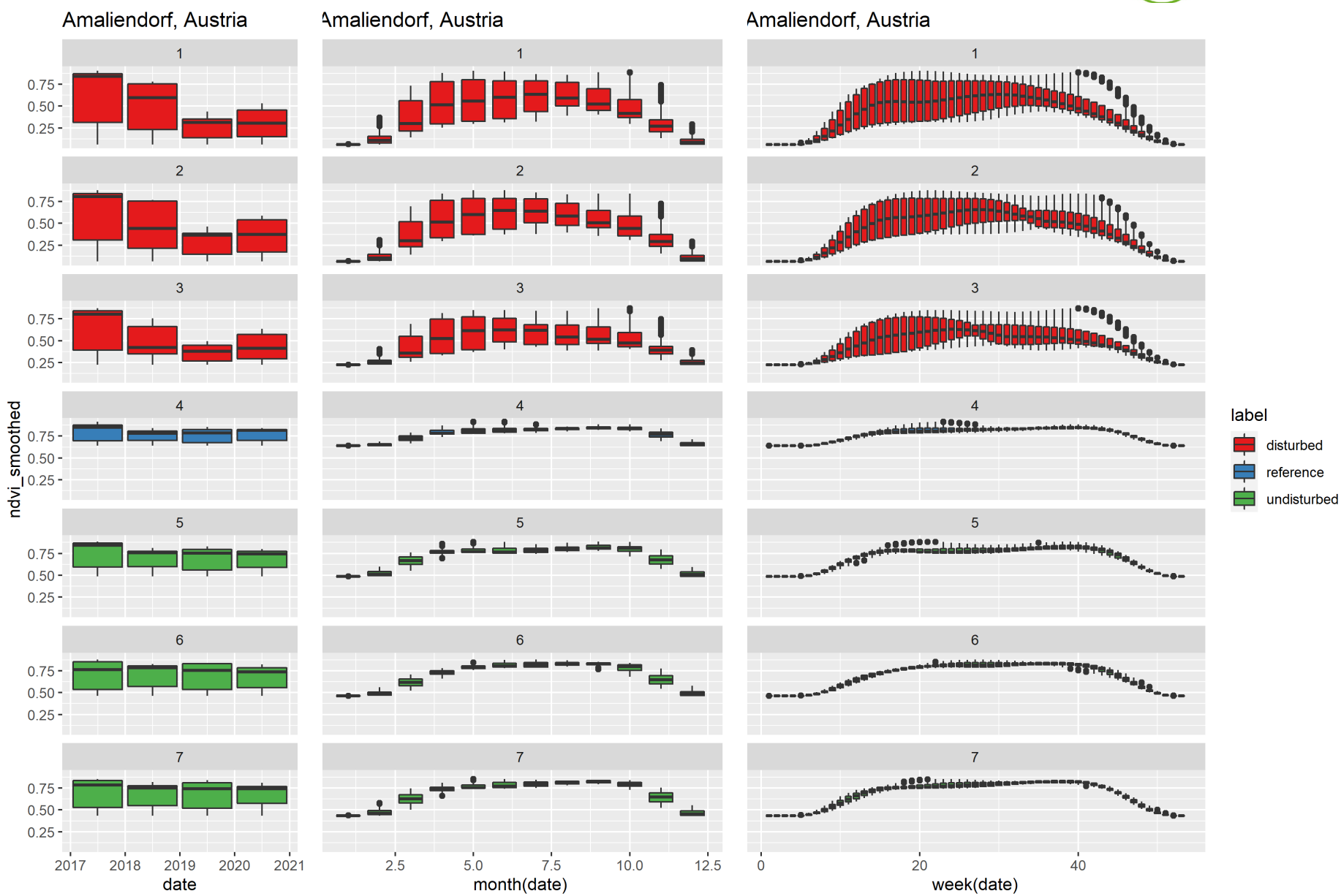
- **Q1:** Which of your time series shows the largest/smallest inter-annual variability?
- **Q2:** Which of your time series shows the largest/smallest intra-annual variability?
- **Q3:** Do the undisturbed time series have a larger variability at a particular time of the year? What could be the reason?

## You‘ve got the choice?

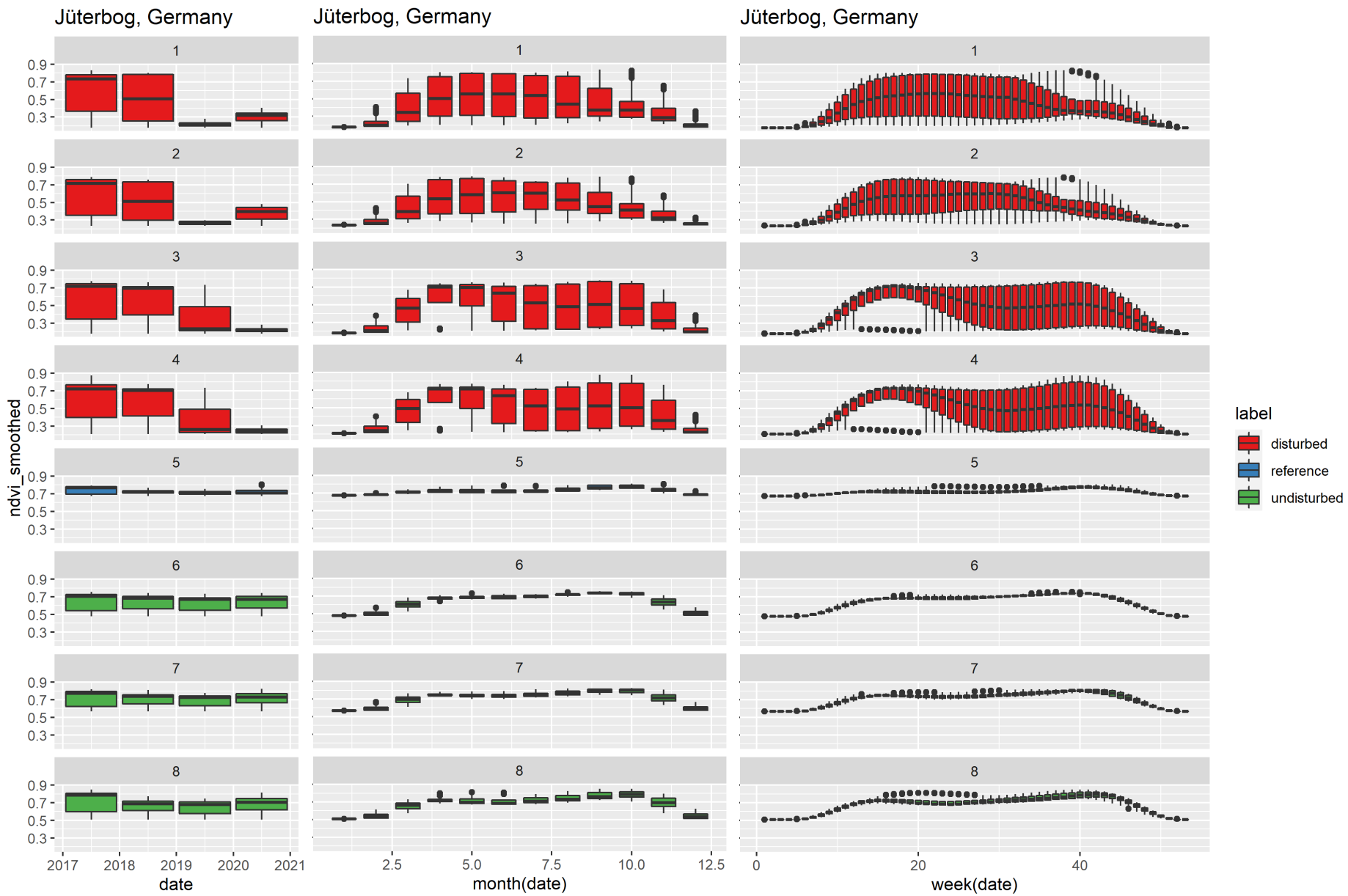
**individual** **or** **breakout session**

**→ Vote on Zoom**

# Is there a temporal variability?



# Is there a temporal variability?



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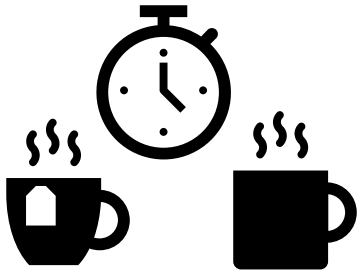
# Exercise 3: Single pixel time series II - processing and analysis



2 min

# Analysis of single pixel time series

## Exercise 3-3:

**Objective:** Develop a methodology for detecting wildfires in natural vegetation (e.g. forests) using the smoothed Sentinel-2 NDVI time series.

**Patterns in vegetation time series:**

- Trend
  - Gradual changes such as inter-annual climate variability, e.g. trends in mean annual rainfall, greening or browning of global drylands
  - Gradual change in land management or land degradation
  - Abrupt changes such as disturbances, e.g. storms, floods, fires, insect infestation, pathogens
- Season
  - Ecosystem specific response, e.g. driven by climate, soils, vegetation type and topography
  - Changes in land cover type, e.g. deforestation, urbanization, farming
  - Inter-annual variations in response to weather fluctuations
- Cyclic

...

# Anomaly: deviation from normal behaviour

- **Standardise the smoothed NDVI of each time step:**

= distance between the raw score and the population mean
in units of the standard deviation

→ z-score or standard score

$$Z\,score_i = \frac{NDVI_i - MEAN_t}{STDEV_t}$$

t = 1, …, nptperyear
i = 1, … , n

nptperyear = number of data values per year
n = number of time steps in time series

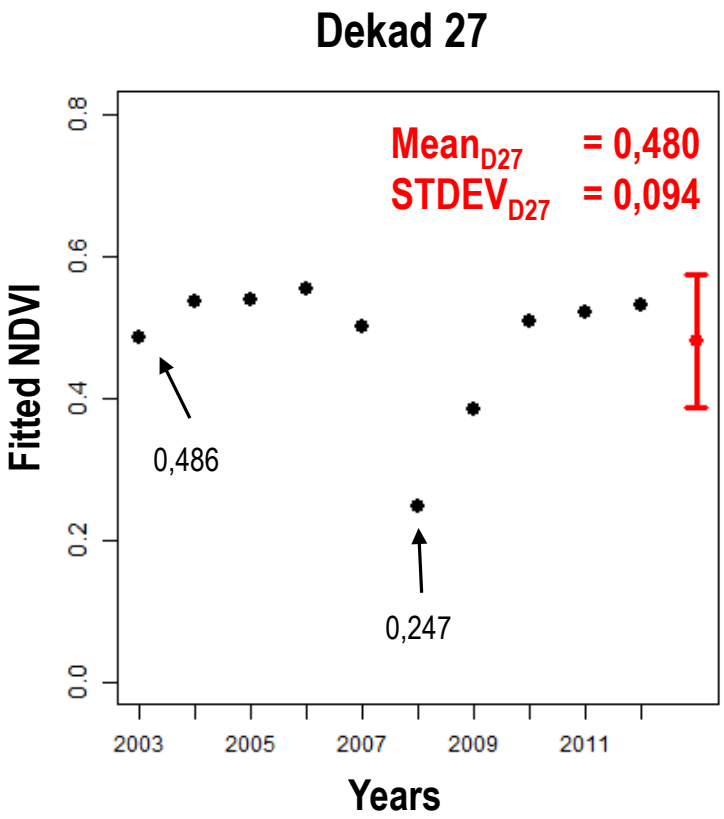
→ disturbances, e.g. storms, floods, fires, insect infestation, pathogens: negative deviation
negative deviation, persisting over time, slow recovery

→ Sentinel-2 data only became available in 2015 (here: 2017)

→ Use reference time series, assuming that it reflects the average undisturbed situation of the past years

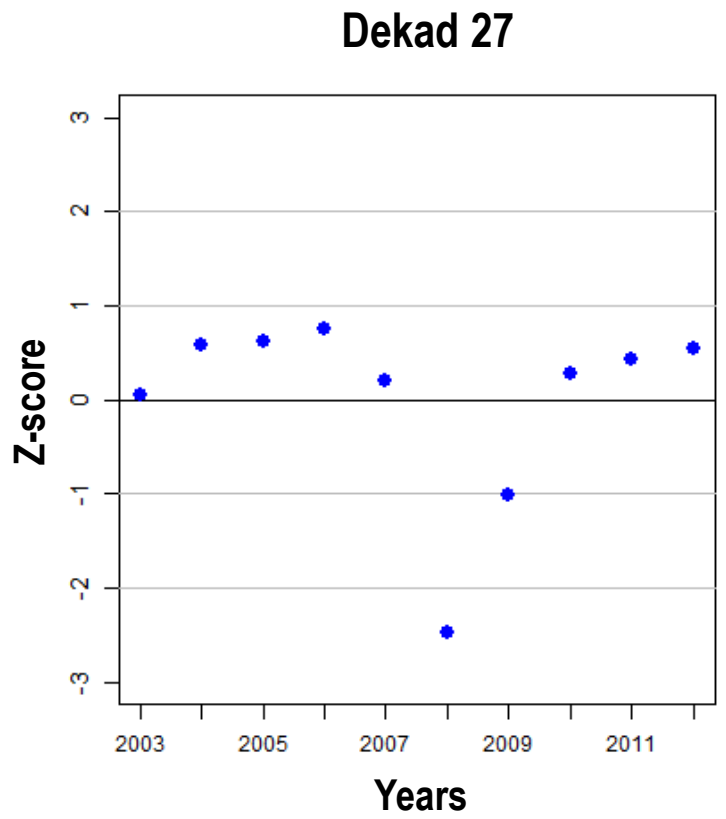
# Calculation of 10-daily z-score

- **Standardise the smoothed NDVI of each time step:**
  = distance between the raw score and the population mean in units of the standard deviation

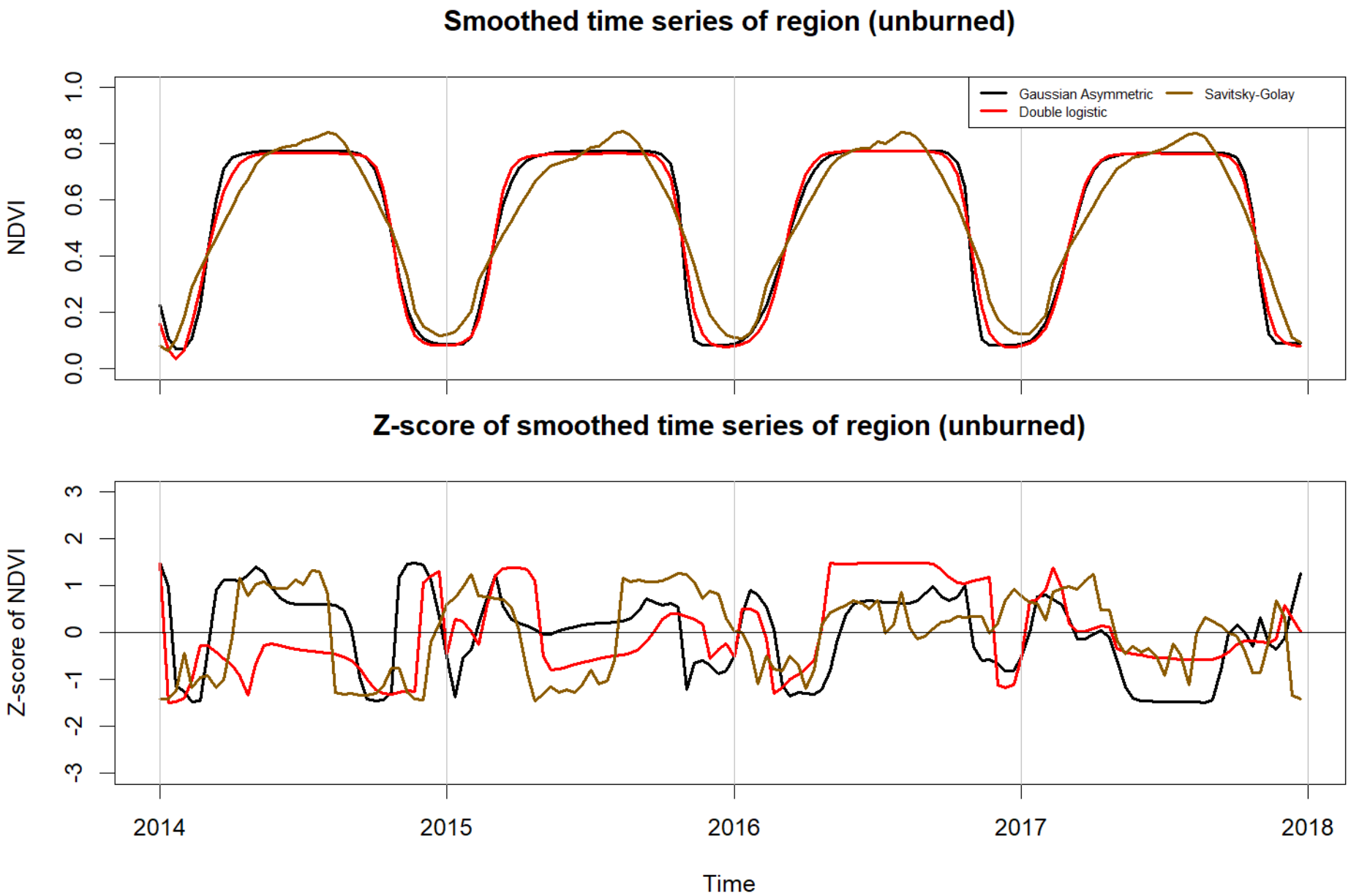



$$Z\ score = \frac{0{,}486 - 0{,}480}{0{,}094} = +0{,}063$$

$$Z\ score = \frac{0{,}247 - 0{,}480}{0{,}094} = -2{,}479$$



# Calculation of 10-daily z-score

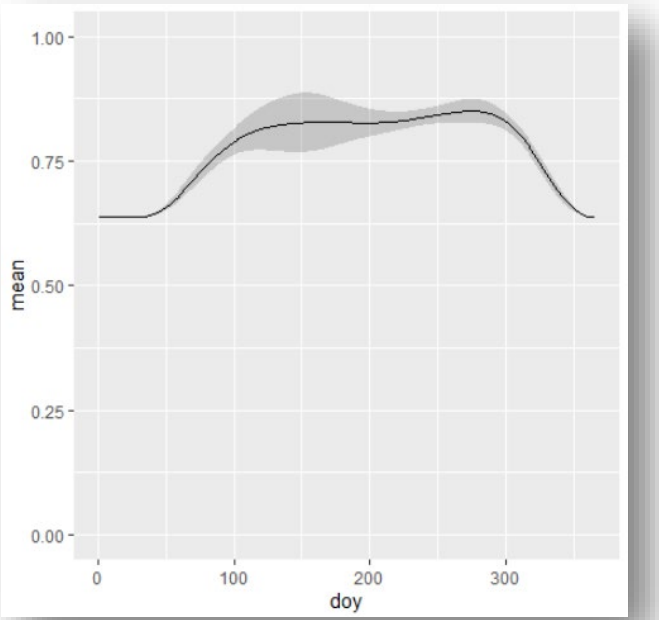


# Analysis of single pixel time series

## Exercise 3-3a: Write an R script for calculating and plotting the z-score

**Together in main session:**

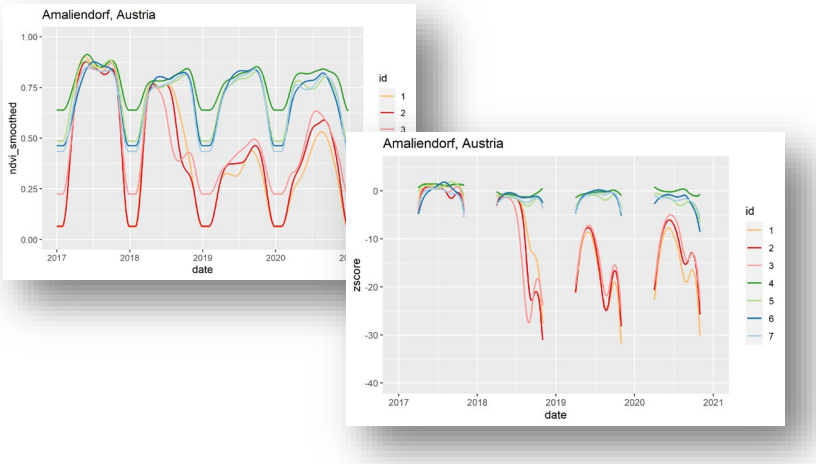
- Use the smoothed time series of Exercise 3-1
- Calculate daily mean and standard deviation from reference time series
- Check the result of the calculations e.g. plot mean with *ggplot2::geom_ribbon* and *sd with ggplot2::geom_line*



# HOMEWORK

## Exercise 3-3b: Write an R script for calculating and plotting the z-score

- Use the smoothed time series of Exercise 3-1
- Calculate daily z-score for all time series only form March to November (otherwise NA)
- Plot smoothed NDVI and z-score of all time series with different colors using the *ggplot2* package




**→ Finalise the script and apply it to your data until the next lesson on 26.05.2021**

### Answer the following questions:

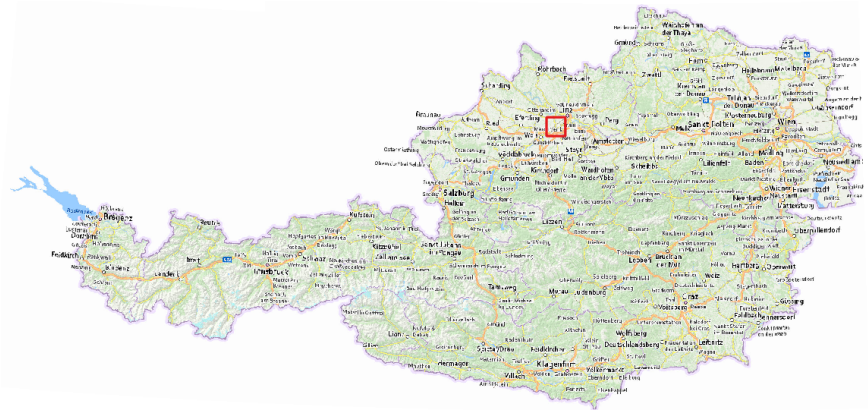
- **Q1:** Is there a year with a particularly high z-score?
- **Q2:** Do the disturbed time series show lower z-scores as expected?
- **Q3:** Are there particularly lower z-scores at beginning/end of the year? If so, why?
- **Q4:** Is there a feature in the data that you can not explain?

# Preparation of Exercises 4 & 5:

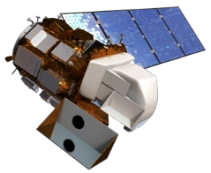
## Case study vegetation/crop types in Upper Austria

### Objective

Develop a tool (methodology)
to control the farmers declarations for the
Integrated Administration and Control System
(IACS) of the European Commission



Use the Harmonized Landsat Sentinel-2 data



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# HOMEWORK

## Learn about the HLS data

The Harmonized Landsat Sentinel-2 (HLS) project uses data from the joint NASA-USGS Landsat 8 and the European Space Agency's (ESA) Sentinel-2 series satellites to generate a harmonized, analysis-ready surface reflectance data product available every two to three days.

*https://www.usgs.gov/media/audio/eyes-earth-episode-45-harmonized-landsat-sentinel*

https://earthdata.nasa.gov/learn/data-chat/data-chat-jeff-masek

**→ Listen to the podcast until the next lesson on 26.05.2021**
**→ If not yet done, please install QGIS**

## The complete R script of todays exercises will be available on BOKUlearn:

*Rscript: exerc3_processTS - final*

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