Environmental analysis using satellite image time series in R

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OpenGeoHub Summer School 2023

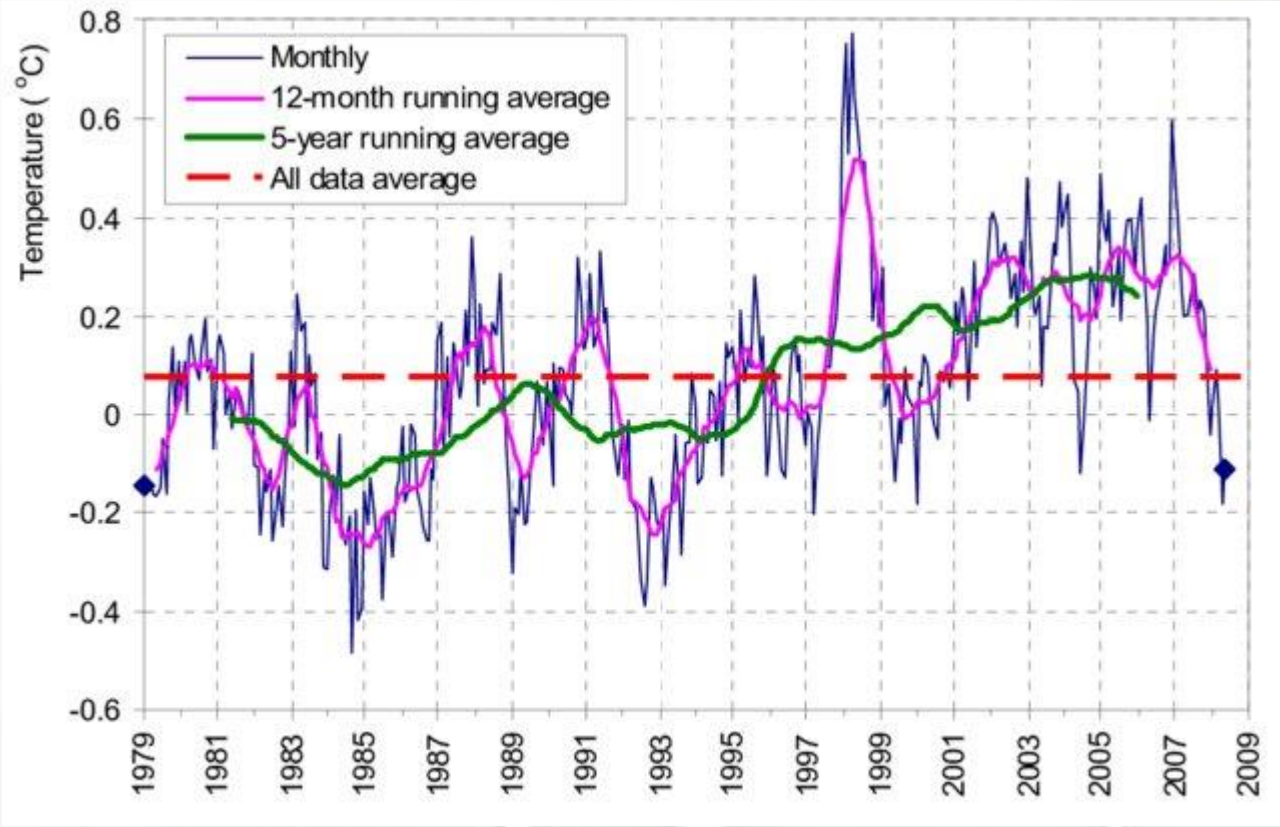
What are satellite image time series?

- Collection of repeated observations or measurements obtained by satellites over a specific geographical area over a period of time
- Observations typically captured at regular intervals but, particularly in the case of optical imagery often irregular due to clouds
- Can be also regular products, like 8-day series from MODIS
- Useful in a wide range of applications, telling us how different objects or places have changed over time

Applications

- Agriculture
- Forestry
- Climate change modeling
- Glaciers monitoring

And many more!



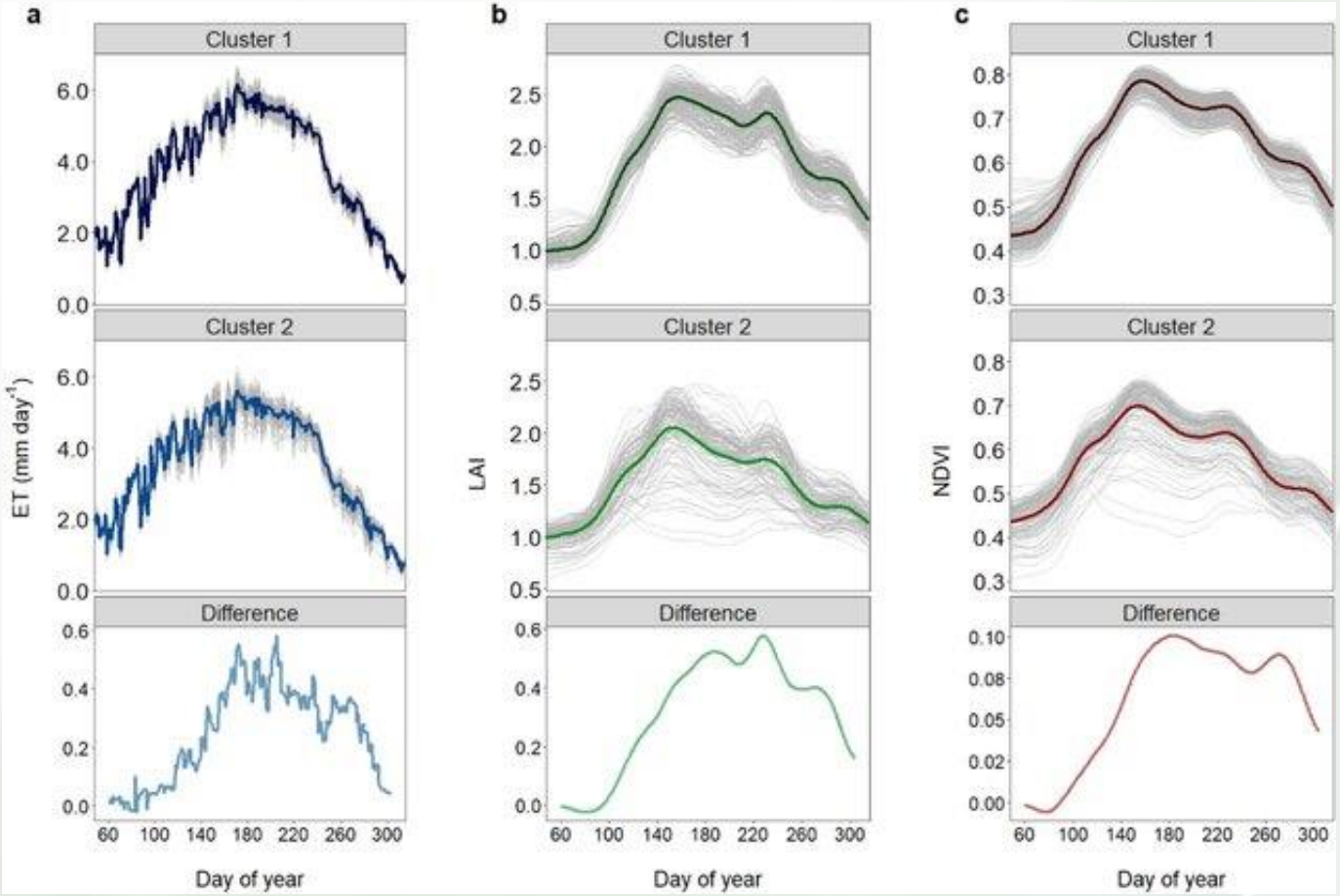
time series of global average of temperature of the lower troposphere as e stimated from satellite observations

https://www.researchgate.net/publication/241712557_Climate_hydrology_and_freshwater_towards_an_interactive_incorporation_of_hydrological_experience_into_climate_research-DISCUSSION_of_The_implications_of_projected_climate_change_for_freshwater_resourc

Agriculture - vineyards

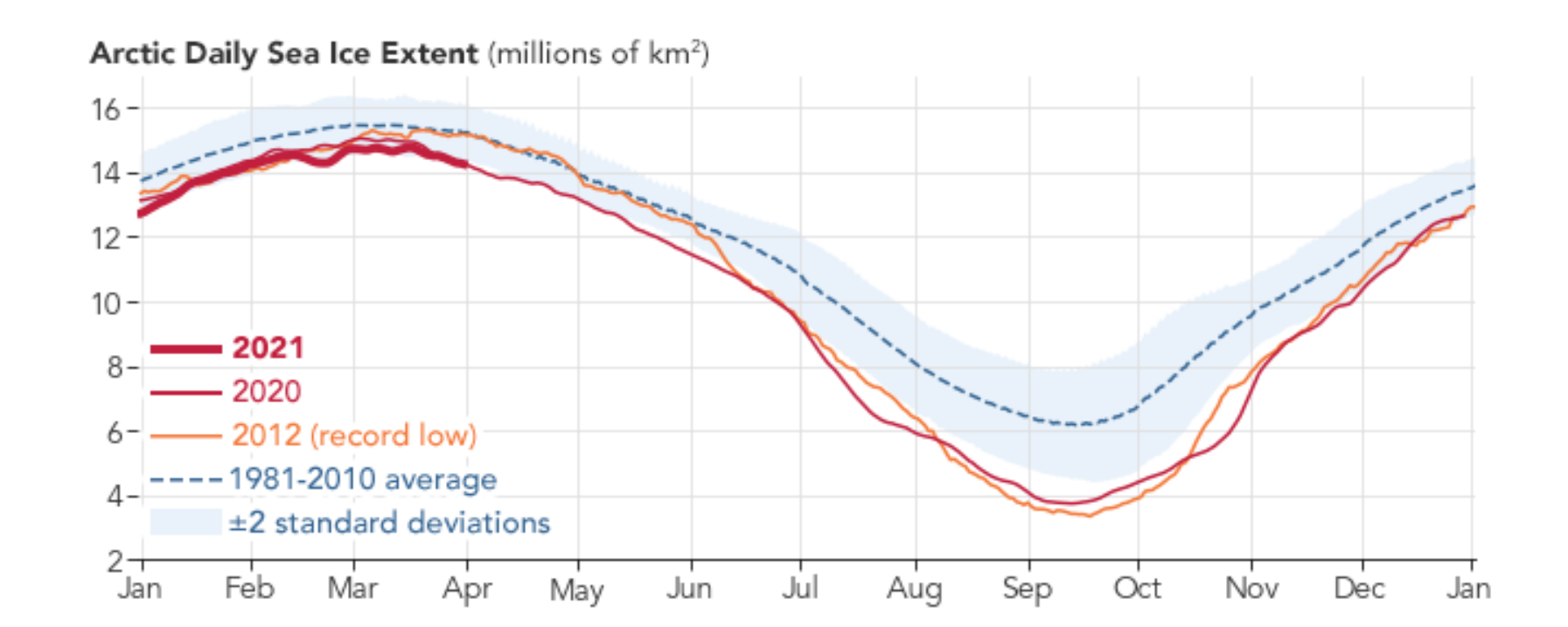
Time-series clustering of remote sensing retrievals for defning management zones
in a vineyard

https://www.researchgate.net/publication/355385813_Time-series_clustering_of_remote_sensing_retrievals_for_defining_management_zones_in_a_vineyard/figures?lo=1



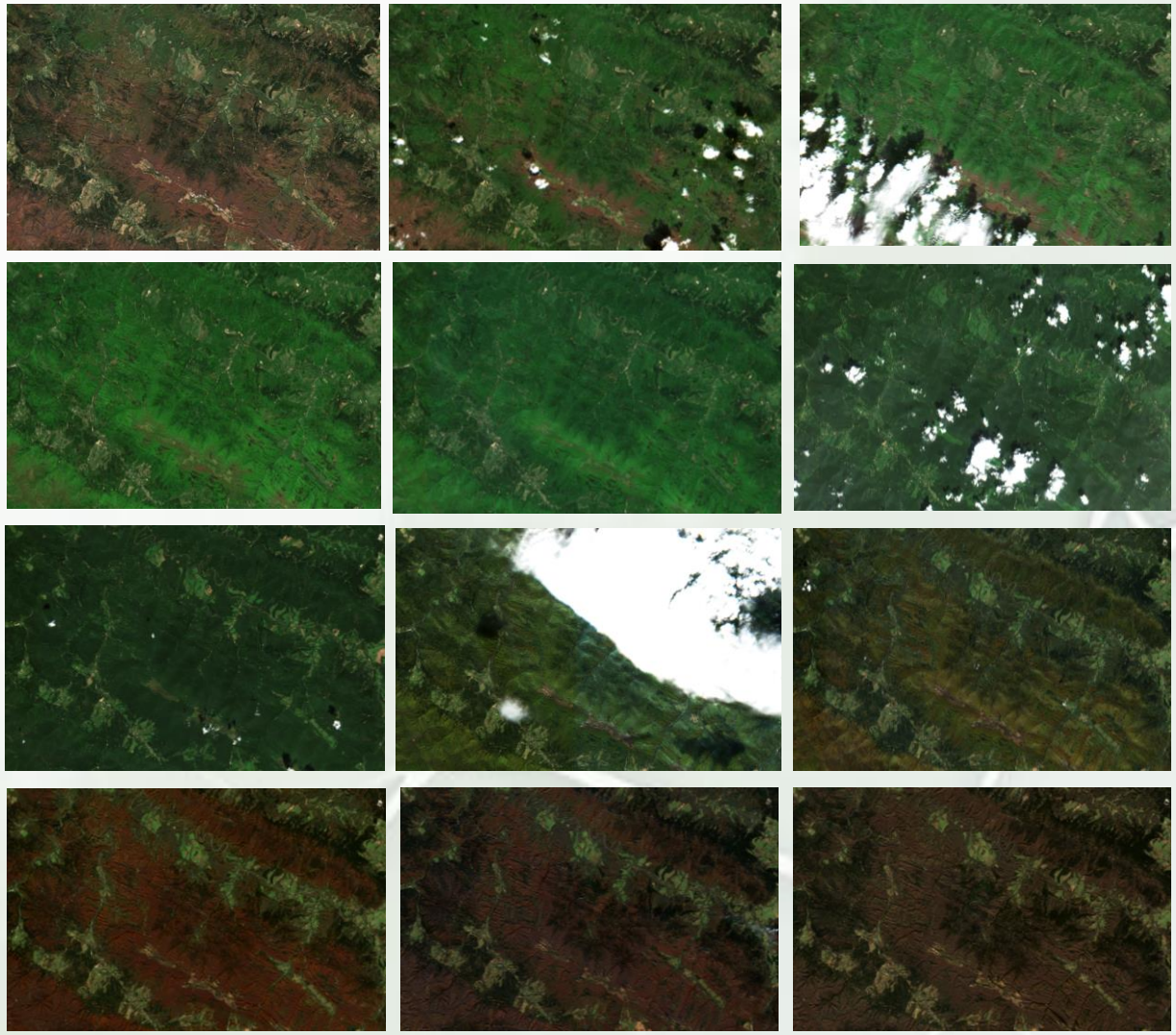
Ice extent

- https://earthobservatory.nasa.gov/world-of-change/sea-ice-arctic



Satellite time series

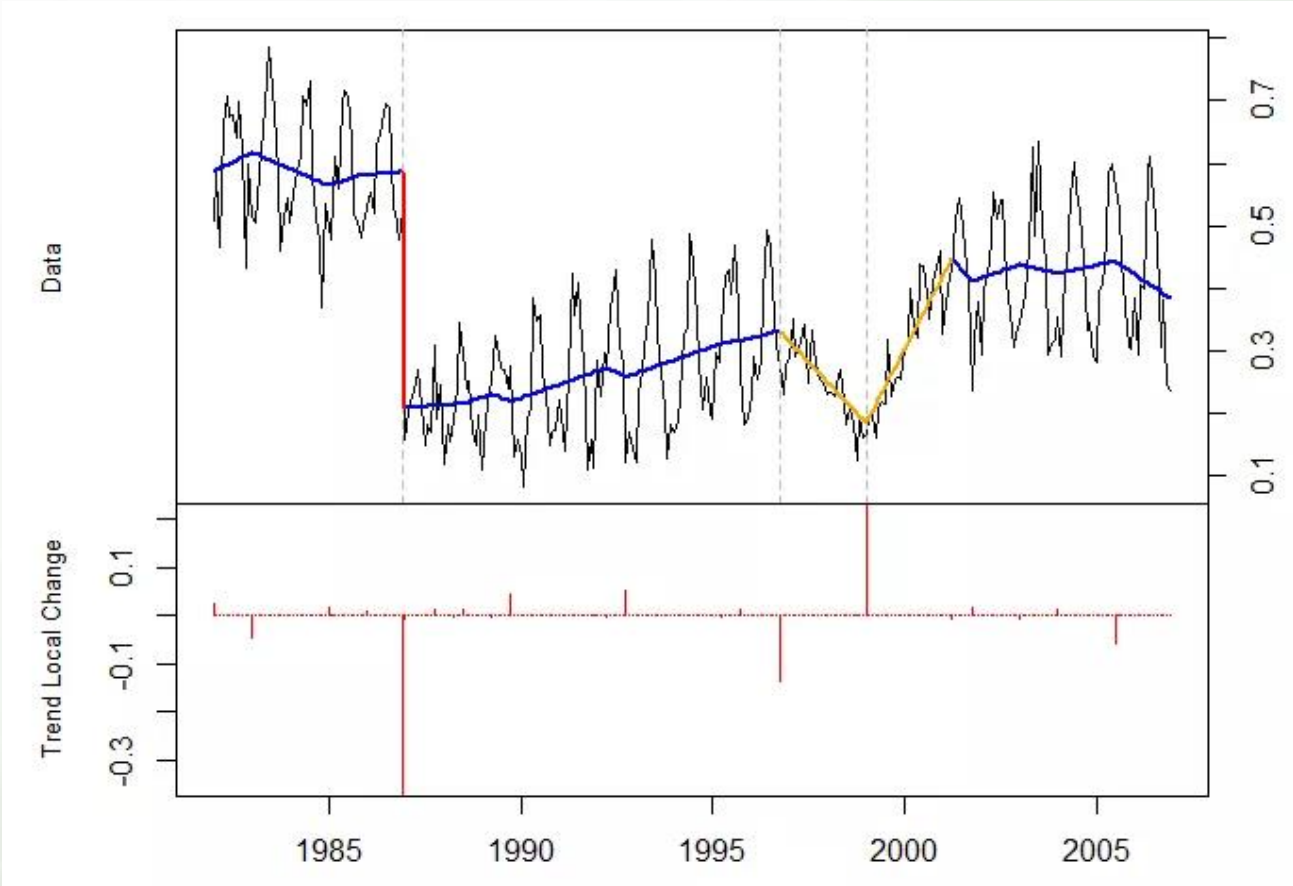
- Require pre-processing, such as cloud masking, removing outliers
- After that, can be fitted (smoothed)



Types of changes

- seasonal changes, such as related to phenology
- abrupt changes, e.g., forest logging, new built-up area or reservoir
- gradual changes - increasing or decreasing trends
- seasonal abrupt changes, e.g., meadow mowing

DBEST change detection algorithm - NDVI time series (black): the estimated trend component (ilue) one abrupt change (red) and two gradual changes (orange).



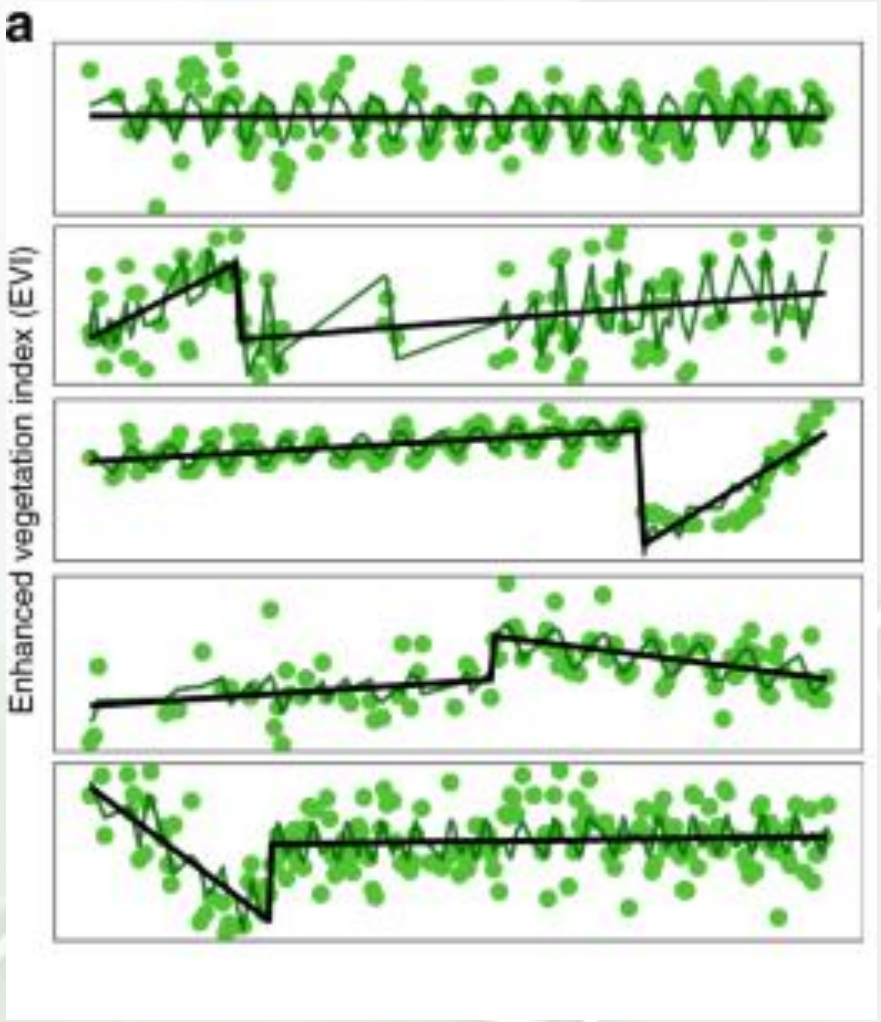
https://www.nateko.lu.se/research/remote-sensing-and-earth-observation/lund-earth-observation-research-group/time-series-analysis-remote-sensing

Abrupt changes

https://www.nature.com/articles/s41467-019-13452-3

Changes in land cover/use derived from enhanced vegetation index (EVI) :

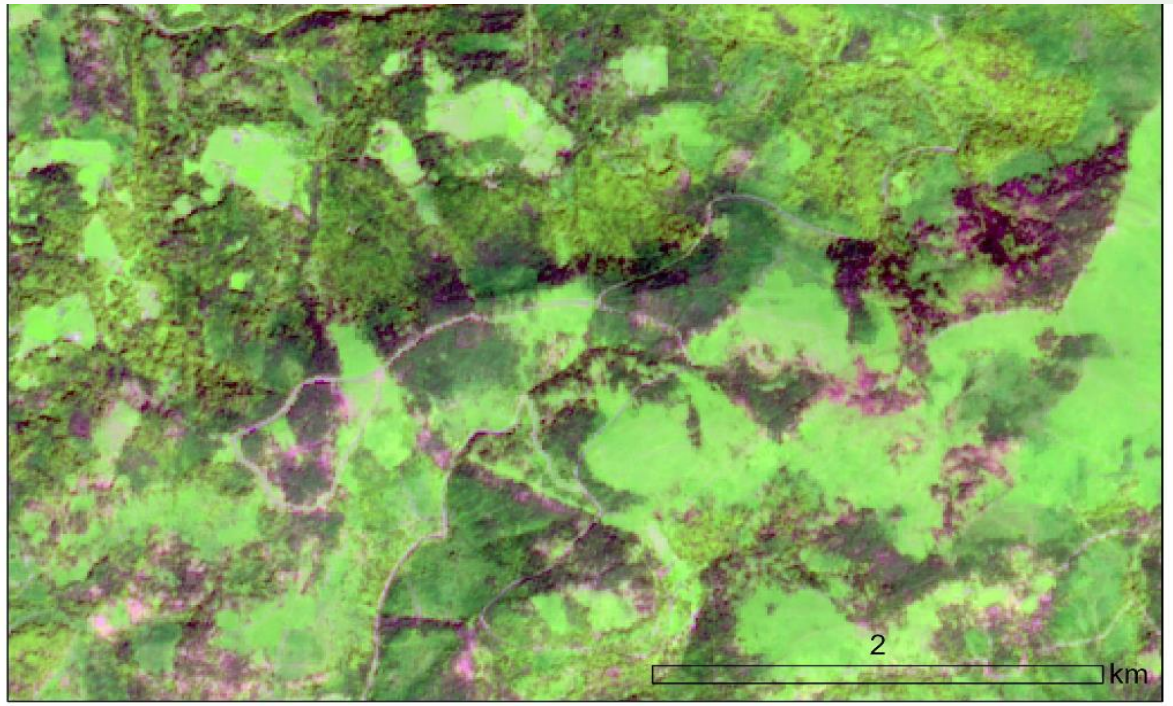
- unchanged site (top panel)
- four sites with an abrupt change (both increase and decrease in EVI).
- black lines represent linear and dark green lines - seasonal fits of the change detection algorithm

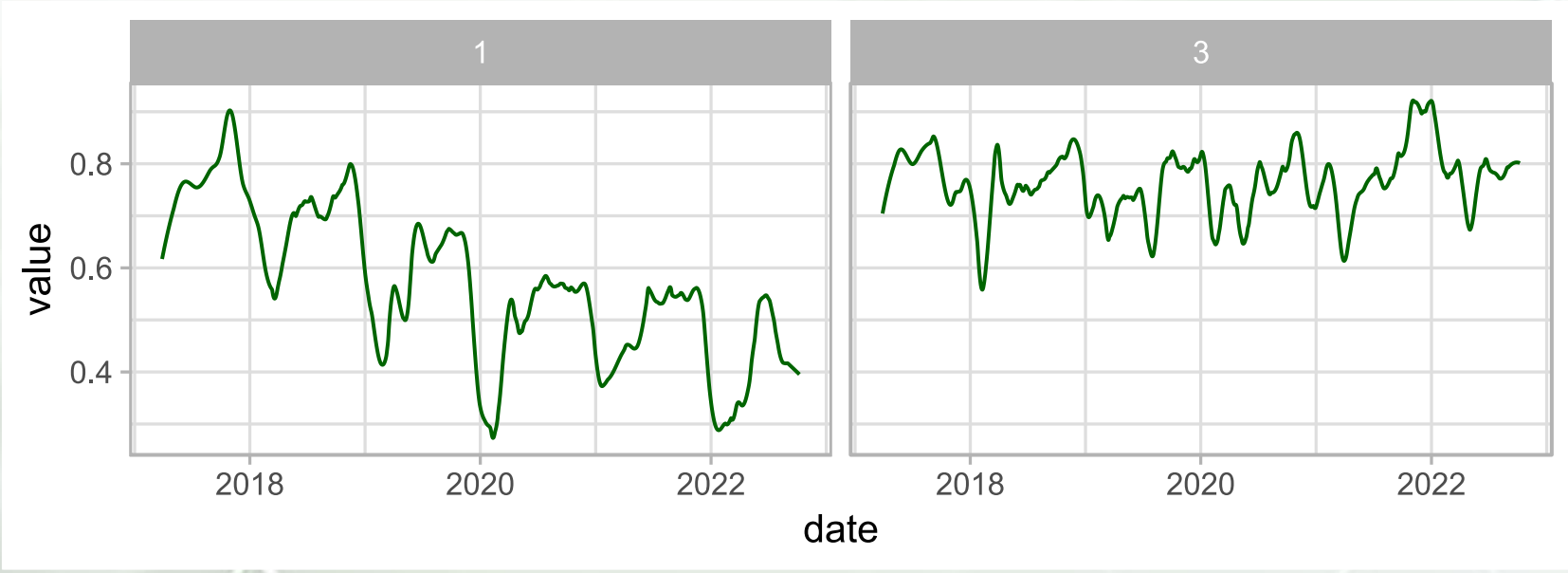


Source: Jung, M., Rowhani, P. & Scharlemann, J.P.W. Impacts of past abrupt land change on local biodiversity globally. *Nat Commun* **10**, 5474 (2019). https://doi.org/10.1038/s41467-019-13452-3

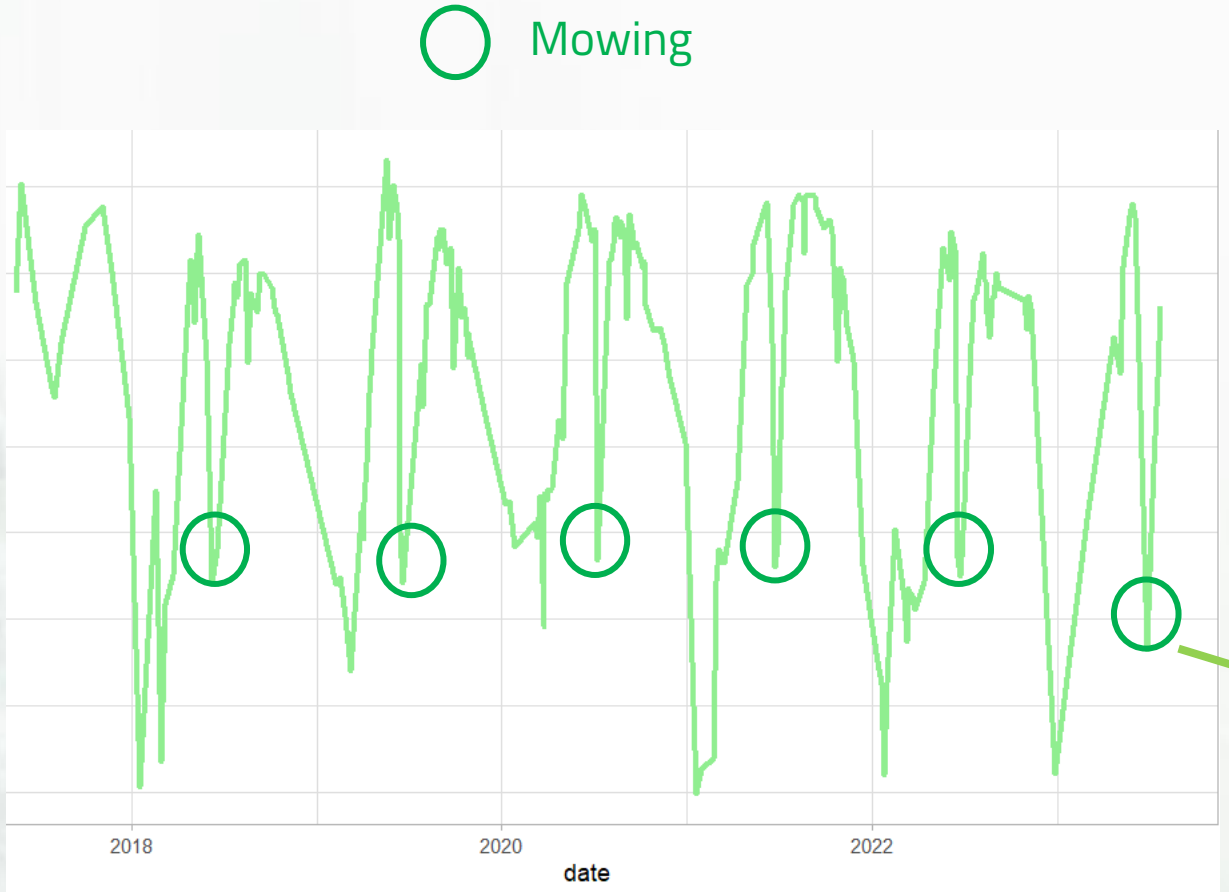
Gradual changes

- Norway spruce disturbances in Beskid Śląski





Can we detect when grassland are mowed?



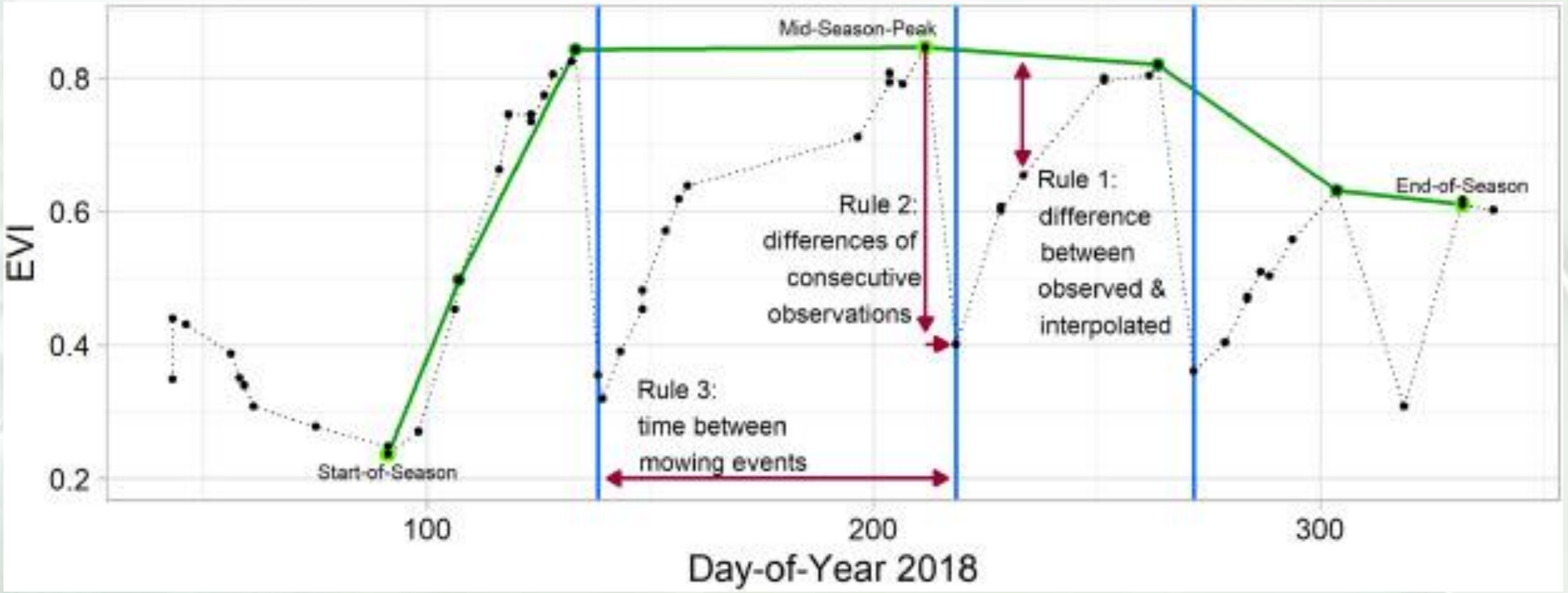
18/06/2023

03/07/2023

26/06/2023

16/07/2023

Example of detecting meadow mowing



Source: https://www.sciencedirect.com/science/article/pii/S0034425721005150

Workshop plan

1. Analyzing STS using GAM and Savitzky-Golay – example of trees phenology based on Sentinel-derived MTCI (vegetation index related to chlorophyll content)
    - *Tree species*

2. Detecting trends, changes and breaks in STS based on NDVI (Normalized Difference Vegetation Index):
    - *Poznań – new built-up area*

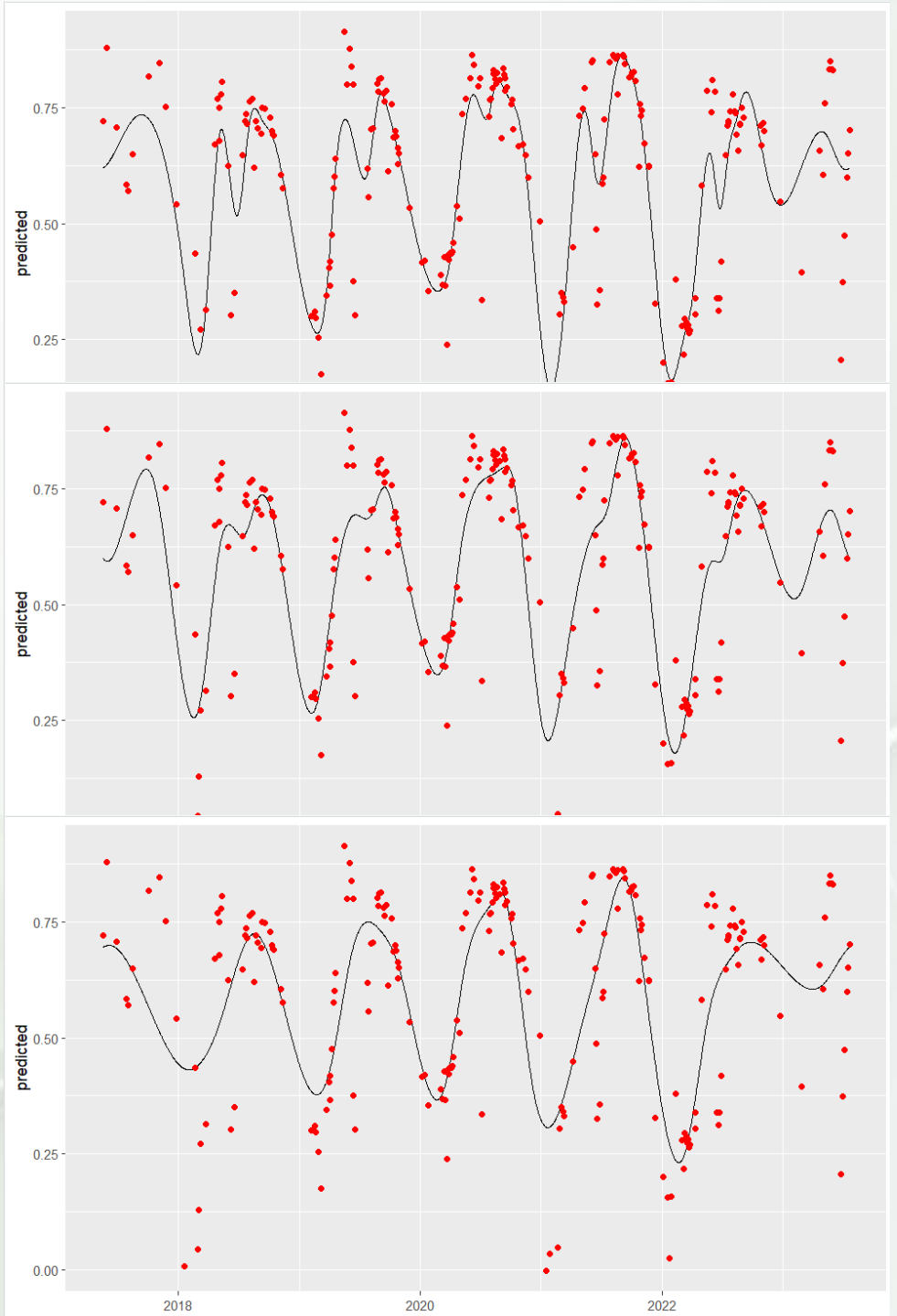
3. Introducing SITS package*

Smoothing time series

- Removing noise in time series
- Types:
  - **Moving average** - statistic capturing the average change in a data series over time. It calculates mean values in selected window length, e.g. 5 or 10 days
  - **Savitzky-Golay** - is a generalization of the moving average. Instead of the calculating mean in selected window length, it fits a polynomial of a given order over each window.

GAM

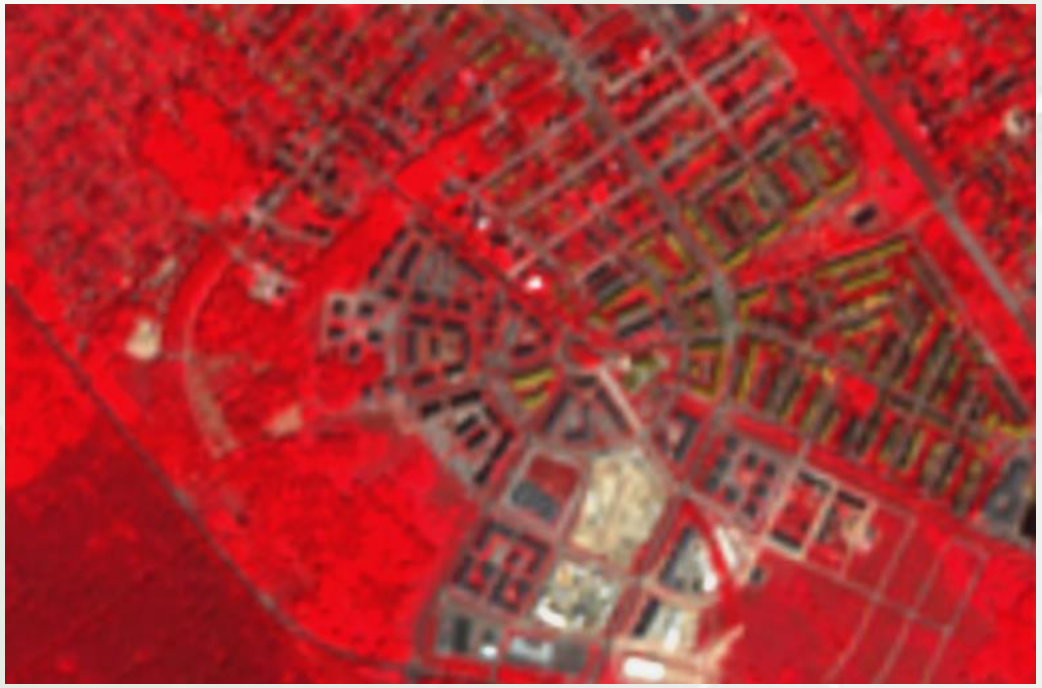
- Generalized Additive Models - allows to model non-linear data
- Coefficients from linear regression are replaced with a flexible function which allows nonlinear relationships
- This flexible function is called a spline (can be set to polynomial and quadratic or more complex thin-plate and Duchon splines)
- Measurements do not have to be evenly spaced
- Date as a predictor variable; k – knots number
- Figure is showing k decreasing k from 48 to 24



What is the history behind pixels?

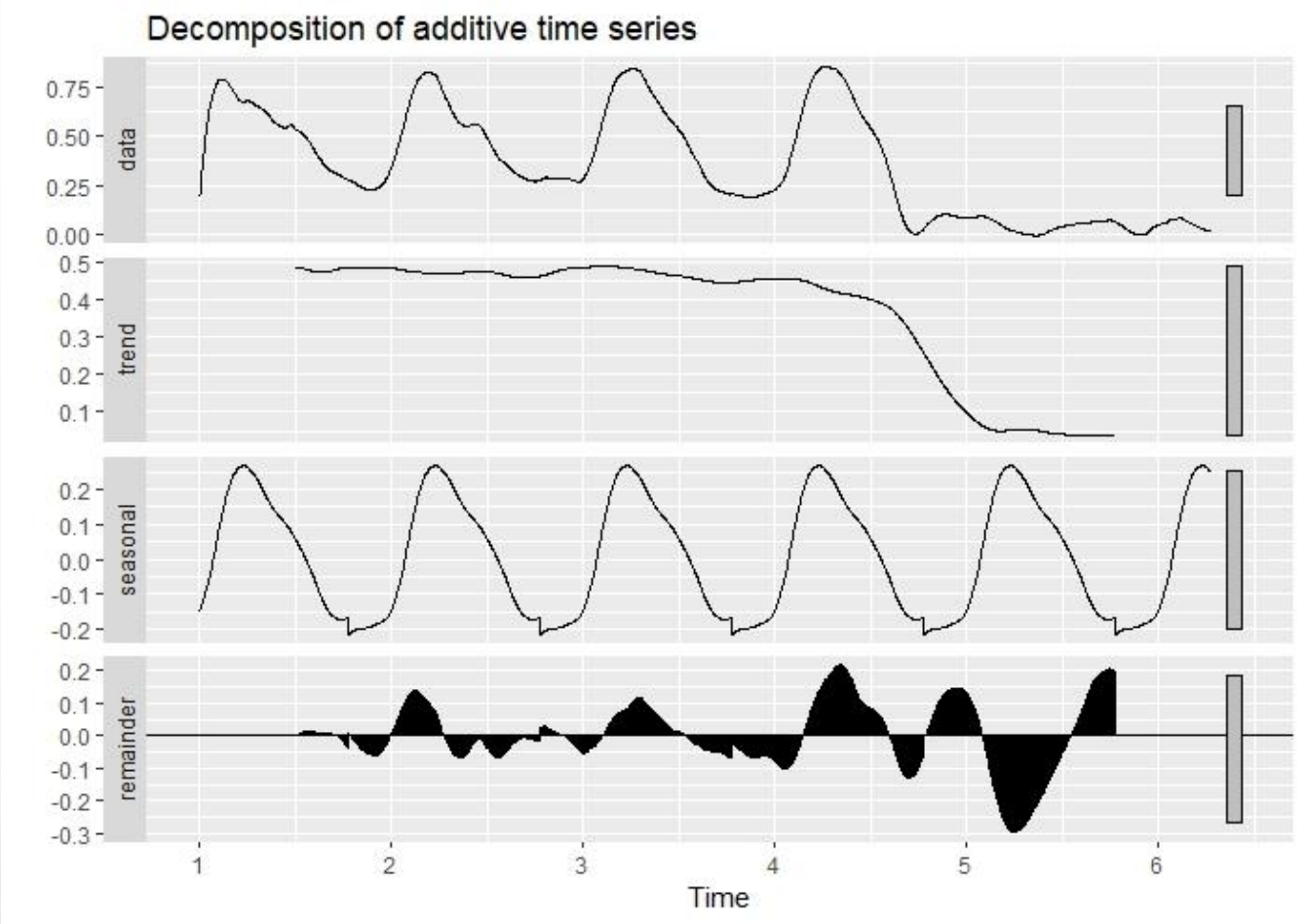
- Decomposing time series – trend detection
- Breaks detection

2017 vs 2023



Time series decomposition

- Trend, seasonal and remainder component:
    1. Estimate the trend
    2. „De-trend" time series
    3. Estimating seasonal factors on de-trended data
    4. Estimating random (irregular) component
- decompose() vs stl()

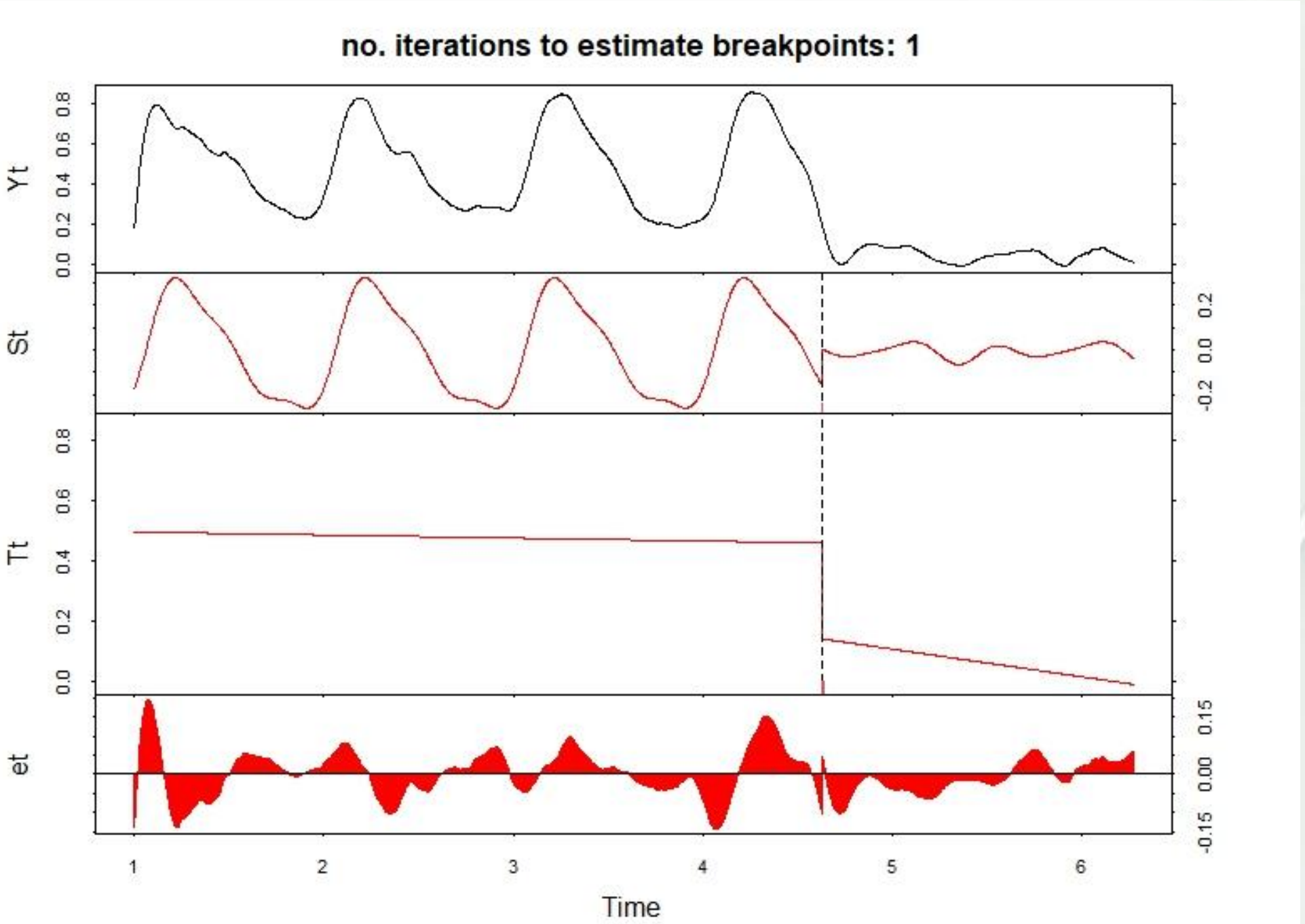


Breaks detection – BFAST

- https://cran.r-project.org/web/packages/bfast/bfast.pdf ; Verbesselt et al. 2021:
  - It combines the decomposition of time series into three components with methods for detection of abrupt changes
  - Can be used to examine satellite image time series but also in other disciplines where seasonal or non-seasonal time series are used, e.g. hydrology, or climatology
- bfast() - decompose ts into three components and then each component is checked for at least one significant break - the result allows differentiating between breaks in trend and seasonality.

breaks in trend and seasonality

bfast()



SITS package*

- Based on cubes, provides tools for time series processing
- https://github.com/e-sensing/sits
- https://e-sensing.github.io/sitsbook/earth-observation-data-cubes.html

Some further reading

- http://bfast.r-forge.r-project.org/RSE_ChangeDetection_InPress_JanVerbesselt.pdf
- https://eos.com/blog/detecting-changes-trends-and-seasonality-with-satellite-time-series-data/
- https://www.researchgate.net/publication/284914127_Long_term_analysis_of_time_series_of_satellite_images
- https://otexts.com/fpp2/decomposition.html