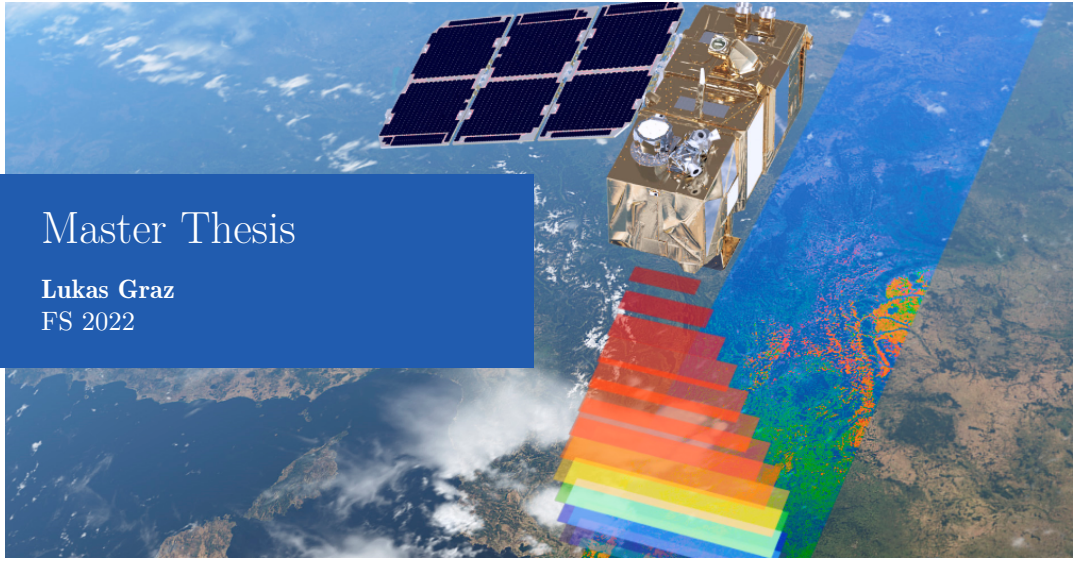
ETH zürich

D-MATH — Seminar for Statistics
D-USYS — Crop Science



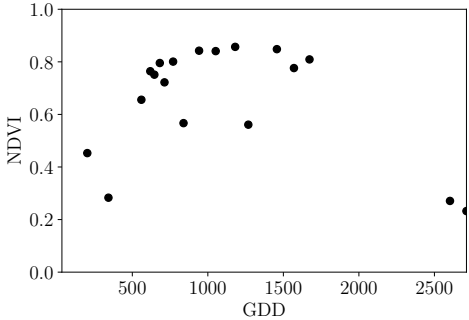
Master Thesis

Lukas Graz

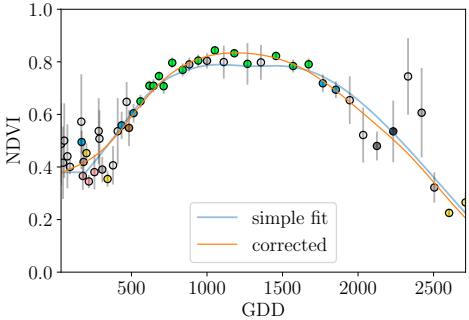
FS 2022

How to get ...

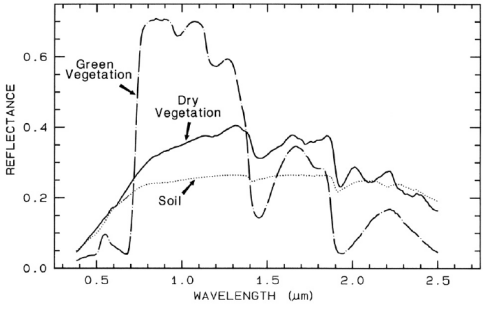
from ...



to ...



NDVI From S2 Images

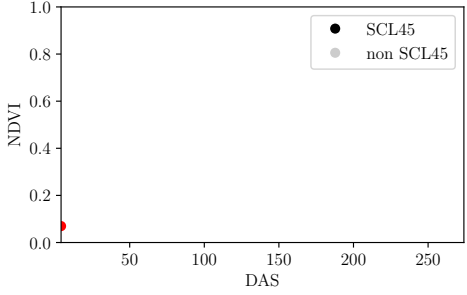


$$\text{NDVI} = \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + \text{Red})}$$

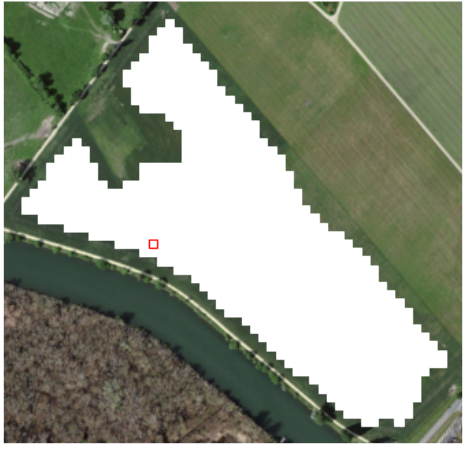
[0] Spectral Reflectances https://www.researchgate.net/figure/Reflectance-spectra-of-photosynthetic-green-vegetation-non-photosynthetic-dry_fig4_236677371

Sentinel 2 Image + NDVI Time Series

→ Cloud high probability



Sentinel 2 Image + NDVI Time Series



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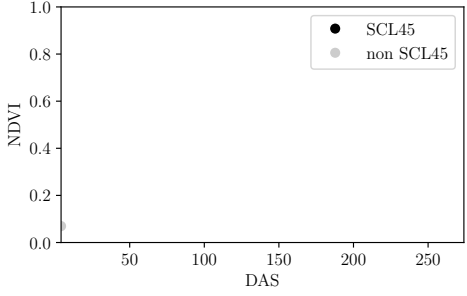

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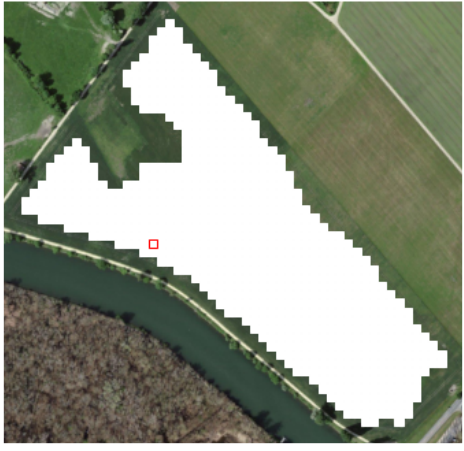
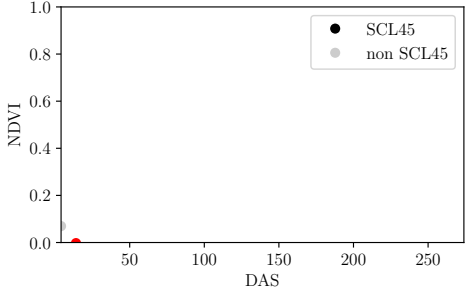
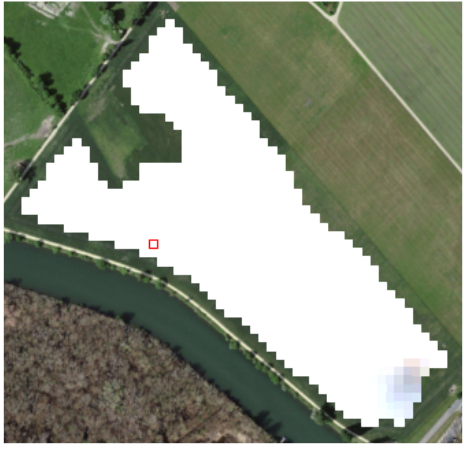


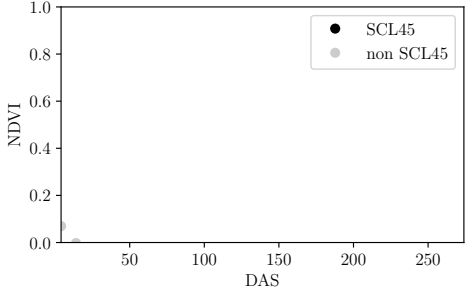
→ Cloud high probability



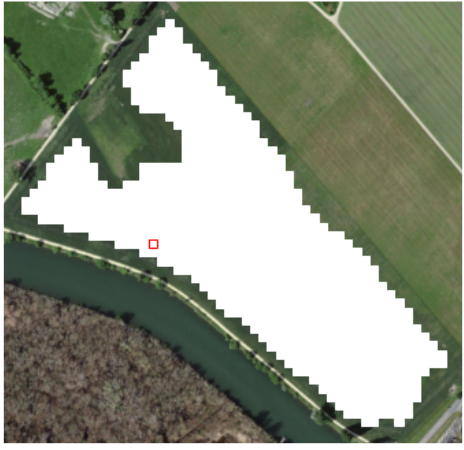
Sentinel 2 Image + NDVI Time Series



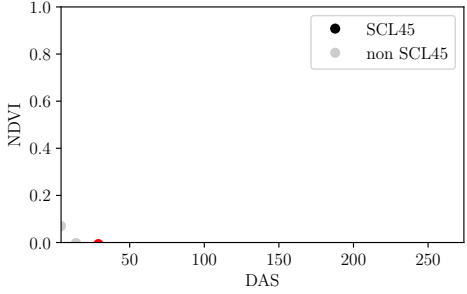
→ Cloud high probability



Sentinel 2 Image + NDVI Time Series



→ Cloud high probability



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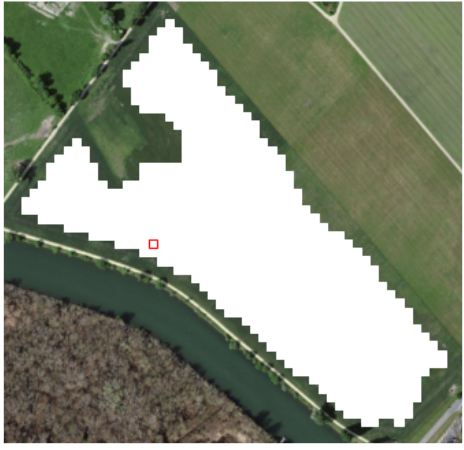
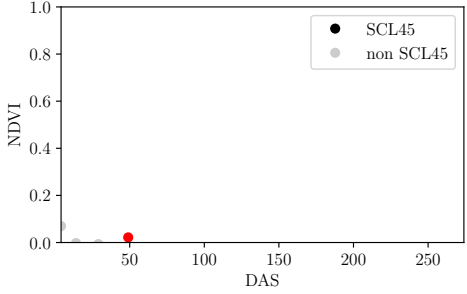
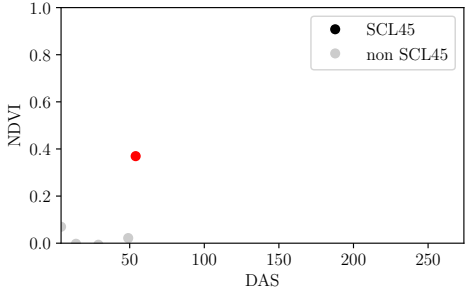


→ Cloud high probability



Sentinel 2 Image + NDVI Time Series

→ Thin cirrus cloud



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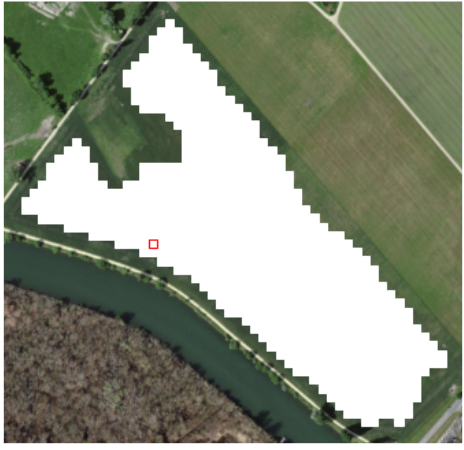
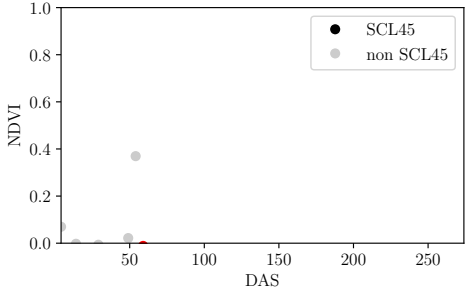
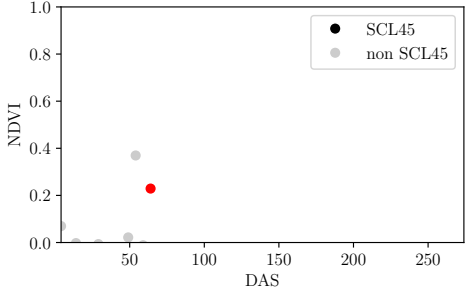


→ Snow or ice



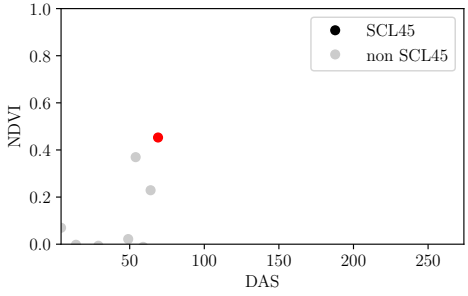
Sentinel 2 Image + NDVI Time Series

→ Cloud medium probability



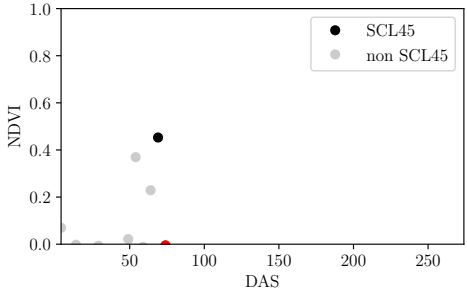
Sentinel 2 Image + NDVI Time Series

→ Bare soils



Sentinel 2 Image + NDVI Time Series

→ Snow or ice



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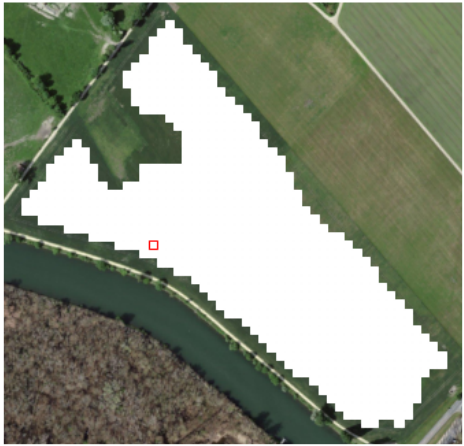
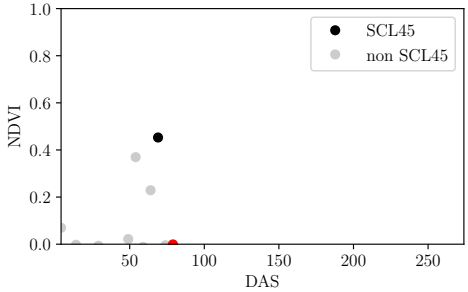
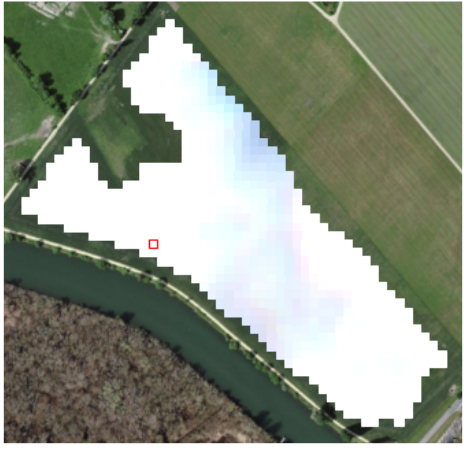


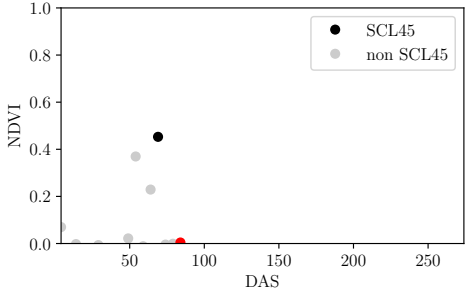
→ Snow or ice



Sentinel 2 Image + NDVI Time Series



→ Cloud high probability



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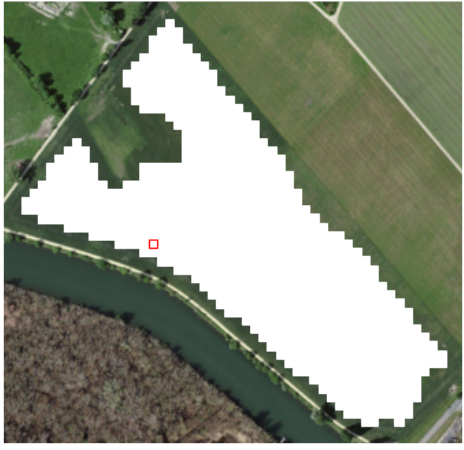
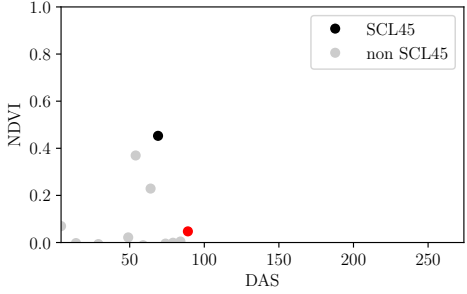


→ Cloud high probability



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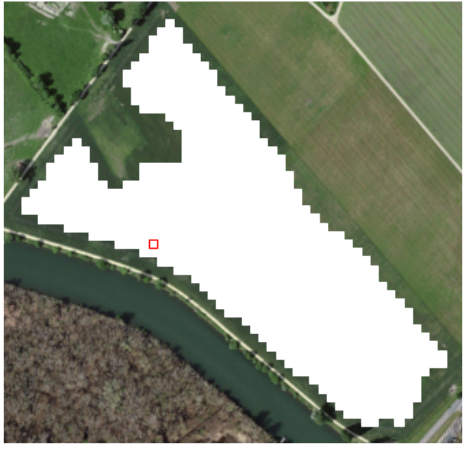
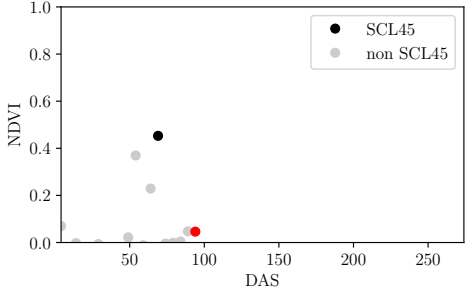
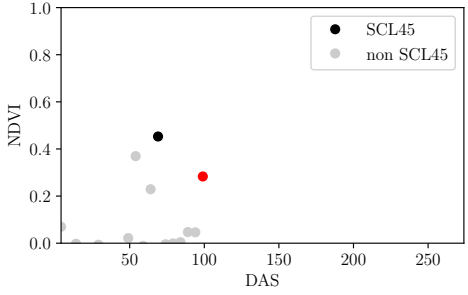


→ Cloud medium probability



Sentinel 2 Image + NDVI Time Series

→ Bare soils



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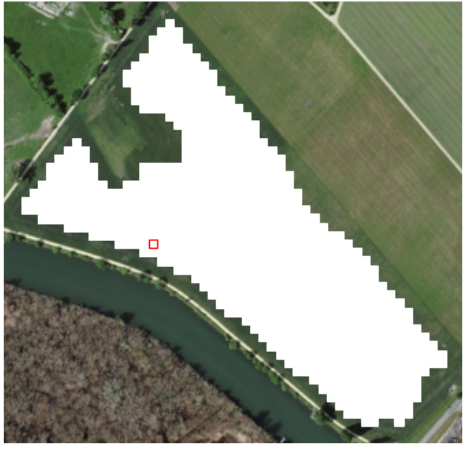
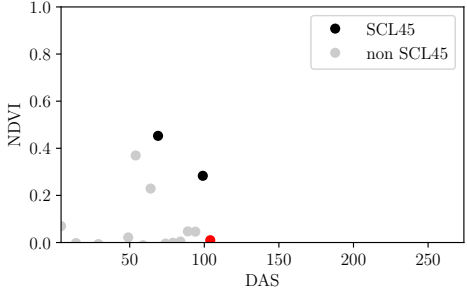


→ Cloud high probability



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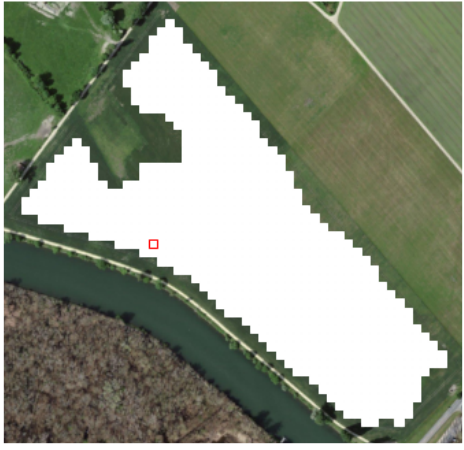
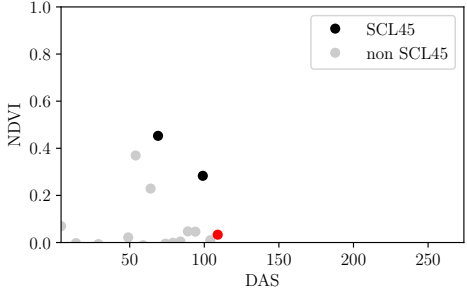
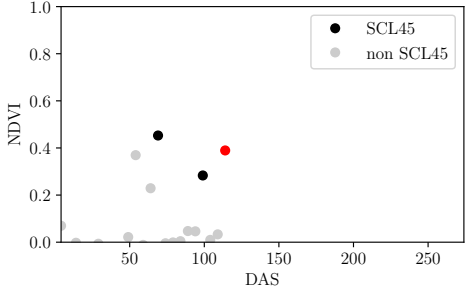


→ Cloud high probability

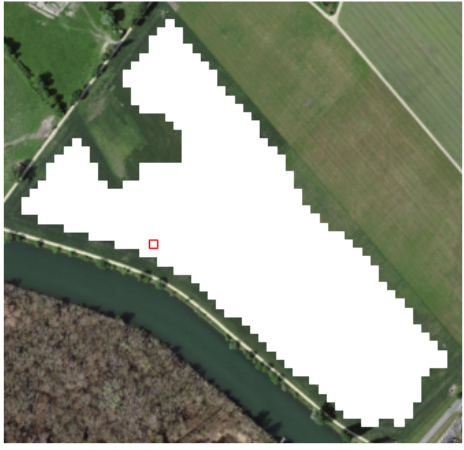


Sentinel 2 Image + NDVI Time Series

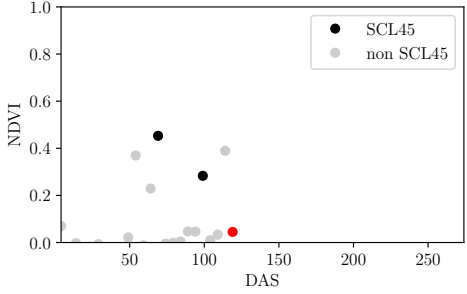
→ Thin cirrus cloud



Sentinel 2 Image + NDVI Time Series

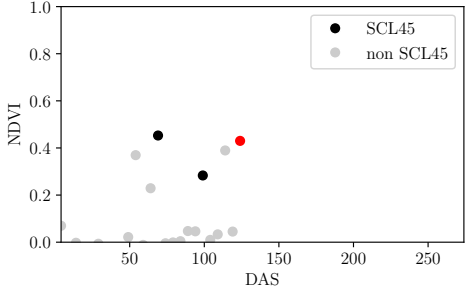


→ Cloud high probability



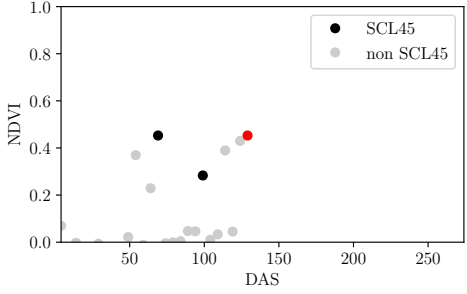
Sentinel 2 Image + NDVI Time Series

→ Cloud shadows



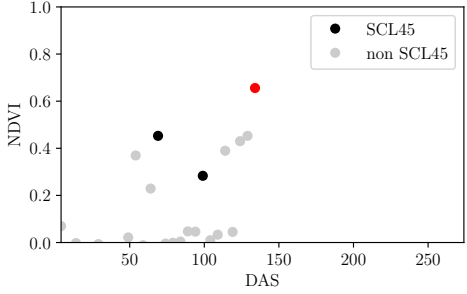
Sentinel 2 Image + NDVI Time Series

→ Thin cirrus cloud



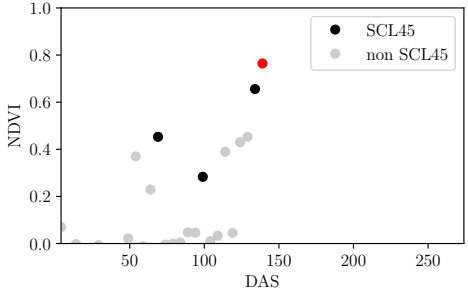
Sentinel 2 Image + NDVI Time Series

→ Vegetation



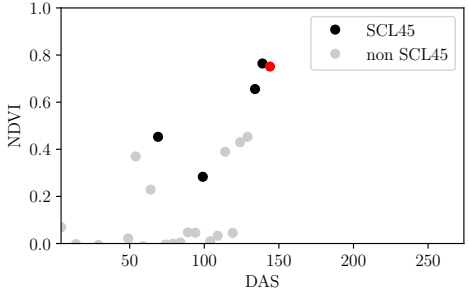
Sentinel 2 Image + NDVI Time Series

→ Vegetation



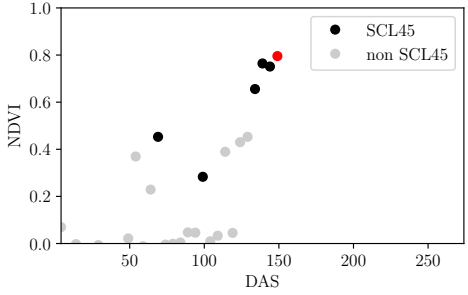
Sentinel 2 Image + NDVI Time Series

→ Vegetation



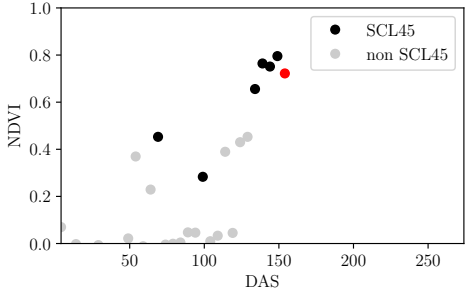
Sentinel 2 Image + NDVI Time Series

→ Vegetation



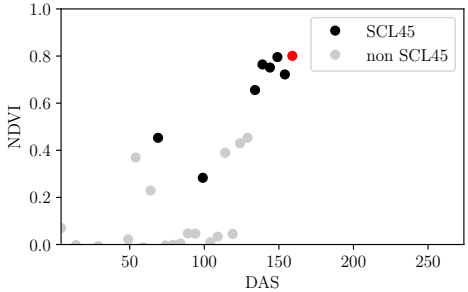
Sentinel 2 Image + NDVI Time Series

→ Vegetation

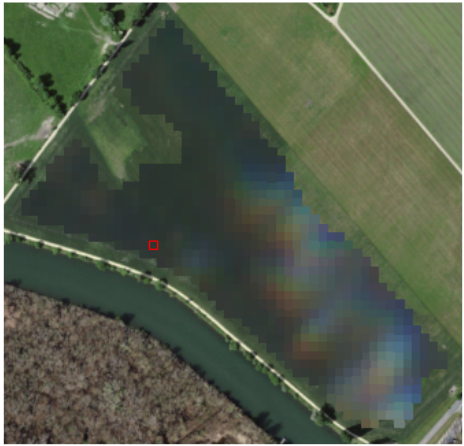


Sentinel 2 Image + NDVI Time Series

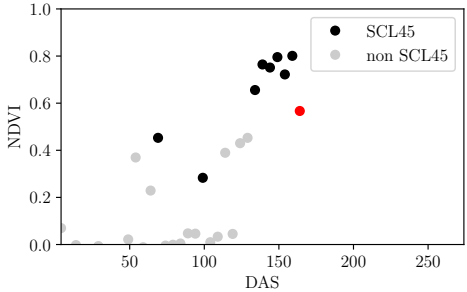
→ Vegetation



Sentinel 2 Image + NDVI Time Series

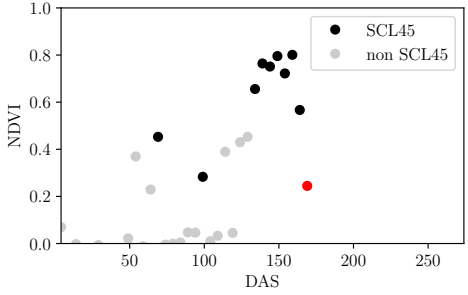


→ Vegetation



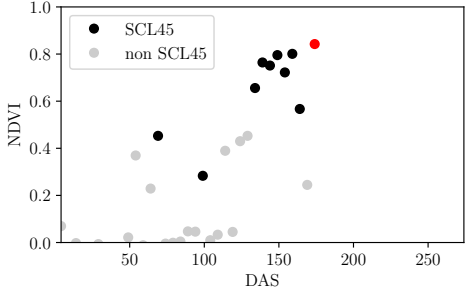
Sentinel 2 Image + NDVI Time Series

→ Cloud medium probability



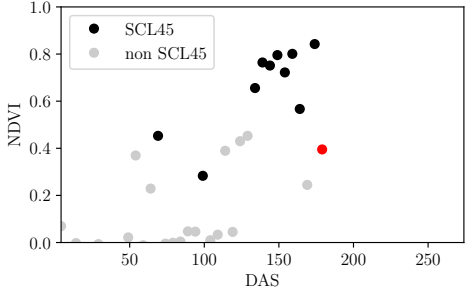
Sentinel 2 Image + NDVI Time Series

→ Vegetation



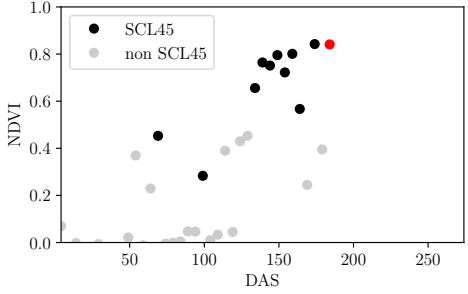
Sentinel 2 Image + NDVI Time Series

→ Cloud medium probability



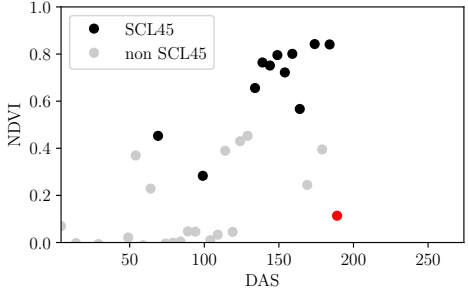
Sentinel 2 Image + NDVI Time Series

→ Vegetation



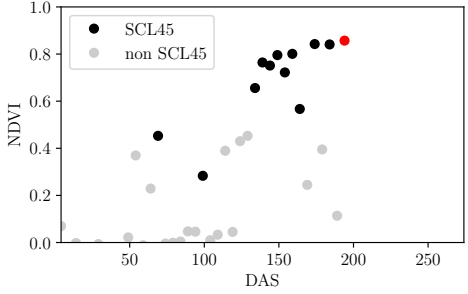
Sentinel 2 Image + NDVI Time Series

→ Cloud high probability

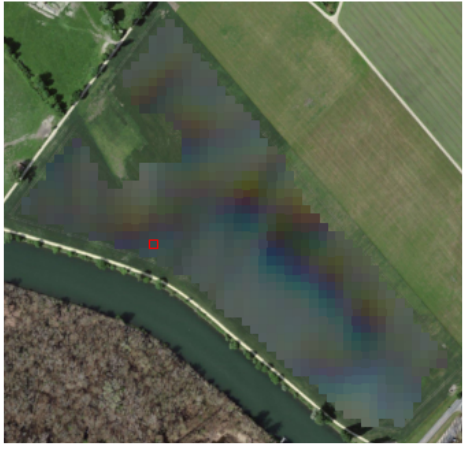


Sentinel 2 Image + NDVI Time Series

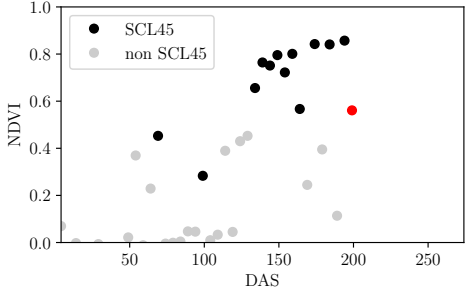
→ Vegetation



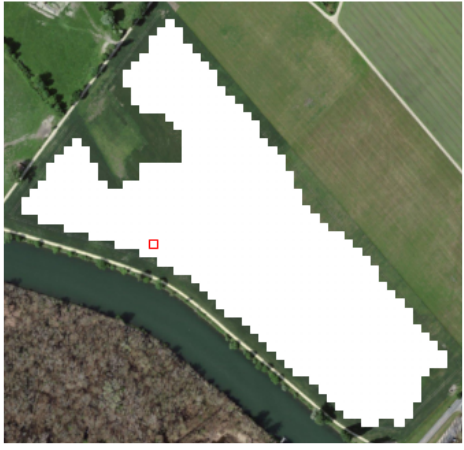
Sentinel 2 Image + NDVI Time Series



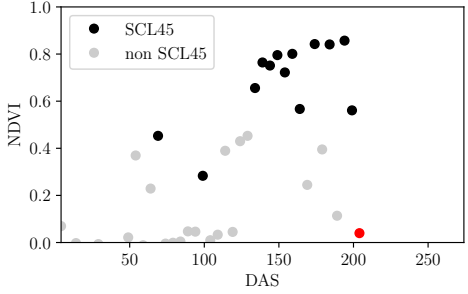
→ Vegetation



Sentinel 2 Image + NDVI Time Series

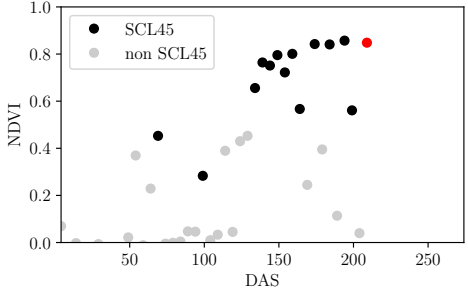


→ Cloud high probability



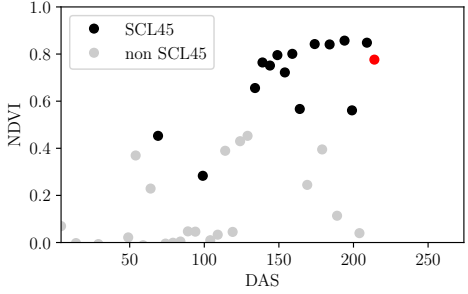
Sentinel 2 Image + NDVI Time Series

→ Vegetation



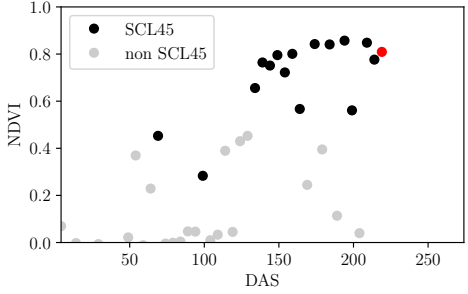
Sentinel 2 Image + NDVI Time Series

→ Vegetation



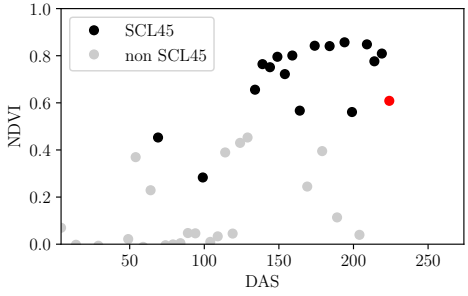
Sentinel 2 Image + NDVI Time Series

→ Vegetation

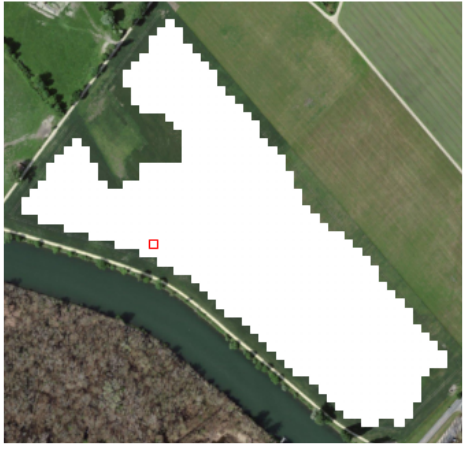


Sentinel 2 Image + NDVI Time Series

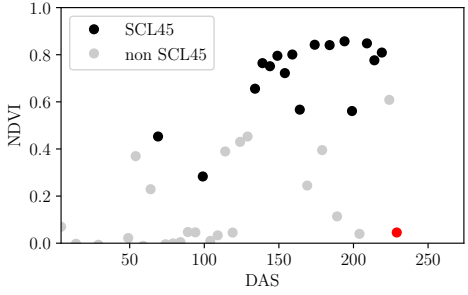
→ Thin cirrus cloud



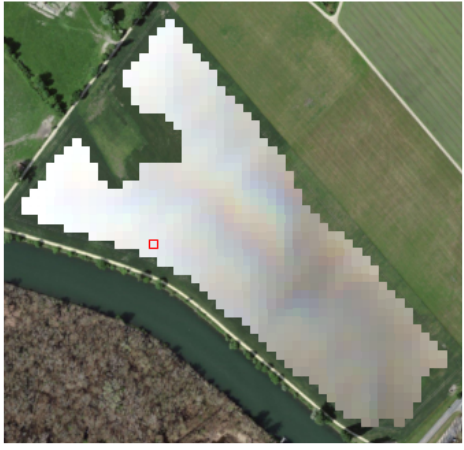
Sentinel 2 Image + NDVI Time Series



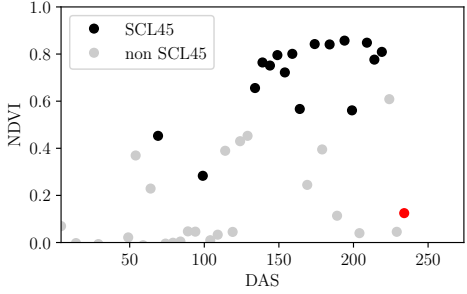
→ Thin cirrus cloud



Sentinel 2 Image + NDVI Time Series

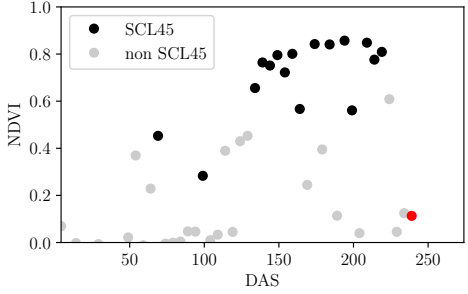


→ Cloud high probability



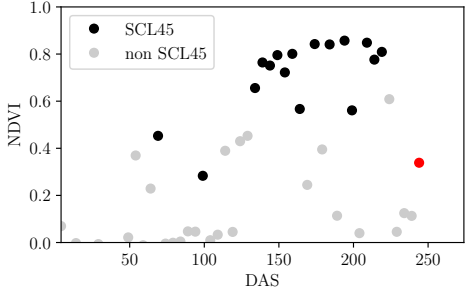
Sentinel 2 Image + NDVI Time Series

→ Cloud high probability



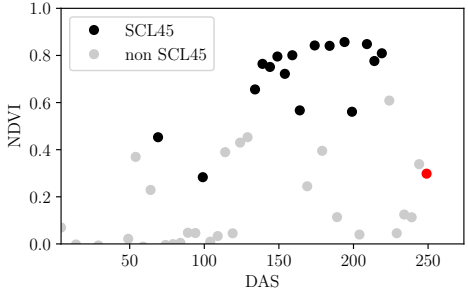
Sentinel 2 Image + NDVI Time Series

→ Cloud low probability

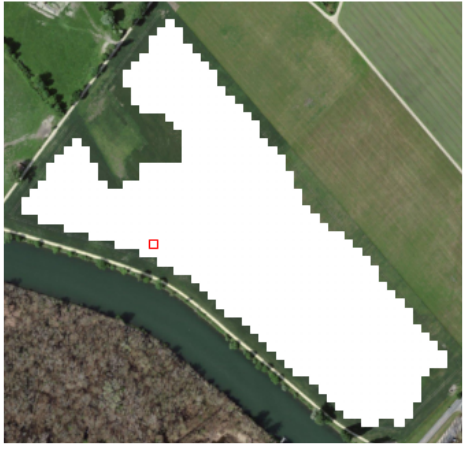


Sentinel 2 Image + NDVI Time Series

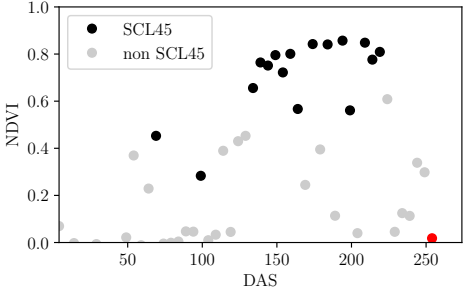
→ Dark features / Shadows



Sentinel 2 Image + NDVI Time Series

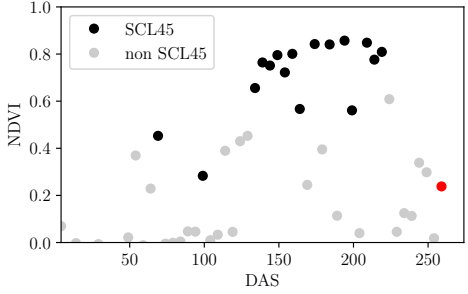


→ Cloud high probability

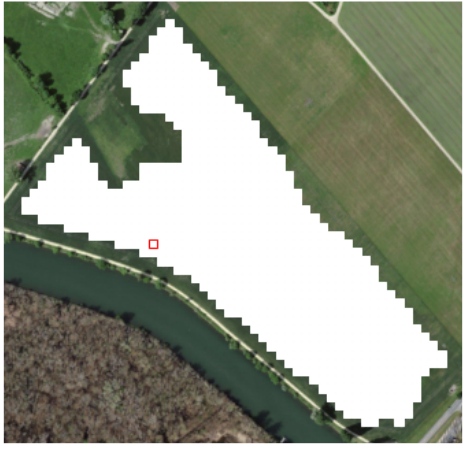


Sentinel 2 Image + NDVI Time Series

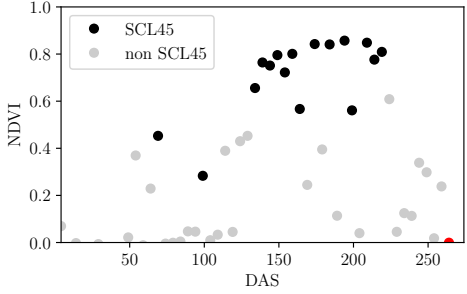
→ Cloud medium probability



Sentinel 2 Image + NDVI Time Series

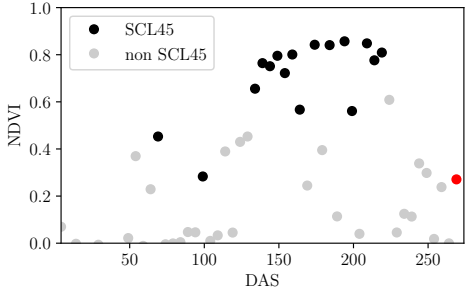


→ Cloud medium probability

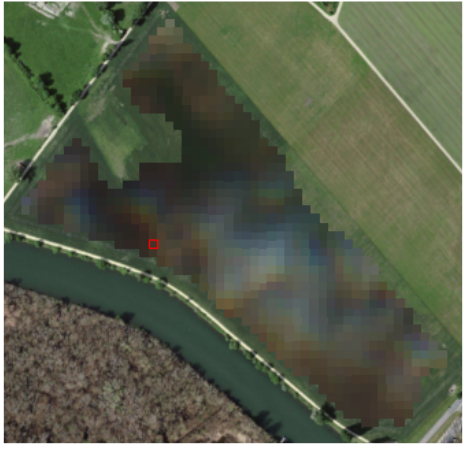


Sentinel 2 Image + NDVI Time Series

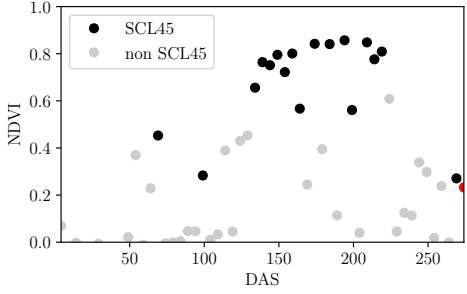
→ Bare soils



Sentinel 2 Image + NDVI Time Series

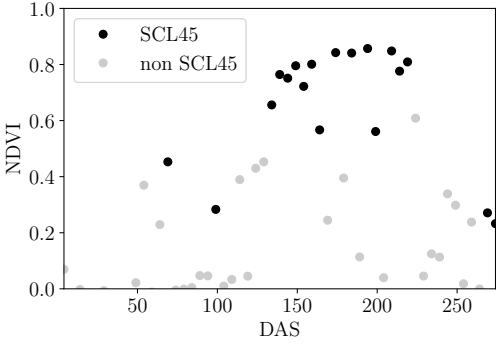


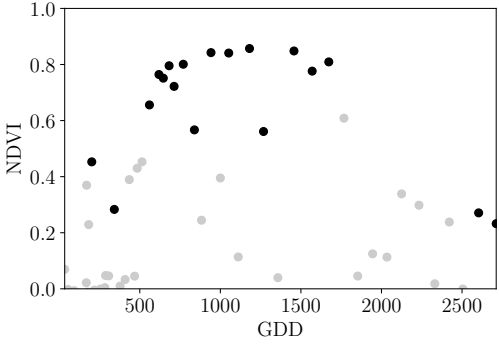
→ Bare soils

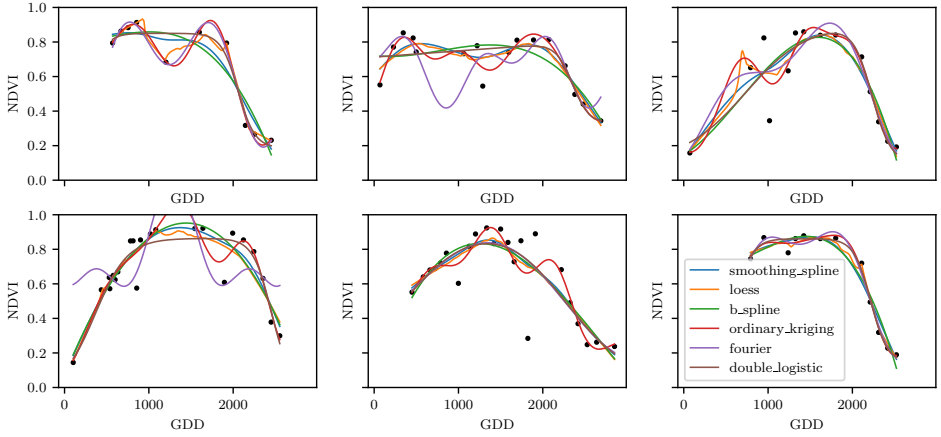


Timescale Transformation: DAS vs GDD

$$GDD_n := \sum_{i=0}^{n} \max(T_i - T_{base}, 0). \tag{1}$$



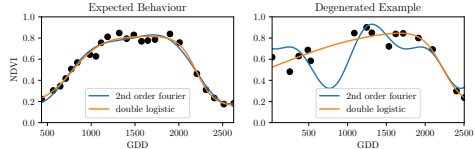



NDVI
GDD
0.0
0.2
0.4
0.6
0.8
1.0
0
1000
2000
smoothing_spline
loess
b_spline
ordinary_kriging
fourier
double_logistic

Double Logistic Approximation

Curve fully determined by parameters (no data)

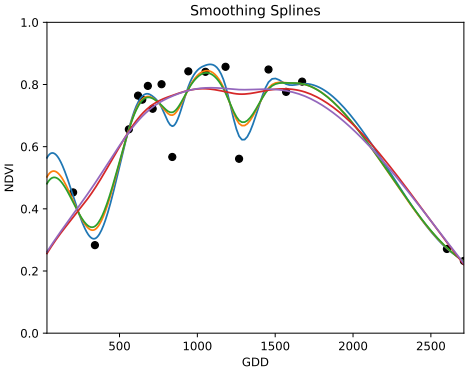
$$NDVI(t) = f(a, b, c, d, e)$$



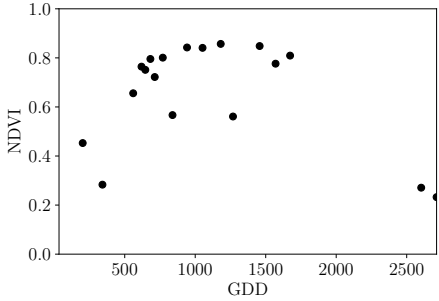
Smoothing Splines

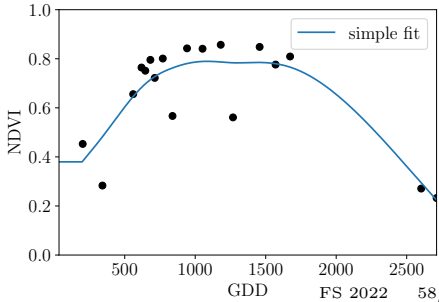
$$\widehat{NDVI} := \underset{f \in \mathcal{F}}{\operatorname{argmin}} \underbrace{\sum_{i=1}^{n} \left(Y_i - f\left(x_i\right)\right)^2}_{\text{sum of squares}} + \lambda \underbrace{\int f''(x)^2 dx}_{\text{smoothness}}$$

Similar to the Whittaker (but more general)



1. Interpolation

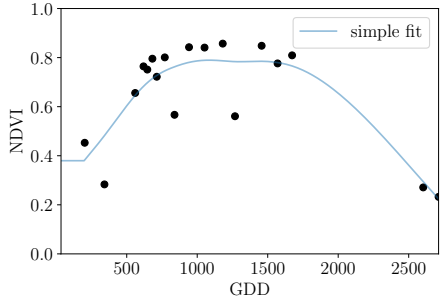


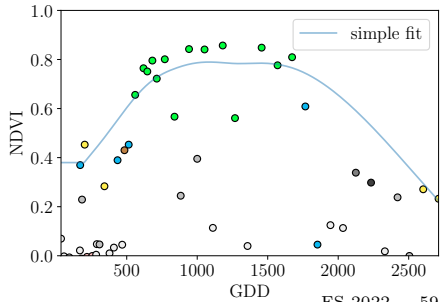


2. Other SCL-Classes

Label	Classification
0	NO_DATA
1	SATURATED_OR_DEFECTIVE
2	DARK_AREA_PIXELS
3	CLOUD_SHADOWS
4	VEGETATION
5	NOT_VEGETATED
6	WATER
7	UNCLASSIFIED
8	CLOUD_MEDIUM_PROBABILITY
9	CLOUD_HIGH_PROBABILITY
10	THIN_CIRRUS
11	SNOW

SCL = **S**cene **C**lassification **L**ayer

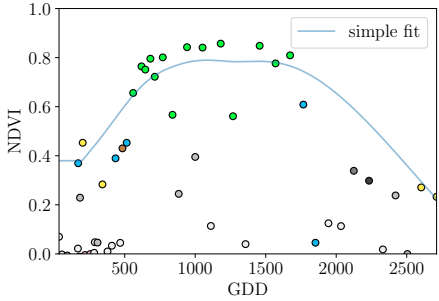


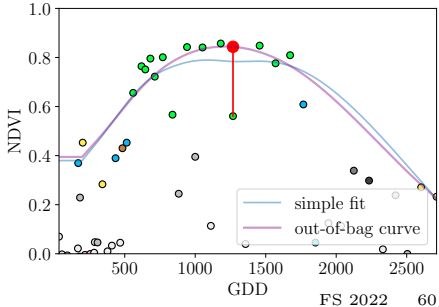


3. Correction

- get “true” NDVI
- get table:

“truth”	observed	scl-class	B2-B10	weather
“truth”	observed	scl-class	B2-B10	weather
...	...	...	...	...



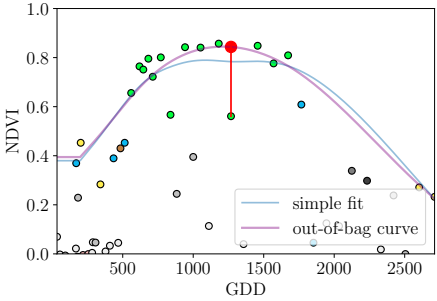


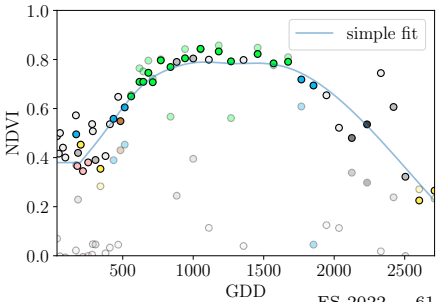
3. Correction

- get “true” NDVI
- get table:

“truth”	observed	scl-class	B2-B10	weather
“truth”	observed	scl-class	B2-B10	weather
...	...	...	...	...

- Statistical model
- predict/correct NDVI
- weather – yes or no?



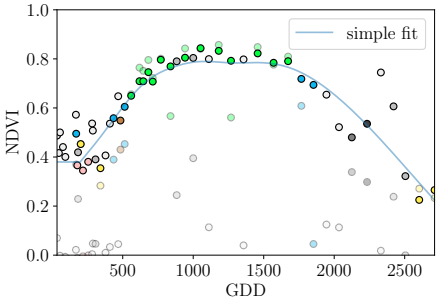


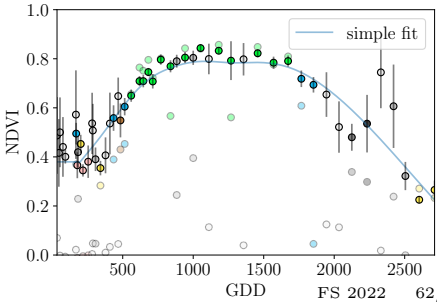
4. Uncertainty Estimation

- Table with residuals:

residuals	observed	scl-class	B2-B10	weather
residuals	observed	scl-class	B2-B10	weather
⋮	⋮	⋮	⋮	⋮

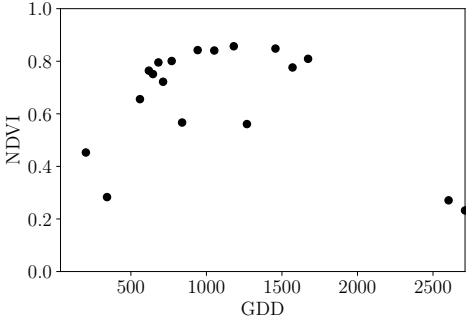
- Statistical model
- predict residuals
- $weights = \frac{1}{|residual|}$

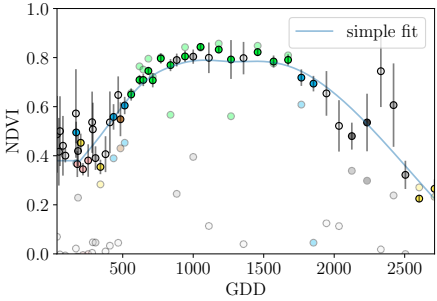


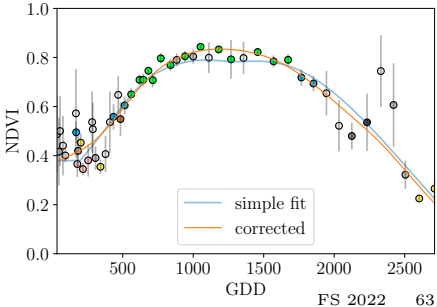


5. Robust Fit to Corrected NDVI

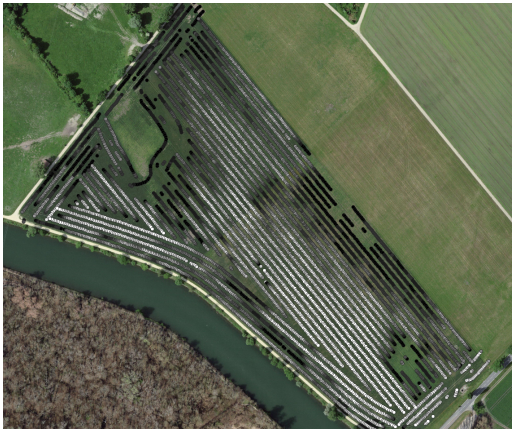
Reminder: Original Situation

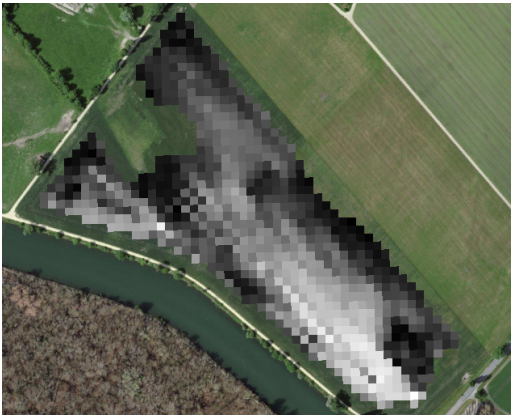






Yield Mapping Data





R-Package Provided

```
library(CorrectTimeSeries)
data(timeseries_list) # load NDVI-TS data

# Train RF
  # Add "true" NDVI (or generally the response), by Out-Of-Bag estimation
    timeseries_list <- lapply(timeseries_list, function(df) {
      df$oob_ndvi <- OOB_est(df$gdd, df$ndvi_observed) # gdd is the time-axis
      df})
  # Train correction model
    formula <- "oob_ndvi ~ B02+B03+B04+B05+B06+B07+B08+B8A+B11+B12+scl_class"
    RF <- train_RF_with_fromula(formula, timeseries_list, robustify=TRUE)
# ADD CORRECTION
  timeseries_list <- lapply(timeseries_list, function(df) {
    df$corrected_ndvi <- randomForest:::predict.randomForest(RF, df)
    df})

# Get interpolation for each timeseries
  lapply(timeseries_list, function(df){
    ss <- smoothing_spline(df$gdd, df$corrected_ndvi)
    predict(ss, 1:1000)$y})
```