Analyzing climate with Satellite data and Machine learning

Overview of today's session

Digital Innovation Season, 20.4.2022.

~ Vít Růžička

GitHub repo:

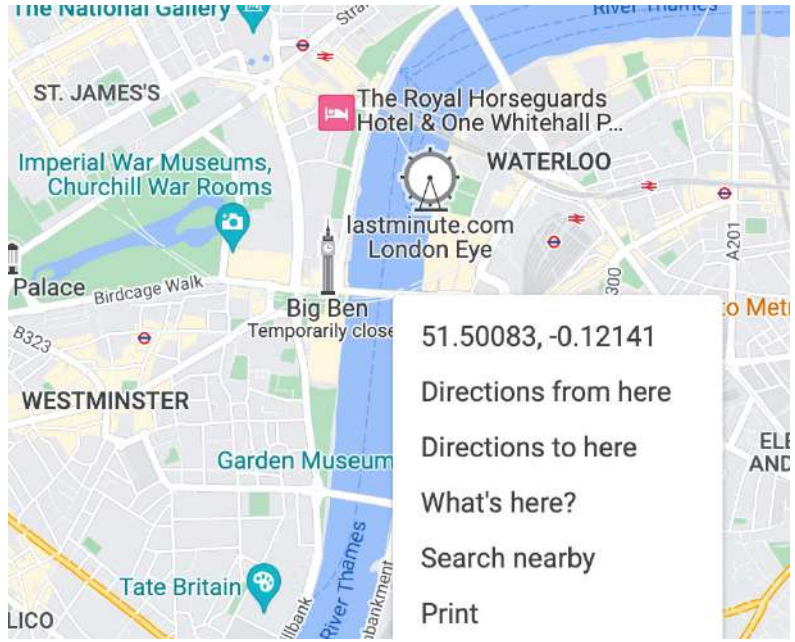
github.com/
previtus/Workshop_RaVAEn_CSM

Step 1:
Pick any location on our planet

Step 1: Pick any location on our planet

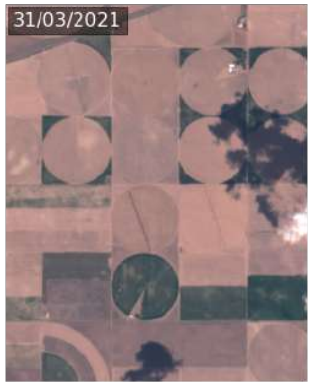
- Use Google Maps to find a location we will download:

For example:

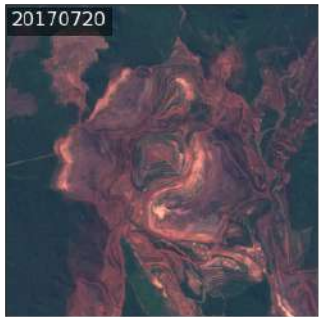


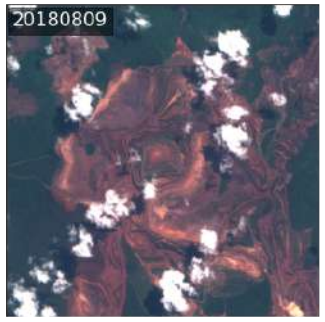
Potential inspiration and use cases

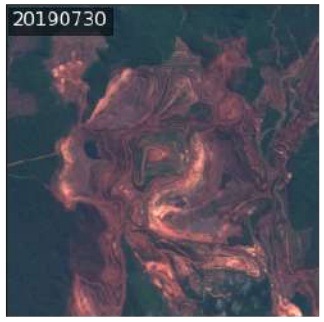
- For crop health monitoring:

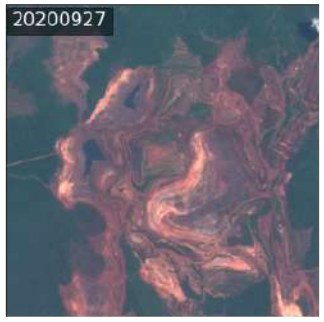


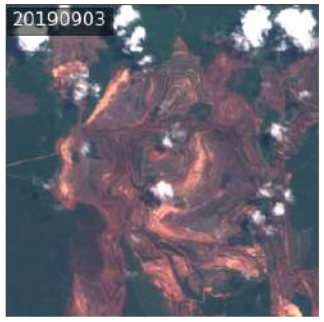
- For mining activity tracking:









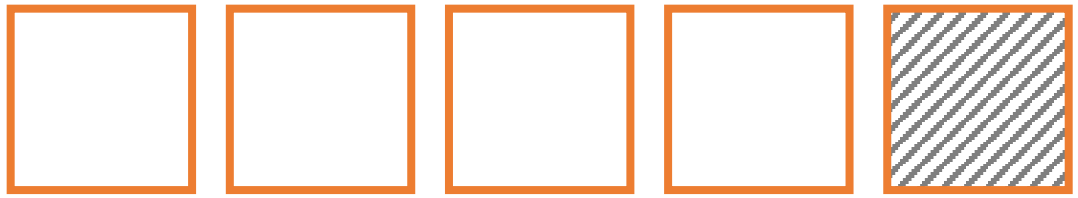


Kyiv region on March 11, towers nearby Antonov International Airport (more details)

- Current events / finding evidence

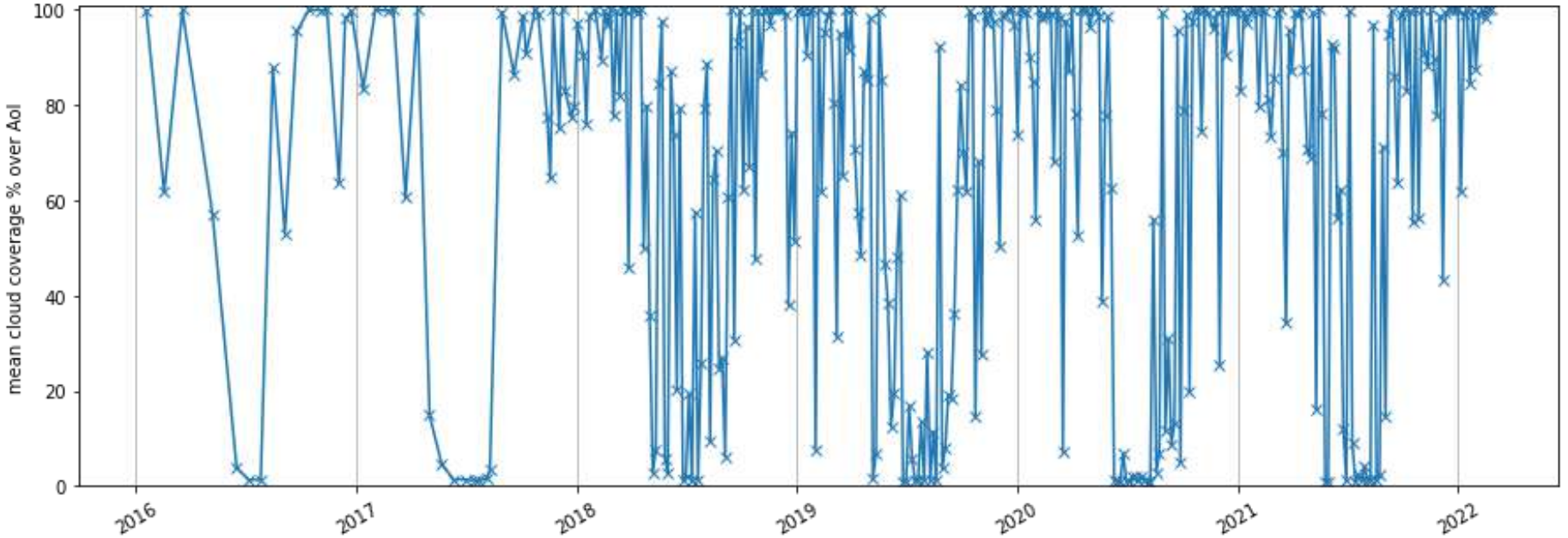
Potential inspiration and use cases

- Disaster events tracking, analysis and potentially prediction



Revisit over time

- We have around 5 days revisit with Sentinel-2 satellite



Missing data *Clouds*

Big Picture

- Why do we care – as scientists? As artists?

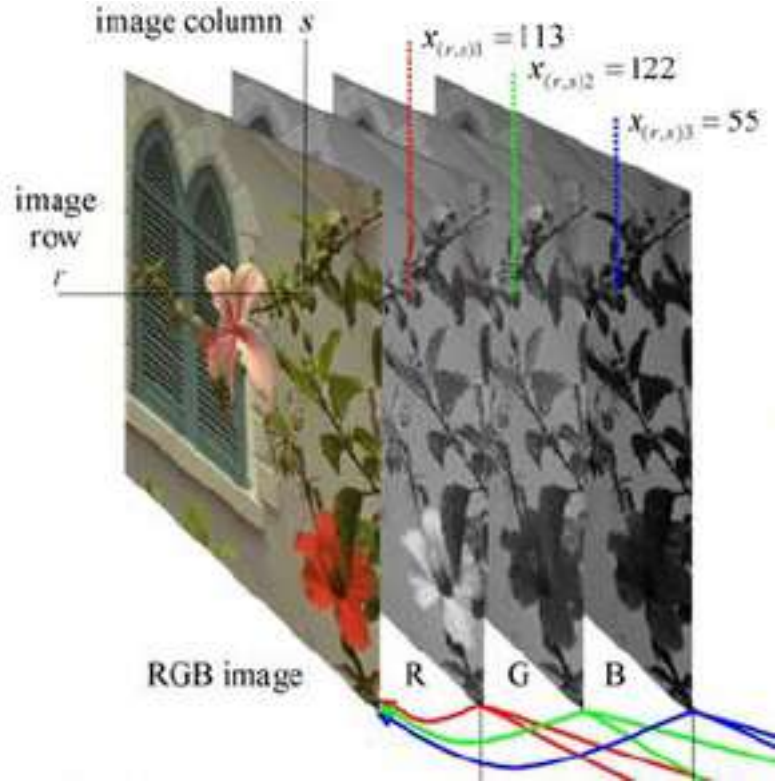
We need data …

- to conduct **research** on the problem
- To make a **statement**
- To **create artworks** inspired by natural patterns

Uncanny Valleys at ML4Creativity workshop, NeurIPS 2019

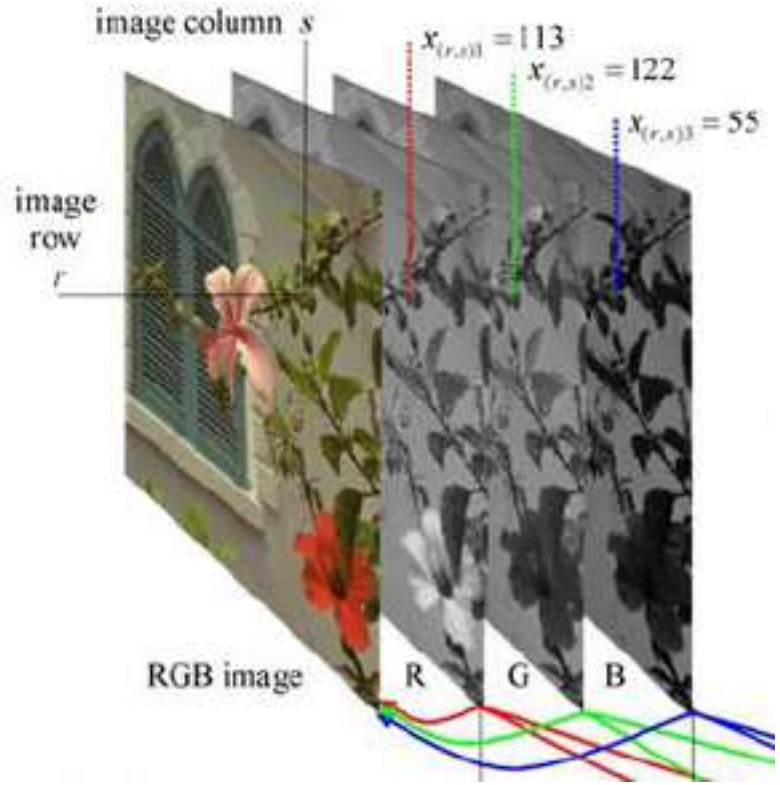
Step 2:
Data visualization

Data visualization and bands

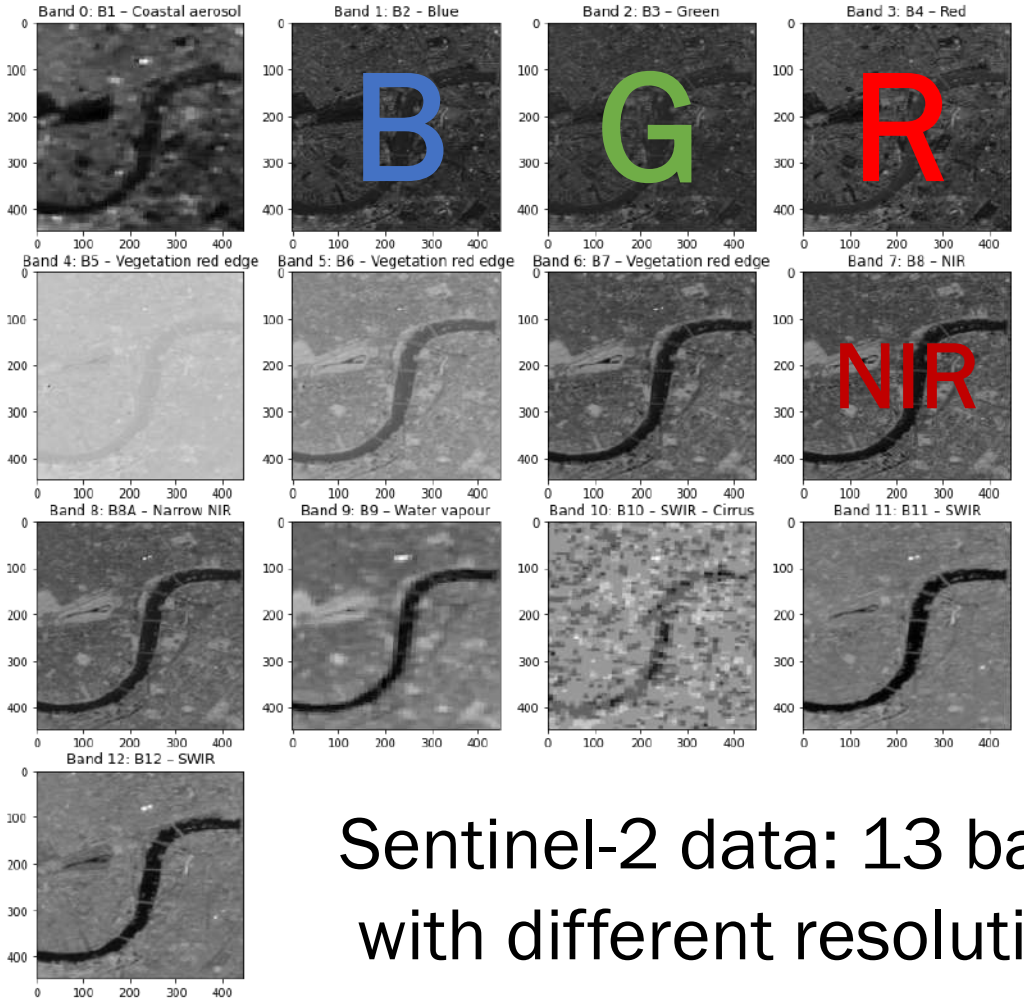


Typical photographs:
3 bands

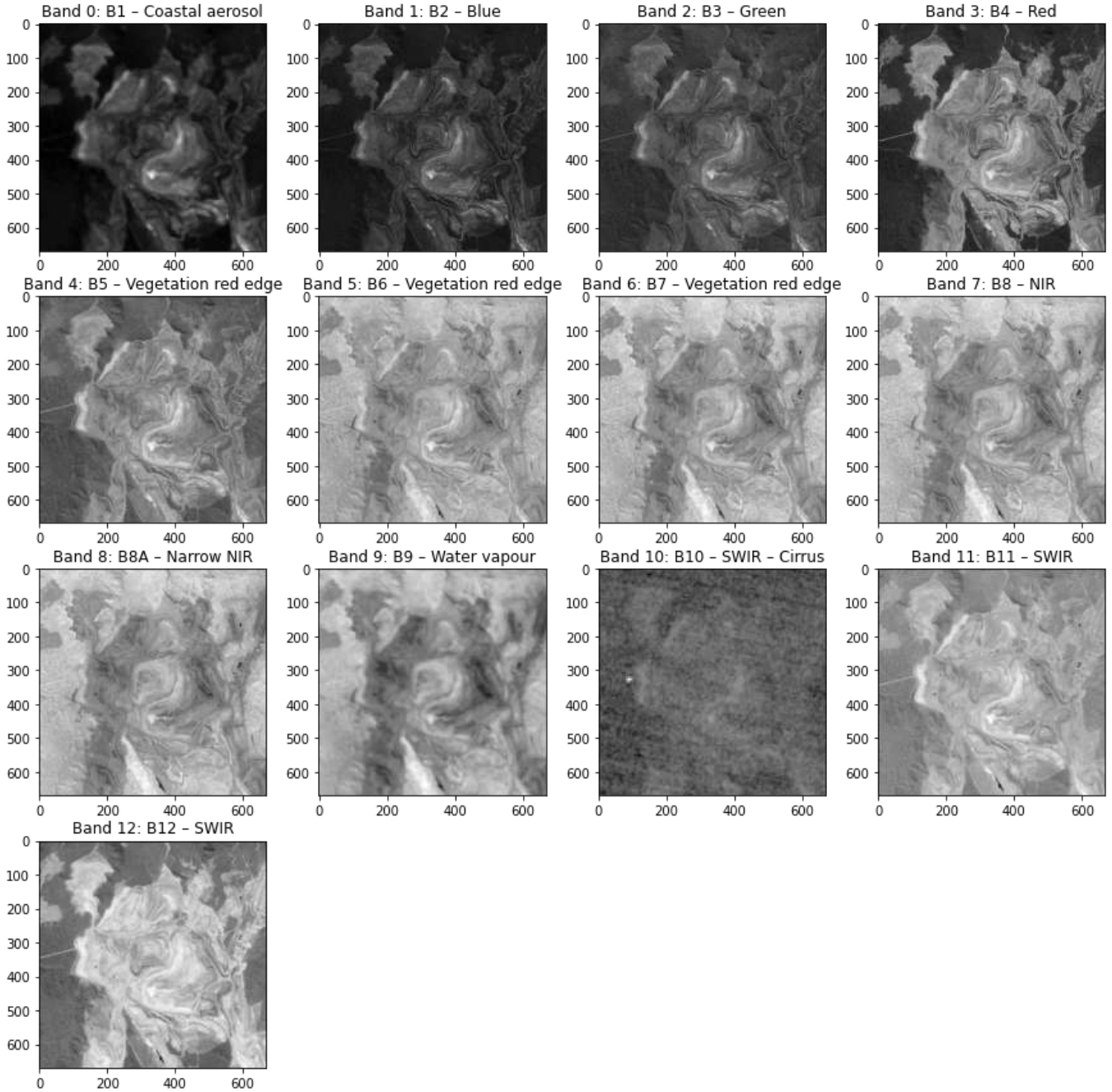
Data visualization and bands



Typical photographs:
3 bands

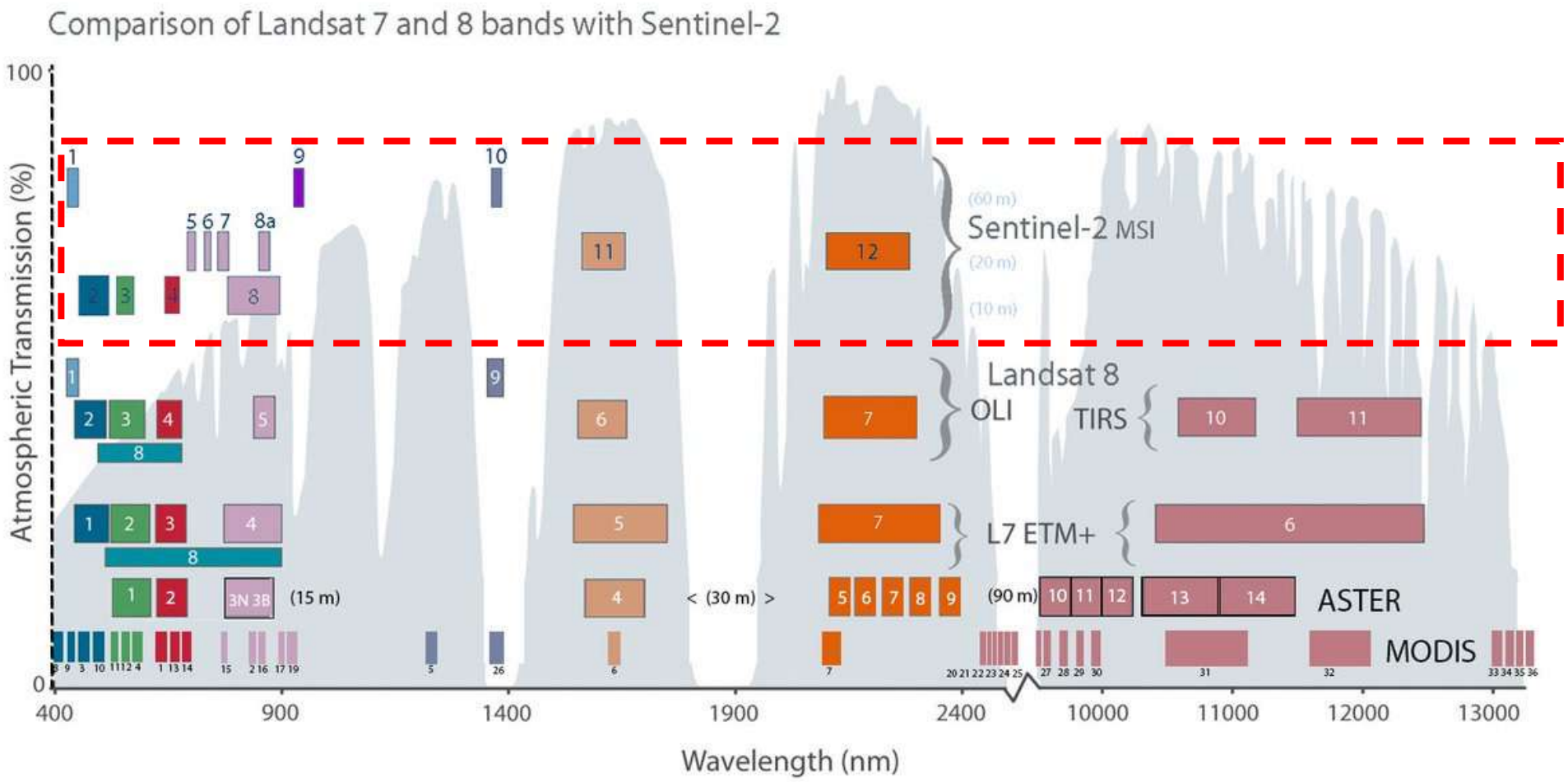


Sentinel-2 data: 13 bands
with different resolutions



Sentinel-2 bands	Resolution (m)
Band 1 – Coastal aerosol	60
Band 2 – Blue	10
Band 3 – Green	10
Band 4 – Red	10
Band 5 – Vegetation red edge	20
Band 6 – Vegetation red edge	20
Band 7 – Vegetation red edge	20
Band 8 – NIR	10
Band 8A – Vegetation red edge	20
Band 9 – Water vapour	60
Band 10 – SWIR – Cirrius	60
Band 11 – SWIR	20
Band 12 – SWIR	20

Bands across satellites



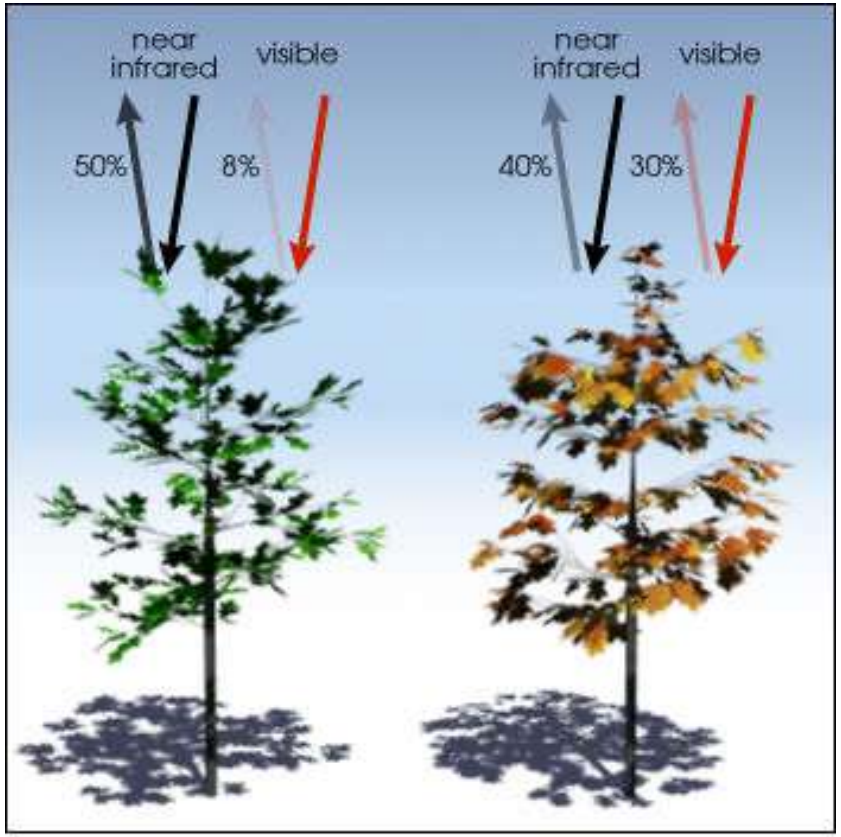
Sentinel-2 bands

Step 2b:
Special visualizations

Normalized difference vegetation index (NDVI)

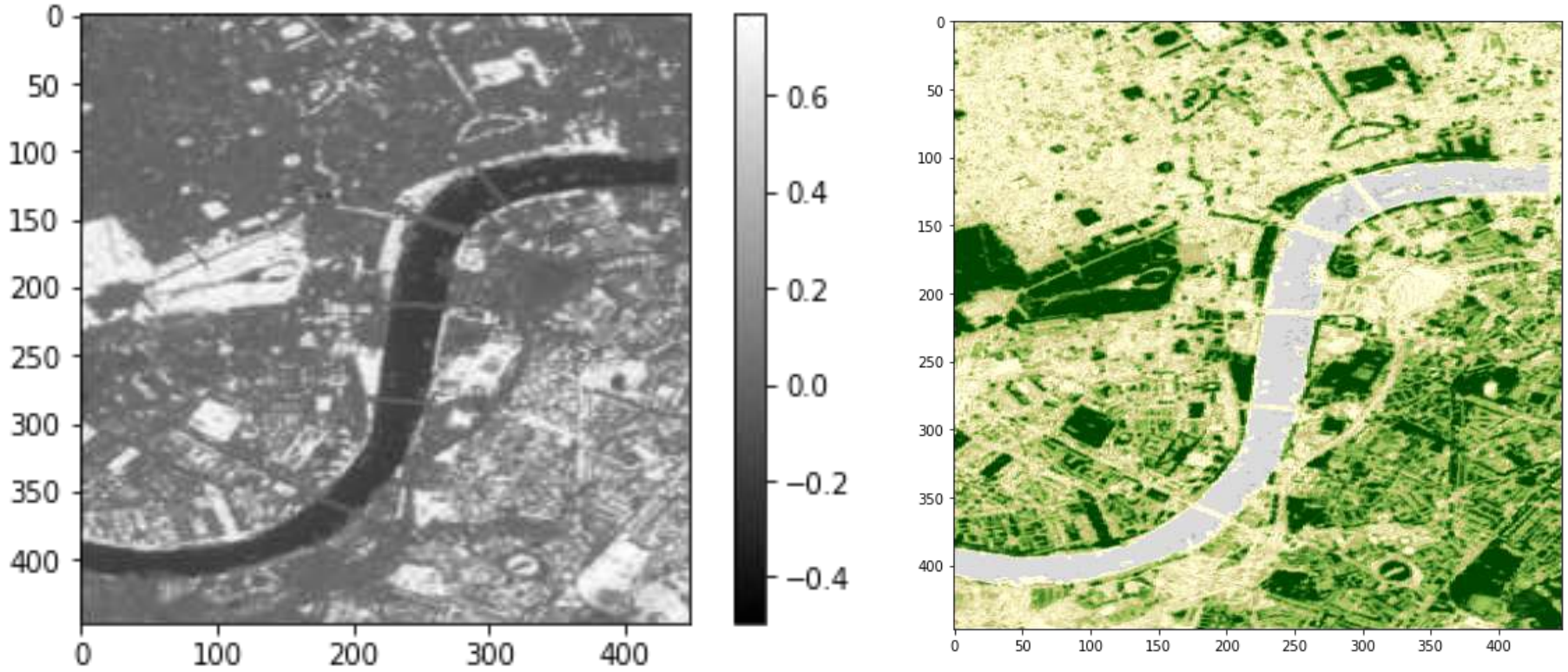
- The **NDVI** is an index that describes the difference between visible and near-infrared reflectance of vegetation cover and **can be used to estimate the density of green on an area of land** (Weier and Herring, 2000).

NDVI = (NIR-Red) / (NIR+Red)



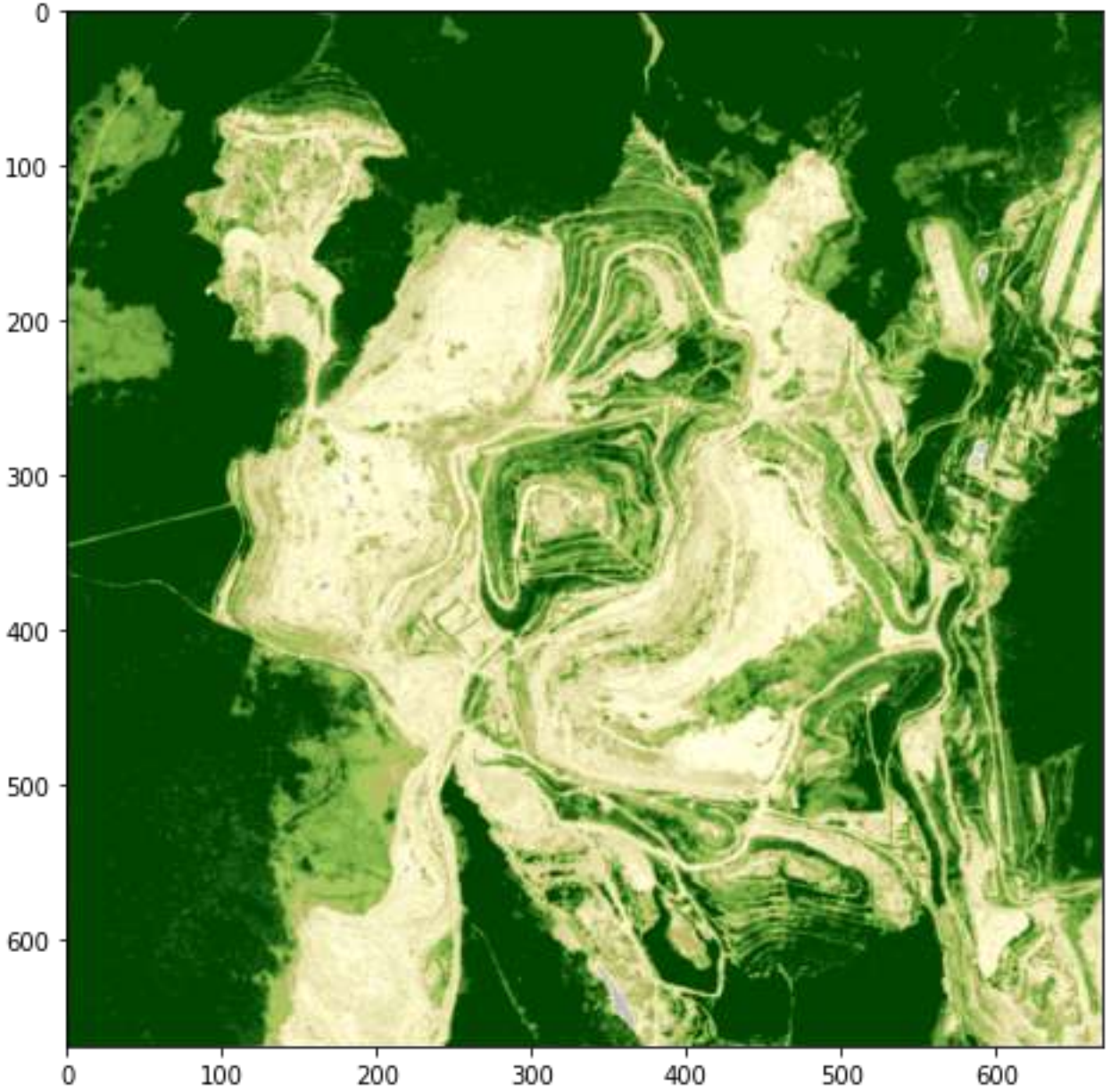
Normalized Difference Vegetation Index (NDVI)

NDVI = (NIR-Red) / (NIR+Red)



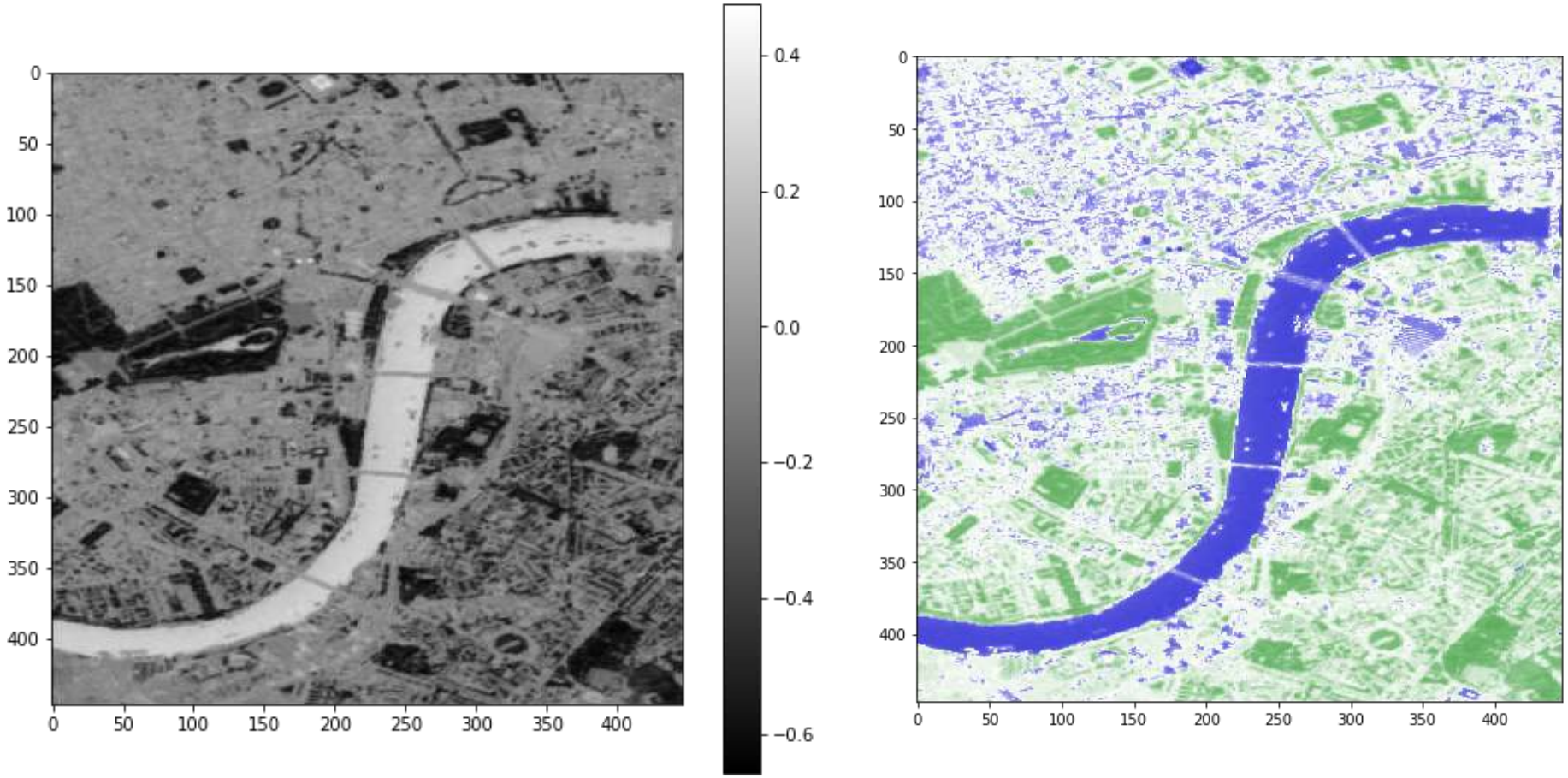
- NDVI values range from +1.0 to -1.0. Areas of barren rock, sand, or snow usually show very low NDVI. Sparse vegetation may result in moderate NDVI values.

Example:



Normalized Difference Water Index (NDWI)

NDWI = (NIR-SWIR) / (NIR+SWIR)

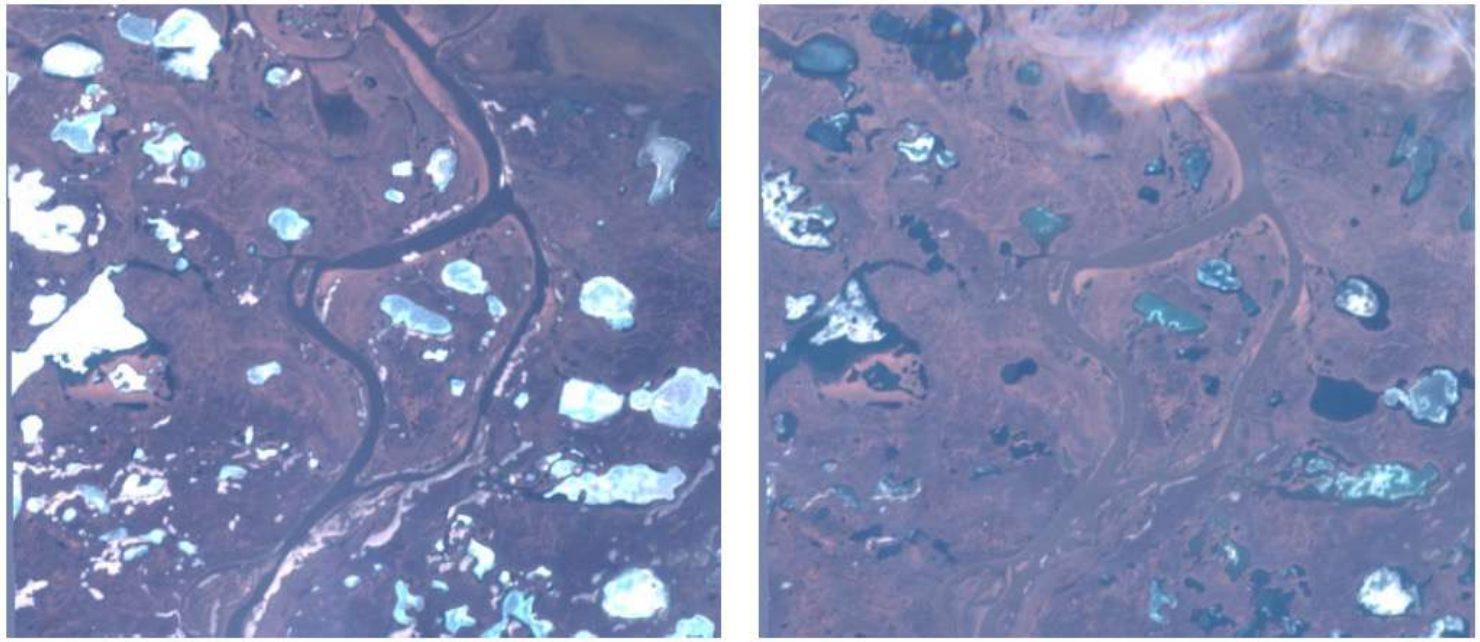


- The **NDWI** used to monitor changes in water content of leaves, using near-infrared (NIR) and short-wave infrared (SWIR) wavelengths

Step 3:
Data analysis

Task: Change detection

- Detecting *"what has changed"* in a sequence of images
- Useful for detecting certain types of events

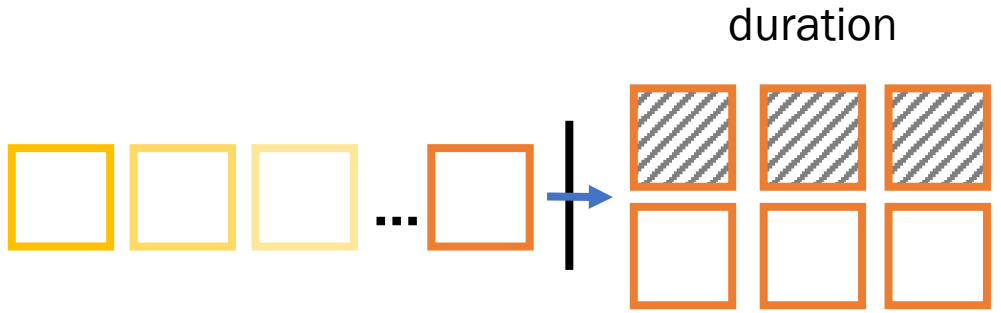


time -2 time -1

What kind of change?

Open research question:

Disentangle normal cyclic and seasonal processes with anomalous transient and permanent changes



Change detection – image differencing

- A basic baseline method to estimate change – just by subtracting the two images

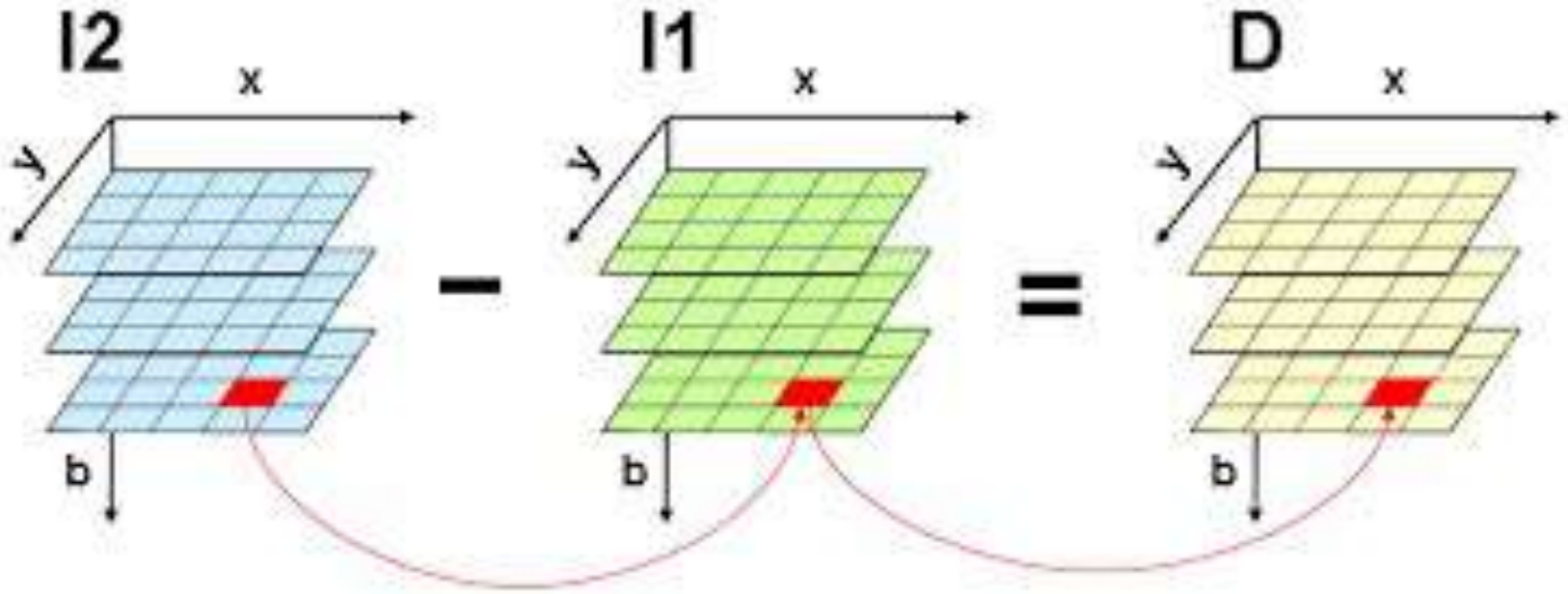


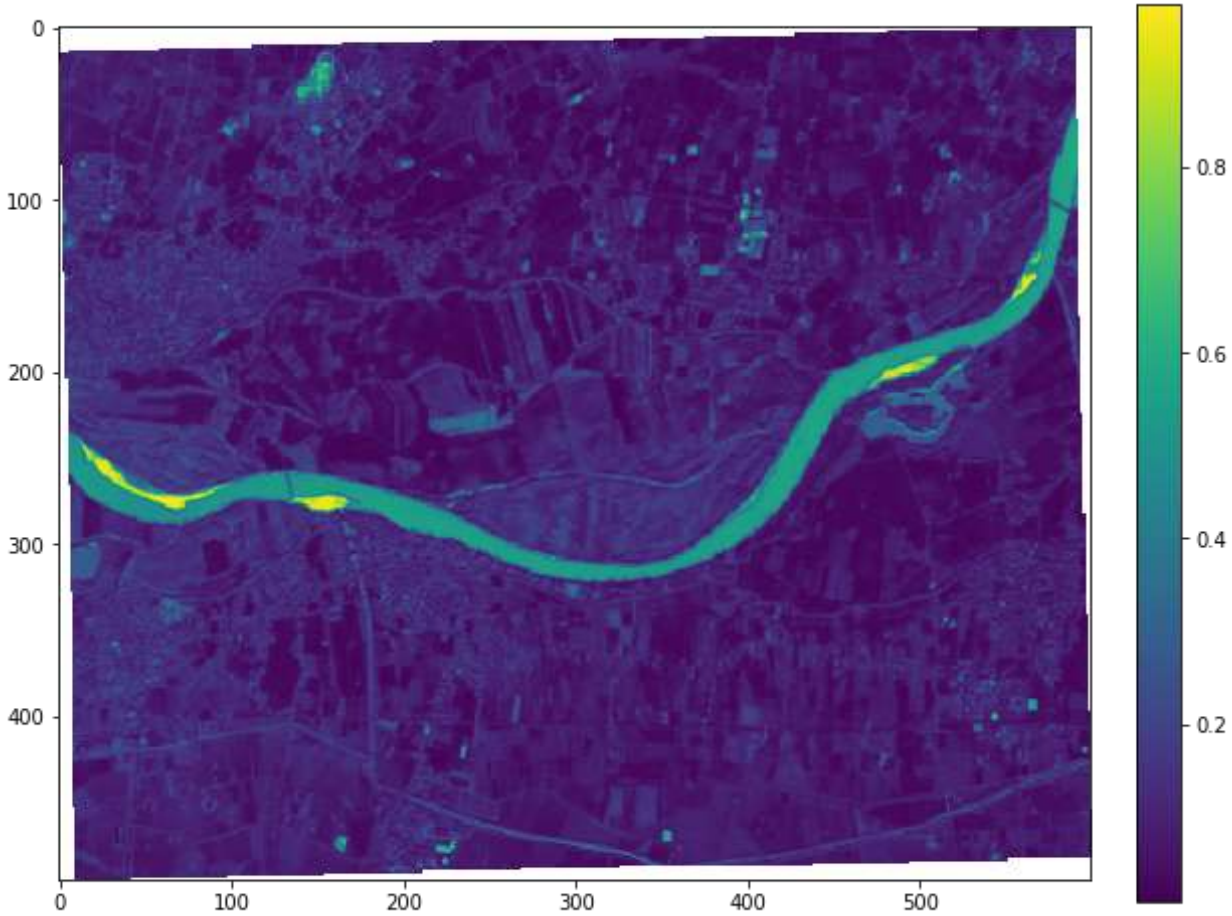
Image differencing of pixel data

RGB before

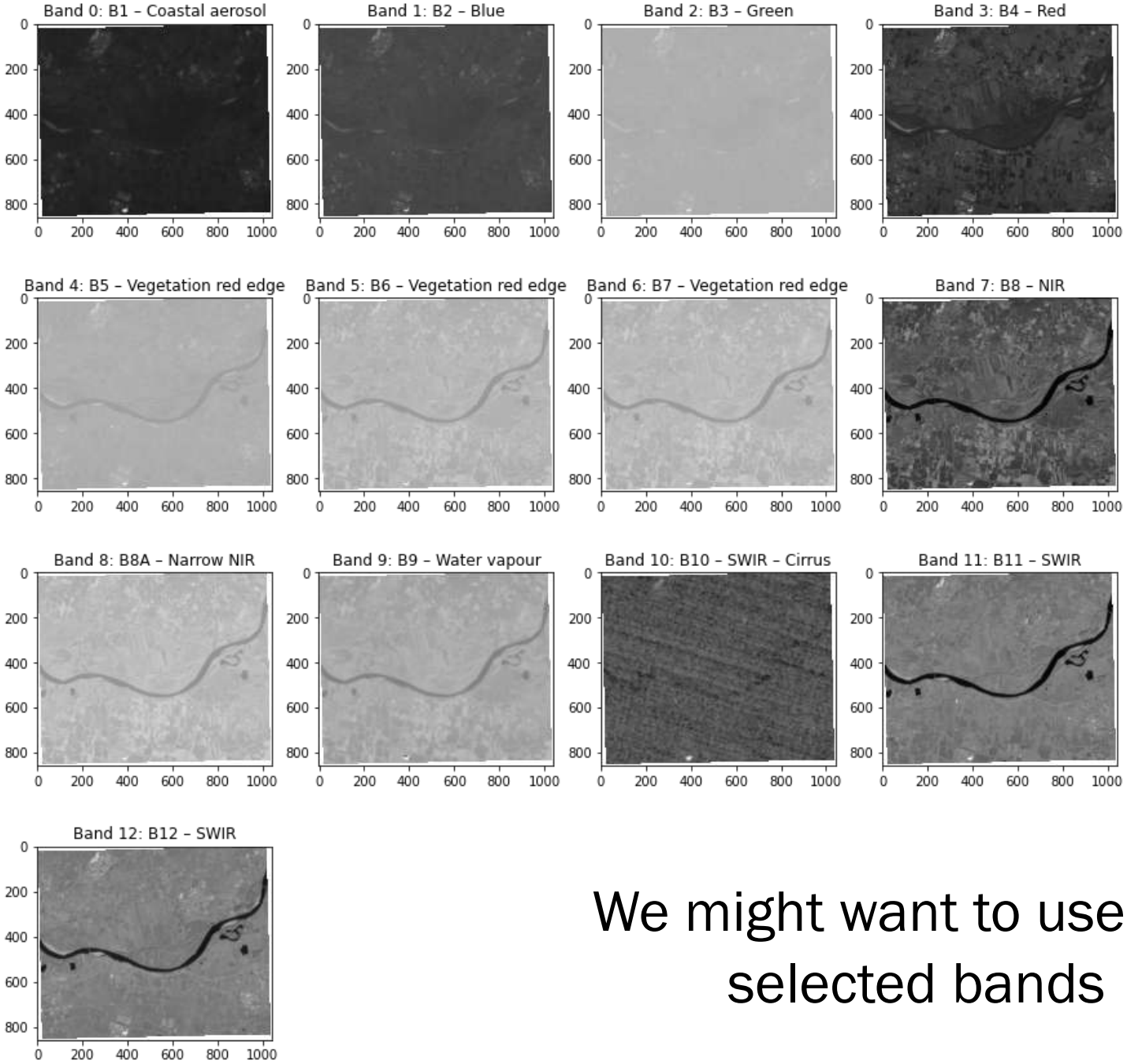
RGB after

Difference between all 15 bands creates a diff image with 15 bands

- Some will be > 0, some < 0, we need to look at the absolute value
- Also apply max over all bands



PS:

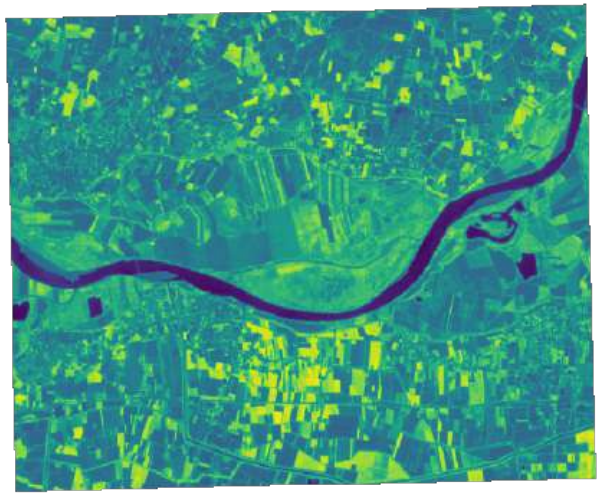


Sentinel-2 bands	Resolution (m)
Band 1 – Coastal aerosol	60
Band 2 – Blue	10
Band 3 – Green	10
Band 4 – Red	10
Band 5 – Vegetation red edge	20
Band 6 – Vegetation red edge	20
Band 7 – Vegetation red edge	20
Band 8 – NIR	10
Band 8A – Vegetation red edge	20
Band 9 – Water vapour	60
Band 10 – SWIR – Cirrius	60
Band 11 – SWIR	20
Band 12 – SWIR	20

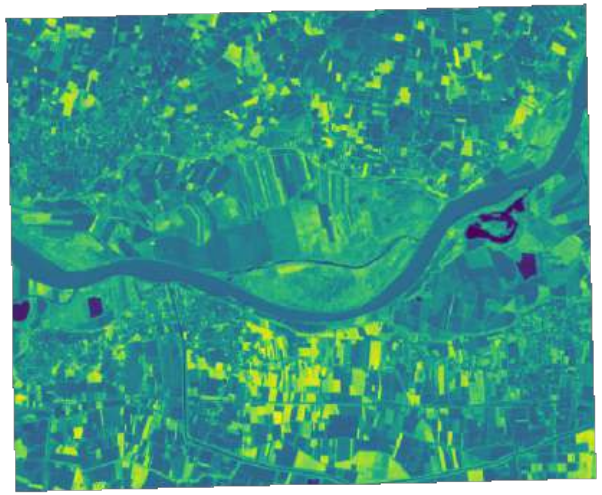
We might want to use only selected bands

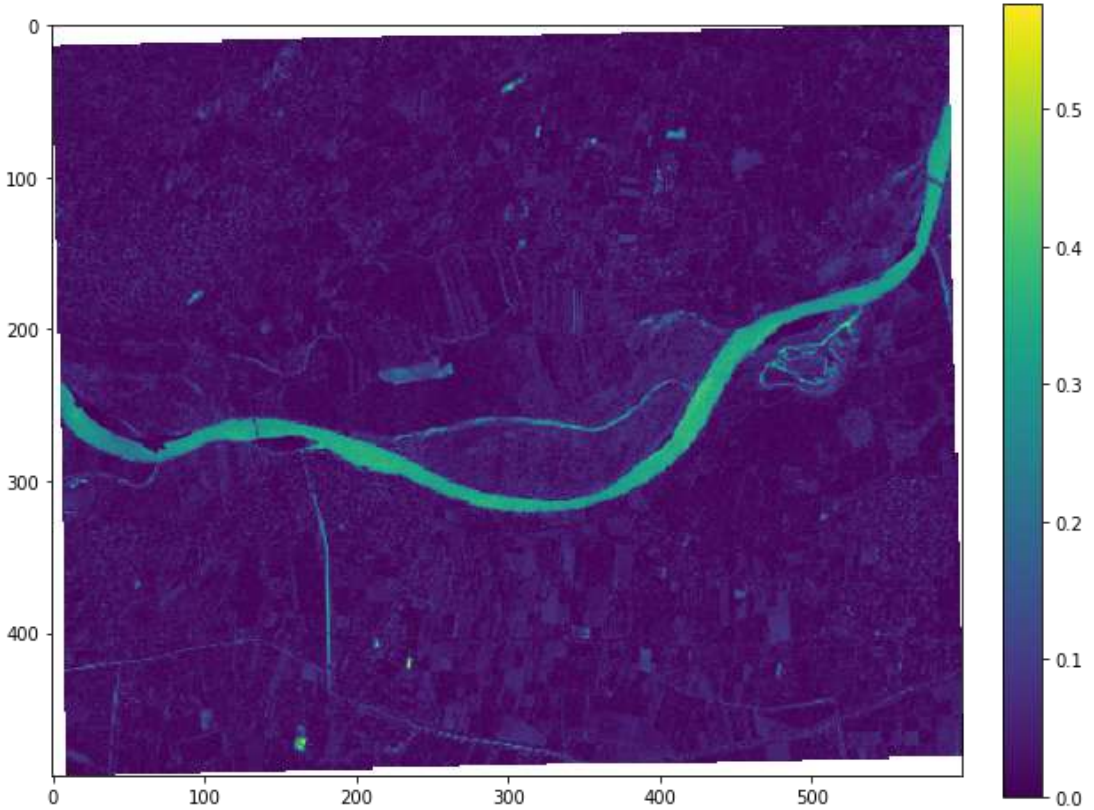
Image differencing of calculated NDVI's

NDVI before



NDVI after





Difference between the calculated NDVI visualizations directly produces 1 band

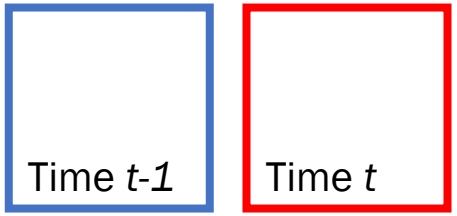
Visualization as a sequence (animation)

Notice the jitter!

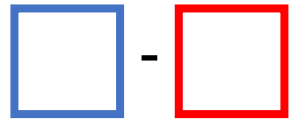
We might need something more robust!

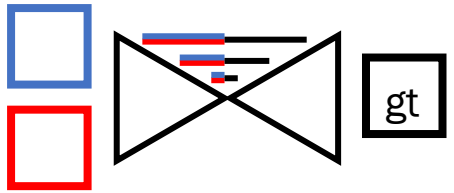
Change Detection Taxonomy

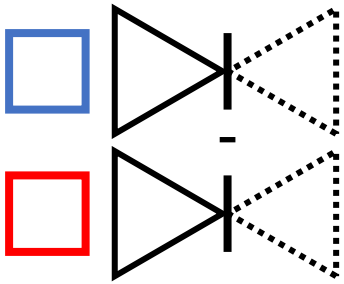
pair:



- CD
  - Classical image differencing methods
  - Deep learning
    - Supervised Siamese U-Net models
    - Unsupervised (V)AE models
    - *timeseries*
      - *Long temporal sequence unsupervised LSTM models*







Our work: RaVAEn system

Task: Extreme event detection in series of remote sensing data

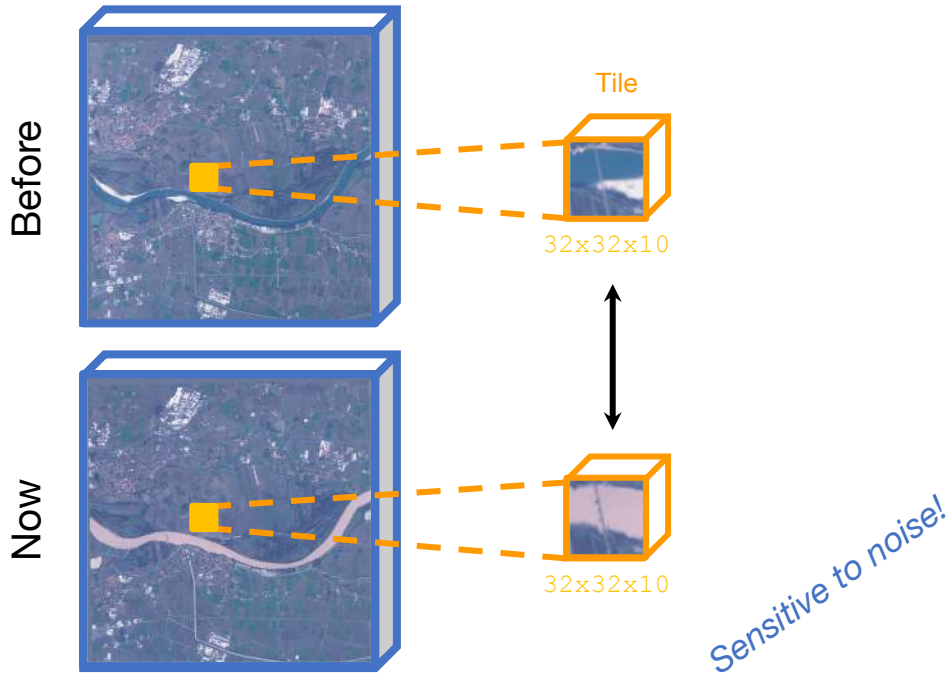


Image space comparison

Unsupervised Change Detection of Extreme Events Using ML On-Board

Vít Růžička[1]*, Anna Vaughan[2], Daniele De Martini[1], James Fulton[3], Valentina Salvatelli[4], Chris Bridges[5], Gonzalo Mateo-Garcia[6], Valentina Zantedeschi[7]
[1]University of Oxford, [2]University of Cambridge, [3]University of Edinburgh, [4]Microsoft, [5]University of Surrey, [6]University of Valencia, [7]INRIA, University College London

Abstract

In this paper, we introduce **RaVÆn**, a lightweight, unsupervised approach for change detection in satellite data based on Variational Auto-Encoders (VAEs) with the specific purpose of on-board deployment. Applications such as disaster management enormously benefit from the rapid availability of satellite observations. Traditionally, data analysis is performed on the ground after all data is transferred – downlinked – to a ground station. Constraint on the downlink capabilities therefore affects any downstream application. In contrast, **RaVÆn** pre-processes the sampled data directly on the satellite and flags changed areas to prioritise for downlink, shortening the response time. We verified the efficacy of our system on a dataset composed of time series of catastrophic events – which we plan to release alongside this publication – demonstrating that **RaVÆn** outperforms pixel-wise baselines. Finally we tested our approach on resource-limited hardware for assessing computational and memory limitations.

At the *"AI for Humanitarian Assistance and Disaster Response Workshop"*, NeurIPS 2021

Our work: RaVAEn system

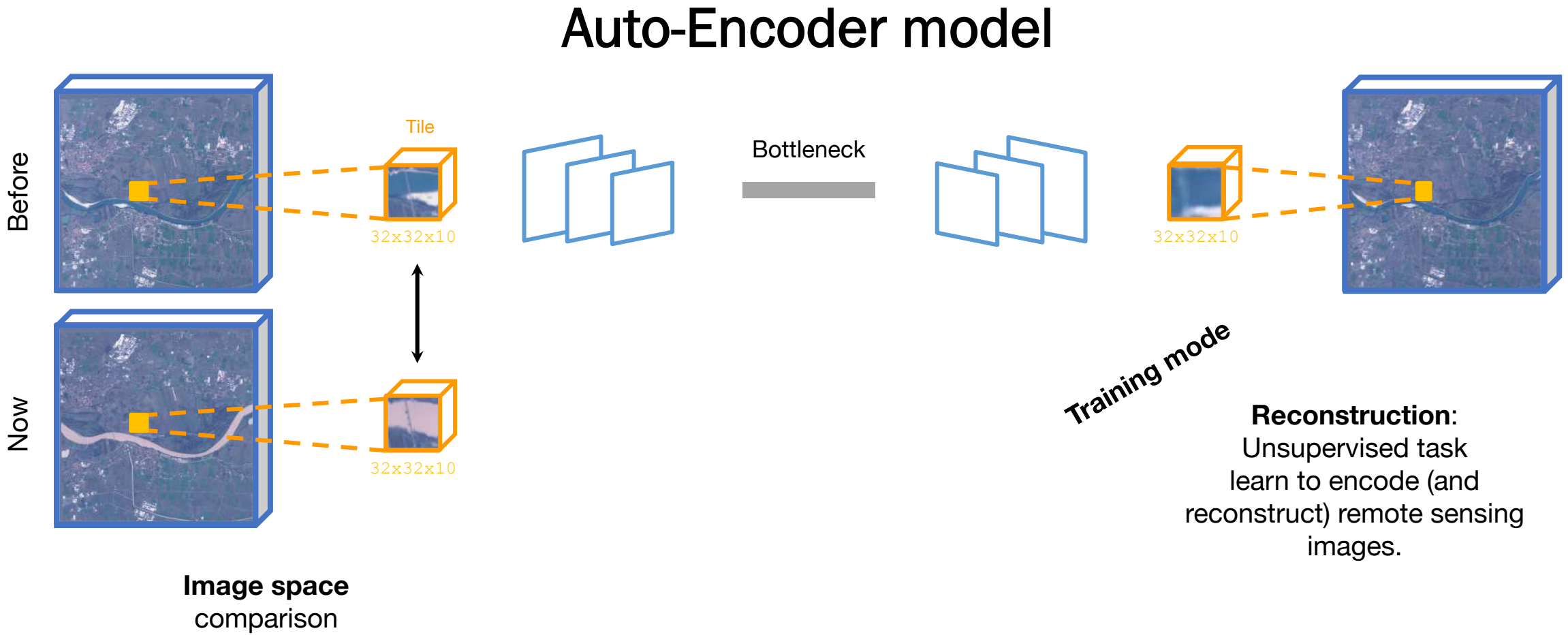


Image space comparison

Reconstruction: Unsupervised task learn to encode (and reconstruct) remote sensing images.

Our work: RaVAEn system

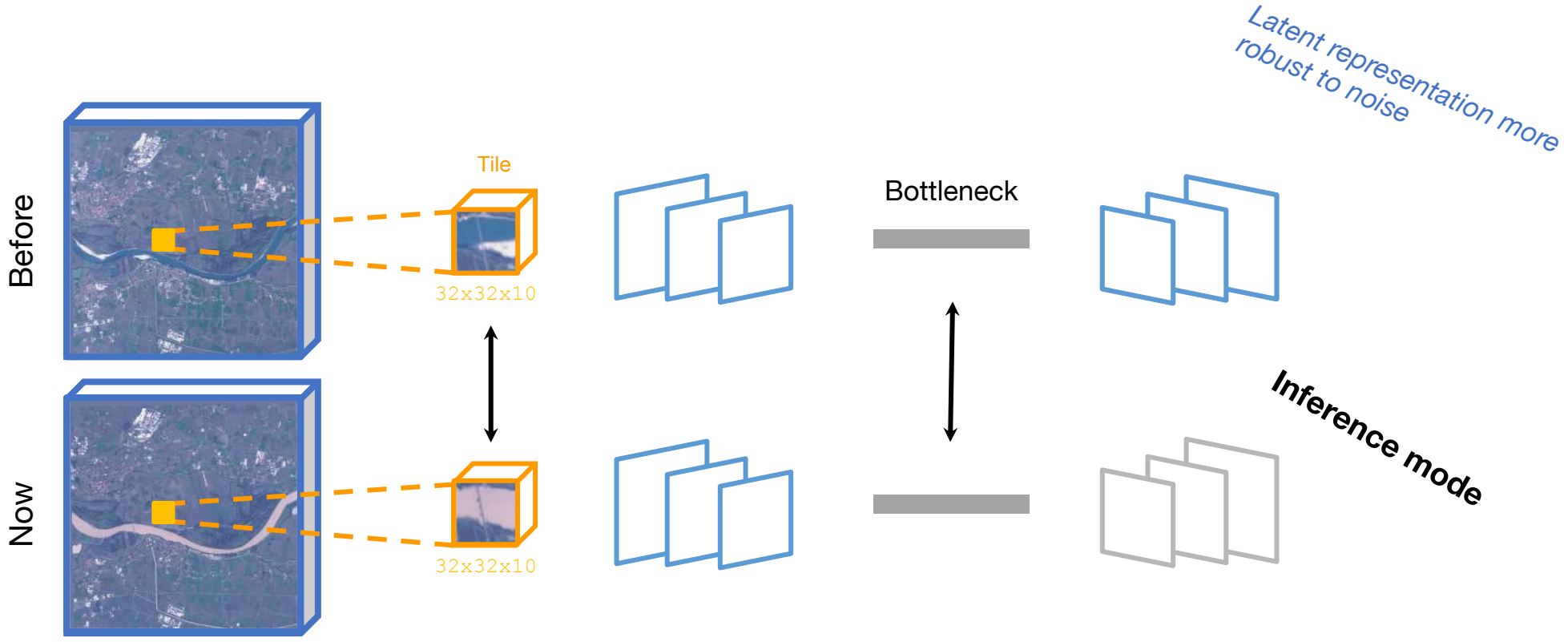
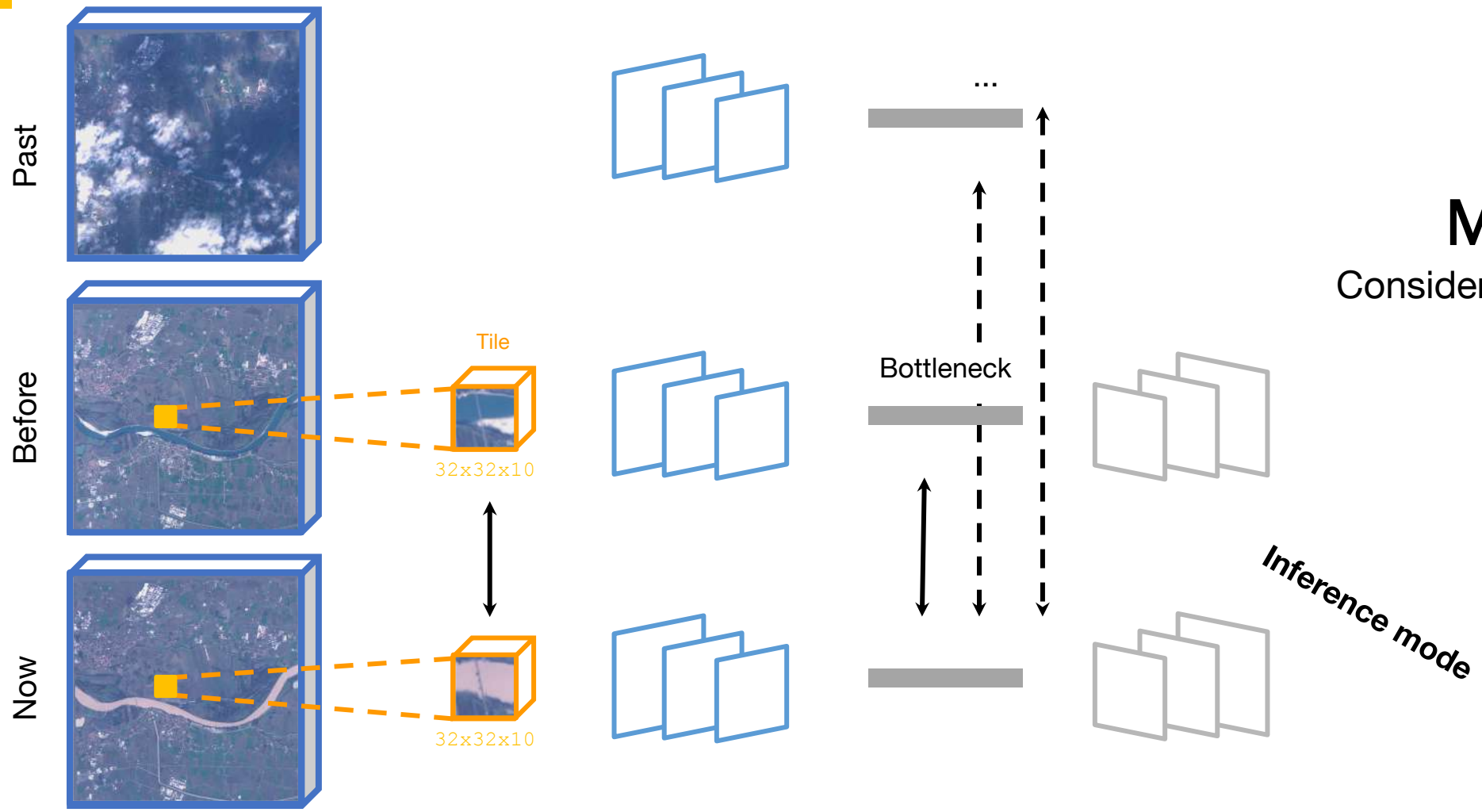


Image space comparison

Latent space comparison

Reconstruction: Unsupervised task

Our work: RaVAEn system



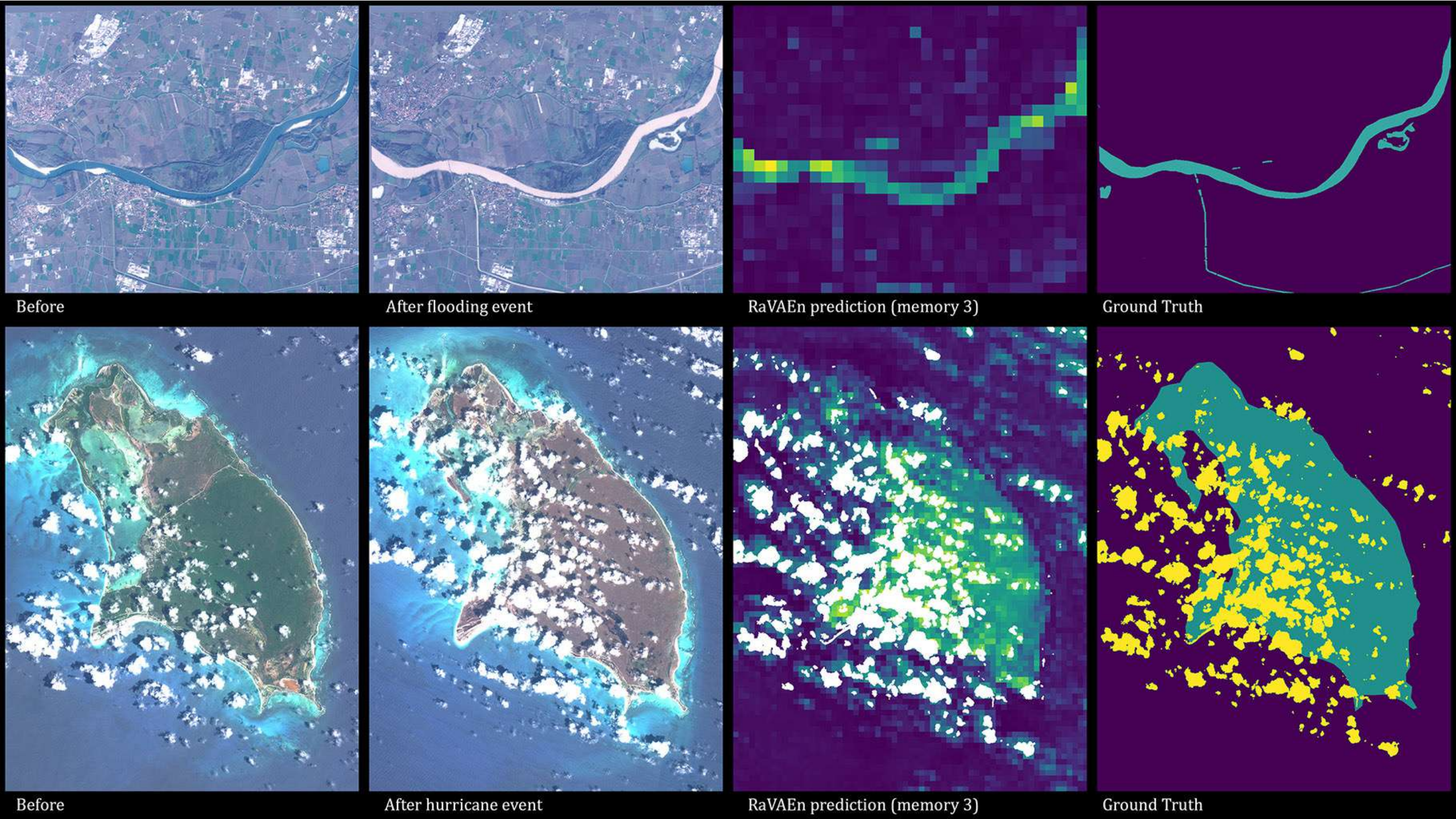
Memory

Considers longer temporal changes

Image space comparison

Latent space comparison

Reconstruction: Unsupervised task


Before
After flooding event
RaVAEn prediction (memory 3)
Ground Truth
Before
After hurricane event
RaVAEn prediction (memory 3)
Ground Truth

RaVAEn project and dataset

- Collected real-world data from Sentinel-2 (level L1C data)

- **Training data** Worldfloods
- **Evaluation dataset:** extreme events, labelled

- **More info and data available on:** github.com/spaceml-org/RaVAEn