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ICSC
Centro Nazionale di Ricerca in HPC, Big Data and Quantum Computing

Advancing environmental monitoring through deep learning: wildfire segmentation using time-series of images from the Sentinel constellation (EGU25-9376)

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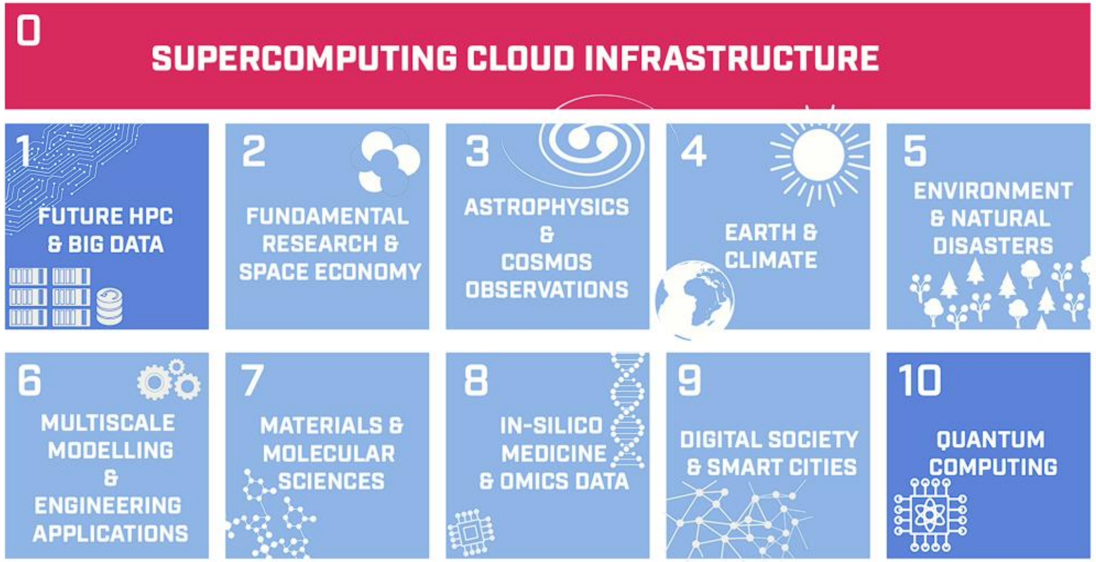
The National Centre for HPC, Big Data and Quantum Computing

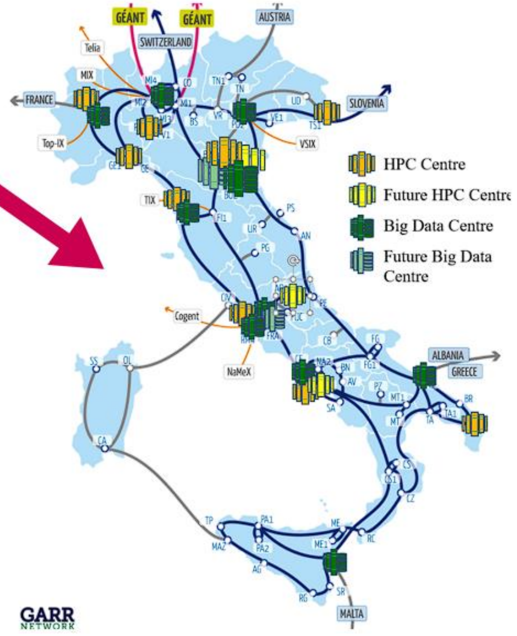
Managed by the ICSC Foundation, one of the five National Centres founded under the Italian PNRR.

Goal : a long-term, national, distributed infrastructure for cutting-edge research and innovation in high-performance and high-throughput computing.

A total investment of almost 320 million Euros
Sept. 2022 – Aug. 2025

Over 50 founding members, to foster synergy between scientific and industrial sectors.





One cross spoke, Spoke 0 ("Supercomputing Cloud Infrastructure"), and 10 thematic spokes.

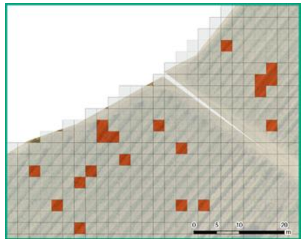
Spoke 2 - Fundamental Research & Space Economy

WP1: algorithms and tools for theor. physics	WP2: applications for exp. high-energy physics	WP3: applications for exp. astroparticle and G.W.
WP4: boost computational performances & porting to GPU, FPGA, etc.	WP5: support for data management & distributed data-lake infrastructure	WP6: Cross Domain initiatives & Space Economy

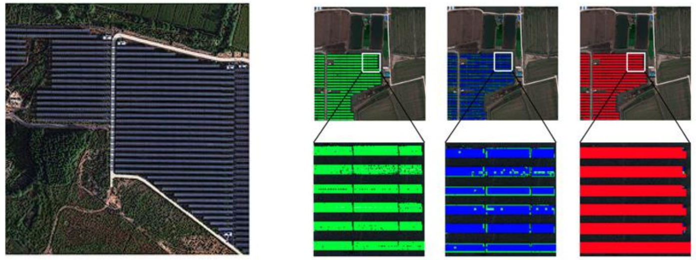
Spoke-2 is coordinated by **INFN** and organized in 6 Work Packages.

WP6 flagship "*AI algorithms for (satellite) imaging reconstruction*" includes **three distinct but interconnected** lines of research.

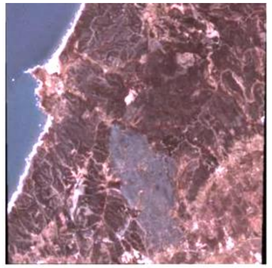
High-resolution image processing based on spectral indexes for disease detection in vineyards

Deterministic learning algorithm for object identification



Deep Learning for satellite imagery analysis

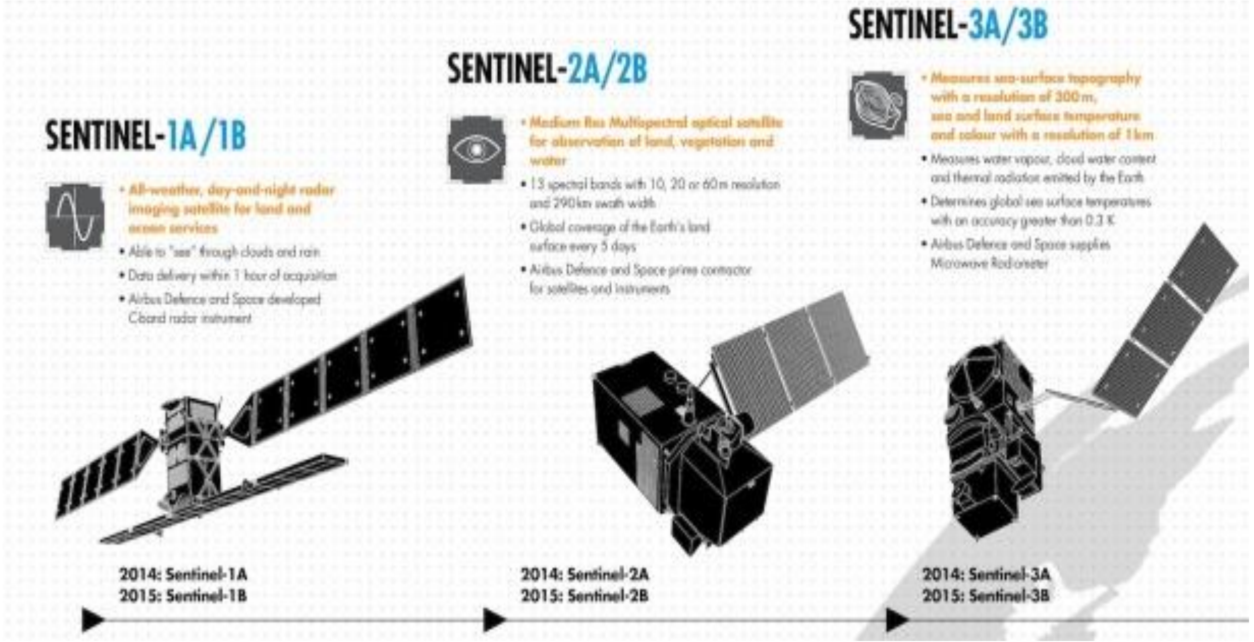

Segmentation of wildfire-affected areas using deep learning

Wildfires: an increasing and critical problem

- In recent years, **forest fires have increased** significantly due to higher temperatures and prolonged periods of drought.
- Aerial data and machine learning can be used for wildfire identification, monitoring, prediction and **mapping of burned area.**
- **Target**: provide new, powerful **deep learning** tools for **large-scale environmental monitoring and disaster management** (damage assessment, post-fire recovery, ...)

Dataset

- **Copernicus Sentinel constellation:** Sentinel-1 (IW mode, dual polarization), Sentinel-2 (L2A), Sentinel-3 (OLCI), Sentinel-3 (SLSTR), Digital Elevation Model (DEM)
- **Custom library** (based on the *Sentinel-HUB API*) for the download & processing of images.



- **178 wildfires**, recorded mainly in the Mediterranean area, from the Copernicus Emergency Management Service (EMS);
- **for each event, a temporal series of images is used:**
  - 3 images (12 days interval) for Sentinel-1 & Sentinel-2;
  - 12 images (3 days interval) for Sentinel-3 OLCI & SLSTR;
- each image has a size of *256 x 256* pixels for Sentinel-3 data, and *1024 x 1024* pixels for Sentinel-1 & 2 and DEM data.

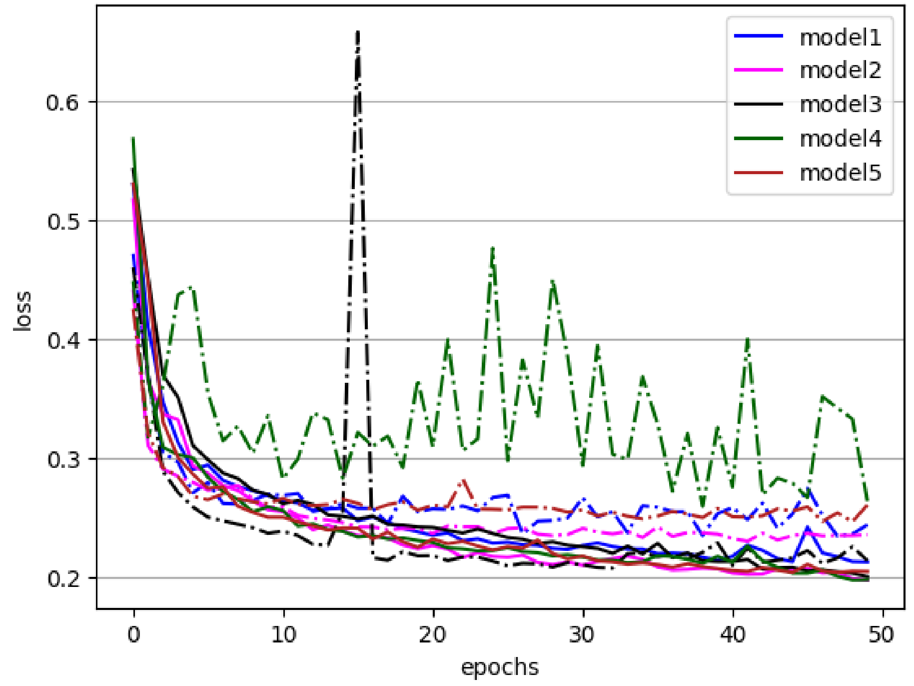
Model architecture and training

- ***UNet-like* model with 5 encoder heads, corresponding to the 5 data sources:**
  - **Convolutional Long Short Term Memory** (*ConvLSTM2D*) + *MaxPooling* in the encoding part, separately for each satellite (3 times for Sentinel-1, Sentinel-2 & DEM data, twice for Sentinel-3 OLCI and SLSTR data);
  - a single decoder with 3 *Conv2DTranspose* + *UpSampling* layers and skip-connections, plus a final sigmoid activation.

- **Input**: patches of dimension *1/16th* of the original images.
- **Output**: binary mask of burnt pixels.
- **Loss function**: optimized sum of binary cross-entropy, Dice loss and Jaccard loss terms.

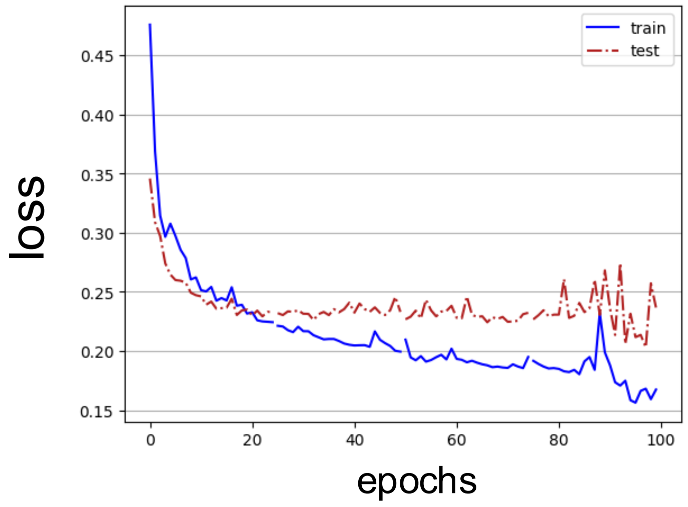
To ensure the robustness of the model, a **5-fold cross-validation** was performed using 130 event, achieving **stable convergence and consistent accuracy** after about 50 epochs**.**

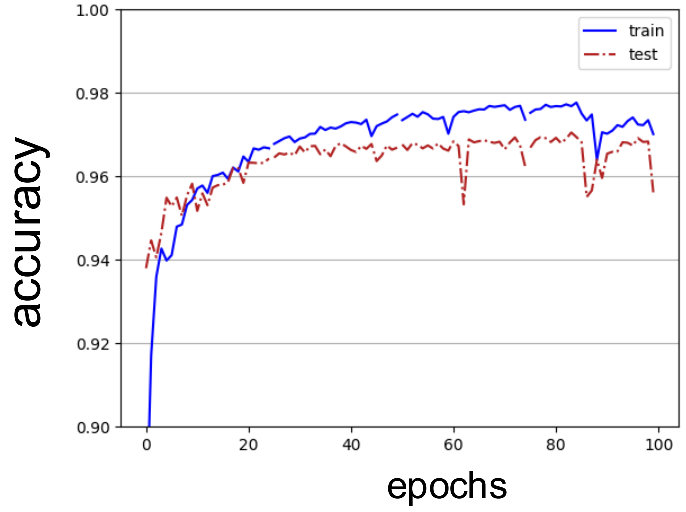
Avg. train. loss: 0.202 ± 0.005
Avg. valid. loss: 0.243 ± 0.010
Avg. train. accuracy: 0.973 ± 0.002
Avg. valid. accuracy: 0.963 ± 0.006



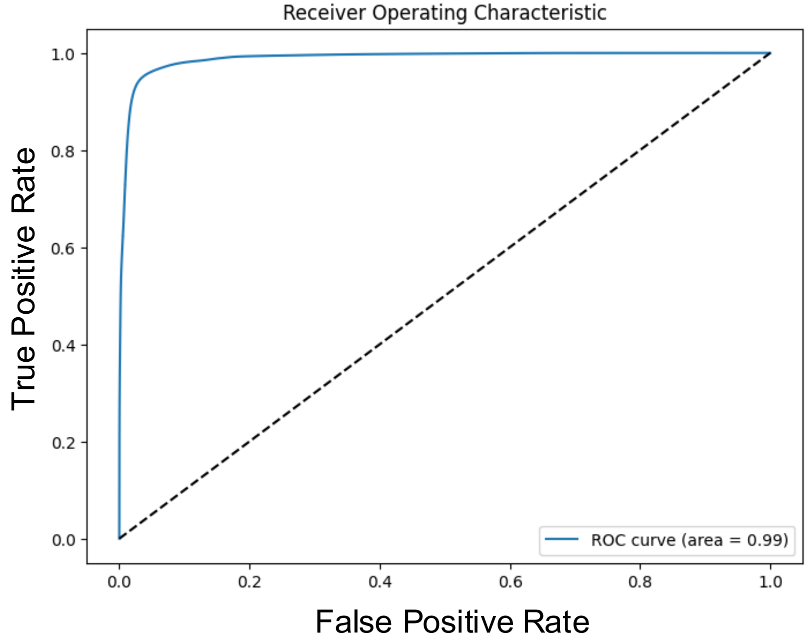
Results and performances

- ✓ The final model was trained for 100 epochs using 130 events, with the remaining 48 used as test set.
- ✓ The final values for the metrics and the ROC curve (with an AUC score close to 0.99) calculated over the test set indicate **strong capability of the trained model in identifying burnt areas**.
- ✓ The Dice (0.90) and Jaccard (0.82) scores confirm the **high discriminatory power** of the trained model, with solid overlap between predicted and affected regions.



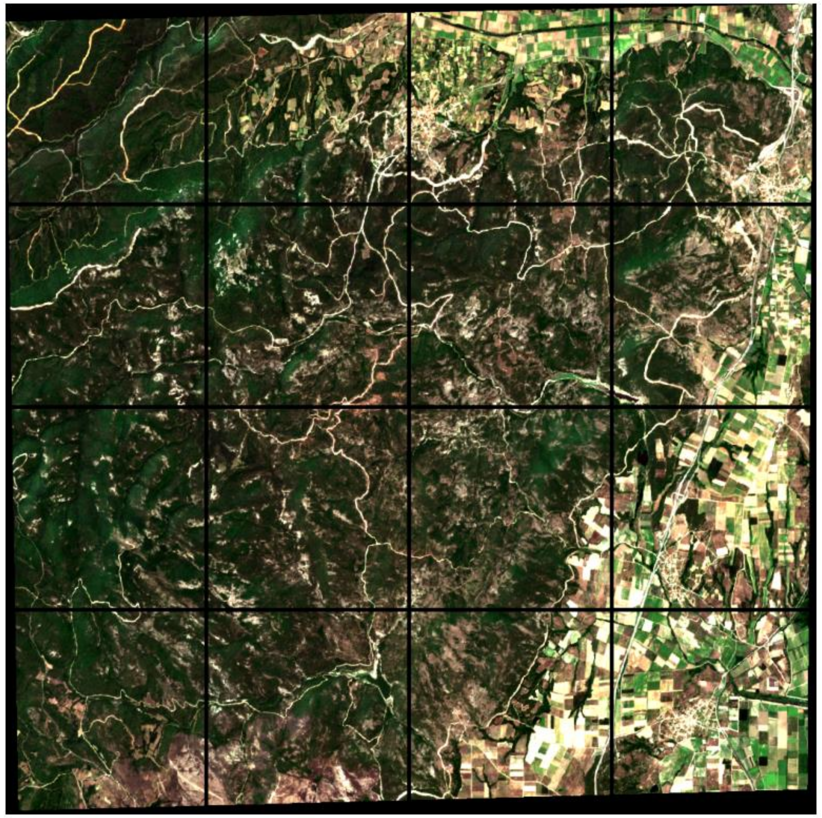


Metrics	
Best Threshold	0.55
Accuracy	0.97
Precision	0.88
Recall	0.92
F1 Score (Dice)	0.90
IoU (Jaccard)	0.82

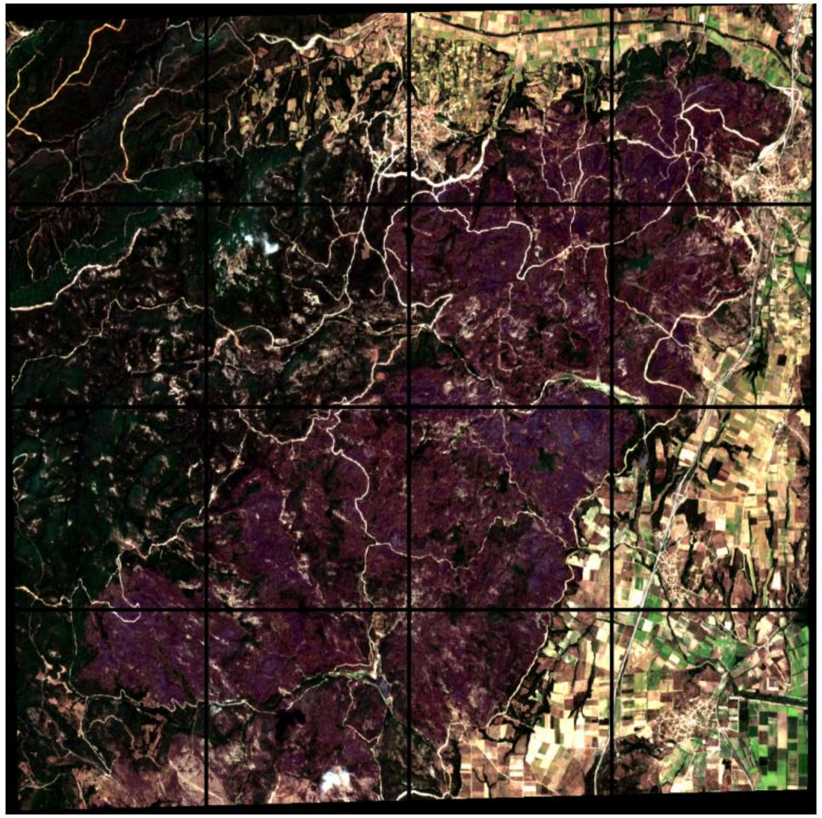


Example of results

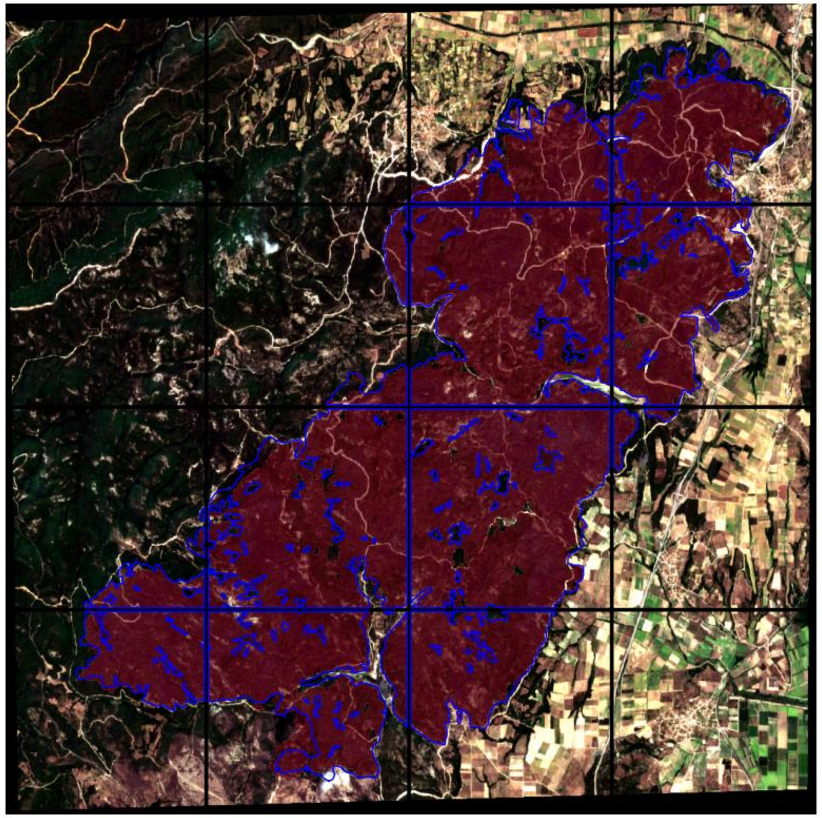
BEFORE FIRE



AFTER FIRE



PREDICTION



Copernicus Emergency Management Service (© 2022 European Union), **EMSR605 AOI01** - available at https://mapping.emergency.copernicus.eu/activations/EMSR605/

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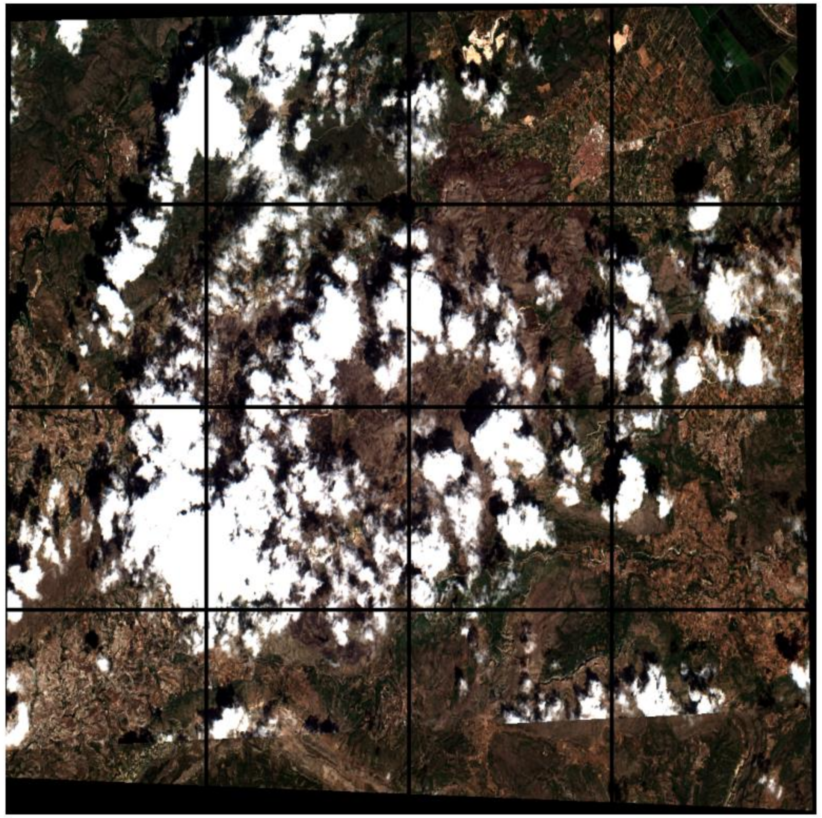
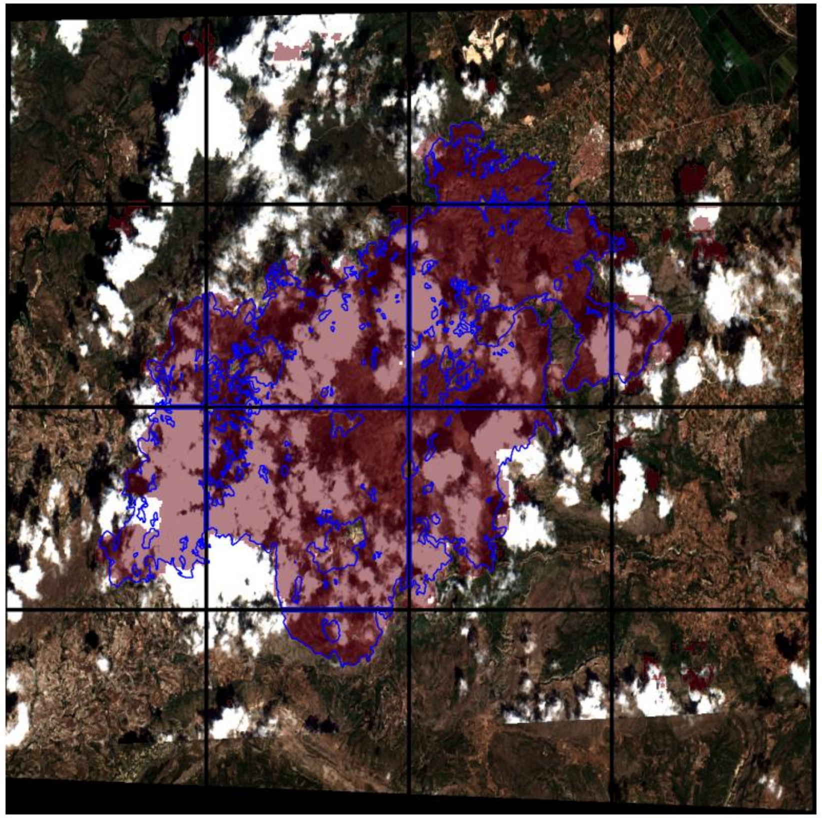
Example of results

BEFORE FIRE

AFTER FIRE



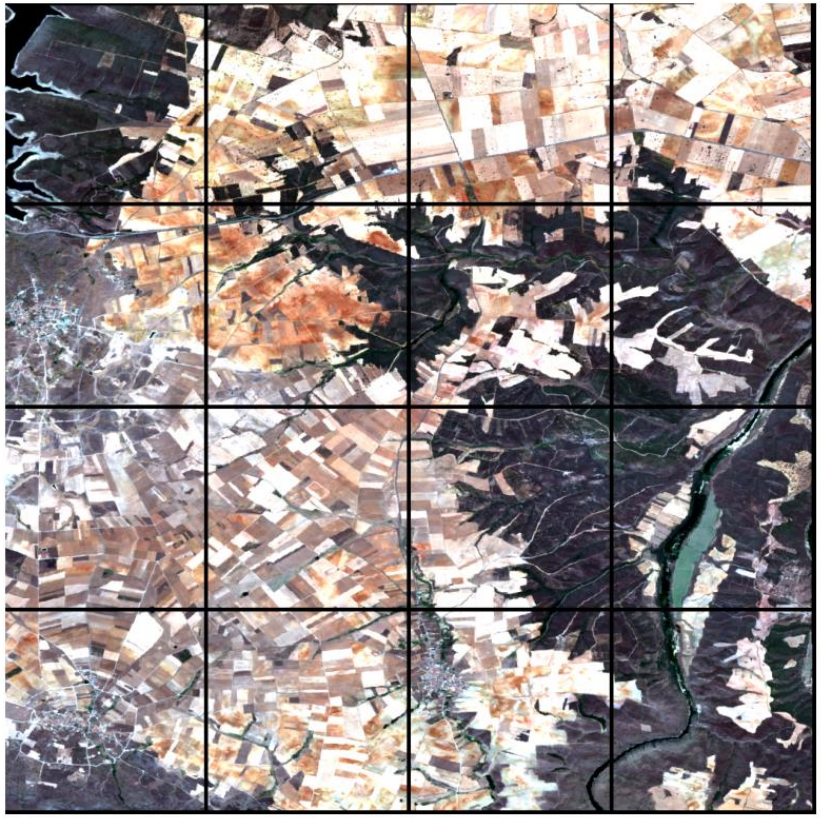
PREDICTION



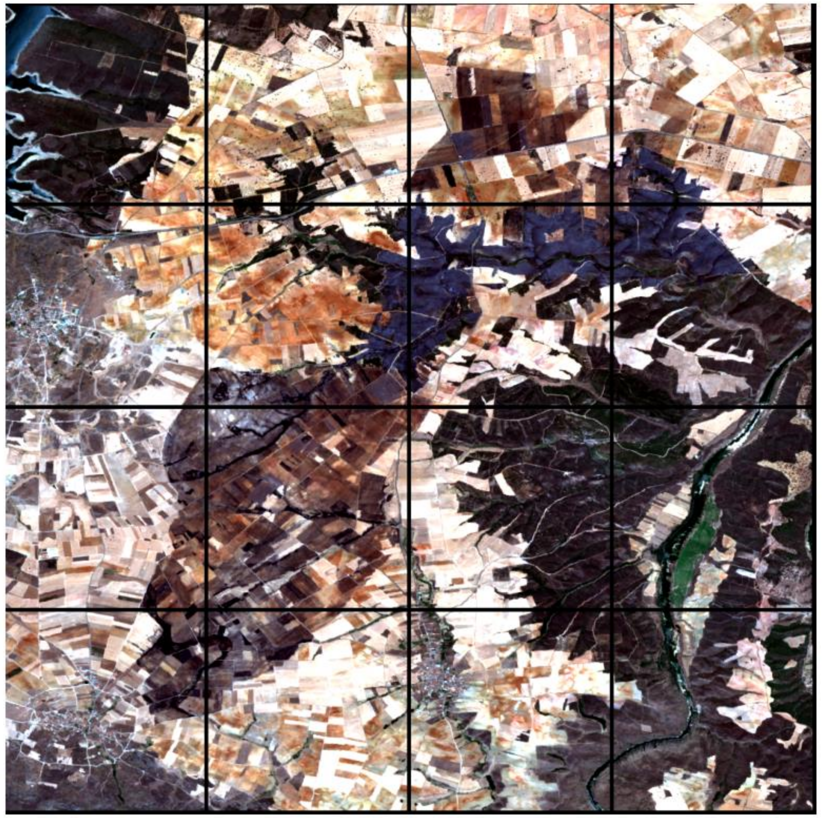
Copernicus Emergency Management Service (© 2022 European Union), **EMSR617 AOI02** - available at https://mapping.emergency.copernicus.eu/activations/EMSR625/

Example of results

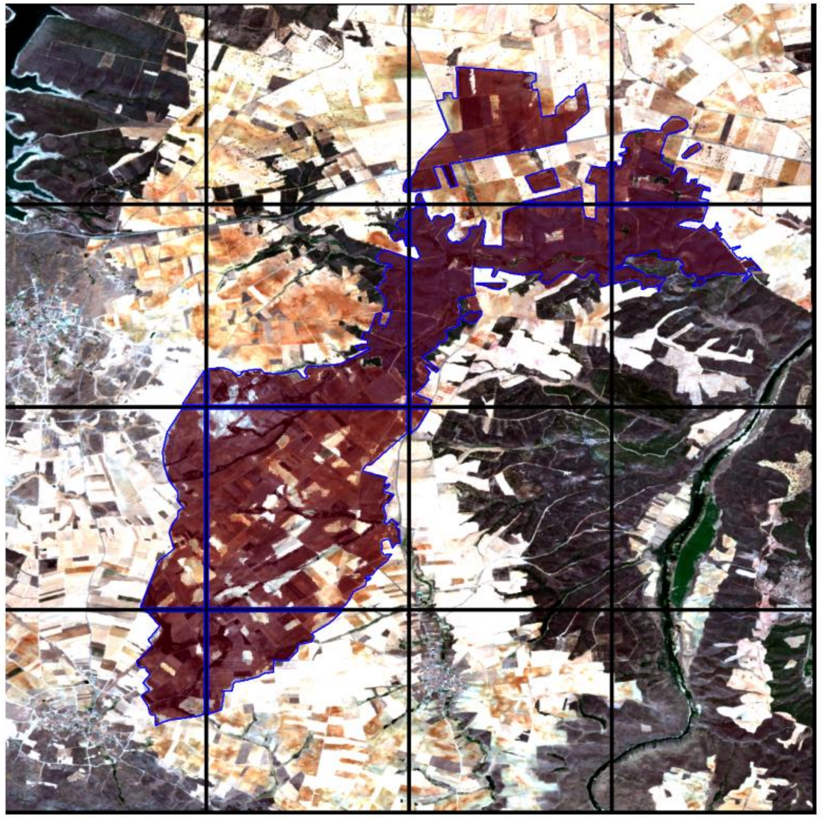
BEFORE FIRE



AFTER FIRE



PREDICTION



Copernicus Emergency Management Service (© 2022 European Union), **EMSR602 AOI09** - available at https://mapping.emergency.copernicus.eu/activations/EMSR602/

Future prospects

EGU25-9376

- The achieved results demonstrate the effectiveness of deep learning models in identifying burnt areas from satellite imagery.
- Deeper and/or more powerful models will potentially deliver even greater accuracy and scalability, particularly when handling complex, high-dimensional satellite data.
- The **computational resources and infrastructure provided by ICSC** will allow extensive experimentation and further refinement of these models.

Thanks for the attention!

This work is supported by ICSC – Centro Nazionale di Ricerca in High Performance Computing, Big Data and Quantum Computing, funded by European Union – NextGenerationEU

Backup

A custom library to download and manage satellite data

Within the project, a ***python*** library has been developed, currently including of 4 modules:

Download module	Download of satellite imagery using the Sentinel-Hub API. Currently implemented for Sentinel2-L2A products only.
DataManipulator module	Produce maps for single spectral band and vegetation indexes (currently 19 implemented) in TIFF format and as ***numpy*** arrays. Also combining downloaded data with **labels**.
Visualiser module	Printing the processed maps in standard formats (PDF, PNG, etc.)
DataHandling module	Pre-processing of data for training deep-learning applications. Currently includes : dataset normalization, discrete mirroring/rotations & image splitting for data augmentation, storage in csv or numpy-native formats.

To be made publicly available as open-source library by the end of the project.

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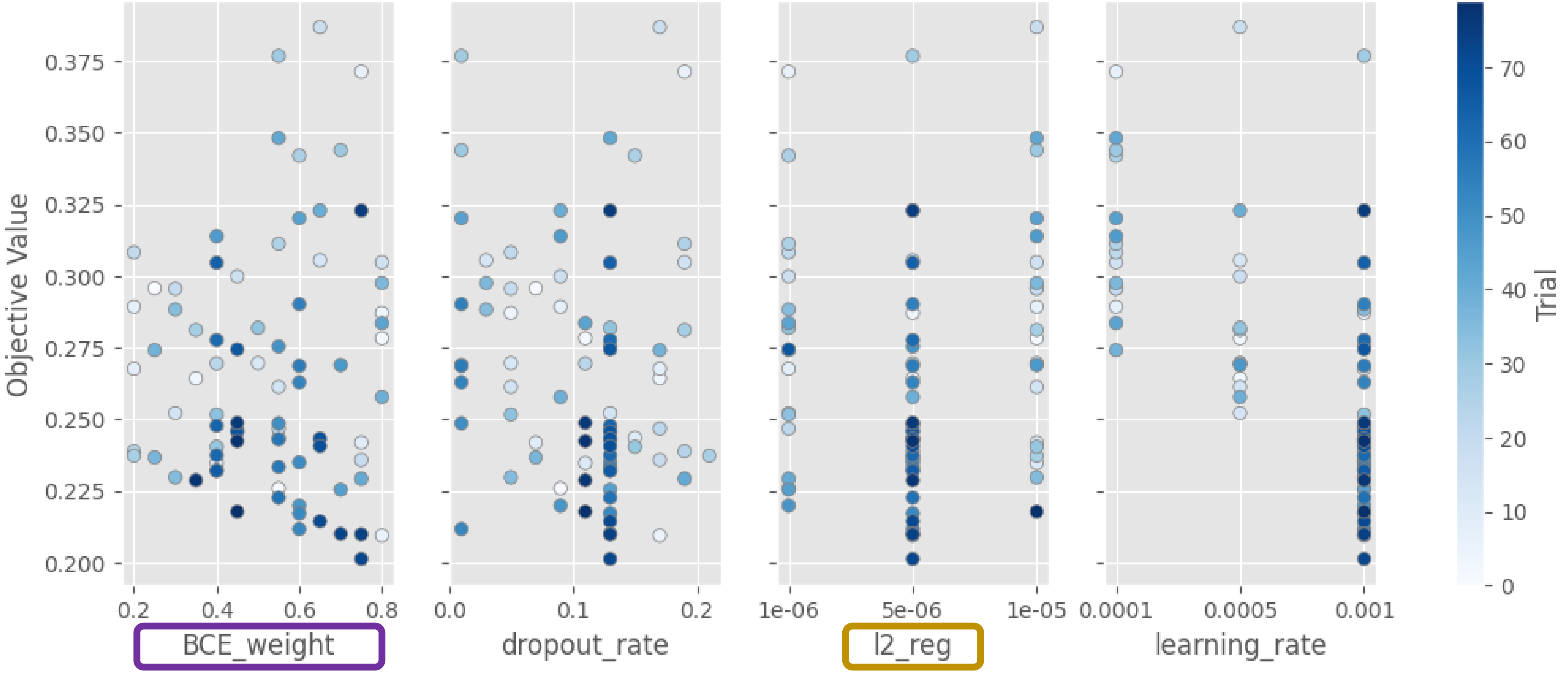
Oputuna study of hyperparameters



Weight of the binary cross-entropy term in the loss
Dice_weight = Jaccard_weight = (1 – BCE_weight)/2

Weight of the L2 kernel regularization term applied to each *ConvLSTM2D, Conv2D and Conv2DTranspose* layer

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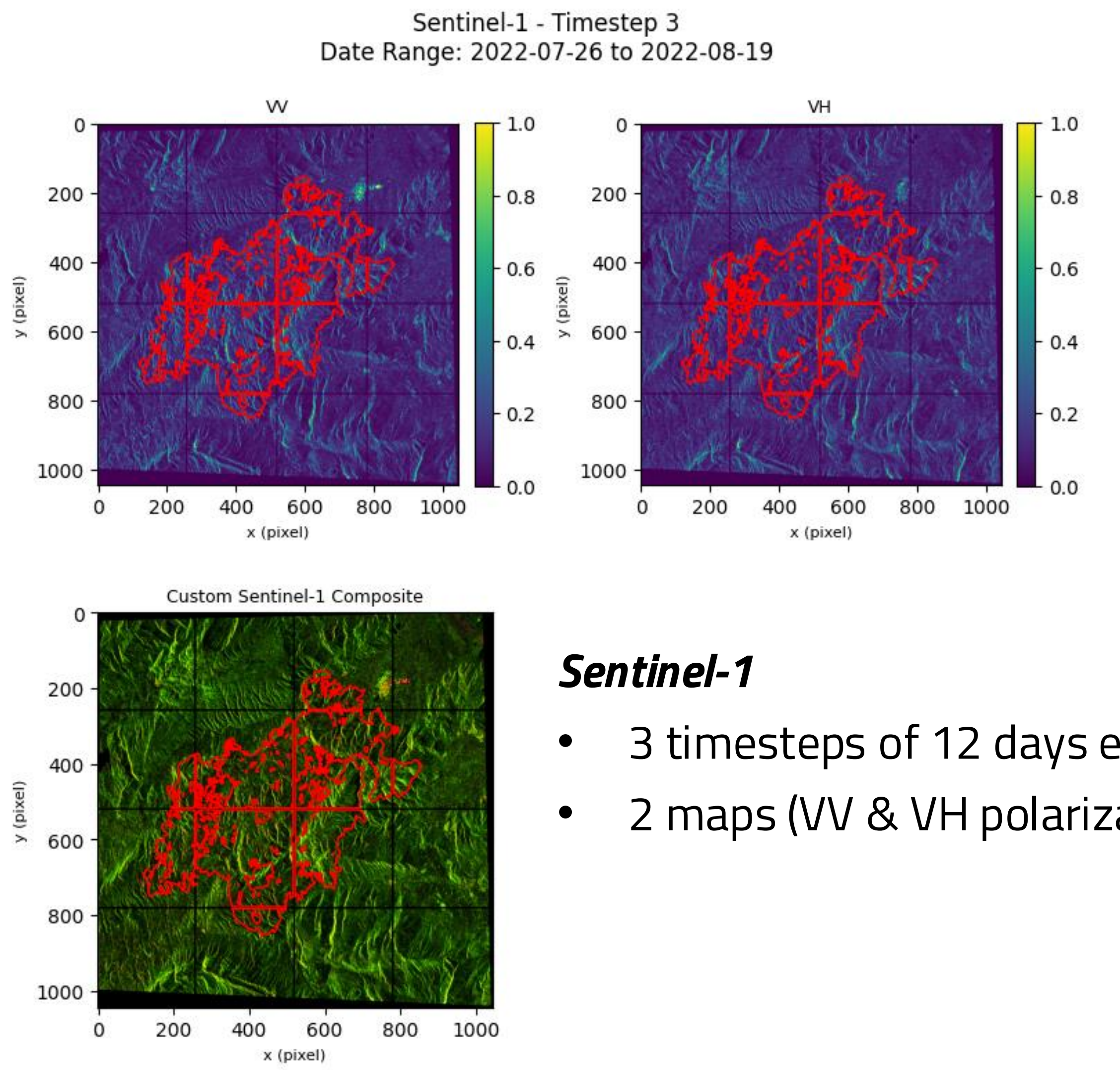
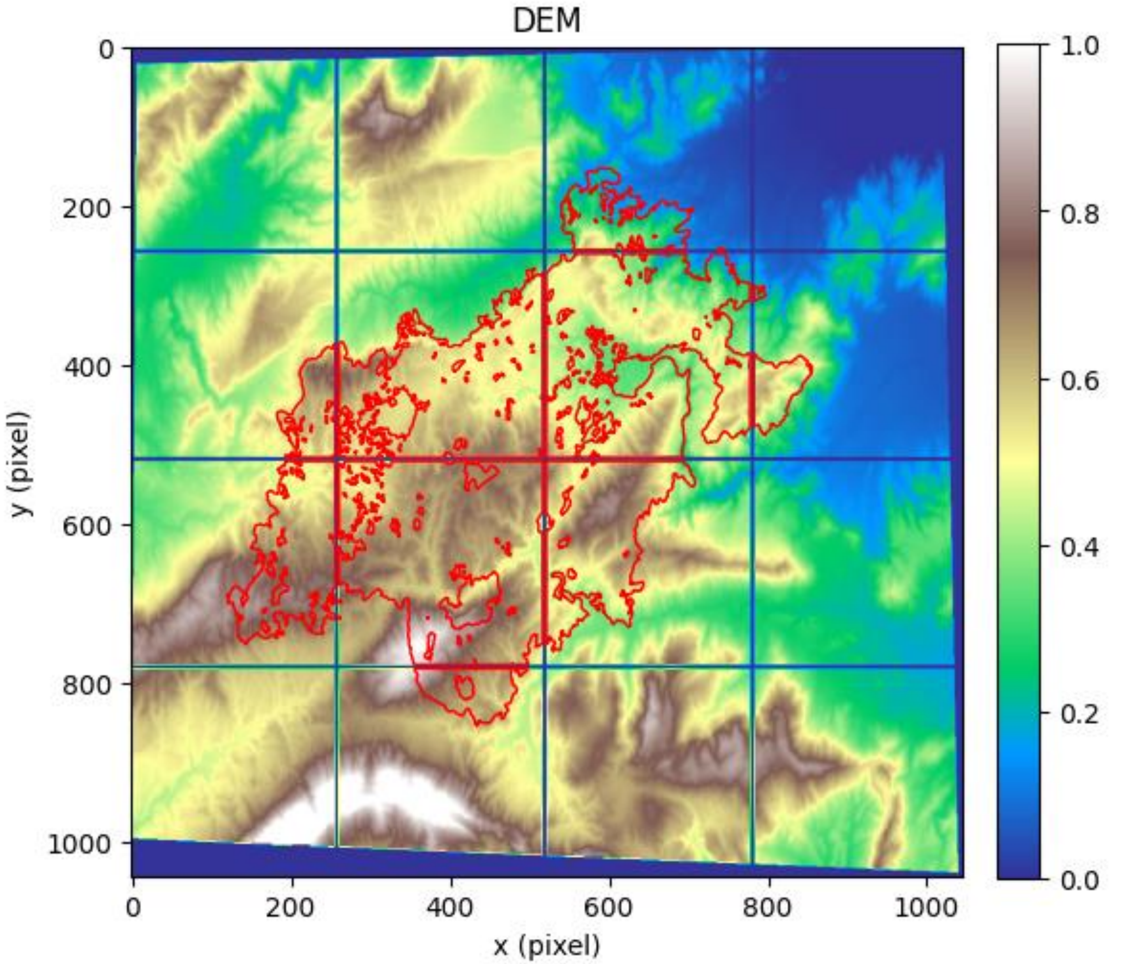
Input data (one example timestep for each source)



Sentinel-1

- 3 timesteps of 12 days each
- 2 maps (VV & VH polarizations)



DEM – single timestep, single map

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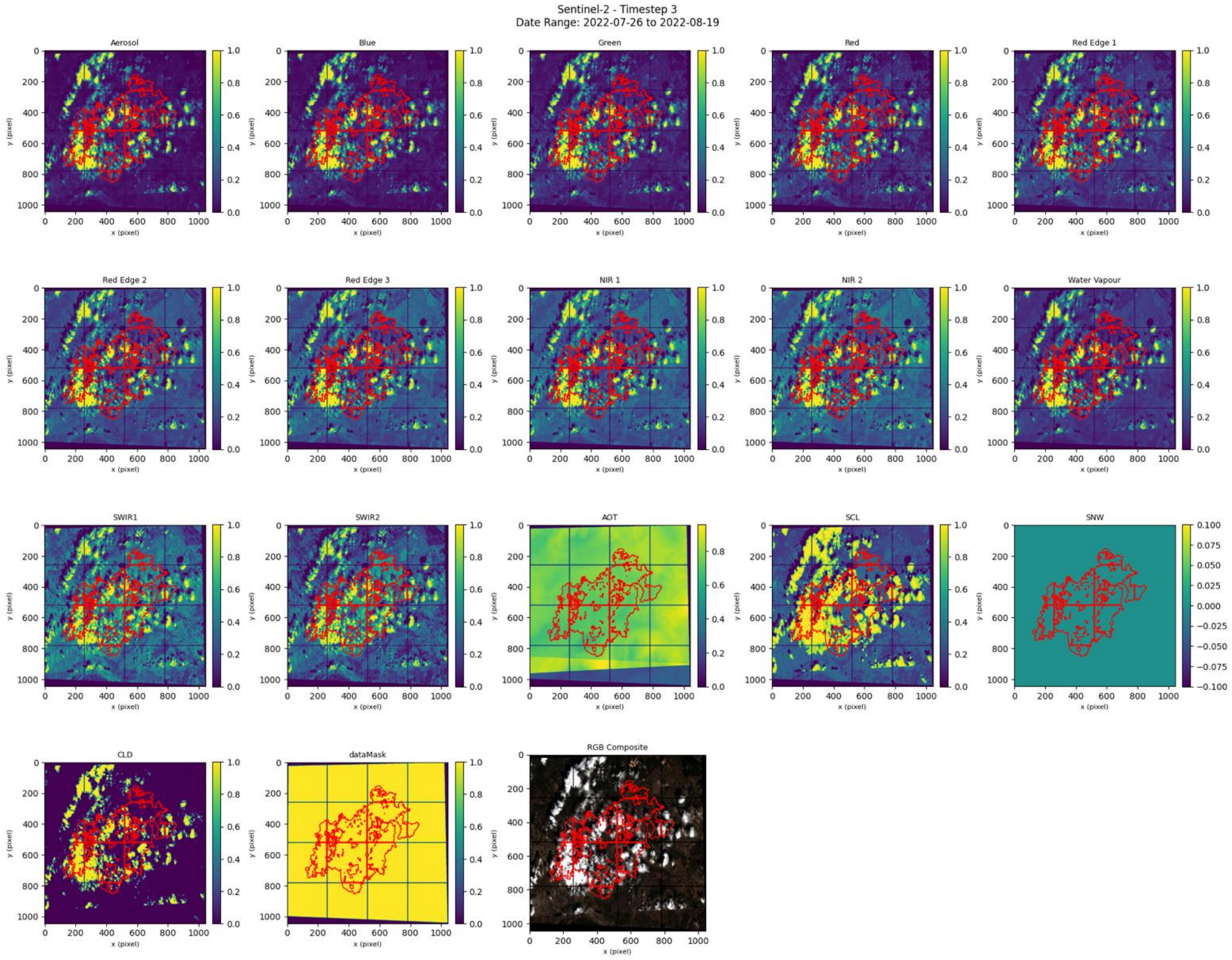
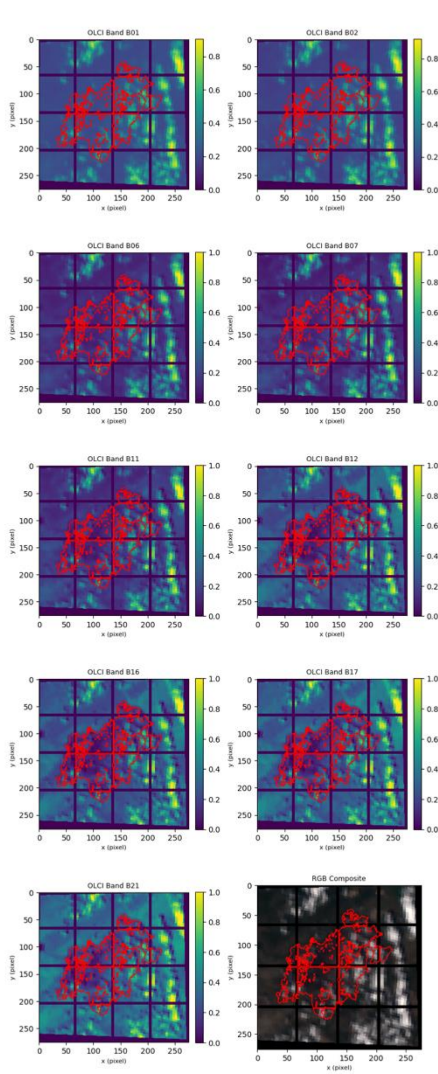
Input data (one example timestep for each source)

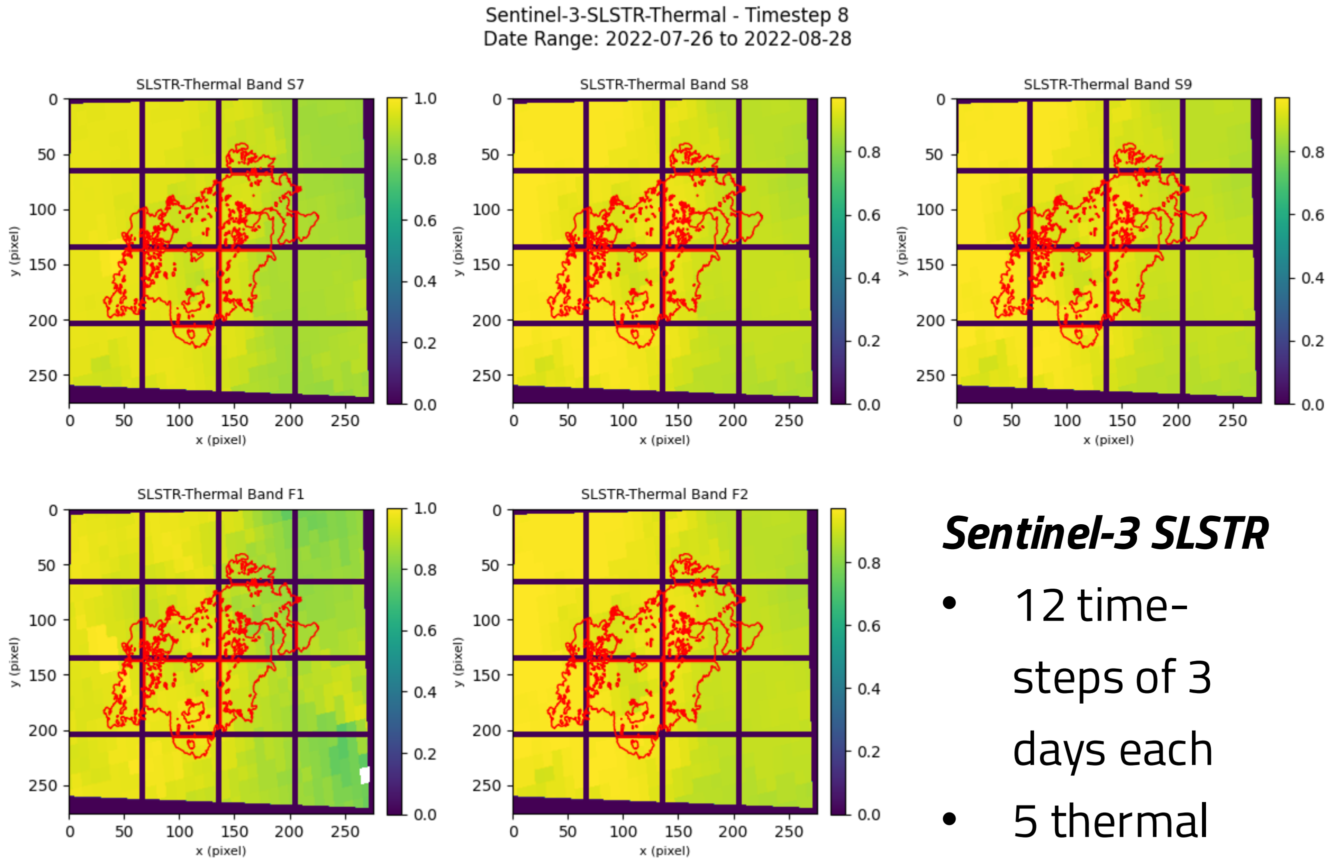


Sentinel-2

- 3 timesteps of 12 days each
- 17 maps:
  - 12 spectral bands
  - Aerosol Optical Thickness (AOT) map
  - Scene Classification (SCL) map
  - Snow probability (SNW) map
  - Cloud Classification (CLD) map
  - mask of data/no data pixels

Input data (one example timestep for each source)





Sentinel-3 OLCI

- 12 timesteps of 3 days each
- 21 spectral band maps

Sentinel-3 SLSTR

- 12 time-steps of 3 days each
- 5 thermal band maps