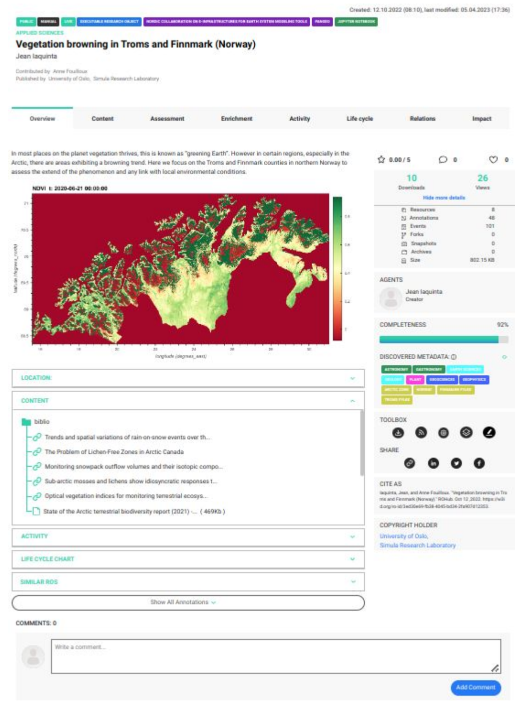

Using FAIR and Open Science practices to better understand vegetation browning in Troms and Finnmark (Norway)

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Introduction

Vegetation thrives with global change over most of the planet: this phenomenon is known as **"greening Earth"**. However, northern counties like **Troms and Finnmark in Norway experience the opposite "browning" trend (*i.e.*, moss and lichen die)** which has dramatic impacts on wildlife and indigenous Sami populations living off reindeer husbandry.

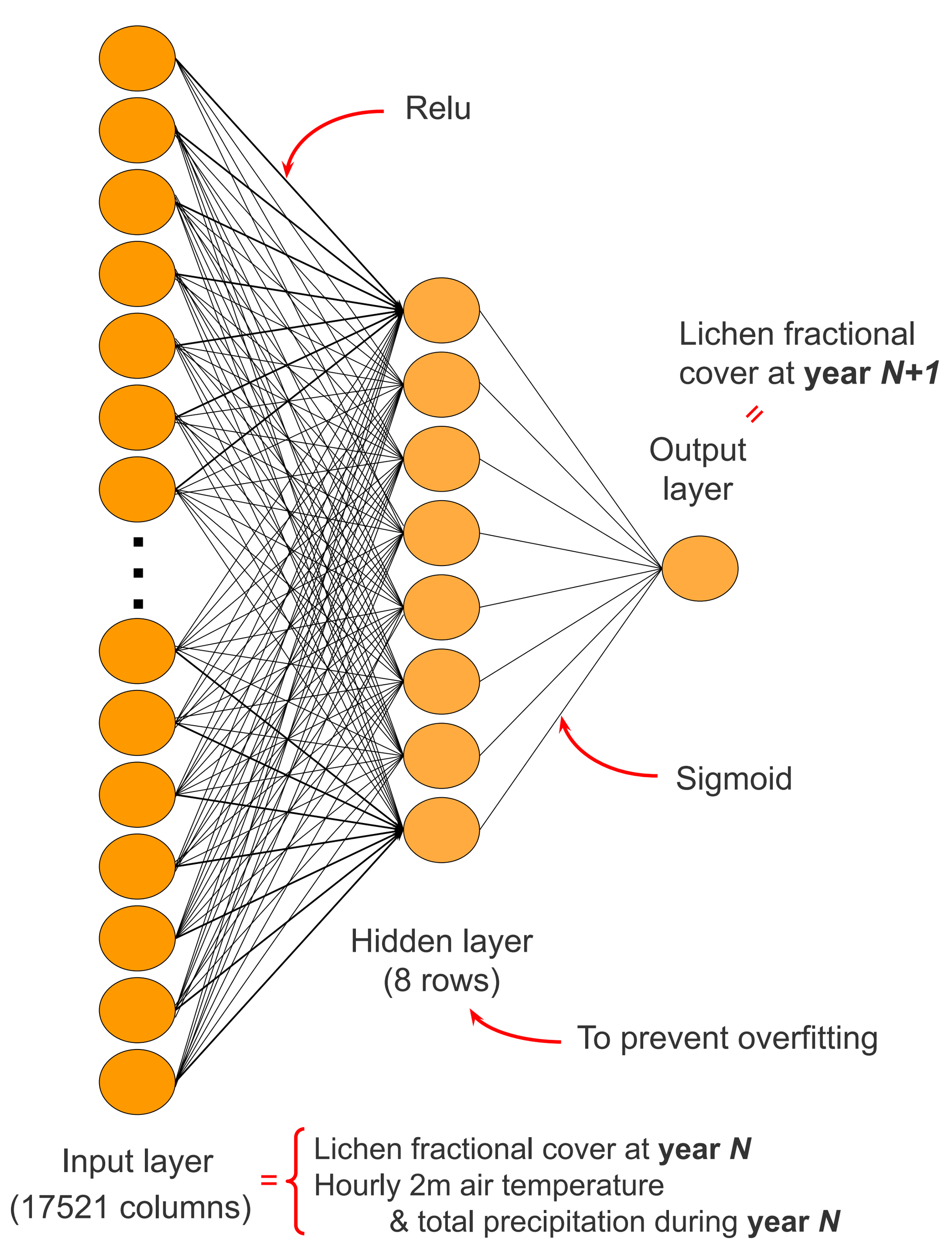
To assess the feasibility of forecasting the fate of moss and lichen with Machine Learning based on weather conditions the previous year we combined fractional vegetation cover derived from Sentinel-2 data by the Copernicus Global Land Service (CGLS) with ERA5-land hourly atmospheric variables time series from ECMWF, then built, trained and validated a feed forward neural network.

These developments were facilitated by innovative and interconnected services including:

- Research Objects (ROs) from the RELIANCE project (Research Lifecycle Management technologies for Earth Science Communities and Copernicus users in the European Open Science Cloud) - https://w3id.org/ro-id/3ed30e69-fb38-4045-bd34-2fa907d12353;
- EGI notebooks and compute/storage resources from CESNET as part of the EGI-ACE project, to work open and share both data (as S3 buckets) and Jupyter notebooks that are fully reproducible and reusable;
- Python libraries from the Pangeo software stack with Tensorflow (https://hub.docker.com/r/pangeo/ml-notebook);
- LUMI supercomputer (3rd on the Top500 list), for the most compute-intensive tasks during the developments.

Machine learning

The model developed in this study benefited from the book https://doi.org/10.1007/978-1-4842-8020-1:



Hypotheses

i) The death of moss and lichen correlates with extreme winter warming, through exposure to positive temperatures then refreezing, according to Bokhorst *et al.* (https://doi.org/10.1111/ppl.13882), therefore a criteria similar to Rücker *et al.* to characterize Rain-on-Snow events (https://doi.org/10.5194/hess-23-2983-2019) was defined and corroborated after talking with locals as:

- total rainfall volume of at least 20 mm within 12 h
- air temperatures above 0 °C = 273.15 K

(and initial snowpack depth of at least 10 cm) ← not used

⇒ This was conveyed through the input data normalization:

ERA5_tp = ERA5_tp / 0.02 * 12
ERA5_t2m = ERA5_t2m / 273.15

ii) Moss and lichen grow very slowly, and in the same general locations, therefore only consider grid cells with at least 1% lichen cover every year for the training.

Sequential model

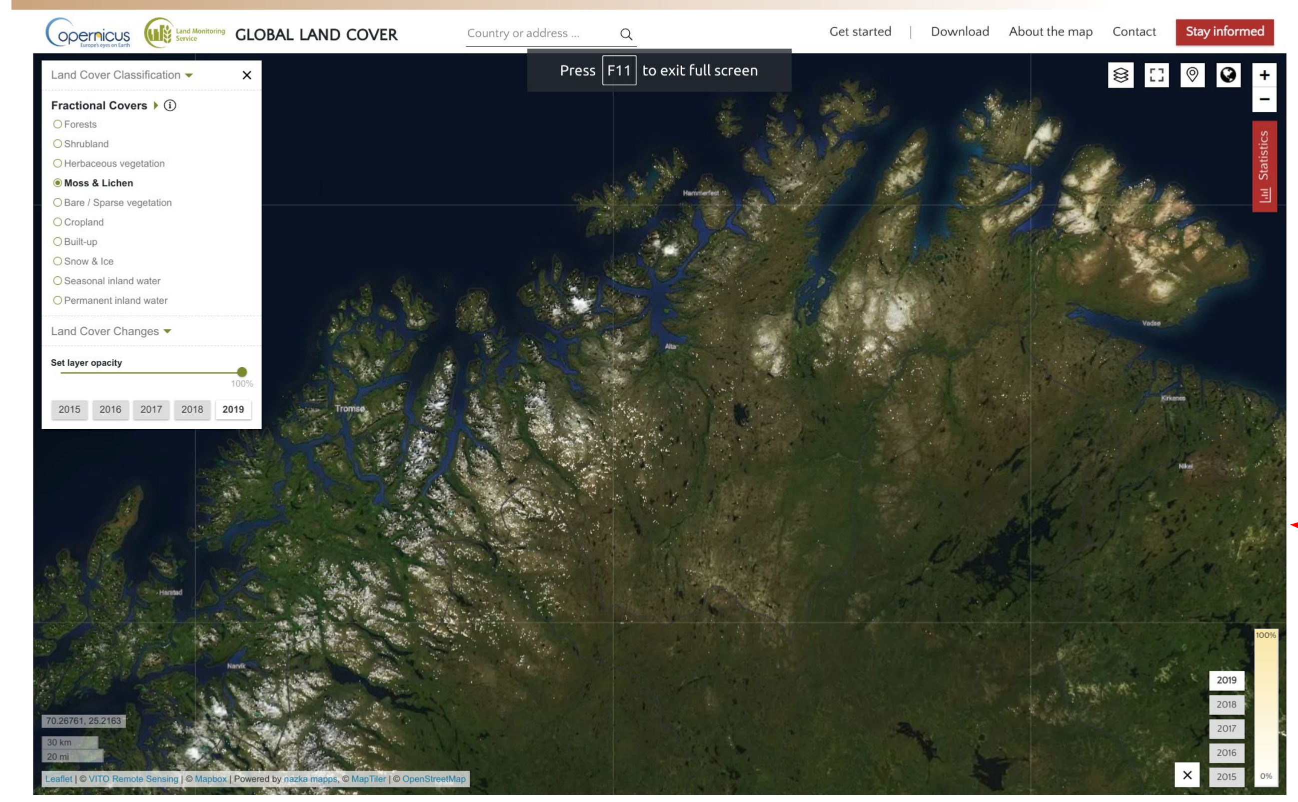
Optimizer: "Adadelta" - Loss function: "Huber"

Layer (type)	Output Shape	Param #
dense (Dense)	(None, 8)	140176
dense_1 (Dense)	(None, 1)	9

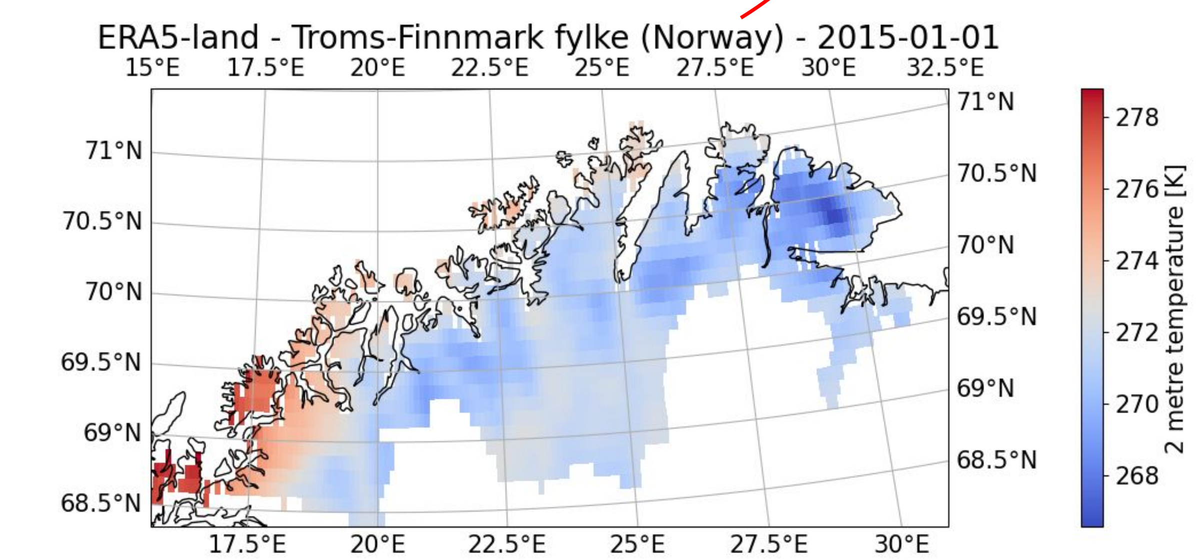
Total params: 140,185
Trainable params: 140,185
Non-trainable params: 0

SCAN ME

Data



Copernicus Global Land Cover provides 100m resolution maps of cover fraction expressed in % ground cover per pixel for 10 base classes including moss & lichen.

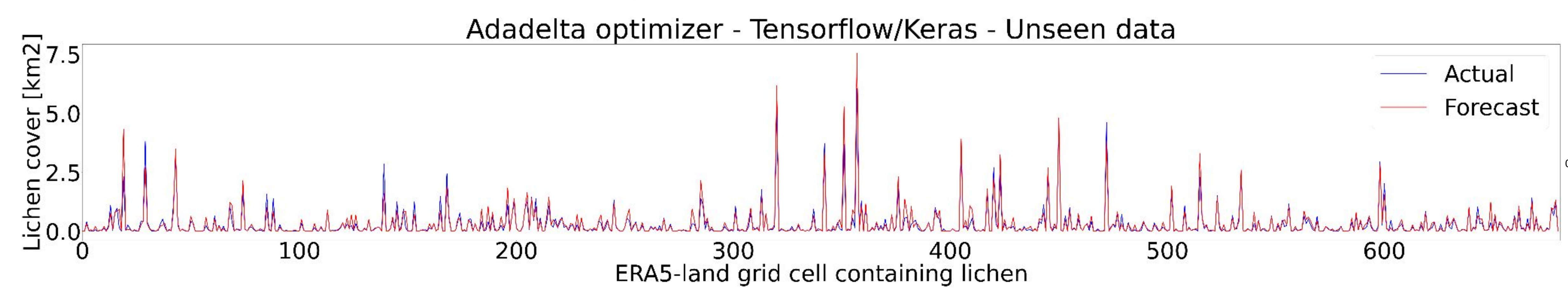


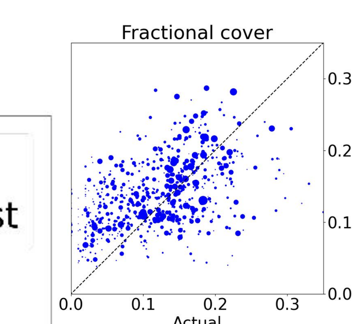
ERA5-land is a meteorological reanalysis dataset providing a consistent view of the evolution of land variables (here 2m air temperature) at an horizontal resolution of 0.1°×0.1° (native 9 km).

Results

After converting the fractional cover to lichen surface cover (in km^2) by taking into account the number of lichen pixels within each grid cell the agreement between forecast and actual values is ≈ 87% (note that it was achieved with little manual hyper-parameter "optimization").

There is no obvious overfitting, and despite a general tendency to overestimate the actual cover, the model fails to match the amplitude of many peaks, but the overall performance is already quite remarquable.





Summary, lessons learned and conclusions

Although simple our model nonetheless captured the main features in the temperature and precipitation pattern leading to the depletion of moss and lichen in this arctic region, however:

- Copernicus Global Land Cover (100×100m) served as reference for years 2015-2019 and, although more refined, ESA World Cover (10×10m) could not be exploited in 2020-2021 for lack of consistency; neither provide long enough time series anyway, therefore
  - ➡ it may be sensible to start from raw satellite images and take advantage of lichen's unique ultraviolet signature;
- information about the depth of the snowpack did not bring any sensible benefit, but
  - ➡ using a Digital Elevation Model (DEM) and details about solar insolation could be valuable;
- meteorological data at higher spatial resolution will definitely improve the forecast.

Given the extreme fragility of nordic ecosystems, the risk associated with disclosing the precise location of endangered resources ought to be carefully considered and discussed with relevant authorities before going any farther.