A Deep Learning Framework for Large-Scale Greenhouse Mapping in Mainland Portugal Using Sentinel-2 Imagery

A Semantic Segmentation Approach for Automated Greenhouse Detection

Technical session topic number: No.4 - Artificial intelligence, Large Language Model, Deep Learning, etc.

Abstract

Greenhouses play an important role in Portugal's agricultural sector by supporting high-value crop production, increasing yields, and enabling extended growing seasons. However, accurate and up-to-date greenhouse mapping over large-scale remains challenging because traditional visual interpretation and change-detection methods are time-consuming, costly, and difficult to scale. This challenge can be effectively addressed through remote sensing-based Sentinel-2 (S2) satellite imagery, which provide consistent, large-scale, and open-source imagery. Therefore, this study develops a scalable and reproducible deep learning framework for large-scale greenhouse mapping in mainland Portugal using S2 imagery.

Monthly cloud-free S2 Level-2A imagery was processed for two crop years, 2018 (October 2017–September 2018) and 2023 (October 2022–September 2023). These years were selected because corresponding reference data were available from the Carta de Uso e Ocupação do Solo (COS), specifically the protected agriculture and nurseries class. Annual median mosaics were generated using all available spectral bands, harmonized to 10 m spatial resolution, normalized, and divided into 256 × 256 image patches. An improved 2023 greenhouse reference mask was developed through NDVI-based refinement, which removed uncovered nursery areas from the original reference data. To address class imbalance, stratified sampling was applied by retaining patches with at least 0.3% greenhouse coverage and including selected pure-background patches.

A U-Net model with a ResNet-50 encoder was trained using S2 pretrained weights with area-weighted binary cross-entropy loss function, and other selected hyperparameters. Both models were trained and validated using the 2018 dataset and independently tested on the 2023 dataset, with two experimental configurations evaluated: one without data augmentation and one incorporating data augmentation. The model trained without data augmentation performed best, achieving precision of 0.93, recall of 0.85, F1-score of 0.89, and greenhouse IoU of 0.80 on the test dataset. The best model

was applied to mainland Portugal for 2023 greenhouse mapping. After post-processing using a 1 ha minimum mapping unit, the final national map detected 4451 ha of greenhouses and achieved a greenhouse IoU of 0.62 against the improved 2023 reference mask.

Temporal change detection and model validation showed that 1,270 ha of new greenhouse area were established between 2018 and 2023. Of this newly established area, the model correctly detected 705 ha, representing approximately 55% of the total increase. In contrast, among the 580 ha of greenhouse area that disappeared during the same period, only 67 ha were incorrectly retained as greenhouses in the model output, with most errors associated with boundary pixels and unlabelled greenhouse areas in the improved 2023 reference mask. The results demonstrate that S2 imagery combined with deep learning provides an effective, operational, and cost-efficient approach for national-scale greenhouse monitoring, land-use planning, and agricultural decision-making.

Keywords

Greenhouse mapping, Sentinel-2 imagery, deep learning, U-Net, ResNet-50

Authors

1º Abran Idrees
abranidrees333@outlook.com
Direção-Geral do Território

2º Pedro Benevides
pbenevides@dgterritorio.pt
Direção-Geral do Território

3º Hugo Costa
hcosta@dgterritorio.pt
Direção-Geral do Território

4º Mário Caetano
mario.caetano@dgterritorio.pt
Direção-Geral do Território