

Physics-based simulation of CHIME and LSTM data to support advanced agricultural monitoring

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Abstract

The upcoming Copernicus Expansion Missions CHIME and LSTM will offer new opportunities for agricultural monitoring, but algorithm development must begin before any data exist. Within the AgriCEM project, we address this gap by generating simulated CHIME and LSTM of sugar beet for monitoring applications development. A physically based end-to-end workflow couples the SCOPE model, which simulates VSWIR reflectance and emitted thermal radiance together with photosynthesis and energy fluxes, to the sensor and ground segment simulator RISE. Three seasonal datasets were produced: a scenario-based dataset representing healthy, drought-stressed and Cercospora-infected sugar beet, and two datasets parameterised from field campaigns in Poland and Italy. The products comprise CHIME-like L2A reflectance and LSTM-like L1C thermal radiance over a 4 km² agricultural area. First applications, including physically based retrieval of canopy water content, show that the simulated time series reproduce the expected spectral and thermal responses to abiotic and biotic stress. The datasets will be made available through the ESA Project Results Repository.

1. Introduction

The European Space Agency's upcoming Copernicus Expansion Missions present unprecedented opportunities to advance current Earth observation (EO), particularly for applications in food systems and agriculture. The Sentinel user preparation projects take up two challenges: to develop algorithms for missions (and data) that do not yet exist, and to familiarize end users with the innovative products that will result. The objective of the AgriCEM project is to leverage this potential by focusing on CHIME (Copernicus Hyperspectral Imaging Mission for the Environment) and LSTM (Land Surface Temperature Monitoring) and exploring their synergies to develop innovative Earth observation products. The main objectives are to deliver (i) representative datasets that reflects the unique capabilities of CHIME and LSTM in terms of spatial resolution, spectral coverage, and revisit time; (ii) development of EO applications for advanced monitoring of sugar beet. This contribution focuses on the dataset creation methodology and preliminary results.

2. Methodology and data

In this study, we simulate CHIME and LSTM data by means of a complex, physically based end-to-end simulation workflow. This includes the collection of measured input data, the simulation of the signal as bottom of atmosphere (BOA) radiance, and its propagation through atmosphere, spaceborne sensor and downlink, and the processing within the ground segment. This comprehensive approach ensures the dataset's relevance and robustness for both scientific research and prototypes for operational applications.

The Soil-Canopy-Observation of Photosynthesis and Energy fluxes (SCOPE) model (van der Tol et al., 2009, Yang et al., 2021) is used to simulate BOA fluxes. The BOA radiances outputs from SCOPE then serve as inputs for an end-to-end space and ground segment simulator RISE (Figure 1).

2.1 SCOPE model

SCOPE goes beyond a radiative transfer model and includes photosynthesis, stomatal regulation, and the turbulent energy exchange with the atmosphere. This allows to simulate both hyperspectral solar reflection and emitted thermal radiance with the same model representation of the crop. SCOPE is a generalized model rather than one specifically tailored for sugar beet. It employs a simplified 1-D turbid medium representation of vegetation architecture, and its photosynthesis module is not crop-specific. Nonetheless, the incorporation of sugar beet architecture and potential disease symptoms is possible through calibration of SCOPE parameters.

Input from various sources including field campaign data, meteorological data, and proxy satellite data from operational missions (Sentinel-2, EnMAP, PRISMA) was used to establish three simulated scenario-based sugar beet datasets. Structurally, leaf angle distribution (LAD), the leaf mesophyll structure parameter N and the hotspot parameter were adjusted to represent sugar beet in SCOPE (Figure 2). Temporal variability was driven by the temporal pattern of leaf area index (LAI), leaf chlorophyll content (Cab), leaf water content (Cw), leaf senescent material (Cs). Spatial variability was forced by a gamma distribution function with south-north (Cab, $V_{\text{cmax}25}$) and east-west (Cw, Cs, BBS) gradients. The output of SCOPE model (BOA radiances) was gridded on a dataset-specific template with four to six classes, differed in sugar beet variety or stress class.

2.2 End-to-end simulator

The BOA radiance and reflectance outputs from SCOPE serve as inputs to RISE, a generic simulator that allows to generate a dataset reproducing the spectral, spatial, and radiometric properties of CHIME and LSTM. RISE first simulates the acquisition geometry, before an atmospheric transfer model is applied to obtain the top-of-atmosphere (TOA) radiance. Two

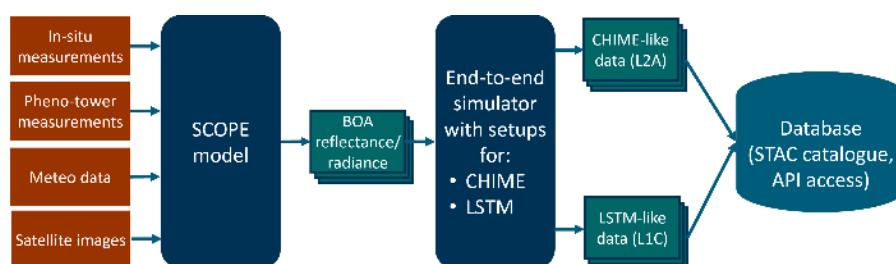


Figure 2-1. Workflow for generation of simulated datasets.

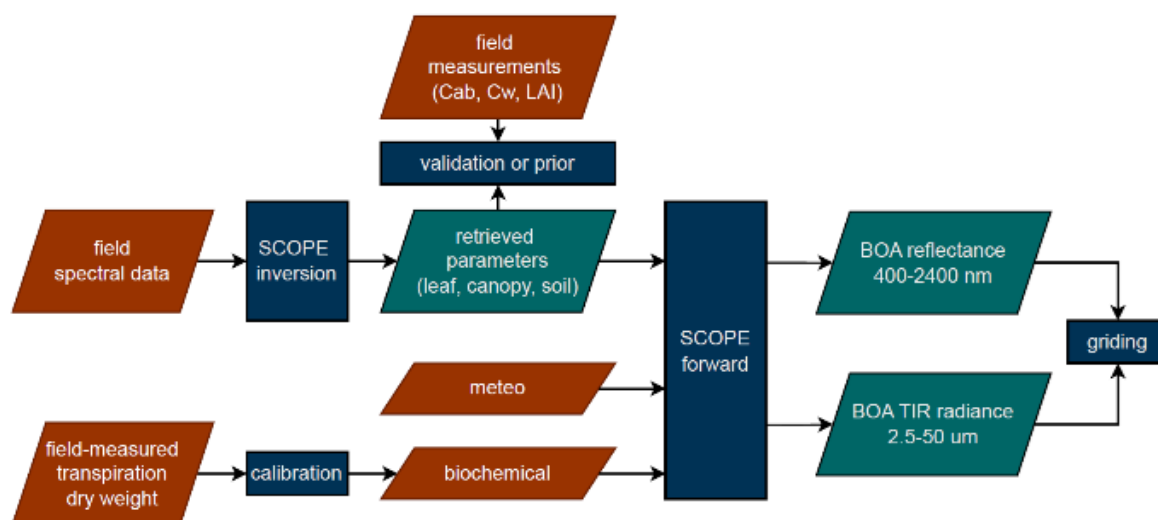


Figure 2. Workflow of SCOPE calibration for sugar beet specific BOA reflectance and radiance generation.

sensor modules are set up for the simulation of both hyperspectral and thermal acquisition and the ground processing chains. The CHIME simulator is based on the heritage from the mission's optical performance simulator, while an existing TIR sensor module is adapted to comply with LSTM specifications.

2.3 Simulated datasets

The simulated datasets synthesize a time series of a 4 km² agricultural area with CHIME-like and LSTM-like imagery over the sugar beet growing season (April–October). The CHIME-like data represent level 2A reflectance with a pixel size of 30 m and a revisit time of 10–12.5 days. The LSTM-like data contains level 1C radiance with a pixel size of 50 m and a revisit time of 1–3 days. An overview about the three simulated datasets is presented in Table 1 and their location is given in Figure 2.

Dataset (Source location)	Temporal coverage	Dataset generation
DS_Scenario (Germany)	April–October 2021	Based on artificial parameter constraints to represent different stress scenarios
DS_PL (Poland)	April–October 2025	Based on in-situ campaign and satellite data to represent different sugar beet varieties
DS_IT (Italy)	April – September 2025	Based on in-situ campaign representing different sugar beet varieties

Table 1. Overview of all simulated datasets within AgriCEM.

2.3.1 Scenario-based dataset: The DS_Scenario contains four land-cover classes: bare soil, healthy sugarbeet, sugar beet under drought stress, and sugar beet under biotic stress caused by *Cercospora spp* fungal disease. The SCOPE inputs are based on data from a permanent eddy-covariance tower in Selhausen Juelich (DE-RuS), where sugar beet was cultivated in 2021. Key biophysical parameters LAI, Cab and Cw were retrieved from Sentinel-2 time-series with an OpenEO BIOPAR algorithm. Biochemical parameters, Vcmax25 and BBS, were optimized against eddy-covariance flux data, accounting for the established correlation between Vcmax25 and LCC. Two types of stresses were simulated based on literature information and expert knowledge. Intermittent drought stress was simulated for 5 weeks, 13 to 18 weeks after planting, by flattening leaves (plagiophile to planophile LAD), closing stomata (reducing BBS), reducing Cw and stopping biomass growth, reflected by reduced LAI. Biotic stress, mimicking *Cercospora spp* fungal disease, was simulated starting from the 15th week after planting. Based on expert knowledge, the first 5 stages of the disease constitute limited visible damage but closed stomata and decreasing water content, however, closer to the end of the growing season, especially with rainy weather, the disease speeds up, resulting in earlier onset of senescence in conjunction with reduced LAI.

2.3.2 PL dataset: The DS_PL is based on a field campaign conducted from May – October 2025 near the town of Glubczyce, Poland. Three sugar beet fields were sampled five times over the season obtaining field spectrometer acquisitions, in-situ biophysical and flux parameters (LAI, chlorophyll content,

biomass, transpiration, etc.). Additionally, currently available hyperspectral satellite missions (EnMAP, PRISMA) were tasked from this site. The collected measurements were used for the parametrization of SCOPE and for the atmospheric components of the end-to-end simulator.

2.3.3 IT dataset: The DS_IT is based on in-situ measurements and stationary VNIR-SWIR and TIR sensors in a plot trial with different sugar beet varieties near the town of Monselice, Italy. LAI, Cab, Cw and dry matter content (Cdm) measurements were clustered into 5 groups, interpolated to daily timestamps and used for SCOPE parameterization. Soil spectra were used to constrain the soil module of SCOPE. The collected measurements were used for the parametrization of SCOPE and for the atmospheric components of the end-to-end simulator. Within the AgriCEM project, the datasets are used for the development and testing of algorithms to retrieve vegetation variables from CHIME-like (e.g., LAI, Cab, ...) and LSTM-like (LST, ET) data, also developing a stress-disentangling approach. The datasets will be available in the ESA Project Results Repository (PRR).

3. Results and discussion

3.1 CHIME L2A BOA reflectance

We focus here on one simulated dataset (DS_Scenario). As an application example we exemplarily show the physically-based retrieval of canopy water content via the inversion of the Beer-Lambert law following the approach of Woher et al. (2018).

The CHIME product in the DS_Scenario dataset consists of a time series of a 2 x 2 km² scene of L2A BOA reflectance in 250 bands, from 400 nm to 2500 nm. The scene contains an agricultural landscape close to Selhausen, Germany. Several sugar beet fields are differentiated into four classes (Figure 5): healthy, biotic stress, abiotic stress, and bare soil. Over the course of the season, with the different growth phases and stresses introduced as exemplatory shown for LAI and Cw in Figure 4, the impact on the spectral response becomes evident as shown in Figure 6.

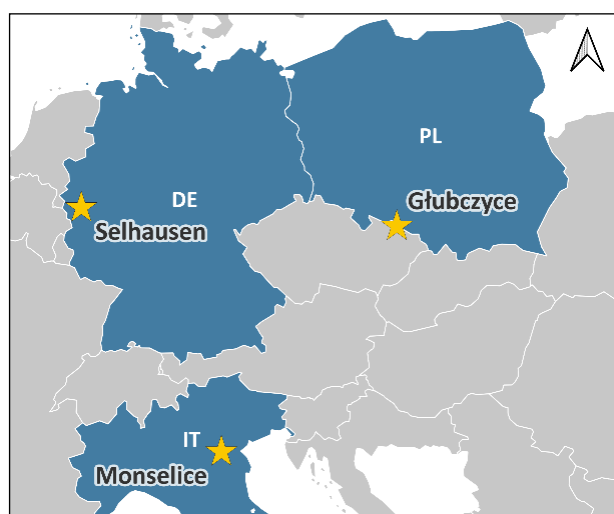


Figure 3. Source location of simulated datasets.

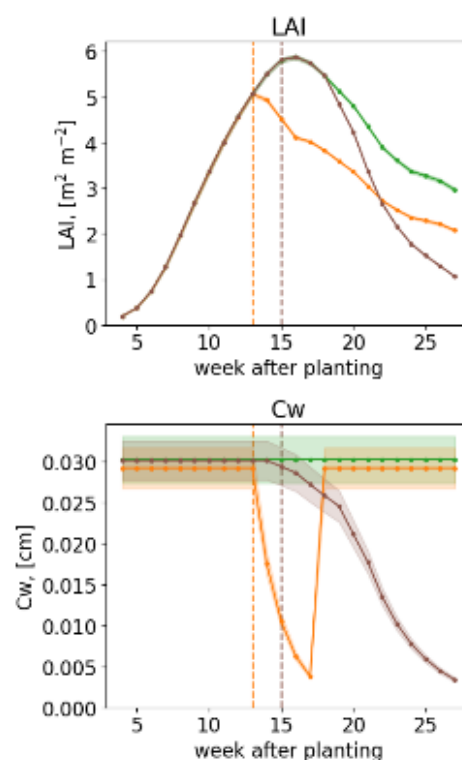


Figure 4. Development of selected SCOPE input parameters (LAI and Cw) over the growing season for three different sugar beet classes in DS_Scenario (Green = healthy, orange = water stress, red = biotic stress).



Figure 5. Example of CHIME L2A data for the scenario-based dataset (DS_Scenario).

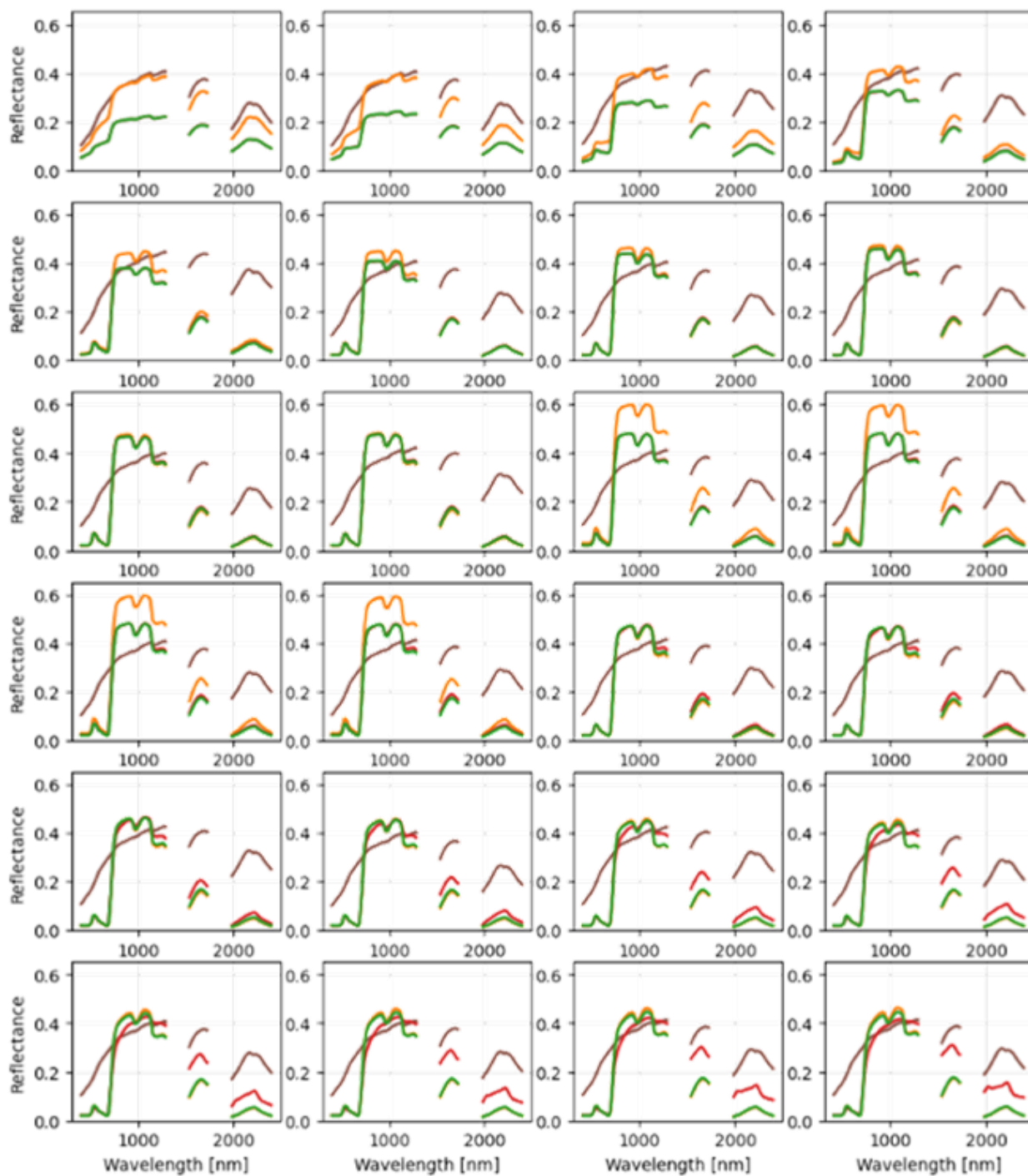


Figure 6: Time series of CHIME-like spectra for different sugar beet classes of DS_Scenario. Green = healthy, orange = water stress, red = biotic stress.

3.2 LSTM L1C TOA radiance

The LSTM product in the DS_Scenario dataset covers the same area and classes (Figure 7) at 50 m pixel size and consists of L1C TOA radiance in five thermal bands, at 8.6, 8.9, 9.2, 10.9, and 12 μm . In contrast to the reflectance in the reflective range, the band radiances' temporal trend is highly impacted by the meteorological conditions and more susceptible to fast changes over time, as can be observed in Figure 8.

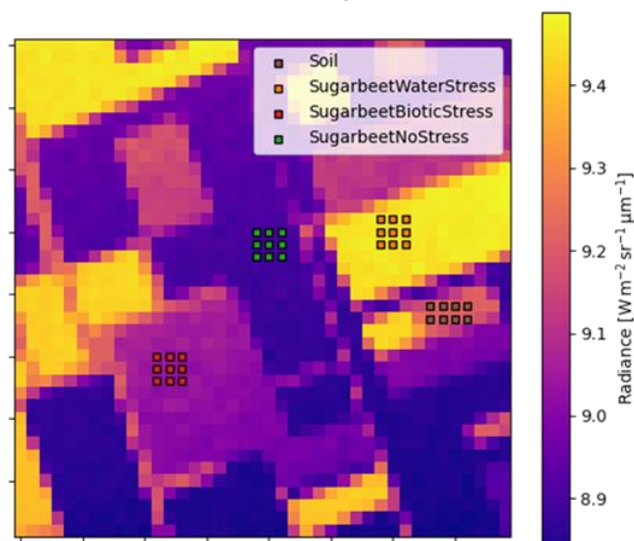


Figure 7. Example of L1C LSTM product for the scenario-based dataset.

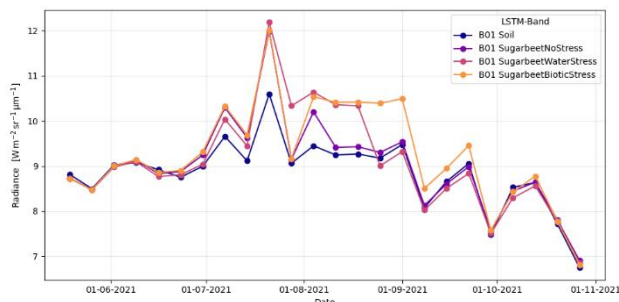


Figure 8. LSTM Band 1 (8.6 μm) radiance over the growing season for the different scenario fields.

3.3 Derived vegetation variables

Spatiotemporal mapping of vegetation variables is exemplarily shown for $\text{EWT}_{\text{canopy}}$ (Figure 9). The onset of water stress due to abiotic stress is visible from July 28th, followed by partial recovery after the simulated drought period 3–4 weeks later. In contrast, biotic stress leads to a more gradual decrease of $\text{EWT}_{\text{canopy}}$ which continues steadily until the end of the season.

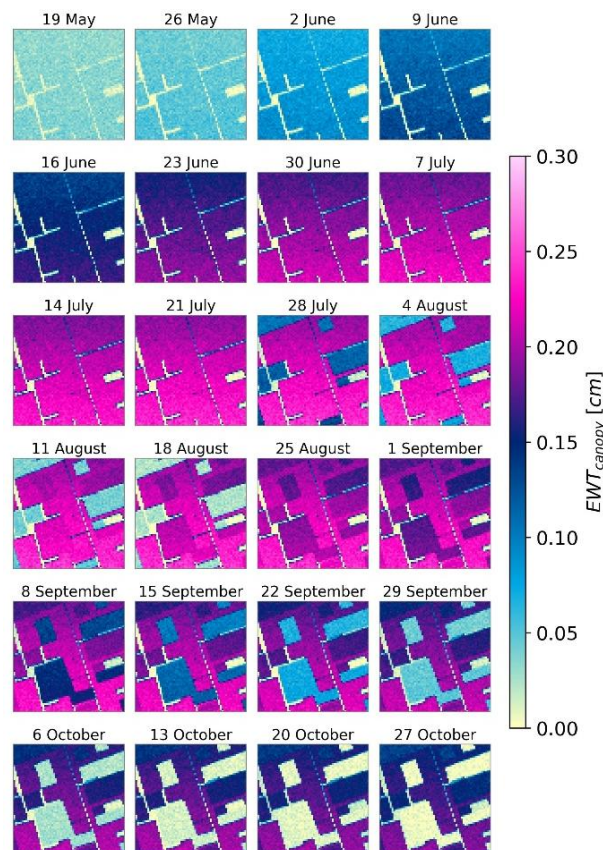


Figure 9. Time series of $\text{EWT}_{\text{canopy}}$ retrievals from CHIME L2A data in DS_Scenario.

4. Conclusions

In preparation of the upcoming Copernicus hyperspectral CHIME and thermal LSTM missions, we generated three simulated datasets of these missions in the context of agricultural applications with a focus on sugar beet monitoring. We combined the SCOPE model and the RISE end-to-end simulator to retrieve time series of agricultural scenes – one for different stress scenarios of sugar beet (DS_Scenario), one based on a field campaign in Poland (DS_PL) and one based on a field campaign in Italy (DS_IT).

The simulated datasets are the basis for the development of retrieval algorithms for vegetation and environmental variables as well as for sugar beet stress indicators. Once these future missions are operational, the developed information products may be used by stakeholders to optimize agricultural management and for timely interventions in case of crop stress to reduce yield losses.

Acknowledgements

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