Dealing with variability in vegetation functional trait retrievals: case study of floodplain forests in Lanžhot, Czech Republic

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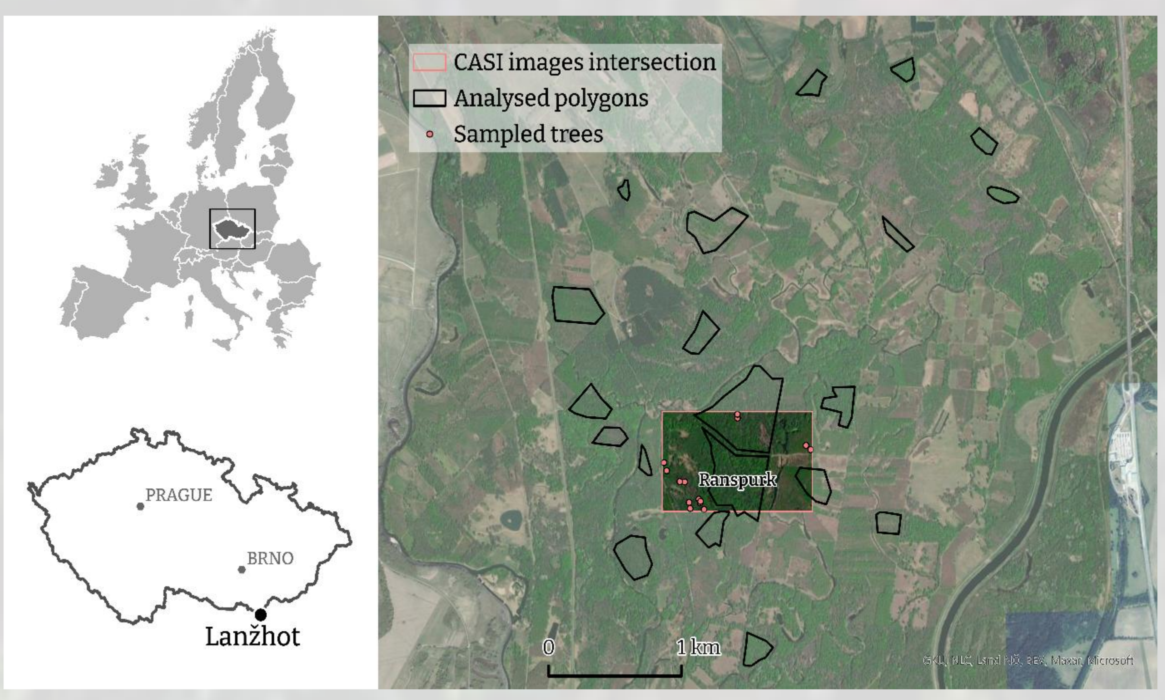
Introduction

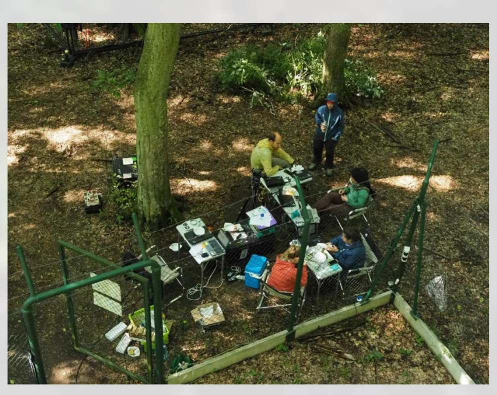
Vegetation biophysical traits are commonly used as indicator of vegetation physiological status. Various approaches are used to retrieve these traits, including physically based Radiative Transfer Models (RTM), empirical Partial Least Squares Regression (PLSR), and Machine learning-based Neural Networks (NN). These approaches are used to monitor vegetation dynamics and understand the impacts of forest management on traits and their allocation in time and space. Retrieving traits that vary within the canopy and within the stand/spatial level remains a challenge that has not been fully addressed yet. Therefore the goal of this study is:

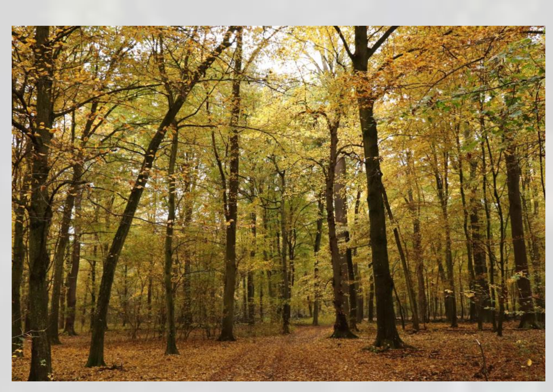
To evaluate the spatial variability of spectra/trait changes from the leaf level (FieldSpec) to the individual tree level (0.5 m CASI data) and to mixed spectral information of multiple crowns (20 m Sentinel-2 data). The other goal was to compare the performance of various approaches such as RTM, PLSR, RF and NN.

Study area and data used

The study uses in situ field and remote sensing observations from the Lanžhot deciduous forest, located in southeastern Czech Republic. This site is a long-term ecosystem research site and part of the national research infrastructure CzeCOS (Czech Carbon Observation System; http://www.czecos.cz/). In the Integrated Carbon Observation System ICOS, the Lanžhot Forest is classified as class 1. It is a lowland floodplain forest located near the confluence of the Morava and Dyje Rivers at an elevation of 150 m above sea level.







Three types of data at different spatial scales were used:
1) Measurements of leaf samples for the leaf level using FieldSpec 4 Hi-Res
2) CASI VHR (0.5 m) hyperspectral data for the individual tree level,
3) Sentinel-2 (20 m)data of mixed spectral information for the forest stand levels

CASI VHR image with 0.5 m resolution
Acquired on 25 April 2019

Sentinel-2 20 m resolution image
acquired on 21 April 2019

We worked with 405 leaf samples collected in the study area of the Lanžhot floodplain forest from 14 trees of the following species: Austrian Oak (2 trees), English oak (2 trees), European hornbeam (4 trees), Narrow-leaved ash (4 trees) and Small-leaved linden (2 trees). Tree samples were collected in seven consecutive campaigns on April 24-25, 2019 (DOY 115), July 18-24, 2019 (DOY 199), September 4-11, 2019 (DOY 254), October 17-24, 2019 (DOY 290), May 11, 2020 (DOY 132), July 23-26, 2020 (DOY 208), October 22, 2020 (DOY 208)

Methodology

Various trait retrieval methods were used in order to compare their performance (based also on the outputs suported by the Technology Agency of the Czech Republic project number SS05010124).

1. RTM (Radiative Transfer Models) PROSPECT4 for the leaf level and inversion of PROSAIL to estimate canopy level traits (Rivera et al. 2014).
2. PLSR (Partial Least Square Regression) and for leaf level (Wang et al. 2021).
3. RF (Random Forest) for leaf level and NN (neural networks) in Machine Learning Regression Algorithms (MLRA) in ARTMO for the canopy scale (Verrelst, Camps-Valls, et al. 2015).

Three leaf traits, Cab, Cm and Cw, as well as Cab together with LAI for the canopy scale were evaluated in this study. Cab content at the leaf level was detected using a handheld fluorometer (CCM-300). Then, Canopy LAI measurements were collected using a Licor LAI-2000 canopy analyser instrument

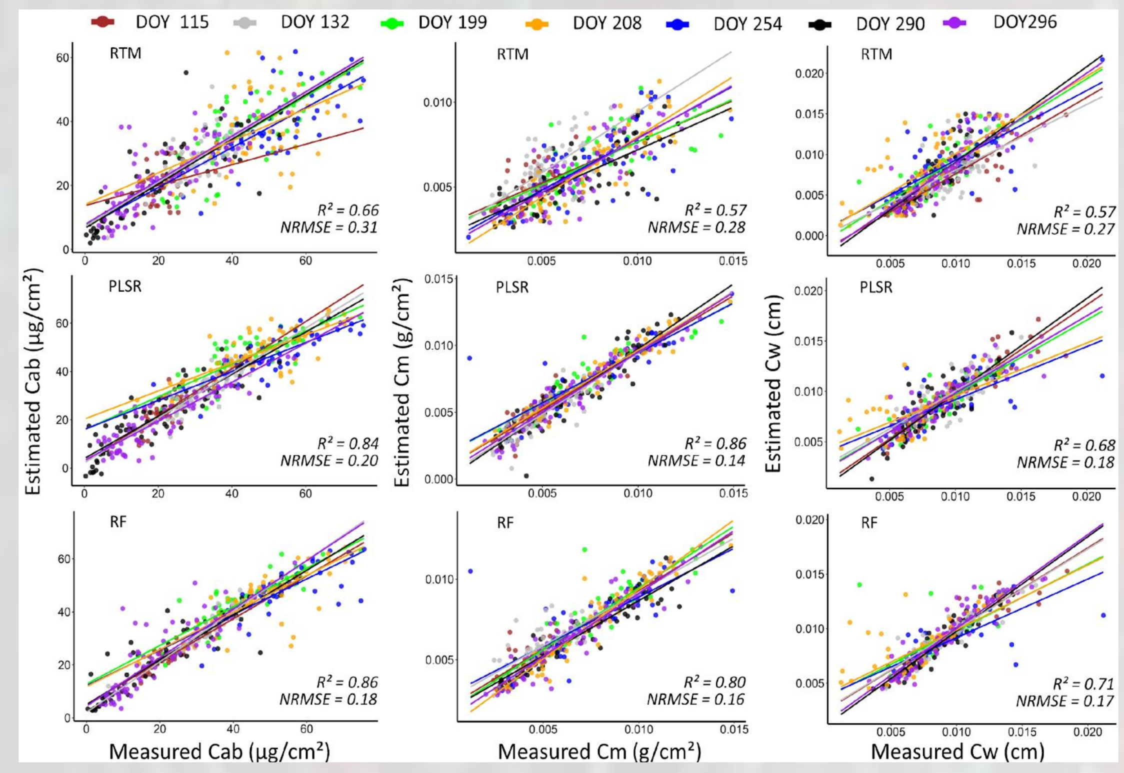
To determine the accuracy of the trait retrieval, we used:
1. Coefficient of determination (R^2)
2. Normalized root-mean-square error (NRMSE)

$$R^2 = \frac{\sum_{i=1}^{n} \quad (y_i - \hat{y_i})^2}{\sum_{i=1}^{n} \quad (y_i - \underline{y})^2}$$

$$NRMSE = \frac{\sqrt{\frac{(\sum_{i=1}^{n} \quad (\hat{y}_i - y_i)^2)}{n}}}{\underline{y}}$$

Where y_i and $\widehat{y_1}$ are the reference and predicted values. $\underline{y}$ is the mean of reference values and n being the number of the samples. The closer R^2 is to 1, the higher the retrieval performance model is. Small NRMSE values indicate less discrepancy within observed and predicted measurement.

Results



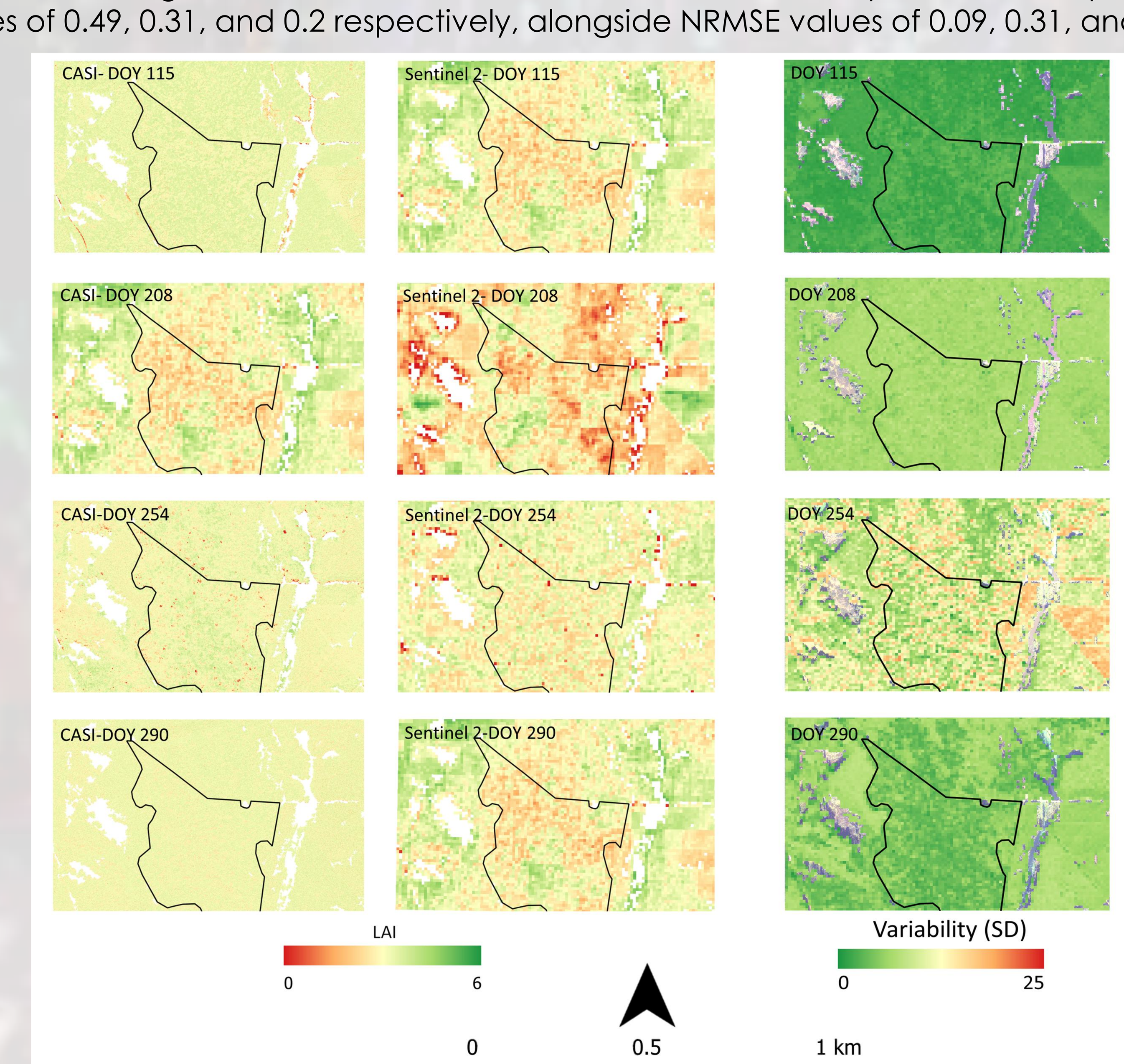
Scatter plots illustrating estimates at the leaf level using RTM, PLSR and RF methods.

- Combinations of spectra from hyperspectral data and all models (RTM, PLSR, and RF) are suitable for accurate estimation of time series of leaf scale traits Cab, Cm, and Cw.
- The results indicate that RF performed best in terms of accuracy for Cab and Cw, with an R^2 value of 0.86 and an NRMSE of 0.18, and an R^2 value of 0.71 and an NRMSE of 0.17, respectively.
- For Cm, PLSR yielded the highest accuracy value of 0.86 and 0.14 for R^2 and NRMSE.

	Chl						LAI					
	RTM		ML (NN)		PLSR		RTM		ML (NN)		PLSR	
	R2	NRMSE	R2	NRMSE	R2	NRMSE	R2	NRMSE	R2	NRMSE	R2	NRMSE
CASI Airborne												
DOY 115	0.95	0.06	0.87	0.1	0.82	0.14	0.9	0.09	0.95	0.06	0.8	0.13
DOY 208	0.81	0.13	0.86	0.11	0.68	0.18	0.92	0.08	0.74	0.13	0.94	0.07
DOY 254	0.53	0.1	0.62	0.2	0.76	0.06	0.49	0.09	0.71	0.33	0.74	0.15
DOY 290	0.68	0.34	0.65	0.39	0.56	0.39	0.61	0.2	0.56	0.29	0.9	0.08
Sentinel 2												
DOY 115	0.92	0.07	0.88	0.09	0.76	0.15	0.95	0.06	0.2	0.49	0.86	0.12
DOY 208	0.9	0.11	0.73	0.17	0.74	0.17	0.65	0.08	0.53	0.24	0.75	0.16
DOY 254	0.82	0.12	0.69	0.16	0.83	0.13	0.86	0.11	0.93	0.07	0.9	0.09
DOY 290	0.58	0.34	0.72	0.29	0.87	0.21	0.31	0.12	0.75	0.14	0.58	0.2

Validation of accuracy estimates for canopy scale from both CASI and Sentinel-2 using RTM, ML (NN) and PLSR

- At the canopy scale, the integration of spectra derived from CASI and Sentinel data with all models (RTM, PLSR, and NN) exhibits a high degree of suitability in forecasting time series of canopy traits, including Cab and LAI.
- Conversely, for LAI retrieval, the combinations of RTM and CASI on DOY 254, RTM and Sentinel-2 on DOY 290, and the integration of ML and Sentinel-2 on DOY 115 also yielded inadequate accuracy, with R^2 values of 0.49, 0.31, and 0.2 respectively, alongside NRMSE values of 0.09, 0.31, and 0.49.



Comparison of Leaf Area Index (m²) retrieval between CASI and Sentinel-2 & Variability of chlorophylls (µg/cm²)upscaled from CASI to Sentinel-2 resolution

- Seasonal LAI retrieval time series were generated utilizing NN techniques, employing CASI and Sentinel 2 image data. Based on these findings, the highest LAI values were observed along the inner perimeter, indicating unmanaged forest areas within the Ranspurck Nature Reserve (inside the black border).
- The variation in Cab content ranges from the individual crown level (CASI 0.5 m) to a combination of several crowns (Sentinel-2 data 20 m). The findings indicate that the retrieval of highest values predominantly occurs in areas of rich forest structure, especially within the unmanaged forest zones (Ranspurck).

Conclusions

The research concludes that the spatial variability of spectral and trait changes is complex across different scales, with distinct patterns observed from the leaf to the individual tree level and further to multiple crown-level analysis. Additionally, the performance of different approaches varied in capturing and interpreting these variations, with certain methods showing promising results while others may require further refinement. The most effective method for obtaining leaf traits is RF, as confirmed by research (Yang et al., 2016). They also discovered that a Partial Least Square Regression (PLSR) modeling approach was able to accurately estimate leaf traits from spectra and capture the variability across time, sites, and light environments for all investigated leaf traits. Schiefer, Schmidtlein, and Kattenborn (2021) demonstrated the efficacy of RTM (PROSAIL) in forecasting crop attributes from hyperspectral data. They achieved the highest accuracies through a lookup-table inversion of PROSAIL couple.

Acknowledgement

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