# Assessing the Potential of High-Resolution Satellite Constellations for Agricultural Monitoring

SAMUEL WILDHABER[1,2], LUKAS V. GRAF[1,2] & HELGE AASEN[2]

*Abstract: Planet-Labs' SuperDove fleet shows potential for agricultural monitoring through high spatial (ground sampling distance <5m) and temporal resolution (multiple scenes per day). We retrieved widely used vegetation indices (VIs) and the leaf area index (LAI) from radiative transfer model inversion for a winter wheat parcel over an entire growing season and compared the data to ground samples and Sentinel-2 imagery. LAI was retrieved with an RMSE of 0.91 m2m-2 (R2=0.87), which was similar to the retrieval performance of Sentinel-2 (RMSE=0.87 m2m-2, R2=0.87). The SuperDove imagery revealed a higher level of spatial detail than Sentinel-2 and replicated spatio-temporal field heterogeneity. Still, issues regarding radiometric stability, spatial co-registration accuracy and quality masks need to be addressed to use the SuperDove imagery for monitoring activities.*

## 1 Introduction

Capturing plant growth conditions at landscape scale offers unprecedented opportunities to improve understanding of plant-environment interactions, which can help increasing sustainability of agricultural production. Remote sensing platforms such as Landsat or Sentinel-2 have already demonstrated their potential for large-scale applications but also at the sub-field level (WEISS et al. 2020). However, in agricultural landscapes with small field sizes and highly diversified spatial patterns as they are widespread in Switzerland, the spatial resolution of the platforms (30 to 10m) is not sufficient to cover all field parcels and small-scaled spatial patterns. Until now, satellite constellations providing high spatial (< 5m) and temporal resolution (up to one day) were limited with respect to spectral information, i.e., the number of spectral channels and their quality was lower compared to Sentinel-2 or Landsat. With the advent of the most recent Super-Dove cube satellites from Planet-Labs, multi-spectral data with eight reflective channels at 3m spatial resolution are available, including the red edge spectral region, which is important for vegetation studies. This makes the use of the Super-Dove constellation potentially interesting for agroecological research.

In the present work, we evaluate the potential of the SuperDove constellation for agricultural monitoring. We use vegetation indices such as the Normalized Difference Vegetation Index (NDVI) as well as the Leaf Area Index (LAI) from the inversion of the radiative transfer model PROSAIL (JACQUEMOUD et al. 2009) over an entire growing season. We compare results to in-situ reference and Sentinel-2 data to provide a comparison to established remote sensing-based agricultural monitoring systems. Based on this, we discuss the advantages and disadvantages of

[1] ETH Zürich, Kulturpflanzenwissenschaften, Universitätstrasse 2, CH-8092 Zürich, Schweiz, E-Mail: lukasvalentin.graf@usys.ethz.ch

[2] Agroscope Reckenholz, Fernerkundung der Agrarlandschaft, Reckenholzstrasse 191, CH-8046 Zürich, Schweiz, E-Mail: helge.aasen@agroscope.admin.ch

 DOI: 10.24407/KXP:1841128120

the SuperDove constellation and present some challenges with regard to a productive use of the data.

# 2 Data and Methods

## 2.1 Study Area and in-situ reference data

To evaluate the suitability of the Super-Dove satellites for agricultural monitoring, a winter wheat field parcel (2.04ha) located close to Lindau-Eschikon, Switzerland (Lat. 47.45, Lon. 8.69) was chosen during the 2022 growing season. The area receives an annual precipitation total of 1200mm with an annual mean air temperature of 10° C (2011-2021 reference period). Soils in the study area are slightly alkaline (pH between 7.2 and 7.8) and are considered loamy with clay content of 20 to 30% and a moderate humus content of 3.0 to 3.6%. The parcel is moderately sloped, which is typical for this region of Switzerland. The field was managed conventionally according to Swiss standards. Mineral fertilizer was applied three times during the vegetation period, organic fertilizer only before sowing in October 2021.

Non-destructive LAI measurements were collected every two to four days at 29 pre-defined locations from April to end of June using a LAI-2200C Plant Canopy Analyzer from LI-COR Biosciences. BBCH ratings were accomplished by eye to record phenological development. This resulted in a total of 942 LAI measurements and BBCH ratings. Figure 1 shows the location of the field parcel in Switzerland (a) and the locations where LAI was measured within the parcel boundaries with underlying Sentinel-2 (Fig. 1b) and SuperDove (Fig. 1c) true-color RGB imagery acquired on May 14$^{th}$ 2022.

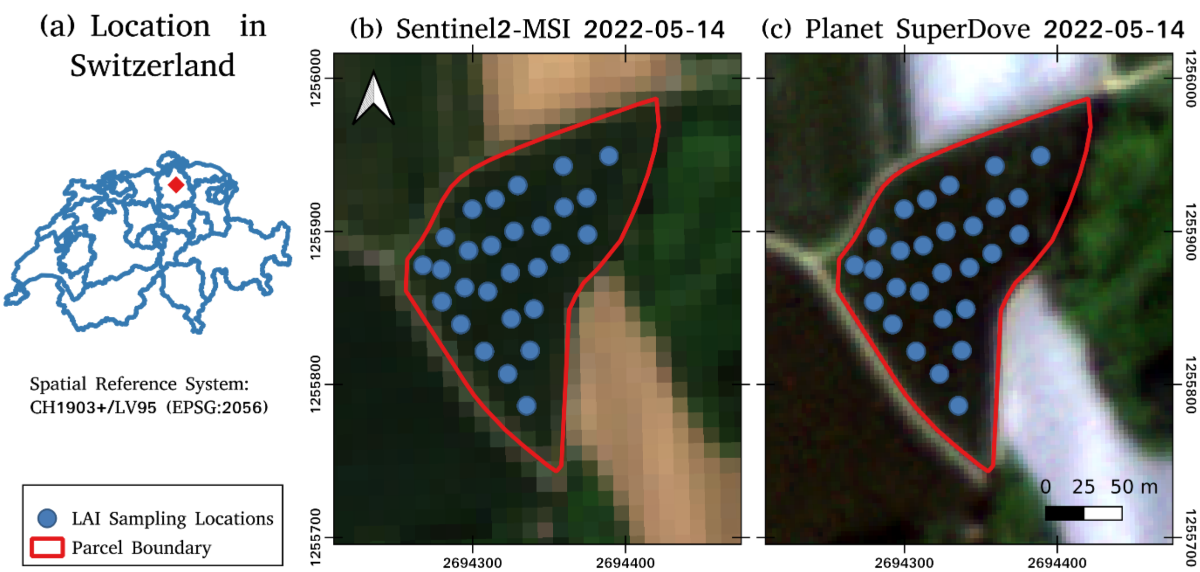


Fig. 1: Maps showing the location of the study area in Switzerland as red triangle in (a) and the locations where LAI samples were taken with underlying Sentinel-2 (b) and Planet SuperDove (c) true-color imagery

## 2.2 Satellite Data

Satellite data acquisition, preprocessing and extraction was undertaken using the open-source Python "Earth Observation data analysis library" (EOdal, GRAF et al. 2022). Both, Sentinel-2 and PlanetScope SuperDove data were acquired in UTM coordinates (Zone 32N).

### 2.2.1 Planet SuperDove

Planet SuperDove 8-band imagery in 3m spatial resolution was downloaded using the Planet Orders API. The data was corrected for atmospheric effects, orthorectified, and converted to surface reflectance factors by Planet and delivered alongside a usable data mask (UDM2-layer) providing clear pixel probabilities. All scenes were co-registered using the "arosics" library (SCHEFFLER et al. 2017). For reference, a clear SuperDove scene from March 10, 2022, was chosen. In total, 53 scenes with a scene-wide cloud cover smaller than 50% were available for analysis. From these, we excluded nine scenes from analysis after visual inspection because of undetected clouds and other distortions.

### 2.2.2 Sentinel2-MSI

Atmospherically corrected Sentinel2-MSI data was downloaded from CREODIAS including a scene-classification layer to filter out cloud or shadow pixels (tiling grid 32TMT). All 20m bands were resampled to a spatial resolution of 10m. We disregarded the 60m bands for further analysis. In total, 17 scenes with a scene-wide cloud cover smaller than 50% were available for analysis.

### 2.2.3 Satellite Data Processing

Clouds and shadows were masked in both satellite datasets using the provided clear pixel masks. We then calculated three widely used spectral vegetation indices sensitive to canopy greenness (NDVI), nitrogen content (Normalized Difference Red-Edge, NDRE) and chlorophyll content (CI_GREEN). Furthermore, we used the radiative transfer model PROSAIL to derive the LAI using a lookup-table based retrieval approach. Lookup-tables were generated by running PROSAIL 50 000 times in forward mode using a distribution of leaf and canopy parameters proposed by DANNER et al. (2021). For inversion, we used the median of the 5000 lookup-table entries in terms of the smallest spectral root mean squared error (RMSE) between PROSAIL-simulated and satellite-observed spectra.
Satellite derived LAI values were compared to in-situ LAI measurements with a maximum temporal offset of one day. We calculated common error metrics such as RMSE, normalized absolute median deviation (NMAD) and the coefficient of correlation (Pearson's R-Square). For the validation of the SuperDove-derived LAI, we used all available sampling points whereas the Sentinel-2 data was validated on a reduced data set due to constraints regarding the spatial and temporal resolution.
To provide a direct comparison between Sentinel-2 and SuperDove, we aggregated the SuperDove pixels into the spatial resolution of the Sentinel-2 pixels: For this, we used the mean of all SuperDove pixels that are fully contained in a Sentinel-2 pixel to allow for a pixel-based comparison of vegetation index and LAI values.

# 3 Results

## 3.1 Leaf Area Index Retrieval

Figure 2 shows the results of comparing Sentinel-2 (Fig. 2a) and SuperDove-derived LAI (Fig. 2b) against ground reference data with a maximum temporal gap between satellite overpass and ground sampling of one day. Due to the coarser spatial and temporal resolution of Sentinel-2 the amount of ground reference data points (N=28) matching the satellite overpasses is significantly lower than in the case of the SuperDove constellation (N=444). In both cases, high LAI values were slightly underestimated resulting in an overall RMSE of 0.87 m2m-2 and 0.91 m2m-2 for Sentinel-2 and SuperDove, respectively. Still, the satellite data explained 87% of the variance in the reference data in both cases. NMAD was high for Sentinel-2 (0.34 m2m-2) and close to zero (0.01 m2m-2) in the case of Planet SuperDove. Although the validation results of Sentinel-2 and Planet SuperDove are not directly comparable both systems reproduce overall LAI values and temporal development with accuracies comparable to findings in the literature (e.g. DANNER et al. 2021).
With regard to phenology, LAI relative retrieval accuracy is lowest during tillering (BBCH stages 20 to 29) with relative errors up to >50% and during flowering (BBCH 61 to 69). Smaller relative errors and higher R2 values can be found during the stem elongation phase (BBCH 31 till 59) where errors drop down to 10% and R2 reaches up to >0.6. These findings are similar for Sentinel-2 and Planet SuperDove. We did not assess accuracy during senescence because of the difficulty to separate green from brown LAI and the inability of the PROSAIL RTM to account for non-photosynthetically active foliage area.

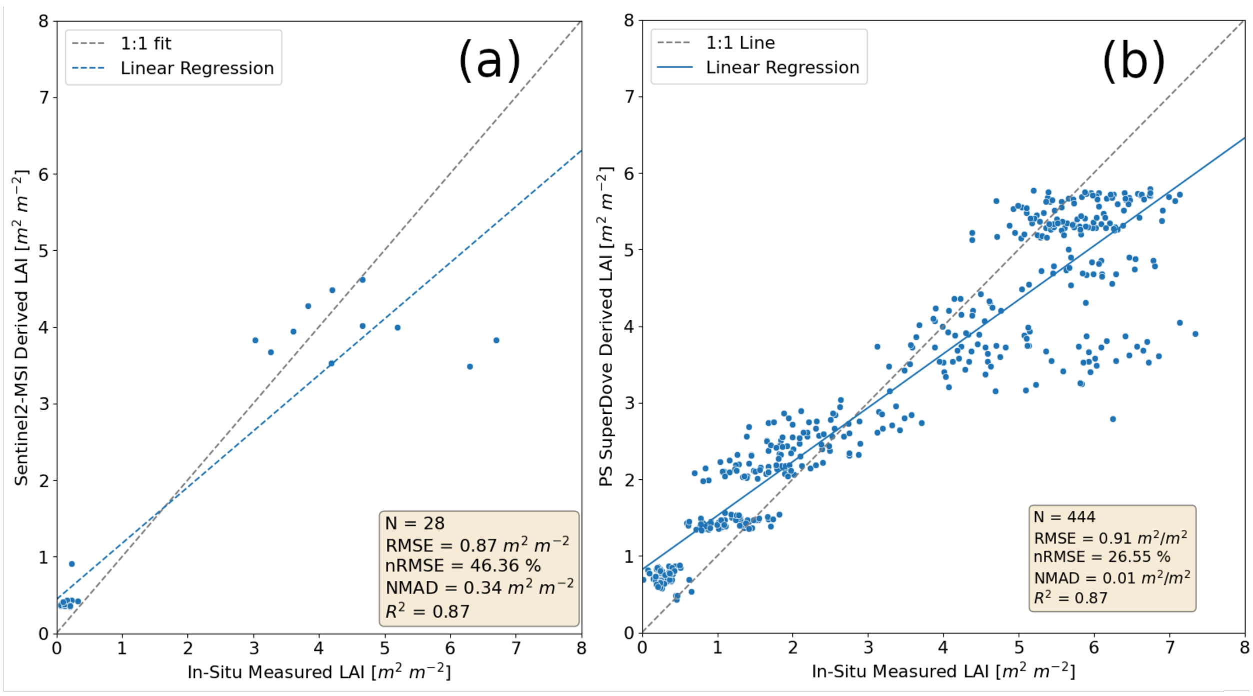


Fig.2: Validation of Sentinel-2 (a) and SuperDove (b) derived LAI values against ground reference data

### 3.2 Pixel-based comparison

Fig. 3 shows maps and pixel-based comparison of NDVI, NDRE, CI-GREEN, and LAI derived from Sentinel-2 and Planet SuperDove imagery on March 25 2022 before the second nitrogen fertilizer application. The plants were in tillering stage (BBCH 21 to 29). The amount of spatial detail in the SuperDove imagery is clearly higher than in the Sentinel-2 derived maps. While LAI shows a relatively strong agreement on the level of the Sentinel-2 10m pixels (R2=0.46, relative error 11.7%), the systems disagree in the vegetation indices with lowest values in the case of CI-GREEN (R2=0.14, relative error 38.4%) and NDRE (R2=0.15, relative error 15%). SuperDove derived values tend to be higher than those from Sentinel-2. In the case of NDVI the relative error is small (10.3%) but R2 is only about 0.27 meaning that a large part of the variance in the Planet imagery is not explained by Sentinel-2.

Still in tillering phase, before the third nitrogen application, on April 19 2022 (Fig. 4), the agreement between Sentinel-2 and SuperDove is higher especially for NDVI (R2=0.71, relative error 2.1%) but also NDRE and CI-GREEN. The SuperDove derived maps show a spot of relatively low values in the upper right part of the field parcel, which is hardly visible in the Sentinel-2 maps. This area of approximately 15 by 15 meters corresponds to a wet spot in the field as confirmed by the local farmer.

## 4 Discussion

### 4.1 Potentials

Both Sentinel-2 and Planet SuperDove can map winter wheat growth dynamics and allow accurate estimation of LAI from RTM inversion (Fig. 2). The SuperDove data, due to its superior spatial and temporal resolution, allows capturing small-scale details and field heterogeneities better compared to Sentinel-2 data. In particular, in the small fields of Switzerland with complex geometric shapes, the area covered by SuperDove is much larger, since a smaller boundary area must be buffered to avoid spectrally mixed pixel effects. The high spatial coverage thus allows establishing agricultural monitoring and decision systems - for example for nitrogen fertilization planning – that consider in-field heterogeneity (Fig. 3 and 4). Due to the high temporal coverage of the Planet data, growth dynamics and changes are captured, as sufficient cloud-free images are available even at high levels of cloud cover in the spring months. In this work, 42 Planet SuperDove scenes were available, compared to 17 Sentinel-2 images.

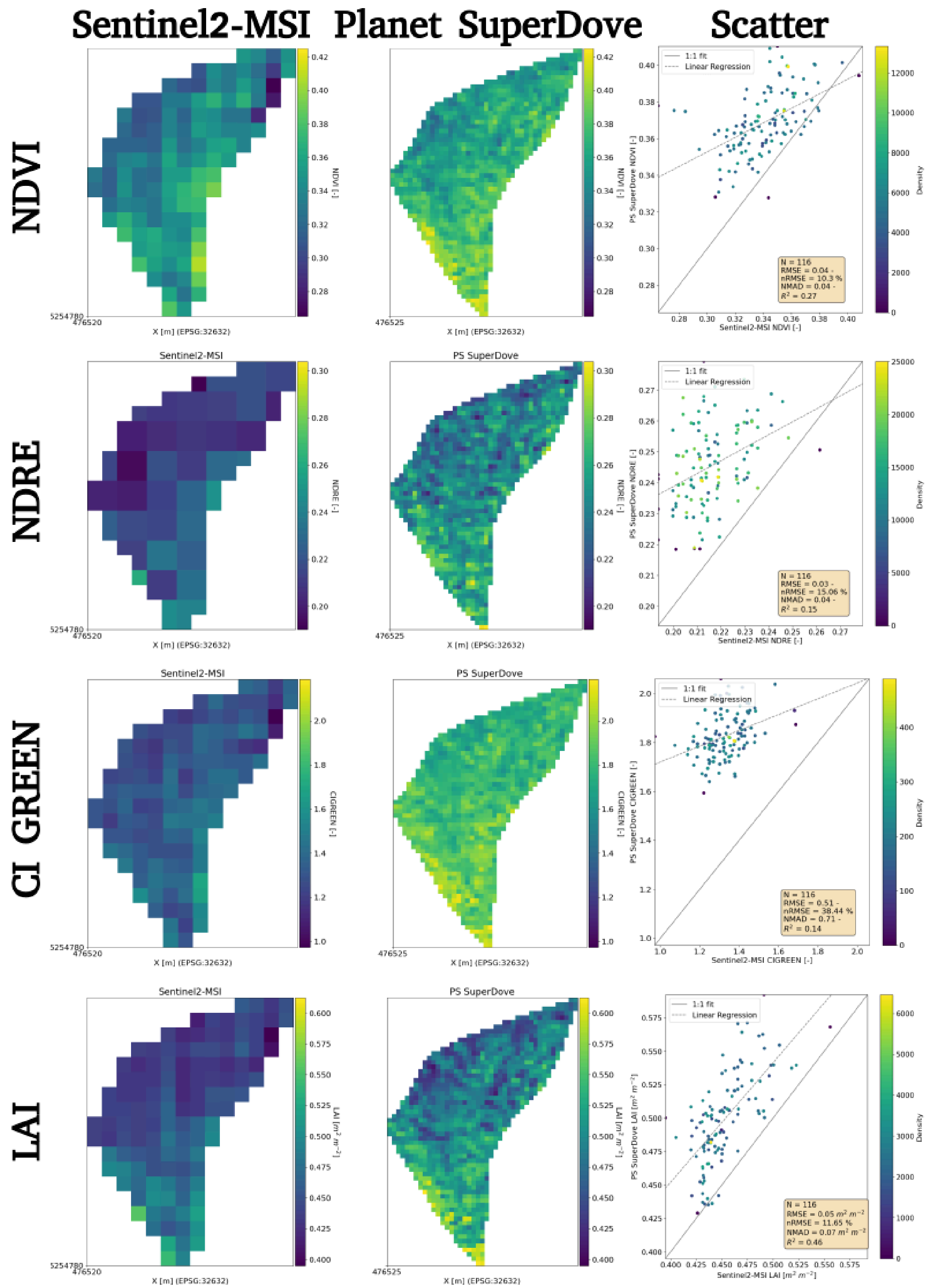


Fig. 3: Comparison of NDVI, NDRE, CI-GREEN and LAI between Sentinel-2 (left column), SuperDove (middle column) on a per-pixel level (right column) using the Sentinel-2 10m pixels for March 25 2022 (before 2nd nitrogen fertilization)

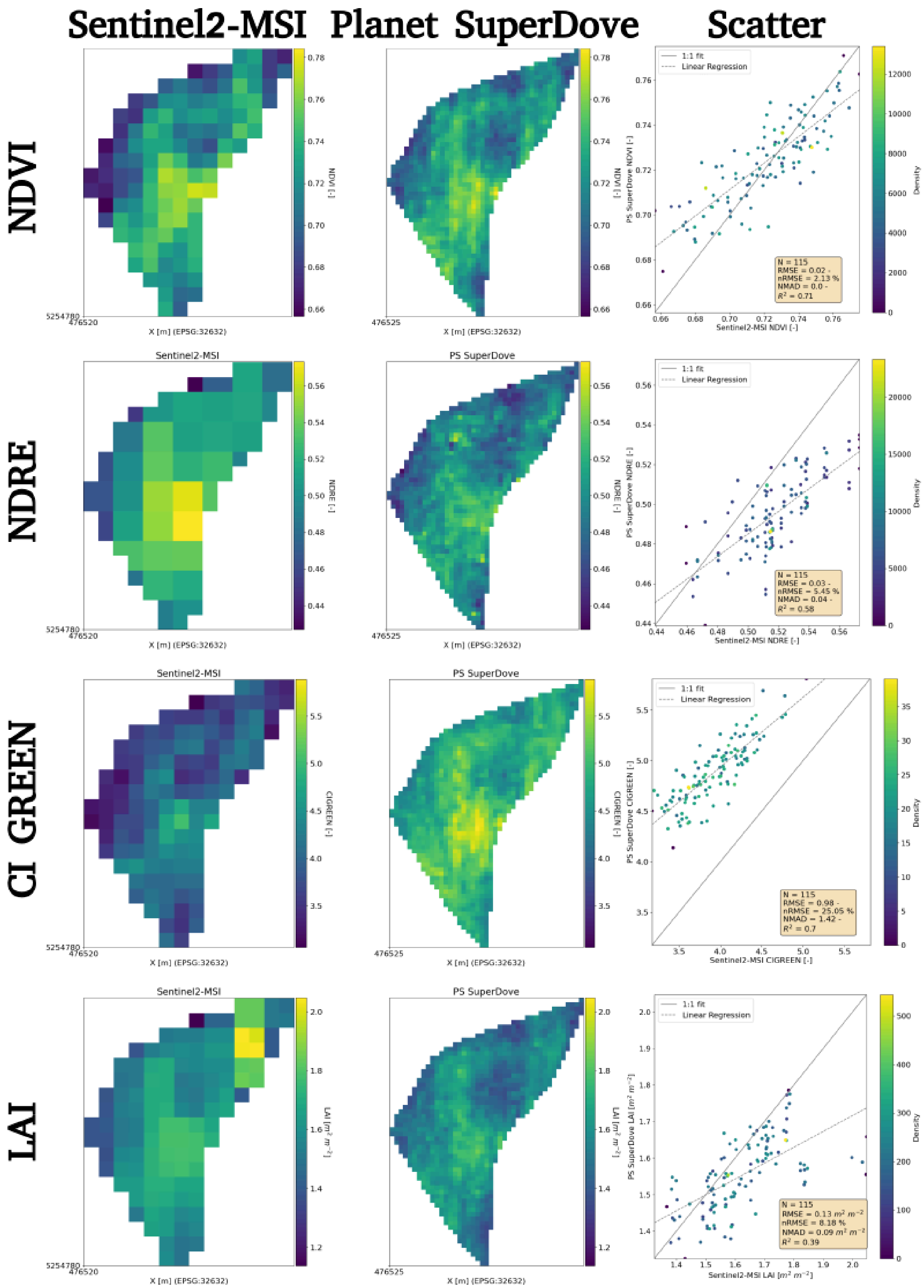


Fig. 4: Comparison of NDVI, NDRE, CI-GREEN and LAI between Sentinel-2 (left column), SuperDove (middle column) on a per-pixel level (right column) using the Sentinel-2 10m pixels for April 19 2022 (before 3rd nitrogen fertilization)

### 4.2 Challenges

Fig. 3 and 4 show only partial agreement between SuperDove and Sentinel-2 vegetation indices and GLAI. We attribute this observation partly to spatial co-registration errors, radiometric stability issues and the quality of the clear pixel mask.

#### 4.2.1 Spatial Co-Registration Error

Accurate spatial co-registration of data is essential for recording vegetation dynamics in agricultural monitoring. While the European Space Agency (ESA) guarantees a co-registration error of <10m since the last major Payload Data Ground Segment (PDGS) baseline update to version N0400, the error in the SuperDove data is specified as less than 10m RMSE at the 90th percentile according to Planet Labs. Internal tests on a spatially invariant target (Zurich airport tarmac), however, showed that the offset of the scenes from each other was larger than specified. Subsequent co-registration with the "arosics" library still resulted in uncorrected spatial offsets.

#### 4.2.2 Radiometric Stability

The fleet of SuperDove cube satellites enables high spatial and temporal resolution. However, the instruments are only conditionally radiometrically harmonized (TU et al. 2022). Although Sentinel-2A and -2B also differ slightly radiometrically, with only two sensors the number is significantly smaller than for Planet SuperDove, where data from 32 different satellites were included for the period under consideration. The high temporal resolution also means that in some cases more than one SuperDove image per day is available resulting in differences in the illumination geometry and bi-directional reflectance (BRDF) effects. We ignored all but the first of several daily scenes, but this is not necessarily the way to go. Radiometric harmonization and BRDF correction are therefore essential for operational use of Planet-Scope data for agricultural monitoring.

#### 4.2.3 Quality of the Clear Pixel Mask

As described in 2.2.1, we sorted out nine SuperDove scenes (~16% of the downloaded scenes) manually. This shows that the clear pixel mask supplied with the scenes is not yet sufficiently reliable to grant automatic selection of the scenes. In particular, we found disturbances due to undetected clouds and shadow pixels as well as radiometric overexposure effects that persisted despite atmospheric correction.

## 5 Conclusions

The high spatial and temporal resolution of the PlanetScope SuperDove cube satellite constellations reveals potential for agricultural monitoring applications including the retrieval of functional crop traits as the LAI. The potential is especially promising for small-scale agricultural structures like those found in Switzerland but also in other parts of the world. Cube satellites can thus complement established platforms such as Sentinel-2 for crop monitoring applications. However, challenges regarding radiometry, spatial co-registration and quality check should be addressed to enable operational use.

# 6 References

DANNER, M., BERGER, K., WOCHER, M., MAUSER, W. & HANK, T., 2021: Efficient RTM-based training of machine learning regression algorithms to quantify biophysical & biochemical traits of agricultural crops. ISPRS Journal of Photogrammetry and Remote Sensing, **173**, 278-296, https://doi.org/10.1016/j.isprsjprs.2021.01.017.

GRAF, L.V., PERICH, G. & AASEN, H., 2022: EOdal: An open-source Python package for large-scale agroecological research using Earth Observation and gridded environmental data. Computers and Electronics in Agriculture, **203**, 107487, https://doi.org/10.1016/j.compag.2022.107487.

JACQUEMOUD, S., VERHOEF, W., BARET, F., BACOUR, C., ZARCO-TEJADA, P.J., ASNER, G.P., FRANÇOIS, C. & USTIN, S.L., 2009: PROSPECT+SAIL models: A review of use for vegetation characterization. Remote Sensing of Environment, Imaging Spectroscopy Special Issue, **113**, S56-S66, https://doi.org/10.1016/j.rse.2008.01.026.

SCHEFFLER, D., HOLLSTEIN, A., DIEDRICH, H., SEGL, K. & HOSTERT, P., 2017: AROSICS: An Automated and Robust Open-Source Image Co-Registration Software for Multi-Sensor Satellite Data. Remote Sensing, **9**, 676, https://doi.org/10.3390/rs9070676.

TU, Y.-H., JOHANSEN, K., ARAGON, B., EL HAJJ, M.M. & MCCABE, M.F., 2022: The radiometric accuracy of the 8-band multi-spectral surface reflectance from the planet SuperDove constellation. International Journal of Applied Earth Observation and Geoinformation, **114**, 103035, https://doi.org/10.1016/j.jag.2022.103035.

WEISS, M., JACOB, F. & DUVEILLER, G., 2020: Remote sensing for agricultural applications: A meta-review. Remote Sensing of Environment, **236**, 111402, https://doi.org/10.1016/j.rse.2019.111402.