living planet symposium | BONN 23–27 May 2022

TAKING THE PULSE OF OUR PLANET FROM SPACE

On the use of UAV systems for in-situ validation of BRDF parameters

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23/05/2022

Overview

Operational algorithms for BRDF correction are based on parameters that are estimated by the integration of acquisitions from satellite MODIS instrument on board of Terra and Aqua platforms.

This work aims to develop an UAV system and flight protocols for collecting **reference in-situ validation dataset** optimal for assessing the quality of operative BRDF correction algorithms.

Key activities:

- Set-up of a system composed by UAV + Multispectral sensor S2 likes
- Design of flight plan for multi-angular acquisitions on selected surfaces
- Dataset elaboration
- Evaluation and modelling of BRDF using Ross-Li model

Under natural condition BRDF can not be derived. For the sake of clarity what we can derive with satellite and UAV measurements is **HDRF** (hemispherical – direct reflectance factor) which can be considered as an approximation.

System Set-up

UAV + Multispectral sensor S2 likes

	Band (nm)	Approx. color
1	433-453	Violet (Coastal)
2	457-523	Blue
3	542-578	Green
4	650-680	Red
5	697-713	Red Edge 1
6	732-748	Red Edge 2
7	773-793	NIR 1
8	784-900	NIR 2
9	855-875	NIR 3

- 9 CMOS sensor with global shutter
- GSD: 6cm at 120m flight height
- FOV: 75m x 60 m at 120m flight height
- Size and weight 10 x 13 x 4,6 cm, 470 g

- **Hexarotor** MTOM up to **6 kg**
- Up to **20 minutes** of flight time
- Automatic flight capabilities
- Execution of flight plan (pilot program)
- Controlled acquisition geometry (azimuth orientation and camera tilt between 0° and 90° zenith angle)

The **Incident Light Sensor (ILS)** measures the level of the down-welling light in each band.

ILS **provides irradiance data at the exact time of shooting for each image and spectral band**, substantially improving the accuracy of radiometric correction.

Multispectral Camera Sentinel-2 likes

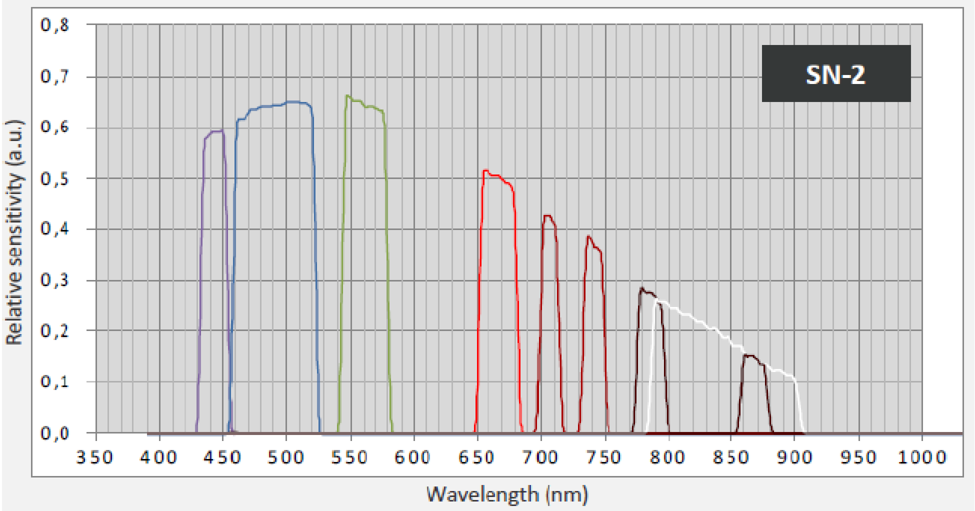
Technical Features	
Sensors	9 CMOS sensor 1.2Mpix (1280x960) with global shutter
Acquisition	Single shot or continuous up to 5fps
Image Format	Multi-layer/multi-band RAW 8 - 10 - 12bits per pixel; TIFF
File Size	from 10.7 to 21.2MB depending on the format
Internal Storage	210GB internal storage
Size and weight	99 x 129 x 46 mm^3, 470 g

Height (m)	GSD (mm/pixel)	FOV (m^2)
50	23	30 x 23
75	35	45 x 34
100	47	60 x 45
150	70	90 x 68

Spectral Specification: Bands compliant with Sentinel-2

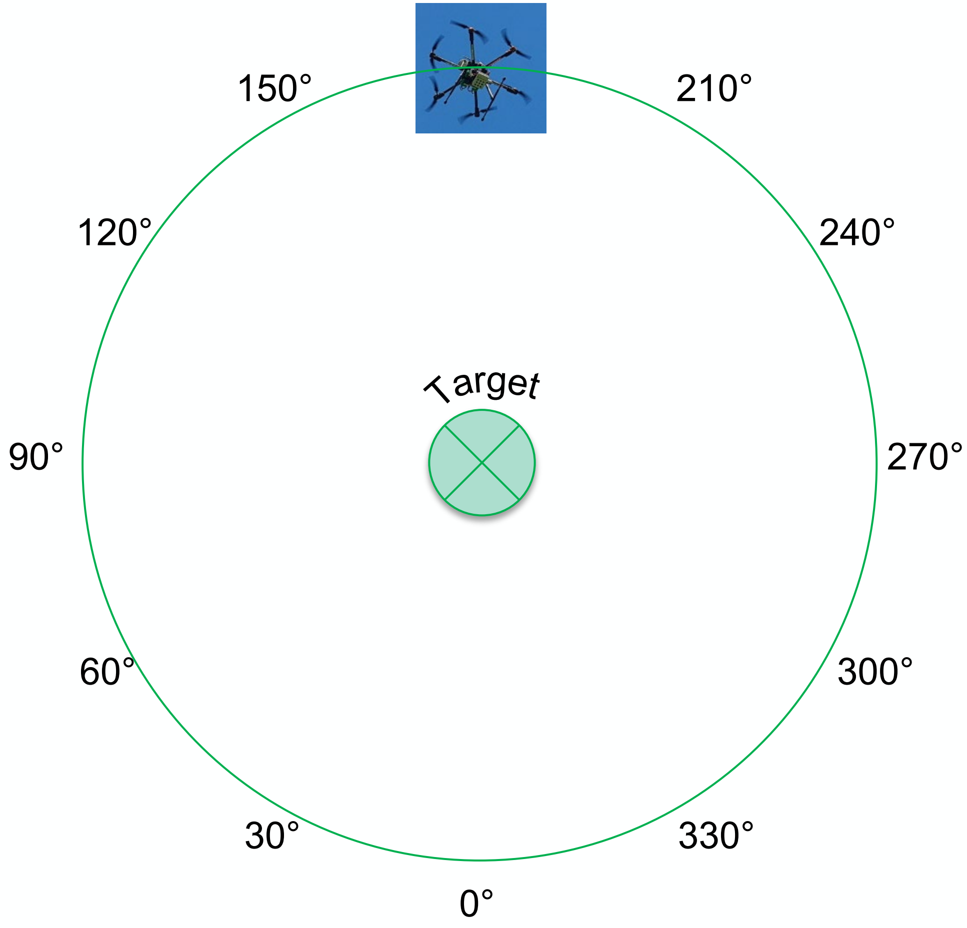
Sentinel-2 bands	Central wavelength (μm)
Band 1 – Coastal aerosol	0.443
Band 2 – Blue	0.490
Band 3 – Green	0.560
Band 4 – Red	0.665
Band 5 – Vegetation red edge	0.705
Band 6 – Vegetation red edge	0.740
Band 7 – Vegetation red edge	0.783
Band 8 – NIR	0.842
Band 8A – Vegetation red edge	0.865
Band 9 – Water vapour	0.945
Band 10 – SWIR – Cirrius	1.375
Band 11 – SWIR	1.610
Band 12 – SWIR	2.190

MAIA SN-2 BANDS	
Band (nm)	Name
433-453	Violet (Coastal)
457-523	Blue
542-578	Green
650-680	Red
697-713	Red Edge 1
732-748	Red Edge 2
773-793	NIR1
784-900	NIR2
855-875	NIR3

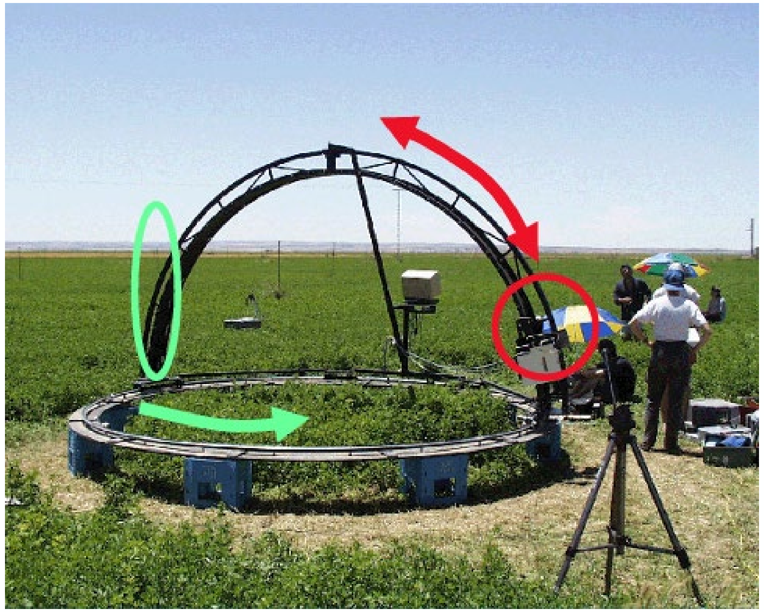


Flight Plan: Acquisition Strategy

View Azimuth Angle (VAA) variation

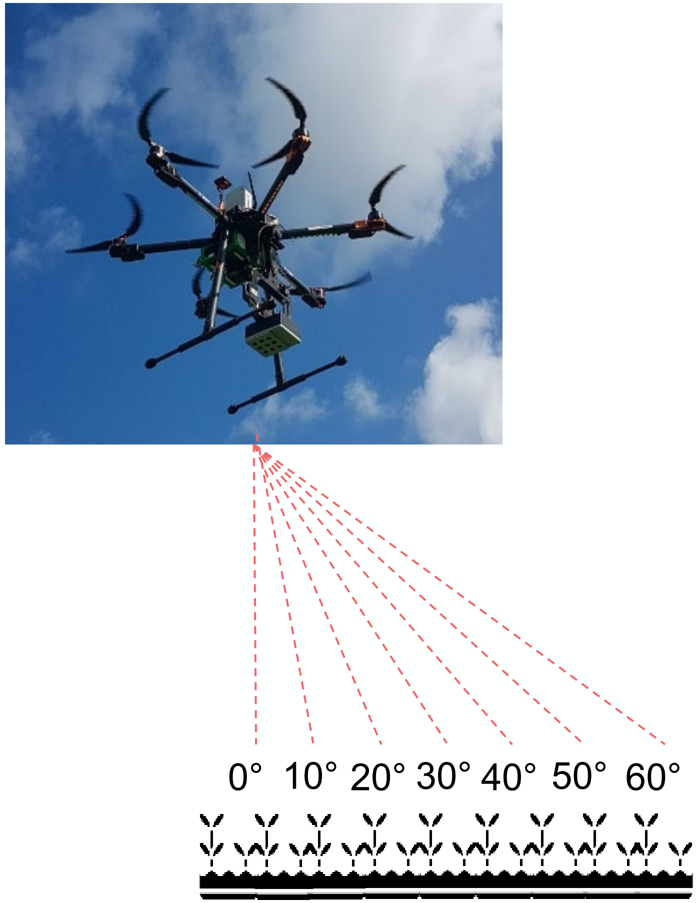


Goniometer Acquisition System for BRDF measurements



Limits:
- Costs
- Accessibility
- Target representation and integrity

View Zenith Angle (VZA) variation

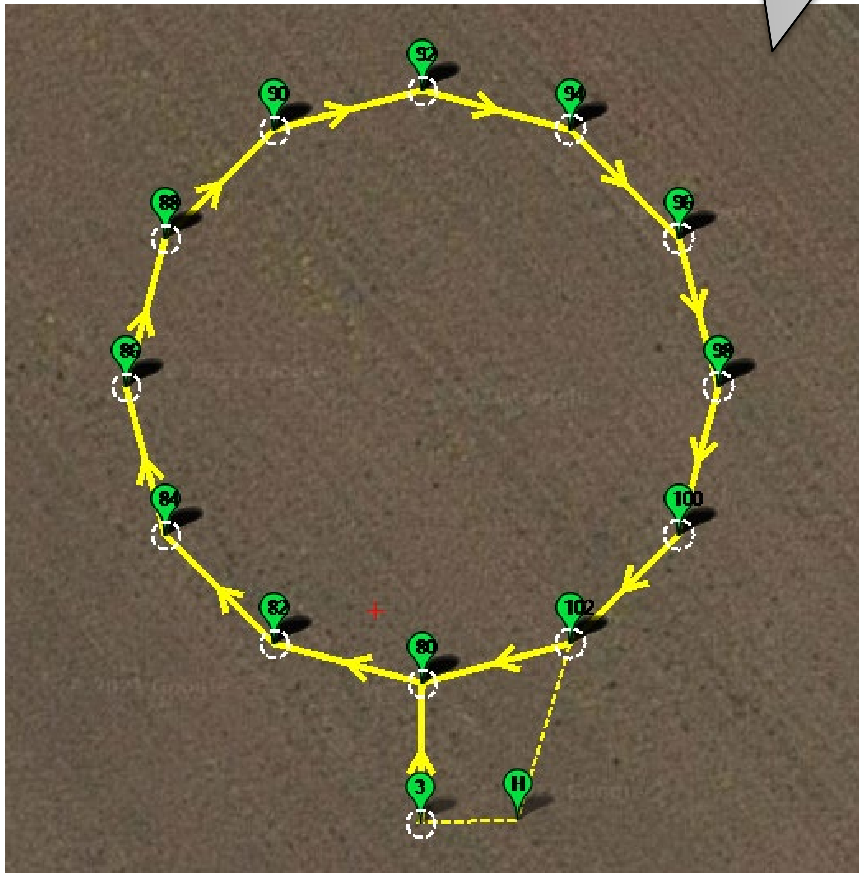


Flight Planning and Dataset Elaboration: Vegetation Surface

Flight Planning – Vegetation Test site

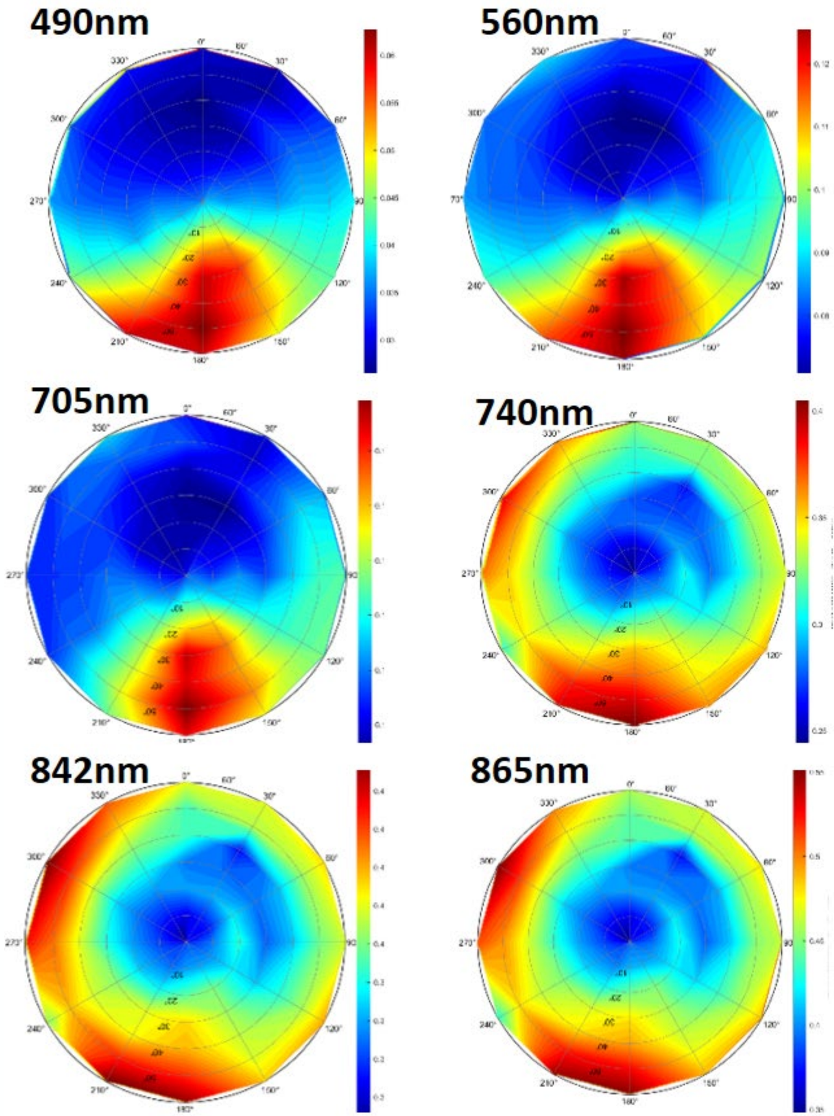
- Acquisition details:
  - **View Azimuth Angles**: 0° to 360° with 30° steps
  - **View Zenith Angles**: 0° to 60° with 10° steps
  - **Dataset amount:** 84 acquisition each survey
  - **More info**:
    - Survey time about 15min
    - Flight altitude: 120m
    - Sun Azimuth angle: 168°
    - Overlapping Sentinel-2 passage (30/04/2021)

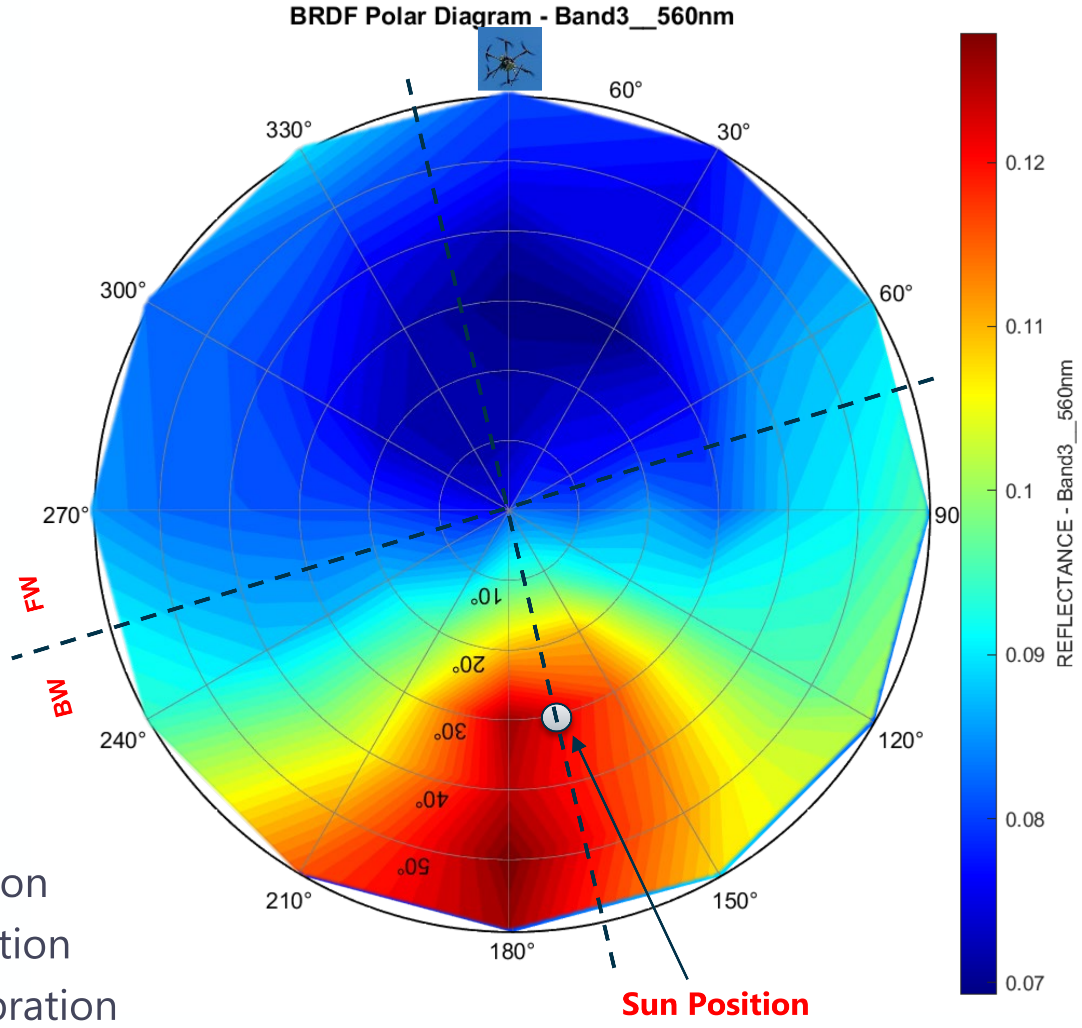
On ground picture: **Wheat Field**



[redacted]

MAIA Field Measurements – Evaluation of BRDF

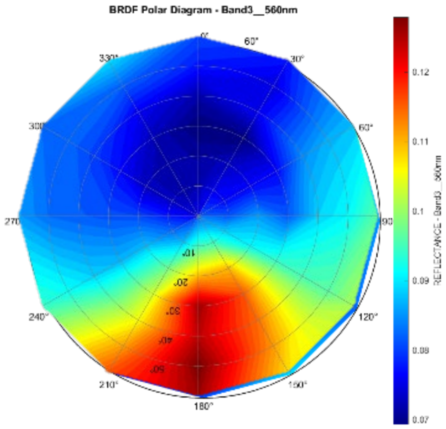




Preprocessing:

- Band Coregistration
- Geometry Correction
- Radiometric Calibration

BRDF Modeling: Ross-Li model



Computing Ross-Li Kernels

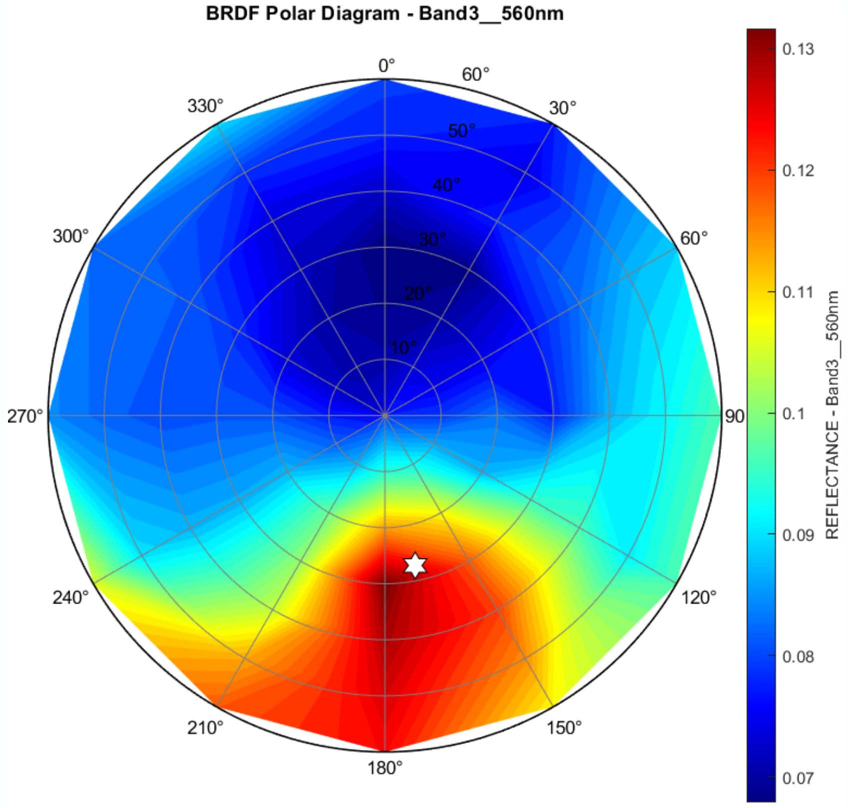
$$K_{RT} = [(\pi/2 - \xi)\cos\xi + \sin\xi]/[\cos\theta_s + \cos\theta_v] - \pi/4$$

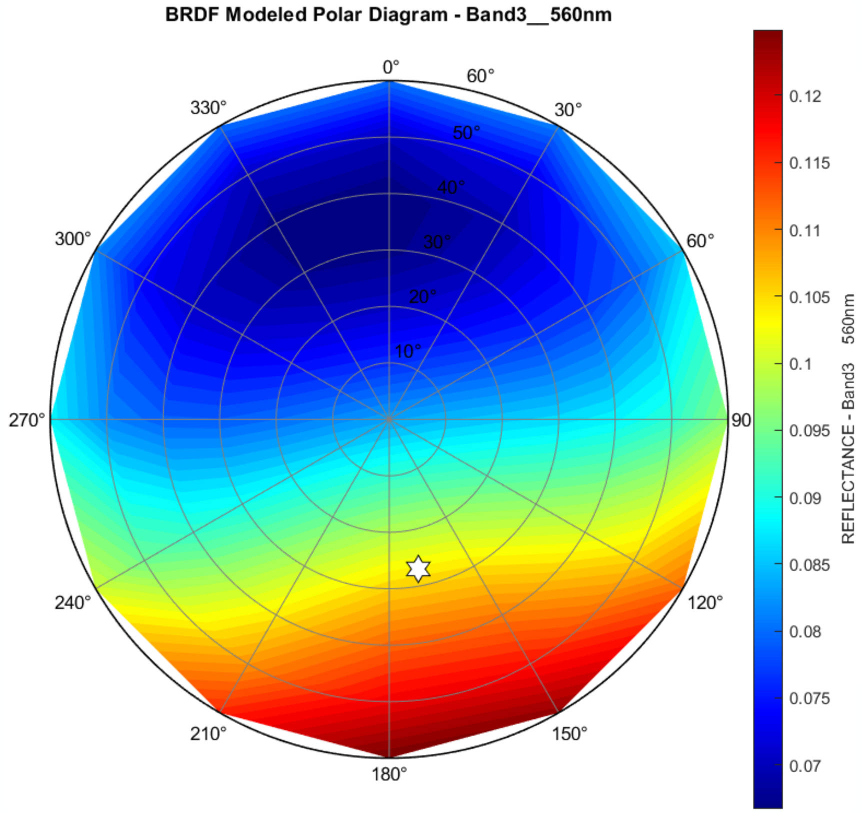
$$K_{LS} = O(\theta_s, \theta_v, \phi) - \sec\theta'_s - \sec\theta'_v + \tfrac{1}{2}(1+\cos\xi')\sec\theta'_s \sec\theta'_v$$

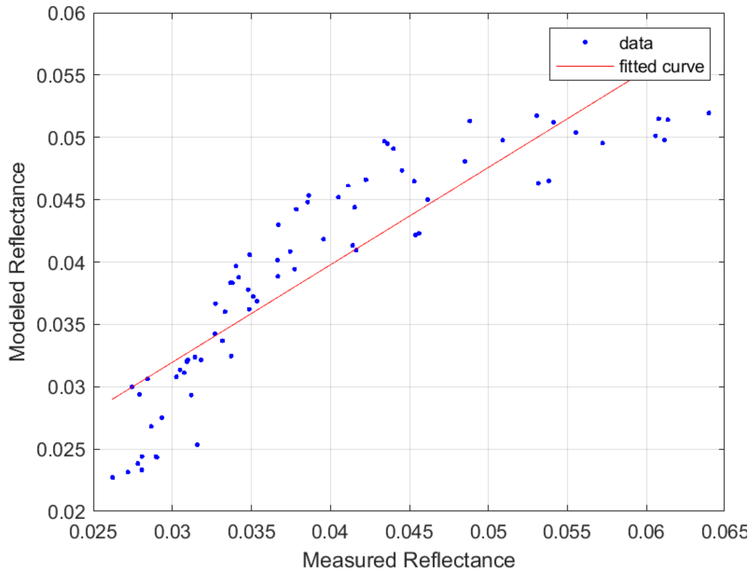
$$R(\theta_s, \theta_v, \phi; \lambda) = f_{\text{iso}} + f_{\text{vol}} K_{\text{vol}}(\theta_s, \theta_v, \phi; \lambda) + f_{\text{geo}} K_{\text{geo}}(\theta_s, \theta_v, \phi; \lambda)$$

Inversion of the model using least squared method

BRDF Comparison: Measured vs Model







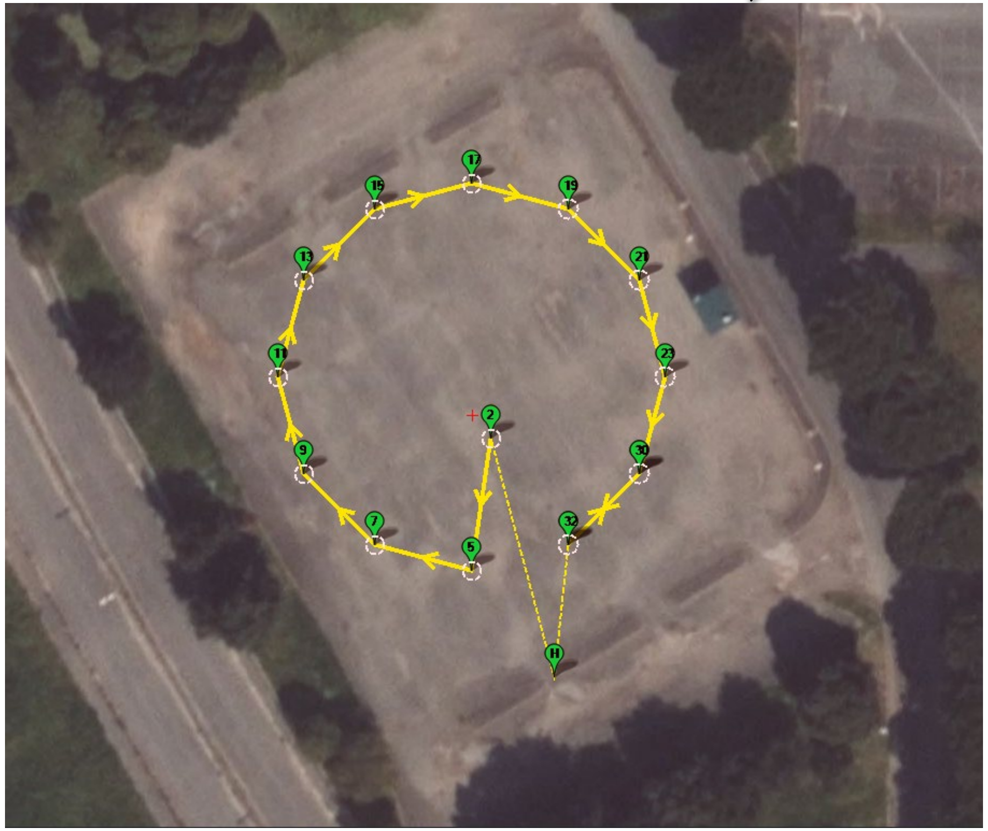
R^2 > 0.8

For all modeled bands

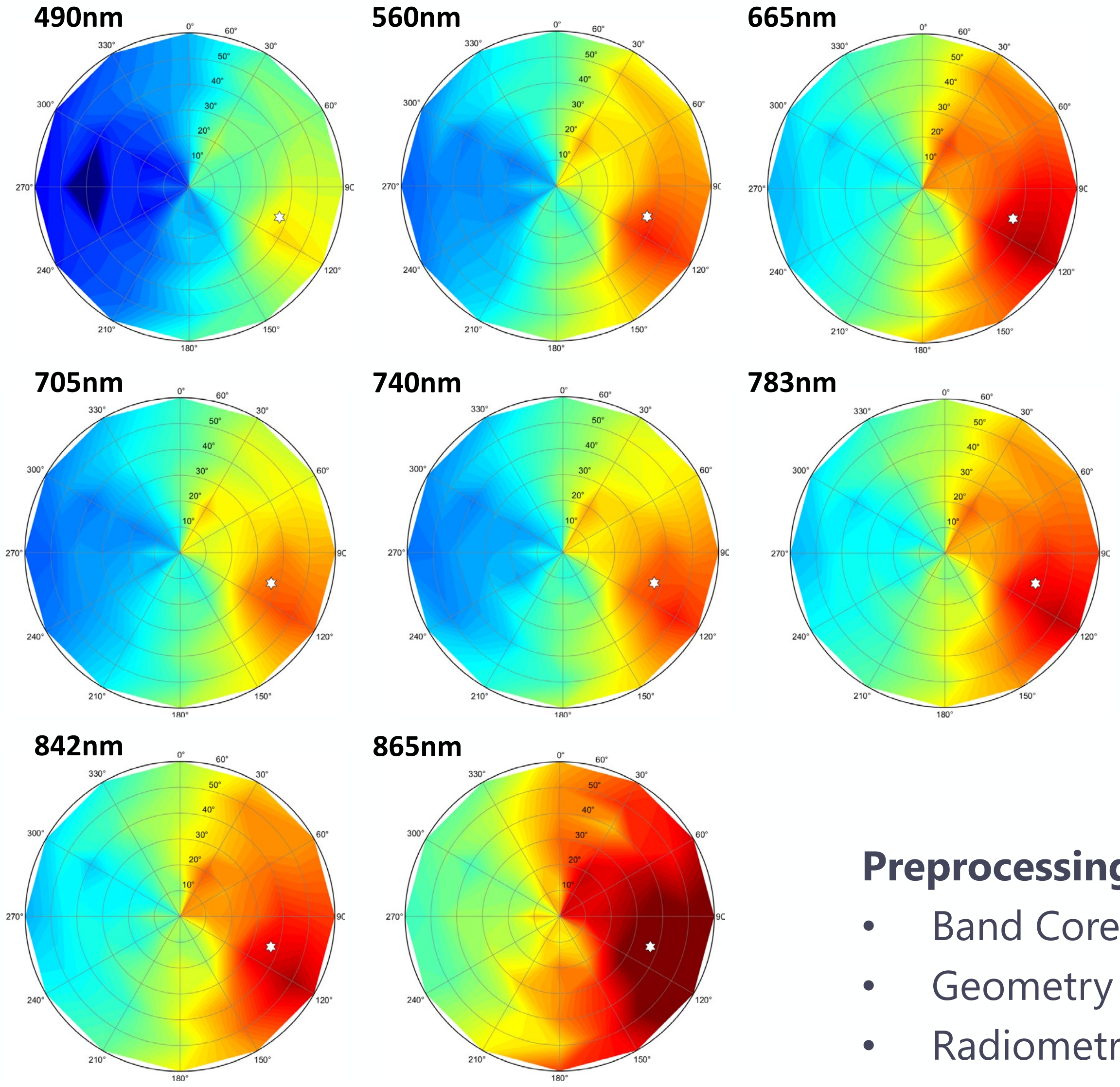
Flight Planning and Dataset Elaboration: Asphalt Surface

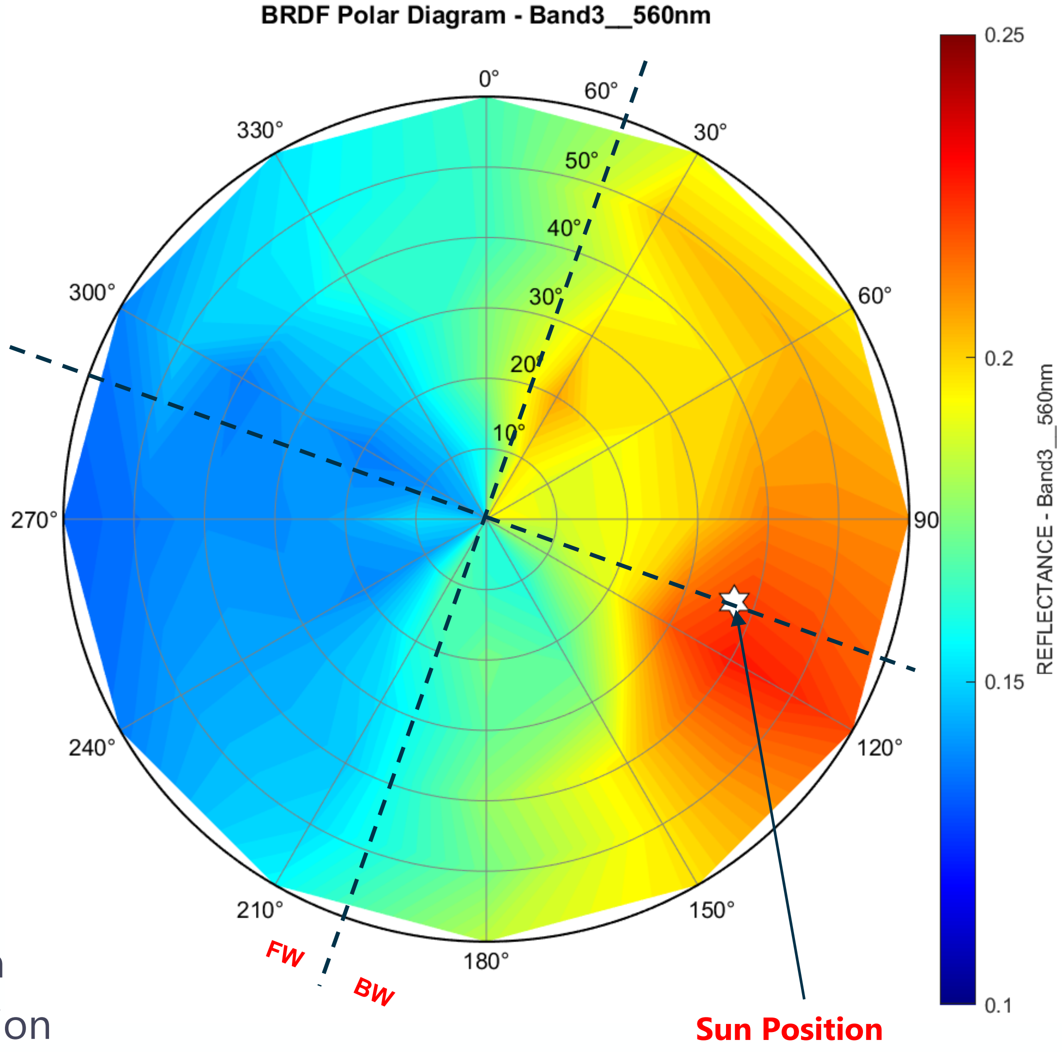
Flight Planning – Asphalt Test site

- Acquisition details:
  - **View Azimuth Angles**: 0° to 360° with 30° steps
  - **View Zenith Angles**: 0° to 60° with 10° steps
  - **Dataset amount:** 84 acquisition each survey
  - **More info**:
    - Flight time about 15min
    - Flight altitude: 120m
    - Sun Azimuth angle: 110°
    - Overlapping Sentinel-2 passage (03/07/2021)



Flight Planning – Asphalt Test site

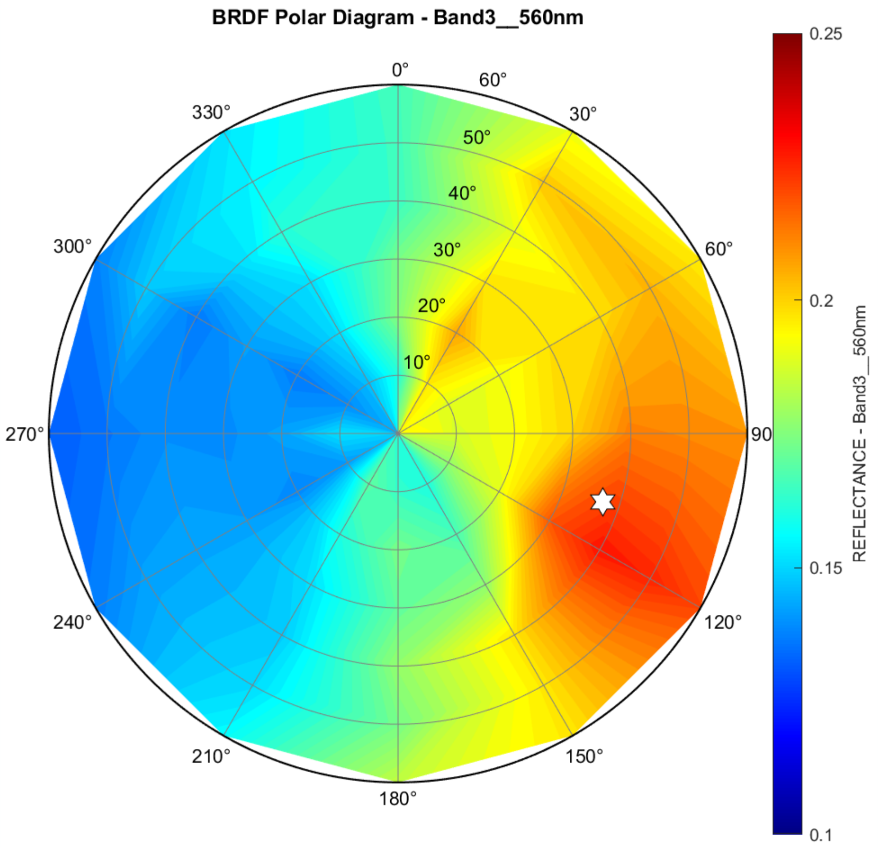


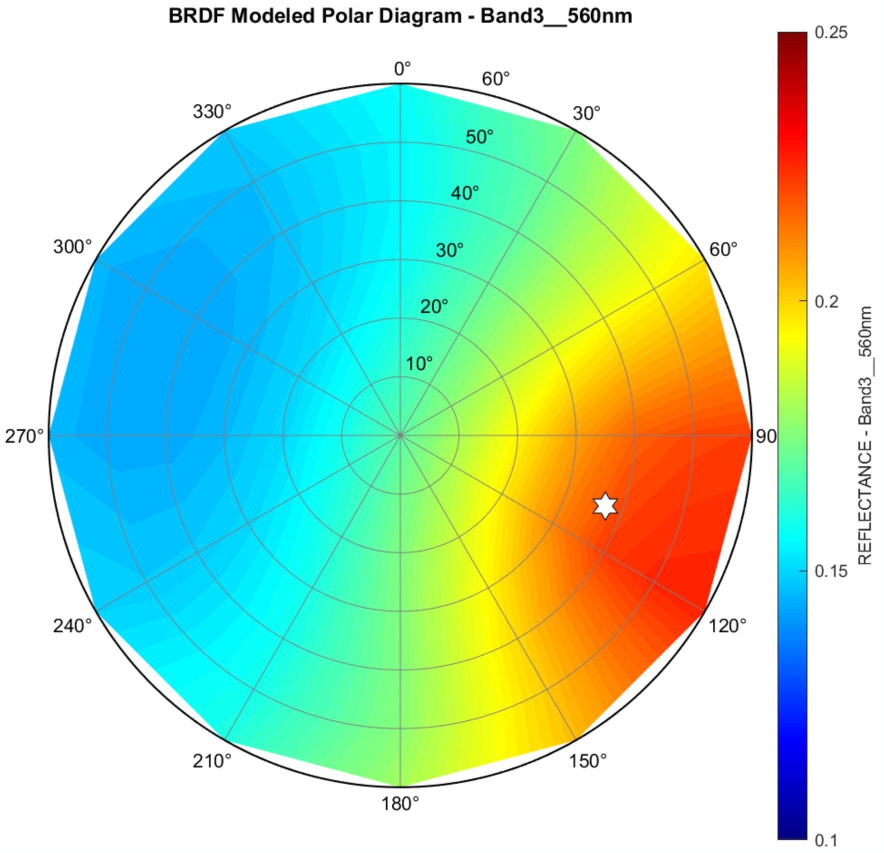


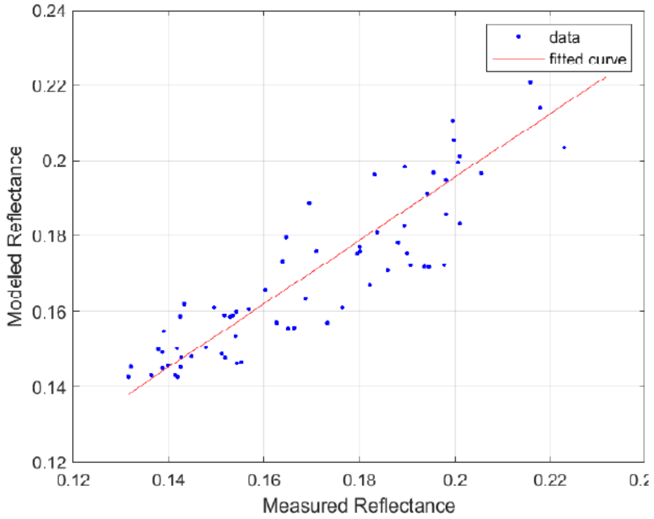
Preprocessing:

- Band Coregistration
- Geometry Correction
- Radiometric Calibration

BRDF Comparison: Measured vs Model







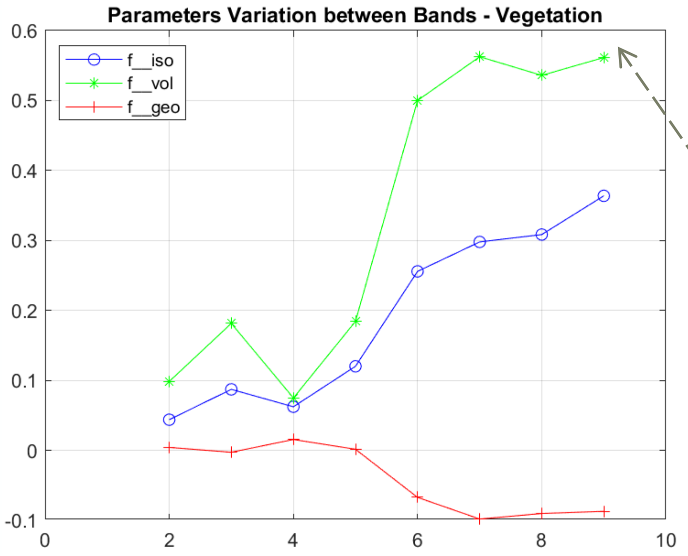
$R^2 > 0.8$

For all modeled bands

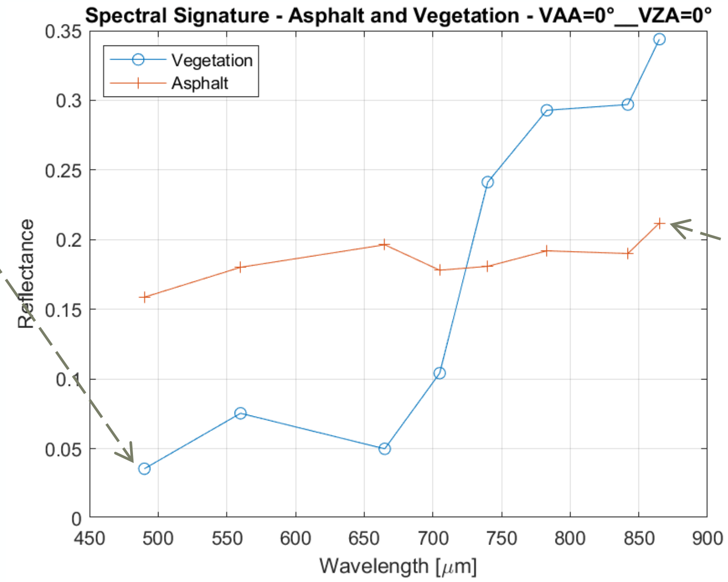
BRDF model parameters: Sensitivity and Statistical analysis

Sensitivity of Ross-Li Parameters to Surfaces and λ

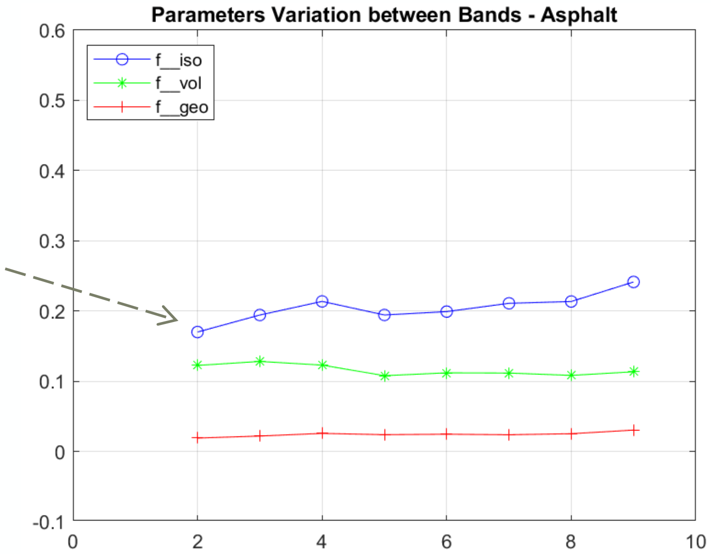
Parameters on Vegetation



Spectral Signature



Parameters on Asphalt



$$R(\theta_s,\theta_v,\phi;\lambda) = f_{\text{iso}} + f_{\text{vol}}K_{\text{vol}}(\theta_s,\theta_v,\phi;\lambda) + f_{\text{geo}}K_{\text{geo}}(\theta_s,\theta_v,\phi;\lambda)$$

f_iso → predominant on asphalt Surface

f_vol → predominant on vegetation surface

f_geo
- Asphalt → constant behaviour
- Vegetation → variable behaviour

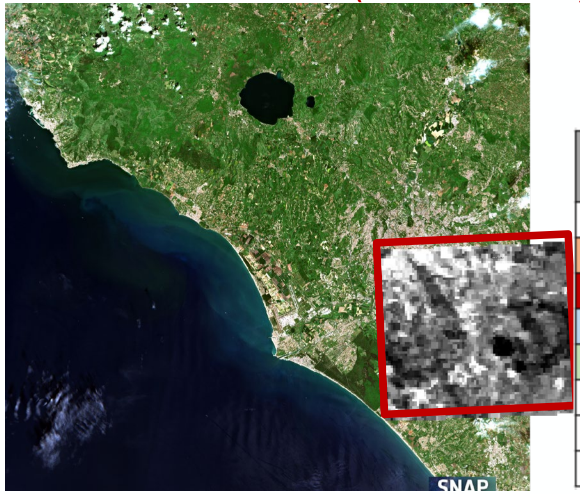
Random Uncertainty - RossLi

	MAIA Band	RMSE	CORRcoeff	f1 - f_{iso}	Confidence Interval - f1	f2 - f_{vol}	Confidence Interval - f2	f3 - f_{geo}	Confidence Interval - f3
Vegetation	Band2__490nm	0.004	0.933	0.044	0.046 - 0.042	0.098	0.109 - 0.087	0.004	0.006 - 0.002
	Band3__560nm	0.007	0.891	0.087	0.091 - 0.083	0.181	0.204 - 0.159	-0.003	0.001 - -0.007
	Band4__665nm	0.005	0.913	0.062	0.065 - 0.059	0.075	0.091 - 0.059	0.015	0.018 - 0.013
	Band5__705nm	0.009	0.859	0.12	0.125 - 0.115	0.184	0.213 - 0.155	0.002	0.007 - -0.004
	Band6__740nm	0.024	0.829	0.256	0.269 - 0.242	0.5	0.577 - 0.423	-0.067	-0.053 - -0.081
	Band7__783nm	0.032	0.813	0.298	0.315 - 0.28	0.563	0.663 - 0.462	-0.098	-0.08 - -0.116
	Band8__842nm	0.031	0.802	0.308	0.326 - 0.291	0.536	0.634 - 0.438	-0.09	-0.072 - -0.108
	Band9__865nm	0.033	0.787	0.364	0.382 - 0.345	0.561	0.666 - 0.457	-0.087	-0.068 - -0.106
Asphalt	Band1__443nm	0.012	0.848	0.168	0.176 - 0.16	0.114	0.143 - 0.085	0.017	0.024 - 0.01
	Band2__490nm	0.014	0.83	0.17	0.179 - 0.161	0.123	0.157 - 0.088	0.019	0.027 - 0.011
	Band3__560nm	0.014	0.853	0.194	0.203 - 0.185	0.128	0.162 - 0.094	0.022	0.03 - 0.014
	Band4__665nm	0.014	0.863	0.214	0.223 - 0.205	0.123	0.157 - 0.089	0.026	0.034 - 0.018
	Band5__705nm	0.012	0.862	0.194	0.202 - 0.186	0.108	0.139 - 0.077	0.024	0.031 - 0.017
	Band6__740nm	0.012	0.867	0.199	0.207 - 0.191	0.112	0.143 - 0.081	0.025	0.032 - 0.017
	Band7__783nm	0.012	0.874	0.211	0.219 - 0.203	0.112	0.141 - 0.082	0.024	0.031 - 0.017
	Band8__842nm	0.011	0.884	0.214	0.221 - 0.206	0.108	0.137 - 0.08	0.025	0.032 - 0.019
	Band9__865nm	0.013	0.887	0.241	0.25 - 0.233	0.113	0.145 - 0.082	0.03	0.038 - 0.023

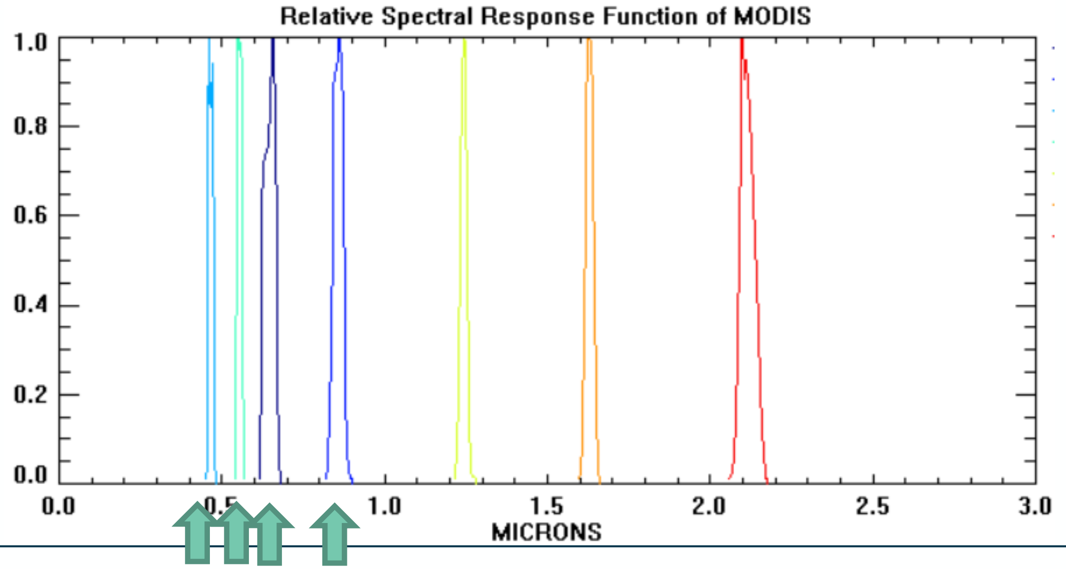
Optimal confidence intervals: Quality and Completeness of multi-angular dataset collected by UAV

Comparison with RossLi Parameters from MODIS

MODIS/MCD43A1 (30/04/2021)

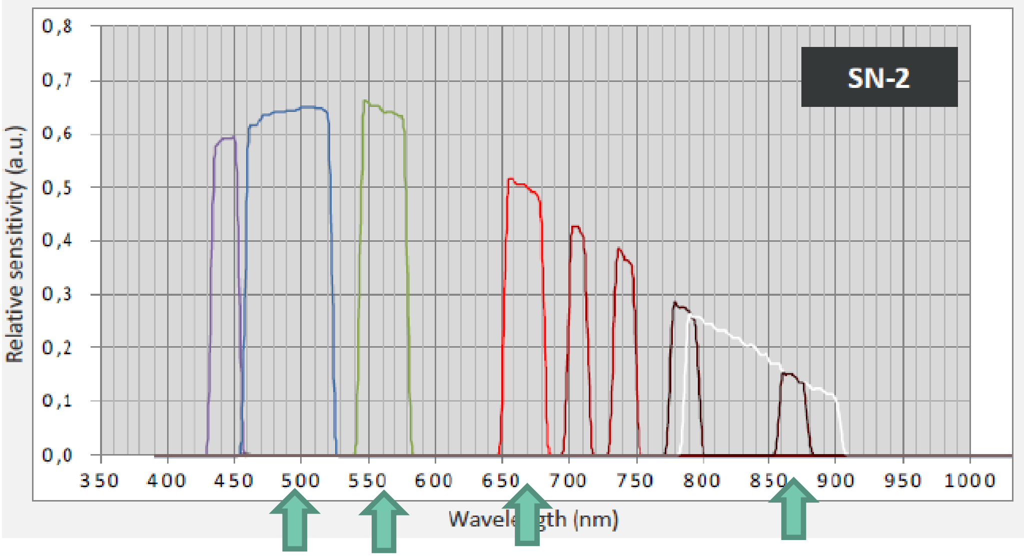


MODIS BANDs used in MCD43A1	Central wavelength MODIS
Band (nm)	
620 – 670 (band 1)	659
841 – 876 (band 2)	865
459 – 479 (band 3)	470
545 – 565 (band 4)	555
1230 – 1250 (band 5)	1240
1628 – 1652 (band 6)	1640
2105 – 2155 (band 7)	2130

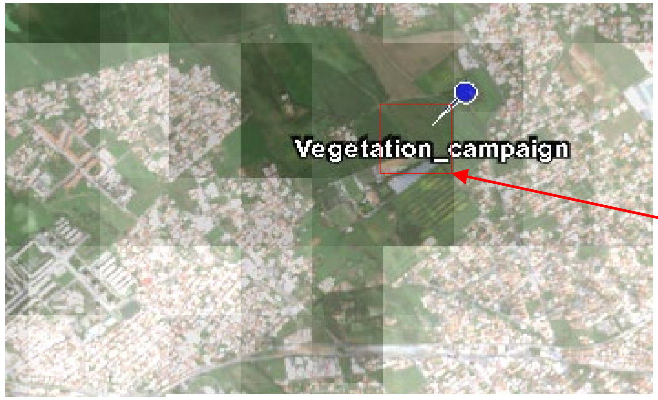


UAV Survey (30/04/2021)

MAIA SN-2 BANDs	Central wavelength MAIA
Band (nm)	
433-453 (band 1)	443
457-523 (band 2)	490
542-578 (band 3)	560
650-680 (band4)	665
697-713 (band 5)	705
732-748 (band 6)	740
773-793 (band 7)	783
784-900 (band 8)	842
855-857 (band 9)	865

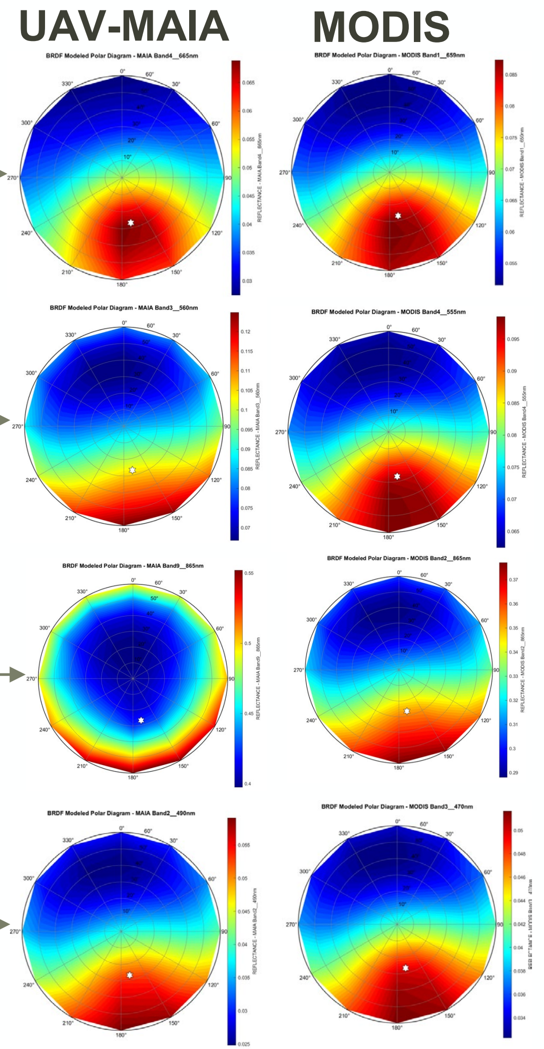


Comparison with RossLi Parameters from MODIS



- MODIS parameters details:
  - **Extracted by integrating 16 days reflectance measurements from TERRA & AQUA satellites**
  - **Narrow spectral bands**
  - **Lower Spatial Resolution: 500m x 500m**

Bands (nm)	Spatial Resolution	Date	Sensor	f_iso	f_vol	f_geo
665	6 cm	30/04/2021	MAIA	0.062	0.075	0.015
659	500 m	30/04/2021	MODIS	0.079	0.085	0.011
560	6 cm	30/04/2021	MAIA	0.087	0.181	-0.003
555	500 m	30/04/2021	MODIS	0.088	0.096	0.009
865	6 cm	30/04/2021	MAIA	0.364	0.561	-0.087
865	500 m	30/04/2021	MODIS	0.328	0.267	0.003
490	6 cm	30/04/2021	MAIA	0.044	0.098	0.004
470	500 m	30/04/2021	MODIS	0.045	0.053	0.004



Weaker shadow effects in NIR caused by the lower chlorophyll absorption

Comparison with RossLi Parameters from literature

Literature Reference Dataset(1)

Table 2 The f_{iso}, f_{vol}, and f_{geo} of the RossThick–LiSparse model for the WFI sensor.

Band	Cover Type	f_{iso}	f_{vol}	f_{geo}
Band1_485nm	Bare Soil	0.1936	0.1193	0.0199
Band2_555nm	Bare Soil	0.2323	0.1331	0.0258
Band3_665nm	Bare Soil	0.2566	0.1373	0.0298
Band4_805nm	Bare Soil	0.2656	0.1308	0.0322

(1) Pan, Z., Zhang, H., Min, X., & Xu, Z. (2020). Vicarious calibration correction of large FOV sensor using BRDF model based on UAV angular spectrum measurements. Journal of Applied Remote Sensing, 14(2), 027501.

MAIA-S2 Dataset

RossLi									
Band	CoverType	RMSE	CORRcoeff_RL	f1 - fiso	Confidence Interval - f1	f2 - fvol	Confidence Interval - f2	f3 - fgeo	Confidence Interval - f3
Band2__490nm	Vegetation	0.004	0.933	0.044	0.046 - 0.042	0.098	0.109 - 0.087	0.004	0.006 - 0.002
Band3__560nm	Vegetation	0.007	0.891	0.087	0.091 - 0.083	0.181	0.204 - 0.159	-0.003	0.001 - -0.007
Band4__665nm	Vegetation	0.005	0.913	0.062	0.065 - 0.059	0.075	0.091 - 0.059	0.015	0.018 - 0.013
Band8__842nm	Vegetation	0.031	0.802	0.308	0.326 - 0.291	0.536	0.634 - 0.438	-0.09	-0.072 - -0.108
Band2__490nm	Asphalt	0.014	0.83	0.17	0.179 - 0.161	0.123	0.157 - 0.088	0.019	0.027 - 0.011
Band3__560nm	Asphalt	0.014	0.853	0.194	0.203 - 0.185	0.128	0.162 - 0.094	0.022	0.03 - 0.014
Band4__665nm	Asphalt	0.014	0.863	0.214	0.223 - 0.205	0.123	0.157 - 0.089	0.026	0.034 - 0.018
Band8__842nm	Asphalt	0.011	0.884	0.214	0.221 - 0.206	0.108	0.137 - 0.08	0.025	0.032 - 0.019

Conclusion

Achievements

- Development of an automatic and repeatable flight plan for acquiring multi-angular UAV dataset using multispectral camera Sentinel-2 likes.
- Planning and execution of the UAV-based Cal/Val surveys over different landcover types (vegetation, asphalt).
- Dataset analysis and estimation of surface BRDF parameters using linear model (Ross-Li).
- Sensitivity and statistical analysis on estimated parameters, comparison with MODIS operative parameters

Next..

- Further investigations and analysis including surveys on different test sites (QA4EO - phase 2).
- Consider the integration with atmospheric measurements (aerosol) on the area of the survey.
- Support to the cal/val activities of Sen2Like processor, providing UAV multi-angular dataset.
- Participation to SRIX4VEG initiative in Barrax (ES) planned in July 2022 (https://frm4veg.org/srix4veg/).

Thanks

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