2024 DRAGON SYMPOSIUM

DRAGON 5 FINAL RESULTS REPORTING

24-26 JUNE 2024

[PROJECT ID. 58817]

[UAVS 4 HIGH-RES. OPTICAL SATS.]

<INSERT DAY & DATE IN PROGRAMME>

ID. 58817

PROJECT TITLE: EXPLOITING UAVS FOR VALIDATING DECAMETRIC EARTH OBSERVATION DATA FROM SENTINEL-2 AND GAOFEN-6(UAV4VAL)

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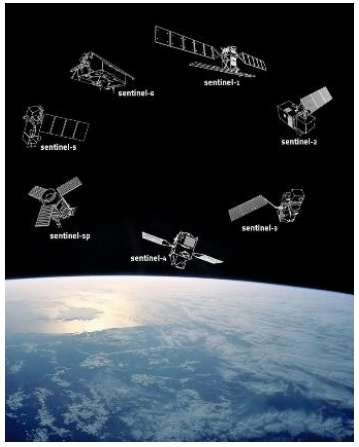
PRESENTED BY: JADUNANDAN DASH

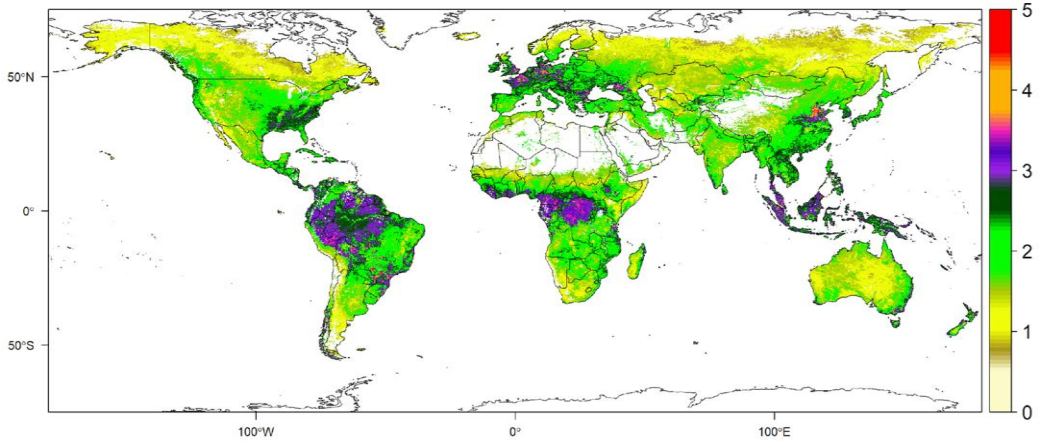
Dragon 5 Final Results Reporting

- Inform on the project's objectives
- Detail the Copernicus Sentinels, ESA, Chinese and ESA Third Party Mission data utilised to achieve the project's objectives (complete slide 4)
- Detail the in-situ data measurements and requirements
- Provide details on field data collection campaigns and periods in P.R. China or other study areas
- Report on the final results after 4 years of activity
- Report on the level and training of young scientists on the project achievements, including academic exchanges (complete slides 5 and 6)
- Report on the peer reviewed publications (nr. of papers, journal name and publication title) after 4 years of activity (complete slide 7)

Background

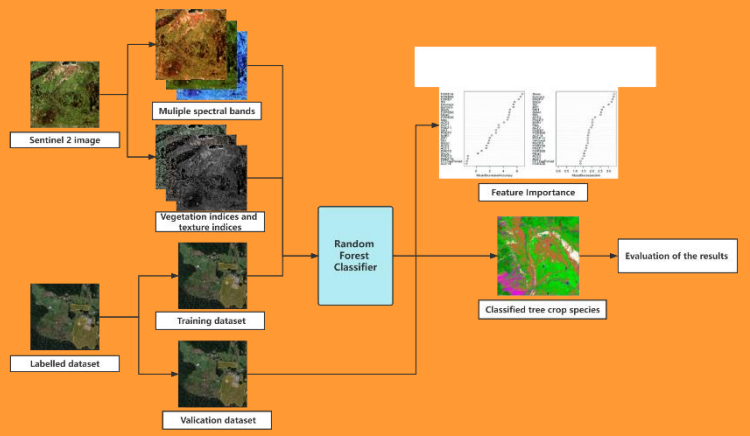
- Vegetation biophysical variables such as Leaf Area Index (LAI), Canopy Chlorophyll content (CCC), Fraction of absorbed Photosynthetic Radiation (fAPAR) are important plant and ecosystem status indicators.
- Advances in sensing and retrieval techniques -> suitability in operational use
- Validation is crucial to ensure fit-for-purpose
- Field campaigns are logistically challenging and resource intensive
- Automated measurement the way forward





Product Development

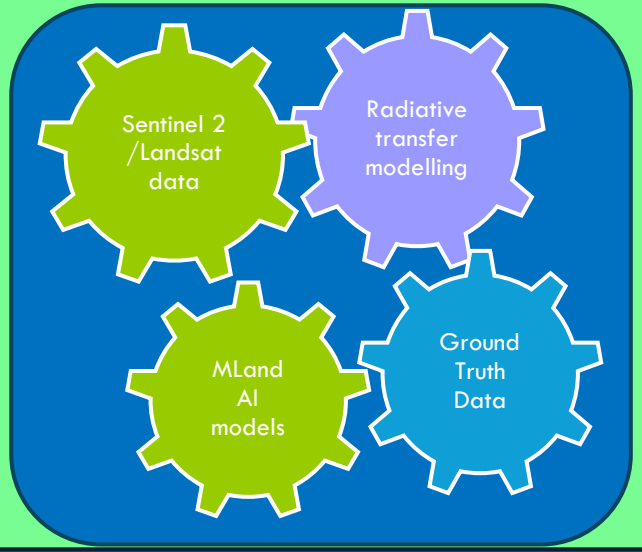
Measuring crop yield



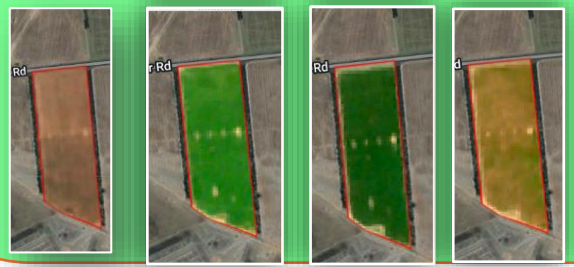
Science and Technology Facilities Council

EO4Agriclimate

EOCIS-CHUK products



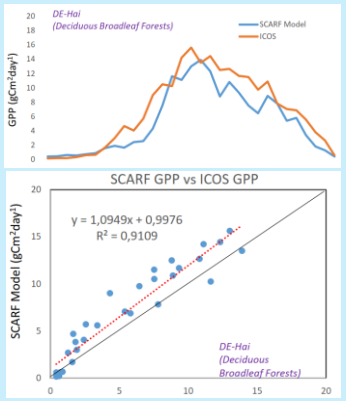
LAI,FAPAR, CCC at 100m every 2 weeks



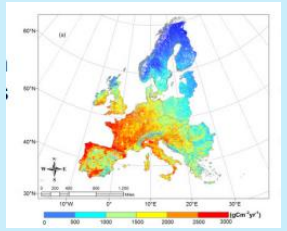
Science and Technology Facilities Council

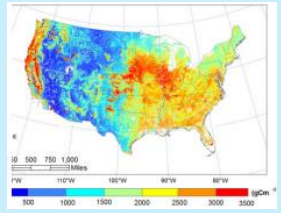
EARTH OBSERVATION CLIMATE INFORMATION SERVICE

Estimating carbon sequestration



$$SCARF\ GPP = PAR * FAPAR_{ps} * [PC_3 \alpha_3 f_{D3} \Psi_e + (1-PC_3)\alpha_4 f_{D4}]$$





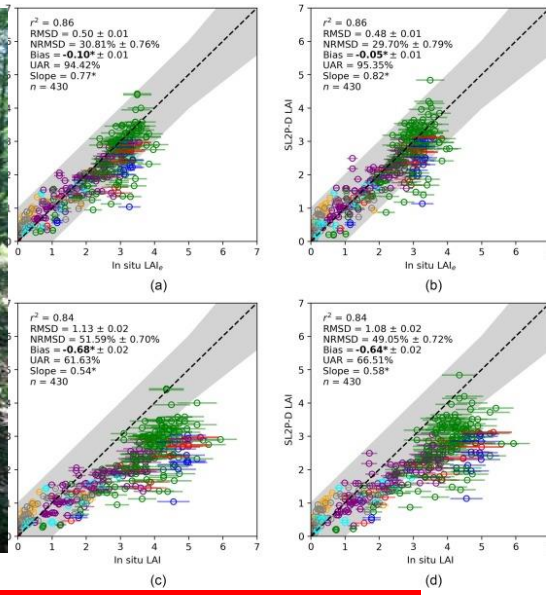
European Space Agency

Validation

Ground-Based Observations for Validation (GBOV)

First major project to provide independent data for quality assessment of Copernicus global land products

UoS Responsible for Vegetation products validation, provided more than 200 site years of data including instalation of permanent station.



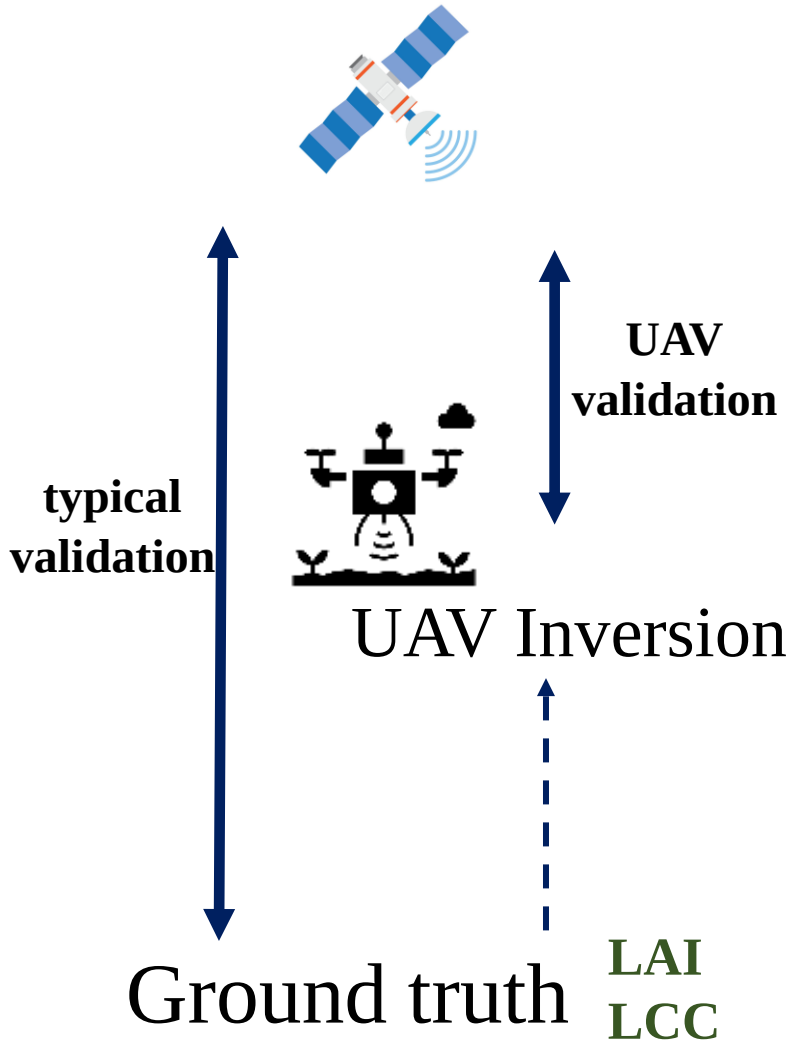
http://gbov.copernicus.acri.fr/

Gap in Upscalling

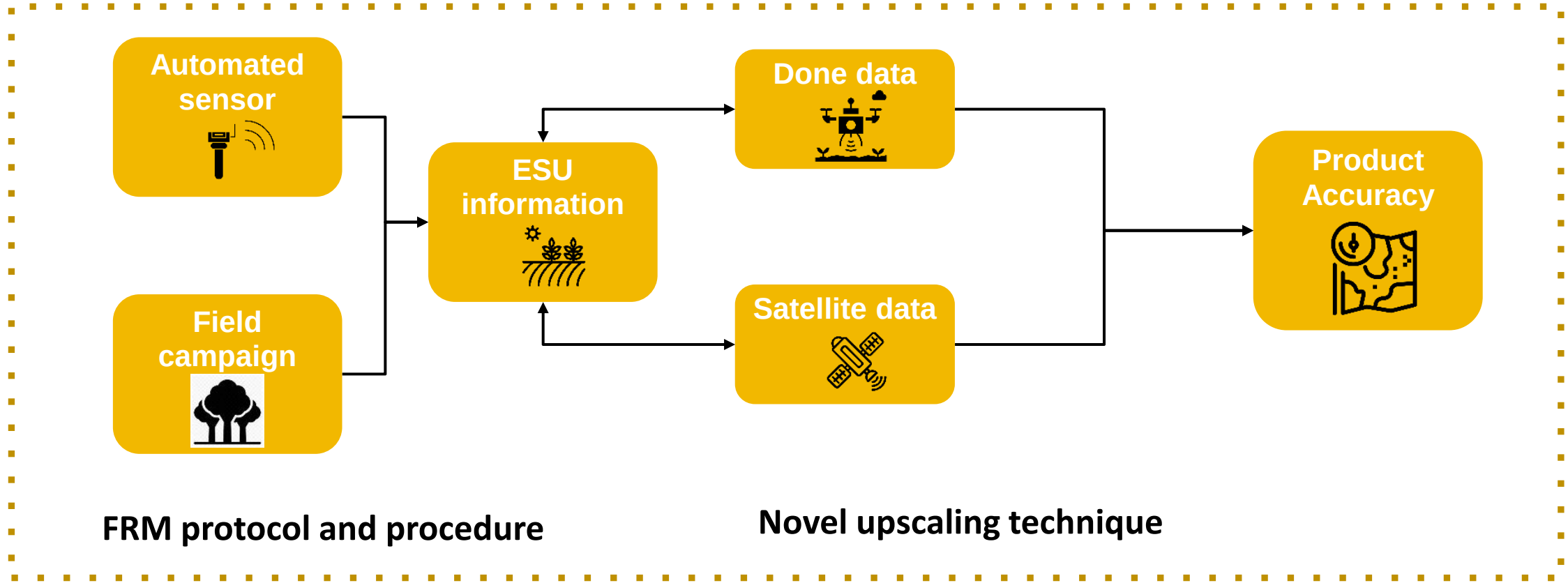
Brown, et al., (2020). Evaluation of global leaf area index and fraction of absorbed photosynthetically active radiation products over North America using Copernicus Ground Based Observations for Validation data. Remote Sensing of Environment, 247, 111935.

Objectives:UAV4VAL

- Evaluate the capability of UAVs as a source of reference data for validating decametric surface reflectance and vegetation products, (specific focus on Sentinel-2 and Gaofen-6)
- Achieved through collection, processing, and analysis of ground measurements over European and Chinese sites, coinciding with UAV acquisitions
- Transfer knowledge gained from existing ESA-funded projects on fiducial reference measurements (FRM), which focus on traceability and uncertainty evaluation in earth observation validation efforts



Objectives


Automated sensor
Field campaign
ESU information
Done data
Satellite data
Product Accuracy
FRM protocol and procedure
Novel upscaling technique

Project team

Dr Yongjun Zhang

Dr Jadu Dash

Dr Yan Gong

Dr Joanne Nightingale

Dr Gareth Roberts

Dr Booker Ogutu

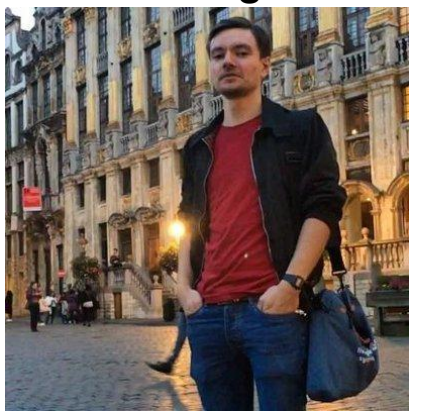
Dr Yansheng Li

Hu Tang

Niall Origo

Rosalinda Morrone

Xuerui Guo



Luke Brown

Harry Morris

University of Southampton

WUHAN UNIVERSITY 武漢大學

NPL National Physical Laboratory

Timeline

Protocols, procedures, training and calibration

Field Campaign in UK and China

Campaign data processing and delivery

Dissemination and outreach

ECR exchange and training

Year 1 | Year 2 | Year 3 | Year 4

Timeline

Initial field data collection

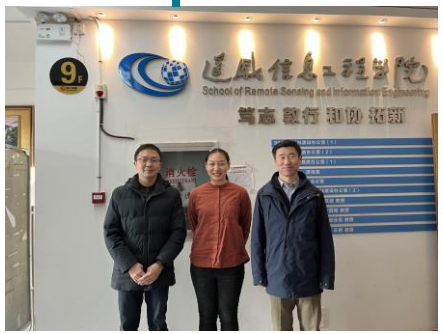
Further field data collection

2021 | 2022 | 2023 | 2024

KO meeting Dec 2020

Application of FRM protocol, training and exchange visit

Online



The in-situ data measurements and requirements

Campaign	Period	Parameters and equipment	Contribution
Taizi Mountain, China (112°48'E-113°03'E, 30°48'N-31°02'N)	31-10-2020 01-11-2020 02-06-2021	LAI-2200C for LAI collection ASD spectrometer for Spectral data collection DJI Phantom 4 for UAV images collection	Wuhan University
Luojia Square, China (114°21'E-114°22'E, 30°32'N-30°33'N)	19-12-2020	ASD spectrometer for Spectral data collection DJI Phantom 4 for UAV images collection	Wuhan University
Wytham Woods, UK (51.769265N, 1.329185W)	19-07-2022	SPAD for LCC collection Digital hemispherical photography(DHP)	University of Southampton, National Physical Laboratory (NPL)

Field data collection campaigns

Taizi Mountain Hubei Province, China

- Deciduous broadleaf forest (Oak and Maple)
- Designated a national park
- Validation of SPOT 6 and GaoFen2 at site
- > 35 remote sensing papers at site

Field data collection campaigns

Taizi Mountain Hubei Province, China

- Deciduous broadleaf forest (Oak and Maple)
- Designated a national park
- Validation of SPOT 6 and GF 2 at site
- > 35 remote sensing papers at site

ASD Fieldspec 4

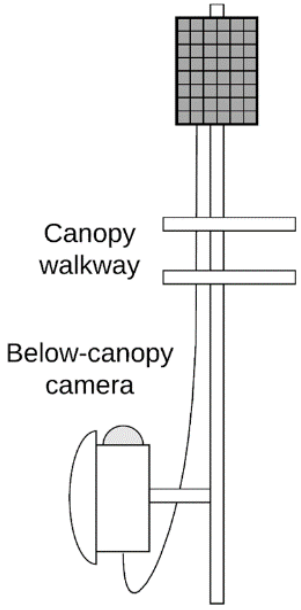
DJI Phantom 4

LAI-2200C

Field data collection campaigns

Wytham Woods, Oxford, UK

- Deciduous broadleaf forest (Oak, Ash, Beech, Hazel, Sycamore)
- Managed research forest with ~75 years of ecological monitoring
- Canopy walkway, Flux tower
- > 200 RS papers at site



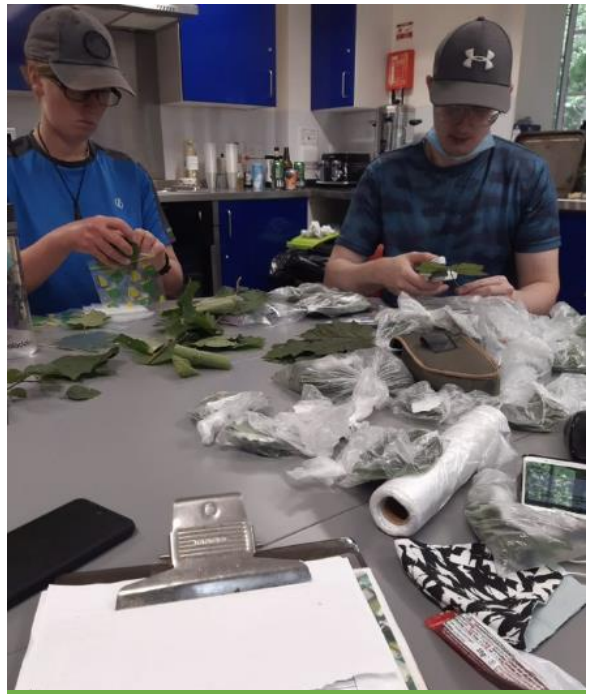
Field data collection campaigns

Wytham Woods, Oxford, UK

- leaf sampling and chlorophyll measure
- DHP measure
- CCC = LCC x LAI

Licor LAI-2200

Digital hemispherical photography

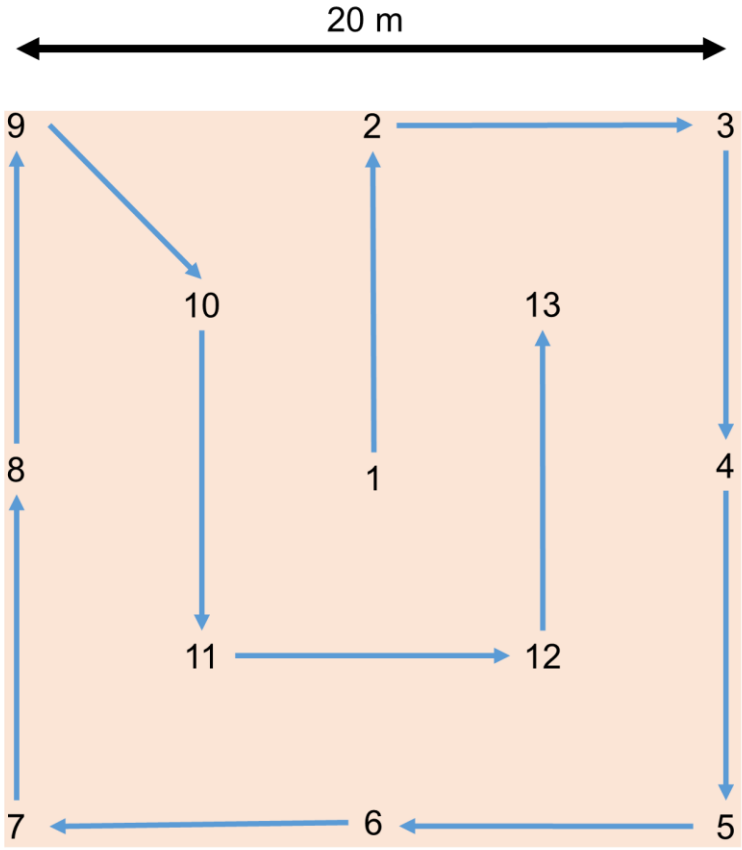


SPAD Chlorophyll meter

Field data collection campaigns

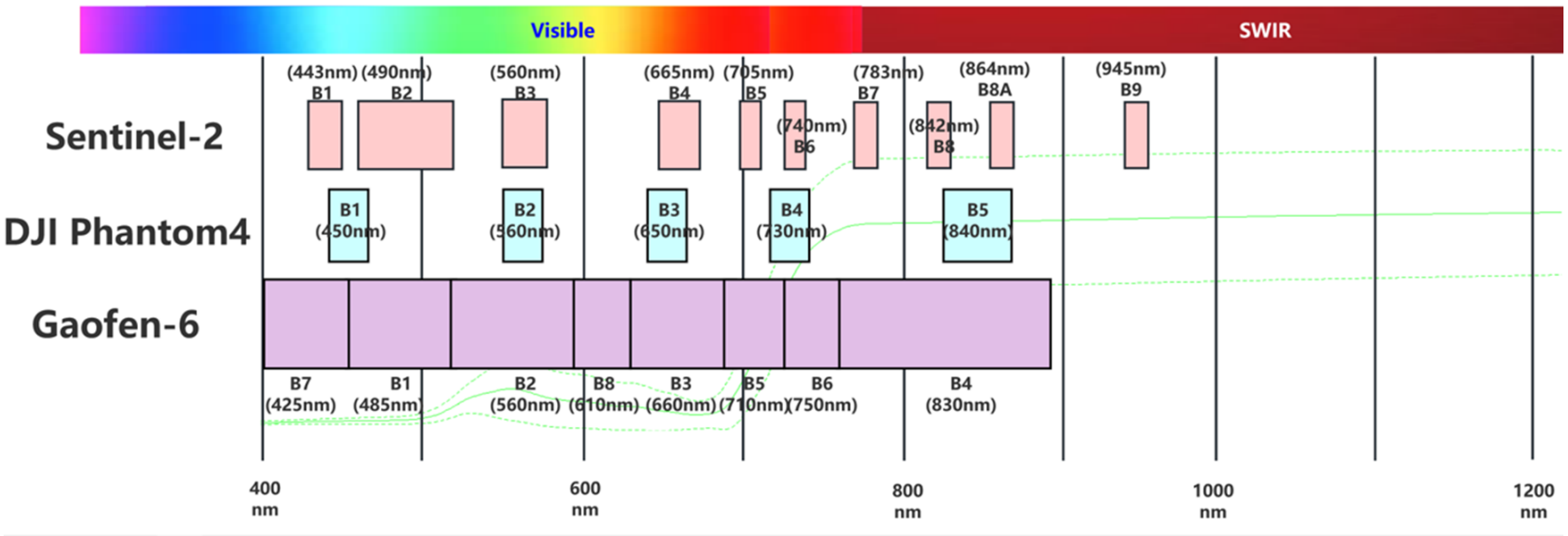
Wytham Woods, Oxford, UK

- **Sampling Strategy**
  - **20 – 30 ESUs sampled**
  - **Adapted from VALERI methodology**
  - **Understory and overstory sampled**
- **LAI**
  - **13 points/ESU**
- **LCC**
  - **3 leaves/point**
  - **6 replicates/leaf**



CEOS LPV protocol-> Training with the Chinese collaborators

Remote sensing datasets collection



Sensor	Band	Central Wavelength (nm)	Resolution(nm)
DJI Phantom 4	B1 (blue)	450	16
	B2 (green)	560	16
	B3 (red)	650	16
	B4 (red edge)	730	16
	B5 (near infrared)	840	26

Data	Collection method	Time
ASD data	ASD spectrometer	2021-06
LAI data	LAI-2200C	2021-06
UAV images	DJI Phantom 4	2021-06
Sentinel-2	EO	2021-06
Gaofen-6	EO	2021-06

Remote sensing datasets collection

Sensor	Band	Wavelength(nm)	Resolution(nm)
Gaofen-6 WFV	B1 (blue)	450 - 520	70
	B2 (green)	520-590	70
	B3 (red)	630-690	60
	B4 (near infrared)	770-890	120
	B5 (infrared 1)	690-730	40
	B6 (infrared 2)	730-770	40
	B7 (violet)	400-450	50
	B8 (yellow)	590-630	40

Sensor	Band	Central Wavelength(nm)	Resolution(nm)
Sentinel-2	B1 (aerosol)	443	20
	B2 (blue)	490	65
	B3 (green)	560	35
	B4 (red)	665	30
	B5 (red edge)	705	15
	B6	740	15
	B7	783	20
	B8 (near infrared)	842	115
	B8A	865	20

Method: Overview

Step 1	Step 2	Step 3	Step 4
Acquisition and processing of UAV imagery and in-suit biophysical measurements. Radiation calibration of UAV images.	LAI Inversion from UAV imagery through Vegetation Indices (VIs) regression model. Sentinel-2 retrieved LAI product from ESA SNAP software.	VIs sensitivity test on a Radiative Transfer Model (RTM)-simulated dataset. LAI inversion from Gaofen-6 dataset through RTM.	Sentinel-2 LAI product validated by the UAV based LAI product. Radiometric Correction Method on UAV images.

Method: LAI inversion from UAV imagery

Parametric regression through Vegetation indices(VIs)

Formulas of the four VIs and the evaluation metrics for LAI-VI relationship modelling

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}}$$

$$SAVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red} + 0.5} \times 1.5$$

$$ARVI = \frac{\rho_{NIR} - (2\rho_{Red} - \rho_{Blue})}{\rho_{NIR} + (2\rho_{Red} - \rho_{Blue})}$$

$$EVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + 6\rho_{Red} - 7.5\rho_{Blue} + 1} \times 2.5$$

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

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

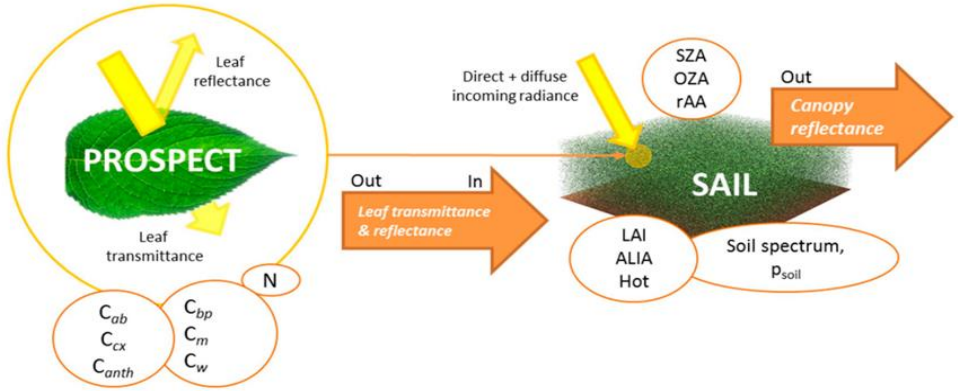
$$MAE = \sum_{i=1}^{n}\left|\frac{y_i - \hat{y}_i}{n}\right|$$

$$ME = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{y_i - \hat{y}_i}{y_i}\right) \times 100$$

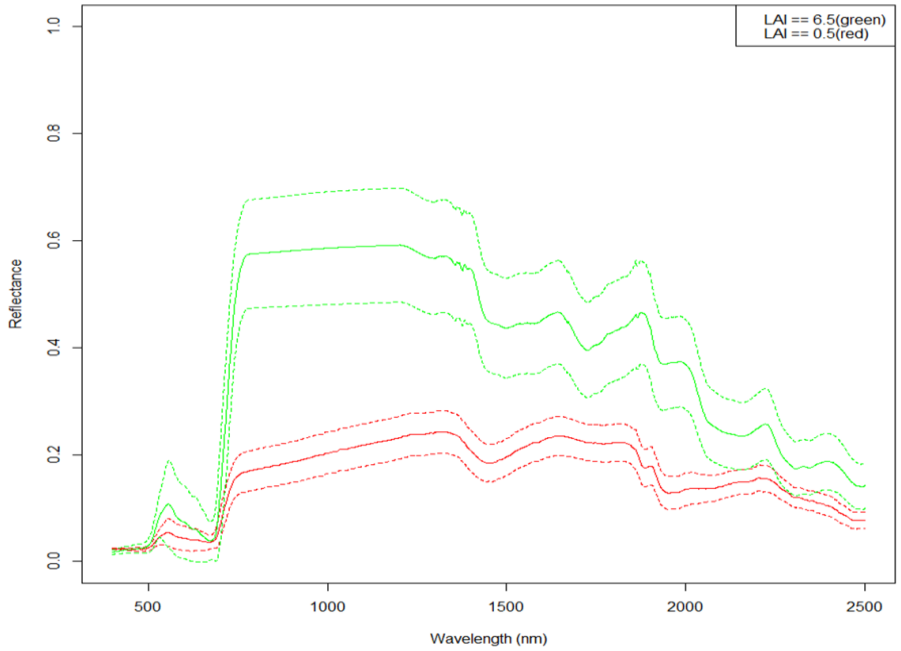
Method: LAI inversion from Gaofen-6 and Sentinel-2

PROSAIL model and machine learning model

- PROSPECT + SAIL model simulate the relationship between canopy reflectance and LAI.
- Machine learning ANN model for Sentinel-2 LAI land product generation through SNAP.
- Look Up Table (LUT) used for customized Gaofen-6 band setting



(source: *Berger et al., 2018*)



Method: LAI inversion from Gaofen-6 and Sentinel-2

Gaofen-6 LAI retrieval from Look Up Table (LUT) approach through PROSAIL

- Define value range and stepwise of each inputs for PROSAIL
- Forward operation with 2000 input combinations
- Find the best match between the simulated continuous spectrum range from 400m-2500m with the cost function.

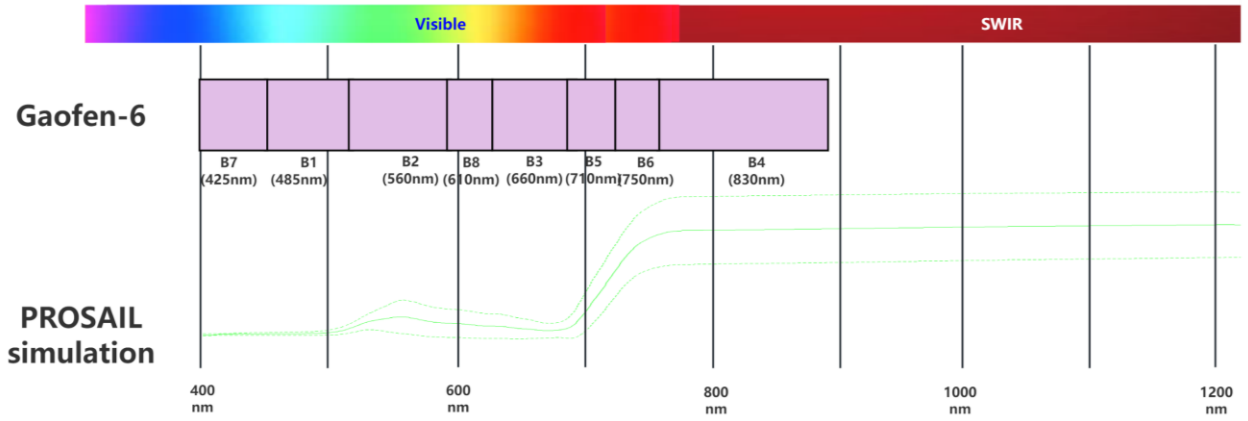


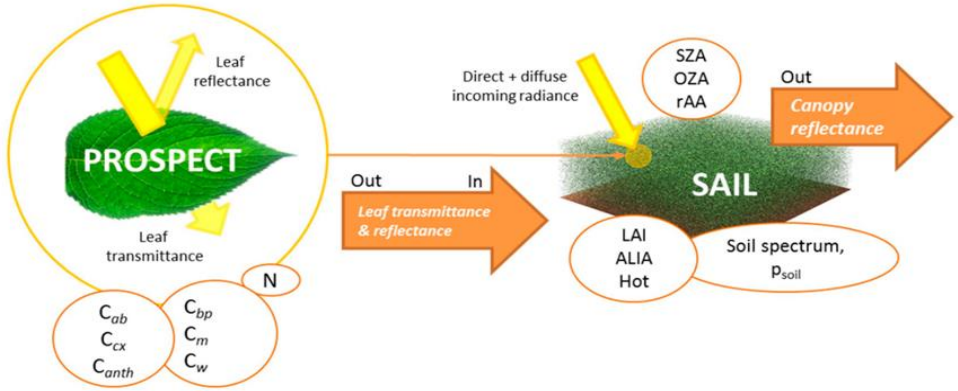
Table 3 PROSAIL input parameter ranges used in LUT generation.

Model	Symbol	Description	Value/range	Stepwise	Unit
PROSPECT	N	Leaf structure parameter	1.5-2.5	0.5	$Unitless$
	C_{a_b}	Chlorophyll $a+b$ content	0-80	5	$\mu\ g/cm^2$
	C_m	Dry matter content	0.012-0.03	0.003	$\mu g/cm^2$
	C_w	Dry matter content	0.03-0.05	0.01	$\mu g/cm^2$
SAIL	LAI	Leaf area index	0-8	0.5	m^2/m^2
	ρ_s	Soil reflectance	0.5	-	$Unitless$
	S_L	Hot spot parameter	0.33	-	$Unitless$
	θ_s	Solar zenith angle	36	-	deg
	θ_v	Viewing zenith angle	0	-	deg

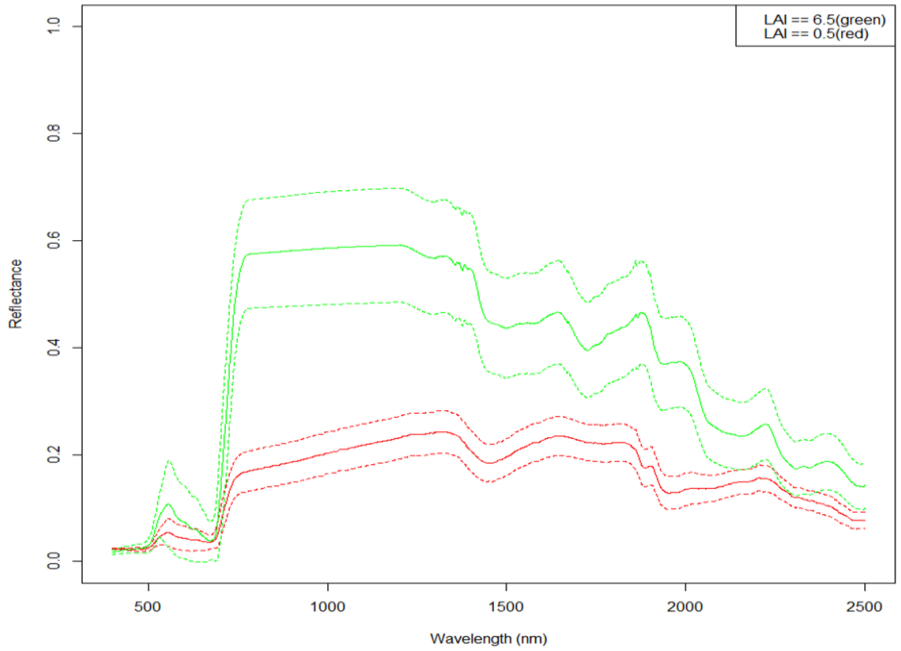
Method: LAI inversion from UAV through PROSAIL

PROSAIL model and machine learning model

- **PROSPECT + SAIL model simulate the relationship between canopy reflectance and LAI.**
- **Machine learning ANN model for Sentinel-2 LAI land product generation through SNAP.**
- **Look Up Table (LUT) used for customized Gaofen-6 band setting**



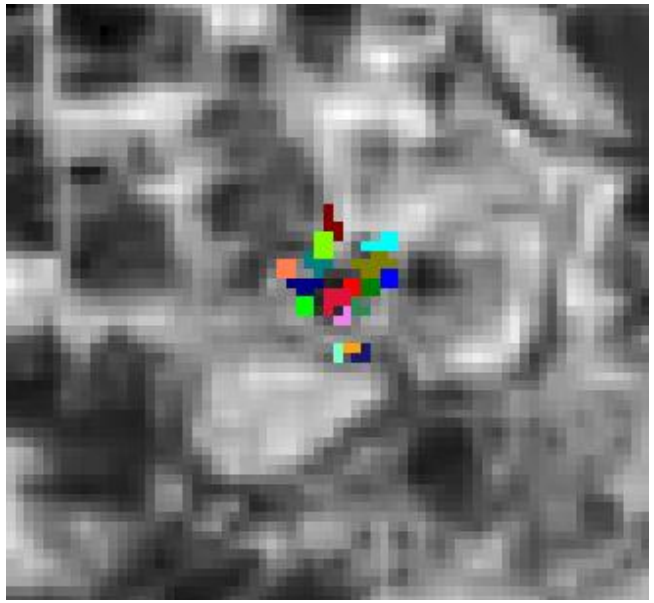
(source: Berger et al., 2018)

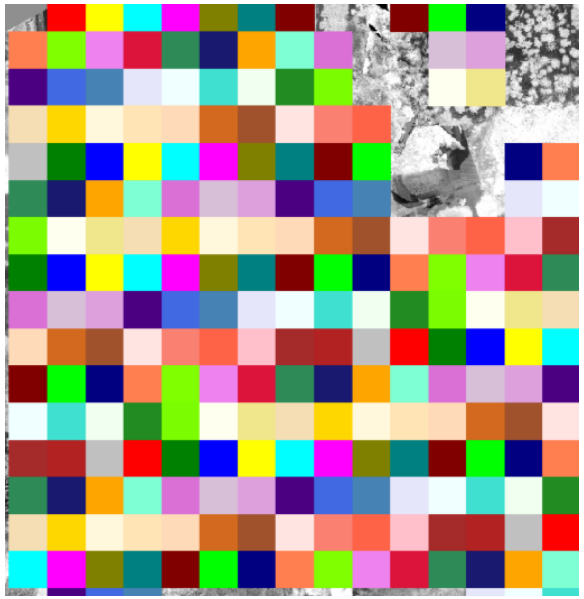


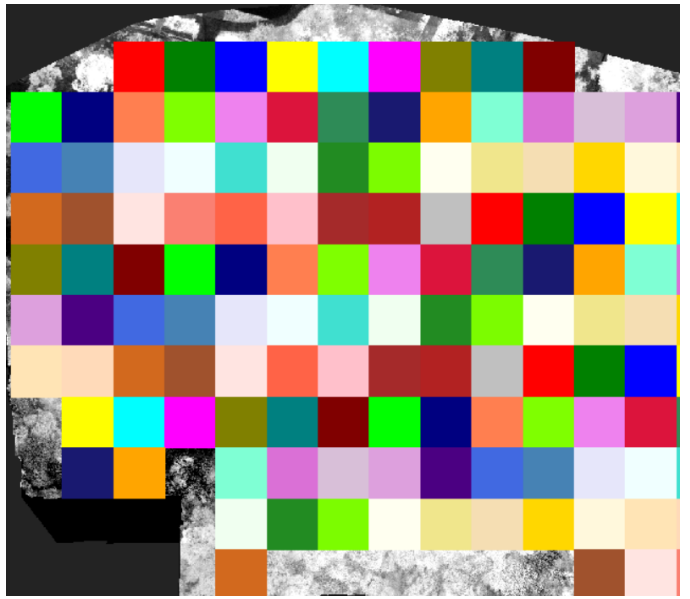
Method: Validation and comparison

Satellite LAI validation using Ground-measures and UAV data

- For ground-measured data (P1)
  - 10 m *10 m Sentinel-2 and 16 m * 16 m Gaofen-6 pixel contained the ground measurements
- For UAV data (P2 & P3)
  - Resampled to Sentinel-2 andGaofen-6 spatial resolutions

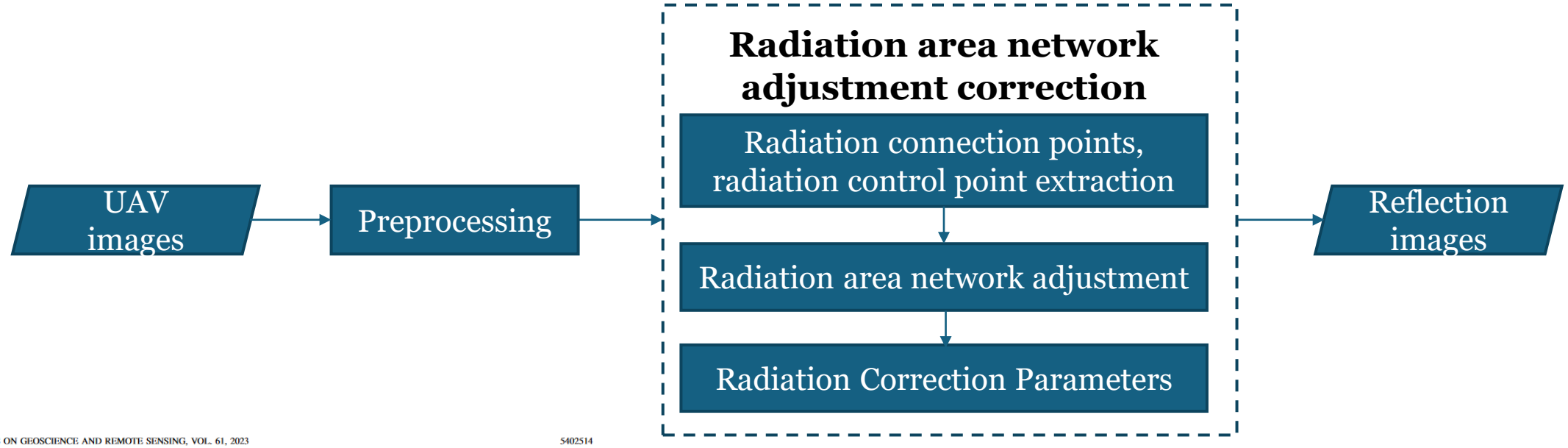






Method: Radiation calibration of UAV images

A Radiometric Correction Method Based on Block Adjustment



IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 61, 2023 5402514

A Radiometric Block Adjustment Method for Unmanned Aerial Vehicle Images Considering the Image Vignetting

Wanshan Peng, Yan Gong, Shenghui Fang, Yongjun Zhang, *Member, IEEE*, Jadunandan Dash, Jie Ren, and Jiacai Mo

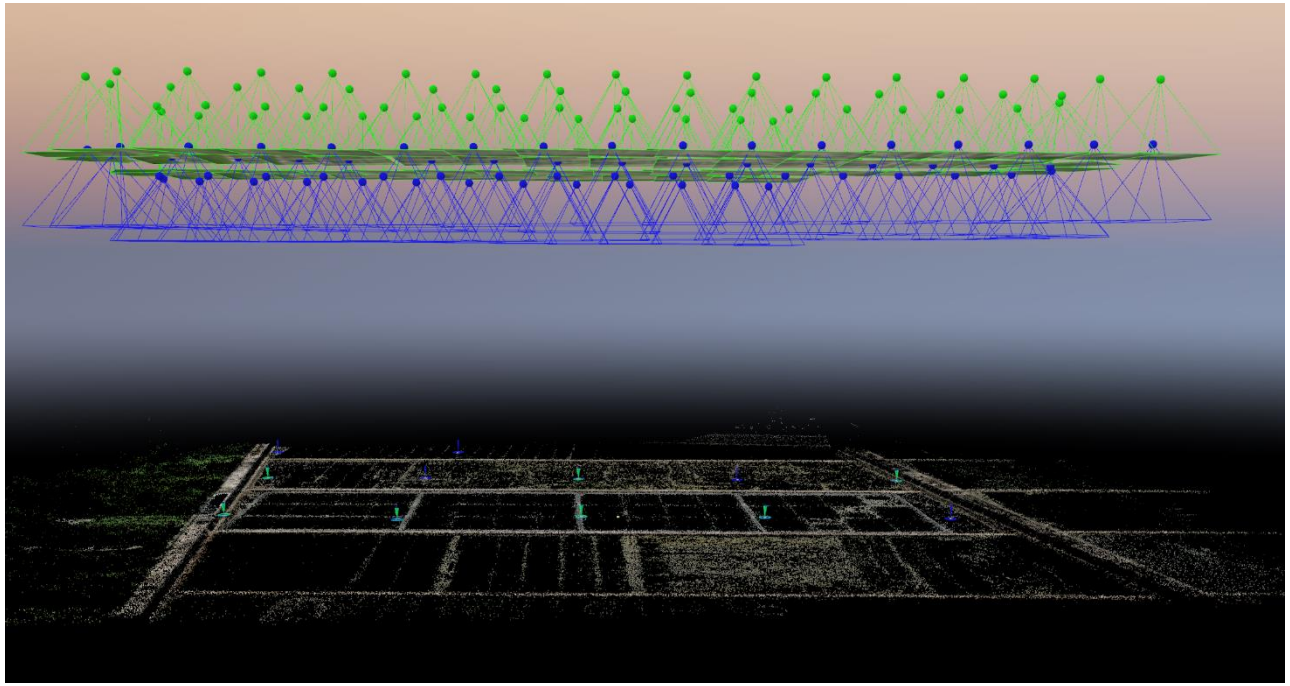
https://doi.org/10.1109/TGRS.2023.3268036

Method: Radiation calibration of UAV images

A Radiometric Correction Method Based on Block Adjustment

- **The reflectivity of adjacent images overlapping parts are the same.**
- **This feature can be used to perform radiation area network adjustment.**
- **Adjustment of light and dark differences between images**

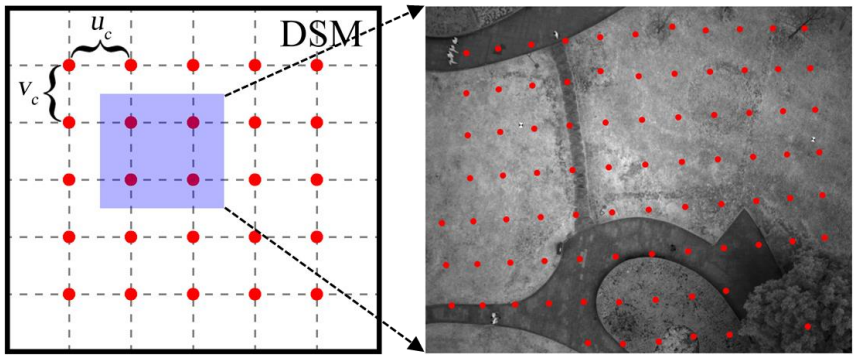
Radiometric differences between adjacent images



Method: Radiation calibration of UAV images

A Radiometric Correction Method Based on Block Adjustment

- **Conversion relationship between DN value and reflectance ρ**
- **Extraction of radial tie points**
- **Generation of stitched reflectance images**



(a) (b)

Fig. 2. Examples of (a) selection of RTPs from DSM. The parameters u_c and v_c are the intervals determined by the UAV image size and (b) distribution of RTPs on a UAV image. The red dots are the selected RTPs.

DIJ Phantom4 Conversion functions

Bands	Linear Function		Power function	
		R^2		R^2
B	ρ=4.588e-06·DN-0.061	0.9767	ρ=1.617e-09·$DN^{1.702}$	0.9985
G	ρ=5.114e-06·DN-0.059	0.9874	ρ=4.706e-09·$DN^{1.621}$	0.9998
R	ρ=5.256e-06·DN-0.052	0.9925	ρ=1.370e-08·$DN^{1.529}$	0.9999
RE	ρ=9.047e-06·DN-0.076	0.9962	ρ=4.265e-09·$DN^{1.708}$	0.9983
NIR	ρ=1.371e-05·DN-0.100	0.9985	ρ=1.472e-09·$DN^{1.871}$	0.9948

Method: Radiometric calibration of UAV images

Radial Area Network Adjustment Algorithm

Reflectivity is an intrinsic property of ground objects. After radiometric correction, the reflectivity of the same ground object should be the same.

Vignetting correction

$$V(u,v) = p_1(u-u_0)^2 + p_2(v-v_0)^2 + 1 = p_1u^2 + p_2v^2 + p_3u + p_4v + p_5$$

Radiation area network adjustment

$$V(u,v)DN_{ij} = a_i b\rho^{a}_{RTP,j} + b_i$$

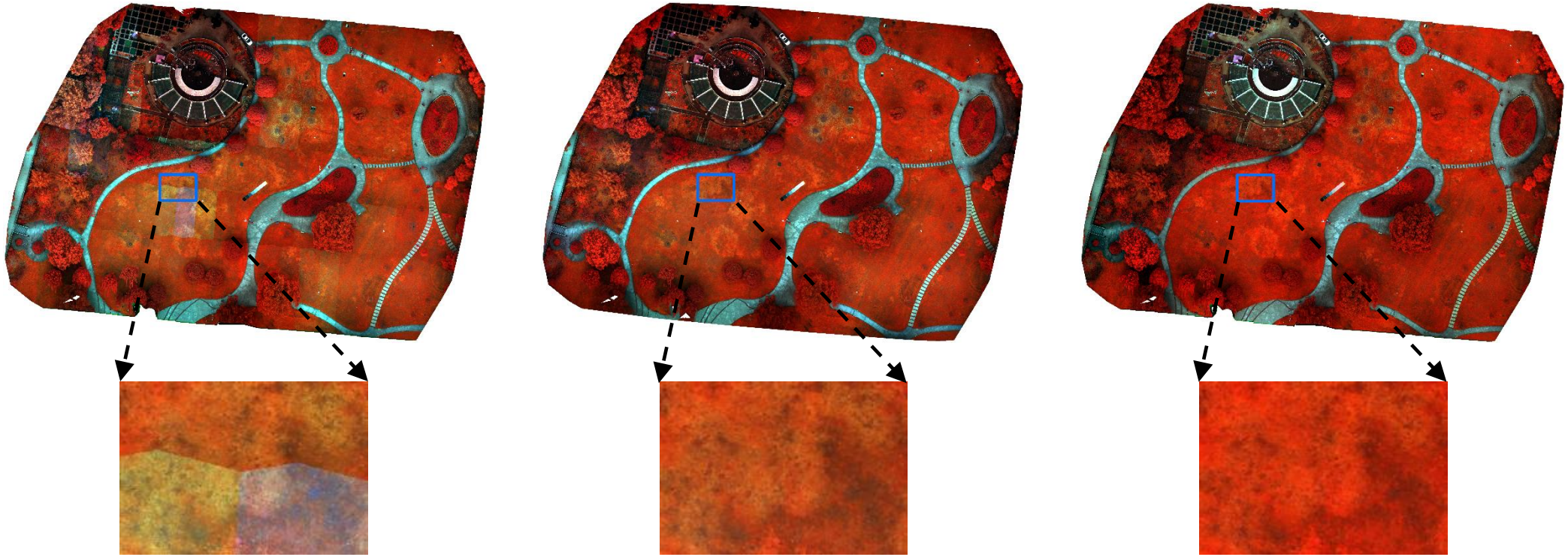
$$V(u,v)DN_{ij} = a_i(a\rho_{RTP,j} + b) + b_i$$

DN_{ij}	**DN value of radiation connection point j on image i**
$\rho_{RTP,j}$	**Reflectivity of radiation connection point j**
a, b	**Absolute correction parameters**
a_i, b_i	**Relative correction parameters**

Result: Radiation calibration of UAV images

Visual radiation calibration results from four different methods

Luojia Square



Direct Mosaic

Color Balancing

RBA

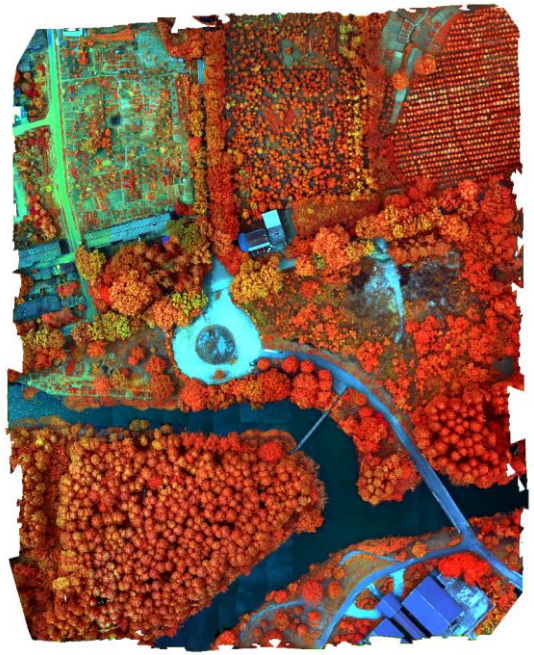
Result: Radiation calibration of UAV images

Visual radiation calibration results from four different methods

Taizi Mountain

Direct Mosaic

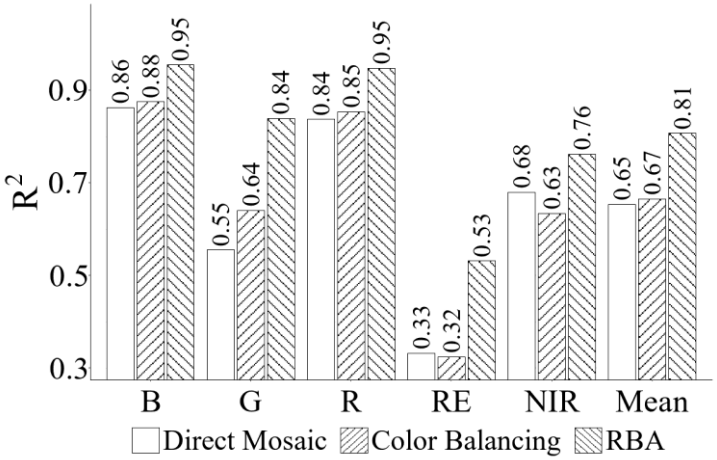
Color Balancing

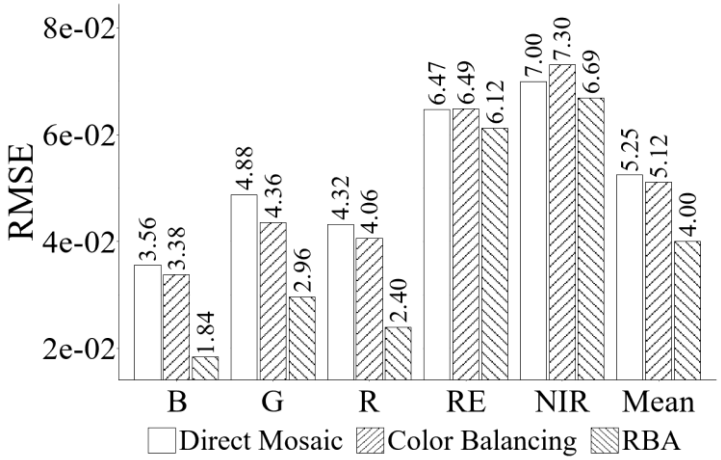


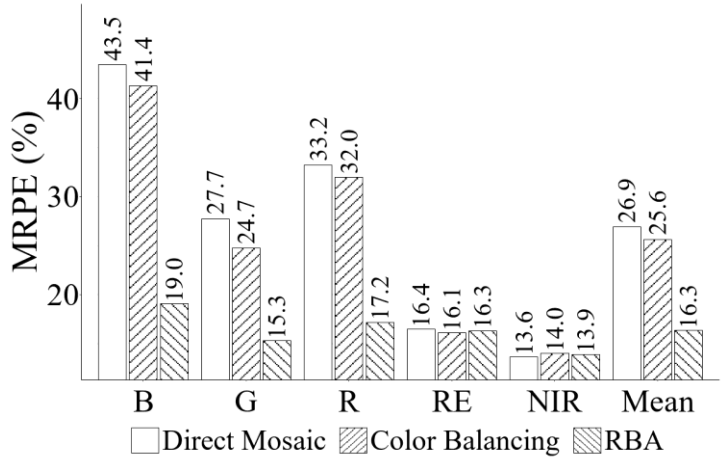
RBA

Result: Radiation calibration of UAV images

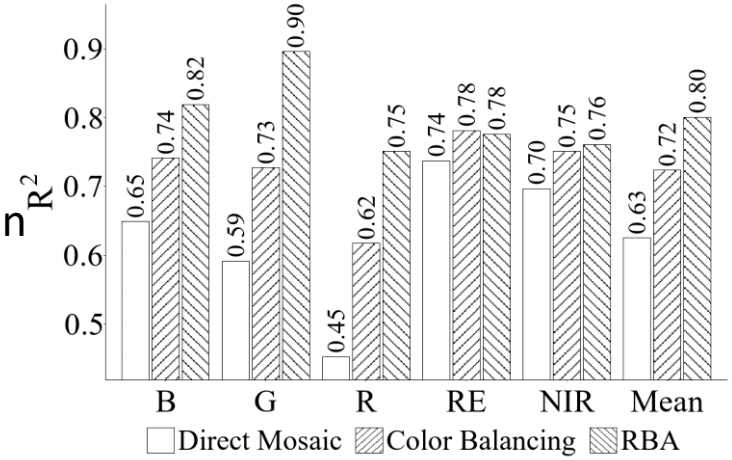
Luojia Square

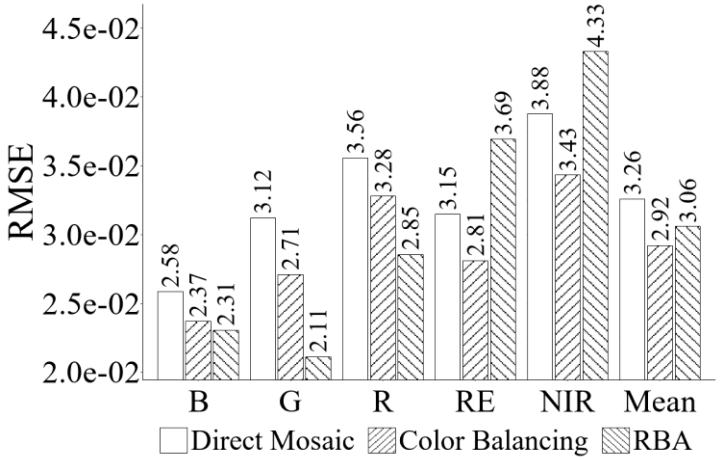


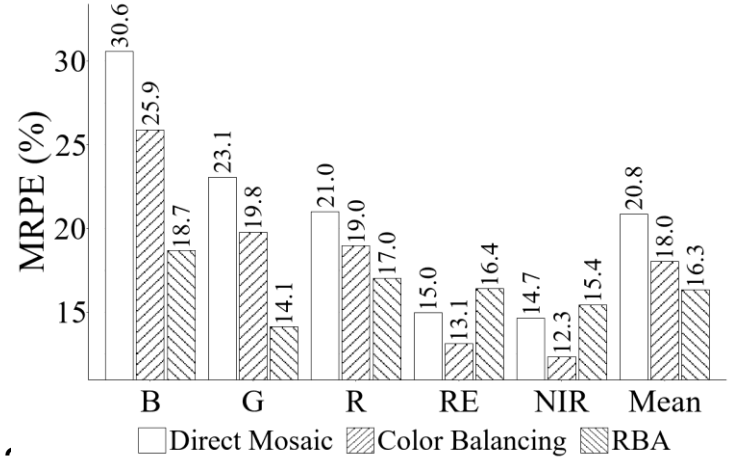




Taizi Mountain



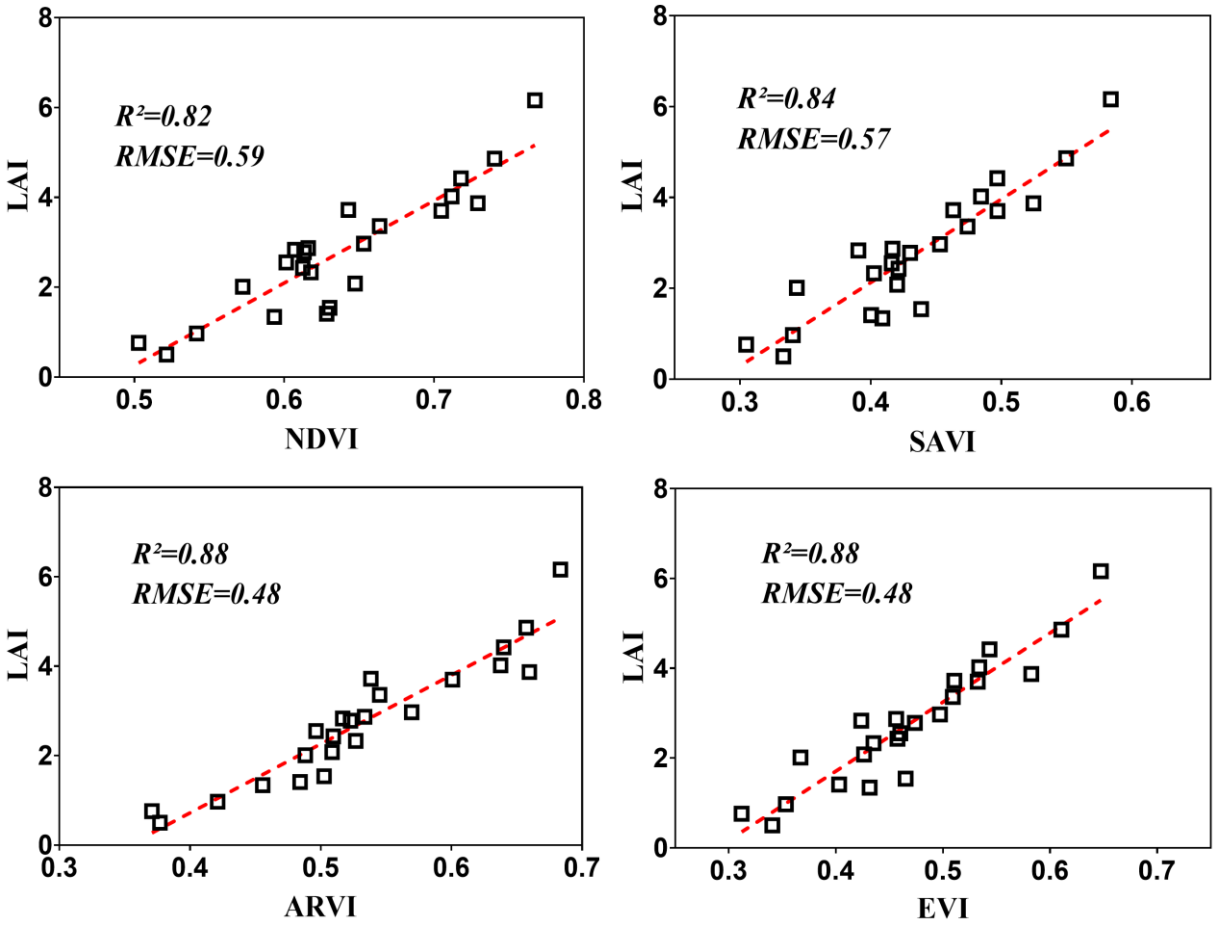




Result: LAI inversion from UAV imagery

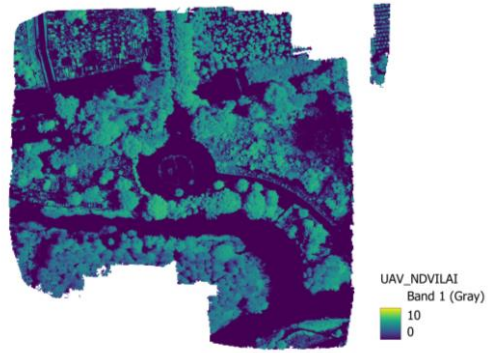
- All R^2 >0.8
- The correlation between LAI and VI is good
- ARVI and EVI perform well

VI	Model Evaluation Metrics		Accuracy evaluation index		
	R^2	RMSE	MAE	ME	RMSE
NDVI	0.8242	0.5985	0.59	0.43	0.65
SAVI	0.8401	0.5706	0.51	0.28	0.63
ARVI	0.8869	0.4801	0.54	0.35	0.57
EVI	0.8798	0.4947	0.48	0.24	0.59

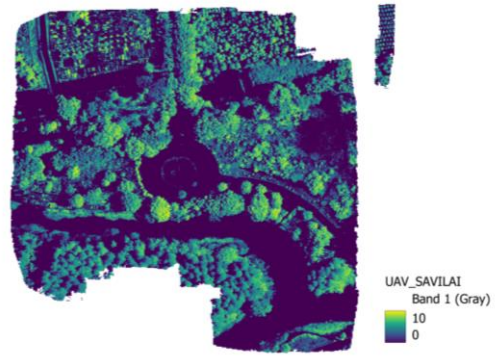


Result: LAI inversion from UAV imagery

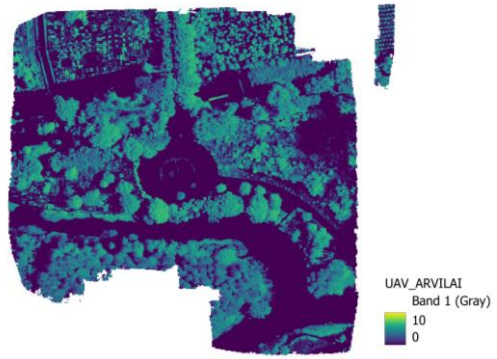
LAI estimate from VIs regression at Taizi Mountain



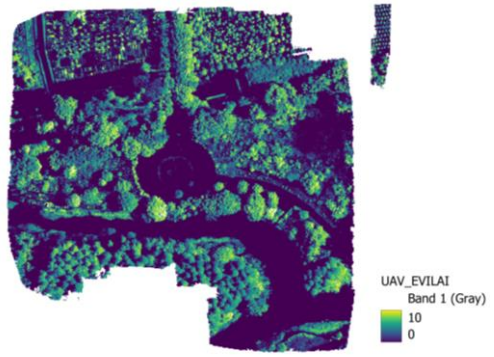
NDVI-LAI



SAVI-LAI



ARVI-LAI

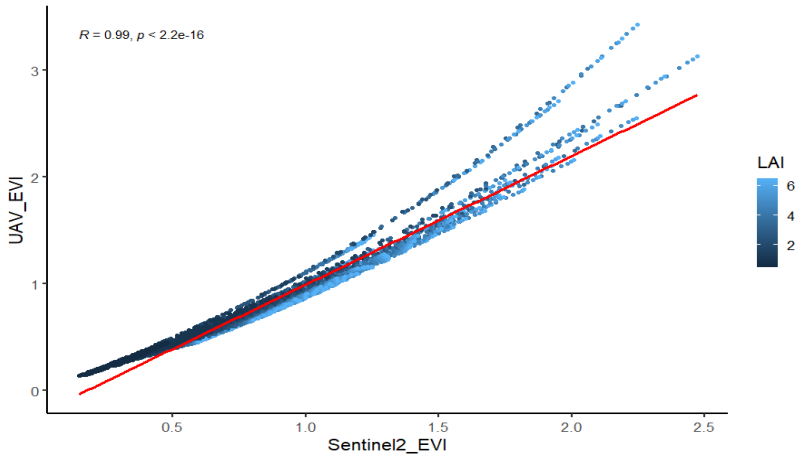


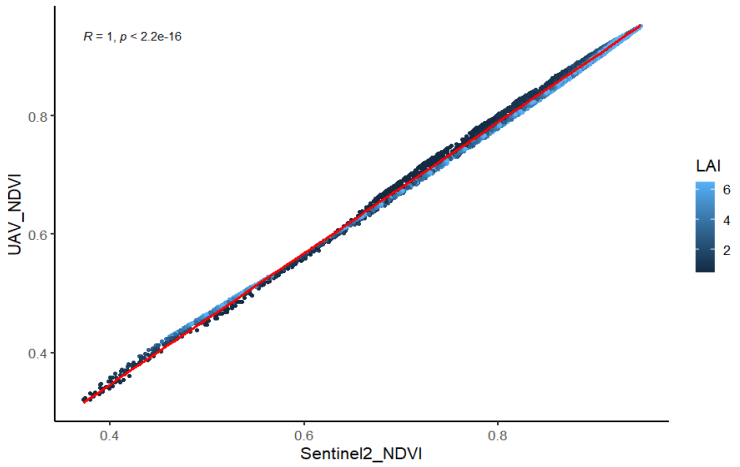
EVI-LAI

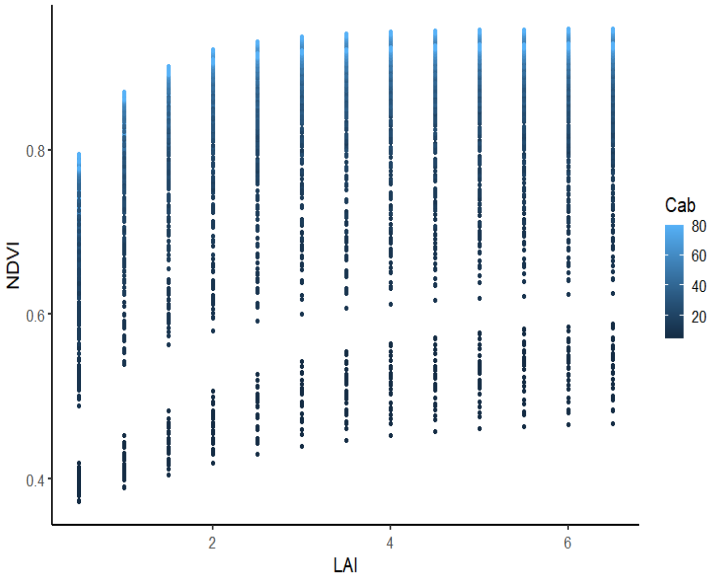
Result: VI sensitivity test

VI sensitivity test from PROSAIL simulations

- VI-LAI relationships are stable for both UAV and Sentinel-2 band settings.
- The large EVI bias was found for dense vegetation.

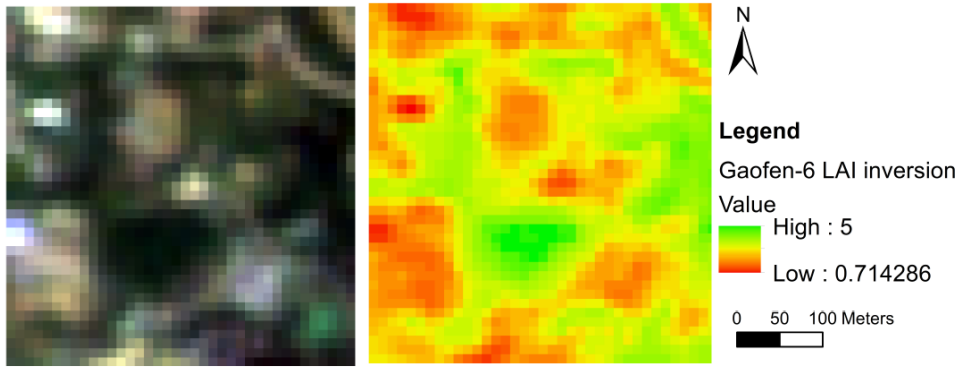


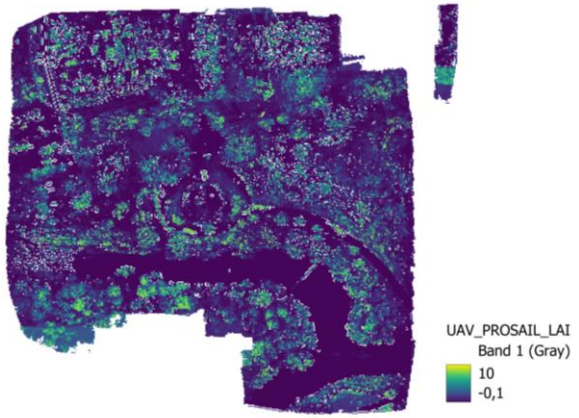


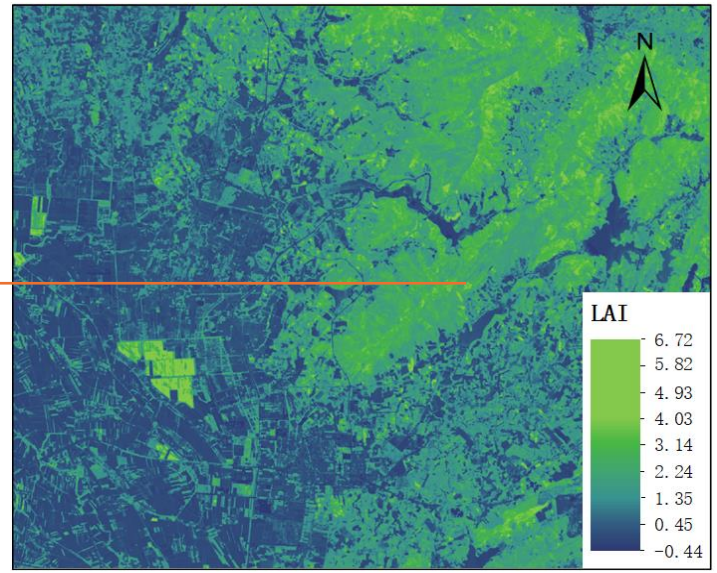


Result: LAI inversion from PROSAIL model

LAI retrieval from PROSAIL model for GF-6 ,UAV, and Sentinel-2 at Taizi Mountain

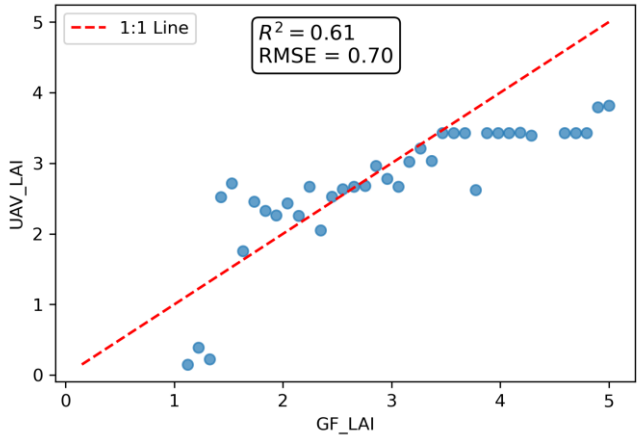


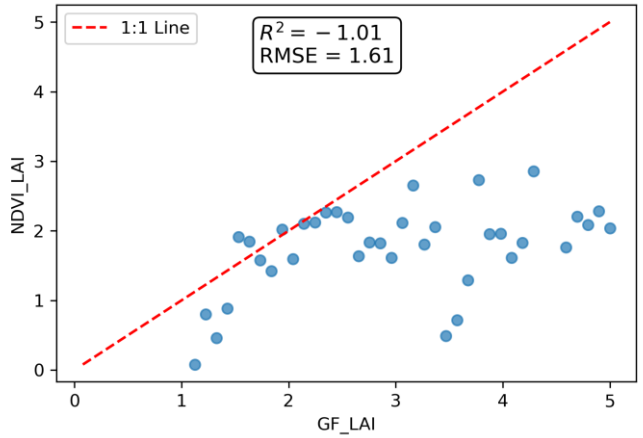


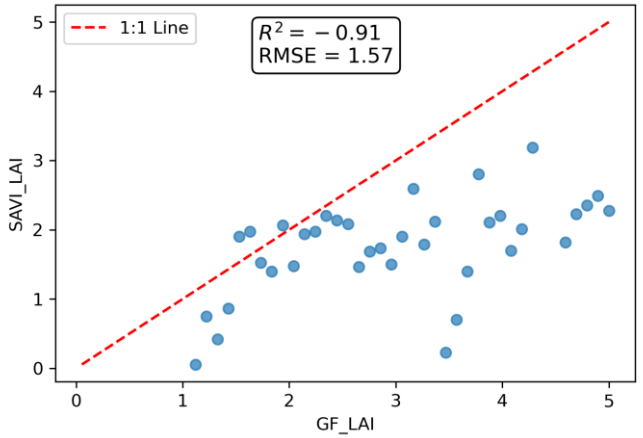


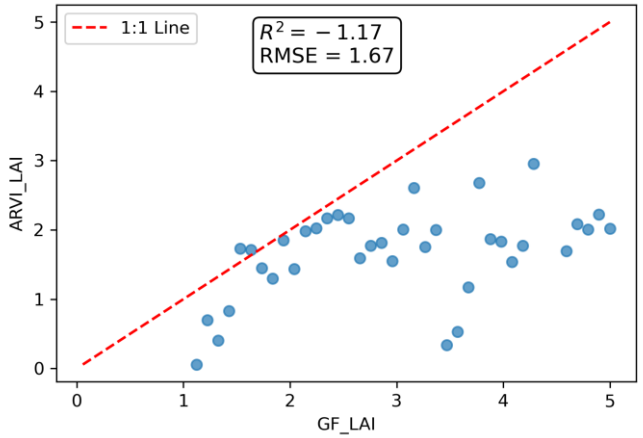
Result : validation and comparison

- **PROSAIL-based inversion perform better than VI-based estimation**
- **Compare with the GF-LAI from UAV, the VI-based estimation has general underestimation**





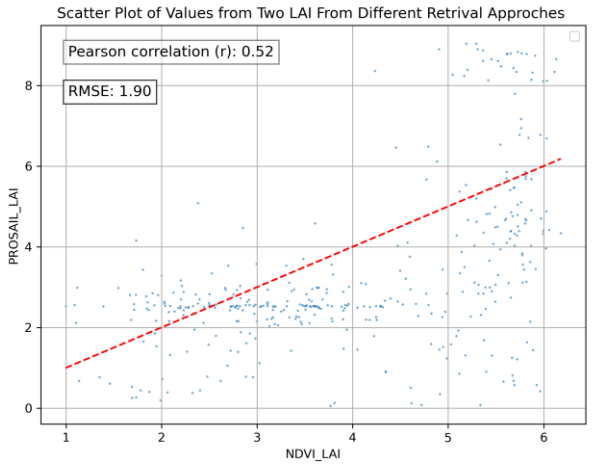


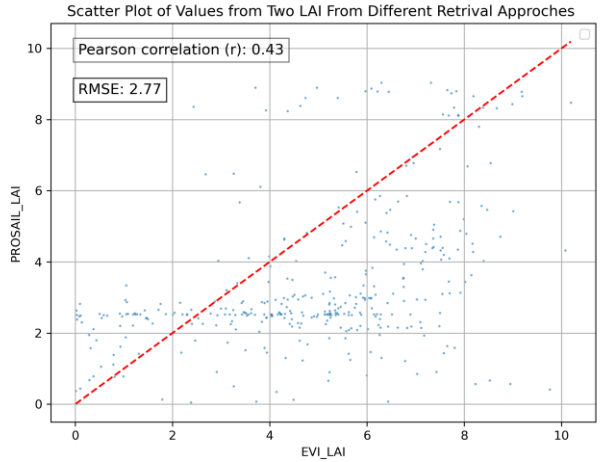


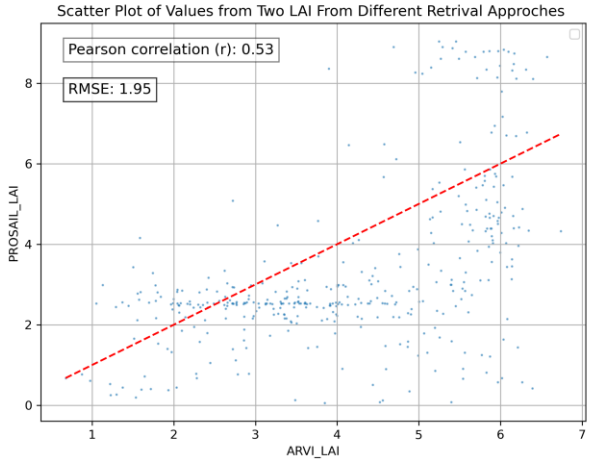
Result : validation and comparison

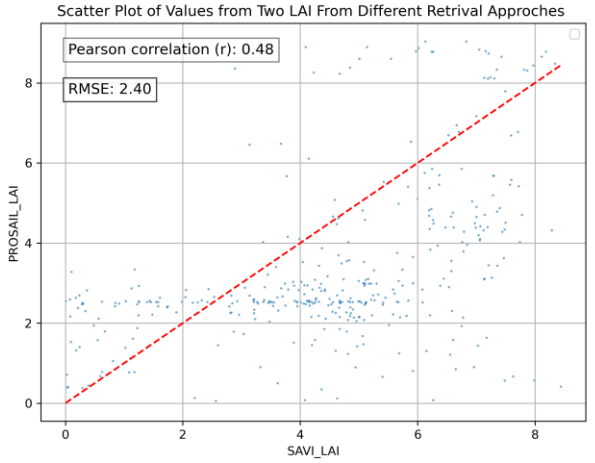
Pure vegetation site comparison between different retrieval methods

- Moderate positive correlation between PROSAIL-LAI and the best performed ARVI-LAI
- The shadows of the dense forest might influence the RTM-based LAI retrieval









Result: Validation and comparison

- **UAV outperform Ground measurements in validating Satellite LAI maps**
- **Compared to Sentinel-2, larger metrics values were found for the Gaofen-6 LAI retrievals**

Direct ground measurements against four UAV VI-based LAI validation for Sentinel-2 LAI retrievals

Validation method	MAE	ME	RMSE
LAI samples based on ground truth	0.80	0.85	1.02
UAV LAI maps generated based on NDVI	0.50	0.55	0.59
UAV LAI maps generated based on SAVI	0.48	0.73	0.58
UAV LAI maps generated based on ARVI	0.48	0.55	0.58
UAV LAI maps generated based on EVI	0.47	0.67	0.56

Direct ground measurements against four UAV VI-based LAI validation for Gaofen-6 LAI retrievals.

Validation method	MAE	RMSE
LAI samples based on ground truth	1.08	1.58
UAV LAI maps generated based on NDVI	0.60	0.77
UAV LAI maps generated based on SAVI	0.70	0.89
UAV LAI maps generated based on ARVI	0.59	0.76
UAV LAI maps generated based on EVI	0.71	0.91

Dragon 5 EO Data Delivery

Data access (list all missions and issues if any). NB. in the tables please insert cumulative figures (since July 2020) for no. of scenes of high bit rate data (e.g. S1 100 scenes). If data delivery is low bit rate by ftp, insert “ftp”

ESA /Copernicus Missions	No. Scenes
1. **Sentinel2 MSI**	10
2.	
3.	
4.	
5.	
6.	
Total:	
Issues:	

ESA Third Party Missions	No. Scenes
1.	
2.	
3.	
4.	
5.	
6.	
Total:	
Issues:	

Chinese EO data	No. Scenes
1. **Gaofen-6**	4
2.	
3.	
4.	
5.	
6.	
Total:	
Issues:	

European Young Scientists contributions in Dragon 5

Name	Institution	Poster title	Contribution including period of research
Xuerui Guo	University of Southampton	Vegetation Index Sensitivity Test Based on PROSPECT+SAIL Model – a Preliminary Test Under the UAV4VAL Project	data collection and data processing paper writing
Harry Morris	University of Southampton	Using A Wireless Quantum Sensor Network To Monitor The Temporal Dynamics Of Vegetation Biophysical Parameters In A Mediterranean Vineyard	data collection and data processing paper writing

Chinese Young Scientists contributions in Dragon 5

Name	Institution	Poster title	Contribution including period of research
Tang Hu	Wuhan University	Exploiting UAS for validating Sentinel-2 LAI map and inverting Gaofen-6 LAI map	data collection and data processing model establishment, data analysis, paper writing
Yang Kaili	Wuhan University	Remote estimation of leaf area index (LAI) with unmanned aerial vehicle (UAV) imaging for different rice cultivars throughout the entire growing season	data collection and data processing paper writing
Zhou Cong	Wuhan University	Combining spectral and wavelet texture features for unmanned aerial vehicles remote estimation of rice leaf area index	data collection and data processing paper writing
Yuan Ningge	Wuhan University	UAV Remote Sensing Estimation of Rice Yield Based on Adaptive Spectral Endmembers and Bilinear Mixing Model	data collection and data processing paper writing
Peng Wanshan	Wuhan University	A radiometric block adjustment method for unmanned aerial vehicle images considering the image vignetting	data collection and data processing paper writing

Dragon 5 List of Peer Reviewed Publications

Report on the peer reviewed publications (publication title, journal name and DOI) after 4 years of activity

Publication Title	Journal	DOI
Remote estimation of leaf area index (LAI) with unmanned aerial vehicle (UAV) imaging for different rice cultivars throughout the entire growing season	Plant Methods	https://doi.org/10.1186/s13007-021-00789-4
Exploiting UAS for validating Sentinel-2 LAI map and inverting Gaofen-6 LAI map		
A Radiometric Block Adjustment Method for Unmanned Aerial Vehicle Images Considering the Image Vignetting	IEEE Transactions on Geoscience and Remote Sensing	https://doi.org/10.1109/TGRS.2023.3268036

Conclusions

- The project developed a strong collaboration between Chinese and UK group with commentary skills.
- Organised 4 field campaign to adapt some CEOS LPV.
- Demonstrated the suitability of UAV data for upscaling and validating decametric vegetation products
- Develop new methods for radiometric adjustment of UAV image (relevant to SRIX4VEG)
- Future opportunity: Apply FRM concepts to UAV based validation, collocated field and satellite data collection, establishment of regular/periodic campaigns

Q&A

Thank you
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