Novel Advances in Cal/Val at the Mer Bleue Supersite

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Collaborators

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- Dr. Maximilian Brell (GFZ)
- Chris Durell (Labsphere)
- Dr. Trond Løke (NEO HySpex)
- Dr. Daniel Lavigne (DRDC-Valcaltier)

Objective

- To present advances of the UAV Hyperspectral research implemented at Mer Bleue for satellite multi and hyperspectral Cal/Val applications (2021-2024).

Timeline Satellite Cal/Val

MBASS

- Interest in satellite-based RS of peatlands - highly affected by climate change (Canada and Europe).
- S2/L8 Data Product Validation Project.
- In 2018 Mer Bleue was designated a CEOS Land Product Validation Supersite for Cal/Val activities.

2016-218

UAV Cal/Val

- First attempt to implement UAV-HSI, and airborne for S2 validation at Mer Bleue.
- Not 100% successful but assessed multispectral system.
- Need to improve UAV-HSI system for cal/val.

2021

SRIX4VEG

- Deployment of UAV-HSI to Las Tiesas, Spain - FRM4VEG Project.
- Full range HSI, best practices, and unique experimental design for the validation of S2 reflectance products.
- Uncertainty methodology implemented in colab. with NPL (peer-reviewed publication ongoing)

2022

LAAHyS & SPARC

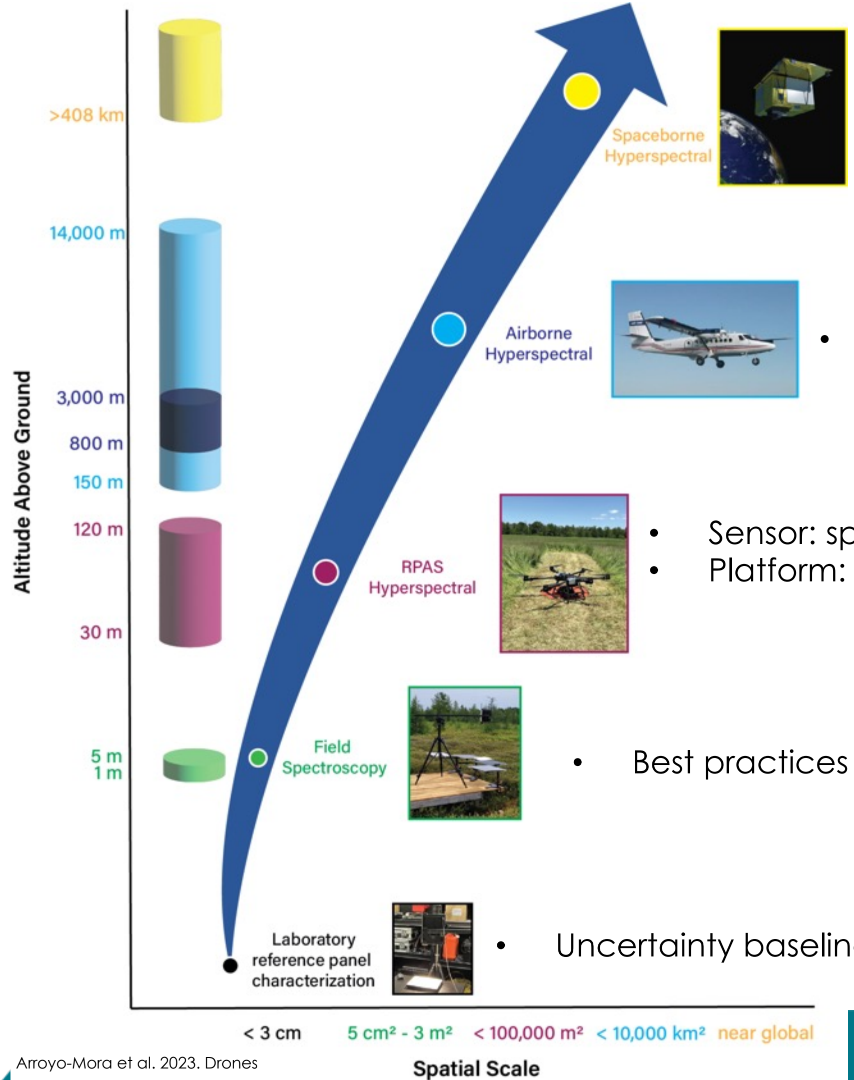
- Development of Low Altitude Advanced Hyperspectral System (NRC internal funding).
- Mer Bleue SPARC Labsphere experiment.
- Support from DRDC-Valcartier with VS-620 instrument.
- Extended to EnMAP validation over Mer Bleue.

2023

QA4EO

serco

esa



Arroyo-Mora et al. 2023. Drones

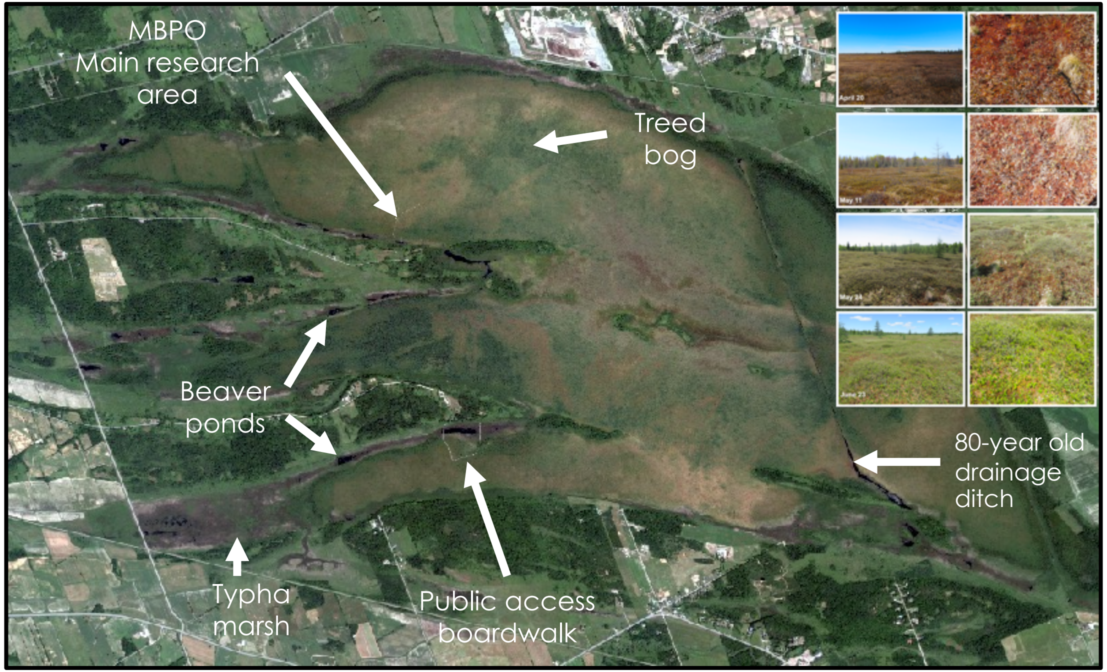
- Fiducial Reference Measurements – traceability, uncertainty budget, protocols, etc.
- Same as RPAS HSI.
- Sensor: spectral uniformity and stability, calibration, good SNR, transparency.
- Platform: safety, stability, reliability, quality.
- Best practices for low error measurements
- Uncertainty baseline

Bottom-up Approach: Satellite products validation.

NRC·CNRC

Mer Bleue Conservation Area

- Highly dynamic complex ombrotrophic peatland(rain fed) – Phenology.
- Ramsar Site.
- Representative of northern boreal peatlands
- 35 km^2 area suitable for multispectral (Sentinel-2/Landsat) and hyperspectral spaceborne validation
- Proximity to NRC aircraft home base (13 km) and ground support teams
- Mer Bleue Peatland Observatory (MBPO)
  - ➢ Existing infrastructure and scientific interest
  - ➢ Boardwalk access
  - ➢ Flux tower (since 1998)
  - ➢ 200+ scientific journal articles



Advance 1 – Technology demonstration

Evaluation of a UAV multispectral sensor limitations for satellite validation at the Mer Bleue Peatland Observatory.

remote sensing

Under review

MDPI

Article

A multispectral UAV sensor's limitations in mapping complex vegetation and satellite validation

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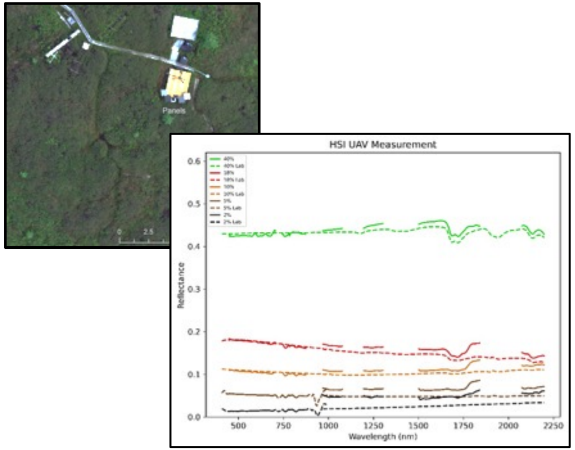
Towards RPAS HSI for Cal/Val

Mer Bleue Campaign 2021

HySpex Mjolnir VS-620



- To assess the spectral accuracy of a UAV mounted MicaSense Altum at different flight altitudes using NRC's validation protocol.
- To investigate the viability of the MicaSense Altum as a validation tool of Sentinel-2 and PlanetScope Dove 8 band satellite products by assessing the sensor against pre-classified hummock-hollow-lawn microtopographic features.

Methodology – UAV Sensors

MicaSense Altum	HySpex VS-620

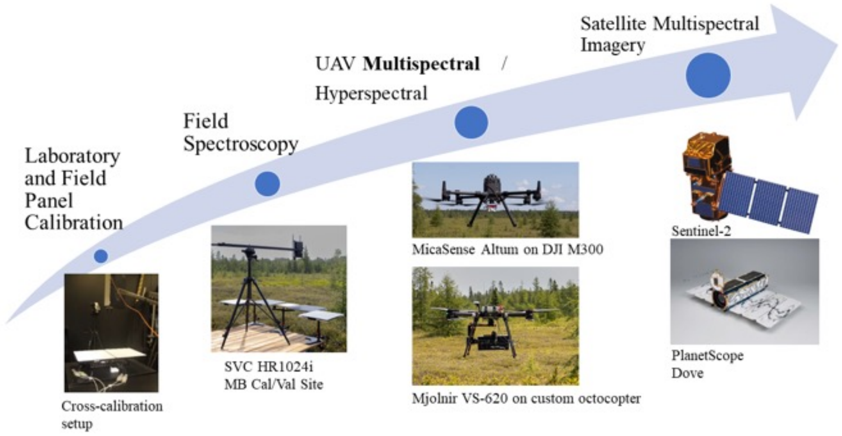
Figure 2. (A) Altum mounted on the M300. (B) Mjolnir VS-620 hyperspectral sensor mounted on an octocopter with a gimbal for stabilization. (C) Six diffuse reflectance panels (2%, 5%, 10%, 18%, 40%, 50%) and the included MicaSense calibration reflectance panel. (D) HR1024i spectroradiometer taking field measurements of diffuse reflectance panels.

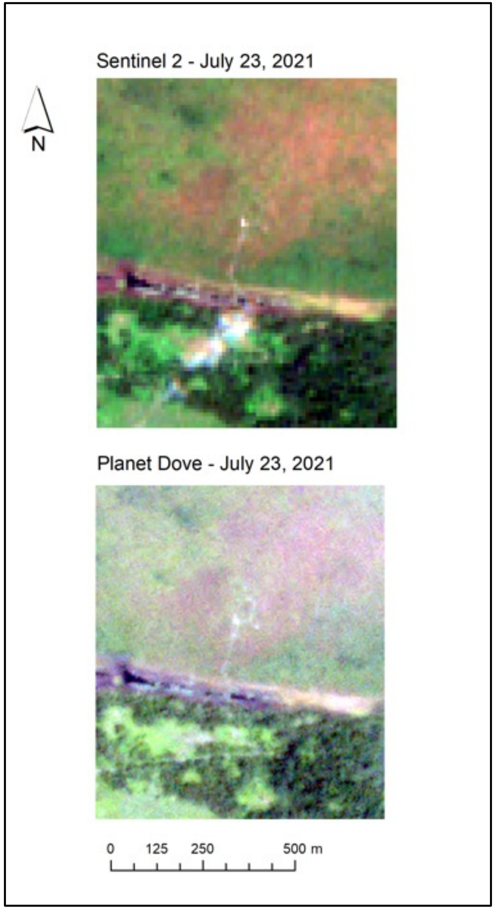
Characteristic	Altum
Pixel Size	3.45 um
Bands (FWHM)	475 nm (32), 560 nm (27) 668 nm (16), 717 nm (12), 842 nm (57)
Resolution	2064 x 1544 px (3.2 MP x 5 sensors)
Aspect Ratio	4:3
Sensor Size	7.12 x 5.33 mm (8.9 mm diagonal)
Focal Length	8 mm
Field of view (h x v)	48°x 36.8°
Intrinsic bit depth (DNG)	12-bit
Output bit depth (TIFF)	16-bit
GSD @ 120 m (~400 ft)	5.2 cm
GSD @ 60 m (~200 ft)	2.1 cm

Characteristic	HySpex V-1240
Spectral range	400–1000 nm
Spatial pixels	1240
Spectral channels and sampling interval	200 bands @ 3.0 nm
F-number	f1.8
FOV	20°
IFOV across/along track	0.27 /0.54 mrad
Bit resolution	12-bit

Methodology – Satellite Imagery

Characteristic	Sentinel 2A	PlanetScope SuperDove
Spectral Range	443 nm – 2190 nm	431 nm – 885 nm
Relevant Bands (FWHM)	442.7 (21) nm 492.4 (66) nm 559.8 (36) nm 664.6 (31) nm 704.1 (15) nm 740.5 (15) nm 782.8 (20) nm 832.8 (106) nm 864.7 (21) nm	443.0 (20) nm 490.0 (50) nm 531.0 (36) nm 565.0 (36) nm 610.0 (20) nm 665.0 (31) nm 705.0 (15) nm 864.0 (40) nm
Ground Sample Distance	10, 20, 60 m	3.7 – 4.2 m (resampled to 3.0 m)



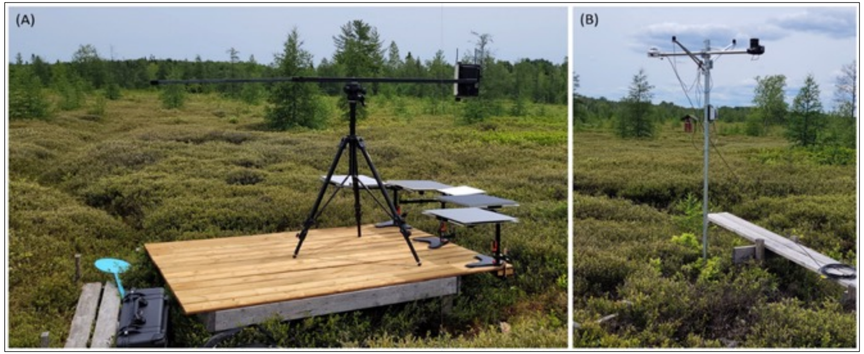


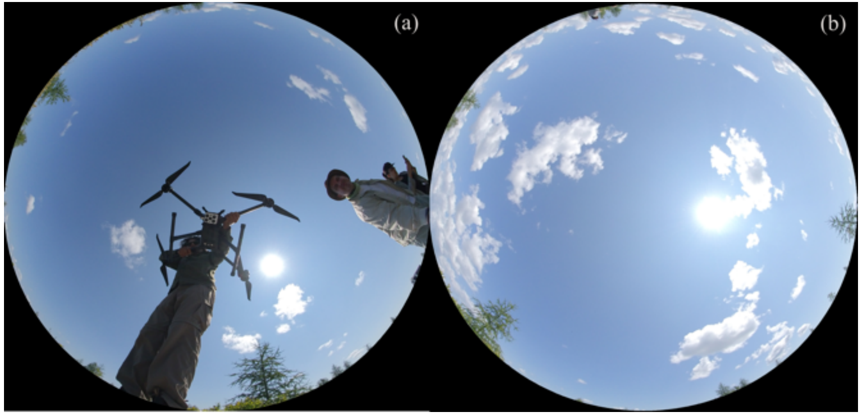
Methodology – Data collection

Altum (July 23rd) and HySpex VS-620 (July 19th)

Altitude	Speed	Area Covered	No. Images	(GSD)
25 m	~3.2 m/s	0.7 ha	925	1.14 cm
50 m	~ 5 m/s	1.5 ha	462	2.24 cm
75 m	~5 m/s	2.5 ha	456	3.36 cm
100 m	~5 m/s	3.6 ha	600	4.40 cm
120 m	~1 m/s	0.5 ha	NA	5 cm

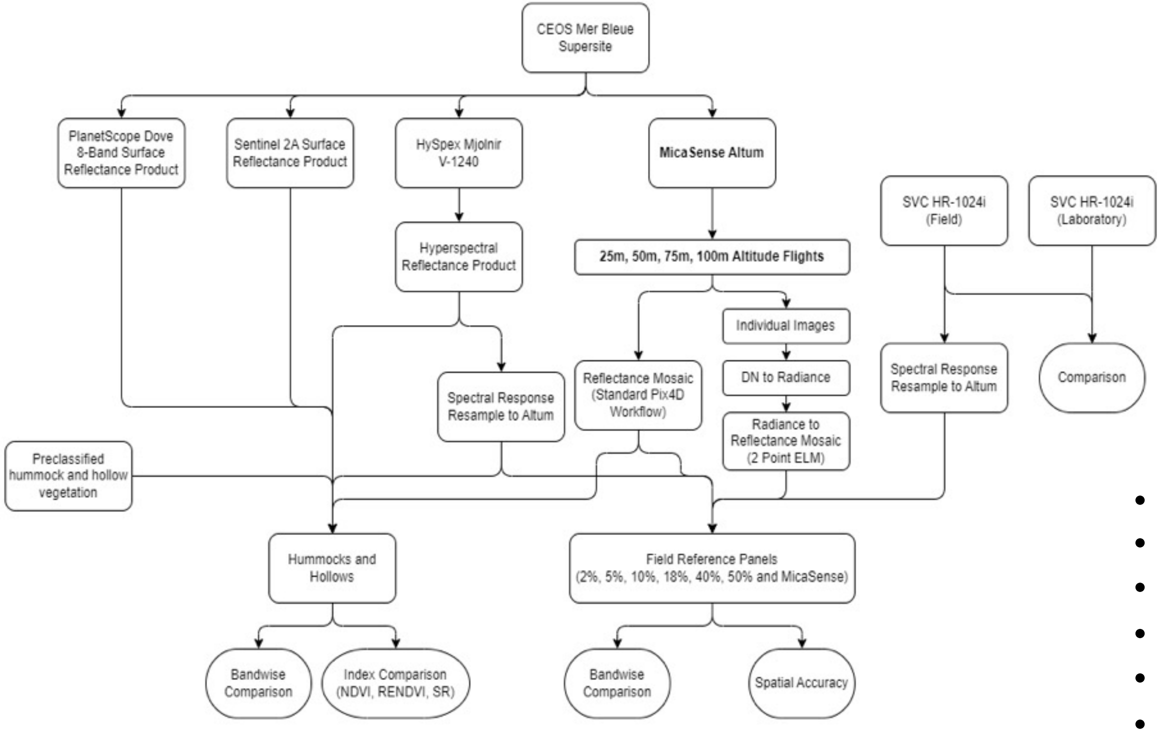
Panel measurements* and sky conditions





MicaSense recommended calibration procedure captured using an Insta360 camera (a) Visible obstruction of diffuse irradiance during calibration (excluding the holder of the Insta360 at bottom) (b) Unobstructed sky

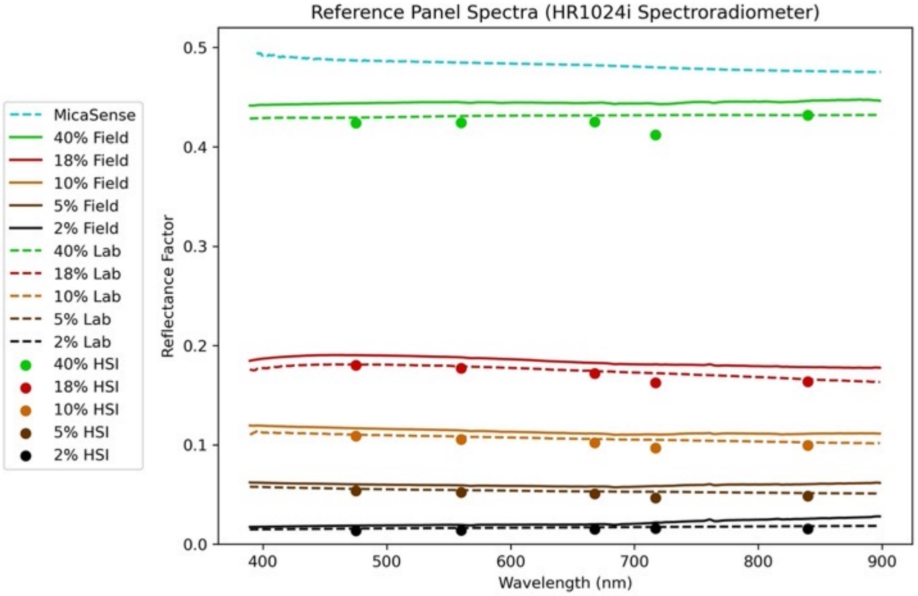
Methodology – Workflow

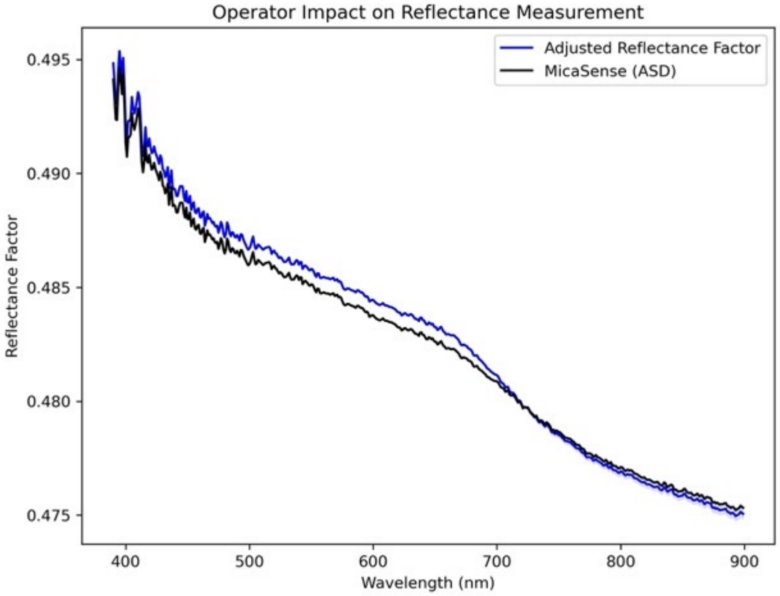


- Diffuse Skylight Error Estimation
- Reflectance product estimation
- Independent reflectance estimation
- Spatial offset for Altum
- Panel comparison
- Peatland vegetation comparison at UAV and satellite levels

Cottrell et al. 2024. Under review

Results





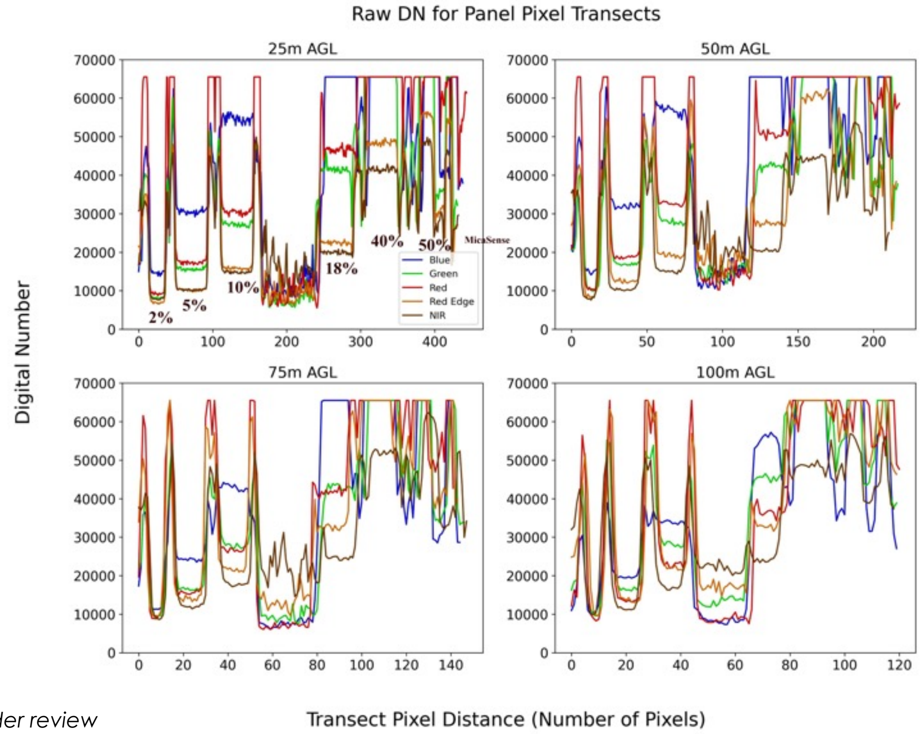
- Laboratory HR1024i panel measurement (dashed) and field HR1024i measurement (solid).
- HSI Mjolnir V-1240 resampled to the 5 bands of the Altum – within 4%of the hemispherical conical reflectance factor.

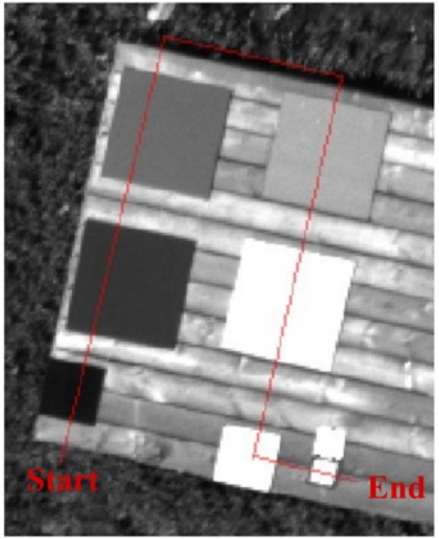
- Diffuse irradiance to total irradiance over 3 hours ranged from 15.43 to 15.53 % ($\bar{x}$ = 15.48 σ = 0.05)
- The proportion of the hemisphere obstructed by the UAV and operator holding it over the panel was 10.9%.

Cottrell et al. 2024. Under review

Results

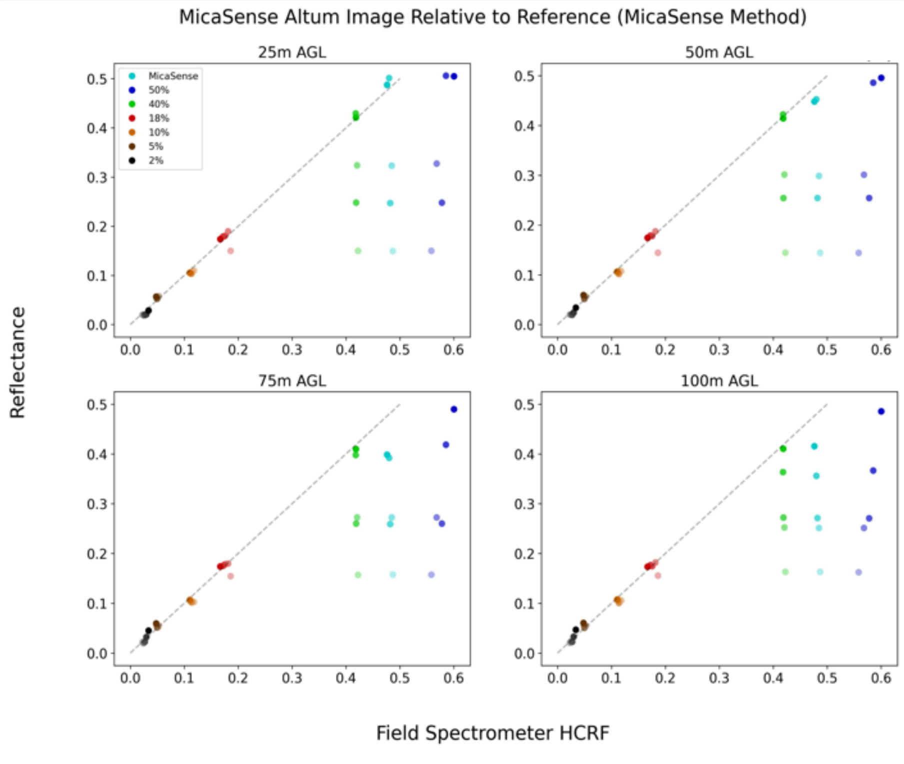
Saturation of the Altum at the 475 nm (Blue), 560 nm (Green), and 668 nm (Red) bands

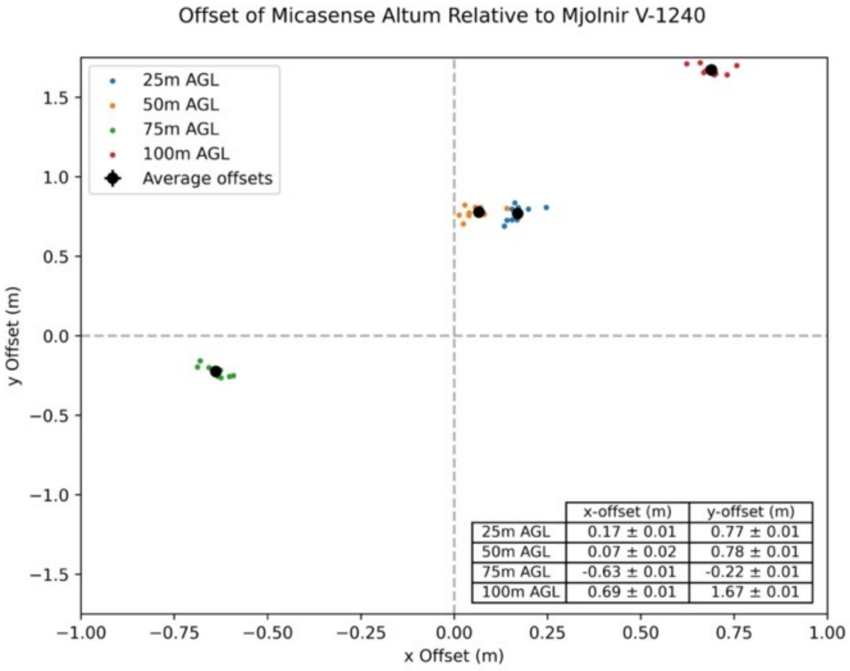




Cottrell et al. 2024. Under review

Results

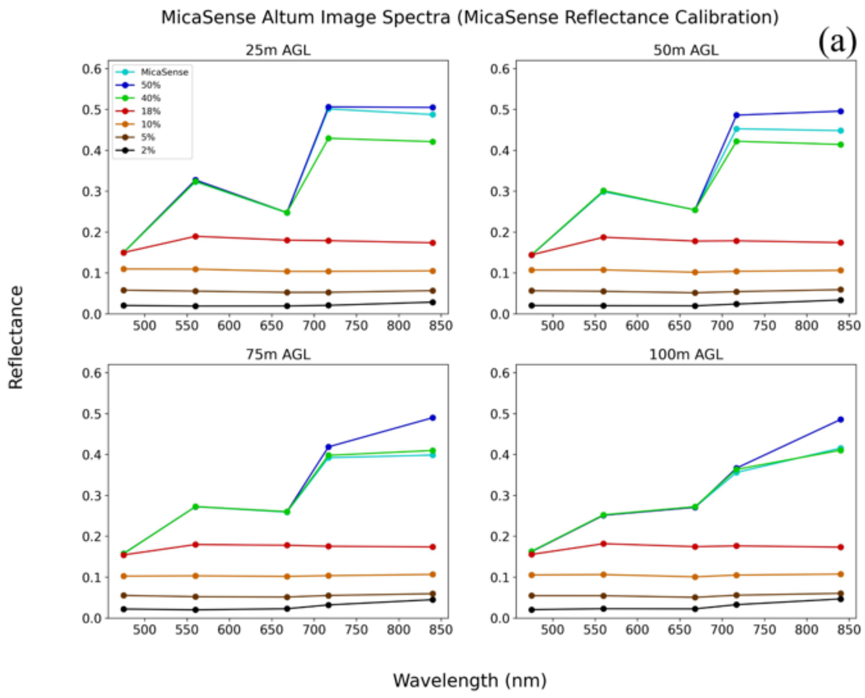




Cottrell et al. 2024. Under review

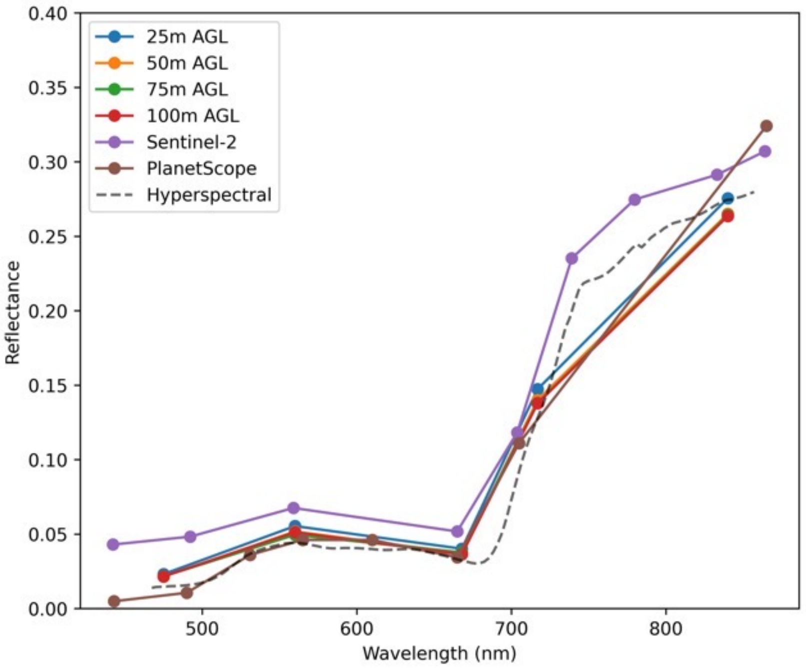
Results

Altum panel spectra using recommended workflow



Cottrell et al. 2024. Under review

Vegetation spectra comparison for same ROI



Conclusions

- This study underscores the critical need for accurate and consistent radiometric calibration in multispectral sensors.
- The Altum's underestimation of reflectance for reference panels at 18%, 40%, 50% reflectance and the sensor provided panel, suggest inconsistency in the settings used to operate the Altum "out of the box".
- This multispectral sensor have potential in vegetation classification, its current limitations in accurate reflectance and spectral vegetation index values restrict its use as a dependable tool for the long-term validation of multispectral satellite products at Mer Bleue.

Advance 2 – Proof of concept.

Application of SPARC Cal/Val Approach to RPAS Hyperspectral Imagery

Testing novel RPAS in-situ method

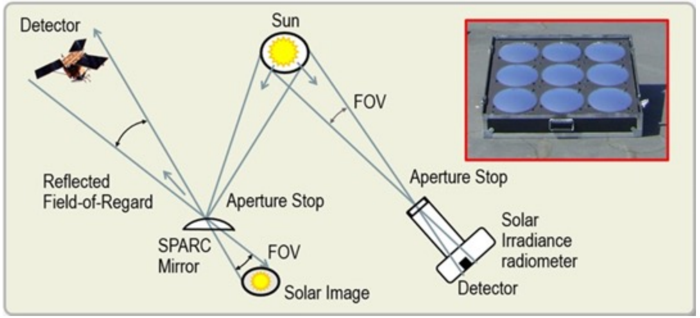
- SPARC Method Overview

- Convex mirrors used to relay an image of the solar disk to an Earth Observation Sensor.

- Used to produce radiometric and spatial calibration and characterization targets for multispectral and hyperspectral imaging systems mounted on satellites, aircraft, and RPAS.

- With simultaneous measurements of the downwelling direct and diffuse solar irradiance, the SPARC point targets are suitable to derive (or validate) calibration coefficients for absolute at-aperture spectral radiance *La*(λ).

- Multiple radiance levels across the sensor's dynamic range can be deployed in a single scene
  - allowing for radiometric calibration using a Mirror-based-Empirical Line Method (MELM) by regression between measured sensor response and derived SPARC target radiance.

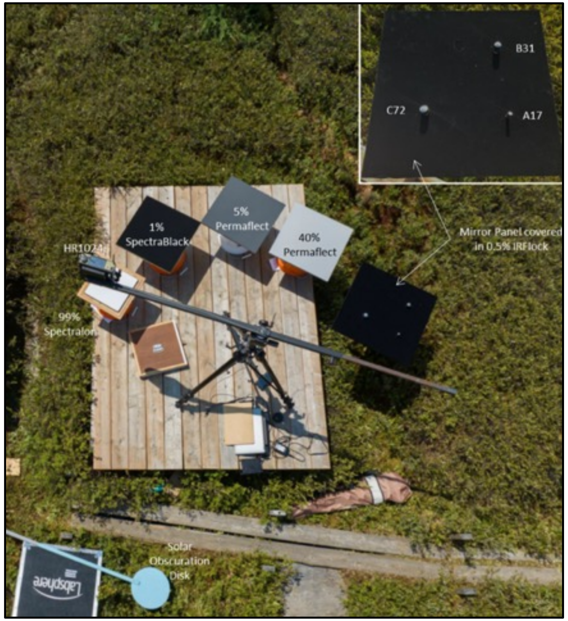


Objective: to assess the SPARC methodology for RPAS HSI cal/val at Mer Bleue.

Methodology – Mer Bleue campaign 2023

Mirror	Radius of Curvature (mm)	Diameter (mm)	Field of Regard (°)	Lambertian Equivalent Reflectance
A72	25.03	25.64	121	72
B31	15.50	24.96	215	31
C17	12.09	11.98	118	17

Mirrors were characterized at the Labsphere facilities.



Panels were characterized at the NRC panel characterization facility

- Biconical Reflectance Factor (BCRF) (0°:45°)
- Panel Uniformity

Hemispherical:Conical Reflectance Factor (HCRF) (0°:h) was performed at Labsphere.

RPAS Hyperspectral System

Low Altitude Advanced Hyperspectral System (LAAHyS) for EO Cal/Val

	V-1240	S-620
Spectral range	400 – 1000 nm	970 – 2500 nm
Combined spectral range	400 – 2500 nm	
Spatial pixels	1240	620
Combined spatial pixels	620	
Spectral channels and sampling interval	200 bands @ 3.0 nm	300 bands @ 5.1 nm
Combined spectral channels	490	
FOV	20°	20°
Bit resolution	12 bits	16 bits
Detector type	Silicone CCD	Mercury Cadmium Telluride (MCT) FPA
Smile and keystone	< 10% per pixel per band	
Radiometric calibration traceability	To a Physikalisch-Technische Bundesanstalt (PTB) standard	
Power consumption*	50 W	
Dimensions (l-w-h)	374 – 202 – 178 mm	
Weight*	< 6.7 kg including standard battery	

Flight/Sensor parameters: 50 m AGL – 3.3 m/s – IT 6.8 ms –FT 7.7 ms

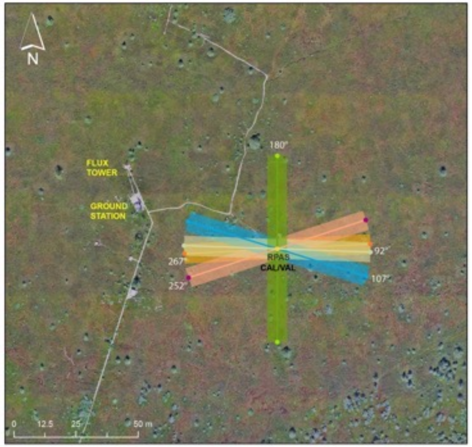
Arroyo-Mora et al. 2023. Drones.

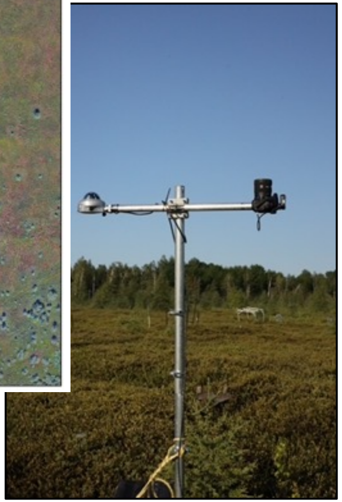
Data collection

Data Acquisition – Hyspex VS620 Imagery – 5 flights

Flight	Time (Local)	SZA (°)	SAA (°)	Sensor Altitude above targets (m)	Sky Conditions
A	12:51 ± 0:03	57.6 ± 0.4	92.6 ± 0.4	49.7 ± 0.5	Clear
B	14:07 ± 0:02	44.6 ± 0.3	107.8 ± 0.4	49.0 ± 0.5	Clear
C	16:28 ± 0:03	25.9 ± 0.2	157.9 ± 0.7	49.3 ± 0.3	Clear solar disk w significant clouds
D	17:56 ± 0:03	41.3 ± 0.3	247.1 ± 0.4	49.9 ± 0.3	Clear solar disk w significant clouds
F	21:19 ± 0:03	56.2 ± 0.3	266.0 ±0.3	49.1 ± 0.3	Significant cloud obscuration of solar disk

- For each flight, 4 HSI flight lines were acquired of the mirrors/panels.
- Imagery was acquired with a heading approximately equal to the SAA.





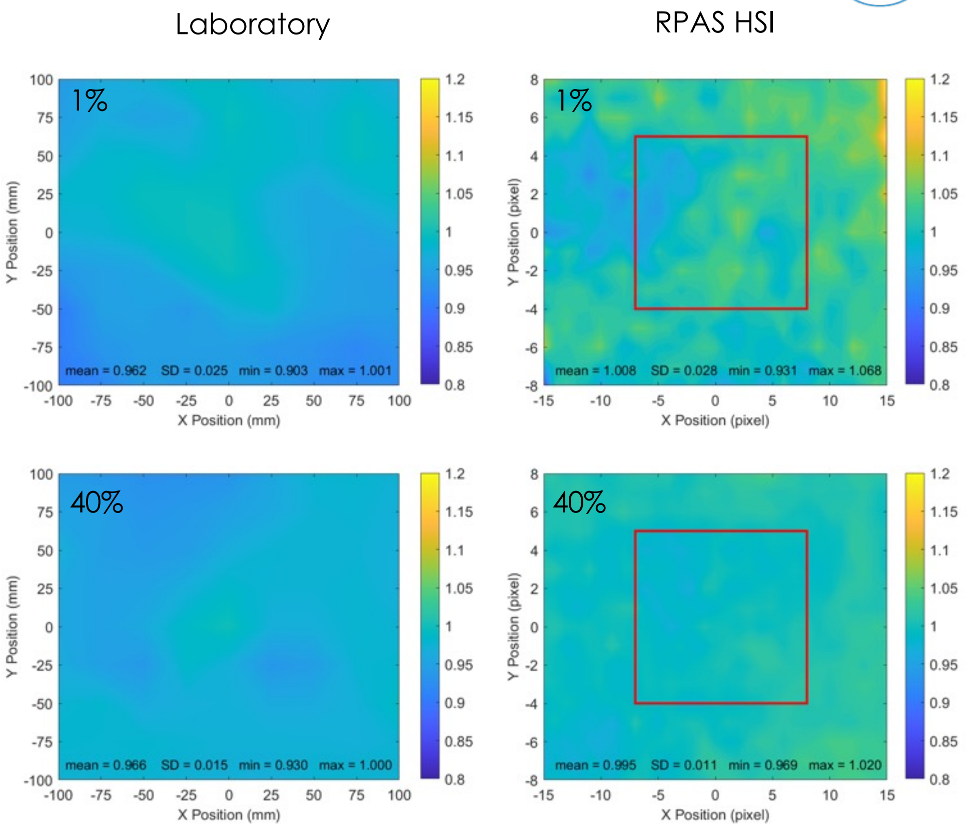
Data Processing and Analysis

- Radiometric Calibration of the HR1024i Field Spectrometer.
- Field reference panel characterization - BCRF (0°:45).
- Hyperspectral imagery processed to non-geocorrected radiance and atmospherically compensated hyperspectral data cubes.
- Spatial response estimation for spatial contribution to each pixel (SR2 Tool).
- SPARC Ensquared Energy Extraction, and SPARC at-sensor modelled radiance (measured or model atmospheric transmission).

Results – Panel Uniformity

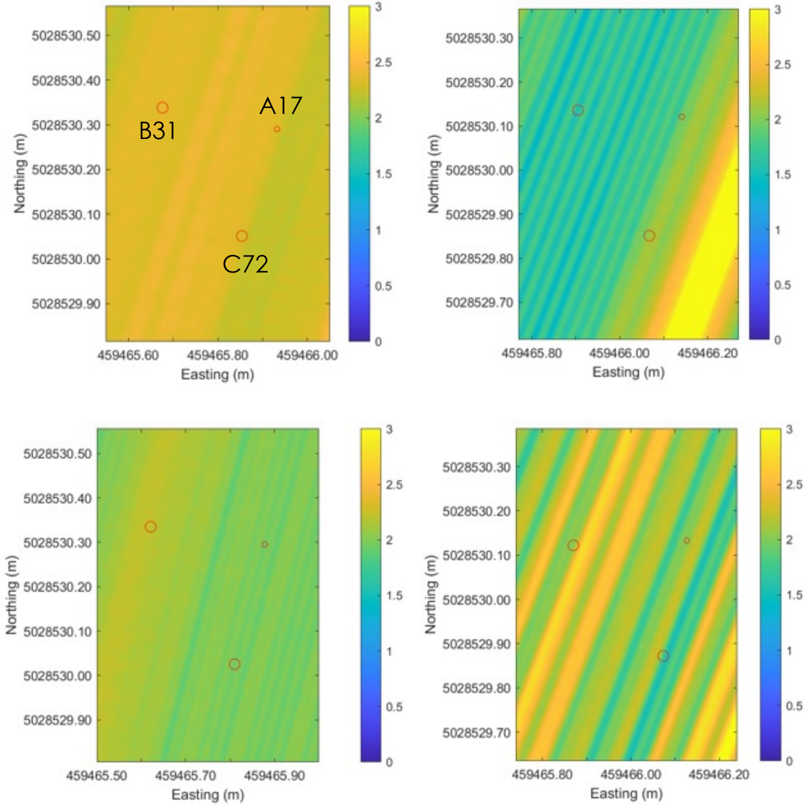
Raw geometry
sum x 1

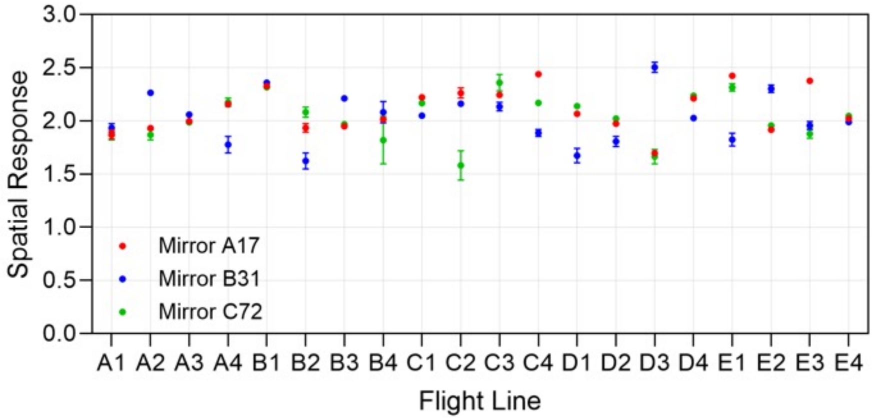
Geocorrected
sum x 2



Results – Spatial Response Estimation

FLIGHT B – Clear sky

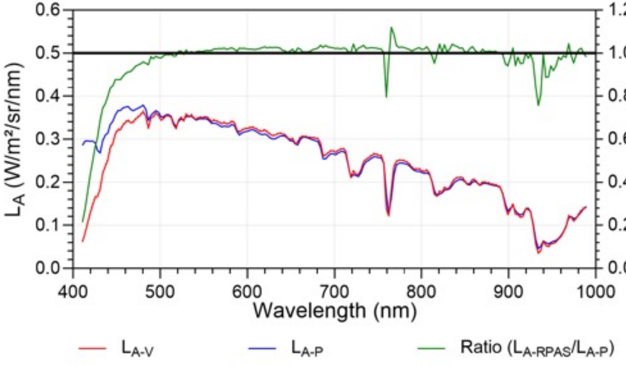




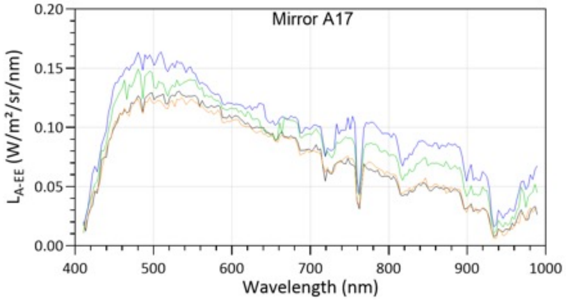
Mean spatial response for the 20 flight lines at each mirror location

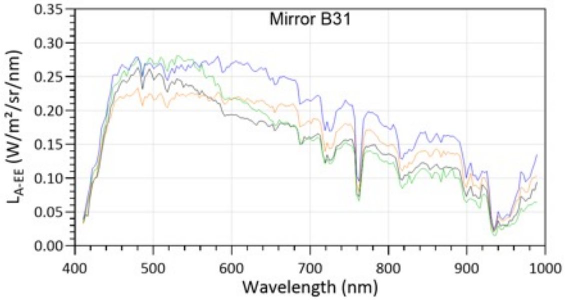
Scale shows how many PSFs are contributing to that mirrors location or point in the image. Pixels is defined as the FWHM of the PSF.

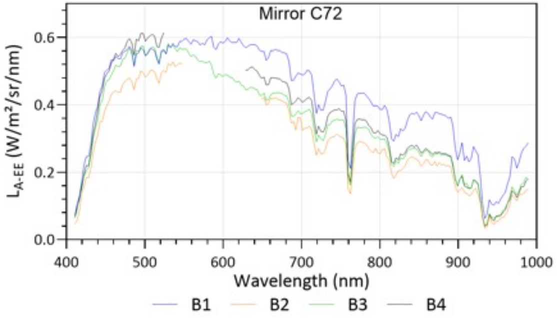
Results – Panels vs Mirror variability - Radiance



V1240 at-sensor radiance spectrum (L_{A-V}) vs derived from the coincidentally acquired field spectrometer spectrum (L_{A-P}).







- At-sensor radiance derived from SPARC method.
- Final sensor radiance show close values between VS1240 sensor and mirror radiance.

Conclusions

- The SPARC method is sensitive to the mirror parameters, in addition to the RPAS HSI flight characteristics, which makes it operationally challenging.
- Processing within the SPARC method might be challenging for the non-expert, so better workflows would required to be developed before its implementation.
- Reference panels still provides a good solution for evaluating the quality of the RPAS HSI data, and can be deployed in areas of low accessibility like Mer Bleue.

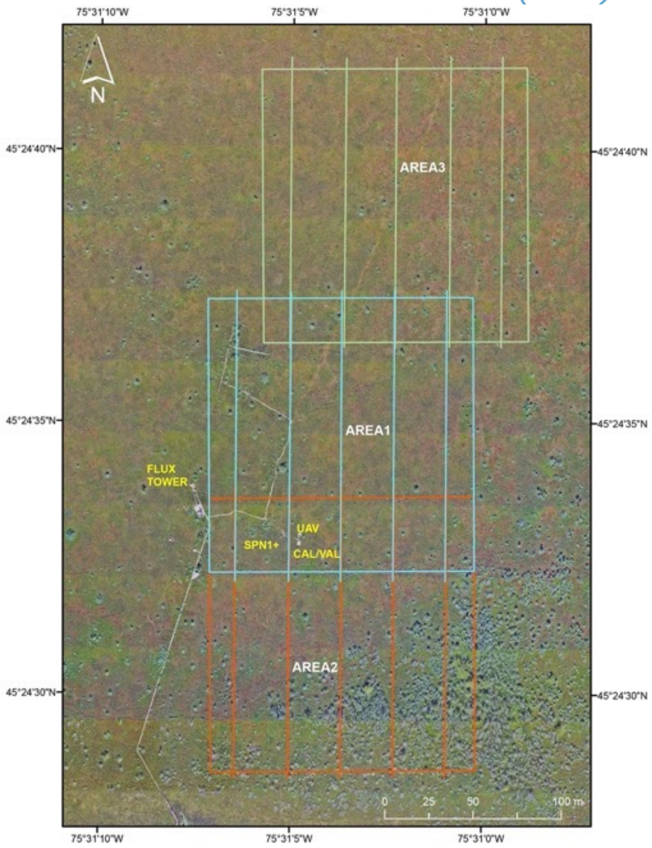
Advance 3 – Towards Hyperspectral EO Cal/Val.

- Flight plan designed for acquiring representative areas for the validation of multispectral and hyperspectral data (2.25 hectares).

- Three 150 m x 150 m (5 x 5 pixels) were planned in ArcGIS 10.7.1 to acquire UAV-HSI near-coincidental with an EnMAP overpass at the Mer Bleue Peatland Observatory (July 24, 2023).

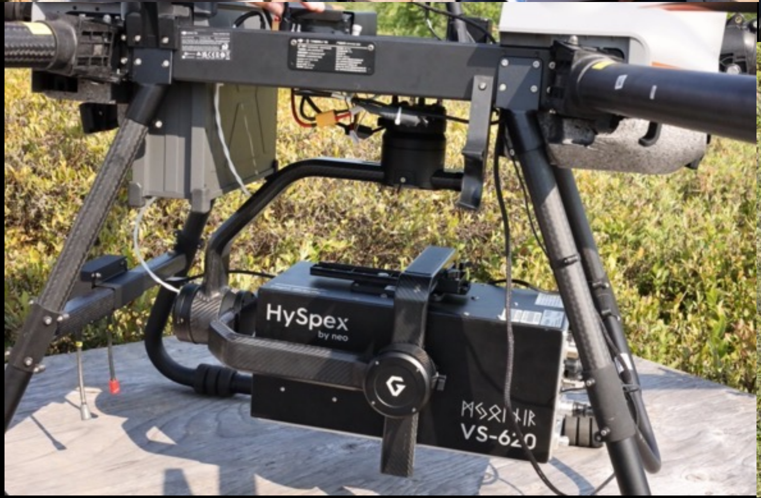
- Suitable T30 parameters were chosen for the data collection: 100 m AGL, 3.7 m/s.

- Cal/Val protocols were implemented during data collection – e.g. nominal reflectance panels.



Fieldwork 2023

Mer Bleue Cal/Val Supersite



Results - UAV HSI Efficiency

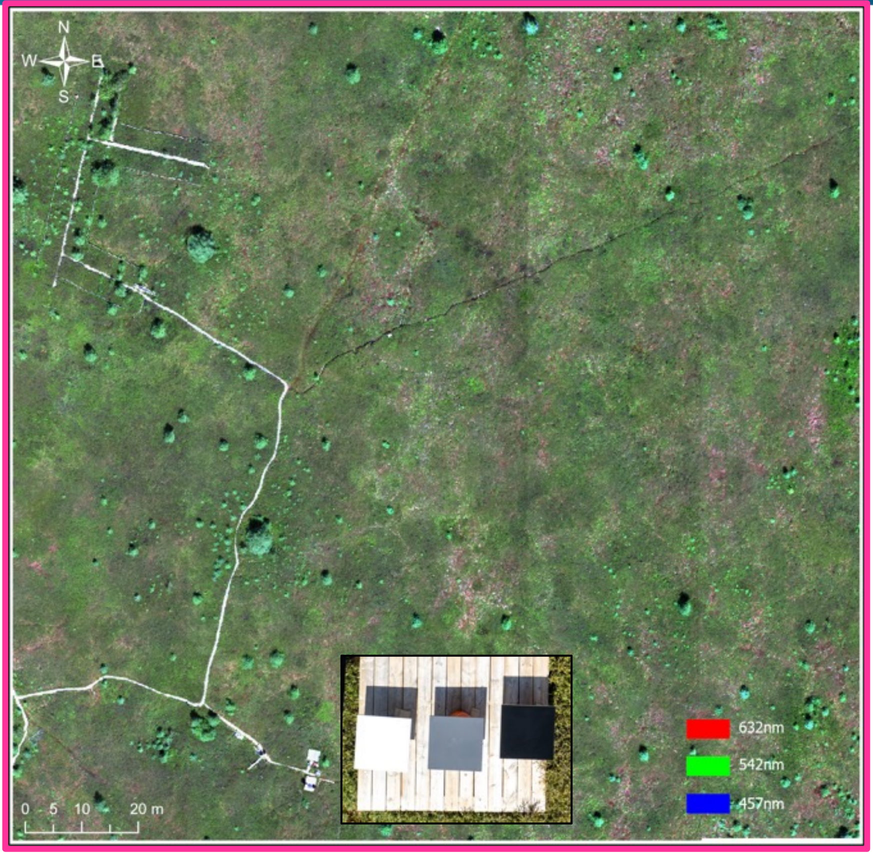
DATE	YEAR	SITE	TARGET	Sensor	Altitude AGL (m)	Speed (m/s)	FT V (ms)	IT V (ms)	FT S (ms)	IT S (ms)	Sequence	RAW_FILENAME
22-Jun	2023	Rigaud	Panels, mirrors	VS-620	50	3	5	10	4.8	9.8	03	A50_S3_IT48_VS_03
22-Jun	2023	Rigaud	Panels, mirrors	VS-620	50	3	5	10	4.8	9.8	04	A50_S3_IT48_VS_04
22-Jun	2023	Rigaud	Panels, mirrors	VS-620	70	4.5	5	10	4.8	9.8	02	A70_S45_IT48_VS_02
22-Jun	2023	Rigaud	Panels, mirrors	VS-620	100	5	5	10	4.8	9.8	04	A100_S6_IT48_VS2_0
14-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	100	3.7	15	14.8	30	29.8	01	A100_S37_FT15_01
14-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	100	3.7	15	14.8	30	29.8	01	A100_S37_FT11v2_01
14-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	100	3.7	15	14.8	30	29.8	02	A100_S37_FT11v2_02
14-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	100	3.7	15	14.8	30	29.8	03	A100_S37_FT11v2_03
14-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	100	3.7	15	14.8	30	29.8	04	A100_S37_FT11v2_04
14-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	100	3.7	15	14.8	30	29.8	05	A100_S37_FT11v2_05
14-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	2.8	10	9.8	20	19.8	01	A50_S28_FT10_01
14-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	2.8	10	9.8	20	19.8	02	A50_S28_FT10_02
14-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	40	2	11	9.8	22	21.8	01	A40_S2_FT11_01
14-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	40	2	11	9.8	22	21.8	02	A40_S2_FT11_02
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	01	A50_Z58_01
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	02	A50_Z58_02
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	04	A50_Z58_04
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	01	A50_Z45_SA107_01
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	02	A50_Z45_SA107_02
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	03	A50_Z45_SA107_03
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	04	A50_Z45_SA107_04
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	01	A50_Z45_SA107_01
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	02	A50_Z45_SA107_02
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	03	A50_Z45_SA107_03
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	04	A50_Z45_SA107_04
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	01	A50_Z25_S180_01
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	02	A50_Z25_S180_02
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	03	A50_Z25_S180_03
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	04	A50_Z25_S180_04
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	01	A50_Z45_SA252_01
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	02	A50_Z45_SA252_02
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	03	A50_Z45_SA252_03
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	04	A50_Z45_SA252_04
19-Jul	2023	Mer Bleue	Beaver Pond	VS-620	70	3.5	10	9.8	20	19.8	01	A70_S35_BP_01
19-Jul	2023	Mer Bleue	Beaver Pond	VS-620	70	3.5	10	9.8	20	19.8	02	A70_S35_BP_02
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	01	A50_Z45_SA252_01
19-Jul	2023	Mer Bleue	Panels, mirrors	VS-620	50	3.3	7.7	6.8	15.4	15.2	02	A50_Z45_SA252_02

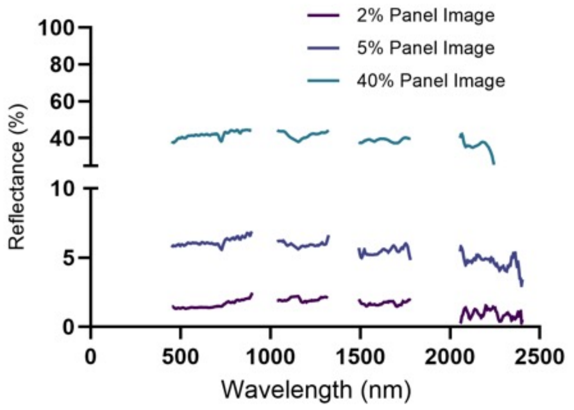
DATE	YEAR	SITE	TARGET	Sensor	Altitude AGL (m)	Speed (m/s)	FT V (ms)	IT V (ms)	FT S (ms)	IT S (ms)	Sequence	FILENAME
23-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	01	A2_100_37_98_
23-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	02	A2_100_37_98_
23-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	03	A2_100_37_98_
23-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	04	A2_100_37_98_
23-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	05	A2_100_37_98_
23-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	01	A1_100_37_98_
23-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	02	A1_100_37_98_
23-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	03	A1_100_37_98_
23-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	04	A1_100_37_98_
23-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	05	A1_100_37_98_
23-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	01	A3_100_37_98_
23-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	02	A3_100_37_98_
23-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	03	A3_100_37_98_
23-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	04	A3_100_37_98_
23-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	05	A3_100_37_98_
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	01	A2_100_37_98E
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	02	A2_100_37_98E
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	03	A2_100_37_98E
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	04	A2_100_37_98E
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	05	A2_100_37_98E
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	01	A1_100_37_98E
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	02	A1_100_37_98E
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	03	A1_100_37_98E
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	04	A1_100_37_98E
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	05	A1_100_37_98E
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	01	A3_100_37_98E
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	02	A3_100_37_98E
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	03	A3_100_37_98E
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	04	A3_100_37_98E
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	05	A3_100_37_98E
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	01	A1_100_37_98E
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	02	A1_100_37_98E
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	03	A1_100_37_98E
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	04	A1_100_37_98E
24-Jul	2023	Mer Bleue	EnMAP	VS-620	100	3.7	10	9.8	20	19.8	05	A1_100_37_98E

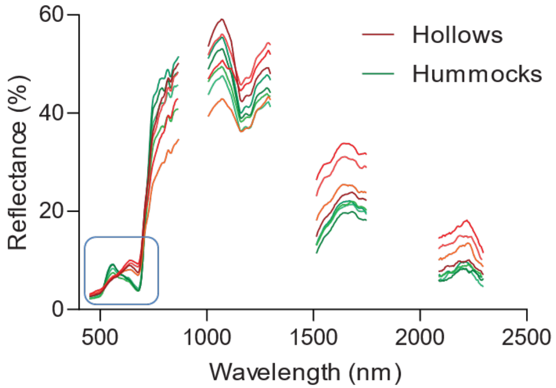
- 35 UAV-HSI flight lines covering the three 2.33 ha areas were collected on July 23rd and 24th, 2023 for EnMAP validation test.
- Flight duration per plot ~11 minutes including transit and IMU maneuvers.
- Data acquired from 1 - 3cm resolution and resample to 10cm.
- 395 GB of raw HSI data.
- UAV LiDAR was also acquired over a 40 ha plot at Mer Bleue.

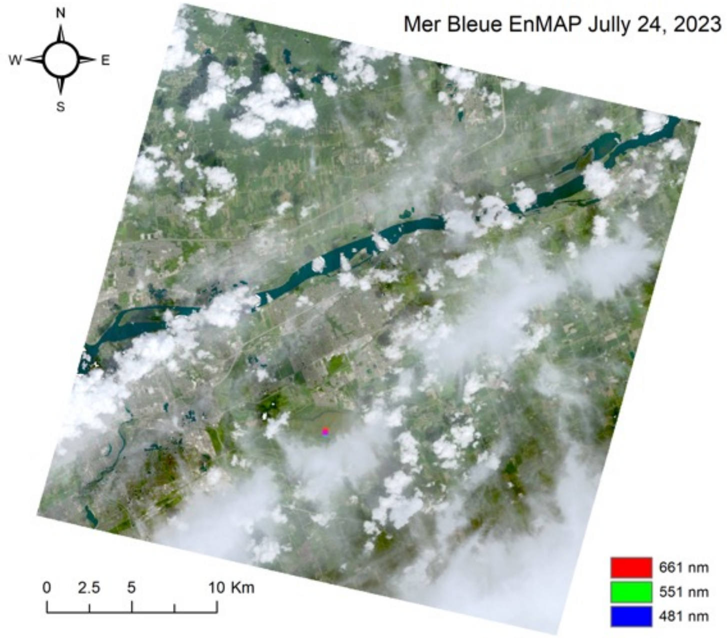
Results Reference Panels and Vegetation

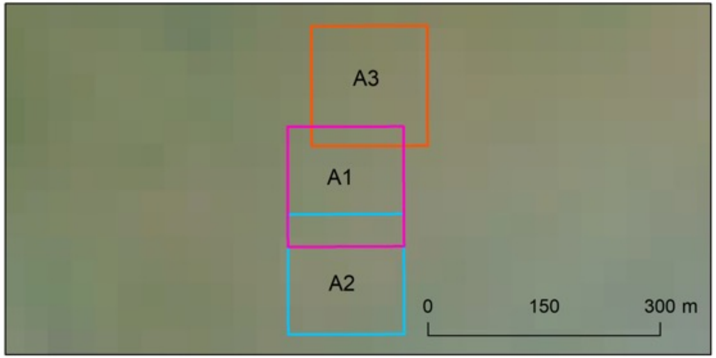
10 cm resampled pixel size and 390 spectral bands = 500,000+ spectra





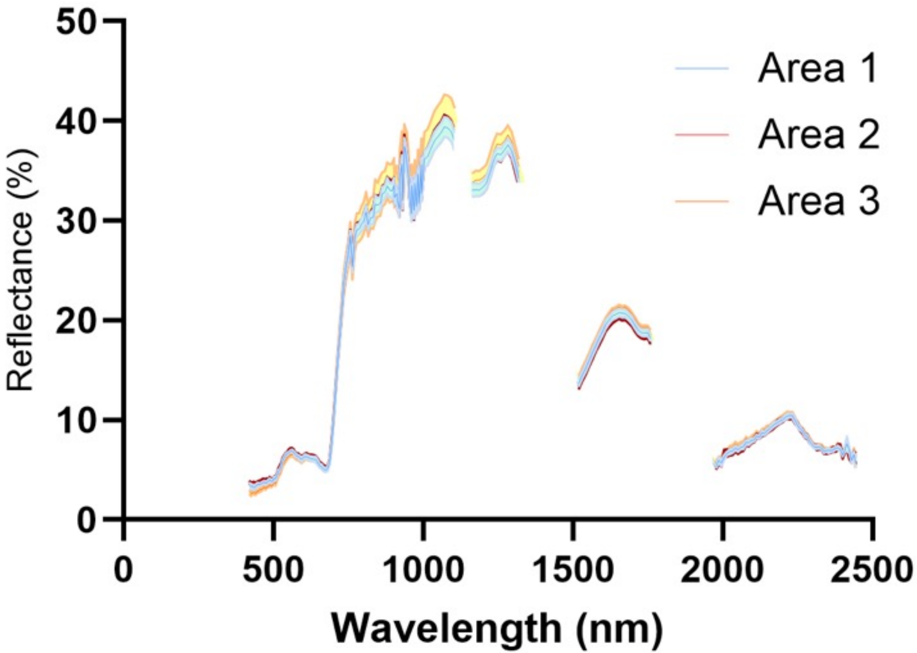






EnMAP (Hazy conditions)

3 x 3 pixels

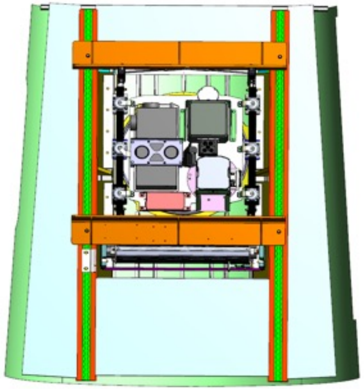


Future Work

RPAS based low altitude gas sampling system (CO_2, temp., relative humidity, vertical and horizontal wind speed, methane).

Goal: to improve atmospheric column characterization.

Advanced Modular EO System (AMEOS)



HSI – LiDAR – FLIR - RGB

+ Airborne Atmospheric Facility

Gas sampling

1. CO_2
2. CH4
3. H2O
4. NO, NO2, NOx

Aerosol sampling

1. Aerosol PSD
2. Aerosol total concentration
3. Aerosol composition

Aircraft and atmospheric states

1. Wind speed, Wind direction
2. Static Temperature
3. Static Pressure
4. Aircraft location
5. Airspeed
6. Spatial orientation

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- ESA/SERCO (WP-2050)
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