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UAV-based fiducial reference measurements for the validation of Sentinel-2 surface reflectance (HCRF)

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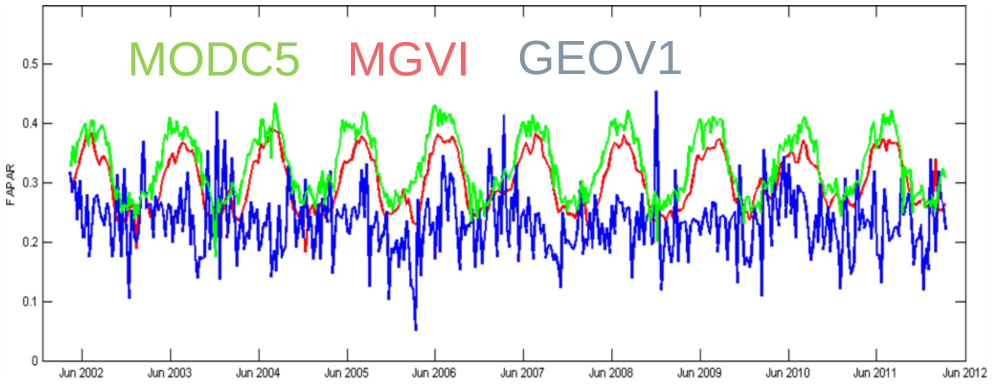
fiducial reference measurements for vegetation

Context for the FRM4Veg project

Converging story:

- vegetation products being different
- lack of traceability in satellite products and remedying this using invariant sites
- lack of uncertainty, traceability and fitness-for-purpose in validation data



Weiss et al 2014 Online validation exercise (OLIVE)): a web based service for validation of medium resolution land products. Application to fAPAR products

2009 CEOS Pilot campaign

ESA-funded Fiducial Reference Measurements for Vegetation (FRM4Veg)

FRMs have the following qualities:

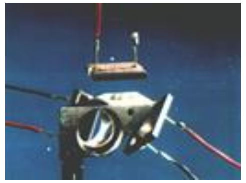
- Documented **SI traceability** (or conform to appropriate international community standards)
- **Independent** from the satellite geophysical retrieval process
- Accompanied by an **uncertainty budget** for all instruments and derived measurements
- Adhere to **community-agreed**, published and openly-available measurement **protocols/ procedures** and management practices
- Accessible to other researchers allowing **independent verification** of processing systems

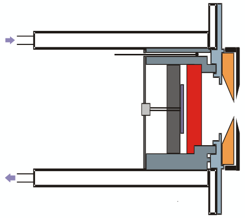
Traceability & uncertainty

“Property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty”

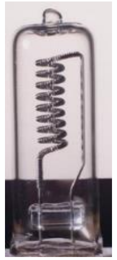
JGCM 200 (2012) International vocabulary of metrology – basic and general concepts and associated terms (VIM), pp. 29.


Cryogenic radiometer


Trap detector

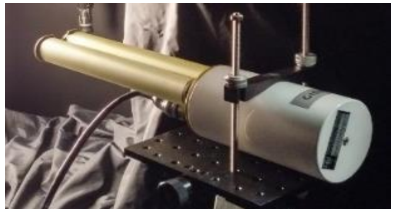

Filter radiometer

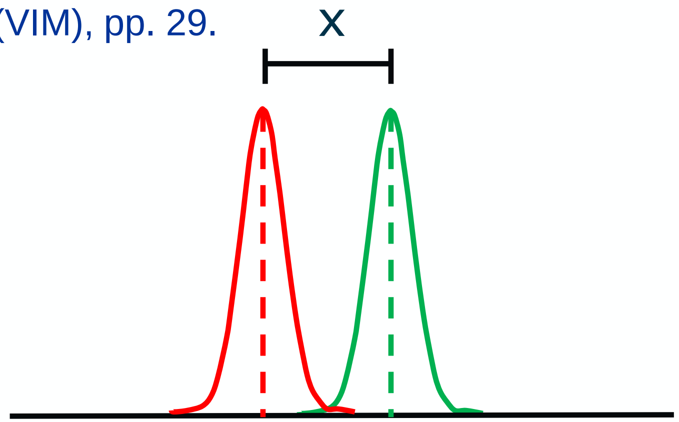

Blackbody

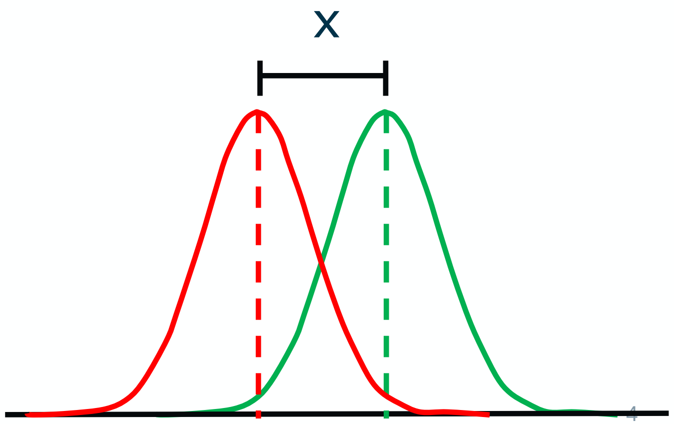

FEL lamp


Transfer spectrometer

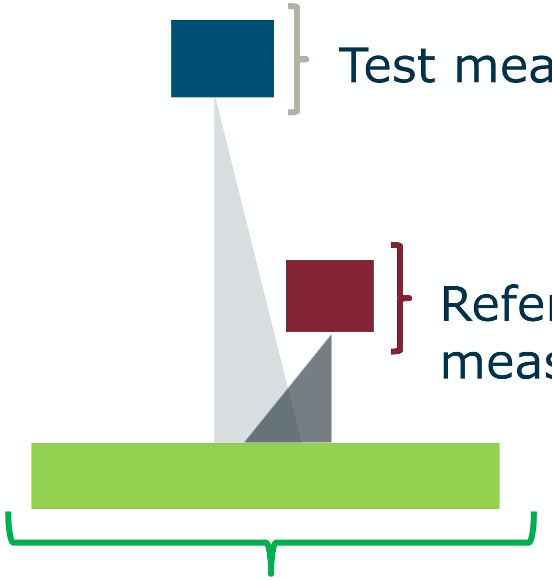

Miner’s lamp

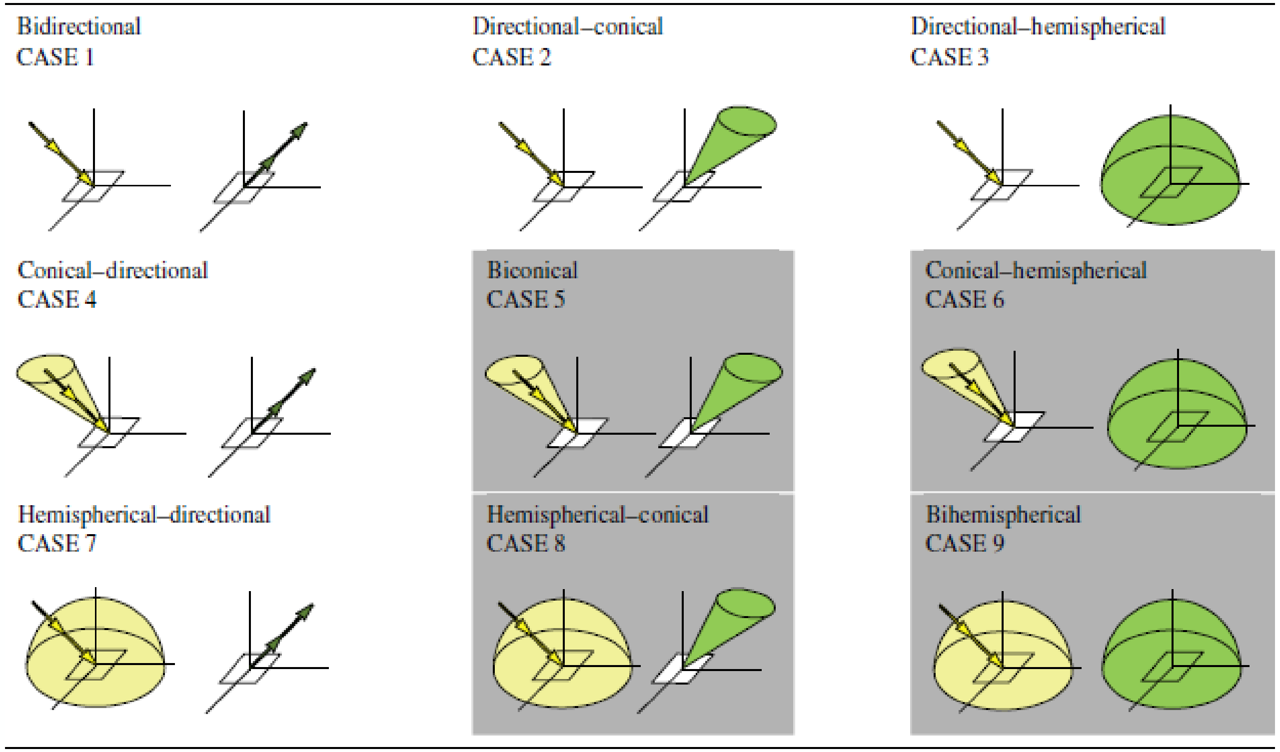

Lunar photometer





Validation procedure





Schaepman-Strub et al (2006) Reflectance quantities in optical remote sensing definitions and case studies. *Remote Sensing of Environment*, **103**:27-42

What factors influence these values?

Accessibility

Homogeneity

Measurement time

Lambertianness

Site size and shape

Calibration

FRM4Veg considerations

DOCUMENT	DATE PUBLISHED
Background Information	
FRM4VEG Overview and Metrology Principles	June 2020
Surface Reflectance	
FRM Protocols and Procedures for Surface Reflectance	June 2020
Validation Methodology for Surface Reflectance	June 2020
Biophysical Variables	
FRM Protocols and Procedures for FAPAR and CCC	June 2020
Validation Methodology for FAPAR and CCC	June 2020

Moving to UAVs

- DJI Matrice 600 Pro UAV
- VNIR Camera (400 nm – 1000 nm)
  640 spatial bands, 273 spectral bands
- SWIR Camera (900 nm – 2500 nm)
  640 spatial bands, 270 spectral bands
- Integrated high-performance GPS/IMU
- 16-channel Velodyne Puck LITE LiDAR

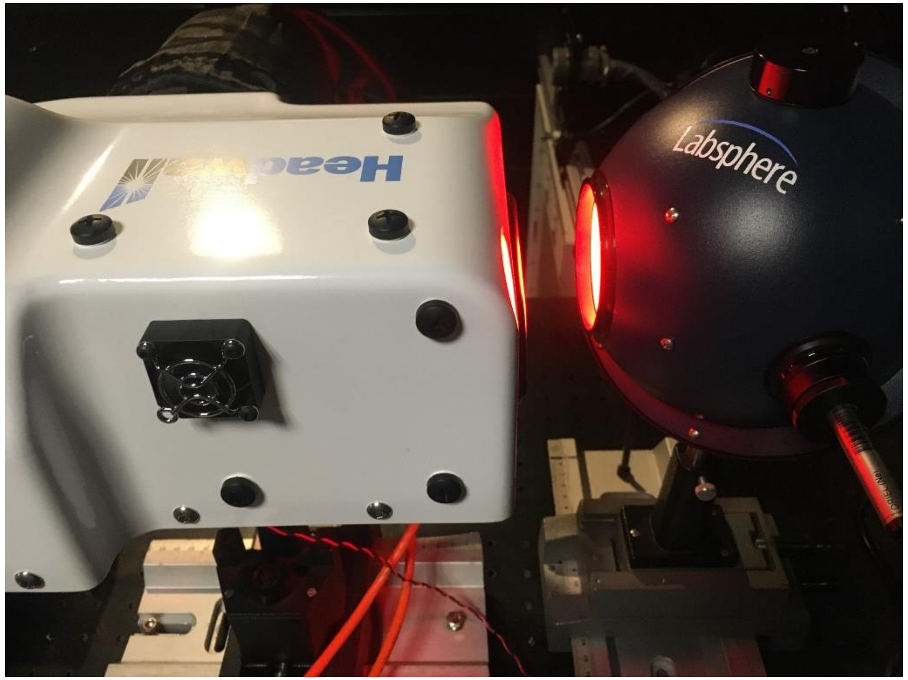
Headwall characterisation

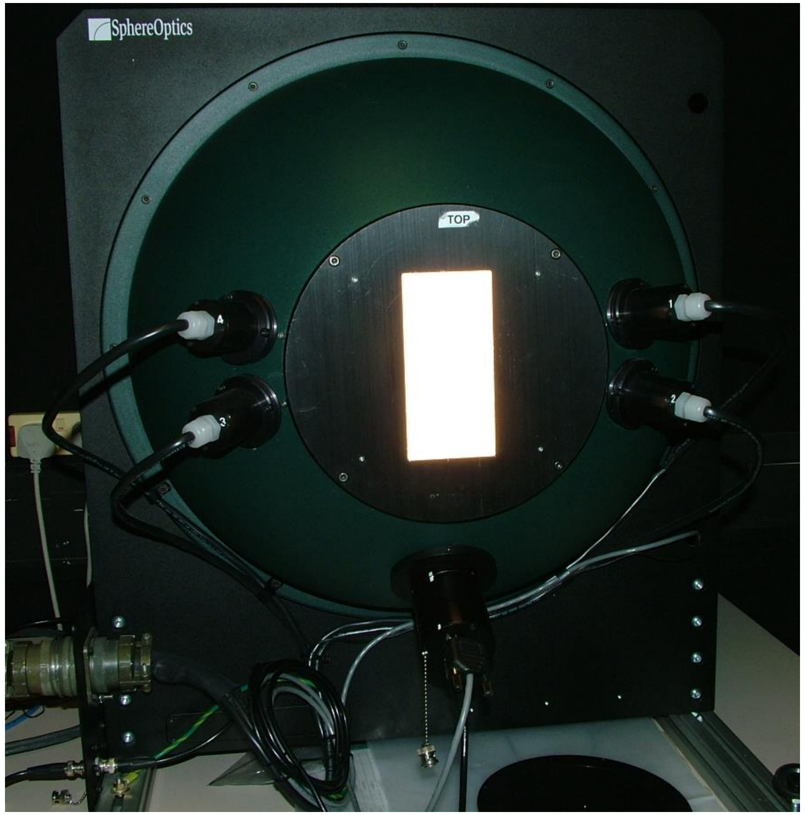
Further characterisation tests on the headwall

Spectral characterisation

Uniformity characterisation

Linearity



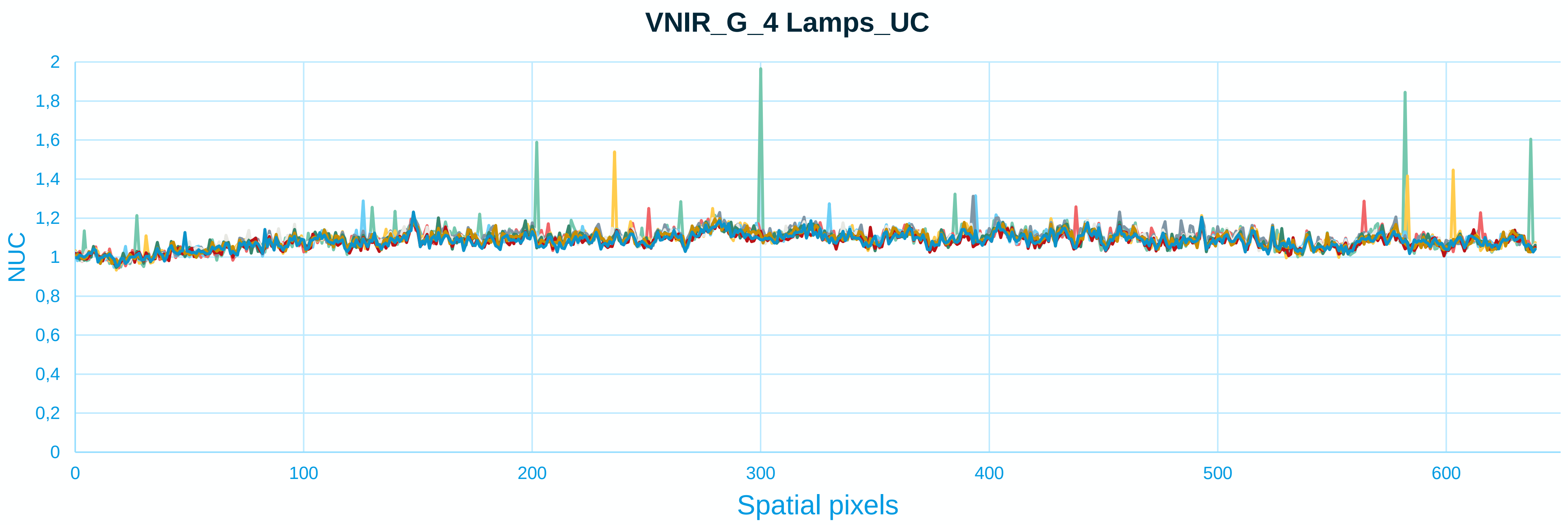


^ Krypton spectral line lamp in an integrating sphere

< broadband source in integrating sphere with rectangular exit port

Non-uniformity correction

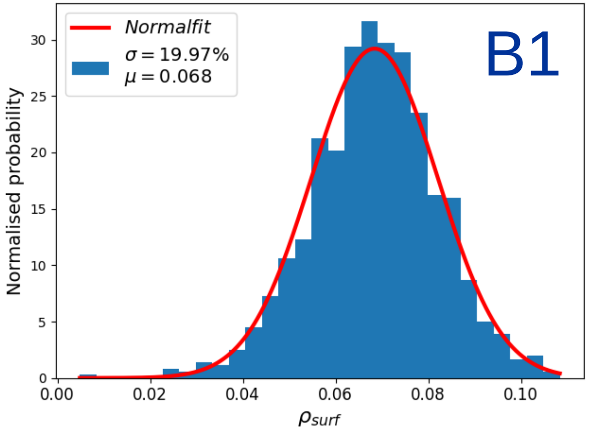
$$\boldsymbol{NUC\ factor, U(cell_n, \lambda_m)} = \frac{Average\ of\ dark\ subtracted\ Raw\ DN(cell_n, \lambda_m)}{Dark\ subtracted\ Raw\_DN(cell_n,\ \lambda_m)}$$

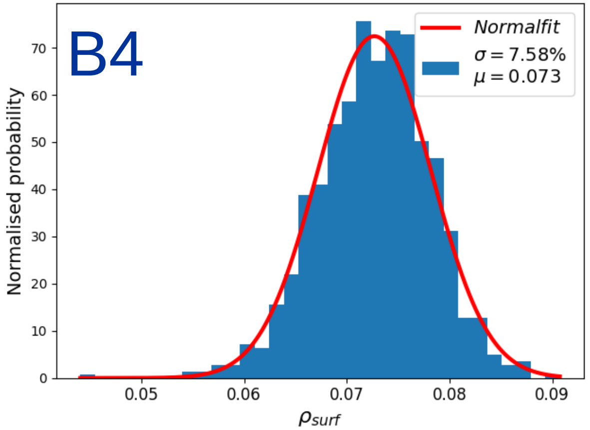


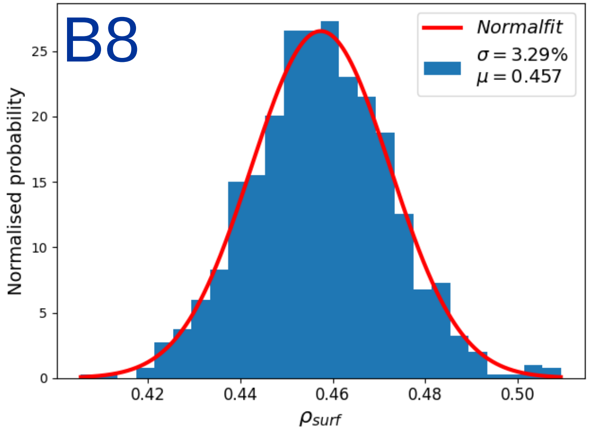
S2 Scene

S2A Product Summary	
Date	2022-07-22T10:56:31.024Z
Identifier	S2A_MSIL2A_20220722T105631_N0400_R094_T30SWJ_20220722T171159
Illumination Azimuth Angle	138.8°
Illumination Zenith Angle	23.7°

Utilised the S2 L2 RUT tool for generating uncertainties on the L2A product (Gorrono *et al*, 2023) https://doi.org/10.31223/X5GM33







Flight design

Flight lines orientated to the Sentinel-2 orbit inclination 8.62°

Overlap % increased to get as many pixels at each angle (70%)

Speed (5 m/s)

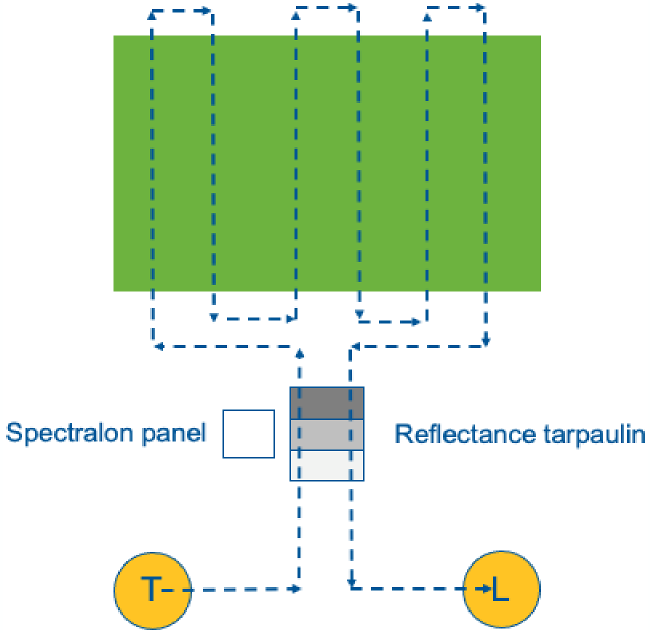
Height (100 m)

GSD resolution (6 cm)

} Optimised to ensure the UAV can cover the area within the battery limits

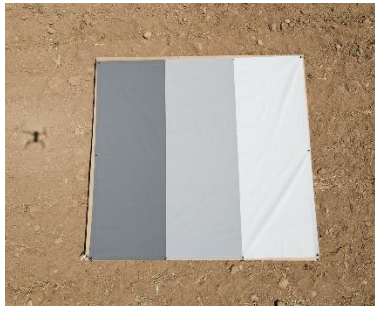
36 °C – 40 °C during measurements

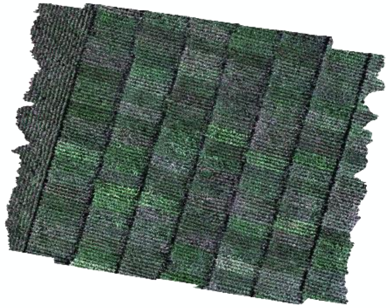
Corn field used for intercomparison exercise

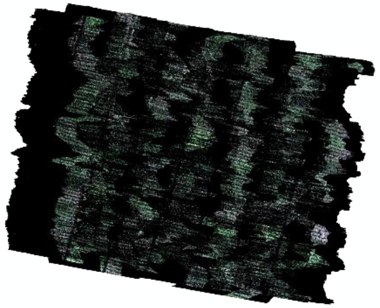


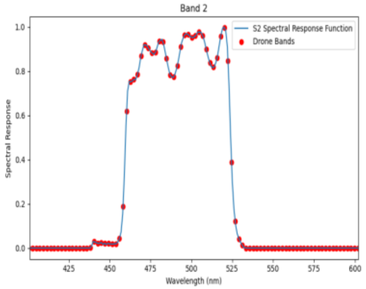
Flight plan including targets

Drone Processing









Convert to reflectance → Orthorectification → VZA filtering → Pixel matchup → Spectral response convolution

43% of pixels remaining

Match up Results

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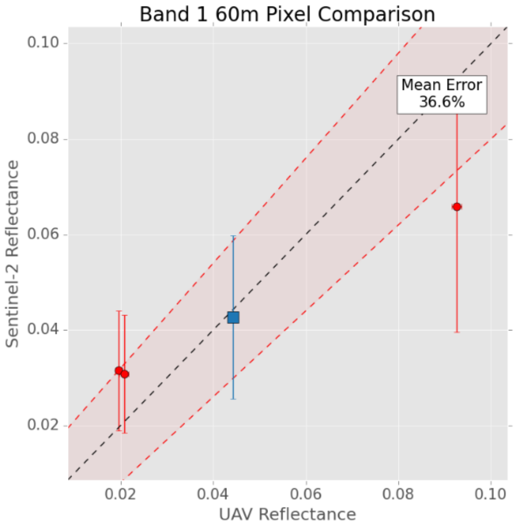
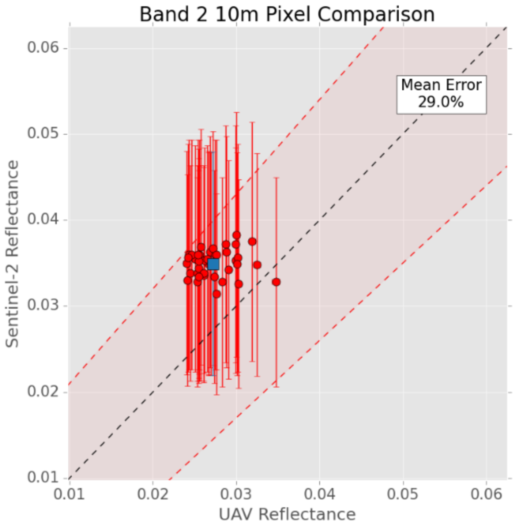
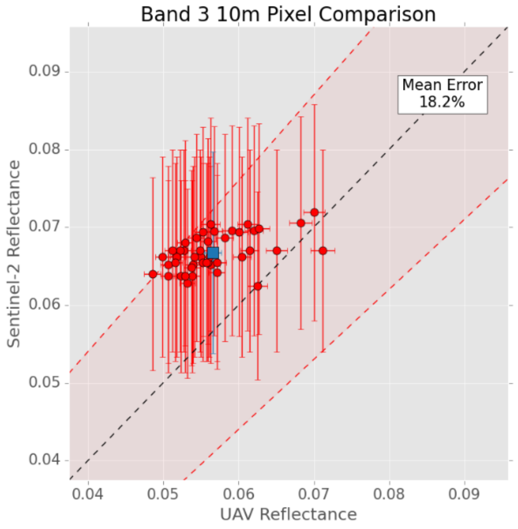
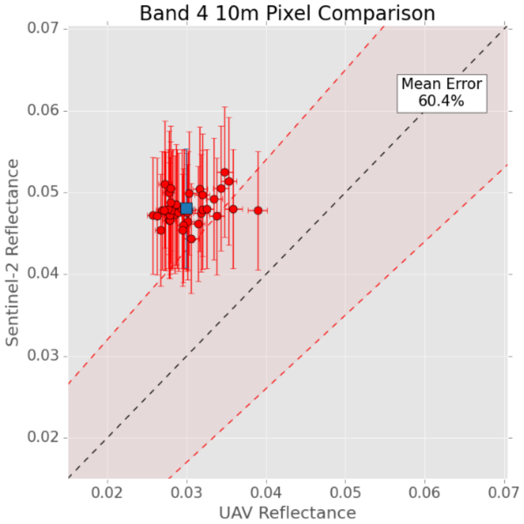
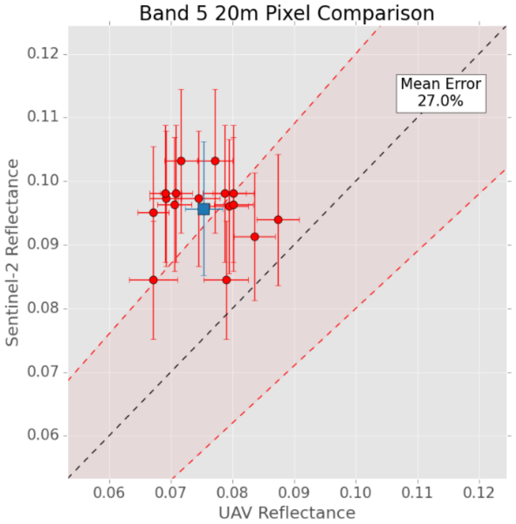
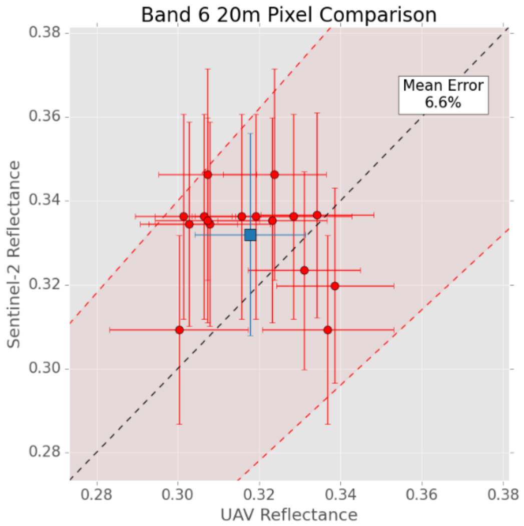




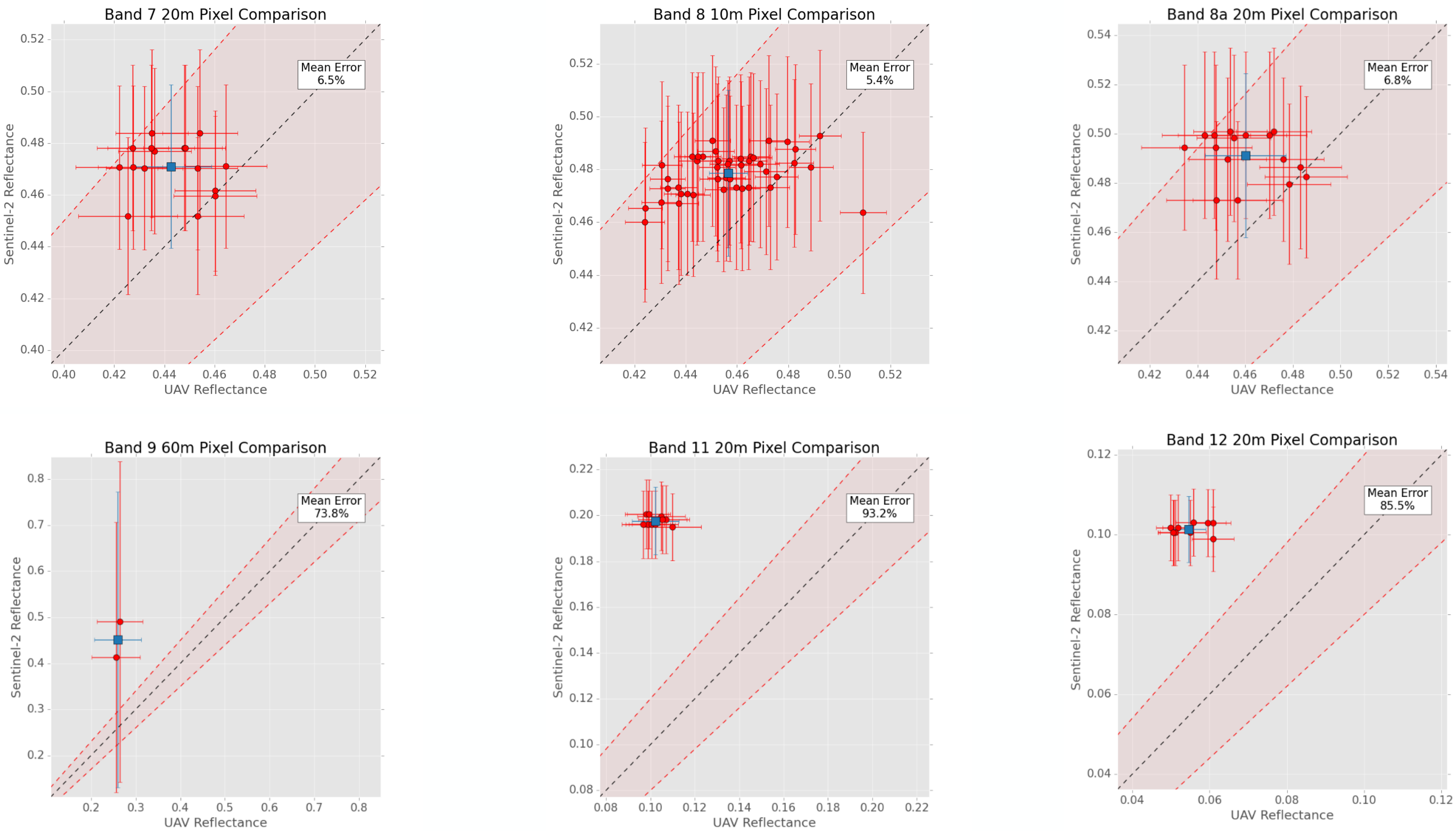








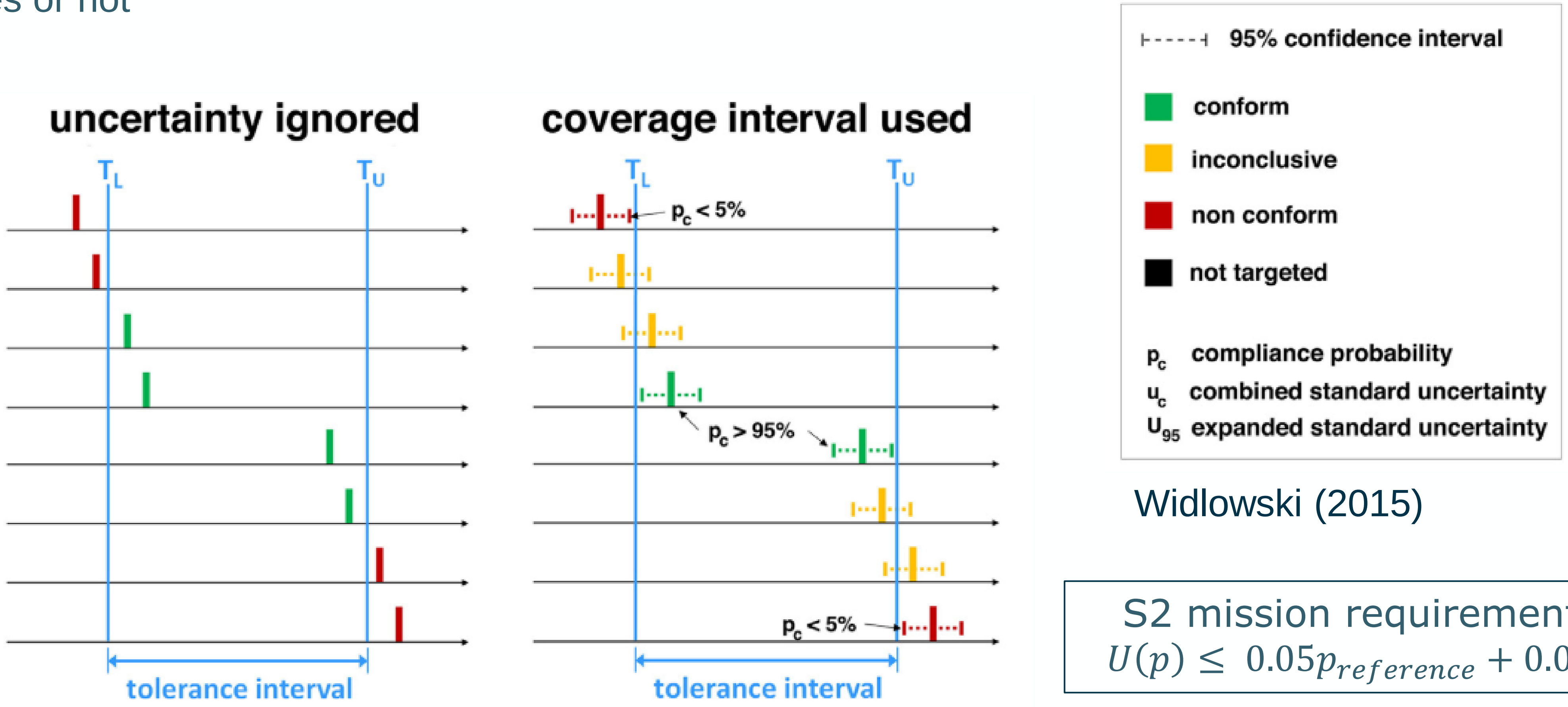
Match up Results



Conformity testing

- Conformity testing is the process that determines whether the estimated target quantity falls within the range of tolerable values or not

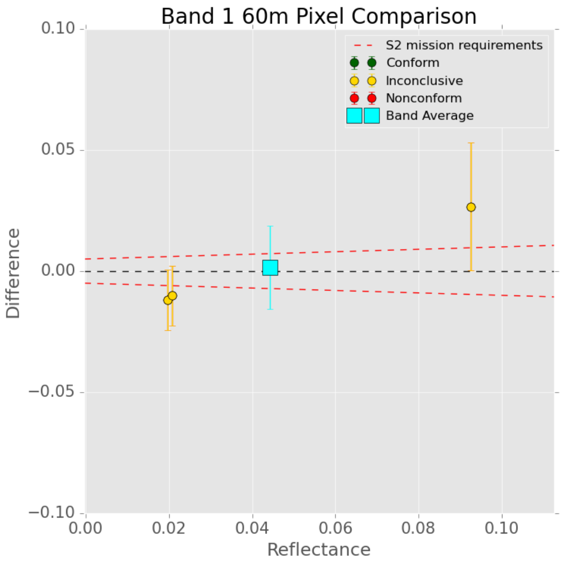
$$U_{diff} = \sqrt{{U_{sat}}^2 + {U_{drone}}^2}$$

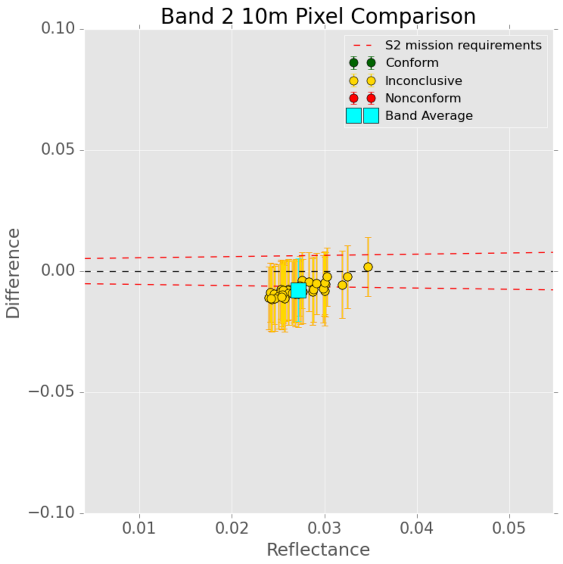


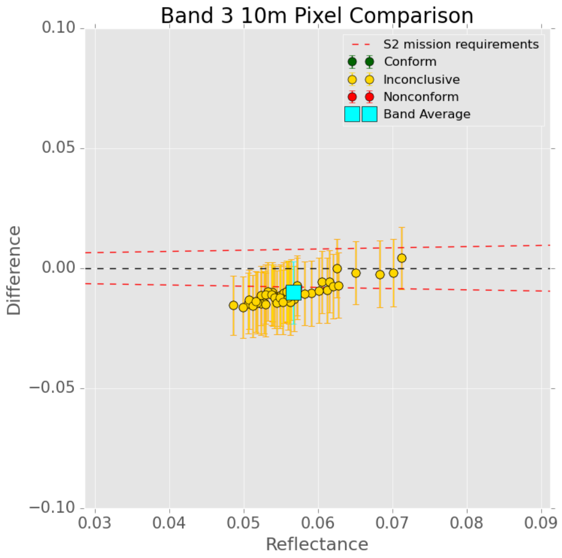
Widlowski (2015)

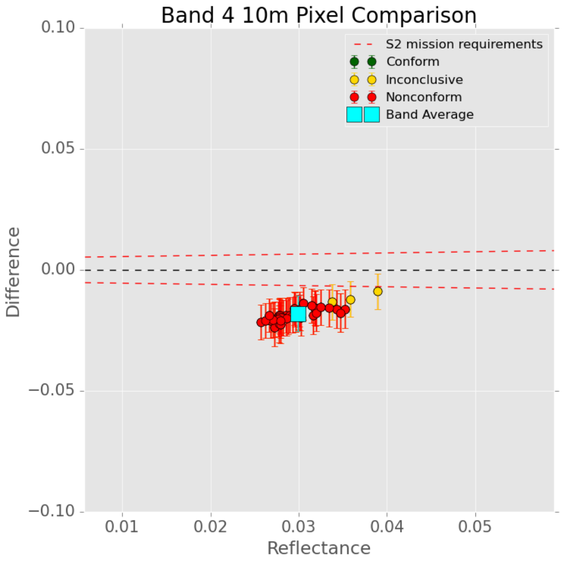
S2 mission requirements
$$U(p) \leq 0.05 p_{reference} + 0.005$$

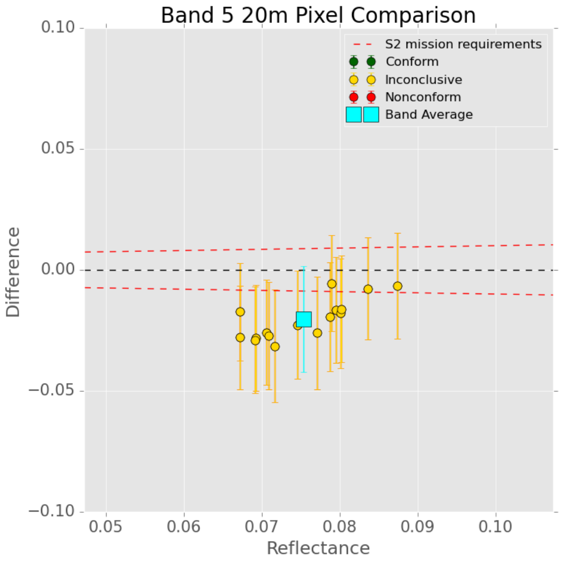
Conformity testing

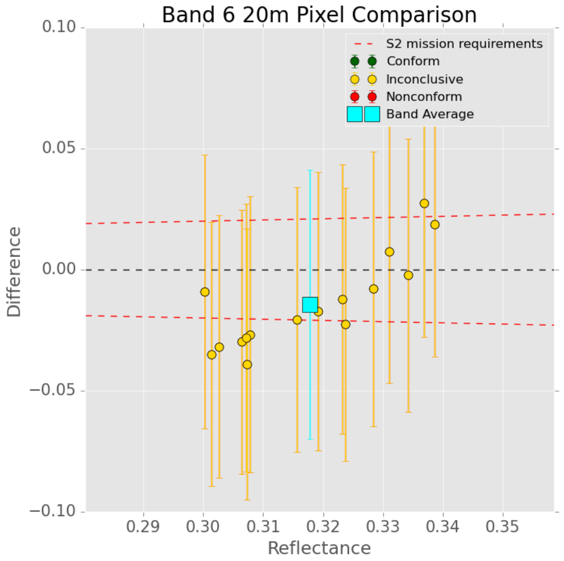




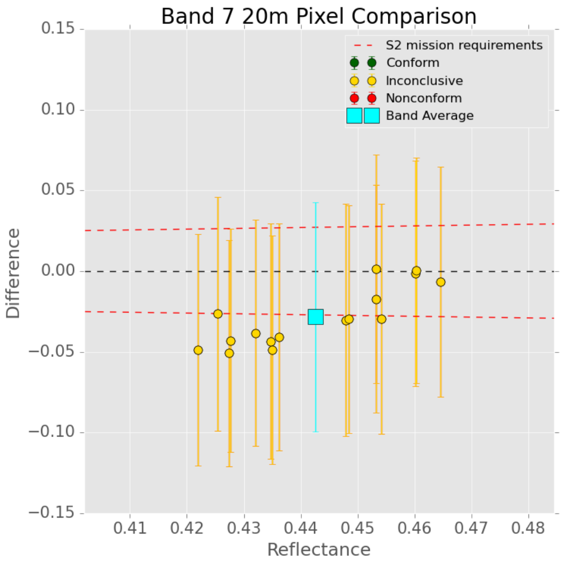


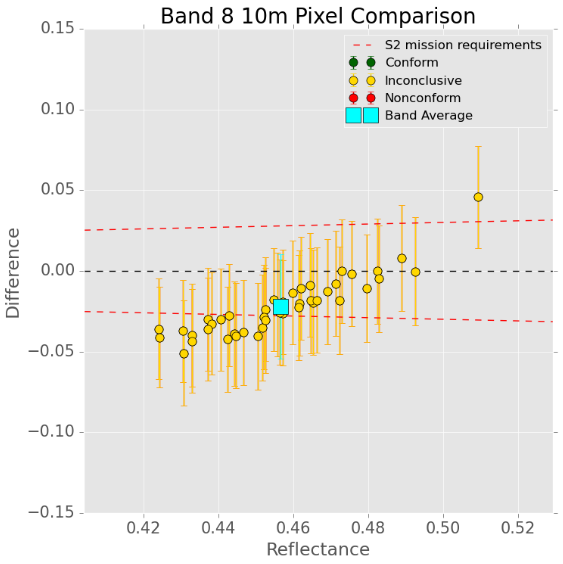


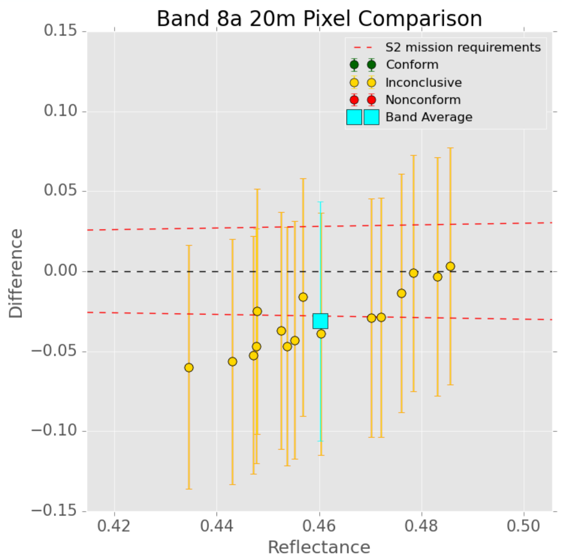


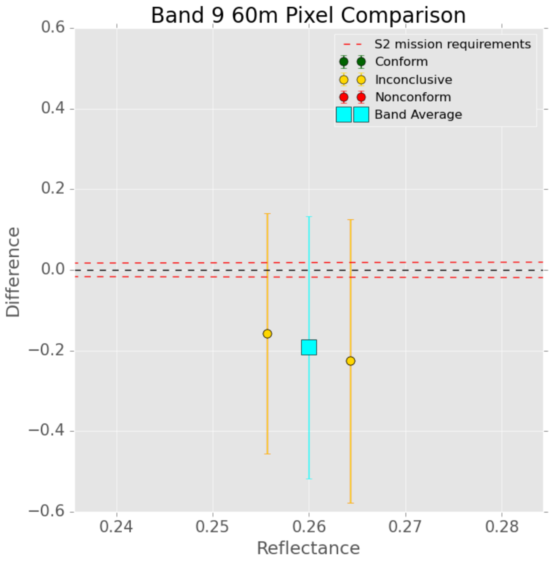


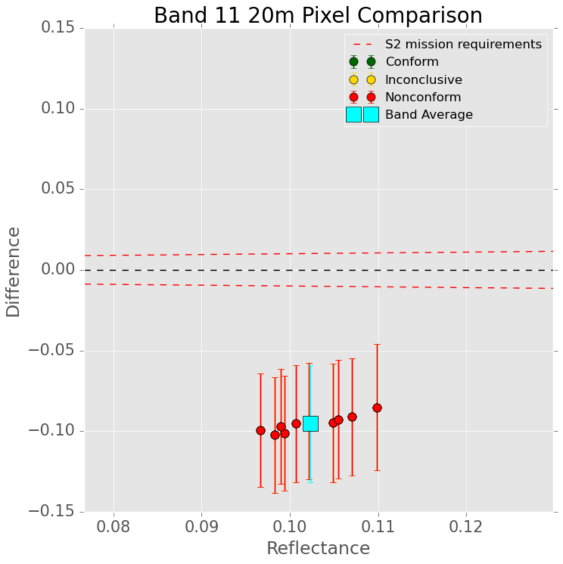
Conformity testing

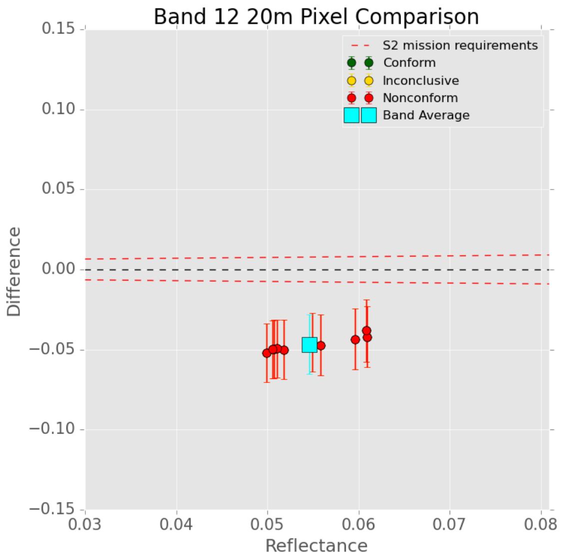












Conclusion

FRM4Veg is about:

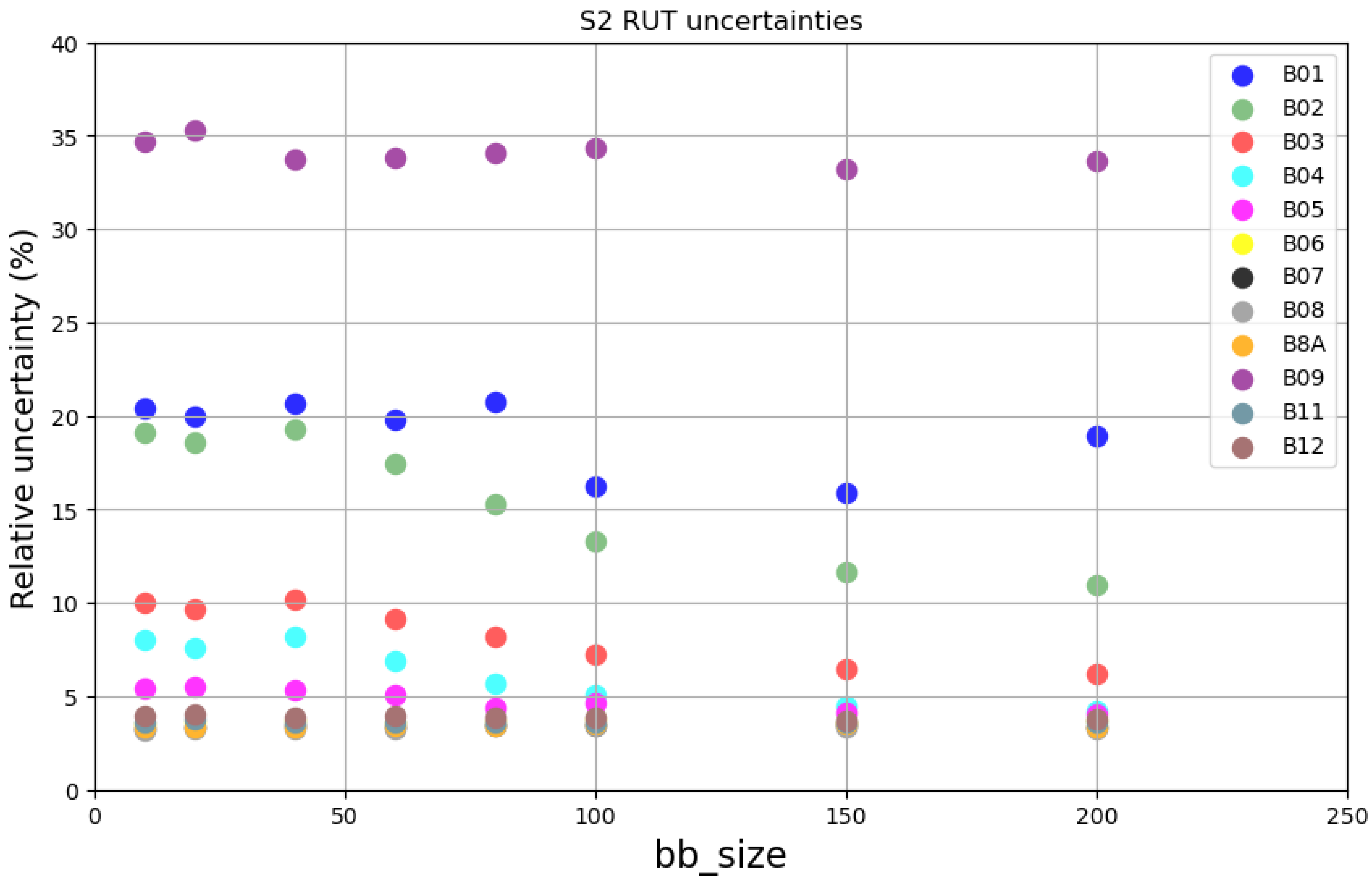
- Consistent and documented validation procedures
- Application of metrological principles to satellite validation
- Development of robust uncertainty estimates
- Providing fit-for-purpose validation data for vegetation products
- Utilising drones for SR is feasible and practical

SAVE THE DATE!

SRIX4VEG 2nd Workshop

23rd – 24th November

Conclusion


S2 RUT uncertainties
Relative uncertainty (%)
bb_size
0
5
10
15
20
25
30
35
40
0
50
100
150
200
250
B01
B02
B03
B04
B05
B06
B07
B08
B8A
B09
B11
B12