Satellite surface reflectance product validation under the Fiducial Reference Measurements for Vegetation (FRM4VEG) project

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FRM4Veg

National Physical Laboratory

FRM4Veg is focused on establishing the protocols required for traceable and independent in-situ measurements of vegetation-related parameters (**surface reflectance, FAPAR, CCC**) to support **Sentinel-2,-3 and PROBA-V product validation.**

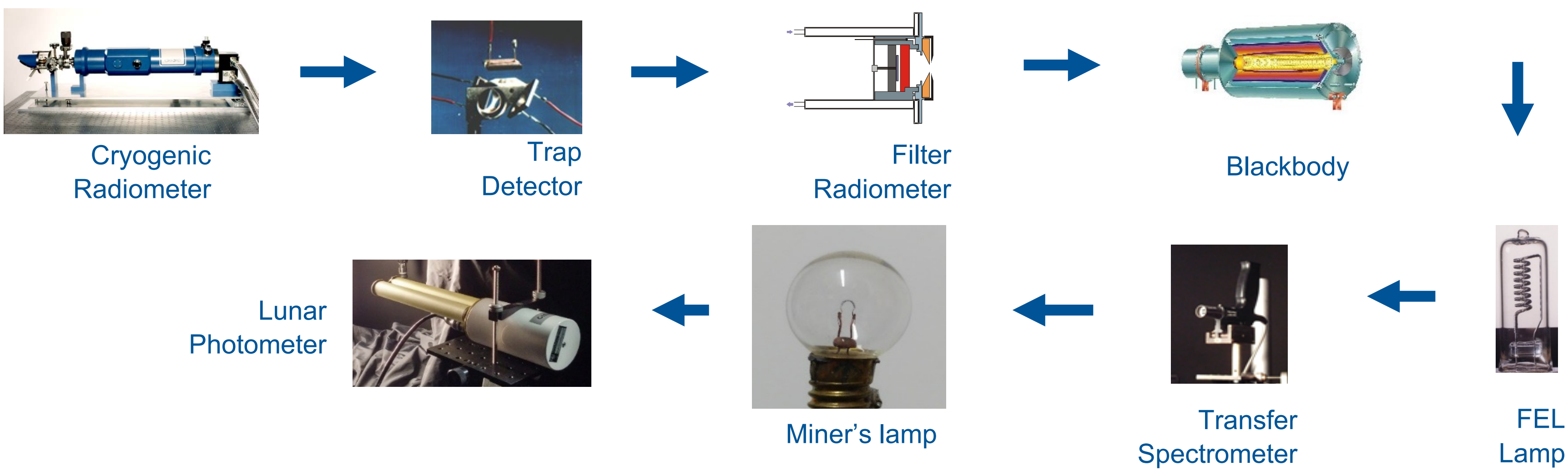
Phase 1 March ‘18 – March ’19

Phase 2 just started

fiducial reference measurements for vegetation

Traceability

"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" JCGM 200 (2012)

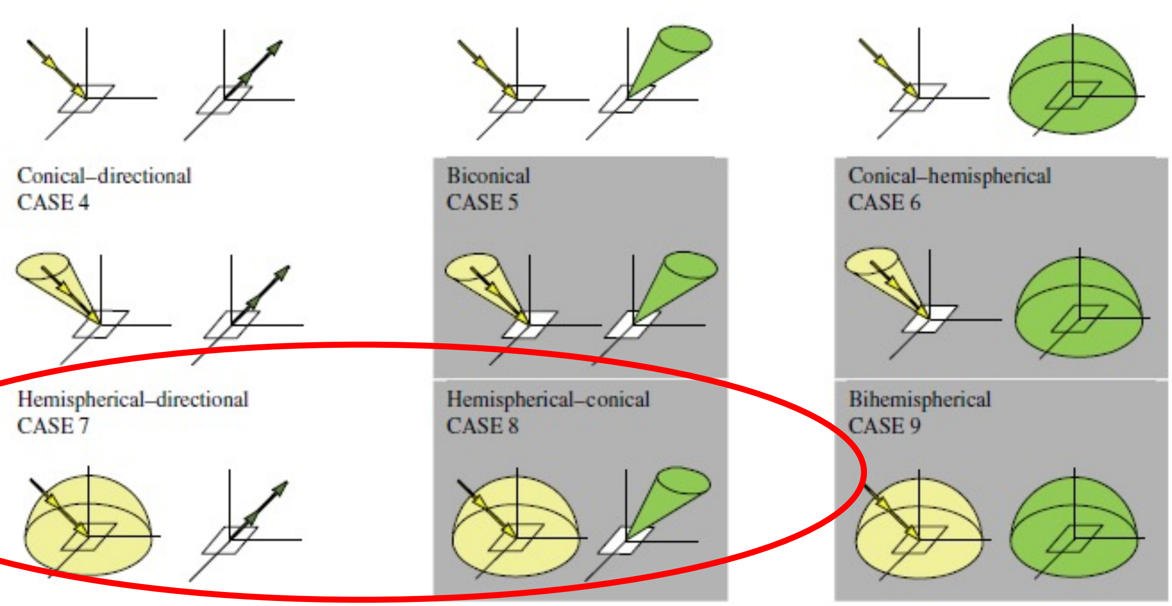


Presentation breakdown

- WP1: Validation and Traceability methods
- WP2: Campaign planning
- WP3: Campaign preparation
- WP4: Campaign execution
- WP5: Campaign data processing and delivery
- WP6: Uncertainty budget and algorithm improvements

Validation procedure

Within this we consider that validation is made up of three components:



Relation of incoming and reflected radiance terminology used to describe reflectance quantities

Incoming/Reflected	Directional	Conical	Hemispherical
Directional	Bidirectional CASE 1	Directional–conical CASE 2	Directional–hemispherical CASE 3
Conical	Conical–directional CASE 4	Biconical CASE 5	Conical–hemispherical CASE 6
Hemispherical	Hemispherical–directional CASE 7	Hemispherical–conical CASE 8	Bihemispherical CASE 9

Comp

procedure/conditions

Schaepman-Strub et al (2006)

Considerations: the site

Consideration	Barrax (w/ASD)
Likelihood of clear sky	High
Accessibility: moving around	Reasonable
Accessibility: canopy height	Good
Homogeneity	Good
Lambertianness	Ok
Canopy cover	Good
Size	Good
Time window	Feasible (trade-off required)
Topography	Flat

Considerations: the measurement

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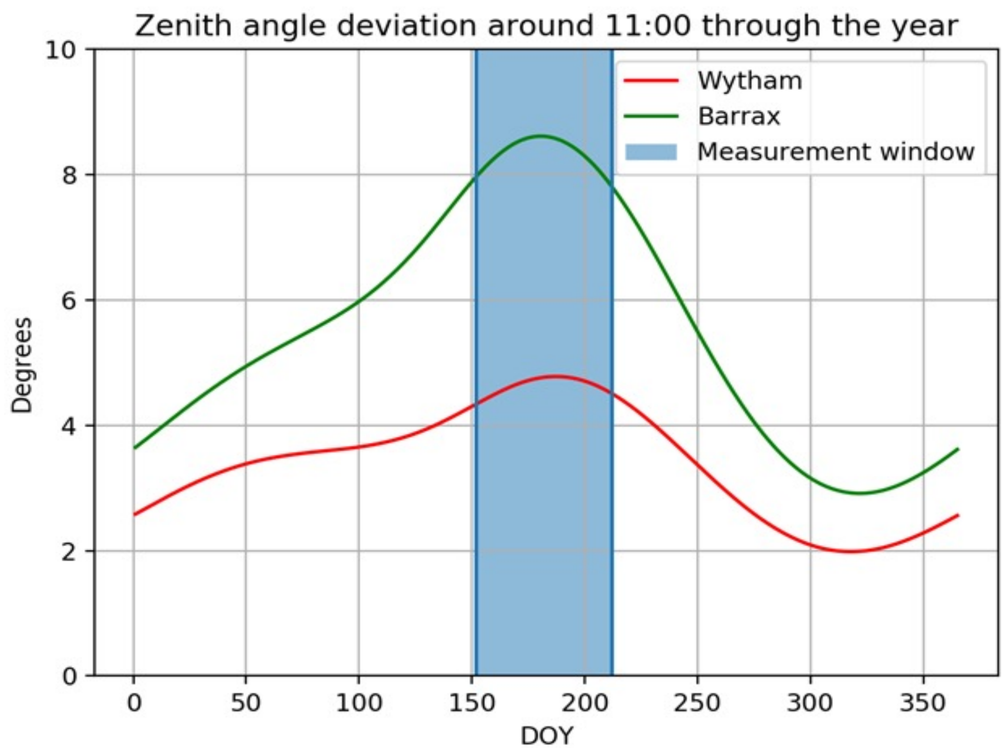
Consideration	ASD	UAV
IFOV (HCRF→HDRF assumption)	8°	<0.1°
DN→HDRF	Requires measurement of diffuse component and extra panel characterisation	Done directly with irradiance sensor
Sampling scheme	Point measurement	Wall-to-wall
Sample number	Trade-off based on site size	Same as above
Measurement speed	Slow (5 mins per sample)	Fast (10-20 mins for whole area)

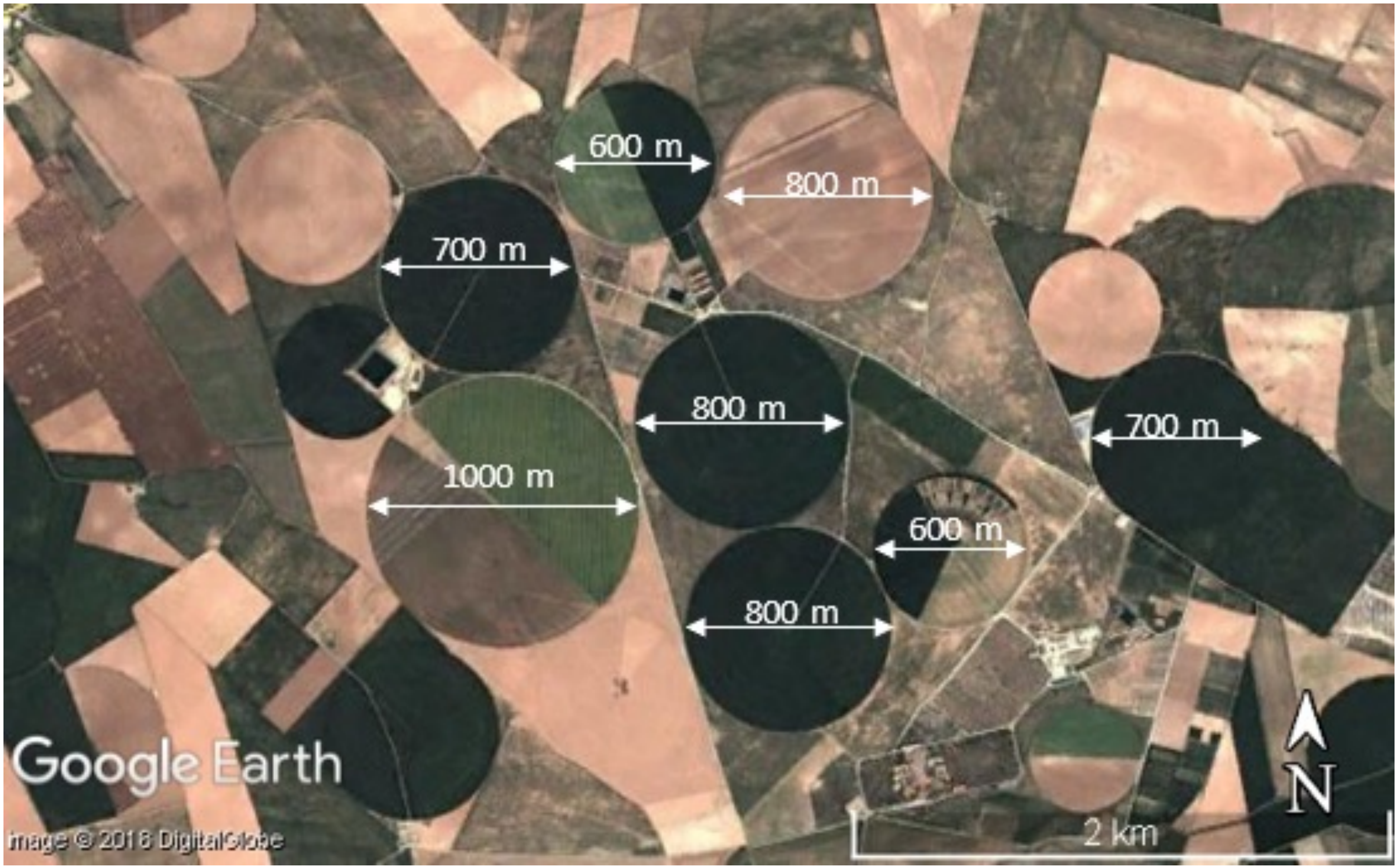
Data collection time

- The change in the illumination geometry within 30 minutes around 11:00 coordinated universal time (UTC) at Las Tiesas is high
- Meaning: challenging directional effects over Alfalfa fields - minimise the collection time (# samples vs directionality)



Size

Las Tiesas, Barrax, Spain (39.054 N, 2.101 W)



Map of Las Tiesas, with indicative field sizes. High spatial resolution image acquired in August 2012.

Instrumentation

ASD Fieldspec 4

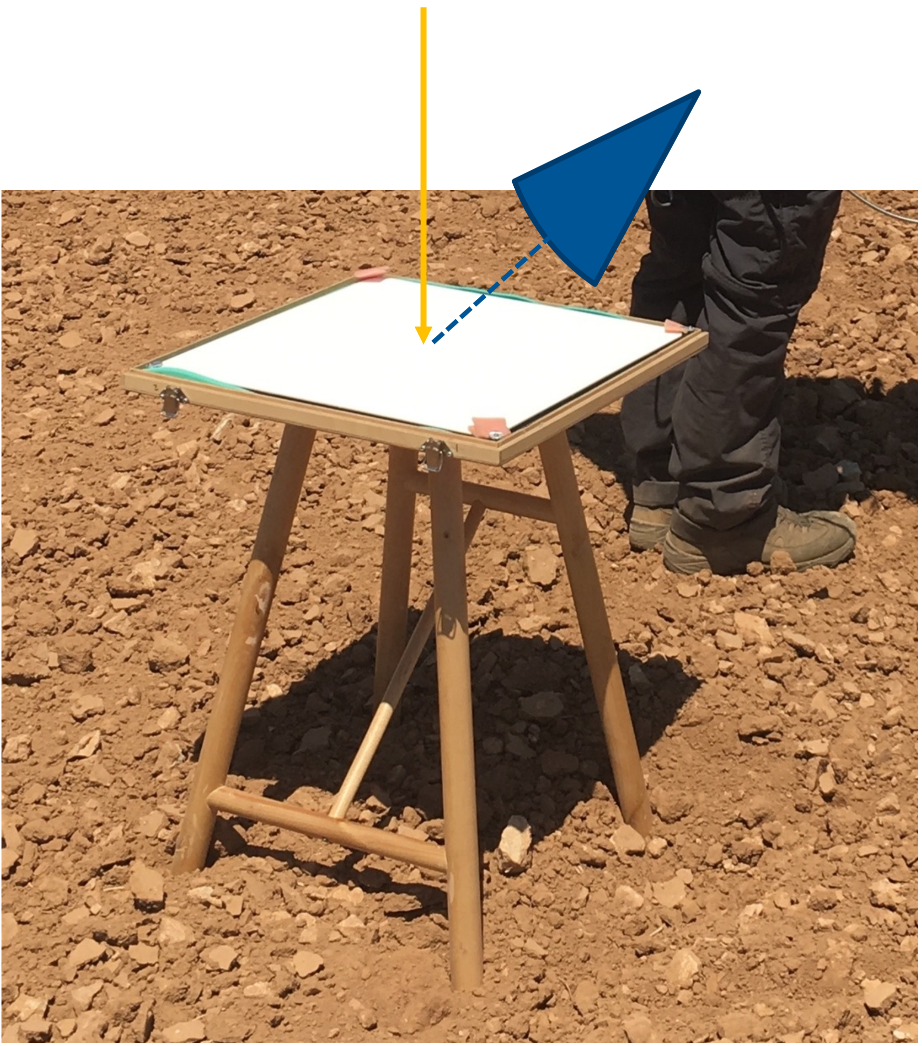
8° Field of view

Spectralon panel

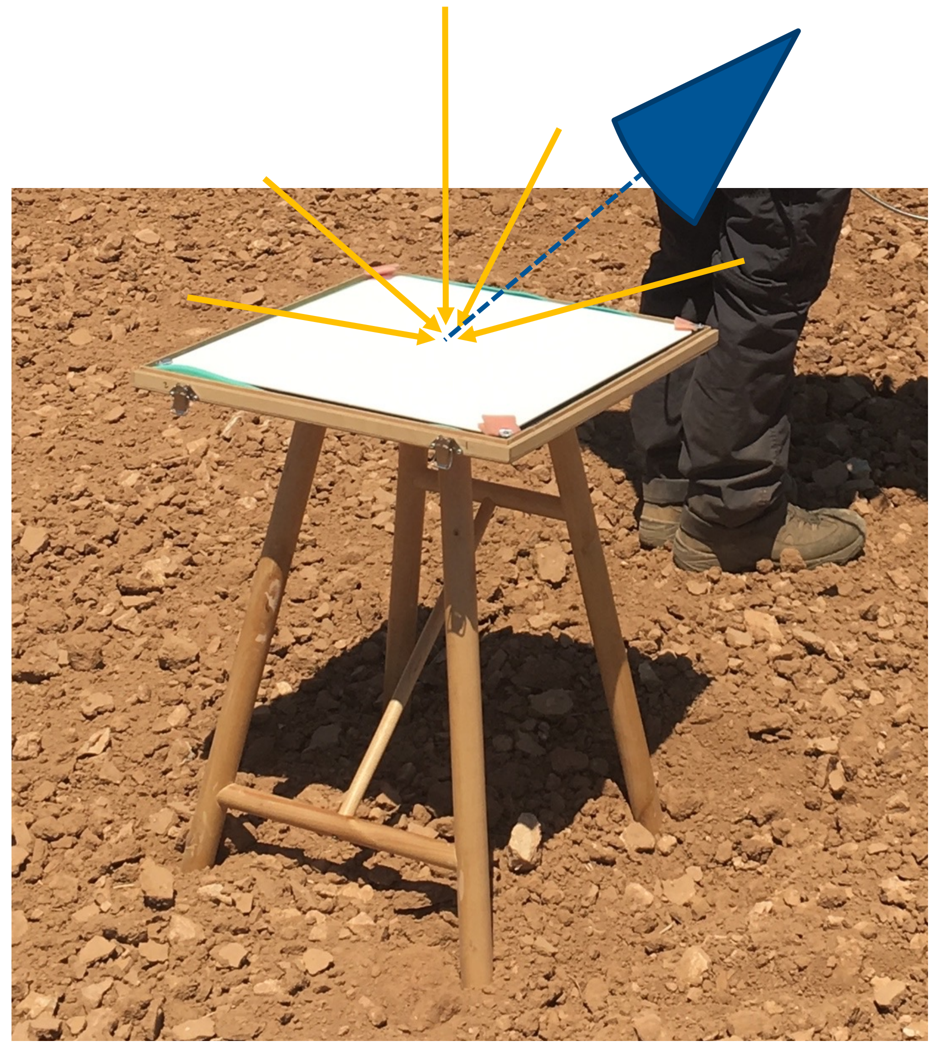
Microtops sunphotometer

DN→HDRF consideration

Direct case



Diffuse case



DN→HDRF consideration

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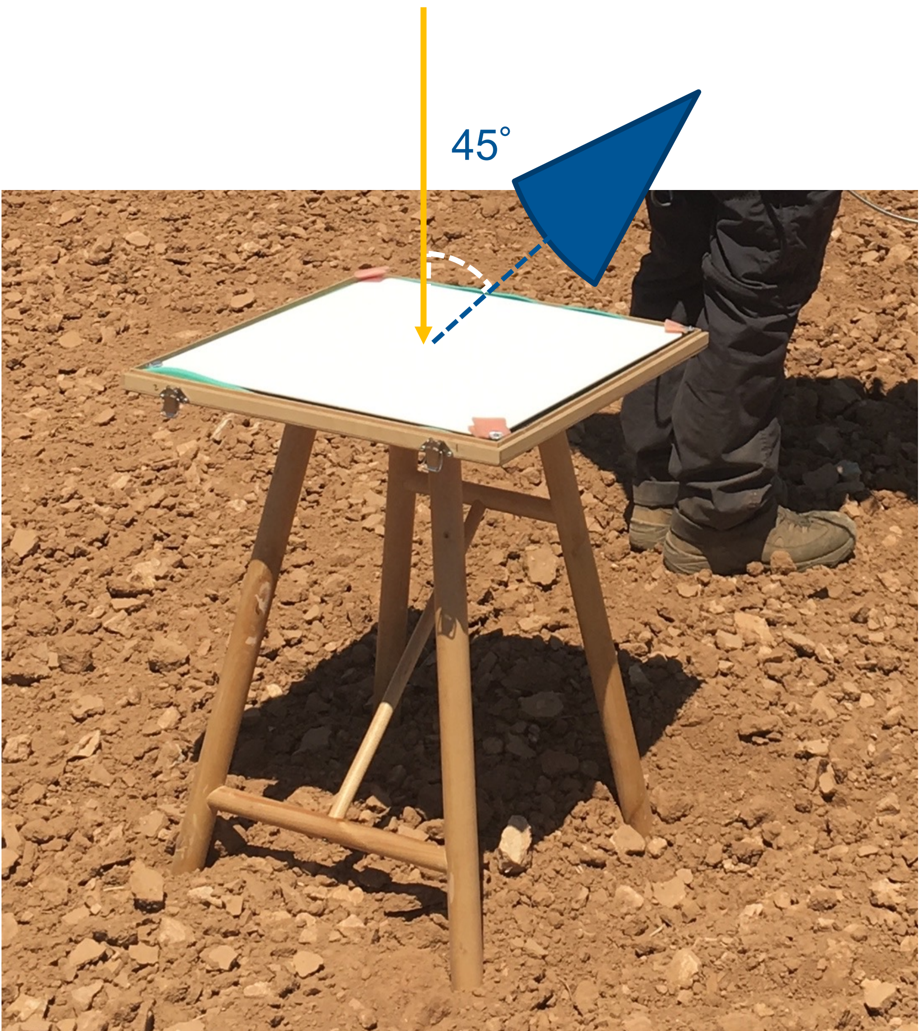
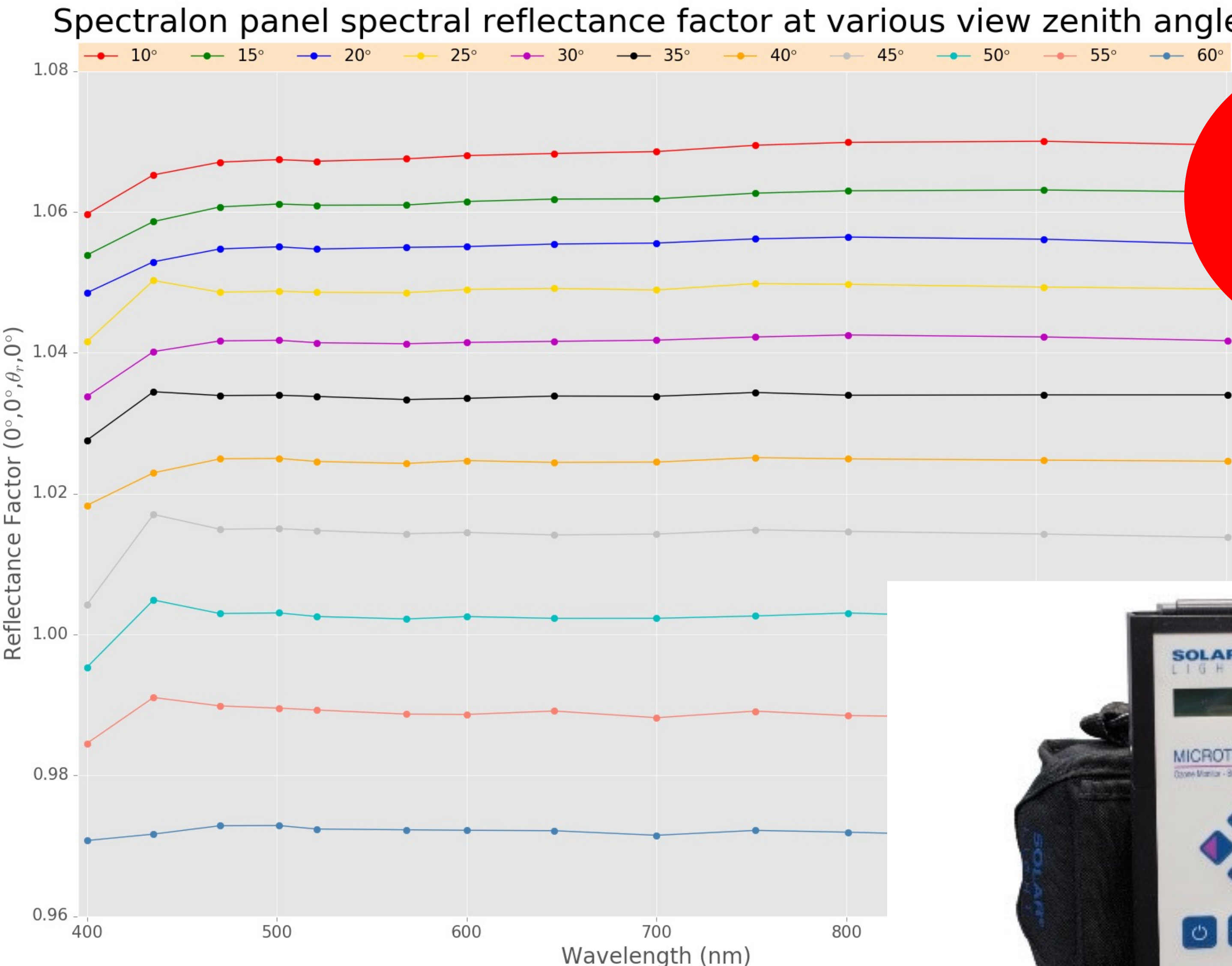
Lab conditions for calibration



Field conditions

Calibration and characterisation



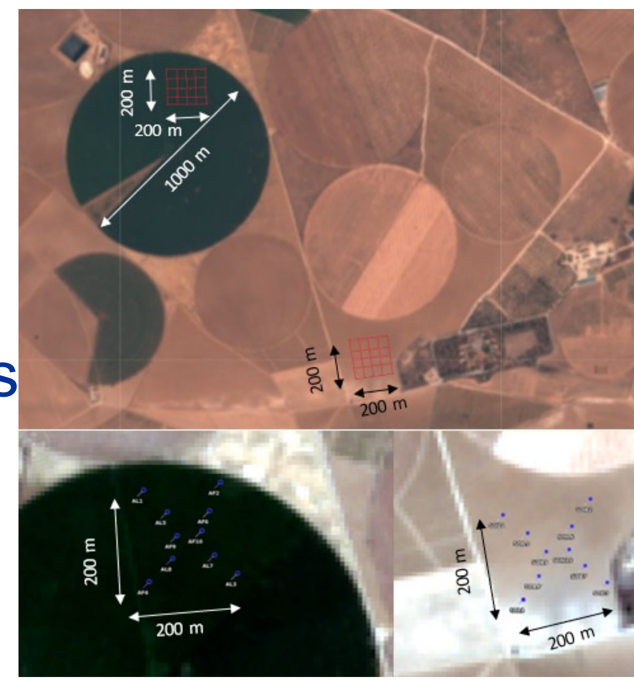
0 panel bration

Before ent

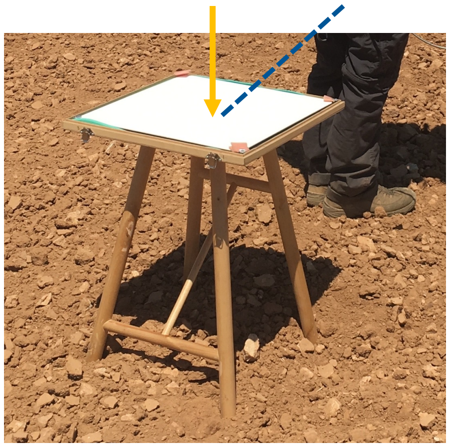
- $0°:\theta_v°$ panel calibration
- When it was new
- Angular correction

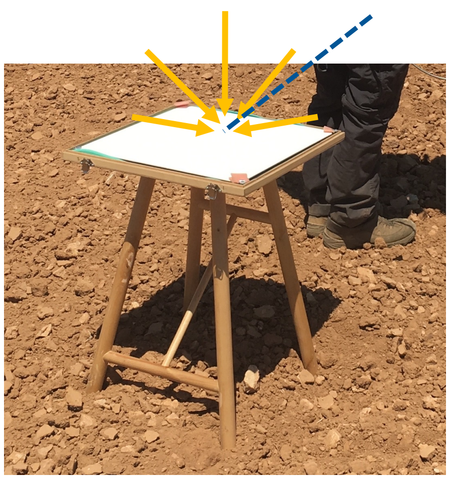
Campaign measurement

- Ten sampling locations in 200 m x 200 m area of interest
- Trade-off between the size of the area to cover and the time taken by the instrument and travel between sample locations.
- Sample locations at least 50 m from the edge of the land cover→ minimise edge effects from adjacent cover types when viewing the site from Sentinel-2 MSI (i.e. > 1 pixel).
- Measurement sequence at each location: six individual measurements (one of the reference panel, four of the surface, and another of the reference panel). Each individual measurement is made up of ten scans In total, sixty scans are collected per location.



Processing





We need to:

1. Determine the diffuse/direct illumination ratio
2. Derive the calibration coefficient specific to the time of measurement and apply
3. Convolve calibrated HDRF with S2 spectral bands

Simple…

From a measurement perspective

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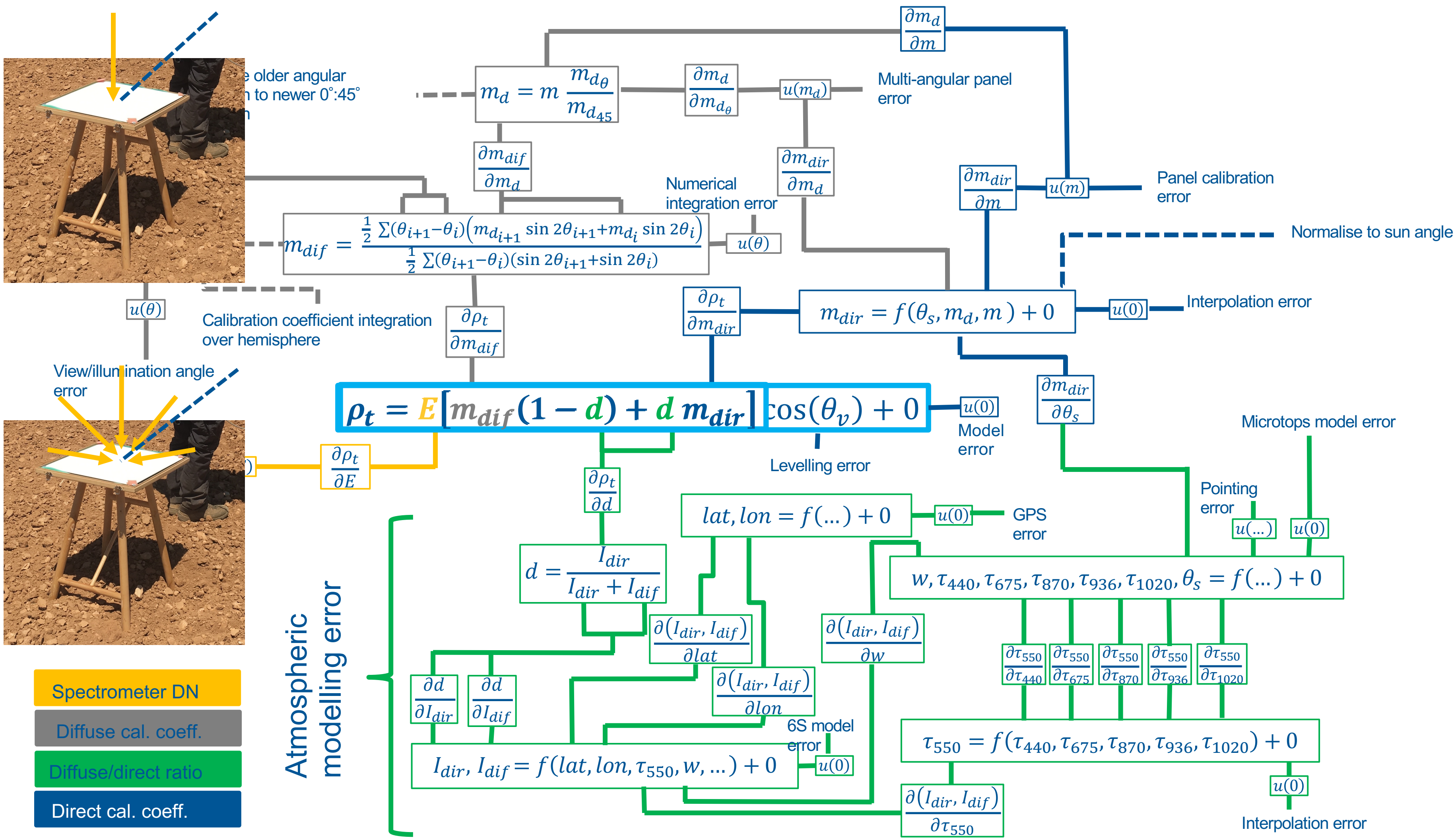

S2A Product assessment

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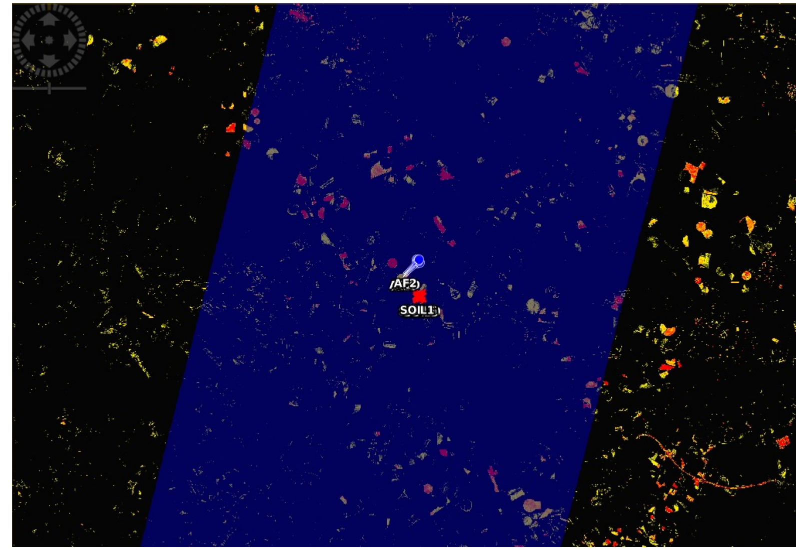
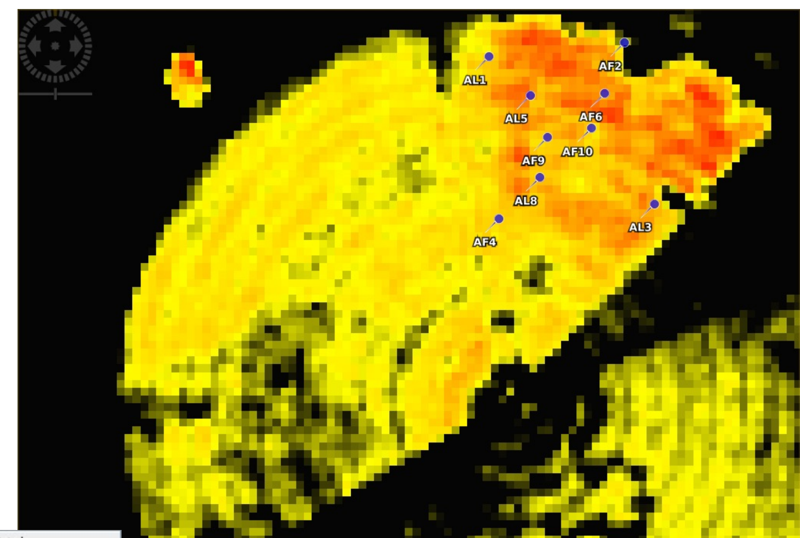
- Barrax overpass middle of the detector 10 (there are 12 staggered) → Low effect of the spectral non-uniformity issues.
- 2nd of August 2018 overpass with no defective pixels, cloud, cirrus, saturated…
- Sen2Cor classification: Alfalfa as "vegetation" and soil as "bare soil"
- SZA 25°. Spectralon correction required
- VZA 6° in forward scattering plane. i.e. no hot-spot or large non-nadir effect





Colour	Value
black	0.48
yellow	0.51
orange-yellow	0.54
orange	0.57
red	0.6

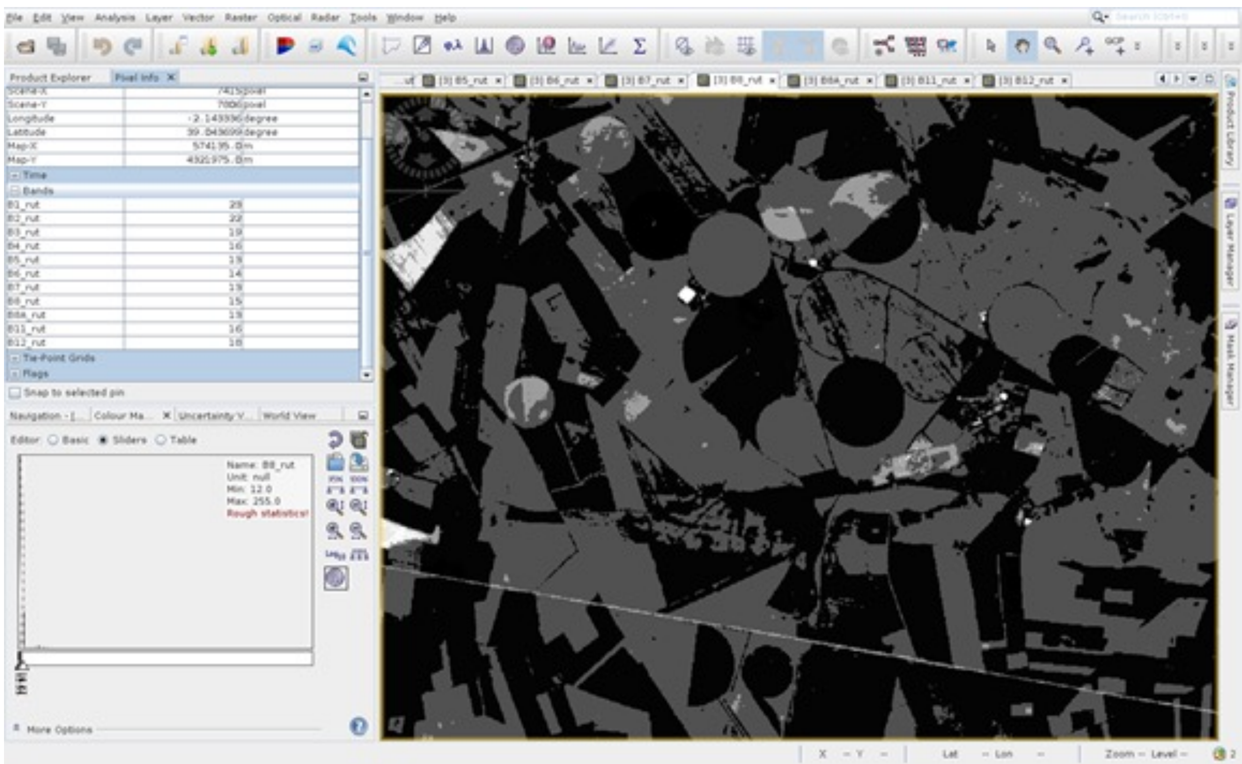
Uncertainty analysis

- Three main strands of work:
- In situ data uncertainty:
  - ASD calibration uncertainty, pointing accuracy, spectral stray-light…
  - CURUC
- S2 L2A uncertainty:
  - L1 uncertainty done through radiometric uncertainty tool (RUT)
  - ROI uncertainty also done through RUT
  - L2 propagation through Sen2Cor
- In situ to S2 transfer:
  - Spectral uncertainty (see example below)
  - Geometric (spatial) uncertainty (different techniques)
  - ~~Angular uncertainty S2-ASD (comparison using default BRDF models)~~

S2A L2A uncertainty

- L1C uncertainty has been processed using the S2-RUTv2 over a ROI considering the correlated components

```
S2_L1C_ROIUNC = {'AL': [2.4, 2.3, 2, 2.5, 1.5, 1.3, 1.2, 1.2, 1.2, 1.2, 1.6, 2],
                 'SOIL': [2.2, 2, 1.6, 1.3, 1.2, 1.4, 1.2, 1.4, 1.3, 1.3, 1.6, 1.8]}
```



- L2A uncertainty is not provided yet as a systematic process. Specific effort is needed in the near-future.

S2A L2A uncertainty

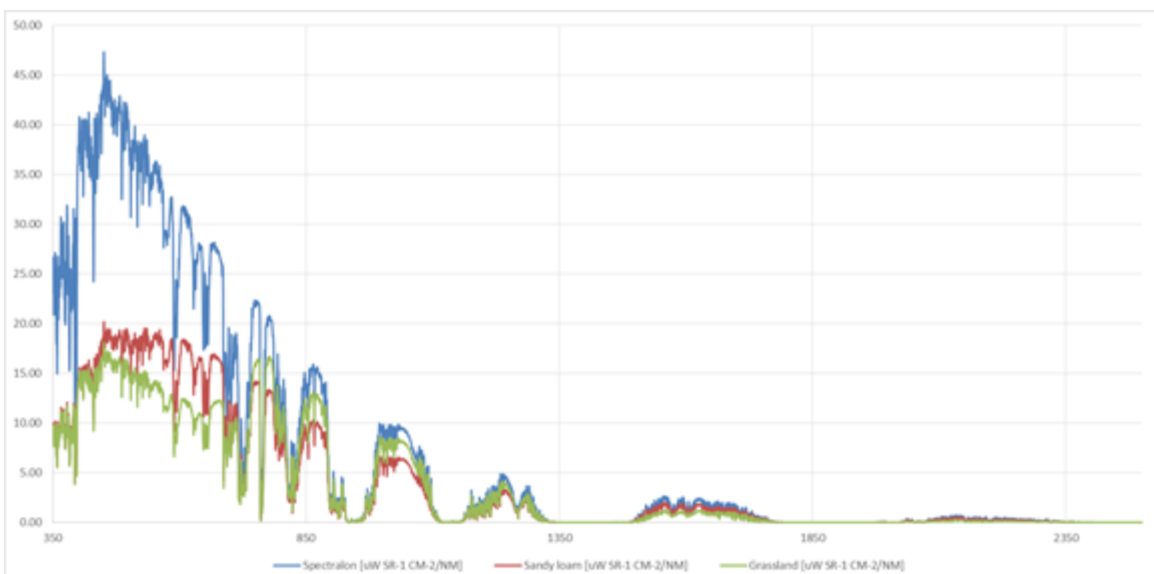
Through Sen2Cor, several key components:

- Aerosol optical thickness
- Water vapour
- Atmospheric correction code

- MC involves copying the S2 file and altering the JPEGs to reflect each sample from unc. distribution out of the RUT
- Bring in 6S to estimate the posterior distribution resulting from changes in AOT and water vapour
- Estimate of AC uncertainty from Richter & Schläpfer (2016)

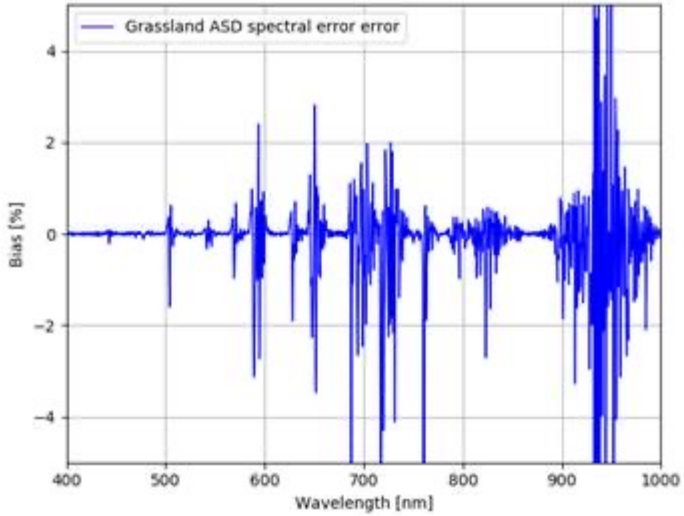
Spectral uncertainty

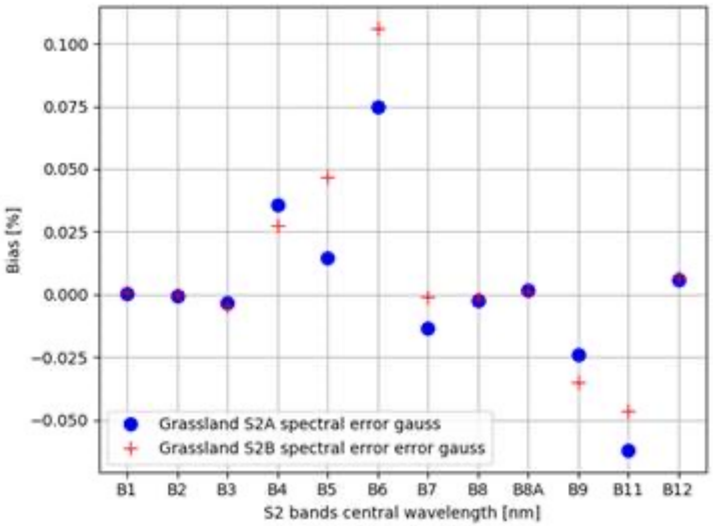
- Joint effect of the in-situ measurements and the satellite spectral response. The study brings in the following effects: 1) ASD spectral sampling/resolution, 2) ASD spectral knowledge and 3) S2 spectral knowledge.
- Reference spectra is “realistic” surface reflectance signals as would be measured in the Barrax site. We have used MODTRANv5 in order to simulate radiance signals at surface level for a “spectralon”, “grassland” and “sandy loam”.



Spectral uncertainty

- The results show the low impact of the ASD spectral resolution/sampling in the S2 reference measurements. The ASD per-band uncertainty is larger and for specific wavelengths can be considerable (especially if absorption peaks are close to the measurement area). These errors are random in nature and when convolved with sufficiently broad bands, as the case of S2, the uncorrelated nature of the errors produces a much lower effect on the S2 bands.
- Left image is single channel error of ASD





Uncertainty budget

Condensed uncertainty budget for in situ measurements

Source	**Distribution**	**Uncertainty level (k=2)**	**Correlation / comments**
Direct panel calibration	Gaussian	0.75% (400 nm<λ<800 nm) 2.3% (λ>800 nm)	Systematic (all)
Diffuse panel calibration	Gaussian	1% (all wavelengths)	Systematic (all)
ASD raw counts	Rectangular	Variable (w. wavelength) Max 80%, Min <1%	Random (between measurements)
Diffuse/direct ratio	Gaussian	4-10% (λ<500 nm) 1-4% (λ>500 nm)	Systematic (all derived from one AOD measurement)
Levelling	Gaussian	2%	Random (between measurement)

SR Val Results - Barrax

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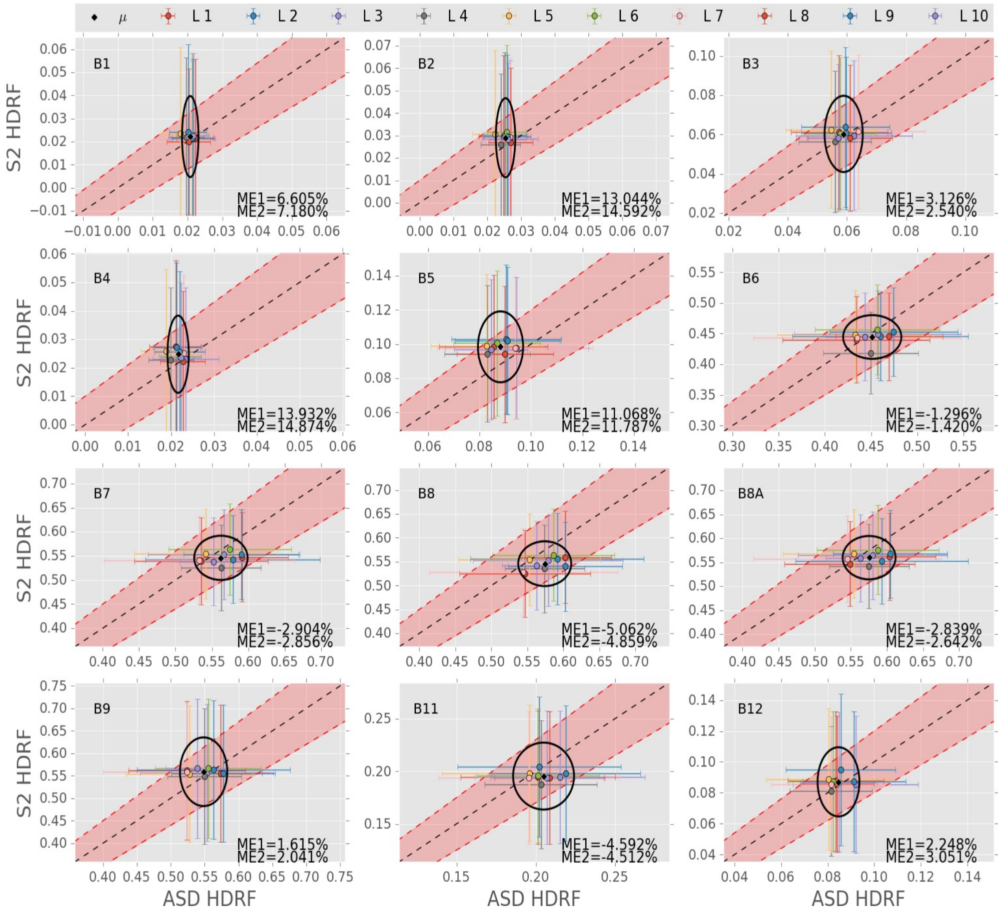
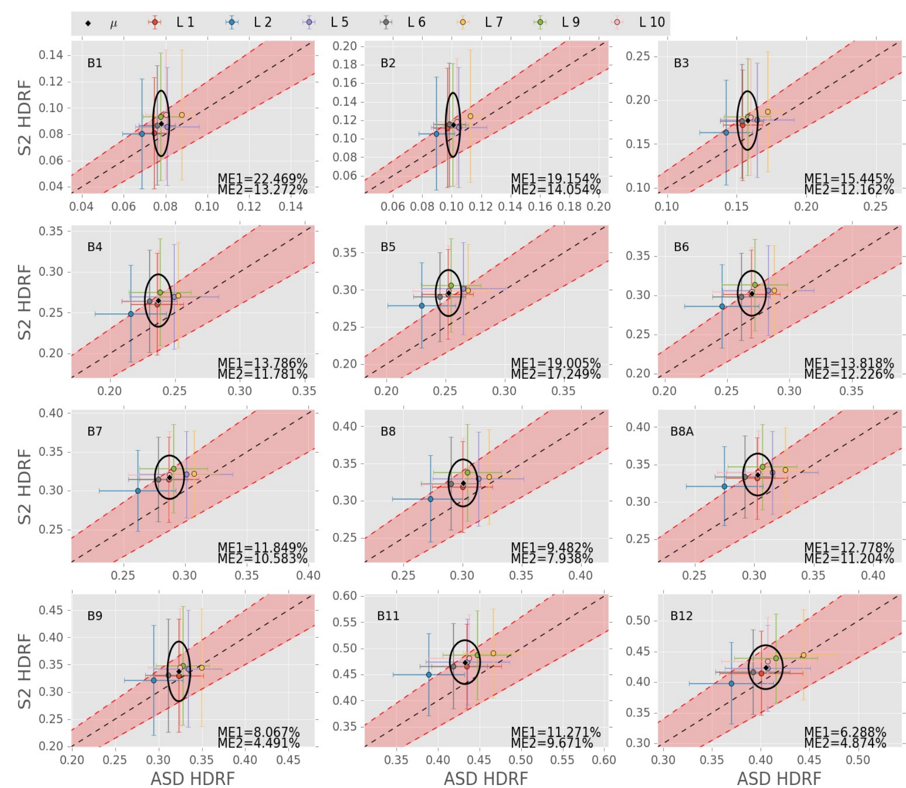


(<) Alfalfa

Sentinel-2 surface reflectance product agreed (within the stated uncertainty) with the ground data collected over the Alfalfa field at both the pixel and area scales



Bare soil (>)

Lower level of agreement due to mismatch in overpass vs. sampling and non-uniformity issues

Origo et al. (2020)

Uncertainty S2

S2A	$\sigma(\rho^{6S}_{L2A})_{Alfalfa}$			$\sigma(\rho^{6S}_{L2A})_{Soil}$		
	TOA	TOA + AOT + WV	TOA + AOT + WV + AC	TOA	TOA + AOT + WV	TOA + AOT + WV + AC
B1	13.3%	19.6%	79.1%	5.4%	6.7%	26.1%
B2	9.6%	14.3%	61.4%	4.0%	4.8%	28.8%
B3	4.6%	6.6%	32.0%	2.5%	2.9%	18.4%
B4	6.3%	9.7%	54.9%	1.8%	1.9%	11.9%
B5	2.7%	3.7%	21.2%	1.6%	1.7%	10.3%
B6	1.6%	1.7%	8.0%	1.6%	1.7%	9.3%
B7	1.4%	1.4%	8.4%	1.6%	1.7%	8.7%
B8	1.6%	1.8%	8.6%	1.9%	2.0%	9.6%
B8A	1.7%	1.8%	8.1%	1.9%	1.9%	8.2%
B9	2.8%	11.2%	13.7%	3.0%	11.5%	15.7%
B11	2.2%	2.3%	16.3%	1.8%	1.8%	8.7%
B12	3.2%	3.3%	25.85%	2.0%	2.1%	8.3%

ASD FOV issues…

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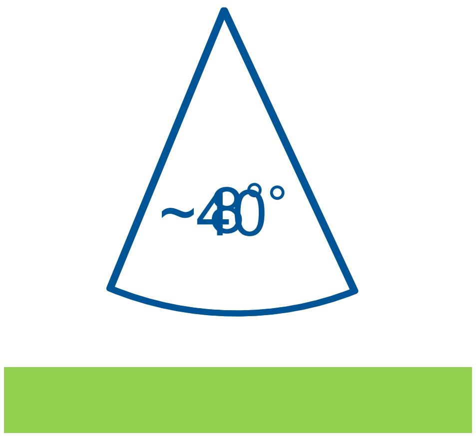
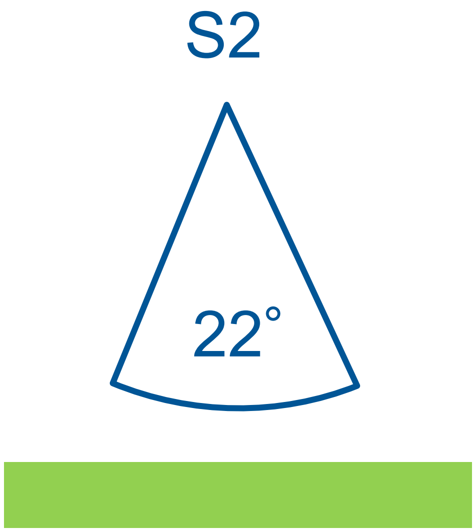


FOV of focal plane – each pixel ~0.1˚



FOV of focal plane – each pixel << 0.1 ˚

Validation of surface reflectance using an ASD is limited by broadness of viewing optics and lack of pointing agility.

Proposed improvements / lessons learnt

- [**Reference measurement**] moving towards more explicit treatment of diffuse component
  - Either using a dedicated sensor
  - Or modelling (e.g. Zibordi-Voss model)

- [**Calibration transfer**] we need to account for directional effects
  - in the field
  - reflectance panels

If we want to reach new validation uncertainty levels demanded by the community

Spectral sunshine sensor

Conclusions

- Barrax campaign has stretched the utility of the ASD for this kind of work to the limit, although if more work is done with this then gains can be made by:
  - Measuring spectral diffuse/direct ratio
  - Angular characterisation of reflectance panels
  - Improved sampling

- Proper treatment of uncertainty can be difficult to implement for satellite products

- Proper treatment of uncertainty in the validation data requires understanding of the measurement equation and experimentation to determine which factors need to be considered

Questions…

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References:

- Origo et al (2020) Fiducial Reference Measurements for validation of Sentinel-2 and Proba-V surface reflectance products. *Remote Sensing of Environment*, **241**:111690

- Richter, R. & Schläpfer, D., 2016. Atmospheric/Topographic Correction for Satellite Imagery (ATCOR-2/3 User Guide, Version 9.0.2, March 2016). In: Technical report. ReSe Applications Schläpfer

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

Spectral uncertainty

- `Error = [100 * (((s2a_asdmeas / s2a_asdspectralon) - (s2a_fullmeas / s2a_fullspectralon)) / (s2a_fullmeas /s2a_fullspectralon))`
- `s2a_asdmeas` Refers to the “grassland” or “sandy loam” reconstructed “as measured” by the ASD
- `s2a_asdspectralon` Refers to the “spectralon” reconstructed “as measured” by the ASD
- `s2a_fullmeas` Refers to the “grassland” or “sandy loam” MODTRANv5 original signal
- `s2a_fullspectralon` Refers to the “spectralon” MODTRANv5 original signal
- The results produces a per-S2band spectral resolution/sampling error as well as an ASD per-band uncertainty. Here the results for ASD grassland in the VNIR and for each of the S2 bands again in “grassland”.