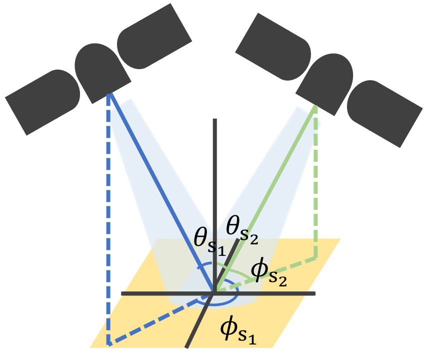
TRUTHS studies for Sensor-to-Sensor Calibration

ESR3 – TRUTHS for Climate Workshop 27/06/2024

Maddie Stedman, Sam Hunt, Nigel Fox (NPL)

Calibration & Validation Techniques



Simulated References

PICS Sites

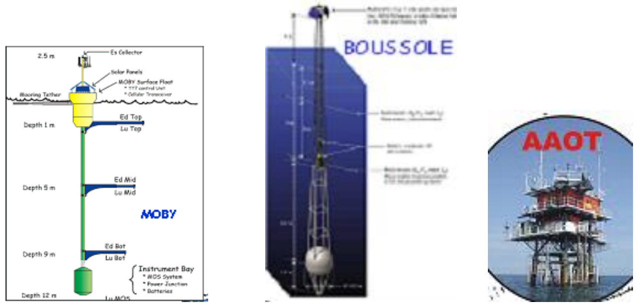
esa

truths

Natural Phenomena

RadCalNet

SI



Ocean Observations

Field Measurements

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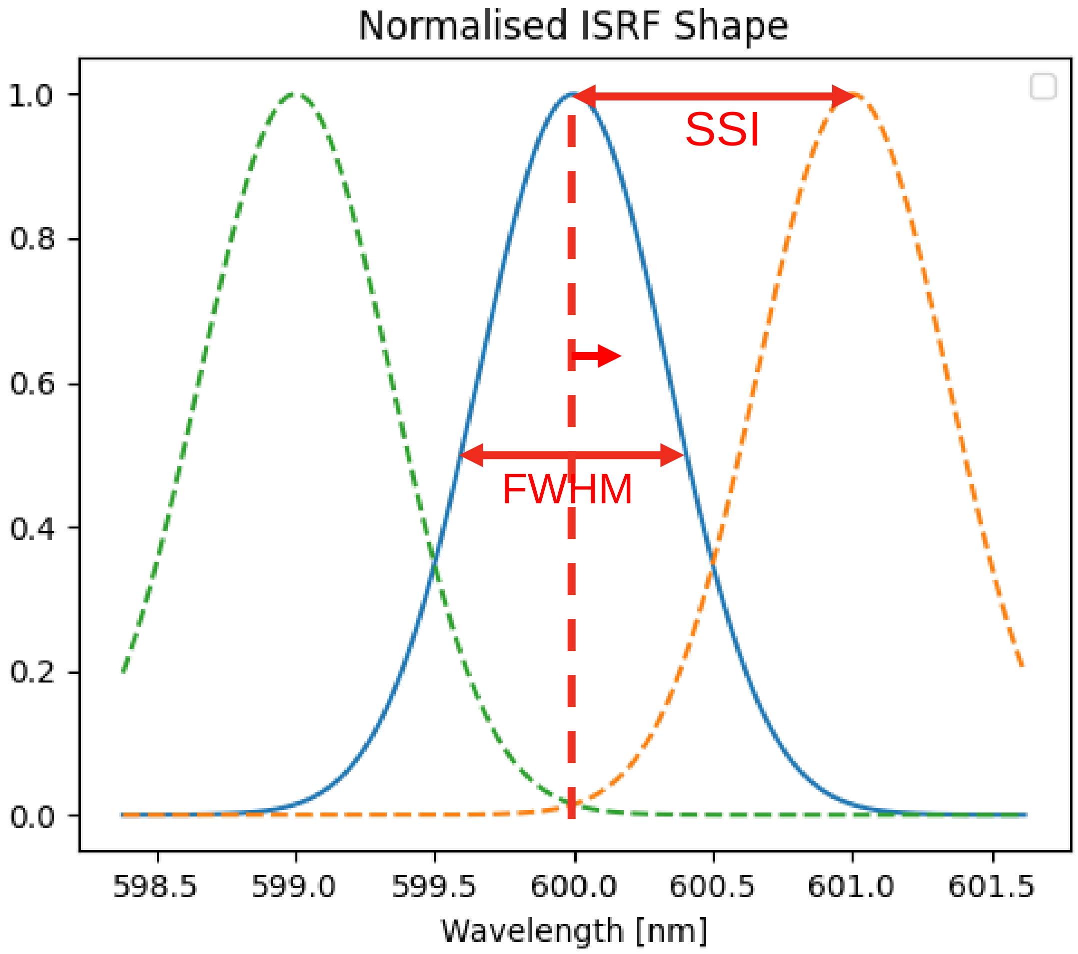
BAND SPECIFICATION ANALYSIS

TRUTHS Spectral Band Specification

Undertook analysis to evaluate requirements for HIS spectral band specification

Spectral Band Parameters investigated:

- Bandwidth (FWHM) and spectral sampling interval (SSI)
- ISRF knowledge:
  - Central wavelength knowledge
  - Bandwidth knowledge
  - Band shape knowledge (skew & kurtosis)



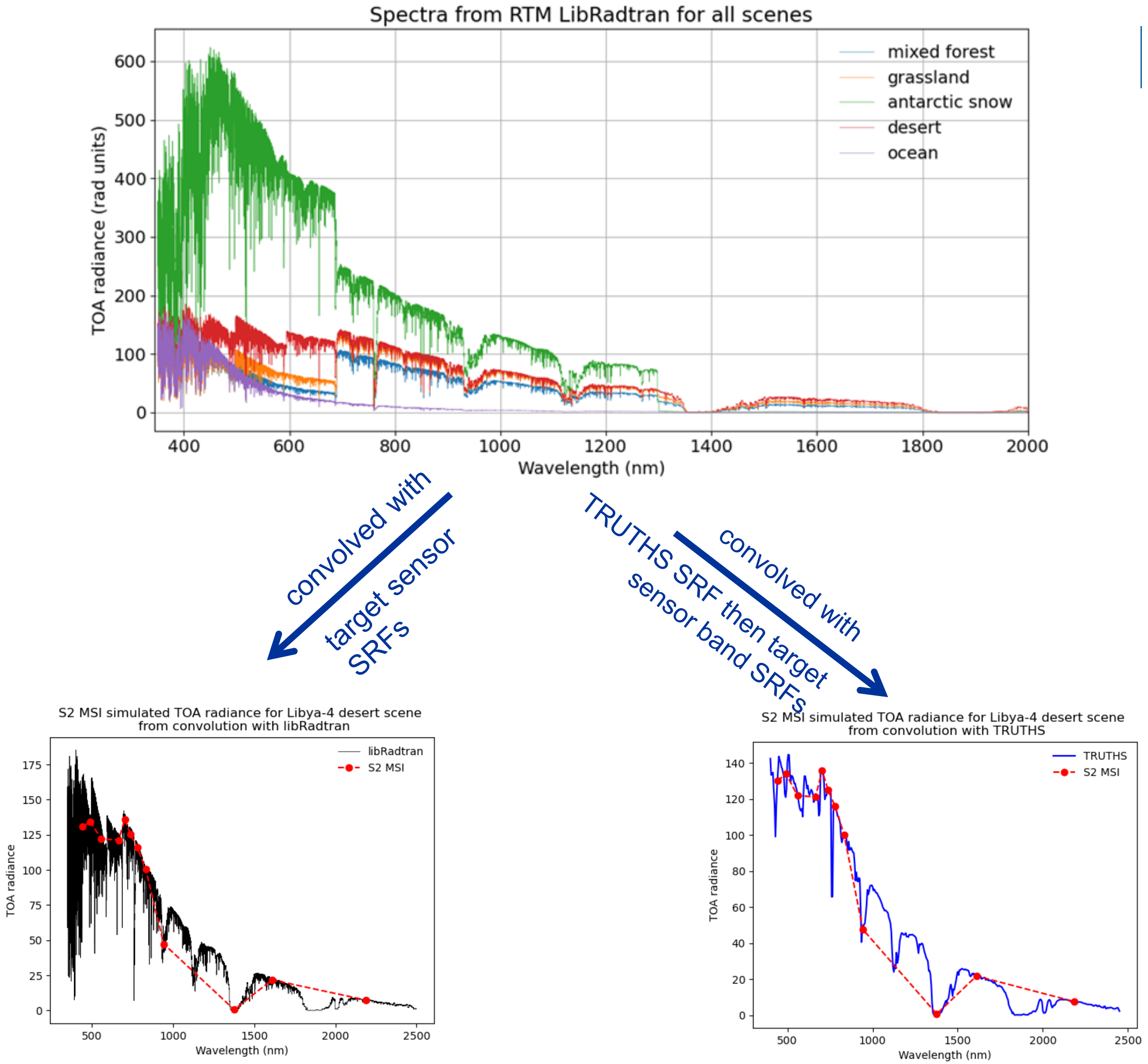
TRUTHS Spectral Band Specification

Method

Simulated representative spectra for different scenes using RTM *LibRadtran:*

- Mixed forest
- Grassland
- Snow
- Desert
- Ocean

Evaluated impact of TRUTHS band specification parameters on intercalibration performance for representative target sensors (MSI, OLCI, VIIRS)



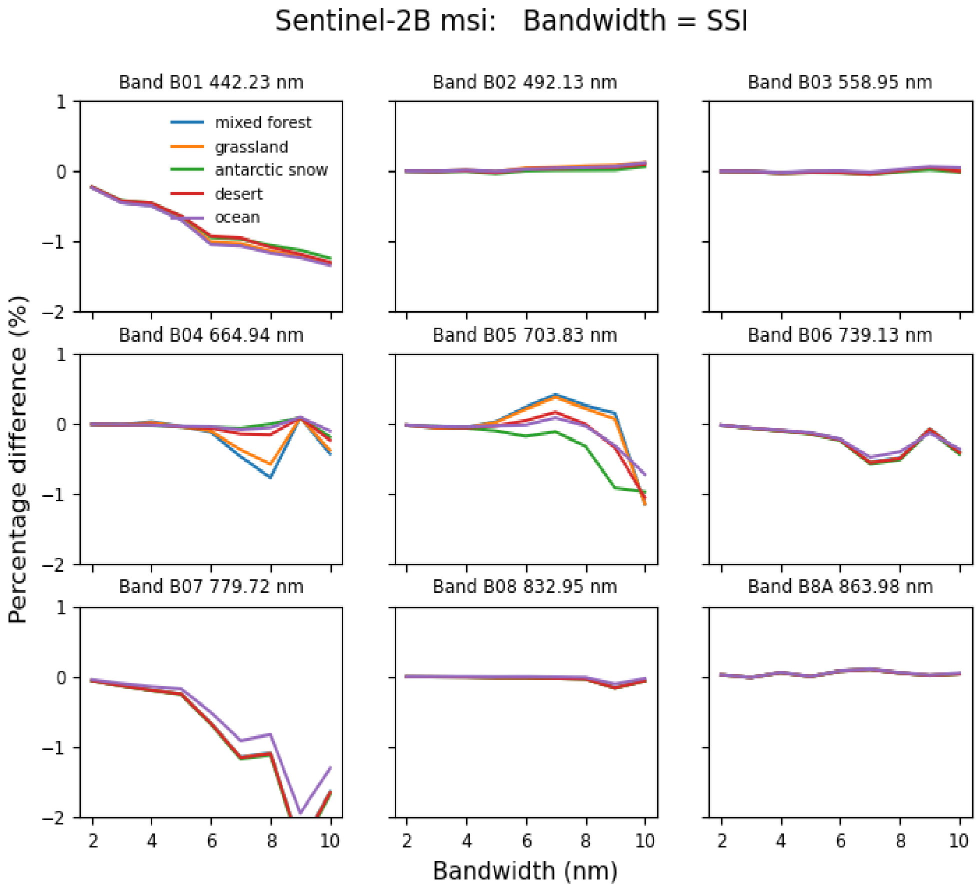
TRUTHS Spectral Band Specification

Results

Bandwidth (FWHM) & Spectral Sampling Interval (SSI)

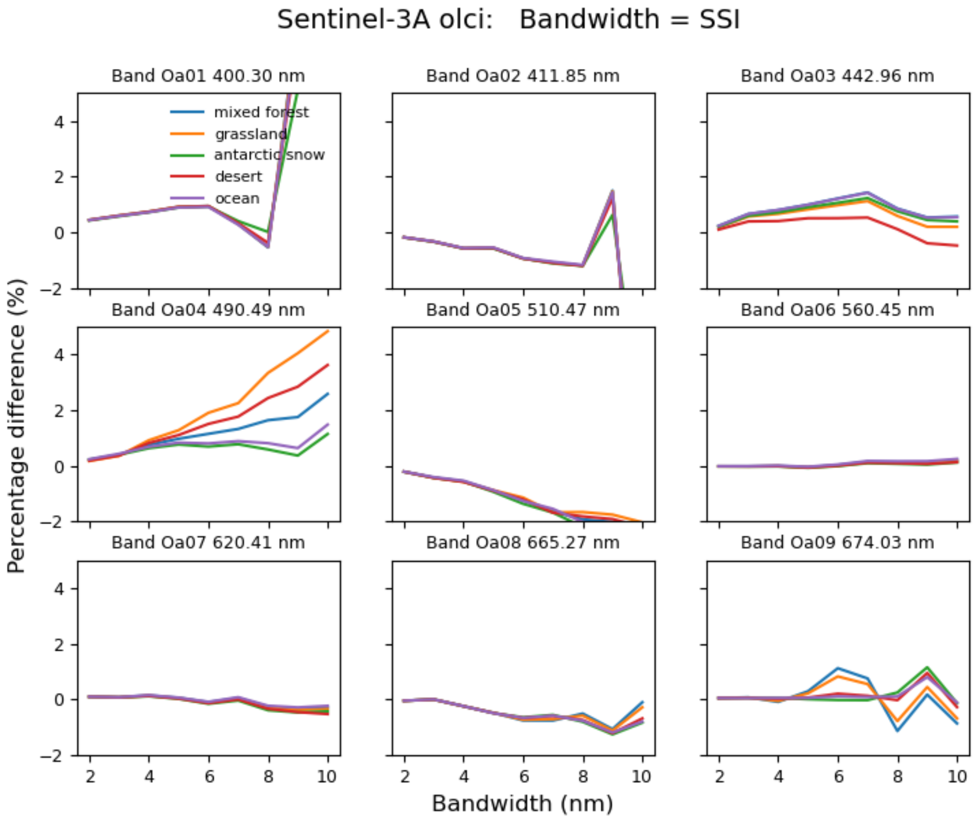
MSI

- For non-absorption bands, bandwidth of 4 nm resulted in % difference of < 0.1 % for all scenes



OLCI

- Higher % differences than MSI due to narrower bands
- For non-absorption other bands, bandwidth of 4 nm resulted in % difference of < 0.5 %



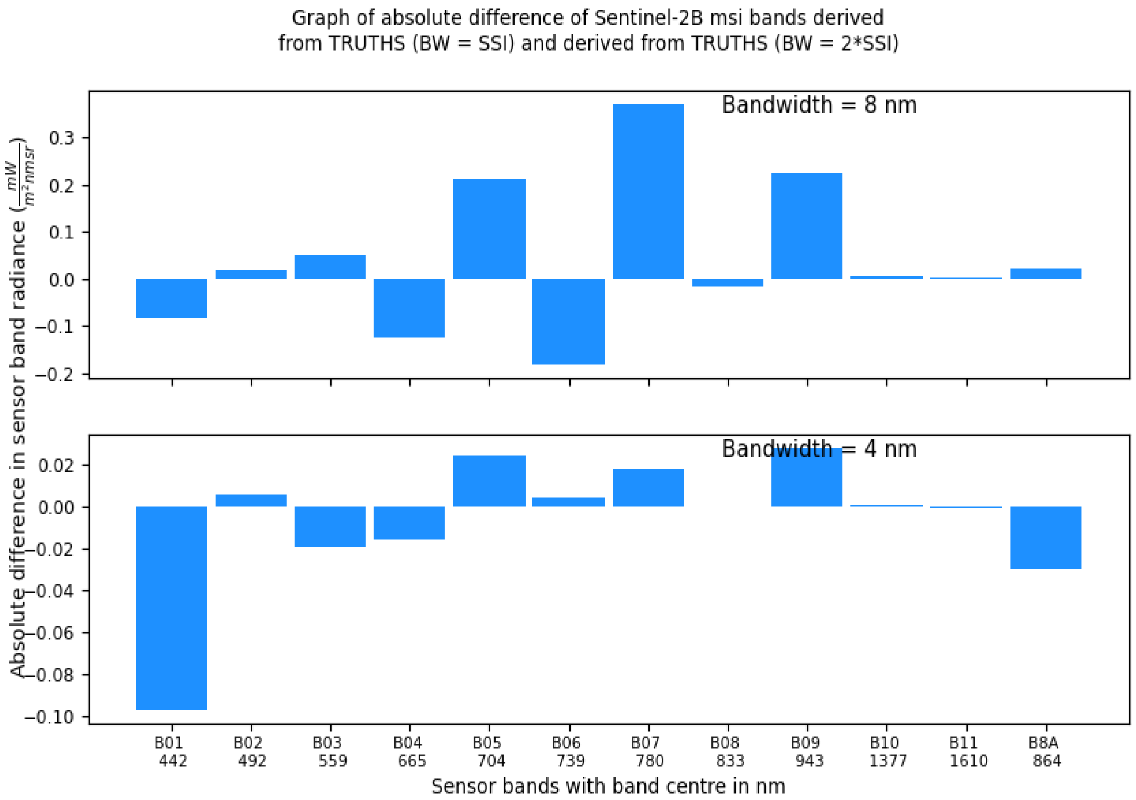
TRUTHS Spectral Band Specification

Results

Ratio of Bandwidth (FWHM) to Spectral Sampling Interval (SSI)

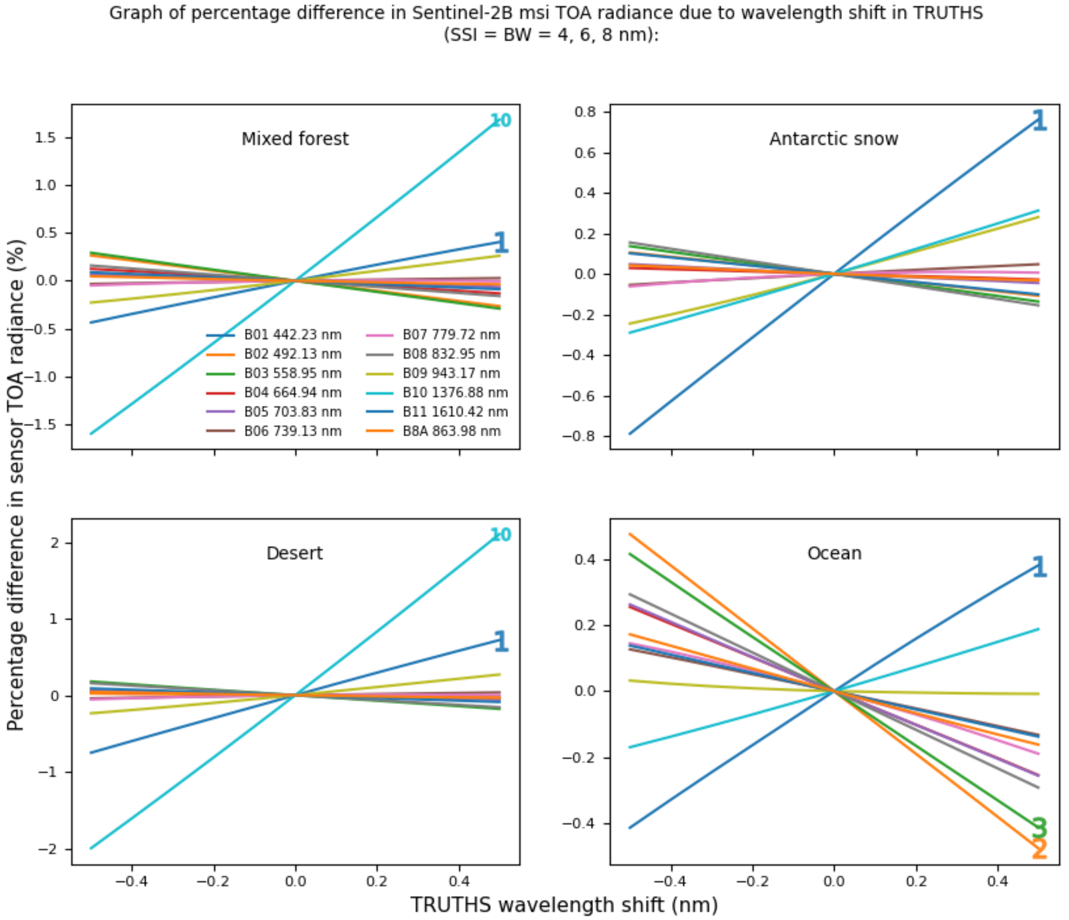
For bandwidth = 4 nm, absolute difference is < $0.1\ \mathrm{mW\,m^{-2}nm^{-1}sr^{-1}}$ for all bands

SSI equal to bandwidth is sufficient for intercalibration performance



Band Central Wavelength Knowledge

For desert scene, all bands (except B01, B09, B10) resulted in < 0.1 % difference for 0.1 nm shift



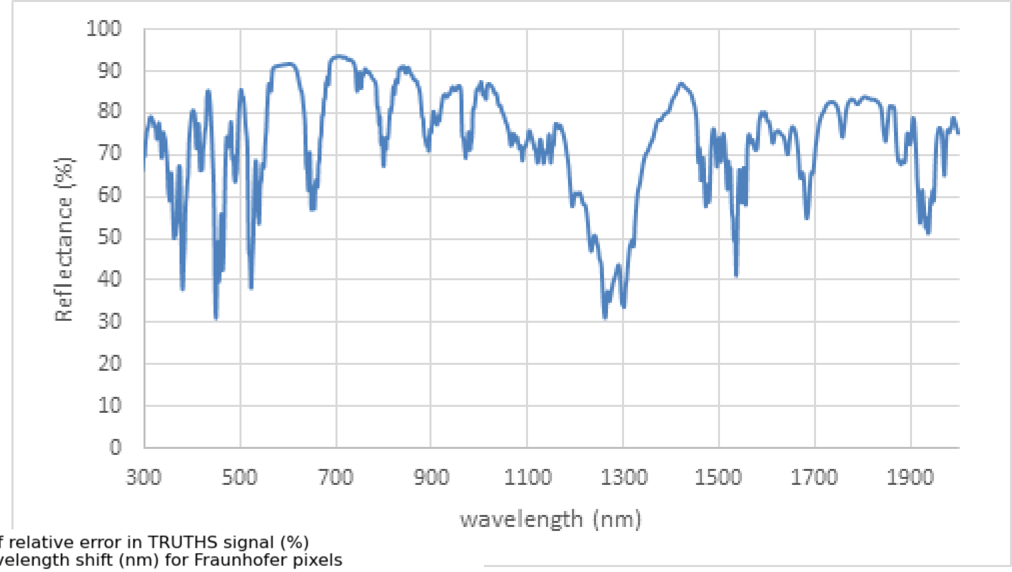
TRUTHS Spectral Band Specification

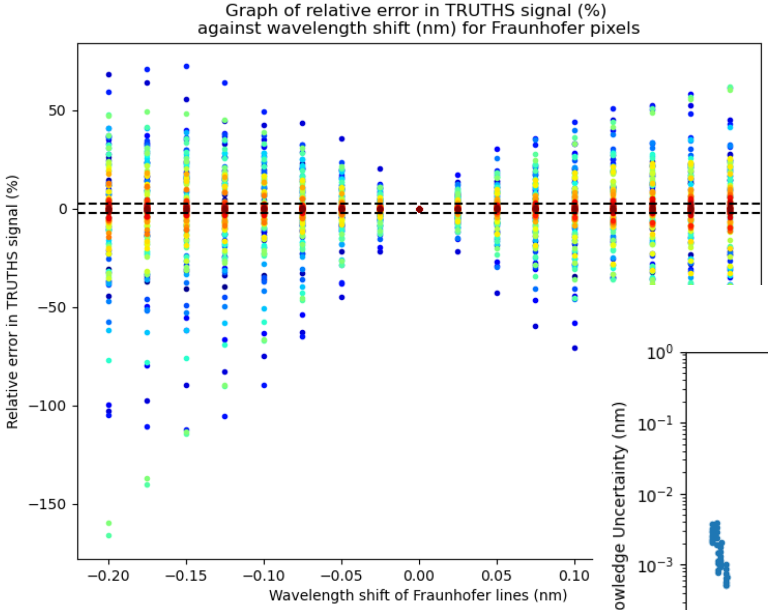
ISRF Shape Knowledge

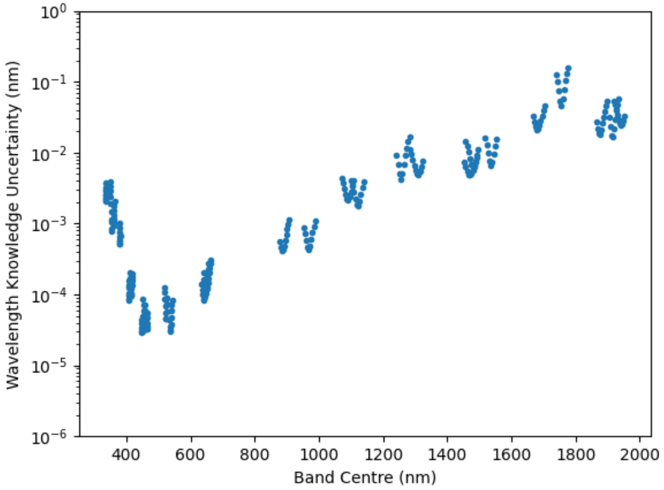
In-flight Calibration of ISRF Band Shape

- Investigated methods for in-flight calibration of ISRF band shape
  - Using **Fraunhofer lines** and **Onboard Rare-Earth oxide doped diffuser** reflectance

- Undertook analysis to evaluate performance of methods







TRUTHS Spectral Band Specification

Conclusions

- Analysis performed to contribute to formulation of HIS band specification requirements to achieve intercalibration performance requirements

- Considered requirements on band specification parameters:
  - Bandwidth (FWHM) & spectral sampling interval (SSI)
  - ISRF knowledge (central wavelength, FWHM, skew, kurtosis)

Requirement Parameter	Goal (k=2)	Threshold (k=2)
Band central wavelength knowledge	0.1 nm	0.4 nm
Bandwidth knowledge	0.5 %	1 %

- Impact evaluated for different scene types (desert, ocean, rainforest, snow) and different sensors (MSI, OLCI, VIIRS)

- Most sensitive spectral bands are those in absorption windows

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MATCHUP COMPARISON PROCESSING CHAIN

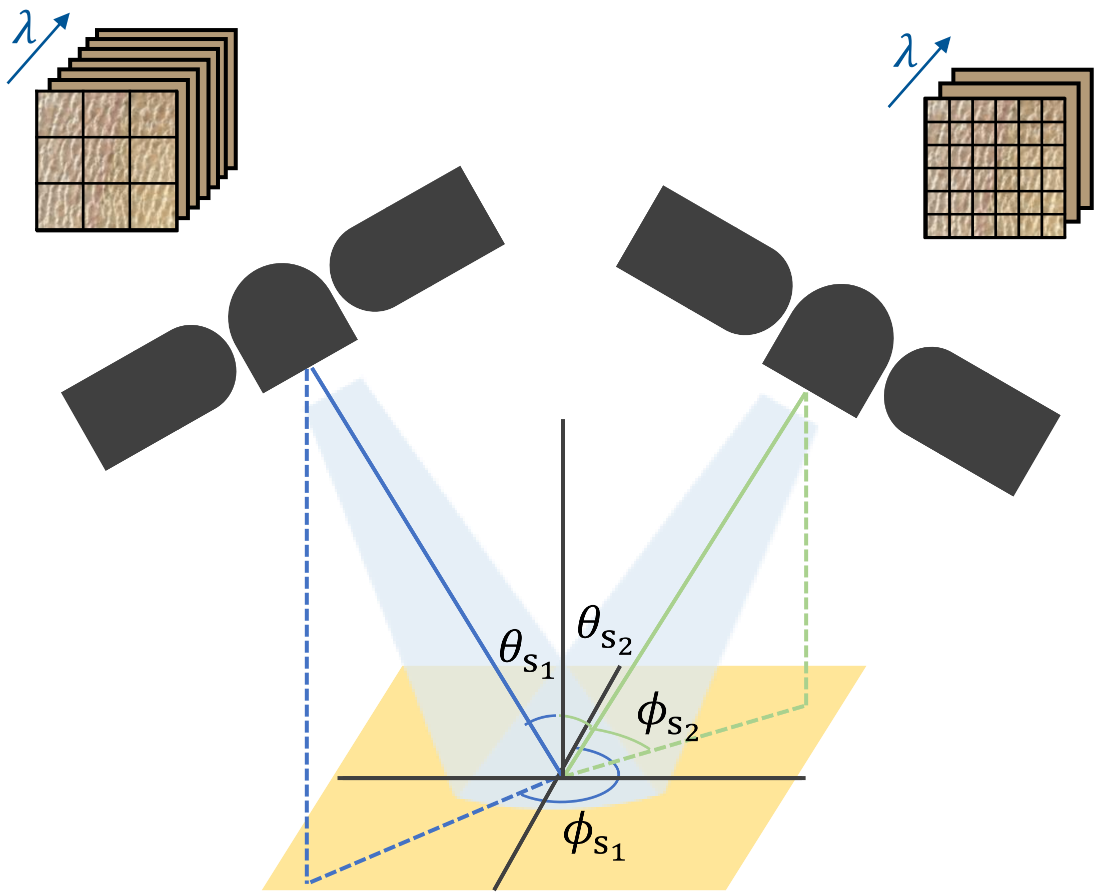
Satellite Match ups Comparison Performance

A matchup is defined as an event where two satellite sensors observe approximately the same location at approximately the same time.

Analysis of matchups is a key technique to compare and cross-calibrate EO sensors in flight.

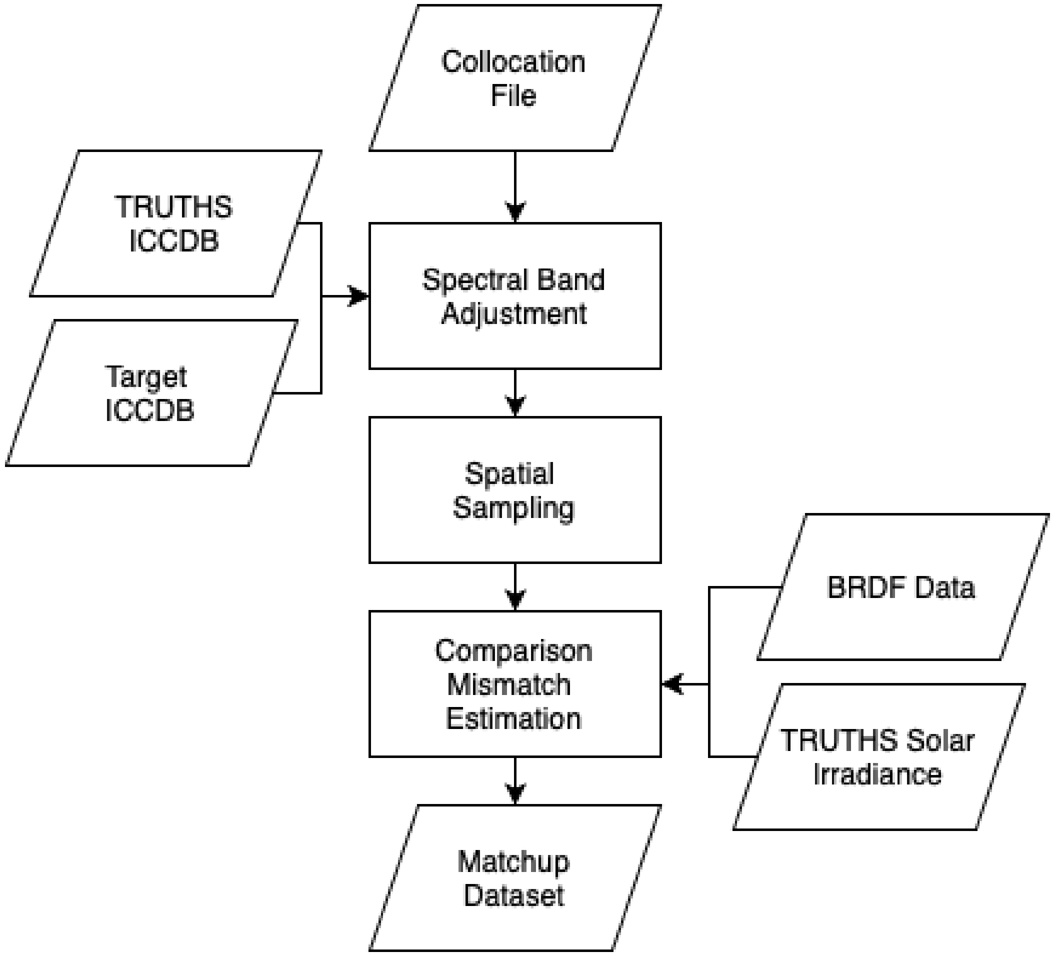
A number of aspects of satellite match up comparison make this challenging:

1. Spectral sampling differences
2. Spatial sampling differences
3. Viewing geometry mismatch – changes surface reflectance, polarisation
4. Temporal mismatch – changes in sun angle, atmosphere



Matchup Comparison Processing Chain

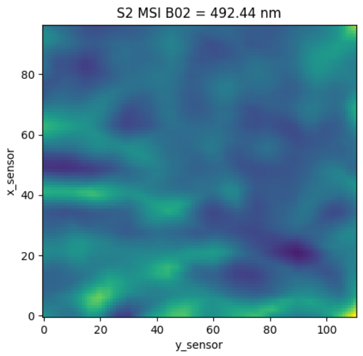
- Defined a processing chain to prepare comparison samples for two sensors for uncertainty-quantified calibration
- Prototype software suite implemented for end-to-end processing chain
- First, matchups are identified and collocated images extracted
- Following this, samples are prepared for comparison



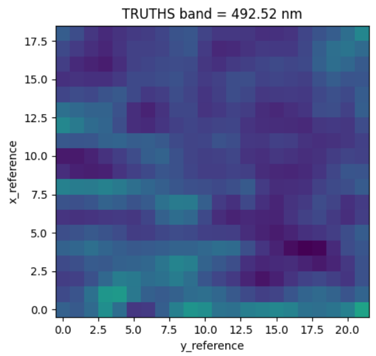
Matchup Comparison Processing Chain

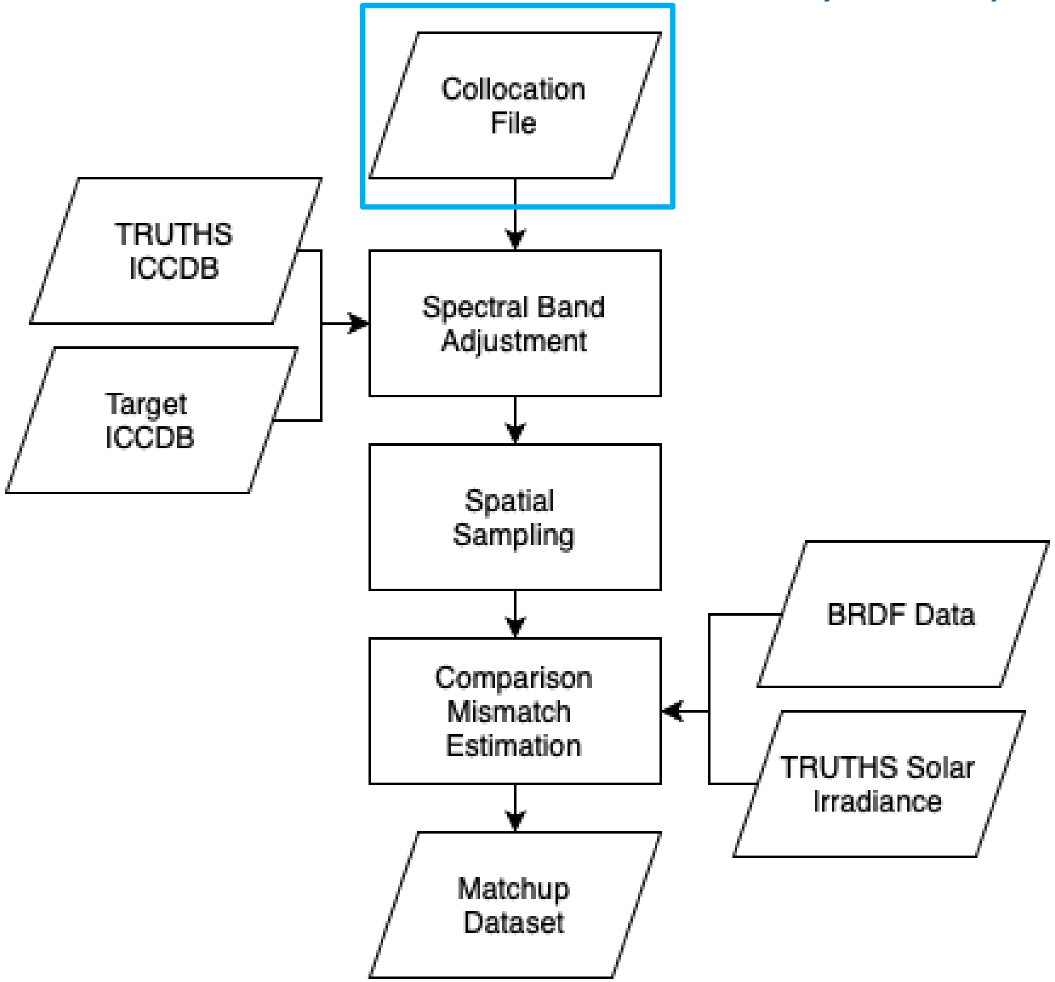
Before processing

Target (S2 MSI)



Reference (TRUTHS)



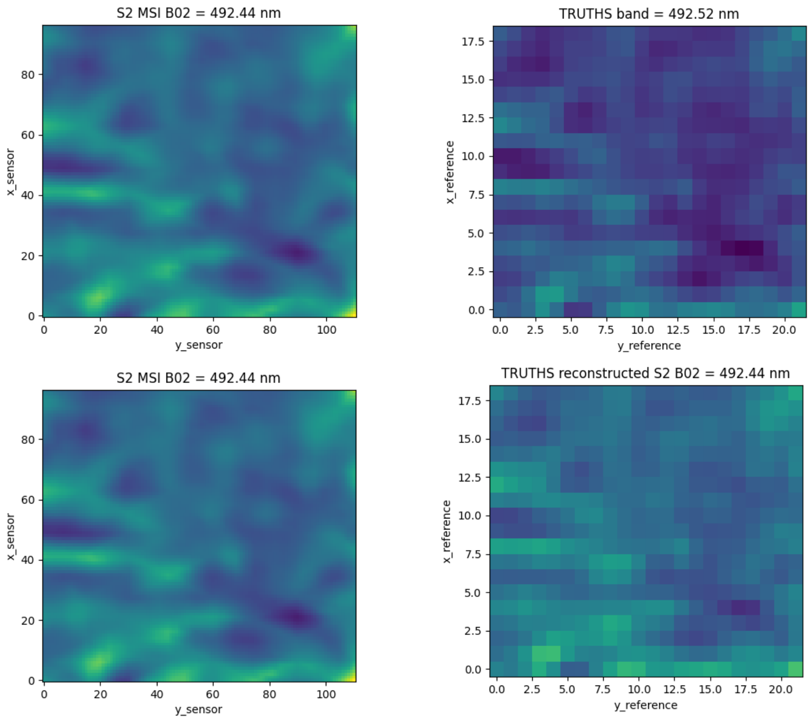


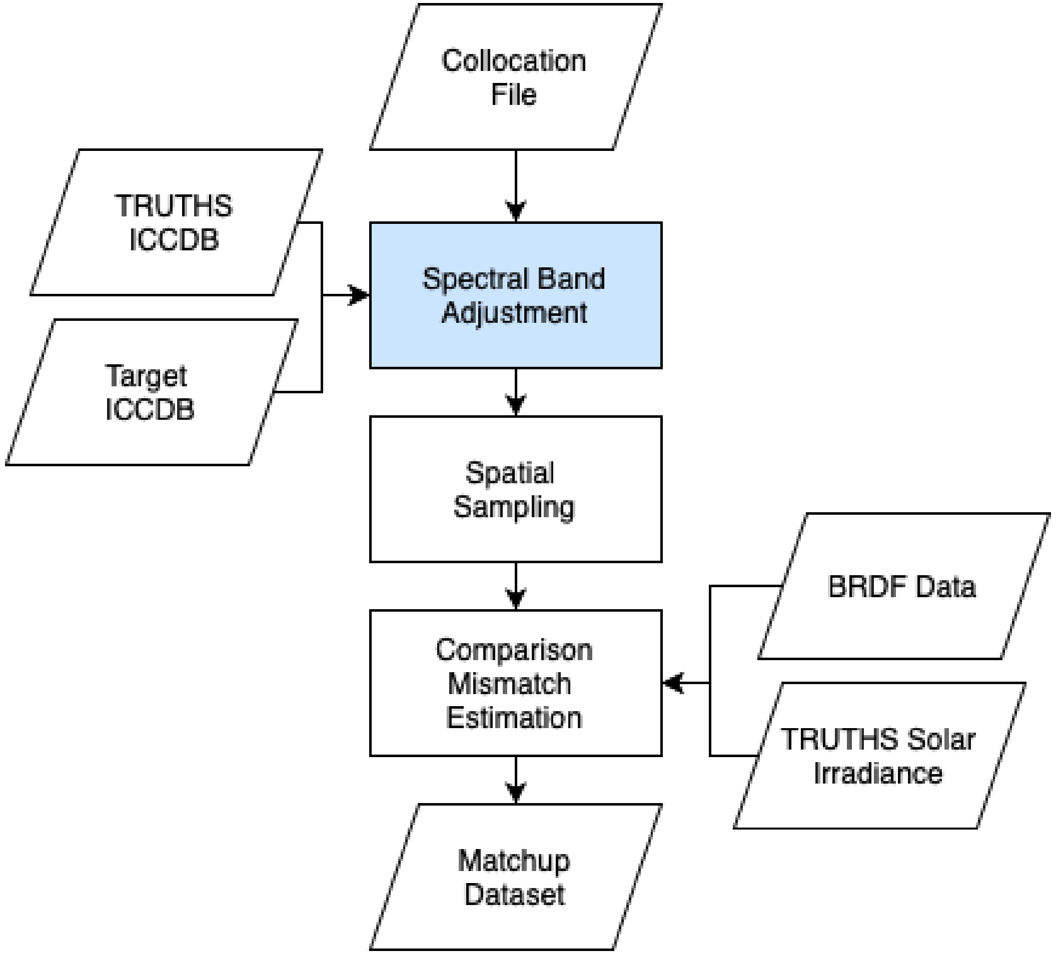
Matchup Comparison Processing Chain

Target (S2 MSI) | Reference (TRUTHS)

Before processing

After spectral processing





Matchup Comparison Processing Chain

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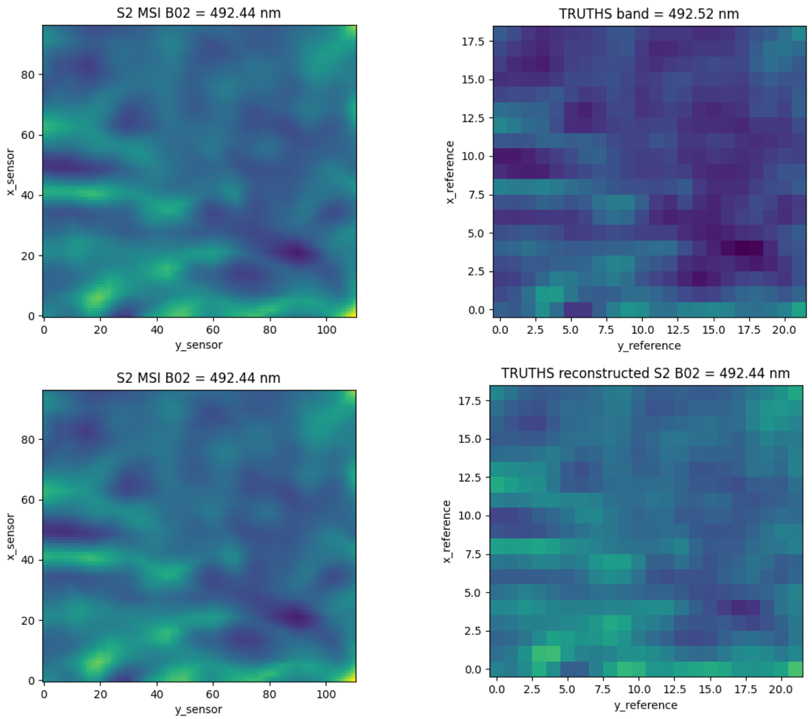
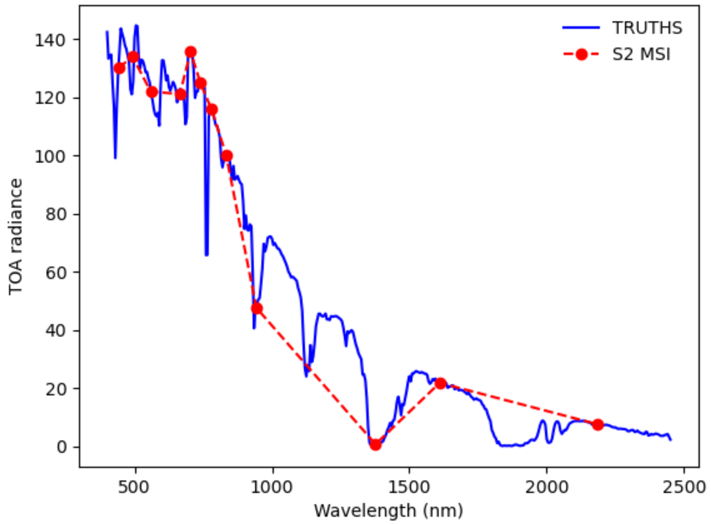
Target (S2 MSI) | Reference (TRUTHS)

Before processing

After spectral processing



- Reconstruct an equivalent sensor measurement from the TRUTHS spectrum
- Band integration performed to spectrally align TRUTHS to sensor using sensor SRF data



Estimated S2-equivalent observations from simulated TRUTHS spectrum

Matchup Comparison Processing Chain

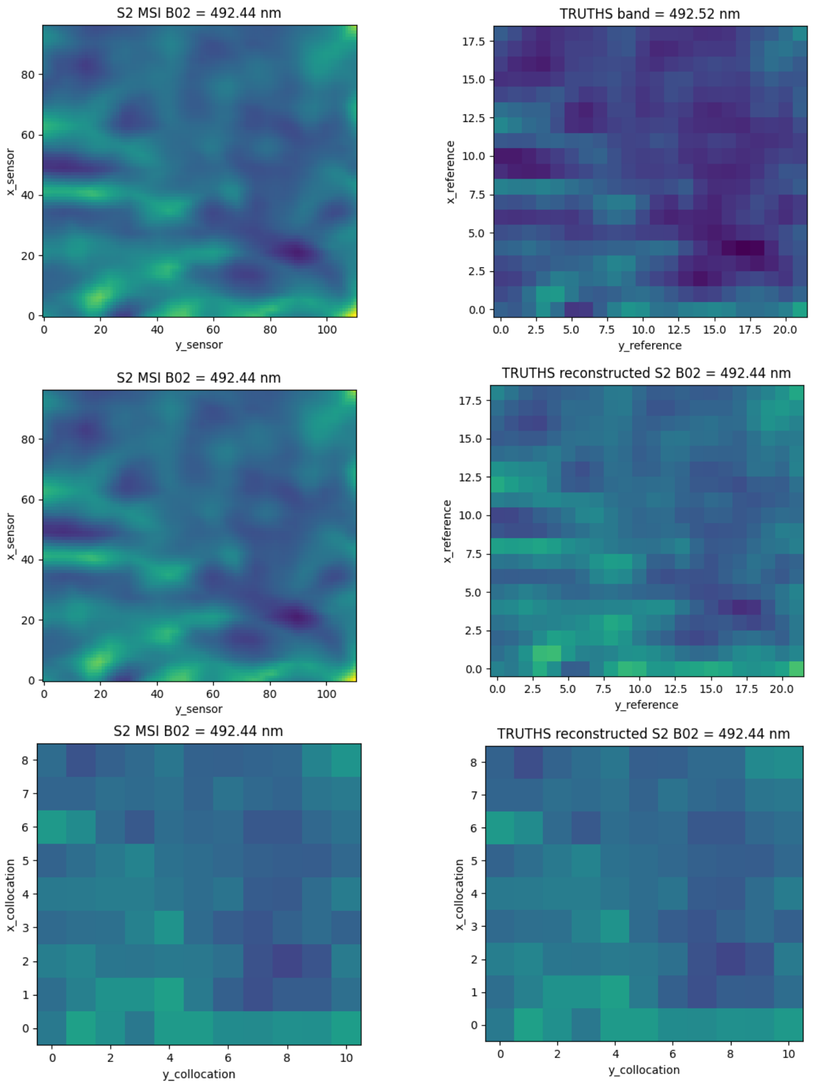
NPL National Physical Laboratory

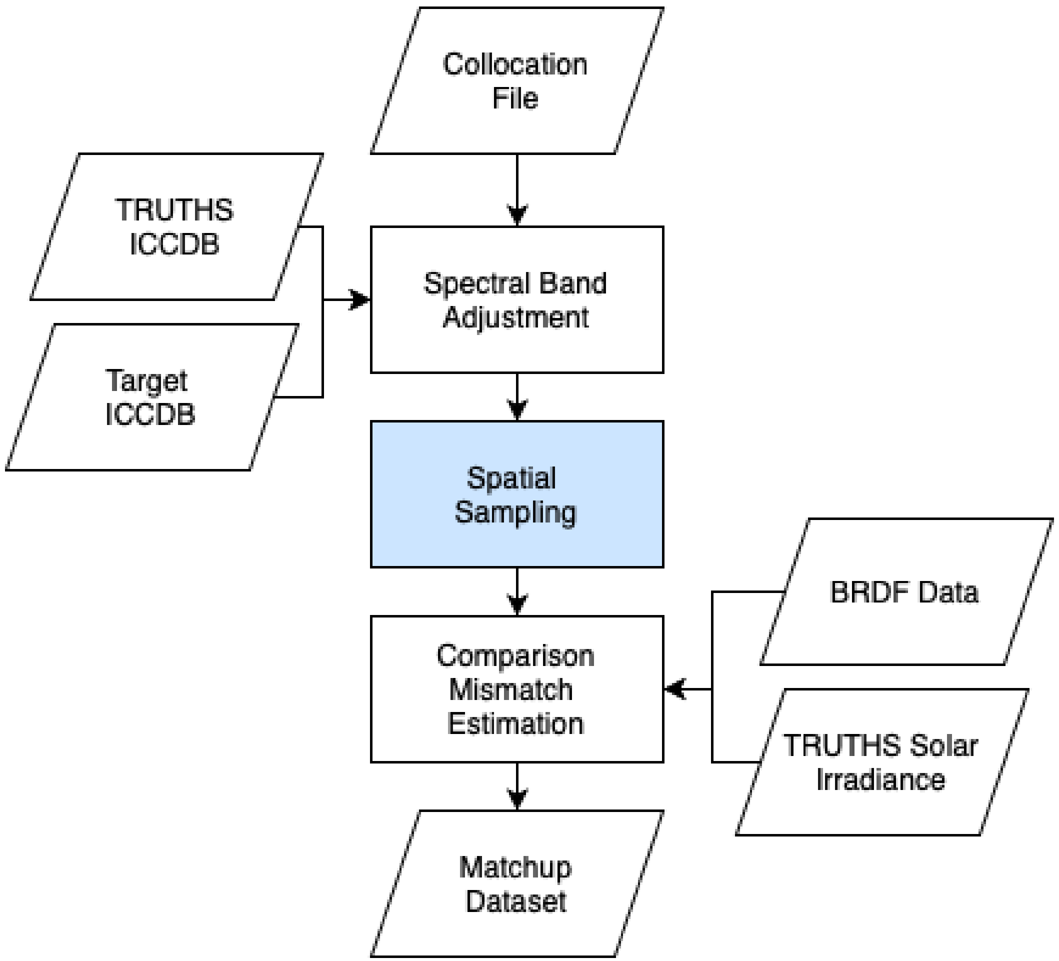
Target (S2 MSI) | Reference (TRUTHS)

Before processing

After spectral processing

After spatial processing





Matchup Comparison Processing Chain

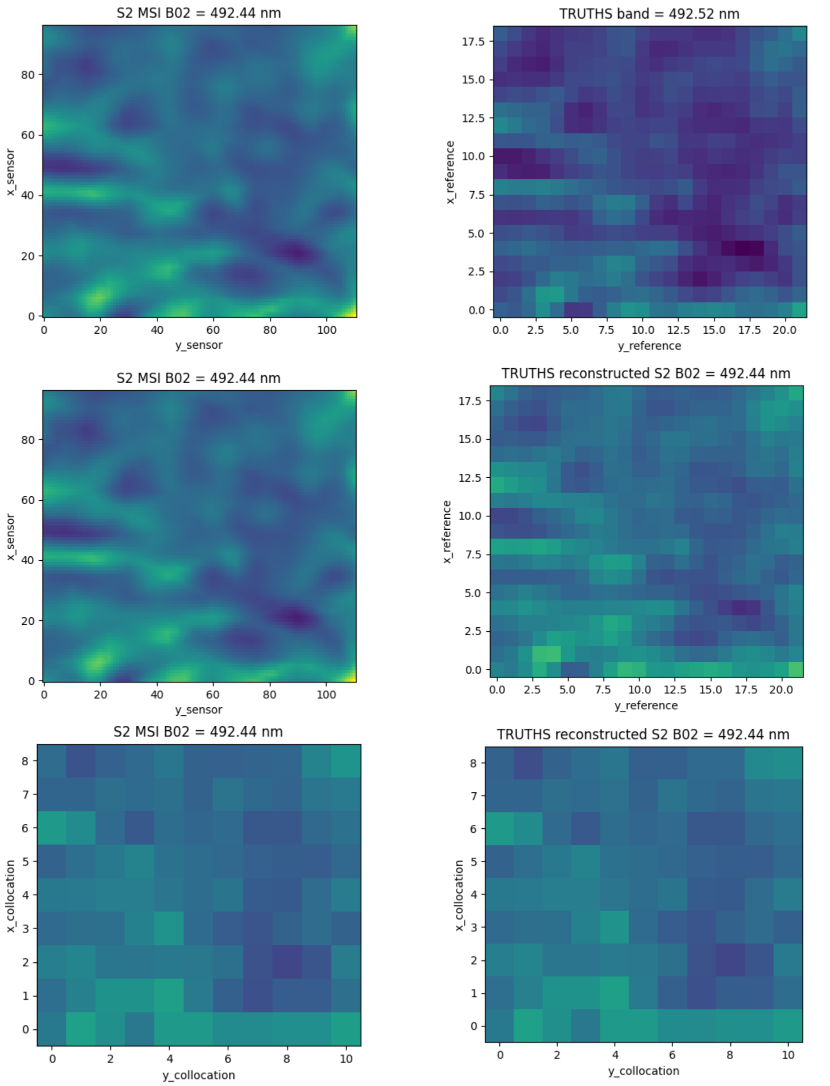
NPL National Physical Laboratory

Target (S2 MSI) | Reference (TRUTHS)

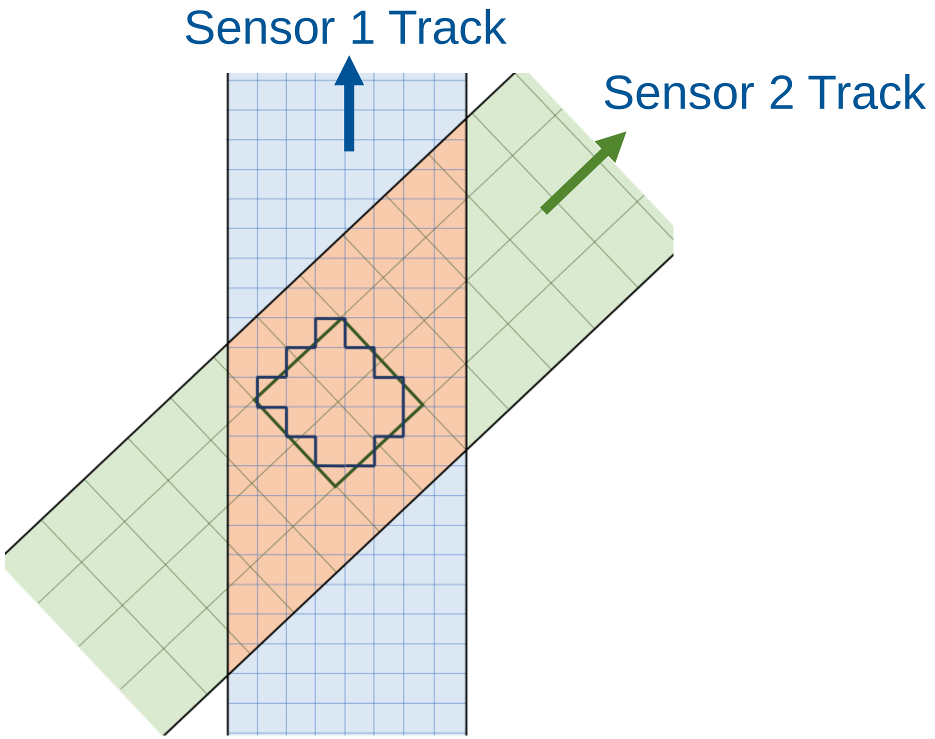
Before processing

After spectral processing

After spatial processing



- A challenge to compare different field-of-views over heterogenous surfaces
- Reconstruct equivalent field-of-view for each sample by aggregating pixels using nearest neighbour averaging



Matchup Comparison Processing Chain

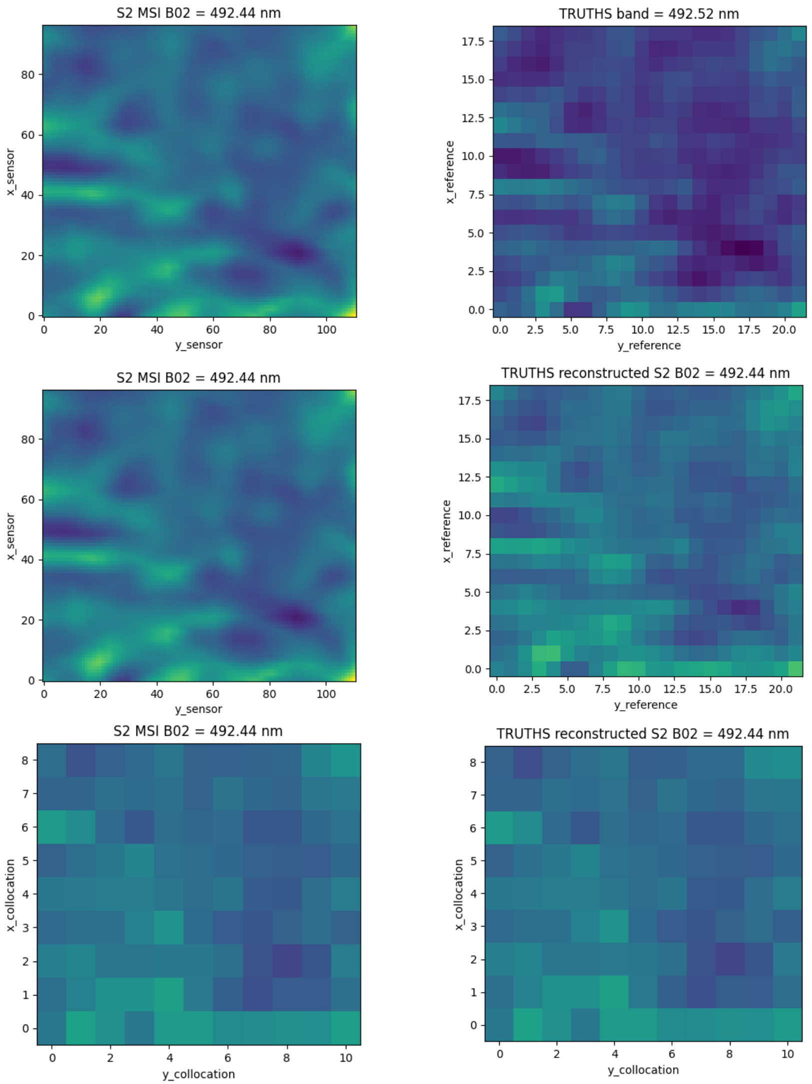
NPL National Physical Laboratory

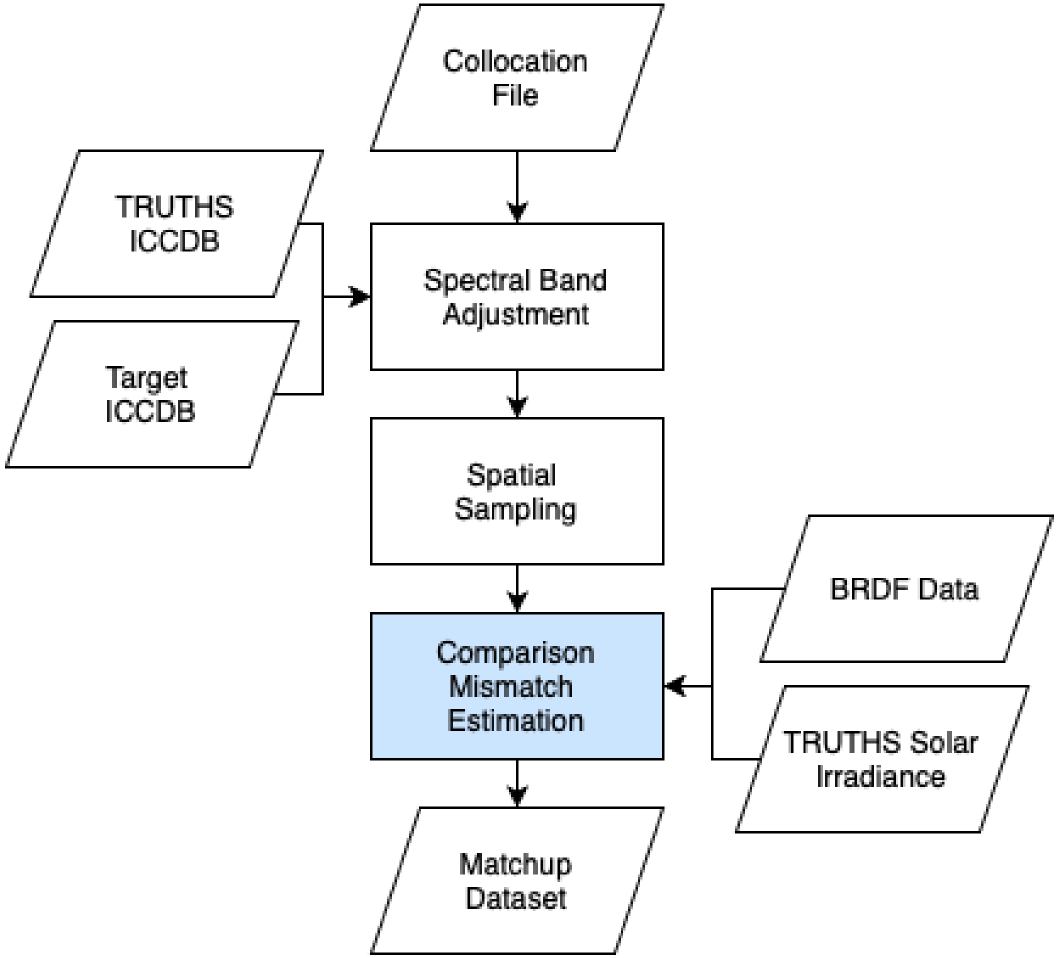
Target (S2 MSI) | Reference (TRUTHS)

Before processing

After spectral processing

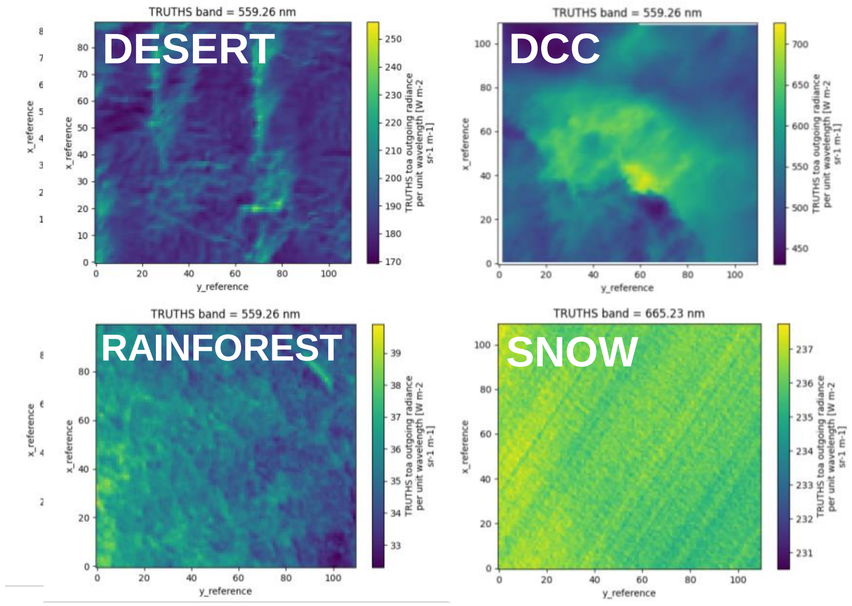
After spatial processing





Matchup dataset, containing samples, m:

$$K_m(\lambda_{s,i}) = L_{\mathrm{sensor},m}(\lambda_{s,i}) - L_{\mathrm{TRUTHS},m}(\lambda_{s,i})$$



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MATCHUP PROCESSING SIMULATION STUDY

Matchup Processing Simulation Study

Simulating Reference Scenes from Reflectance Data

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- Simulated TOA Radiance Earth scenes prepared, based on PRISMA L2D surface reflectance product for different surface types: **desert, rainforest, Antarctic snow**.

Bottom of atmosphere
L2 reflectance cubes

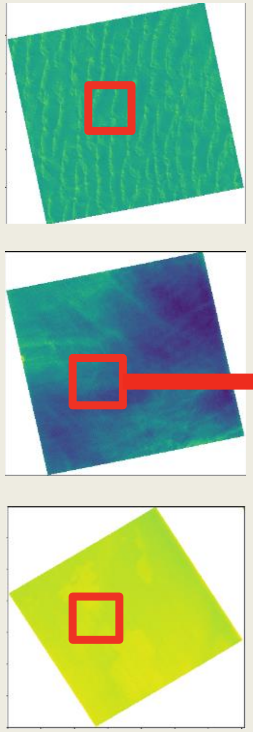
PRISMA L2D
30 m resolution

Simulated **DCC** TOA radiance scenes prepared, based on S2 MSI L1 TOA reflectance product.

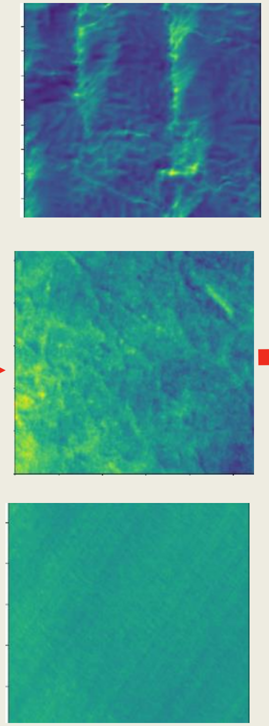
Desert
Libya-4

Rainforest
Amazon

Snow
Dome-C



Subset

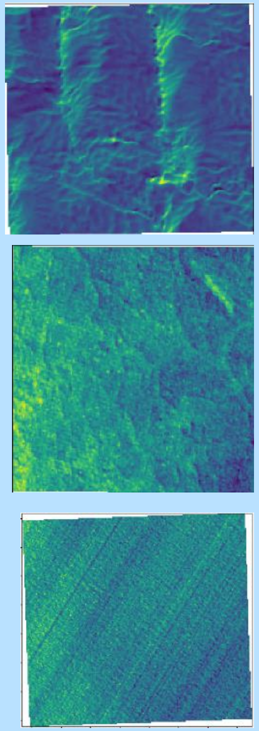


TOA simulation python tool
RTM libRadtran

Atmospheric parameters & solar angles

Top of atmosphere (at-sensor)
L1 radiance cubes

1 m resolution
0.01 nm spectral sampling, 300 – 2500 nm

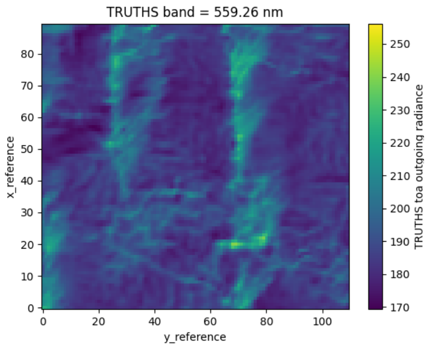


Simulating Sensor Observations

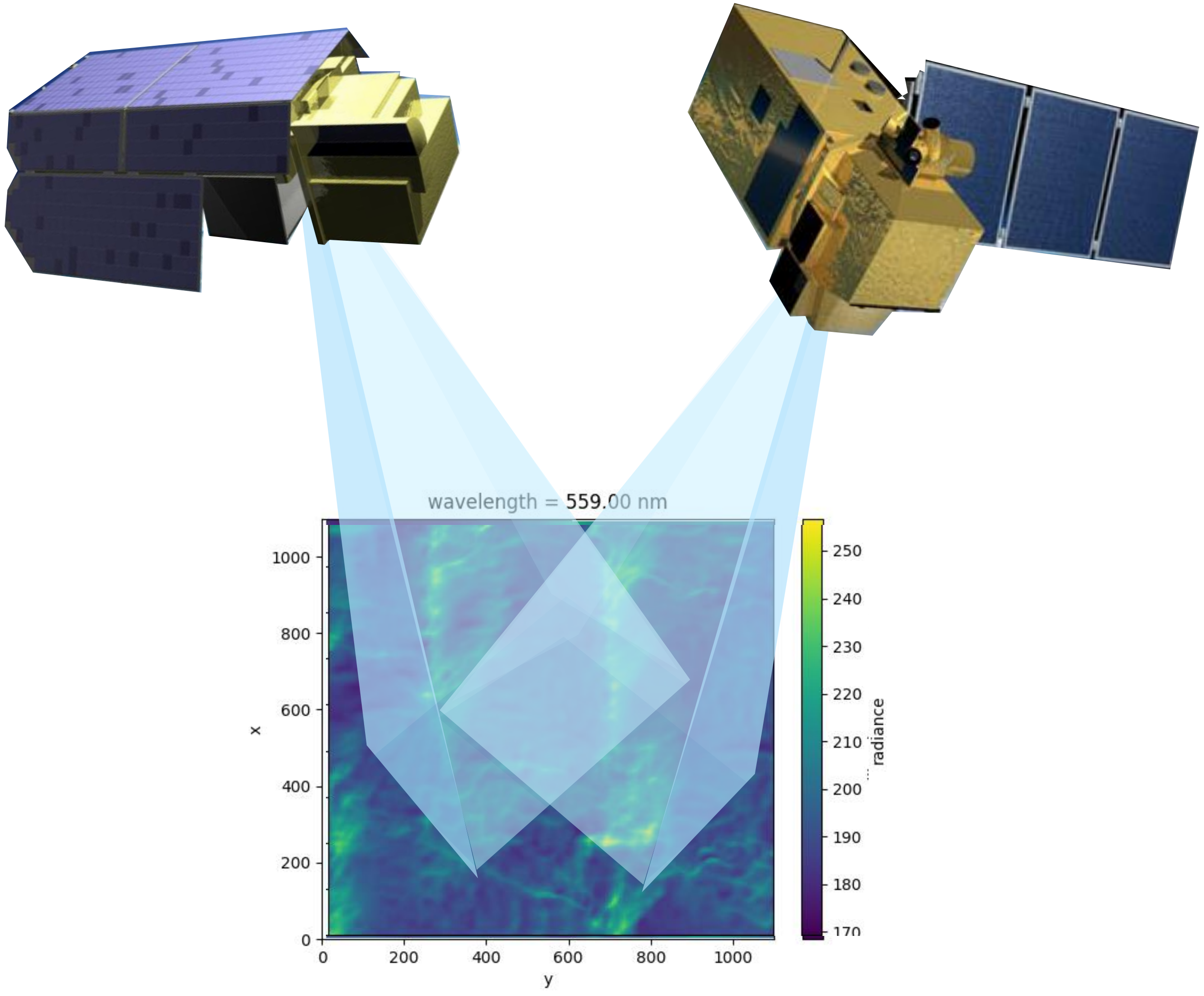
NPL National Physical Laboratory

Reference (TRUTHS)

TOA Radiance
50 m resolution
1024 bands 320-2450 nm



DESERT

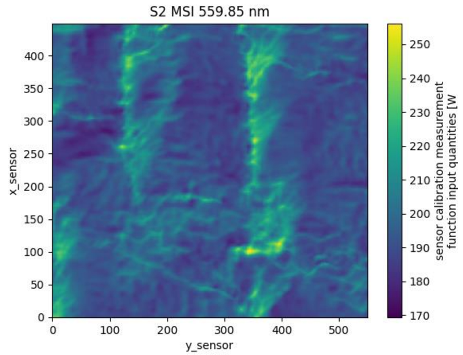


Simulated scene

TOA Radiance
1 m resolution
0.01 nm res 300-2500 nm

Target (S2 MSI)

TOA Radiance
10 m resolution
10 bands 430 – 2300 nm



DESERT

Simulating Sensor Observations

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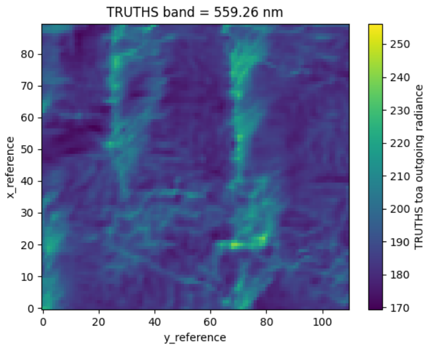

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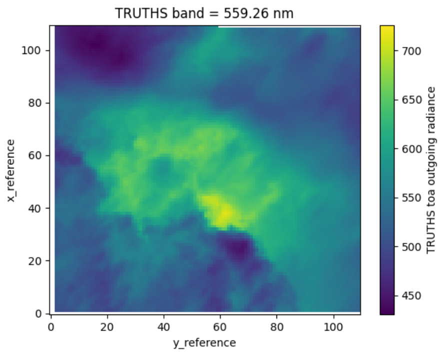
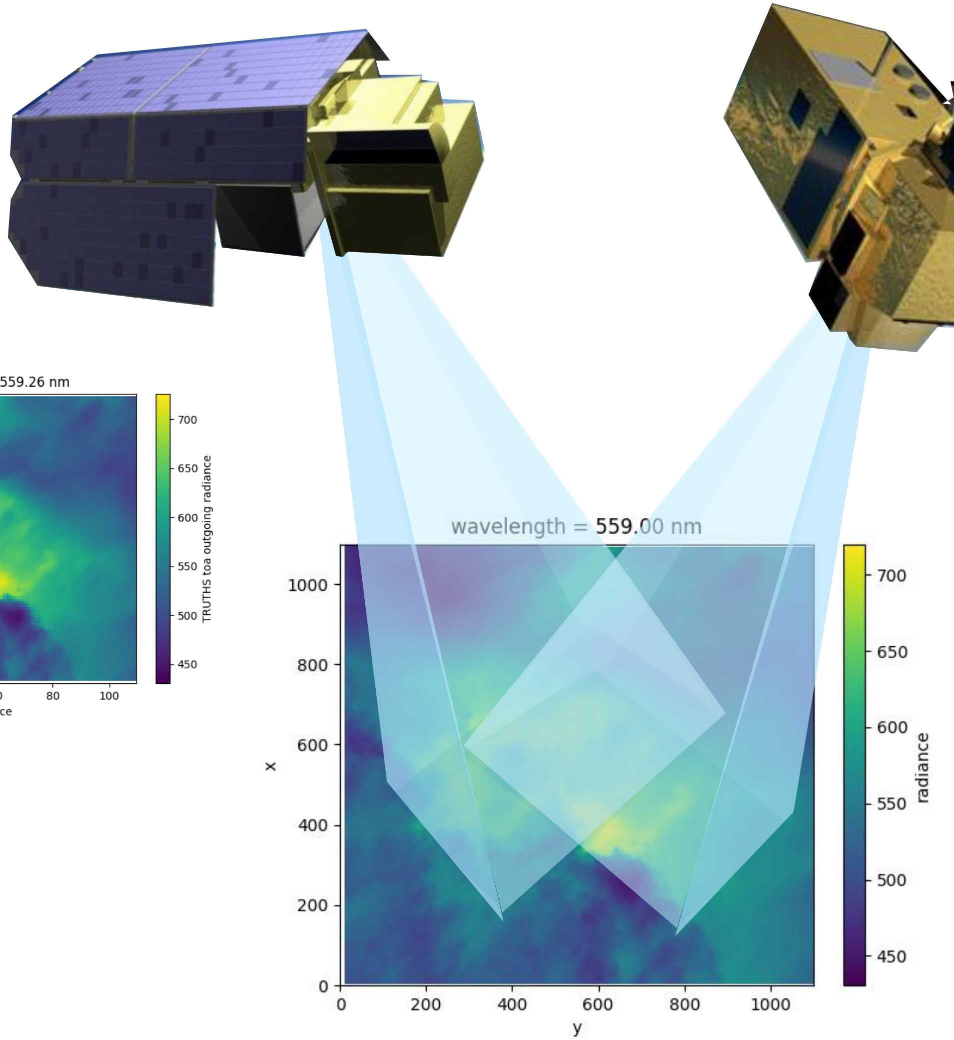


DCC



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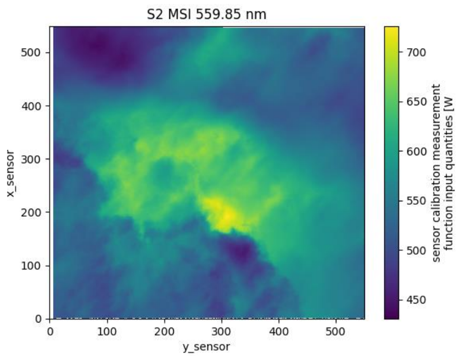

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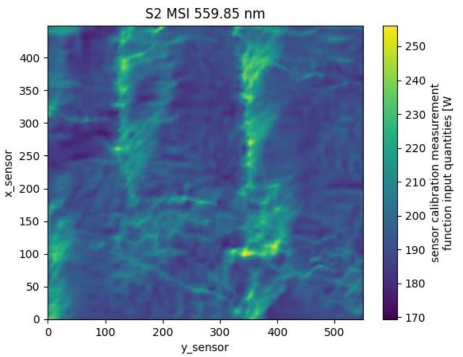

DESERT

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National Physical Laboratory

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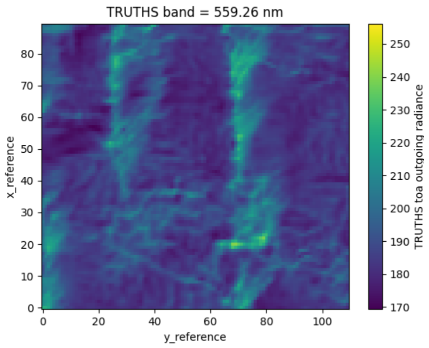

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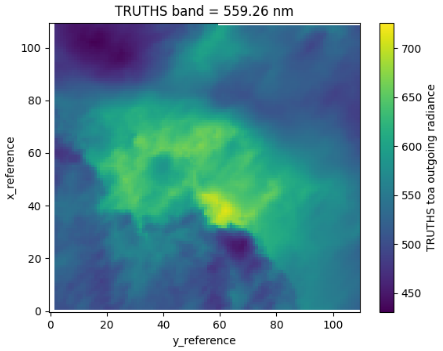

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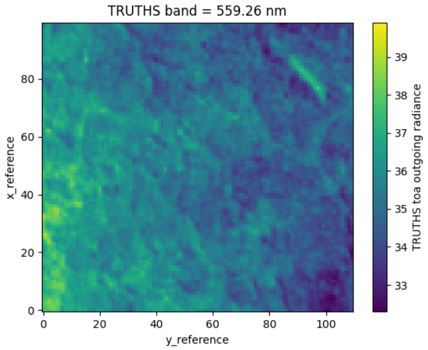
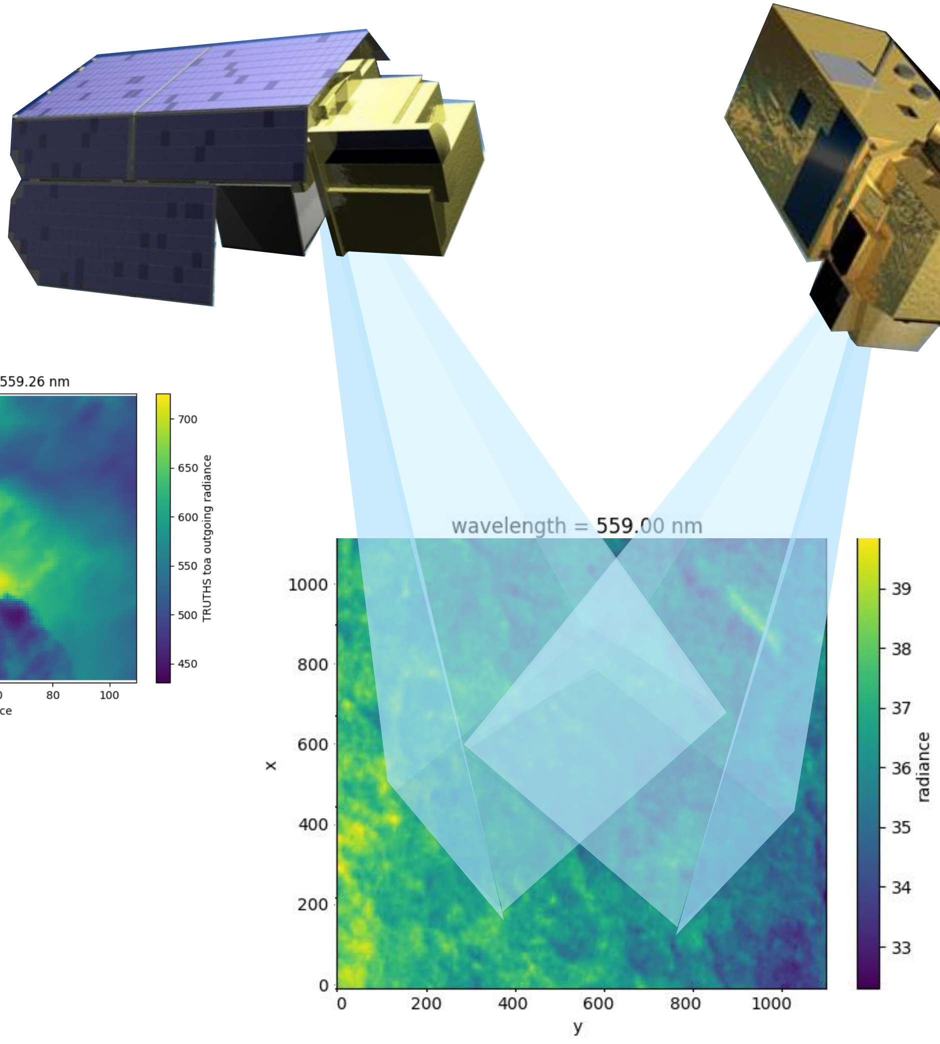
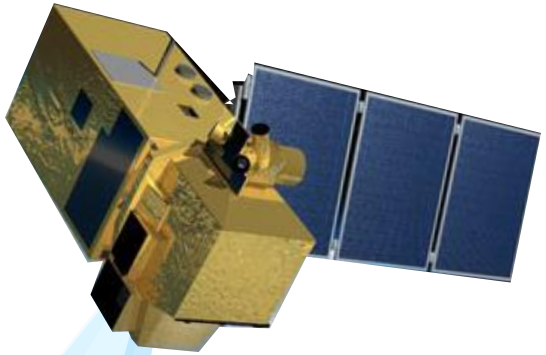


RAINFOREST



Simulated scene

TOA Radiance
1 m resolution
0.01 nm res 300-2500 nm



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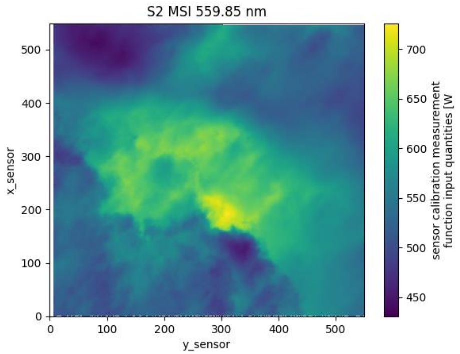

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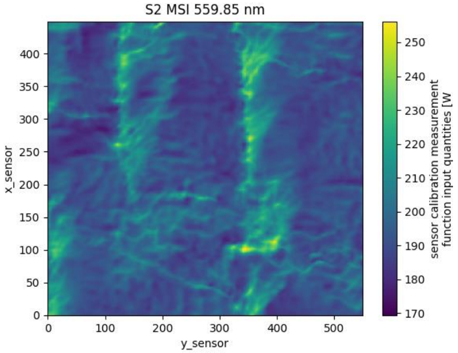

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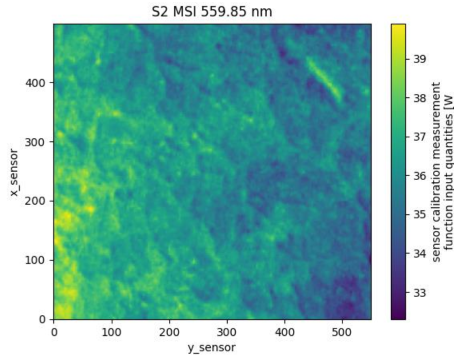

RAINFOREST

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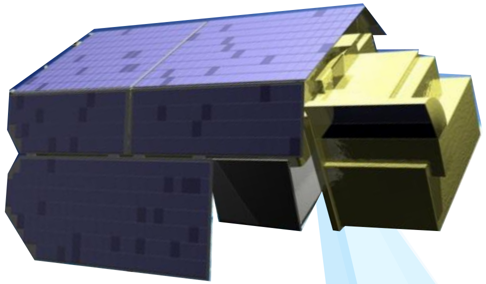

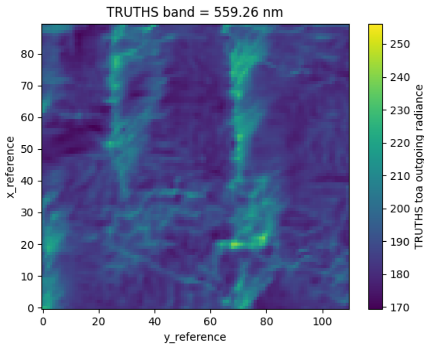

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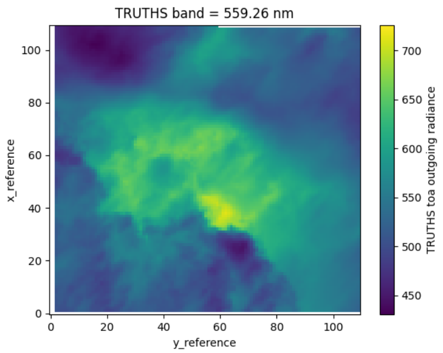

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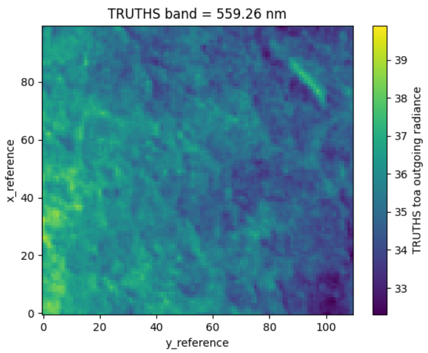
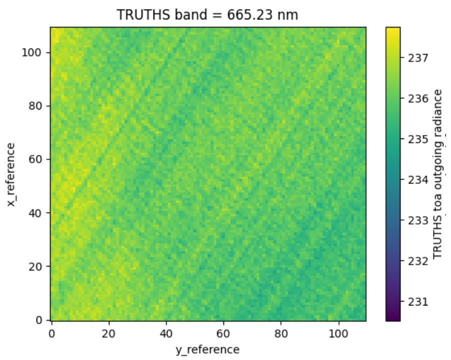
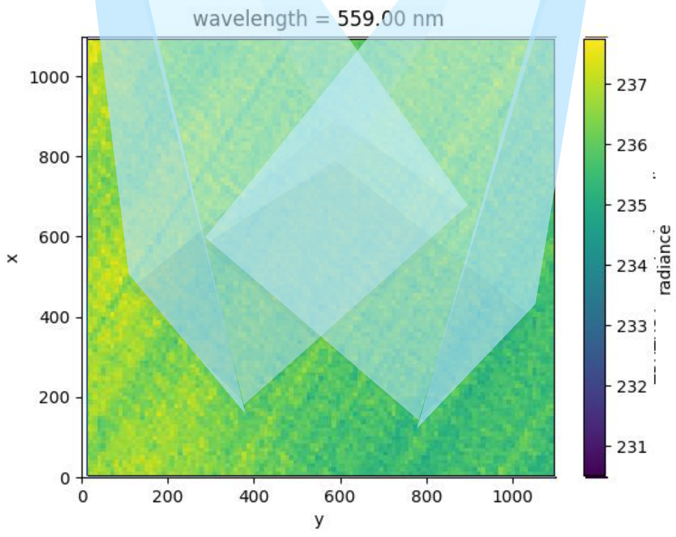


RAINFOREST



SNOW

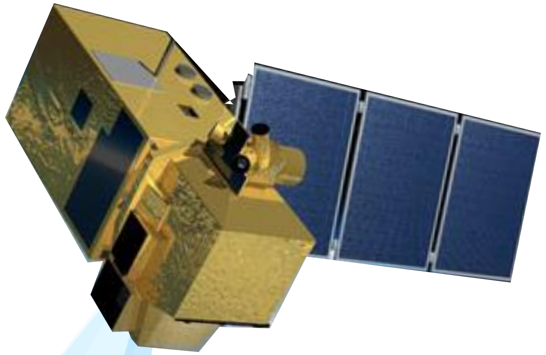


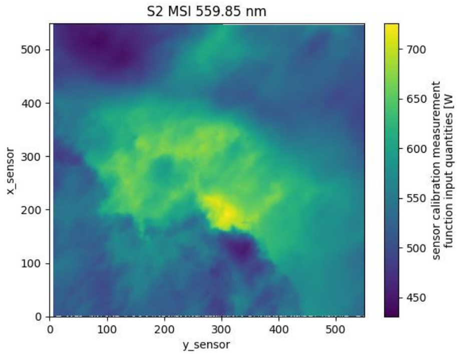
Simulated scene

TOA Radiance
1 m resolution
0.01 nm res 300-2500 nm

Target (S2 MSI)

TOA Radiance
10 m resolution
10 bands 430 – 2300 nm





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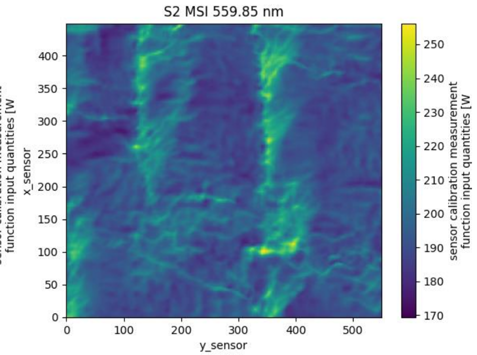
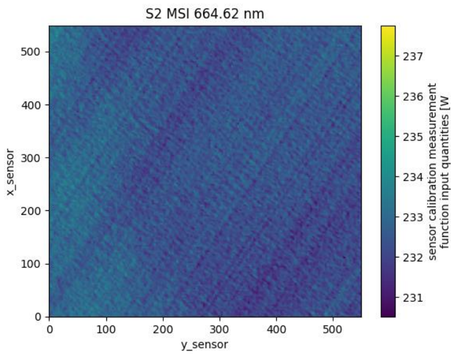
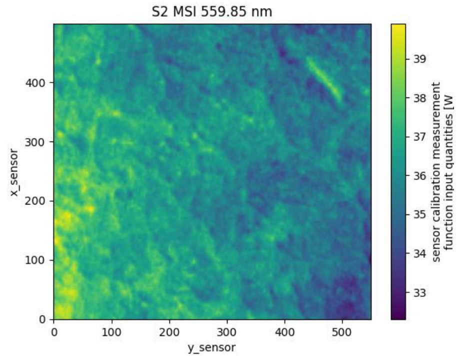


DESERT



SNOW



RAINFOREST

Performance Analysis

Matchup Processing Uncertainty Trees

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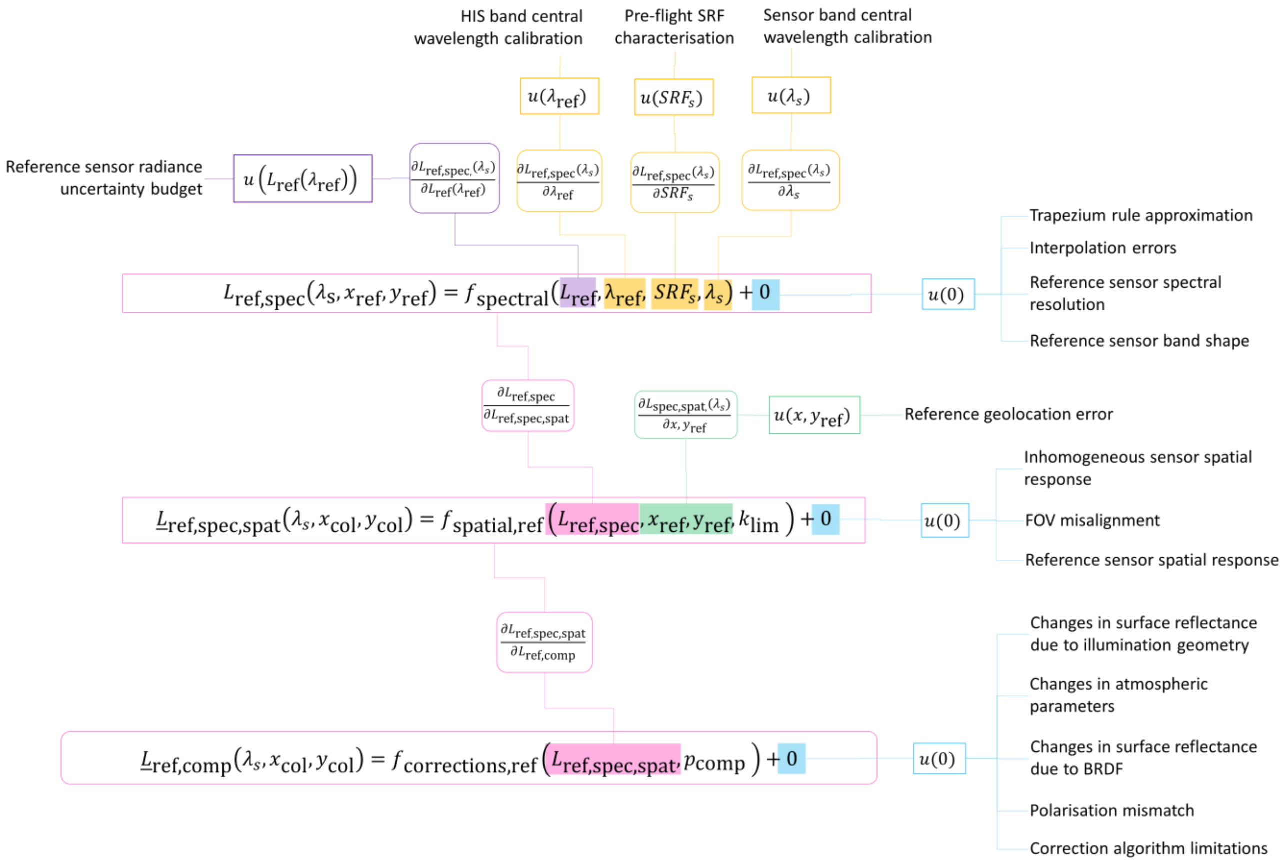
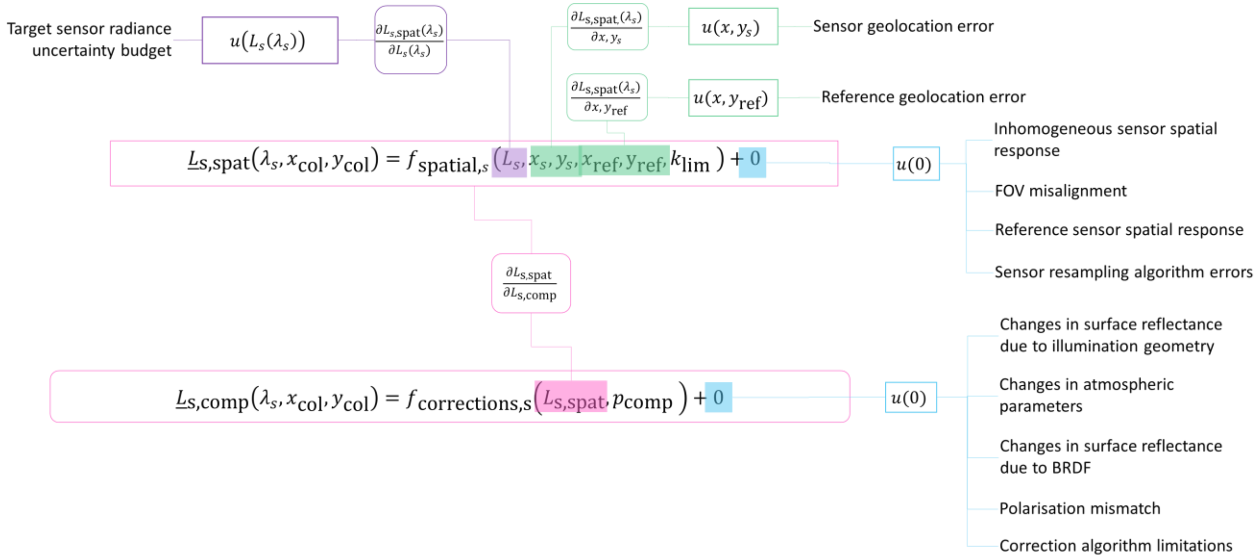




Reference Matchup Comparison Processing Uncertainty Tree

Sensor Matchup Comparison Processing Uncertainty Tree

Performance Analysis

Uncertainties Associated with Reference Imagery Processing

- Error correlation form evaluated for effects identified in uncertainty tree
- **NPL's CoMet toolkit** used to store error-covariance information associated with collocated imagery within collocation datasets & propagate this through matchup comparison processing chain using Monte Carlo method

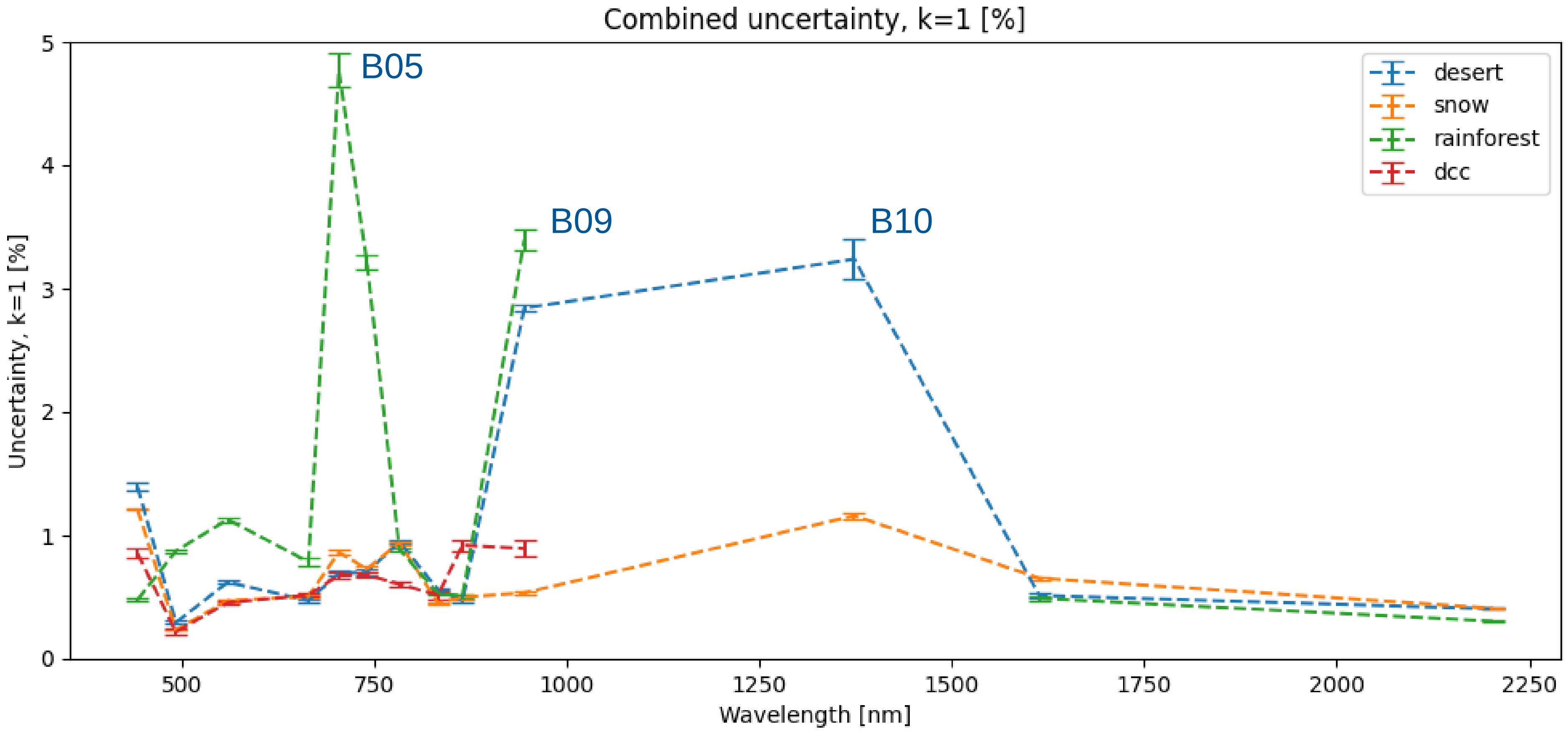
Effect	**Term in Measurement Function**	**Correlation Form**		**Uncertainty Magnitude (k=1)**	**Uncertainty units**	**Source**
		Wavelength	Between samples			
TRUTHS noise	L_{TRUTHS}	SNR data	Random	SNR data	N/A	Industrial Consortium
TRUTHS Calibration	L_{TRUTHS}	Systematic	Systematic	0.15	%	Target HIS Radiometric Accuracy
HIS Band Central Wavelength knowledge	$\lambda_{\mathrm{TRUTHS}}$	Systematic	Structured	0.05	nm	Target HIS Wavelength Accuracy
MSI Band Central Wavelength knowledge	$\lambda_{\mathrm{SRF,sensor}}$	Systematic	Structured	1	nm	Technical Guide: S2 Performance

www.comet-toolkit.org github.com/comet-toolkit

Performance Analysis

Comparison of Uncertainties between Scenes

- Uncertainty mostly below 1 % for bands not including spectral features
- A driver is the sensor wavelength characterisation
- Not all uncertainty contributions included (e.g. excludes viewing geometry & temporal mismatch)

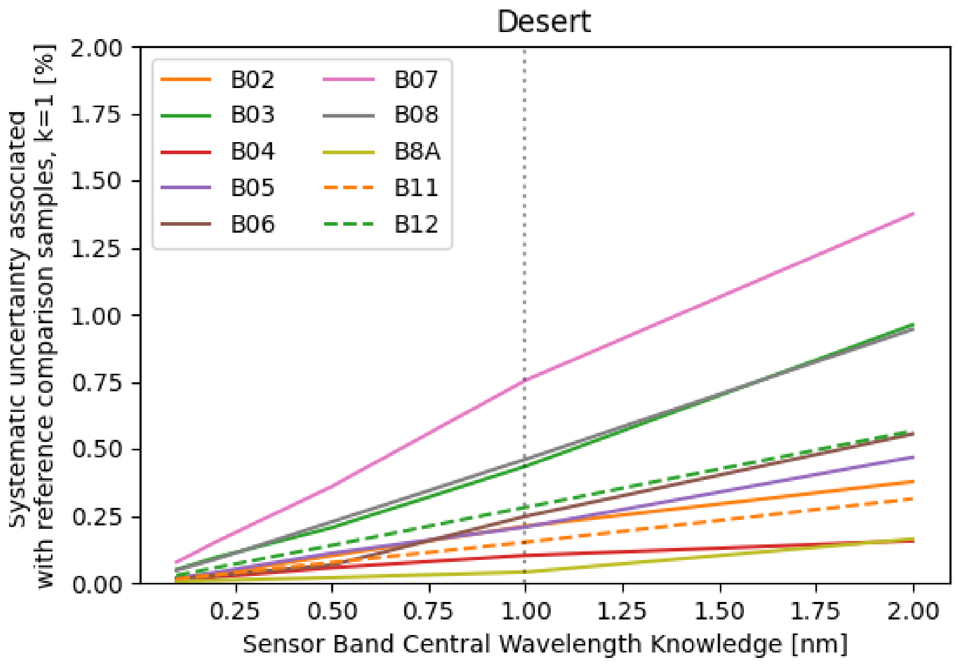


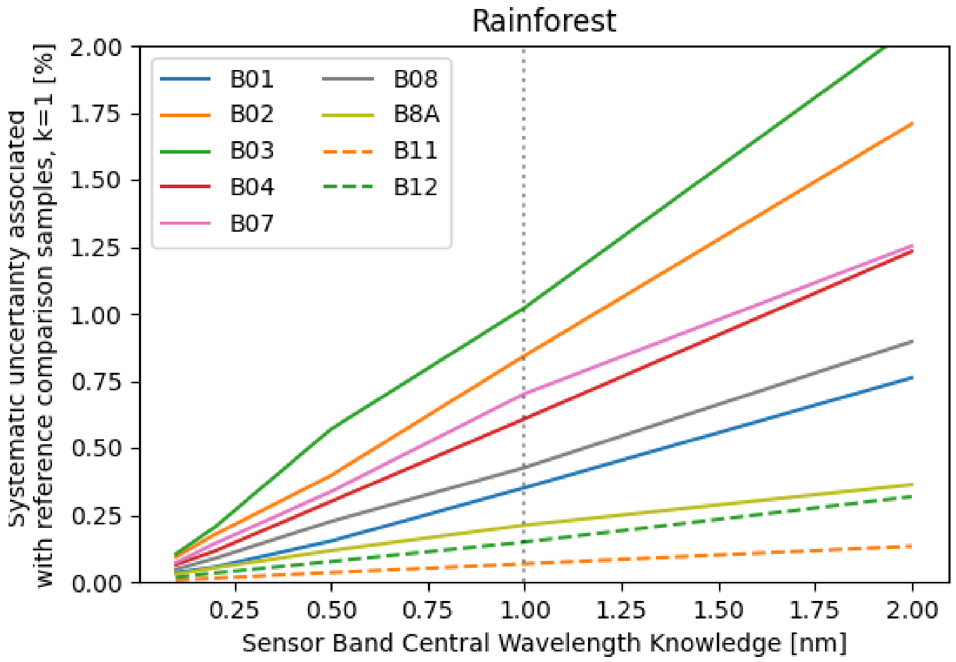
Performance Analysis

Importance of Target Sensor Characterisation to Optimise Cross-Calibration with a Reference Sensor

- In-flight characterisation of sensor wavelength is critical for cross-calibration performance
- Absorption bands have been removed (e.g. B09, B10) – these are the most sensitive but not a priority for cross calibration over this type of terrain

Impact of target sensor wavelength knowledge on uncertainty associated with processed comparison samples:





Desert

Rainforest

Summary

- Key objective for TRUTHS is to act as a SI-traceable calibration reference for the global observing system

- Defined a processing chain to prepare TRUTHS and sensor comparison samples for uncertainty-quantified comparison. This will be developed as an operational processor for the TRUTHS mission.

- Charaterisation of sensors is critical for performance of intercalibration with SITSats (e.g. TRUTHS)

- Publication in preparation on this simulation study to assess the performance of the TRUTHS-S2 MSI cross-calibration