TRUTHS mission update

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Introduction

- TRUTHS mission overview
- CEOI-ST 7 study
  - MRD revisions
  - Hyperspectral Imager design (see Dan Lobb's presentation tomorrow)
  - TRUTHS Calibration method.
  - Cross-calibration uncertainty tool.
  - Options for implementation
- Future studies
- Summary

What's unique about TRUTHS?

UK-led small satellite mission that will measure the solar irradiance and Earth solar-reflected radiance with high radiometric accuracy.

Solar spectral irradiance (320* - 2300 nm) 0.3% (k=2)

Total solar irradiance (0.2 - 30 µm integrated) 0.02% (k=2)

Earth solar-reflected (320* - 2300 nm) 0.3% (k=2)

Previous sensors have been limited to ~2-6% (k=2) due to limitation of on-board calibration & monitoring of degradation over mission lifetime. No traceability on-orbit.

TRUTHS will include a flight-adapted version of the full pre-flight calibration chain on-board maintaining traceable high radiometric accuracy over the mission lifetime.

Underpinning Science Drivers

- The establishment of 'benchmark' observational climate data of sufficient accuracy to allow unequivocal detection of climate change on decadal timescales.
    - NASA (NRC/CLARREO), ESAC report, WMO-GSICS, GCOS, CEOS..
- Provision of sensor "in-flight" SI traceability / use of a 'reference' sensor and its limiting constraints including means to link sensors for climate records
    - CEOS (and individual space agencies) WMO-GSICS
    - Various studies in progress
    - Chinese activities to mimic TRUTHS concept
- Secondary L2 data usage has multiple applications, SMEs, CEMS etc.
    - Studies in progress

Climate benchmark driver

- Sound policymaking requires high confidence in climate (model) predictions.
- High confidence in model predictions is only achieved by verification against decadal-scale change observations with high, rigorously known accuracy.
- Our current observing capability is inadequate to confidently observe the small but critical climate change signals that are expected to occur over decadal time scales.
- Observational measurements are fundamental in assessing the accuracy of climate change projections made by models and for the attribution of climate change.

An observational climate benchmark data set of sufficient accuracy to test model predictions is one of the key challenges laid down by the international climate science community.

TRUTHS (Traceable Radiometry Underpinning Terrestrial- and Helio-Studies) & the US-sister mission **CLARREO** (Climate Absolute Reflectance and Refractivity Observatory) are complementary mission concepts proposed to address this issue.

Climate benchmarking

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What is a climate benchmark?

A snap-shot of the global climate state, when repeated over time allows an observation-based measure of change. Needs high accuracy, anchored to a known reference standard – traceable to SI

What do we need to measure?

The incoming and outgoing energy that drives the climate in parameters that can be directly related to climate model predictions.

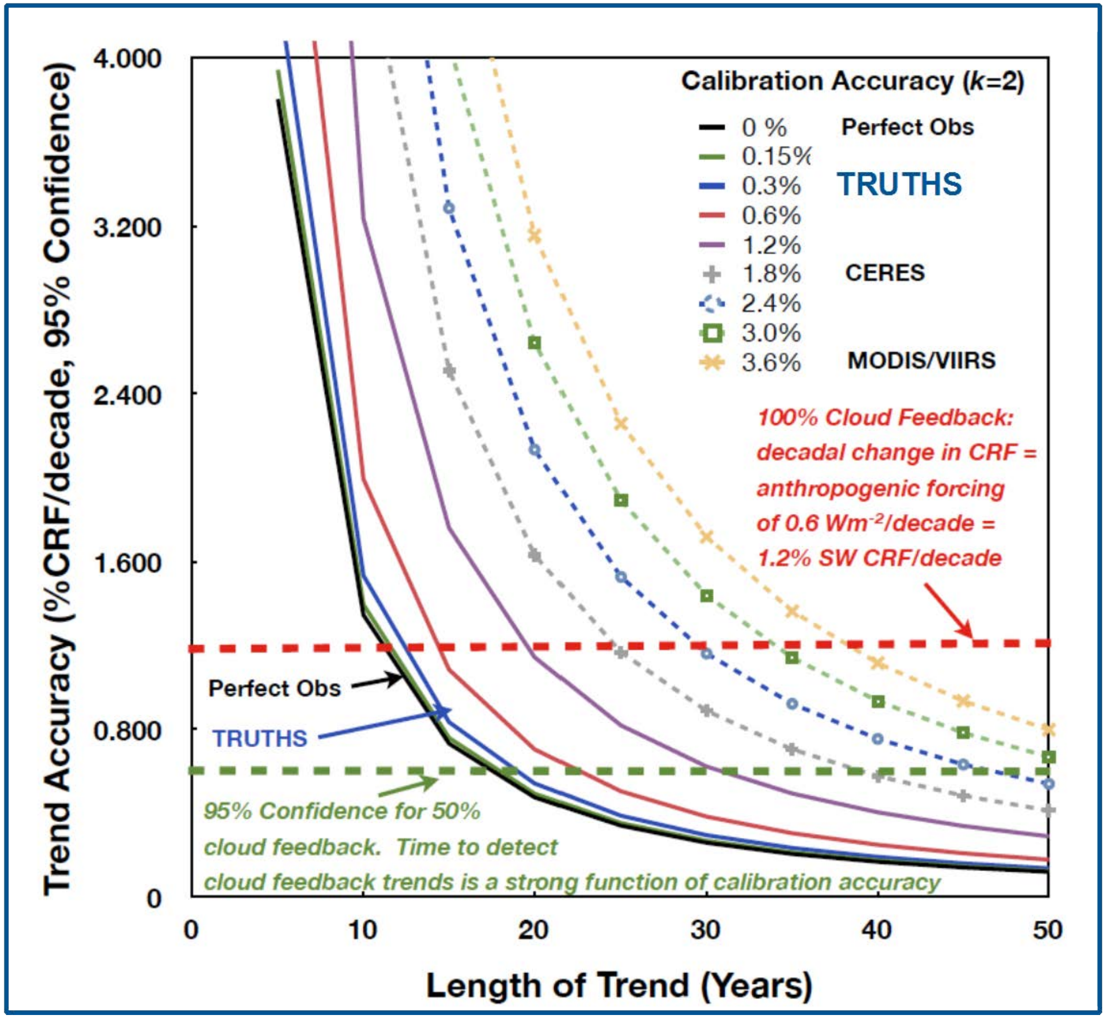
1. The incoming solar irradiance spectrum
2. The reflected solar radiance spectrum of the Earth

Specifics

Spectrally resolved to allow climate process attribution

Moderate instantaneous res. spatially, zonally averaged with true global coverage representative of a typical year.

Why high accuracy?



High accuracy reduces time to detection

TRUTHS or (CLARREO) (proposed satellites) accuracy (0.3% k=2) near optimum to the perfect observing system

for 100% cloud feedback
TRUTHS ~ 12 yrs
CERES ~ 25 yrs
MODIS ~ 40 yrs

For 50% difference > 20 yrs

Sensor inter-calibration

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By crossing orbits of other satellites, viewing the same target (ocean, land, cloud top, instrumented vicarious calibration site, moon) TRUTHS would transfer high accuracy traceable radiometric calibration to other sensors.

- Upgrade performance
- Bridge gaps in climate data record
- Cost effective

Studies are underway to determine the imager specification drivers (spectral (5 nm) & spatial resolution (50-100m), SNR …) to optimise this process & determine achievable accuracy transfer.

MRD specifications (1/4)

MR-ID	Type	Value
MR-TRUTHS-04	Spectral coverage (Earth and Sun) (spectrometer)	320-2300 nm potential relaxation to 350 or ~400 (TBC) following further studies if technology drive to 2300 nm with continuous coverage.
MR-TRUTHS-05	Radiometric Accuracy (spectrometer)	Spectrally integrated reflectance product - 0.3% (k=2) on the reflectance of 0.3
MR-TRUTHS-06	Radiometric Accuracy	Spectrally resolved reflectance product - 0.3% for the key spectral regions, extending to 0.5-1.0% in less sensitive or energetically low-contributing spectral positions.
MR-TRUTHS-11	Radiometric Accuracy (total combined uncertainty)	Spectrally integrated (0.32 to 2.3 um Earth reflected solar radiance product 0.2% (k=2)
MR-TRUTHS-12	Radiometric Accuracy (total combined uncertainty)	Spectrally integrated (0.32 to 2.3 um solar irradiance 0.2% (k=2)
MR-TRUTHS-07	Radiometric accuracy (TSI)	0.2 um to 30 um integrated total irradiance 0.02 % accuracy (k=2)

MRD specifications (2/4)

MR-ID	Type	Value
MR-TRUTHS-08	Spectral resolved spectral range	350 / 400 (TBC) to 2300 nm continuous
MR-TRUTHS-09	Spectral extent (option)	A UV broadband channel from 320 nm to beginning of spectrally-resolved range
MR-TRUTHS-10	Spectral resolution	10 nm bandwidth (for reference calibration need to match comparative sensor: 8 nm bandwidth ~4 nm steps) Can be relaxed to 25 nm for some non-critical wavelength regions.
MR-TRUTHS-13	Signal to Noise Ratio	Adequate to meet accuracy levels in products with appropriate averaging. Reference calibration and level 3 retrievals require >100 and ideally > 300 for at least visible spectral region at highest resolution
MR-TRUTHS-14	Instantaneous spatial resolution	Level 2/3 < 250 meters. ideally 50 – 100 m
MR-TRUTHS-15	Polarisation sensitivity	0.5% (k=2) for λ<1000 nm 0.75% (k=2) for λ>1000 nm

MRD specifications (3/4)

MR-ID	Type	Value
MR-TRUTHS-16	Orbit	polar 90 degree inclination with altitude of 609 km (±200 m)
MR-TRUTHS-17	Swath	50- 100 km or larger
MR-TRUTHS-18	Scene Pointing	(reference calibration ability 1 km knowledge <3x spatial resolution
MR-TRUTHS-19	Reference inter comparison samples	2000 samples (assuming SNR <50 will reduce with improved SNR) within 1deg and ±5 minutes.
MR-TRUTHS-20	Continuity of operation	Sufficiently continuous to not increase the sampling bias error contribution to represent a significant uncertainty contribution.
MR-TRUTHS-21	Revisit	A 61 day revisit as determined by the 90deg polar orbit.

MRD specifications (4/4)

MR-ID	Type	Value
MR-TRUTHS-22	coverage	Global nadir spectral radiances
MR-TRUTHS-23	Sampling time	Continuous during sunlit phase of the Earth
MR-TRUTHS-24	Swath	50 to 100 km minimum
MR-TRUTHS-25	quantisation	14 bit
MR-TRUTHS-26	Pointing accuracy	<1 km
MR-TRUTHS-27	Pointing Knowledge	<3 x IFOV (<300 m)

Platform requirements
Spacecraft Preliminary Configuration

Parameter	Value
Orbit	609 circular orbit at 90° inclination
Total Instrument Mass	100 kg
Maximum Power Requirement	185 W (low) 320W (high)
Instrument Size	< 1x0.75x0.75 m
Pointing accuracy	1 km on ground
Pointing knowledge	~200 m
Slew capability	~ 2 deg/s (TBC)
Lifetime	3 yrs minimum ideally 5 yrs plus
Data generated per day	~ 1.5 TByte

CEOI-ST 7th call project overview

- Run from June 2014 to June 2015.
- Participants: NPL & SSTL
- Start from draft MRD created in previous CEOI-ST funded project
    - Review outstanding specifications identified in MRD
    - Develop the imager design
    - Further develop the on-board calibration system
    - Routes to implementation.

WP1 – Spectral extent & resolution

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- Overall spectral coverage 320 -2300 nm
- Need coverage from 320 nm, else not covering all solar domain. But can be broadband channel to spectrometer shortwave spectral extent.

Starting Wavelength	Unresolved spectrum percentage
320	0.00
350	2.65
400	8.10

- Spectral resolution for climate benchmark < 8nm, but other applications require 5 nm in UV-VIS and 10 nm in NIR.

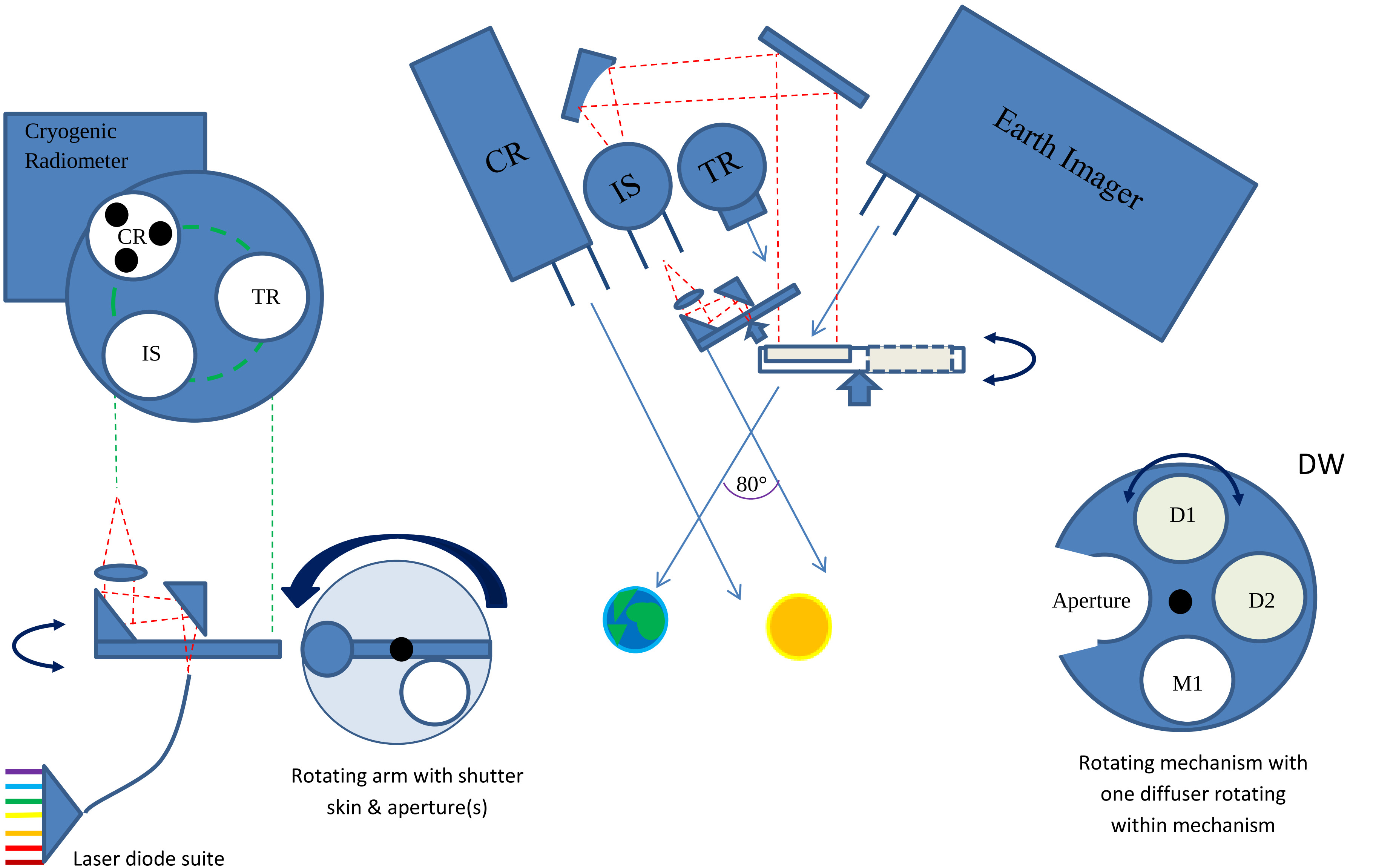
WP3 – Calibration method

- Earth Imager (EI) – measure spectral Earth radiance & solar irradiance (CEOI-7)
- Cryogenic radiometer (CR) – TSI & heart of SI-traceable calibration (measured LD power) (CEOI-8)
- Irradiance sphere (IS) – source homogeniser for solar & laser input to diffuser. (no development needed)
- Transfer radiometer (TR) – Couples laser power measurement to diffuser radiance calibration. (EMRP)
- Diffuser wheel (DW) – EI radiance calibration target (just implement)
- Laser diode suite & delivery arm (LS) – On-board monochromatic sources. (developing in parallel)

WP3 – Calibration method

- On-board calibration scheme simplified – removing movement of TR instrument.
- Now only 3 simple rotations. (Simplification to 2 possible with no key functionality loss.)

WP3 – Calibration method



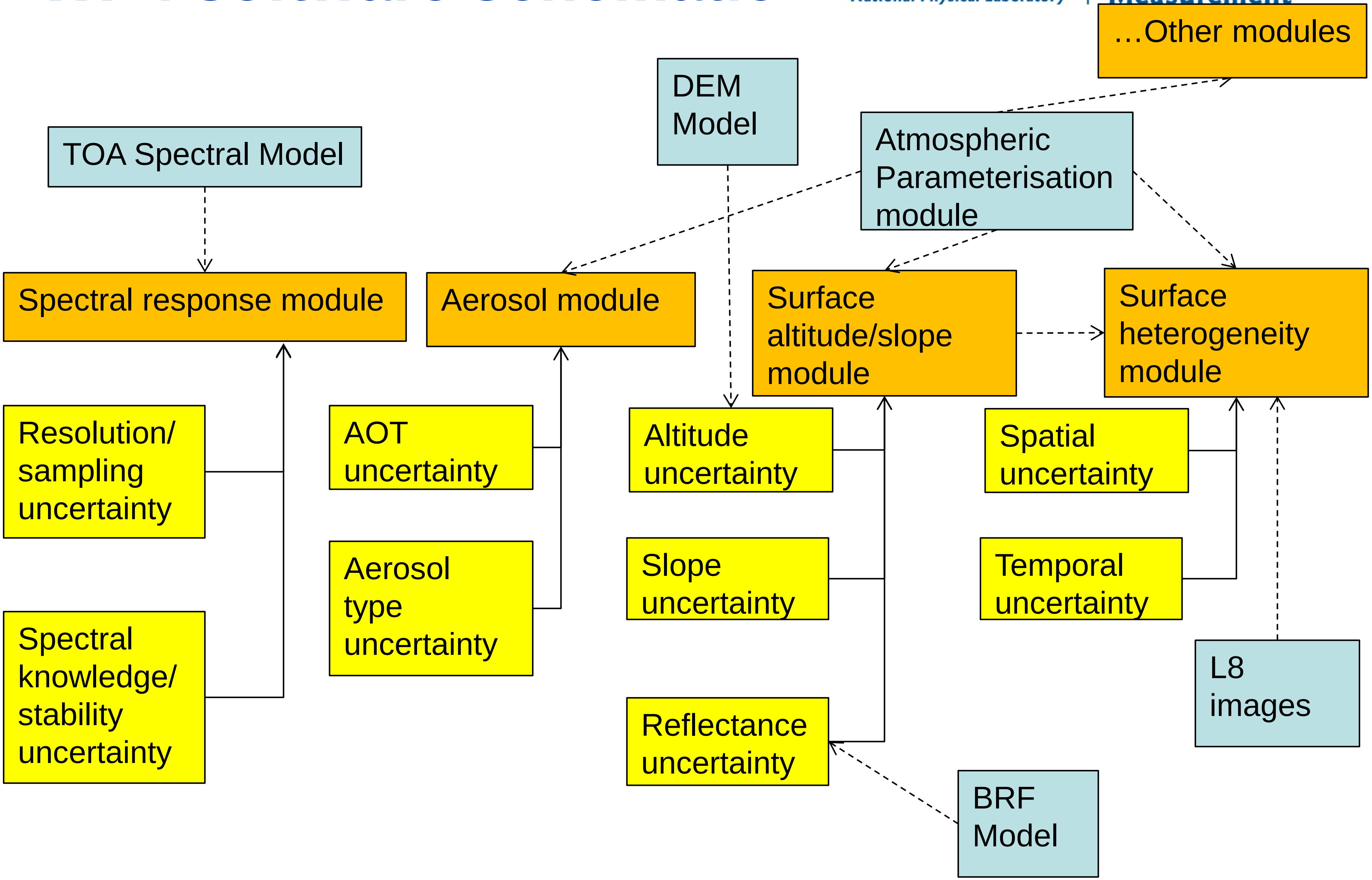
WP4 - Cross-calibration performance tools

- **Objective:** estimation of the radiometric uncertainty of a cross-calibration using TRUTHS as a reference sensor → output to inform the cross-calibration methodology and instrument design.
- **Structure:** initial version of four independent modules addressing the major uncertainty contributions affecting a typical CEOS-prioritized land based calibration site: surface altitude/slope, spectral response, aerosol content, and surface reflectance heterogeneity.
- **Uncertainty methodology:** Monte-Carlo Method for uncertainty propagation as in GUM-S1 and QA4EO → cross-calibration uncertainty estimates based on probability distribution function of the associated parameters.
- **Software implementation:**

  Portable and accessible: open-source code (Python), embedded algorithms (e.g. slope calculation) and open-access libraries (e.g. GDAL)

  JASMIN supercomputer cluster: Memory and processing limitations overcome. Large memory units and code parallelization.

WP4 software schematic



Cross-calibration model: Spectra Module

- **Inputs:**

  TOA reflectance: reference spectrum interpolated to 0.0005 nm. (*DIMITRI*)

  Sentinel 2 spectral response interpolated at 0.0005 nm.

  TRUTHS Imager design: native sampling/resolution and binning.

- **TRUTHS spectral response:**

  triangular shape native bands (low aberration optical design).

  Sampling matches native resolution as FWHM (slit width = pixel size)

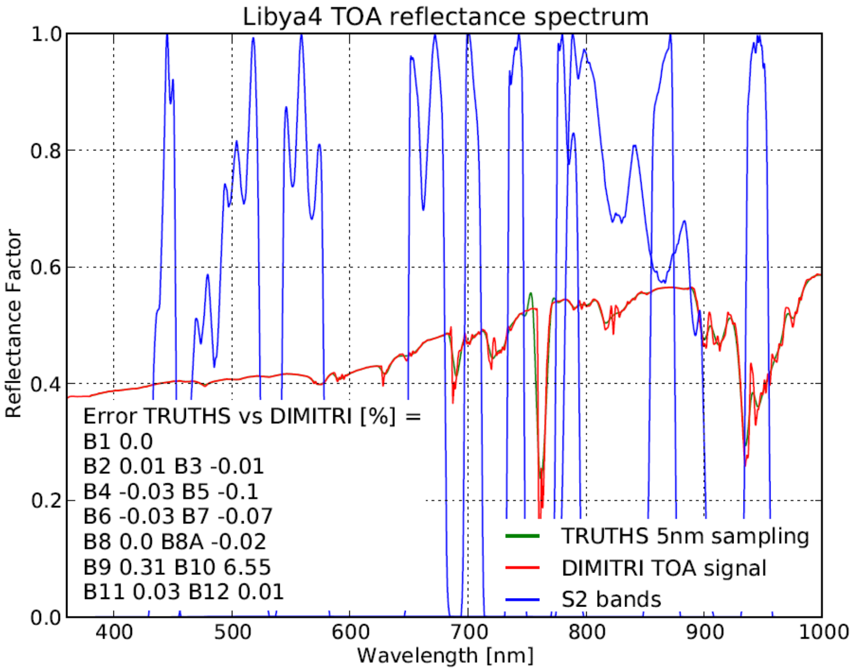
- **TRUTHS TOA measurement:**

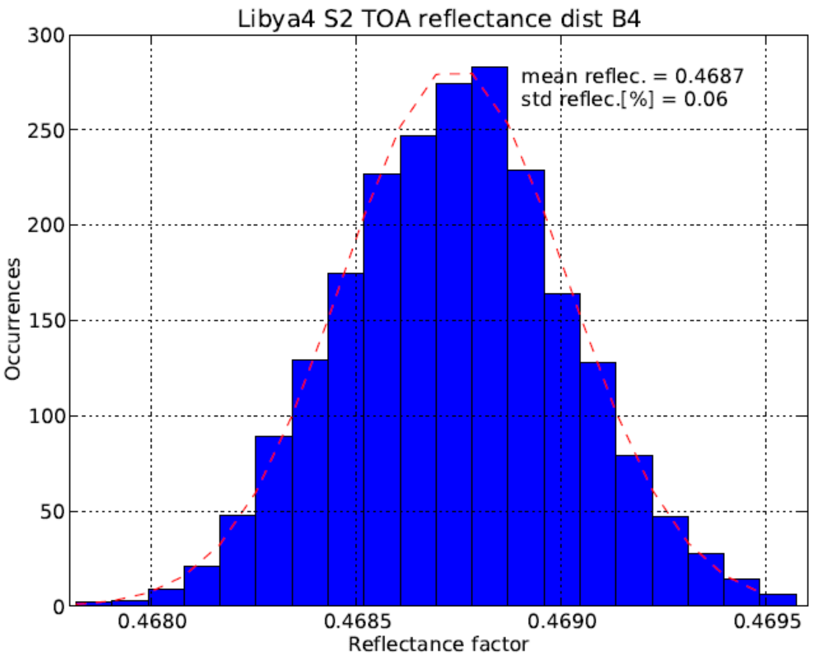
  Convolution with DIMITRI TOA at native bands and binning accounted for final TRUTHS bands

  Reconstruction of the DIMITRI TOA reflectance at same sampling steps using interpolation (justified by the low accuracy of TRUTHS measurements) and no-prior knowledge of the signal assumed (conservative approach).

Cross-calibration model: Spectra Module

- **Sampling/resolution error:** the Sentinel 2 is convolved first with the TOA reflectance reference and then with the reconstructed one by TRUTHS. An error for each Sentinel 2 band is obtained.
- **Knowledge/stability uncertainty:** the TOA reflectance using TRUTHS measurements is reconstructed and convolved with a Sentinel 2 band *n* times. A dispersion of the convolved TOA reflectance is obtained.





Future activities

- CEOI-ST 8th call project, working with ADS UK to:
  - Develop the ADS space cryogenic cooler
  - Investigate new black coatings
  - Integrate cooler with a CSAR EM in vacuum environment
  - Build demonstrator the TRUTHS calibration facility
  - Integrate CSAR & cooler demonstrate within TRUTHS calibration facility.

March 2015 – November 2016.

Summary

- UK-led small satellite mission that will measure the solar irradiance and Earth solar-reflected radiance with high radiometric accuracy.
- Crossing orbits of other satellites - Upgrade performance, bridge gaps in climate data record in a cost effective way.
- Developing the instruments (EI, CR & cooler) via various CEOI-ST funded & other projects. Raising instrumentation to TRL6 in preparation for flight opportunities. (EE-9 application etc.)