Traceable **R**adiometry **U**nderpinning **T**errestrial- & **H**elio- **S**tudies

Enabling a space-based Climate & calibration observatory

‘Principal Investigator’:

Professor Nigel Fox
National Physical Laboratory, UK
Vis Prof Univ of Reading
Chair: CEOS WGCV IVOS

Approved as an ESA Earth WATCH mission (28 Nov 19)

Mission Objectives

TRUTHS is an **operational climate-focused mission**, aiming to:

1. **Climate benchmarking:** enhance by an order-of-magnitude our ability to estimate the Earth radiation budget (and attributions) through direct measurements of incoming & outgoing energy,
2. **Satellites cross-calibration:** establish a 'metrology laboratory in space' to create a fiducial reference data set to cross-calibrate other sensors and improve the quality of their data, robustly anchored to a primary SI reference in space.

and

3. provide SI-traceable measurements of the **solar spectrum** to address direct science questions and climate.

Mission Products

- L1: Earth-reflected Spectral Radiance (ToA), Solar Spectral Irradiance, Lunar Spectral Irradiance – all in the range 320nm to 2400nm;
- L1: Total Solar Irradiance integrated in the range 200nm to 30000nm;

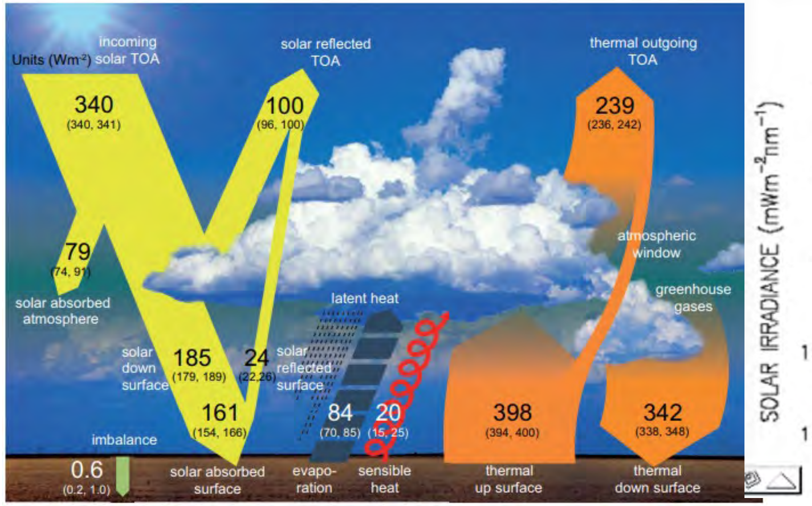
→ **Climate benchmark, solar measurement**

- L2: Spectral Surface Reflectance, at ground level (320nm to 2400nm);

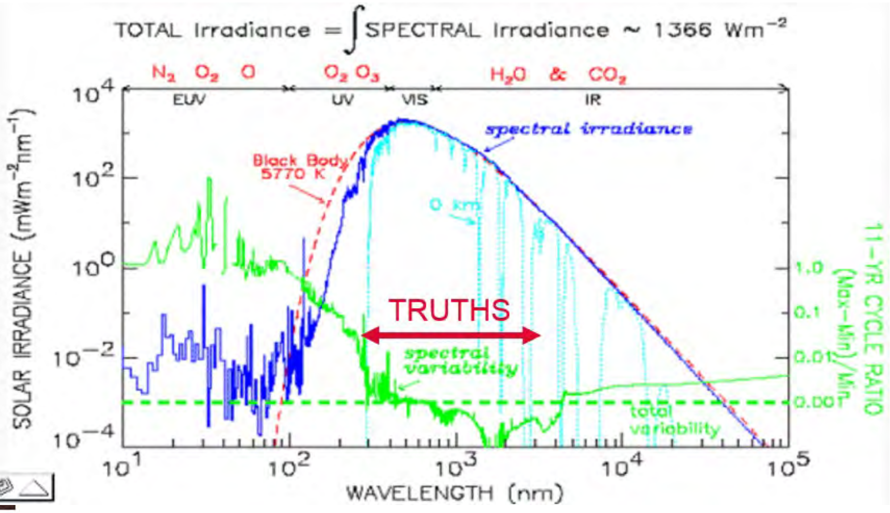
→ **Earth science**

- calibration coefficients & match-up products to determine biases for TBD other sensors over multi-scene types and view angles.

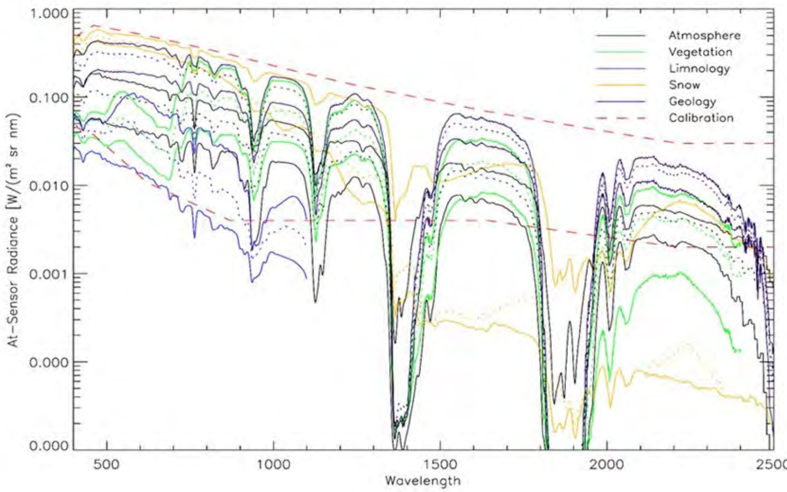
→ **Cross-calibration**



Radiation balance



Solar spectral irradiance



Surface reflectance

Key performance requirements

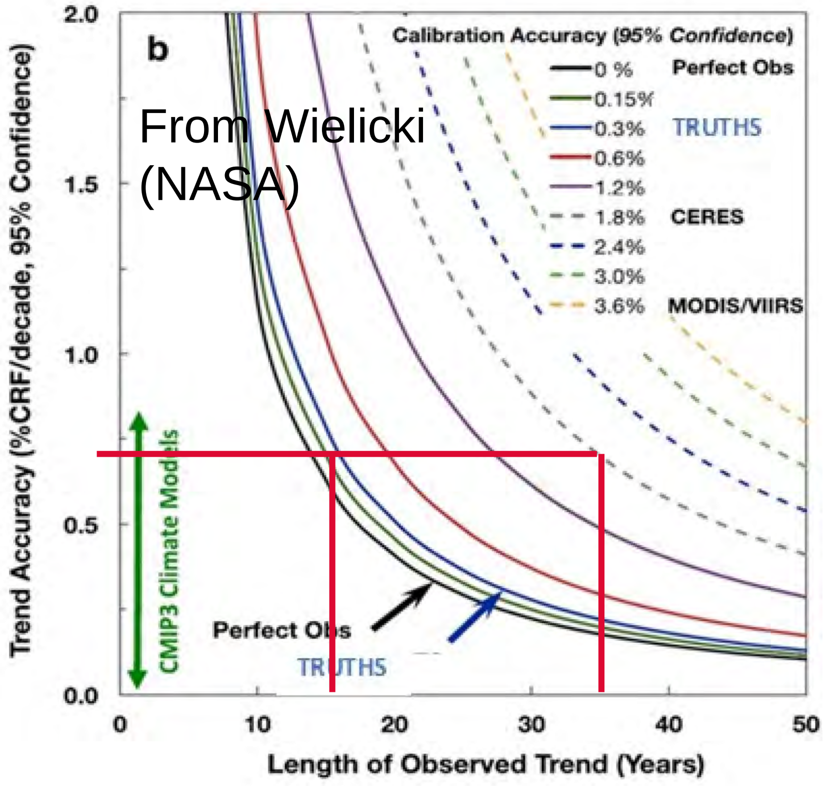
Level 1 products	Mission Requirement				
	Spectral range (nm)	Bandwidth (nm) Spec Samp Int ~0.5 FWHM	Uncertainty (%) (k=2)	SNR	GIFOV (m) @100 km Swath
Earth spectral radiance (Climate Benchmark)	320 - 2400	<8 for < 1000 nm <16 for >1000 nm	0.3 (goal) <1.0 (Threshold)	>~50	250
Solar/lunar Spectral Irradiance	<320 – 2400	1 (<400), <5 (<1000), <10 (<2400)	0.3 (goal) <1.0 (Threshold)	300	NA
Total Solar Irradiance	Total	200-30000	<0.02 (goal) 0.05 (Threshold)	<500	NA
Earth radiance (Calibration / secondary applications)	<400 - 2400	<8 for < 1000 nm <16 for >1000 nm	<1.0	To not limit uncertainty of application >~150 @ 50 m for 500-950nm	50 – 100 m Integrated up for GHG/Ocean Col/Climate Multi-angle sampling

The TRUTHS design is driven by:

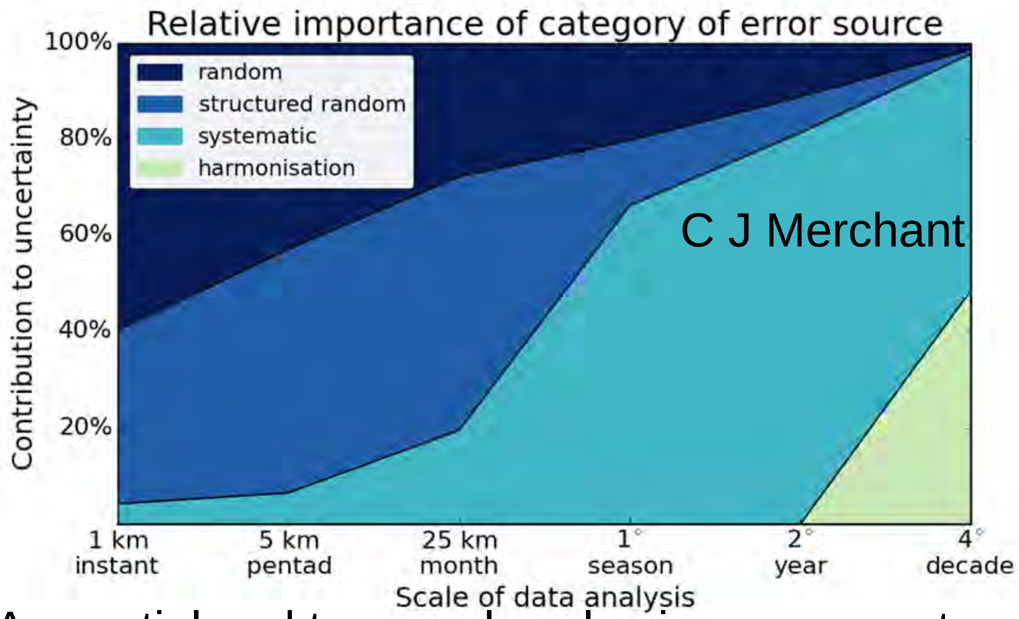
- **Radiometric demands** of the climate application ➔ *Payload and calibration*
- **Geometric** to optimally match other sensors (calibration) and secondary applications ➔ *FoV, Swath & SNR*
- **Orbit**: optimal sampling to quantify the climate and facilitate cross-calibration ➔ *Satellite and launch*

Climate: Examples

- **Robust anchor for long-time-base FCDRs**
  - **Can provide a bridge between data gaps**
  - **Remove any ambiguity in data quality**
- **Enables trends in Key feedbacks like cloud to be detected significantly earlier limited by natural variability**
- **Most accurate measure of Short-wave 'radiation balance' (in and out)**

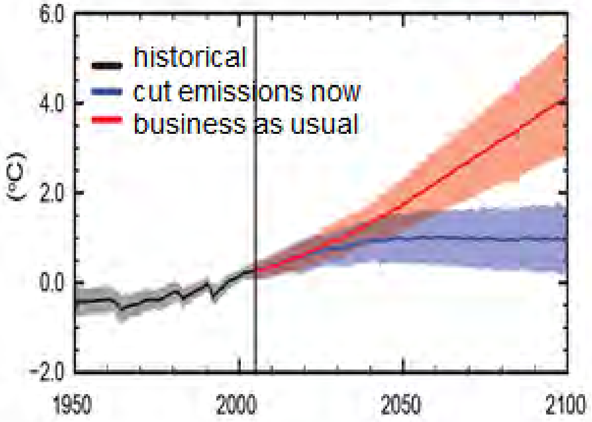


Time to detect trend (e.g. cloud rad forcing) based on Uncertainty of sensor



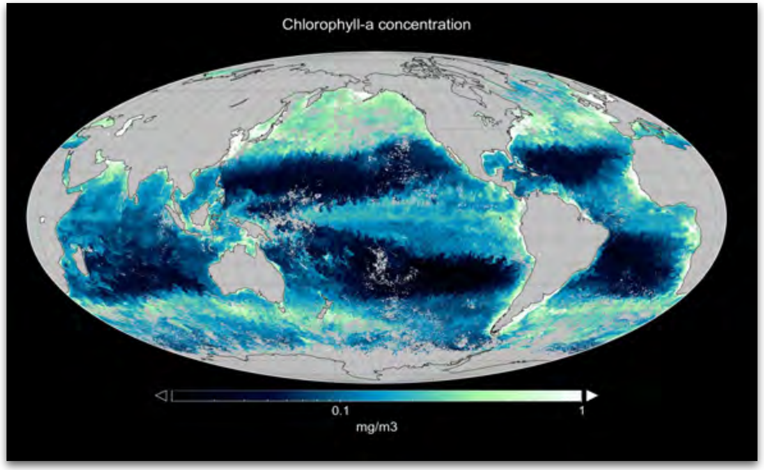
As spatial and temporal scales increase, systematic uncertainties dominate

Need to test & constrain Variance in climate model forecasts (IPCC)

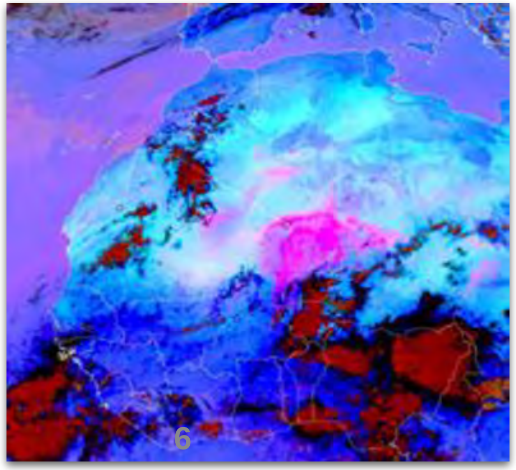


TRUTHS: Underpinning operational ECV retrievals for climate monitoring and model improvement

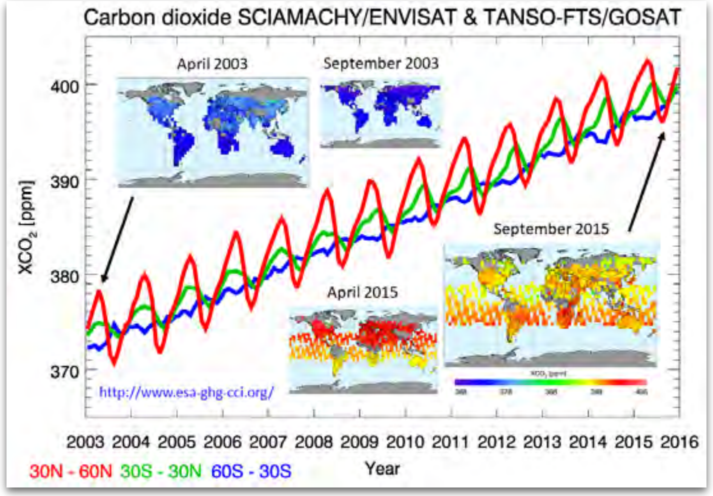
- **Carbon-sink- Ocean colour:** direct TOA cross-calibration of sensors to absolute radiometric accuracy of ~0.5%, meeting GCOS requirements



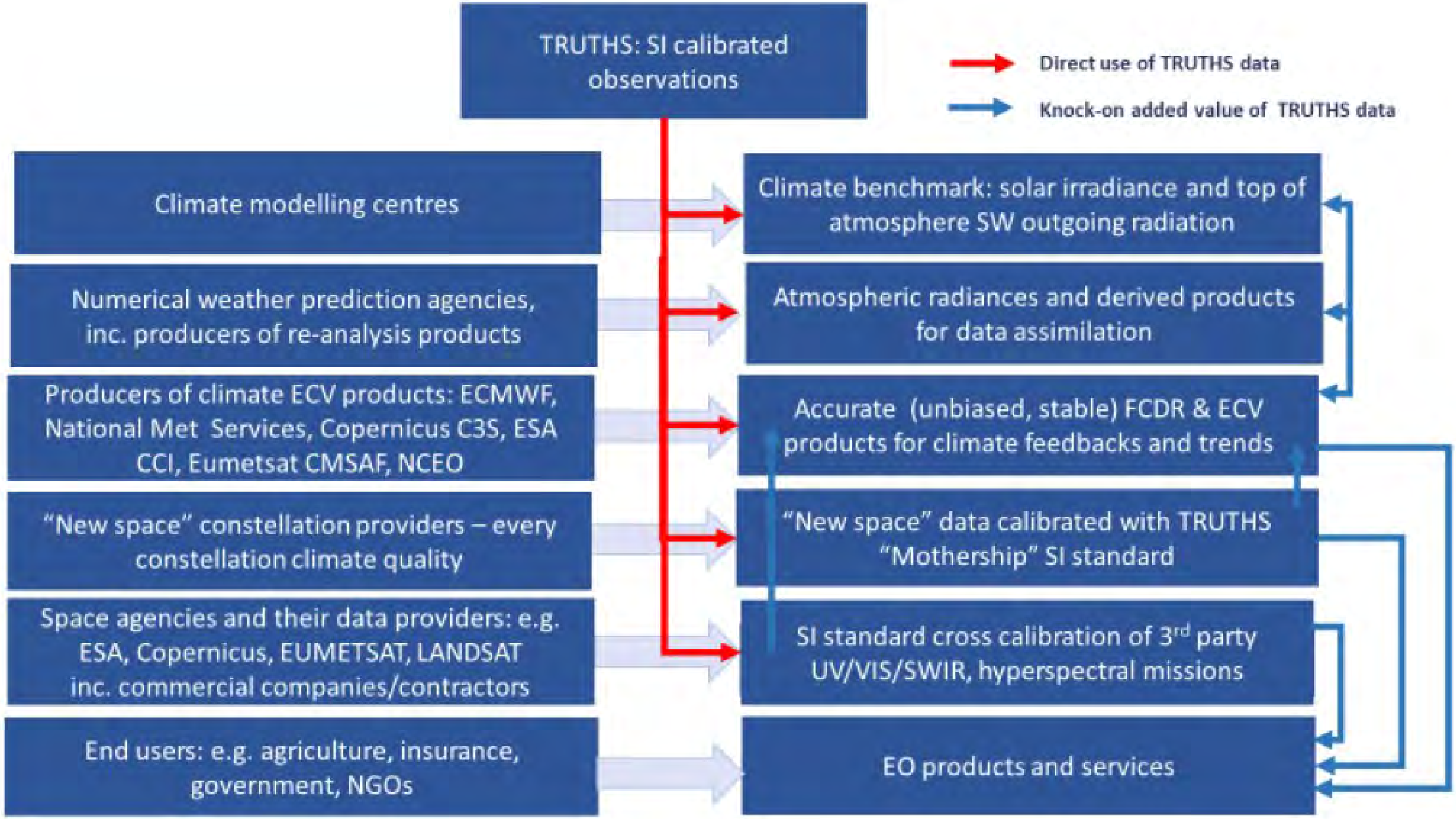
- **Aerosols:** "Climate closure points" unifying ground networks and multiple optical sensors through the TRUTHS FCDR.



- **Emissions- CO_2:** Referencing Copernicus and multi-agency CO_2 constellations at 0.5-1.0% radiometry through cross-calibration.
- Land use change



Many & varied users



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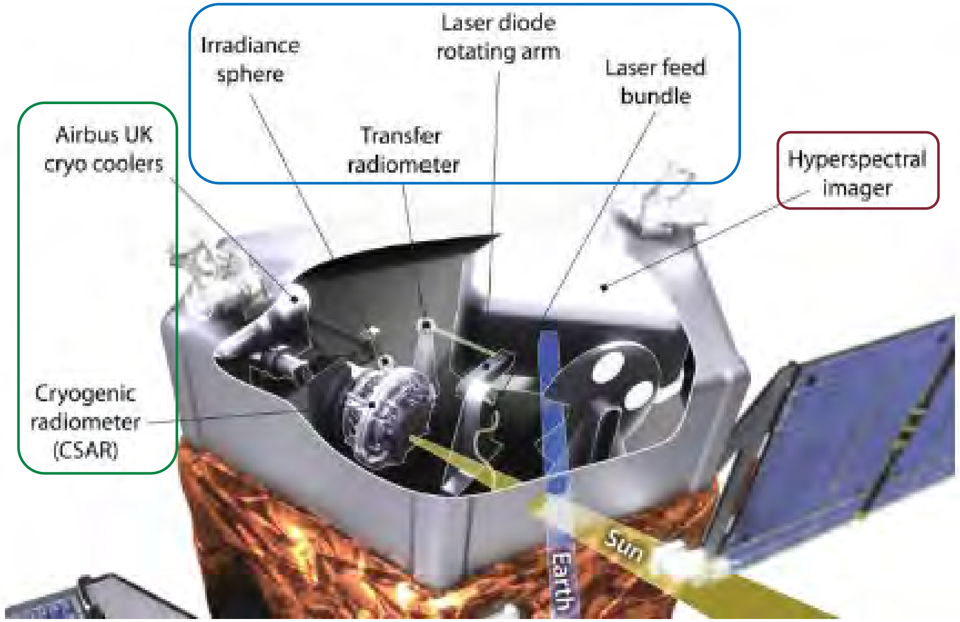
The Satellite

- **Single satellite:**
  - placed on a LEO (~600km) polar (90°, non-SSO, precessing) orbit;
  - Small/medium class” (<1 ton, <1kW);
  - “agile” (repointing at each orbit to Earth / Sun);
  - able to support high payload data volume (~4500 Gbits daily) & rate (X-band, ~600 Mbps), some on-board processing needed.

- **Satellite elements:**
  - **Platform** (reference Astrobus-S/M, TBC);
  - Hyperspectral Imaging Spectrometer (**HIS**);
  - Cryogenic Solar Absolute Radiometer (**CSAR**);
  - On-Board Calibration System (**OBCS**).



TRUTHS Innovations

Mission design - Phase A/B1 to start soon

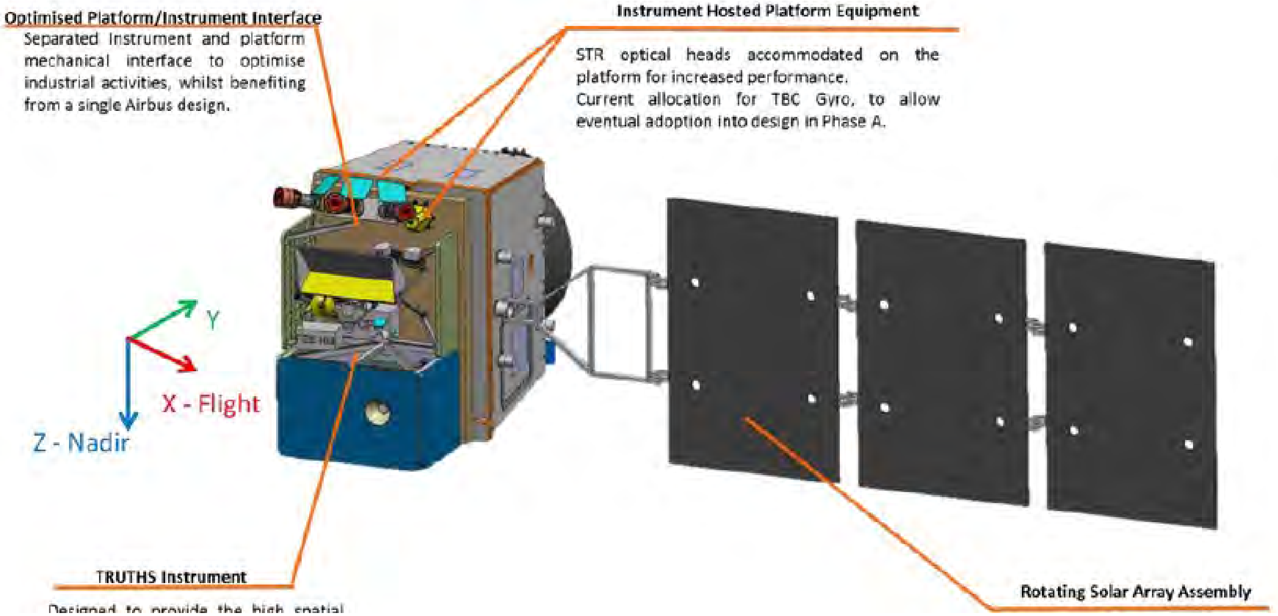
Innovations:

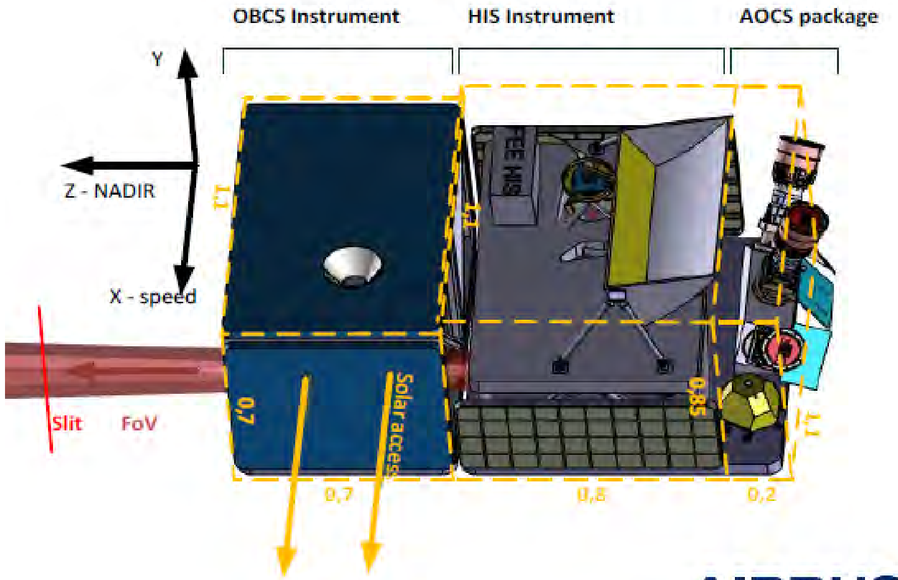
- **Polar orbit**
- **Hyper-spectral imager**

SI- Traceability on-board

- **Calibration system**
  - **Primary standard**

- Establishing 'NPL in space'





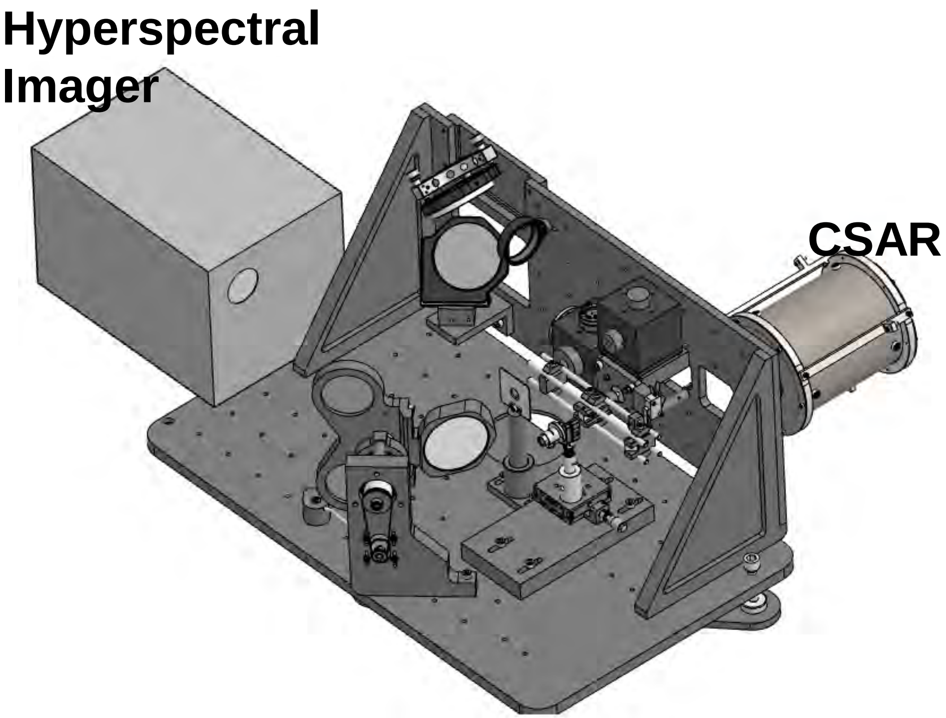
AIRBUS

What makes TRUTHS different to other optical satellite missions?

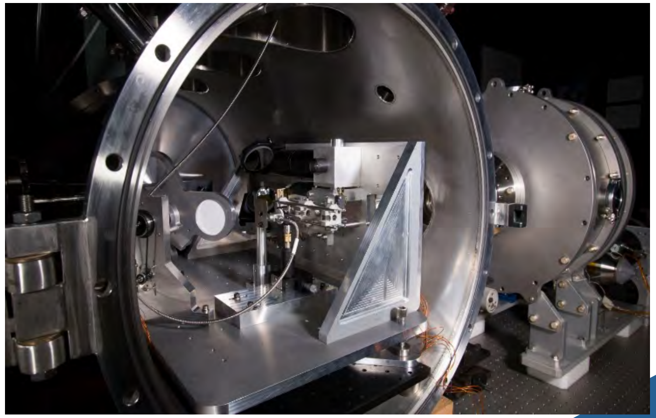
TRUTHS includes an on-board calibration system, that replicates the SI-traceable calibration chain employed in National Metrology Institutes (NMIs) globally, including flight of a primary standard - a Cryogenic Solar Absolute Radiometer (CSAR) (see calibration video).

The hyperspectral imager on-board TRUTHS is routinely re-calibrated, with SI-traceability.

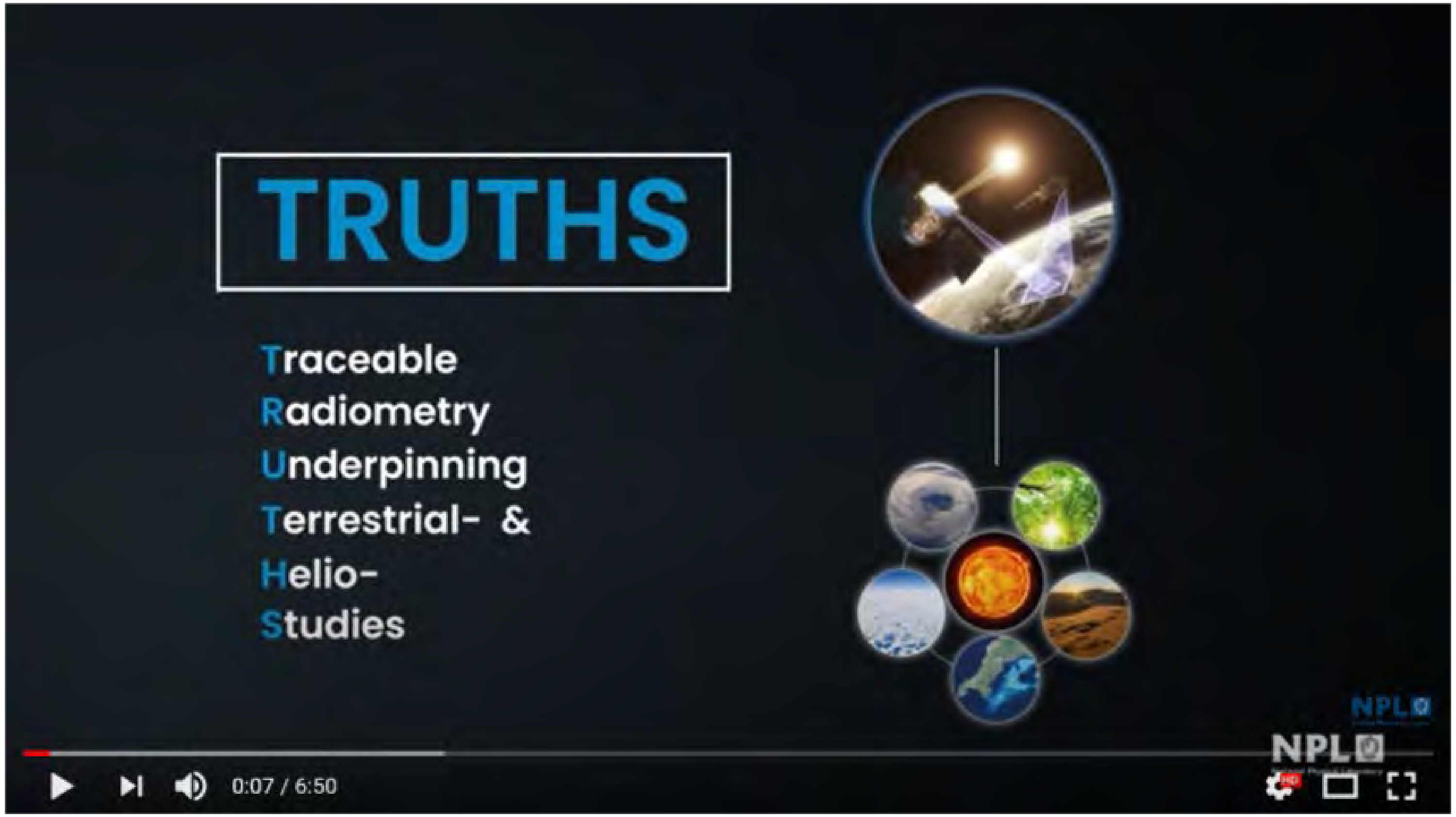
Maintaining it’s SI-traceable high radiometric performance throughout the mission lifetime.



Representation of the TRUTHS calibration system

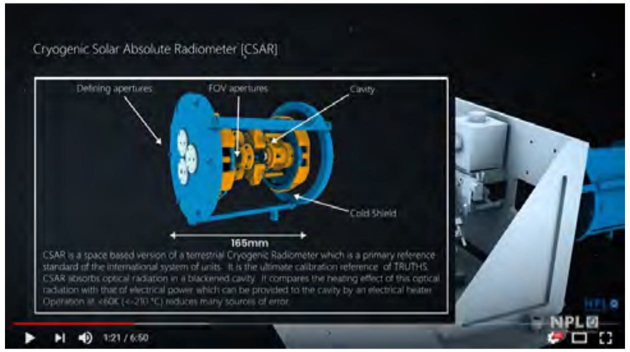


How the TRUTHS on-board calibration system works?

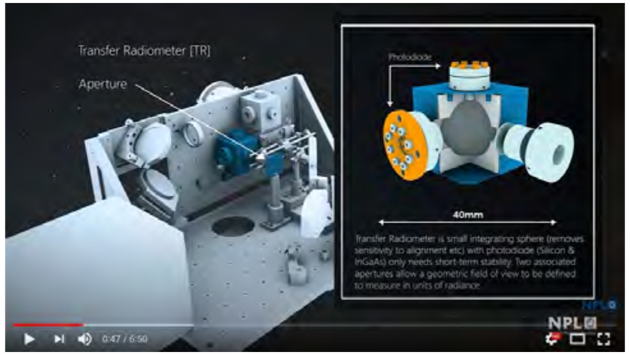


https://www.npl.co.uk/earth-observation/truths/satellite-calibration

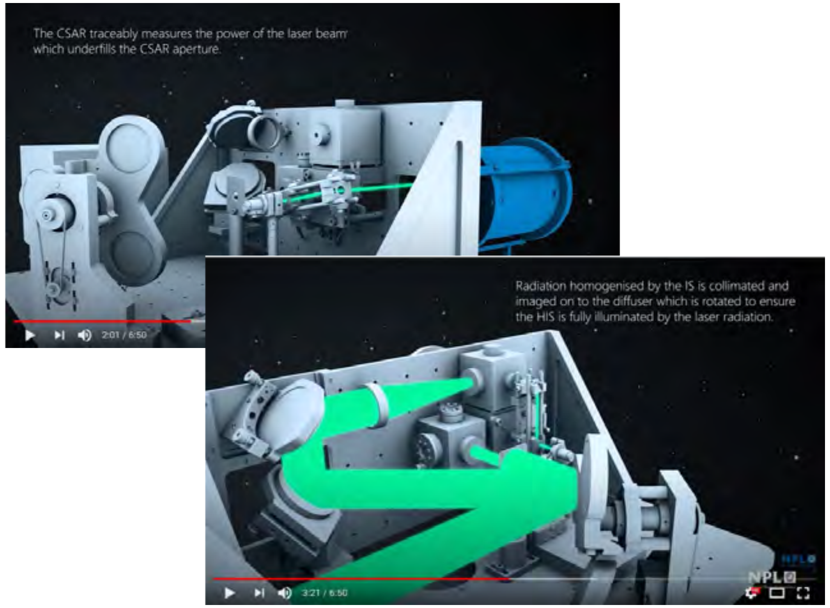
Describes the sub-systems



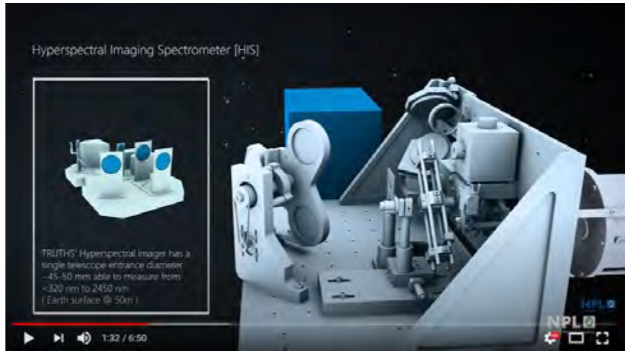
CSAR – Primary standard



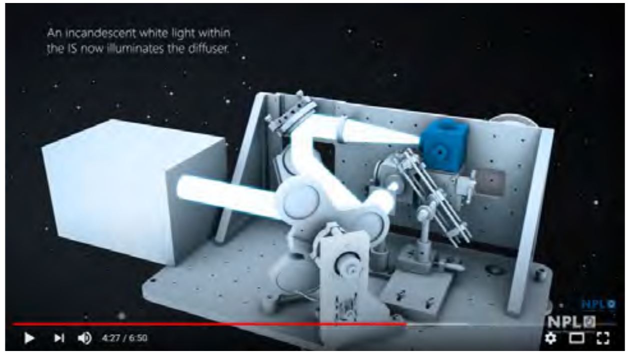
Transfer radiometer



Laser diode & delivery system



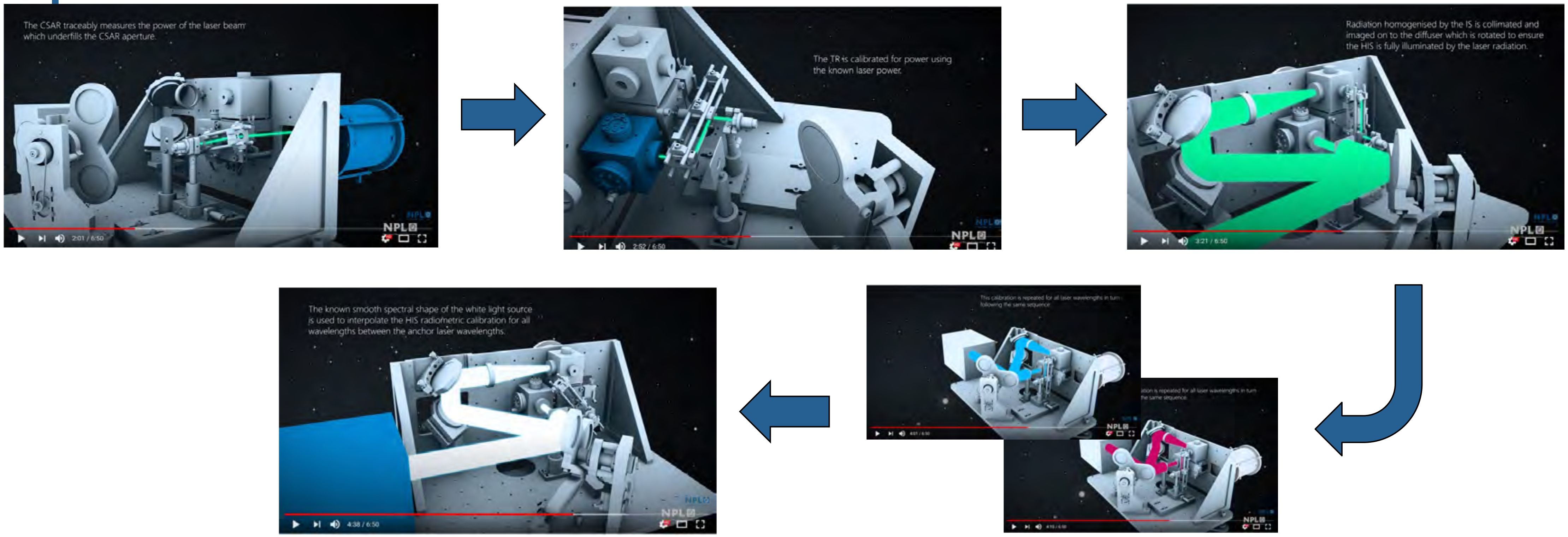
Hyperspectral Imager



Broadband interpolation

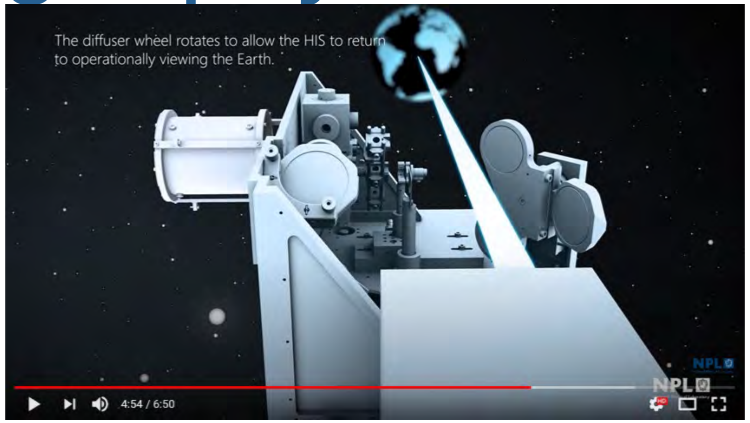
https://www.npl.co.uk/earth-observation/truths/satellite-calibration

Describes the linkages from laser power to spectral radiance calibration



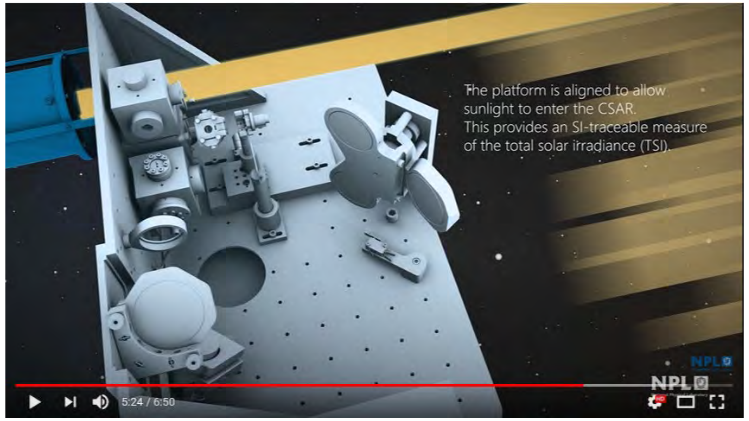
https://www.npl.co.uk/earth-observation/truths/satellite-calibration

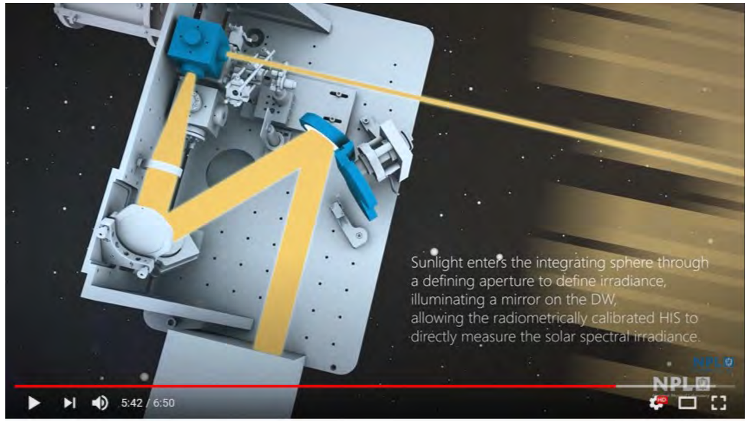
On-board calibration system (OBCS) enables the geophysical measurements



Earth-reflected Spectral Radiance

Total Solar Irradiance





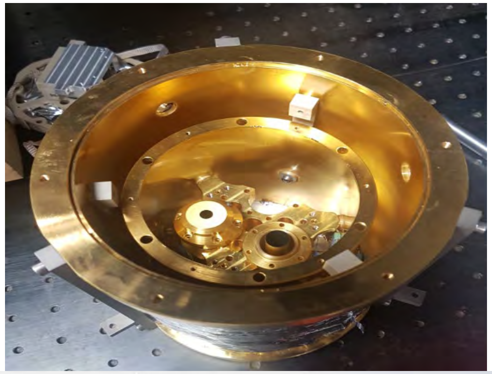
Solar/Lunar spectral irradiance

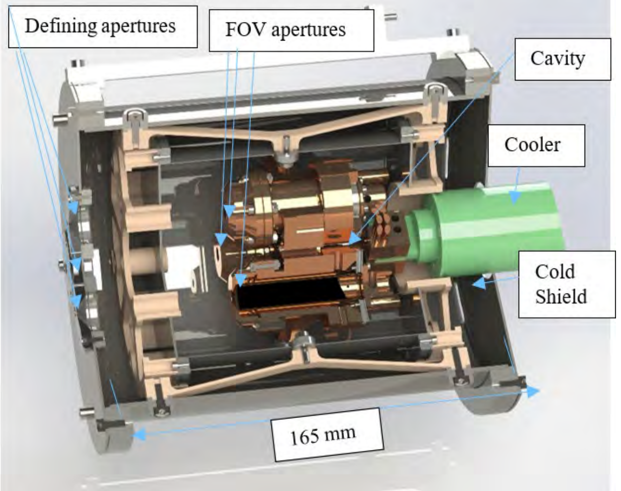
https://www.npl.co.uk/earth-observation/truths/satellite-calibration

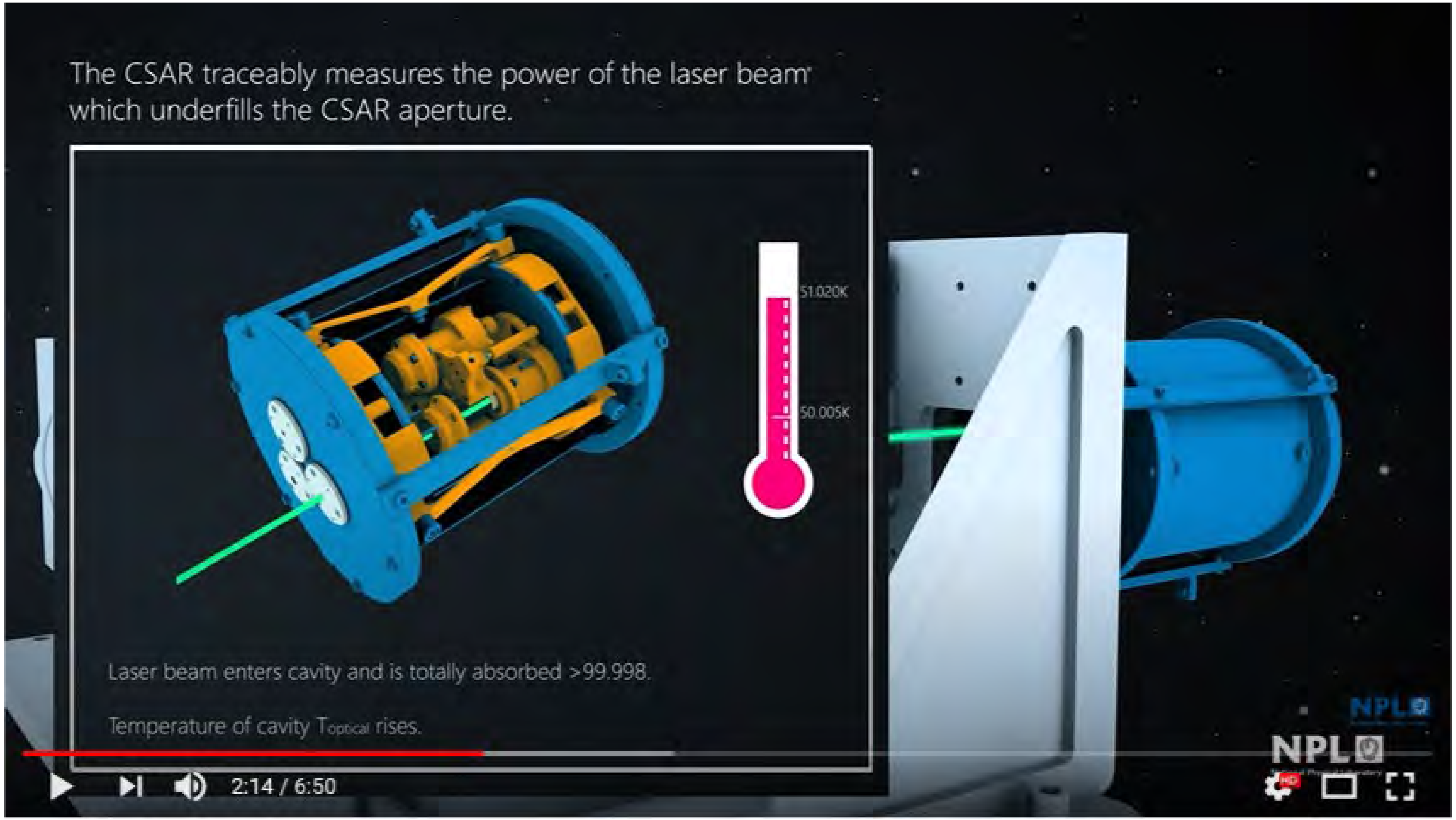
CSAR – a primary standard cryogenic radiometer on-orbit

Provides a primary standard reference for the on-board calibration system

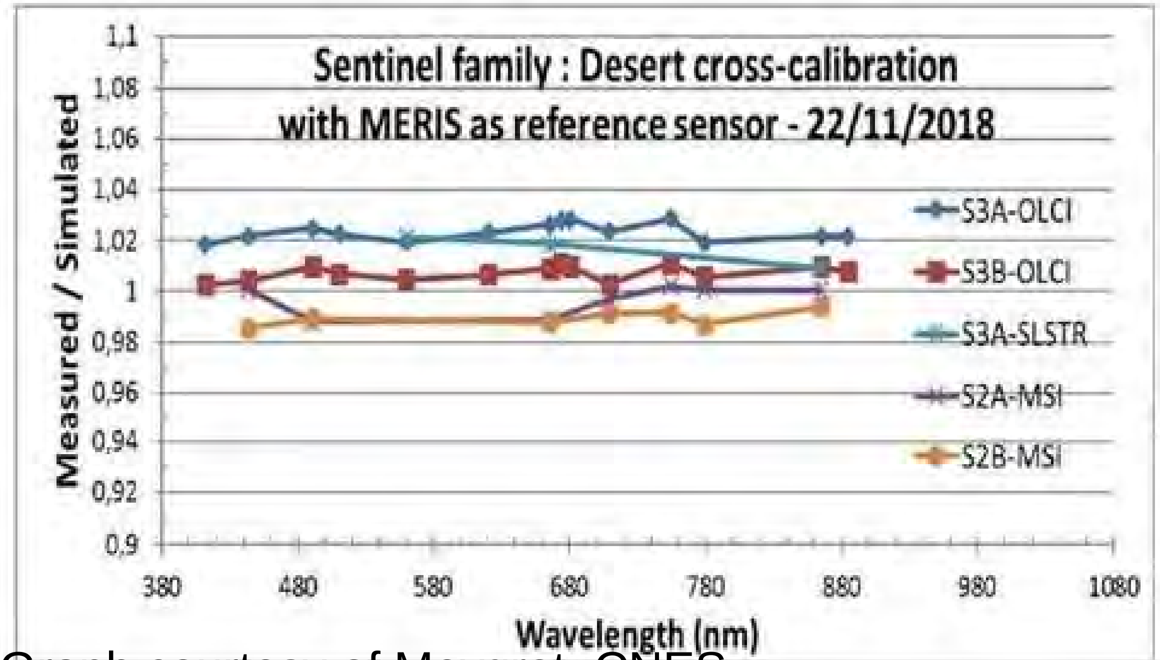
Direct measure of the Total Solar Irradiance



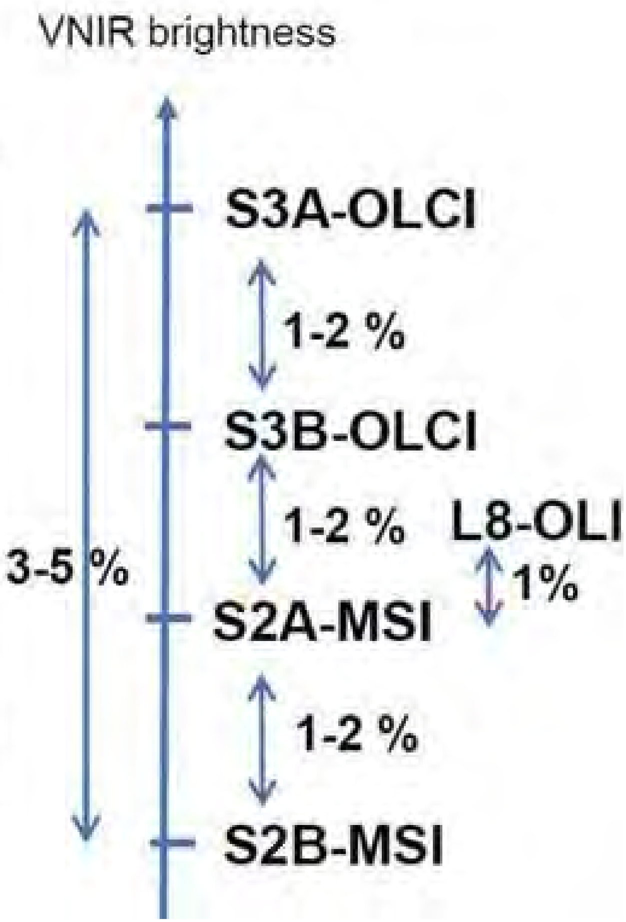




Interpreting & removing bias – Interoperability

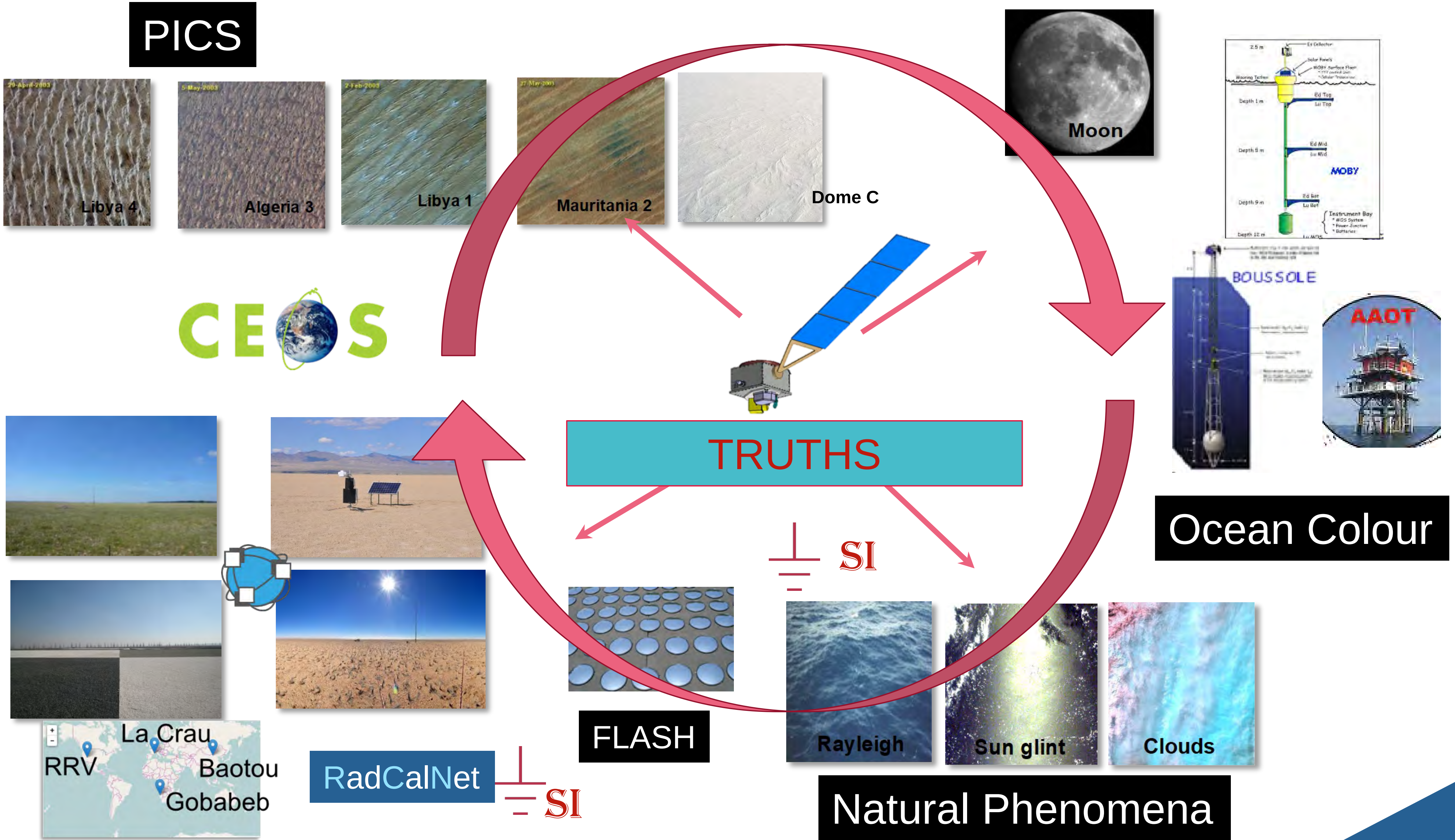


Graph courtesy of Meygret, CNES

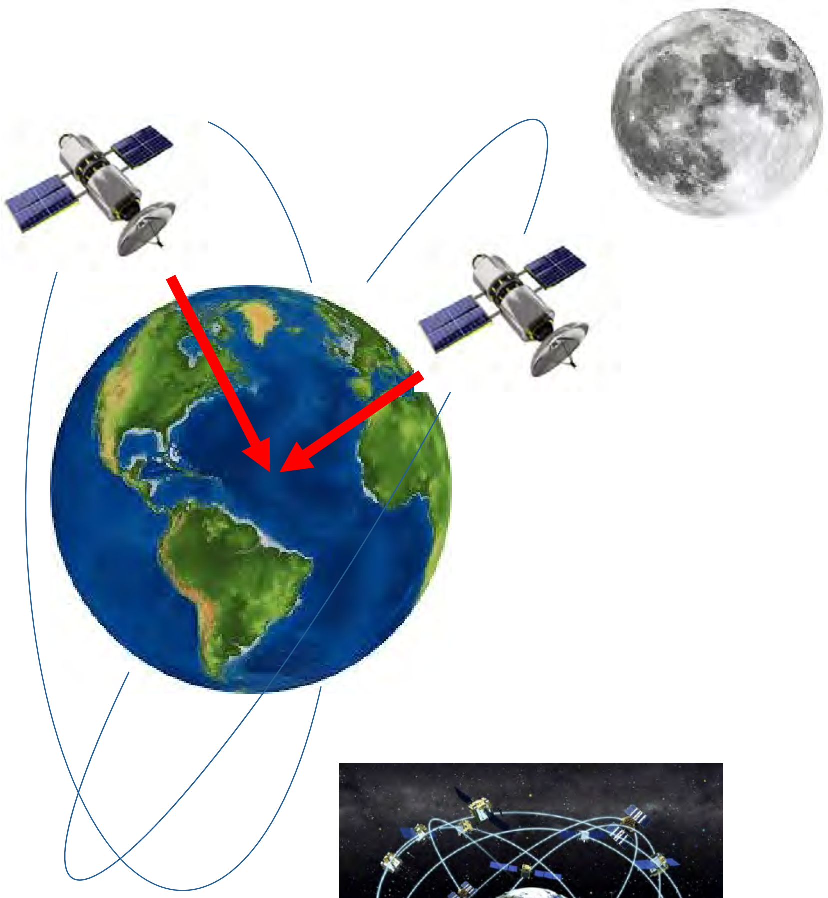


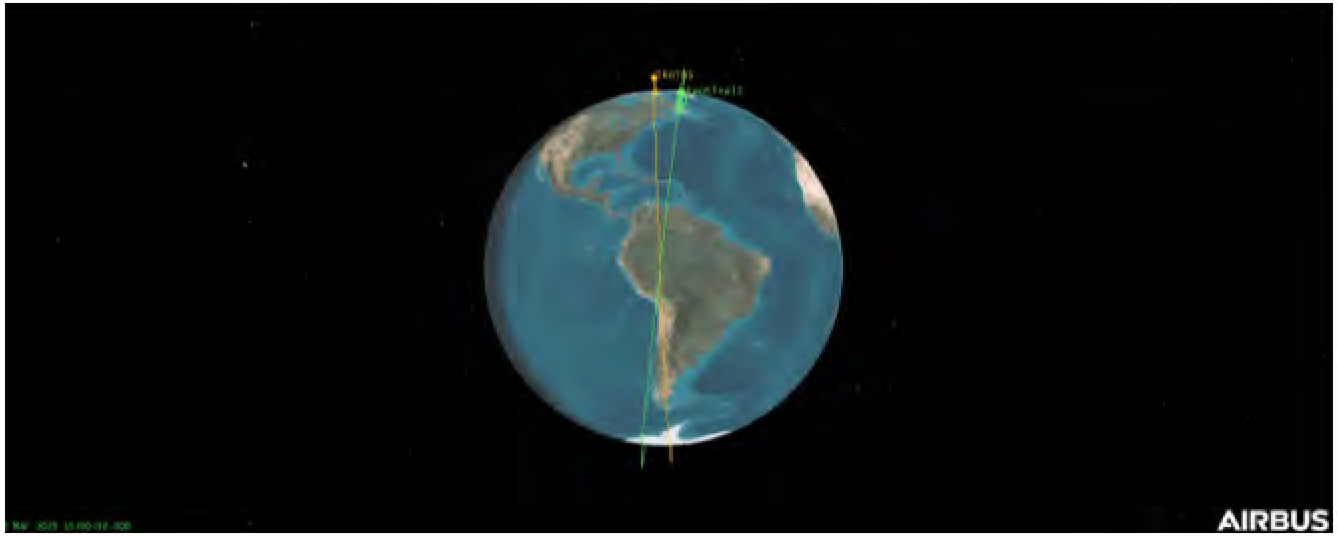
But what is the Truth?

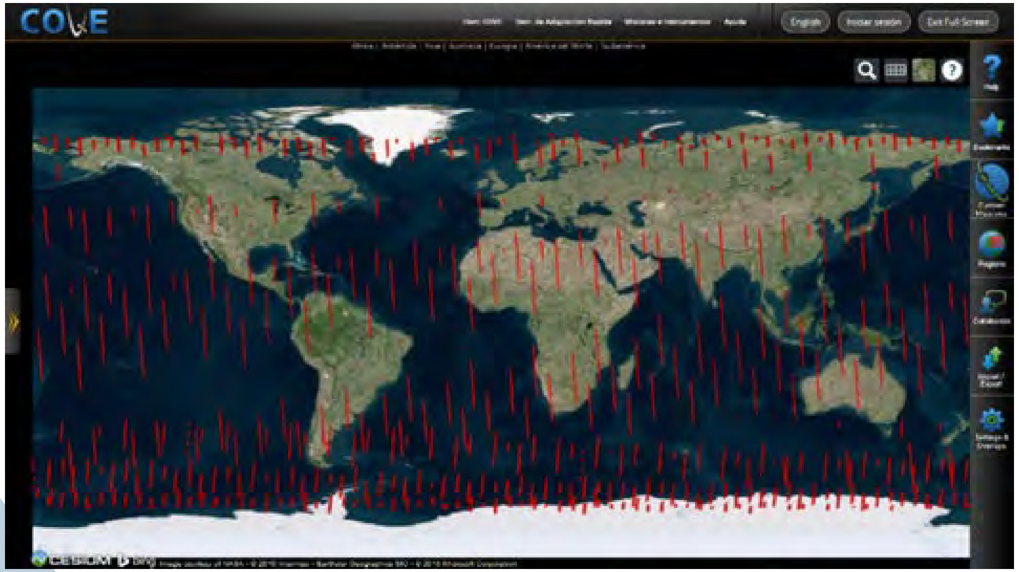
Traceability to CEOS + Cal/Val infrastructure



TRUTHS for inter-operability







Uncertainty budget for TRUTHS – satellite comparisons

(similar analysis results from Chander et al 2013 showing main Uc due to reference sensor and non-simultaneity)

(single overpass – reduces for multiple overpasses)

Uncertainty	Best S2 bands	Worst S2 bands
Spectral resolution TRUTHS	0.1 %	0.6 %
Spectral accuracy TRUTHS	0.1 %	0.2 %
Spatial co-alignment mismatch	0.1 % (Libya) 0.12 % (La Crau)	0.1 % (Libya) 0.5 % (La Crau)
30 minute time difference (atmospheric effects)	0.1 % (if corrected) 0.3 % (if atmosphere not known)	0.1 % (if corrected) 2 % (if atmosphere not known)
30 minute time difference (surface BRF)	0.2 %	0.4 %
Combined with reasonable corrections	**0.4 % - 0.5 %**	**0.7 %**

Unmet potential in current EO investment

Measurement confidence ‘traceability’ the top of the EO agenda

Unquantified drift in the accuracy of key sensors

The Need

Emerging market for trustable climate services

Climate sensitivity predictions are too wide

Interoperability, integrating cubesats/commercial sensors into the mainstream public services

Low cost access to space and climate data

Interoperability: ARD and data cubes

Trustability , litigation quality, data and services

Economically argued ‘green’ investment

Raising functionality of Copernicus & services

Quality data underpinned by UK technology

The Benefits

Public engagement in science and climate

Science/policy exploitation

‘Trustable’ EO/Climate services

Major contribution to CEOS/GSICS/GEO

Encouragement to other Geographical regions: towards building a space-based climate – calibration ‘constellation’