UK SPACE AGENCY

NPL National Physical Laboratory

esa

Traceable Radiometry Underpinning Terrestrial- & Helio- Studies

An ESA Earth Watch mission

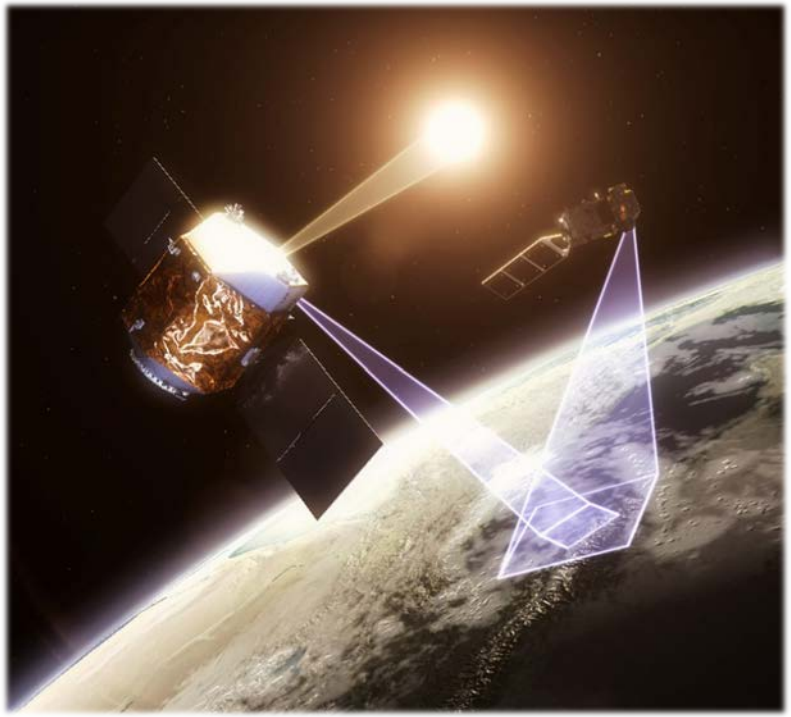
Enabling a space-based climate–calibration observatory

Principle Investigator:

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

What is TRUTHS?

- TRUTHS is a UK-led operational Earth Observation mission that will initiate **a space based climate & calibration observatory**.
- TRUTHS will measure incoming and reflected solar radiation **10 times more accurately (traceable, in-space, to SI units)** than is currently possible.
- This enables TRUTHS to **increase confidence in data** from other EO satellites through in-flight cross-calibration.
- More trustworthy data will **accelerate climate model predictions** and reduce their uncertainty, thus enabling policymakers to make **better and earlier strategic investment decisions**
- In addition**, hyperspectral data** from TRUTHS will address **challenges across all Earth science disciplines**



Traceable
Radiometry
Underpinning
Terrestrial- &
Helio-
Studies

"In addition to providing validation of observations, the TRUTHS mission outputs will lead to a reduction in uncertainties of Earth Observations that will ultimately lead to better evidence to support climate change policy decisions internationally. Furthermore, the personnel with the skills necessary to deliver this mission reside largely within the UK and supporting this mission would preserve these skills and retain the knowledge within the EU"

Professor John Loughhead, Chief Scientific Advisor, Department of Business, Energy and Industrial Strategy

What is the TRUTHS mission?

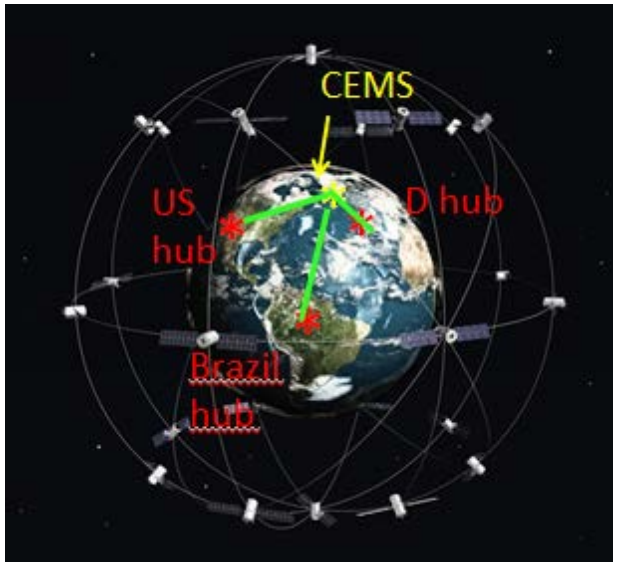
- **TRUTHS is primarily a climate mission.**
  - To measure the incoming & outgoing energy from the climate system, including the spectral fingerprint needed to observationally attribute climate processes & the accuracy needed to detect climate trends in the shortest possible time.
  - **Enabling a space-based Climate-Calibration Hyperspectral observatory through increasing confidence (Trustability) in information derived from EO data**
    - **Near-term**: Facilitate an internationally integrated climate quality Earth observing system
    - **Long-term:** Benchmark state of the planet **(a)** to allow climate model forecast testing **(b)** provide unequivocal observational evidence of climate change in shortest time possible
- **'Reference Calibration' to upgrade performance/confidence of global EO system inc retrieval algorithms**
- **Hyperspectral data to match spectral signature of many Bio/geo-physical/chemical parameters**

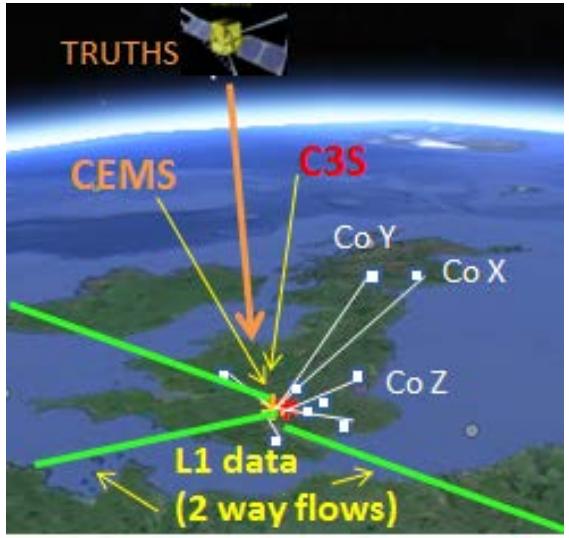
Parameter	Spectral range /μm	Spectral resolution / nm	GIFOV / m	SNR	Sampling	Uncertainty / % (2σ)
Earth Spectral Radiance	0.32 - 2.4	~5 to 10	~50 250	~300 (Vis-NIR) >2000 Blue	Global nadir 50-100 km swath + multi-angle	0.3
Total Sol Irradiance (TSI)	0.2 – 35	NA	NA	>500	Daily	0.02
Solar/Lunar Spectral Irradiance (SSI)	~0.30 - 2.4	1 to 10	NA	>300	Daily	0.3
Surface Reflectance	0.32 - 2.4	~5 to 10	~50 250	~300 (Vis-NIR) >2000 Blue	Global nadir + multi-angle	<1

A vision of the Future:

‘UK the global home for trusted climate data’

- **CEMS/Jasmin (‘UK DIAS’) becomes a global hub linked to national data centres**
- **Existing and planned future missions can be upgraded to a climate monitoring system**





- **TRUTHS provides means to QA & upgrade Worlds EO sensors including potential constellations of micro-sats, encouraging data to flow through UK**
- **Provides the ‘Rosetta stone’ of the QA process allowing the development of future EO ARD & climate services – scene dependant bias correction – interoperability**
  - **Seamless, temporally continuous supply of ‘trustable’ Data & information**
  - **Ready access to high QA data creates national entrepreneurial environment for SMEs to flourish**
- **Policy makers and Financial markets have reliable knowledge of risk for decisions**
  - **Underpins Carbon stocktake**

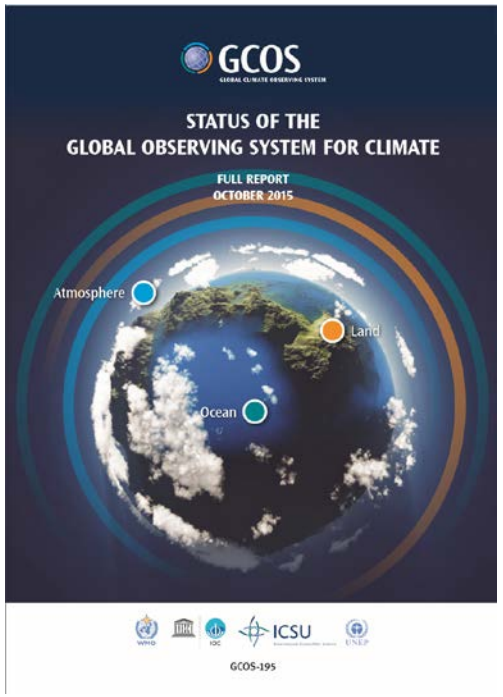





International Demand

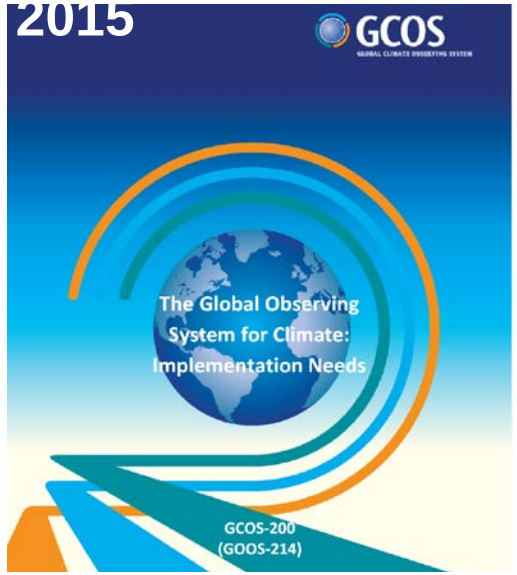
Strategy Towards an Architecture for Climate Monitoring from Space

CEOS



GSICS Global Space-based Inter-Calibration System

"TRUTHS has important potential contributions to make both directly through well-calibrated measurements and indirectly through facilitating inter-calibration of the data from other platforms" **GCOS 2015**



"….a dedicated mission flying an SI traceable calibration reference standard would be an important element of a future architecture (see CLARREO and TRUTHS)."

CEOS/CGMS/WMO (2013)

Action A16:	Implementation of satellite calibration missions
Action	Implement a sustained satellite climate calibration mission or missions
Benefit	Improved quality of satellite radiance data for climate monitoring
Who	Space agencies
Time frame	Ongoing

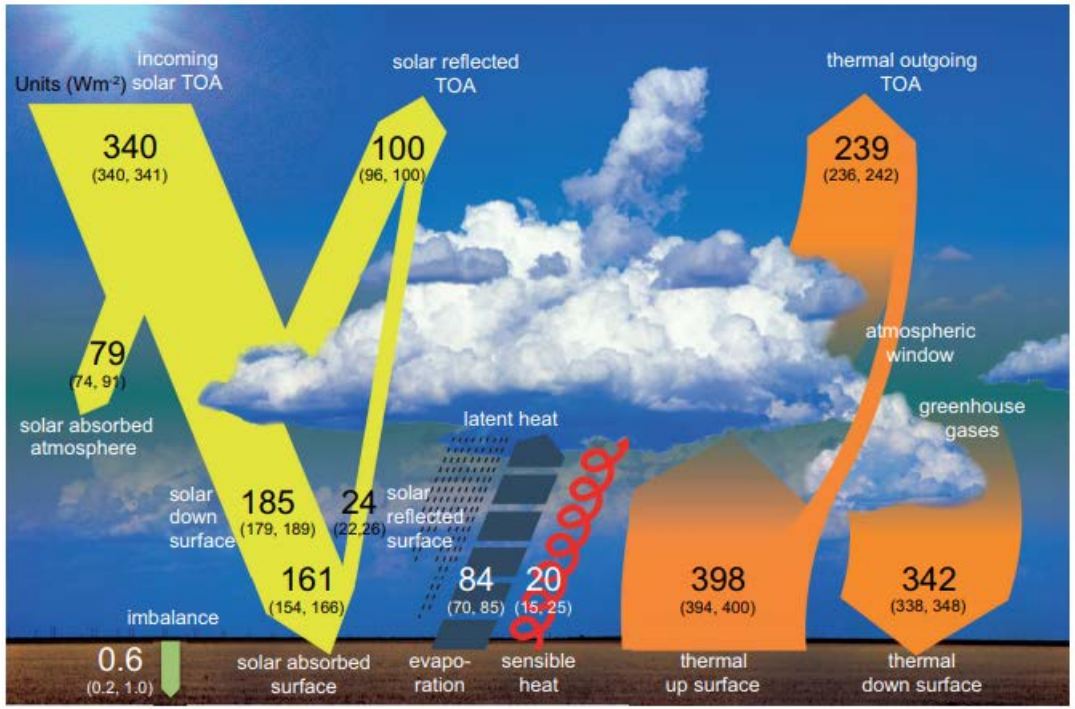
How does TRUTHS impact climate?

TRUTHS provide a benchmark or snapshot of the state of the planet's climate from which to monitor change

<u>Radiation Balance</u>

It provides a high accuracy spectrally resolved measure of SW element of Earth leaving radiation balance
&
All of the incoming radiation

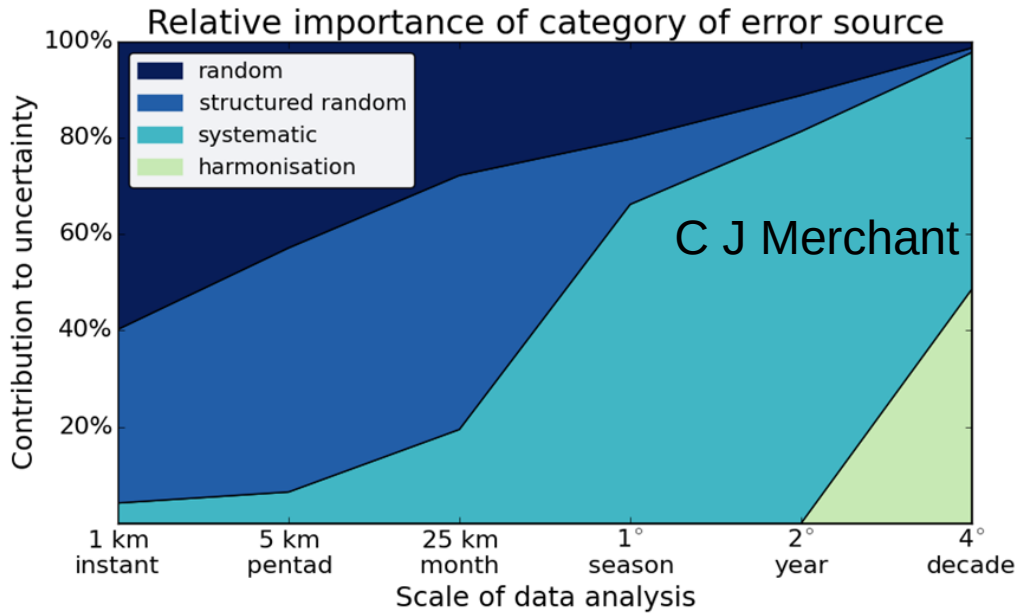
And may provide integrated LW element



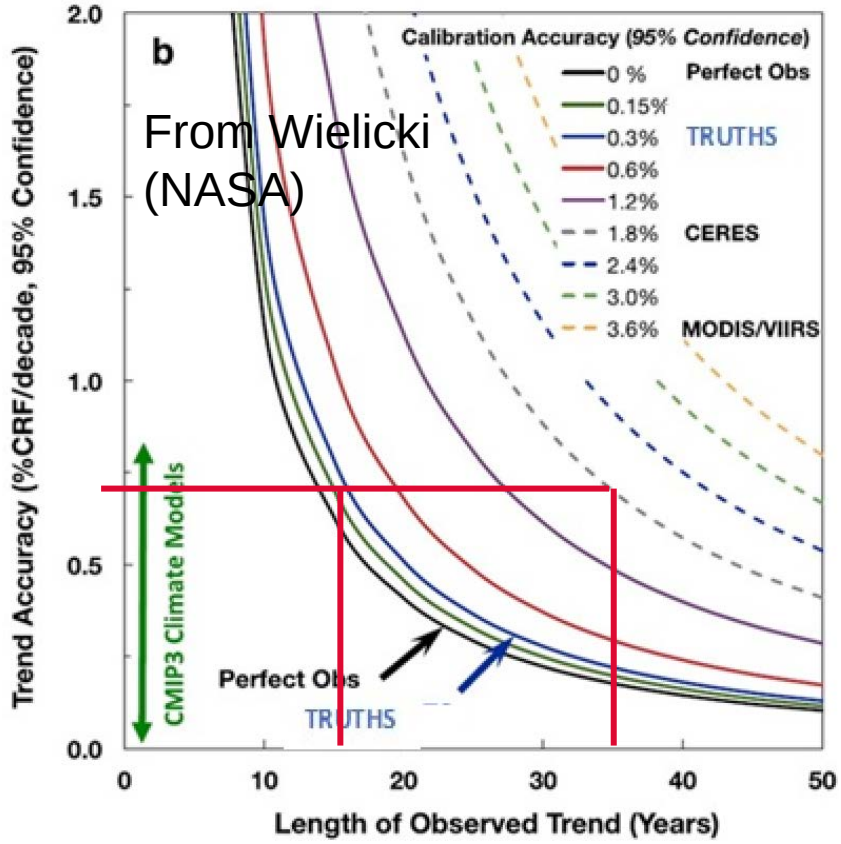
IPCC AR5 02.11

Climate: Examples

- **Robust anchor for long-time-base FCDRs**
  - **Can provide a bridge between data gaps**
- **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)**

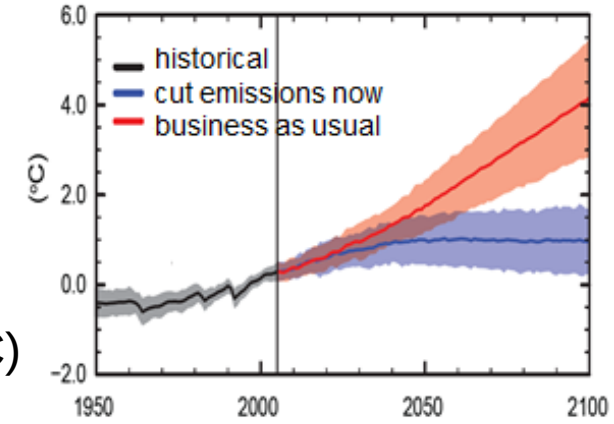


As spatial and temporal scales increase, systematic uncertainties dominate

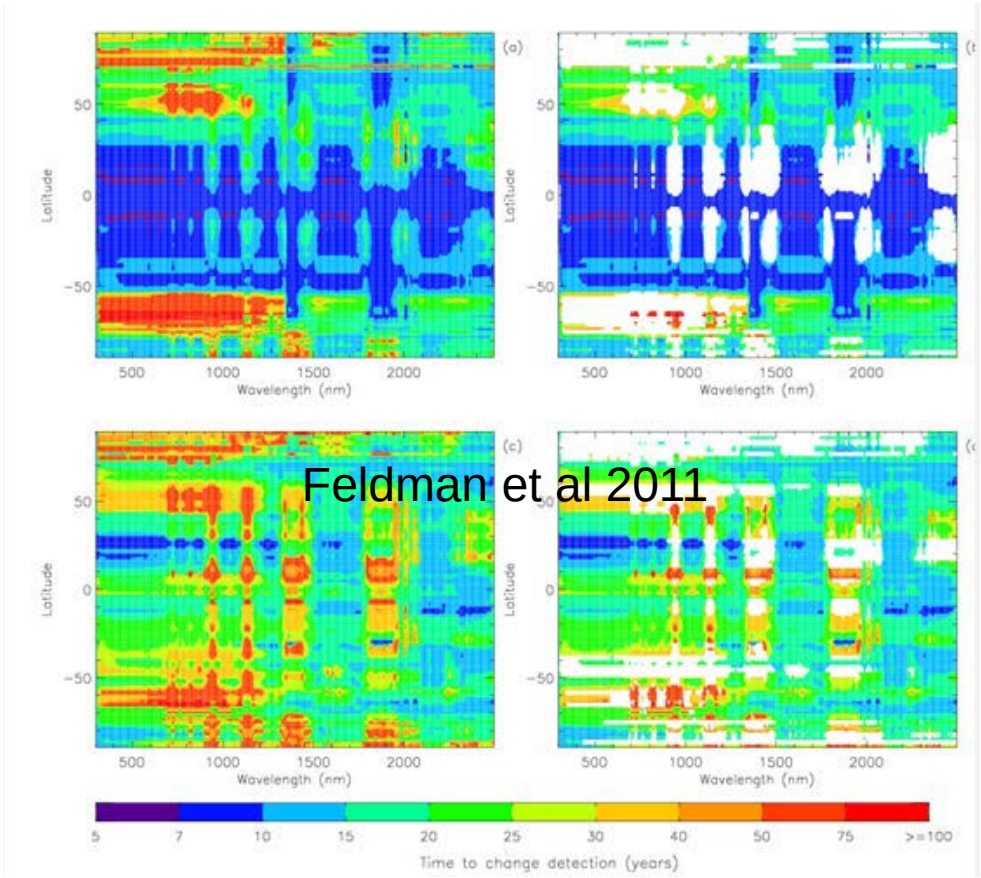


Time to detect trend (e.g. cloud rad forcing) based on Uncertainty of sensor

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



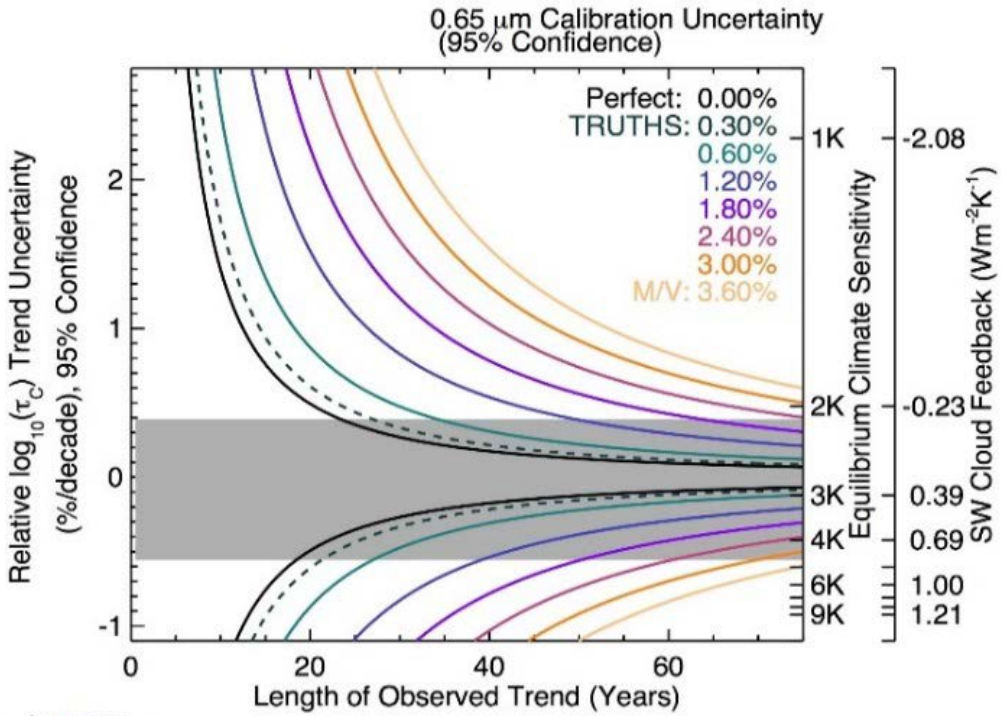
Spectral fingerprinting



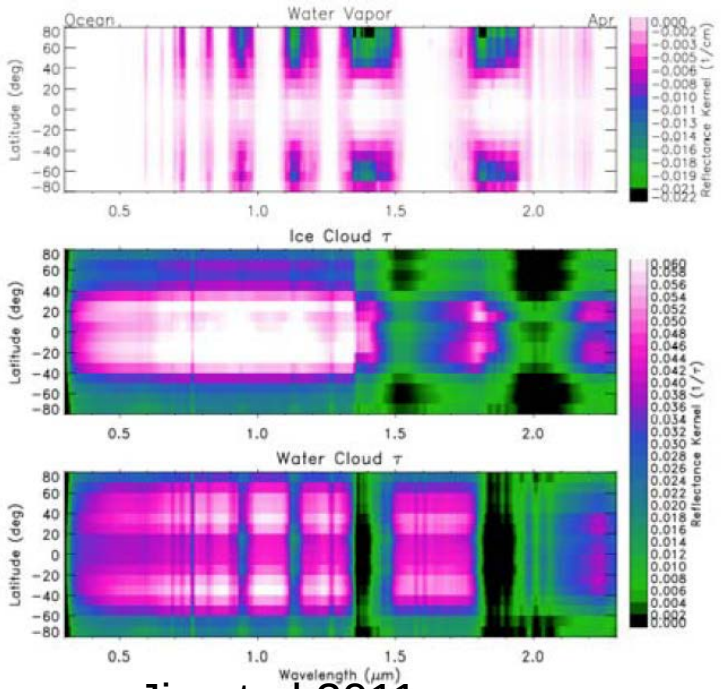
Feldman et al 2011

High spectrally resolved accuracy
Allows:

- Testing of climate models
- Sensitivities to specific ECVs



Shea et al 2017



Jin et al 2011

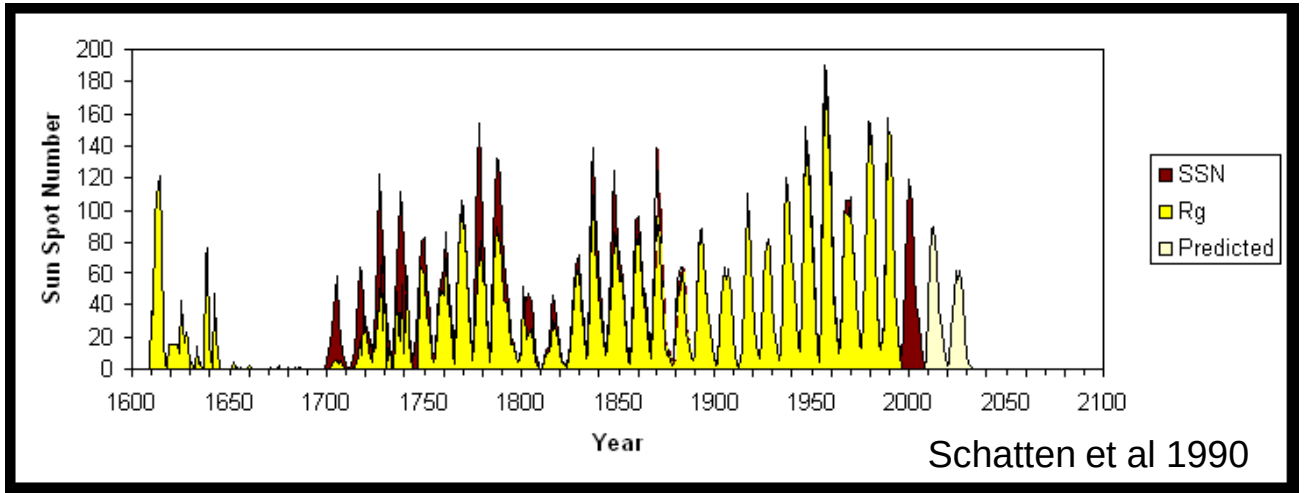
High spectrally resolved accuracy
Allows:

- Detection of trend for cloud optical thickness
- Robust detection of Cloud type

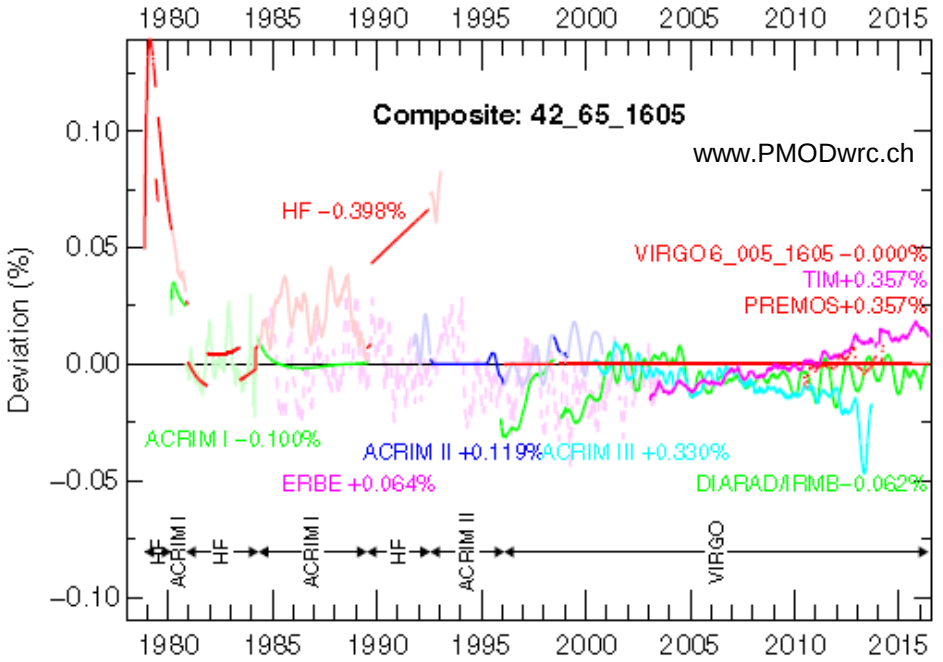
TRUTHS for Solar Impacts on Earth

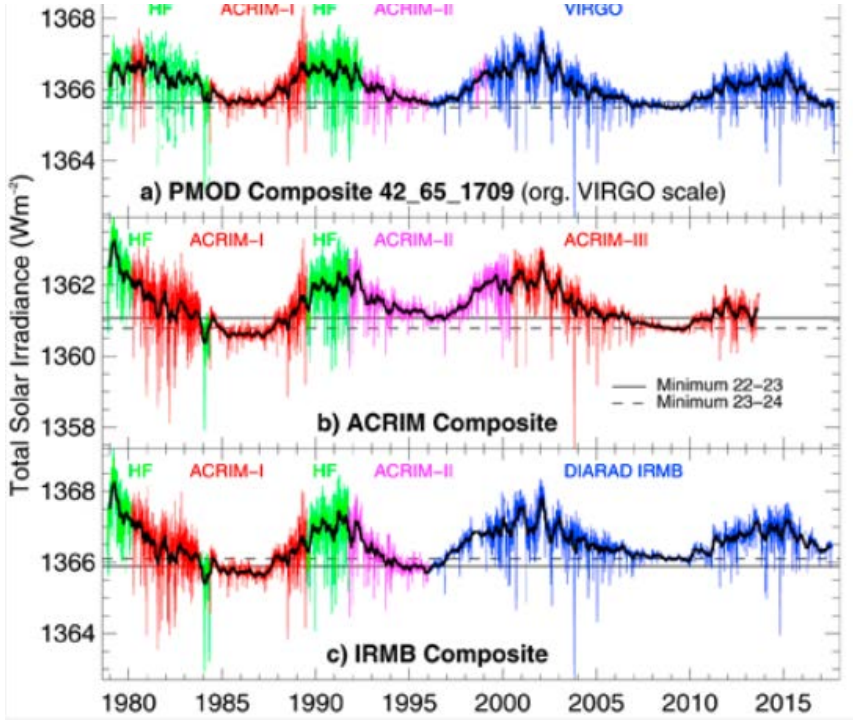
- The Sun is the major source of energy to the earth small changes will have an influence on climate. Over recent (11 yr) cycles Total Solar Irradiance (TSI) output change has been of the order of 0.1%, translating to ~1.4 Wm^{-2}. However, longer-term solar variation is expected to be much higher, and has been so in the past!. Some debate on current change!!

- Although not currently a dominant effect on climate change, this could change in the future (positive or negative)
- To best serve long term records an accuracy of 0.01% (k=1) is needed in TSI.



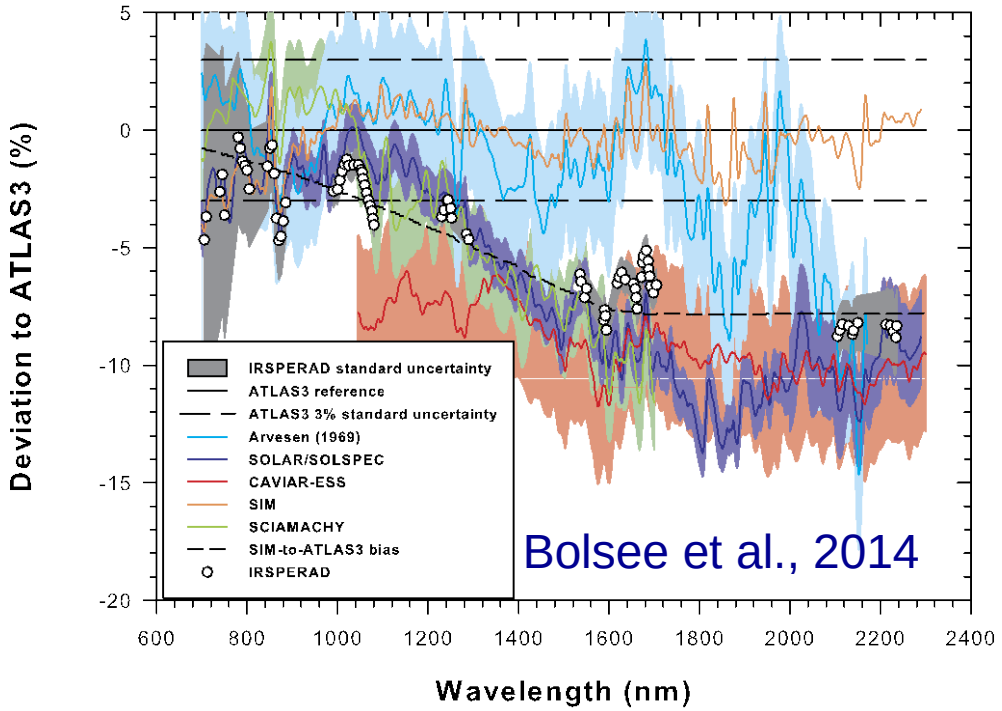
Schatten et al 1990



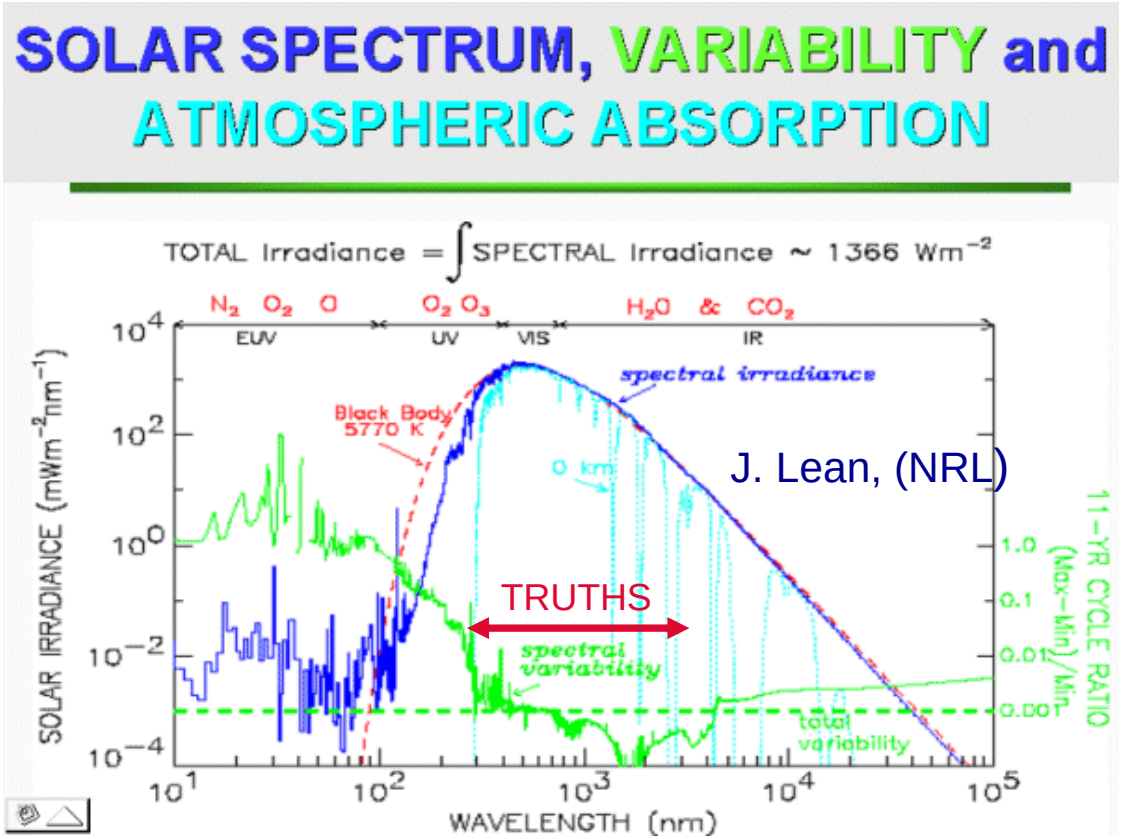


Solar Spectral Irradiance

Most variance in Solar Irradiance is spectral in nature and has direct short-term impacts on climate: UV atmospheric chemistry and heat transfer, NIR/SWIR atmospheric temp/water (vapour continuum)



Note: Significant controversy over satellite observations and instrument corrections – leading to a ~ 10% anomaly > ~1400 nm!



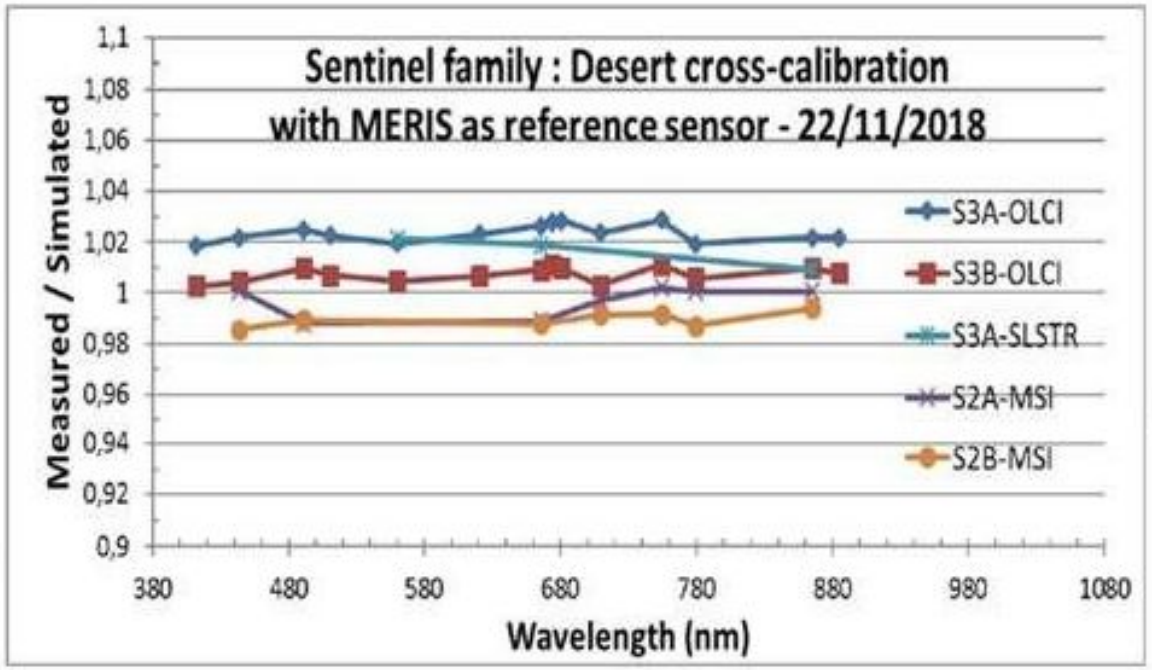
TRUTHS spectral range (limited by technology/complexity) will span a significant part of the solar spectrum (variability) and enable true Earth reflectance products utilising same spectrometer

Focus on Needs of ECV's: indicative

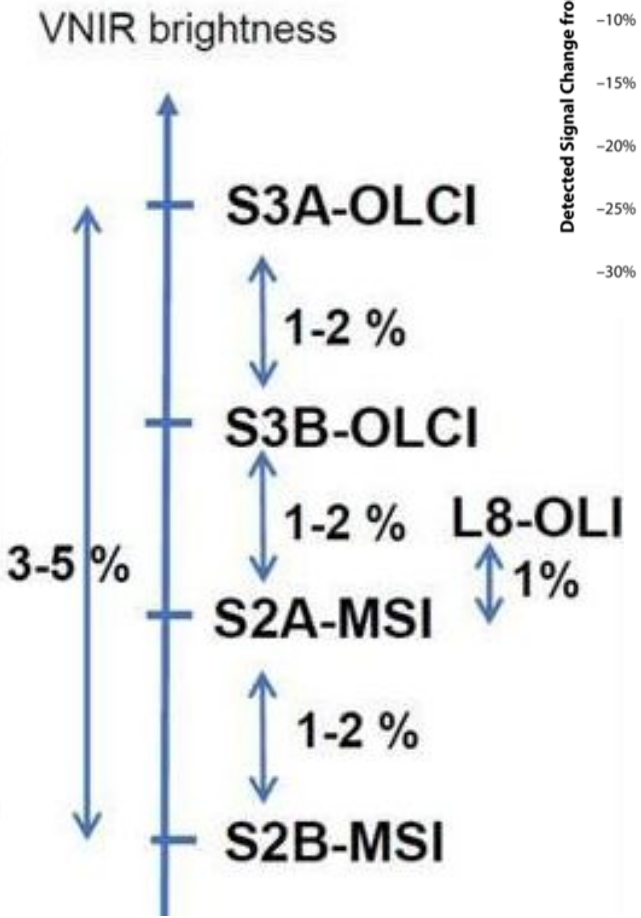
Climate variable	Role	TRUTHS providing direct observation	TRUTHS providing reference calibration
Solar irradiance	Climate forcing	yes	yes
Earth radiation budget	Climate forcing, feedback	yes	yes
Surface albedo	Albedo feedback	yes	yes
Cloud cover	Cloud feedback	yes	yes
Cloud particle size distribution		yes, through spectral benchmarking	yes
Cloud effective particle size			yes
Cloud ice/water content		yes	yes
Cloud optical thickness		yes	yes
Water vapour	Column water vapour response	yes	yes
Ozone	Stratospheric ozone Feedback	no (limited resolution)	yes
Aerosols Optical Depth	Climate forcing Atmospheric correction	no (limited temporal coverage) yes	yes yes
Ocean Colour	Carbon cycle/ sinks	yes	yes
Ice and snow cover	Albedo feedback	yes	yes
Vegetation	Carbon Cycle and Albedo feedback	yes	yes
Land Cover/Land Use	Surface Radiative Forcing	yes	yes
GHGs	Climate forcing: emissions	Yes? Large scale screening	Yes

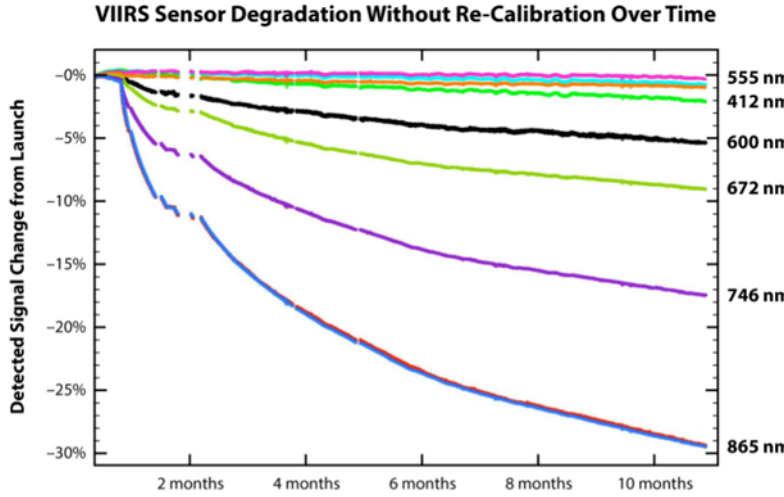
Strategies to identify/remove biases and harmonise the Earth Observing system are well-established:

But what is the Truth?



Graph courtesy of Meygret, CNES





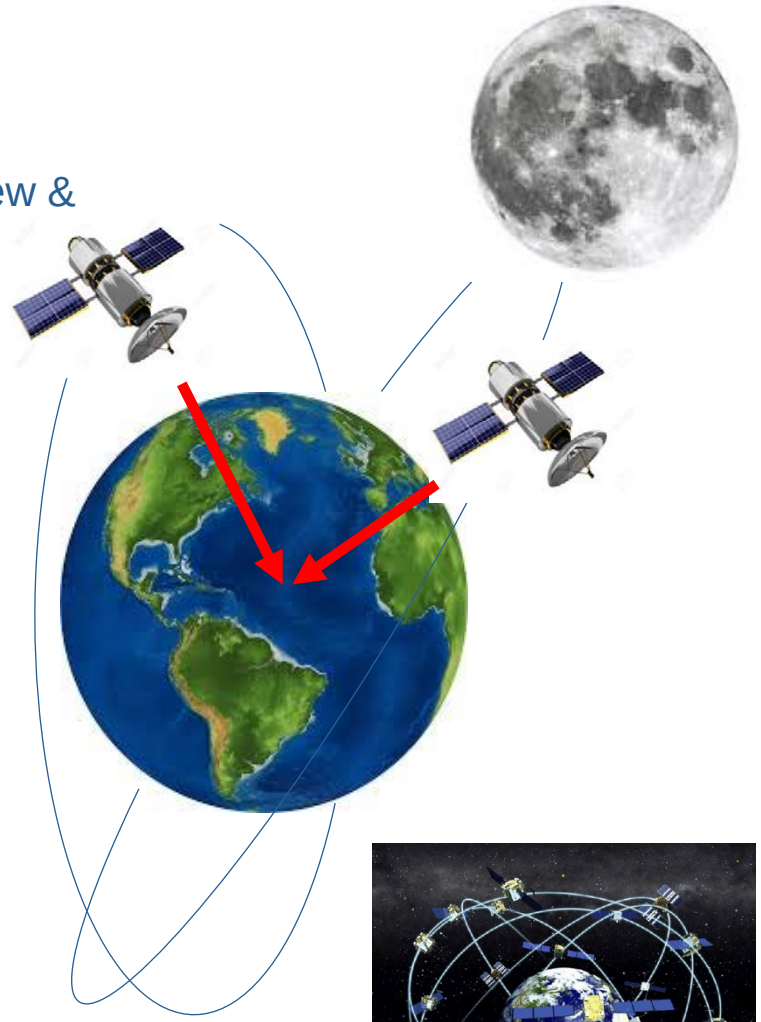
Most optical sensors drift on-launch and with time!!

TRUTHS for inter-operability

- The orbit is asynchronous to the SSO of many EO satellites, to allow match-up with multiple sensors over a variety of scenes, surfaces & times of day – with coincident view & illumination angles
- At each coincident observation the high accuracy calibration of TRUTHS can be ‘transferred’ to the partner sensor.

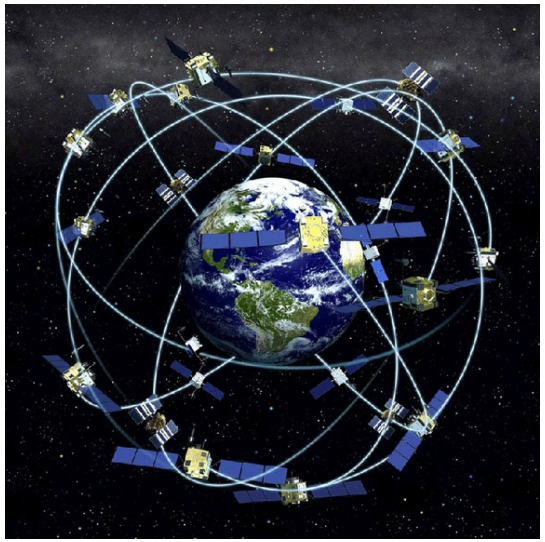
$$L_x - L_{TRUTHS} < \sqrt{\sigma_x^2 + \sigma_{TRUTHS}^2 + \mu^2}$$

- Inter-calibration accuracy is dominated by the reference sensor absolute radiometric calibration uncertainty.
- Studies to determine the inter-calibration accurate consider reference & partner sensor intrinsic uncertainties as well as the representational uncertainties (μ), such as:
  - Spectral (resolution & sampling)
  - Spatial (geolocation knowledge)
  - Viewing angle & SZA
  - Polarisation sensitivity
  - Temporal mismatch (10 - 30 mins) including atmos. Variation.
  - BRF mismatch
- Use the near-simultaneous view [corrected for representative errors (μ)] to assess the partner sensor uncertainty, σ_x and from statistics correct biases enabling inter-operability & data product fusion of global assets.
- Anchoring existing stable Caln targets e.g. Moon - TRUTHS can back correct the satellites already launched – improving the quality of their data makeing the most of our existing and historical investments and improving FCDRs & CDRs.

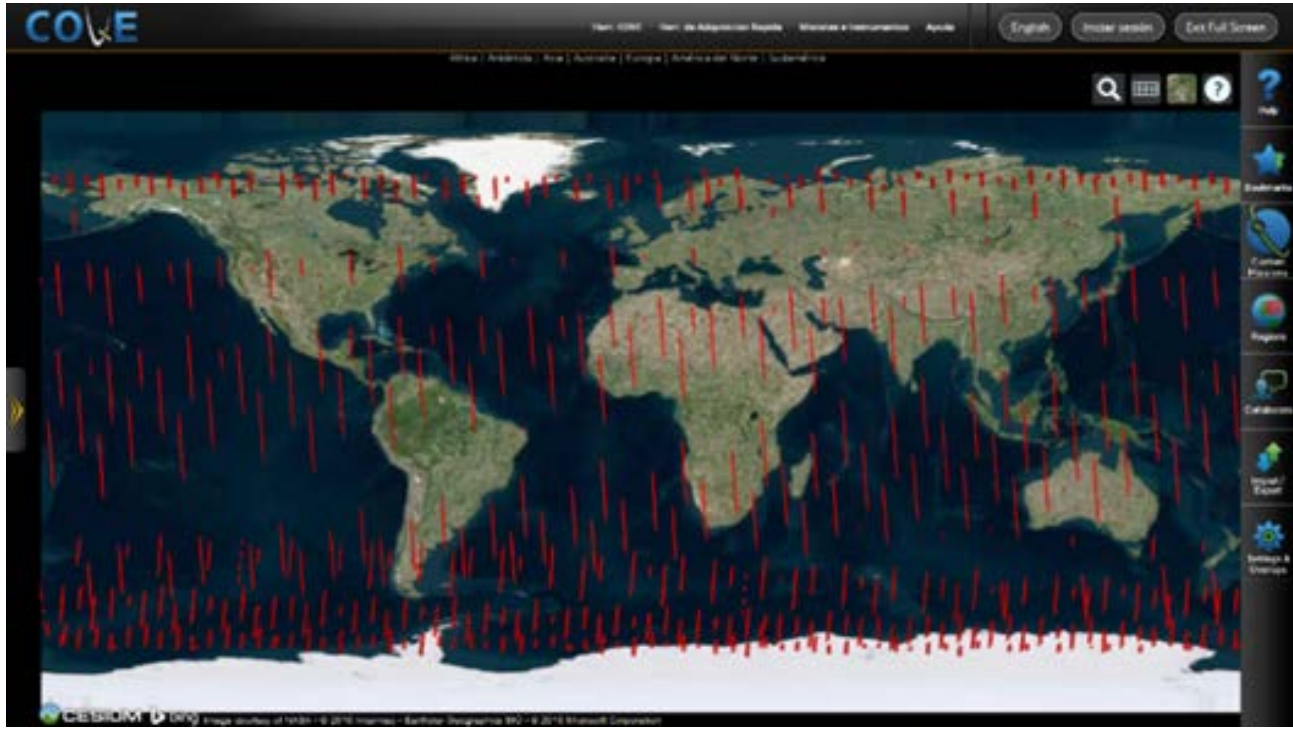


Reference Calibration

- **Enables interoperability & Harmonisation**
- **Spectral & spatial scale allows matching of footprints and bandwidths**
- **For Ocean colour sensors allows TOA SI traceability at uncertainties needed for climate**
  - **multiple sites including coastal zones**



TRUTHS provides the means to transform global EO system, including constellations of micro-sats so they deliver traceable scientific/climate quality observations -



Sentinel 2 & TRUTHS match-ups for 1 yr (30 minute window)

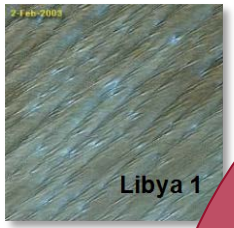
Polar orbit allows many near simultaneous cross-overs with other satellites Nadir (SNO) or by pointing to angle match

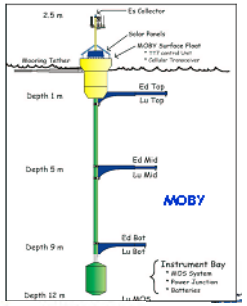
- **Reduces uncertainties due to:**
  - Illumination and view angles
  - Atmospheric changes
  - Allows many scene types

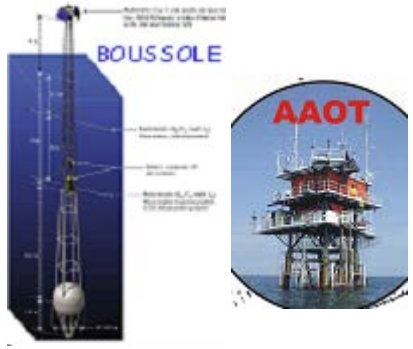
E.g. Sentinel 2 using Libya 4 desert TRUTHS can improve accuracy <1 % for all bands

Traceability to CEOS Cal/Val infrastructure

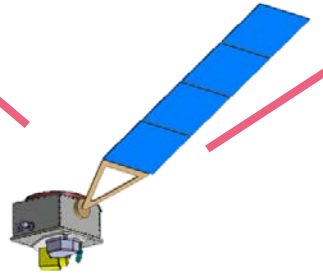
PICS



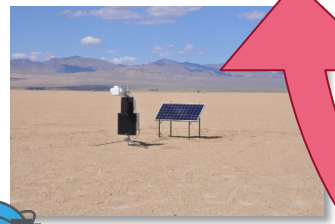




Ocean Colour



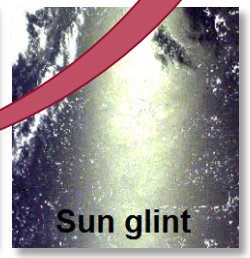
TRUTHS



RadCalNet

SI

SI



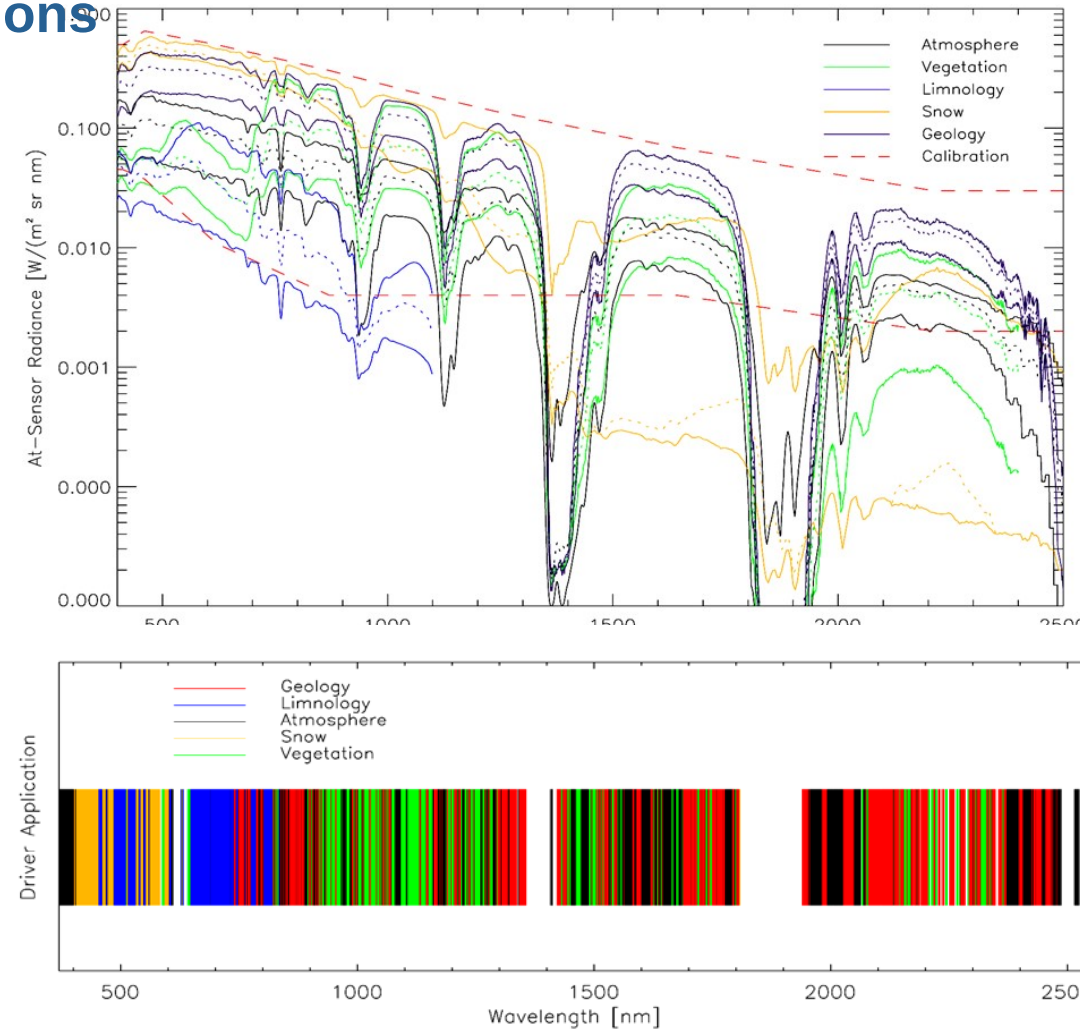
Natural Phenomena

Hyper-spectral applications

Hyperspectral data can be convolved for many applications enabling an earth system science approach:

- directly
- upgrading other sensors
- Test & Improve retrieval algorithms

- **Complimentary to EnMAP, PRISMA, CHIME ….**
- **Land-cover change**
- **Agriculture**
- **Pollution**
- **Resource prospecting**
- **…….**



Unmet potential in current EO investment

Measurement confidence ‘traceability’ the top of the EO agenda

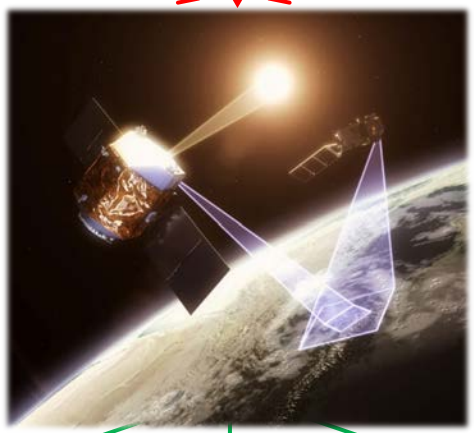
Unquantified drift in the accuracy of key sensors

The Need

Emerging market for trustable climate services

Climate sensitivity predictions are too wide

Differentiator for UK ‘data hub’



Low cost access to space and climate data

Economically argued ‘green’ investment

Raising functionality of Copernicus & services

Quality data underpinned by UK technology

The Benefits

Public engagement in science and climate

Repeat business & downstream opportunities

Science/policy exploitation

Geo-political positioning

‘Trustable’ EO/Climate services

Major contribution to UKSA/SGP vision

Now What?

Prepare for the future?

- Develop infrastructure to Generate, utilise and exploit higher accuracy data
  - What else needs to be done in readiness – Upstream and Downstream
  - National DIAS?

- Consider what science/applications can benefit from improved accuracy and/or hyperspectral data

- Encourage and train next generation scientists and engineers

- Establish framework of QA (certification) from customer to data provider

- Cross-public sector awareness and coordination

- A National ‘TRUTHS’ exploitation program to start now in readiness for launch