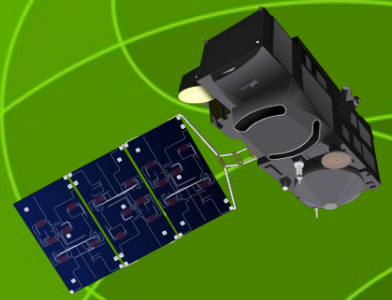
NPL

Metrology for Earth Observation & Climate








Professor Nigel Fox

Nigel.fox@npl.co.uk

CLIMATE AND OCEAN OBSERVATION

Societal Challenge: sustainable growth in a changing environment

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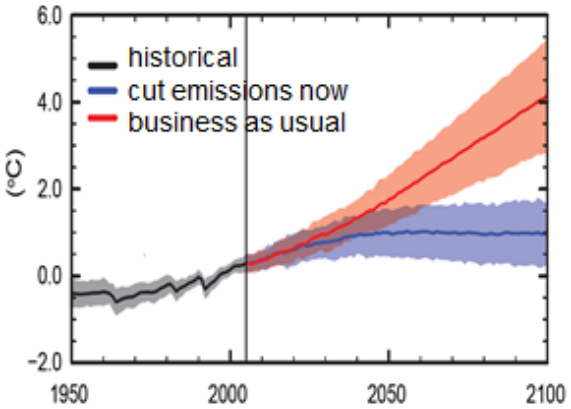
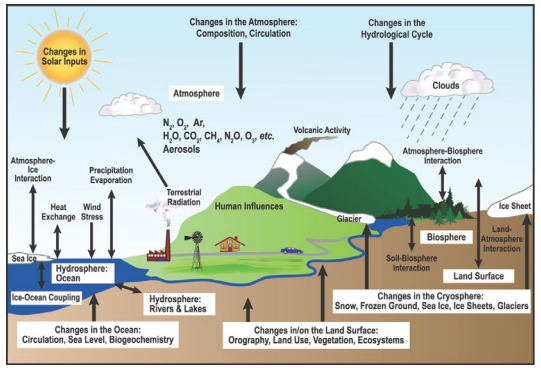


NEED

Trustworthy observations to monitor, understand and mitigate impact and contributors to climate change and their relative sensitivity: facilitating necessary timely action, assessing success, constraining/testing forecasts and models.

REQUIRES

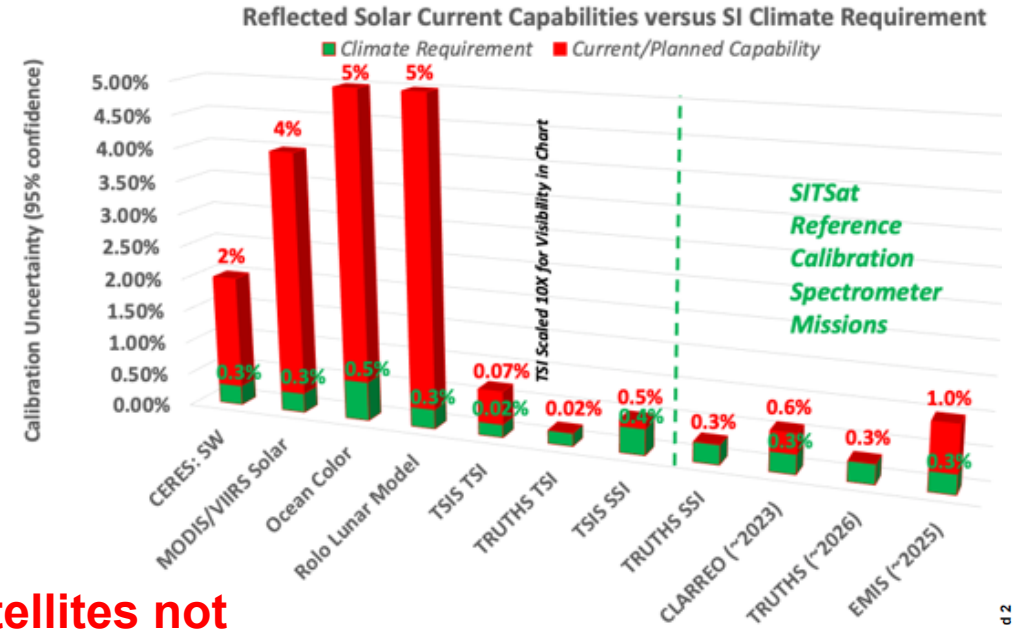
- **Integrated, interoperable, coherent global observing system, (increasing dependency on space)**
- **Quantitative, comprehensive (adequate) accessible measurements of the Earth system with robust uncertainties (clarity of confidence) that can be relied upon for decades (and trusted by modellers)**
- **Sufficient accuracy, to enable detection of a signal and/or 'trend' from a background of natural variability in as short a timescale as possible**
- **Transparency and international acceptance**



Metrological Traceability to internationally agreed standards, the SI

(at the location of making the measurement)

Climate Need & observation challenges



CEOS GSICS

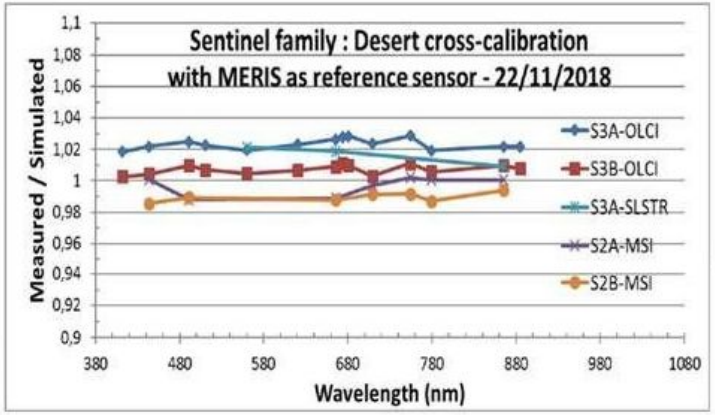
SI-Traceable Space-based Climate Observing System:
a CEOS and GSICS Workshop
National Physical Laboratory, London, UK,
9-11 Sept. 2019

SITSCOS Workshop Report

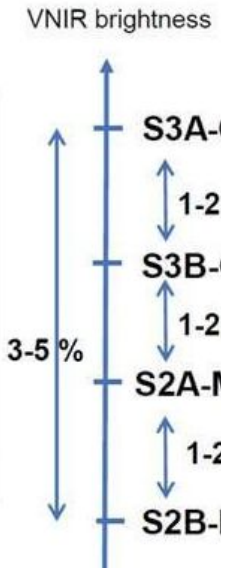
Editors: Nigel Fox, Tim Hewison, Greg Kopp, Bruce Wielicki

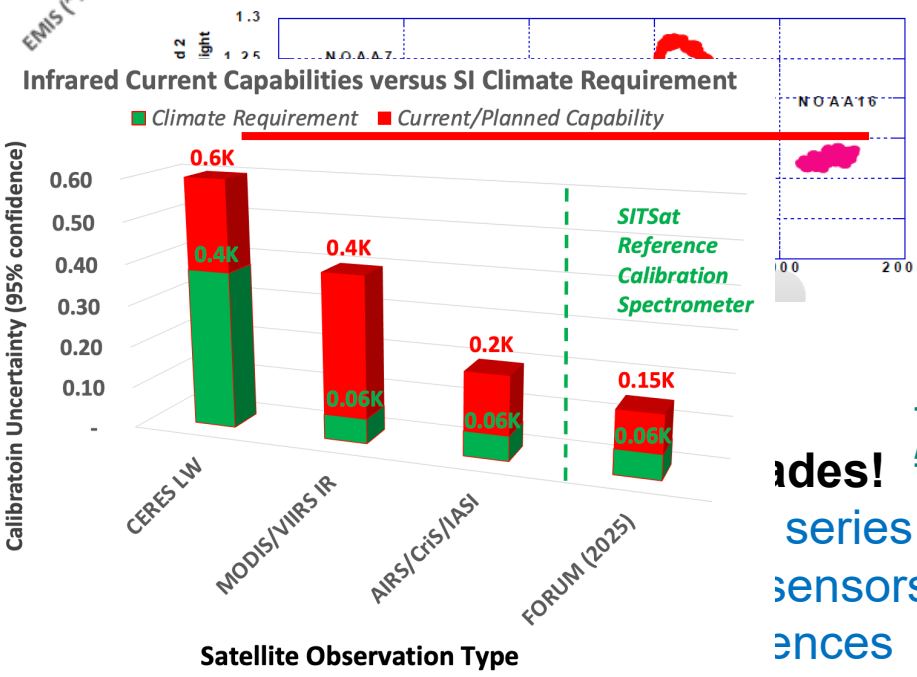
Most satellites not designed for climate: performance to suit application

Satellite Observation Type



What is the Truth?





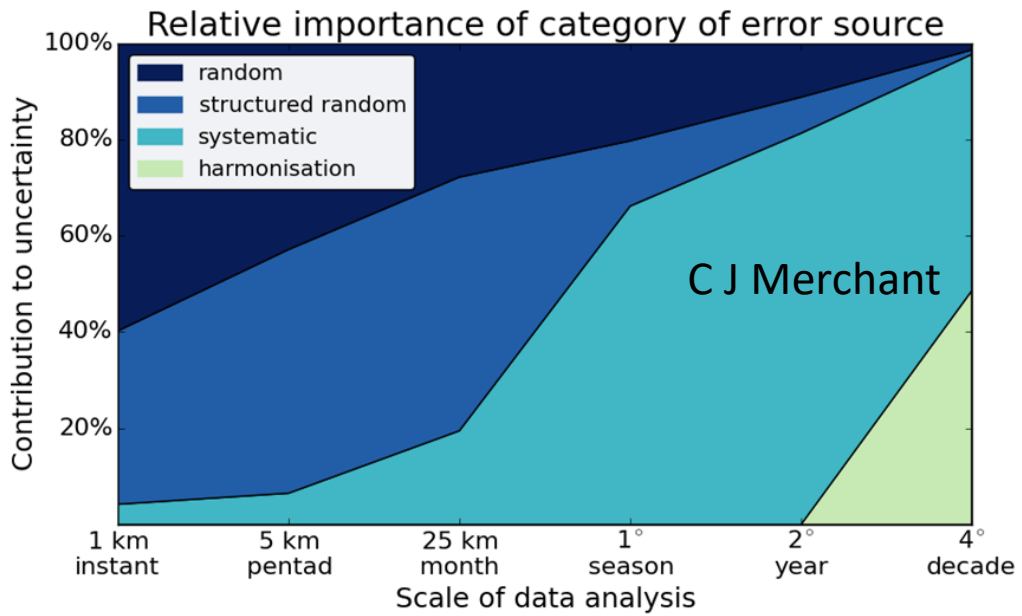
http://calvalportal.ceos.org/report-and-actions

Published Sep 2021

ades!
series
sensors
ences

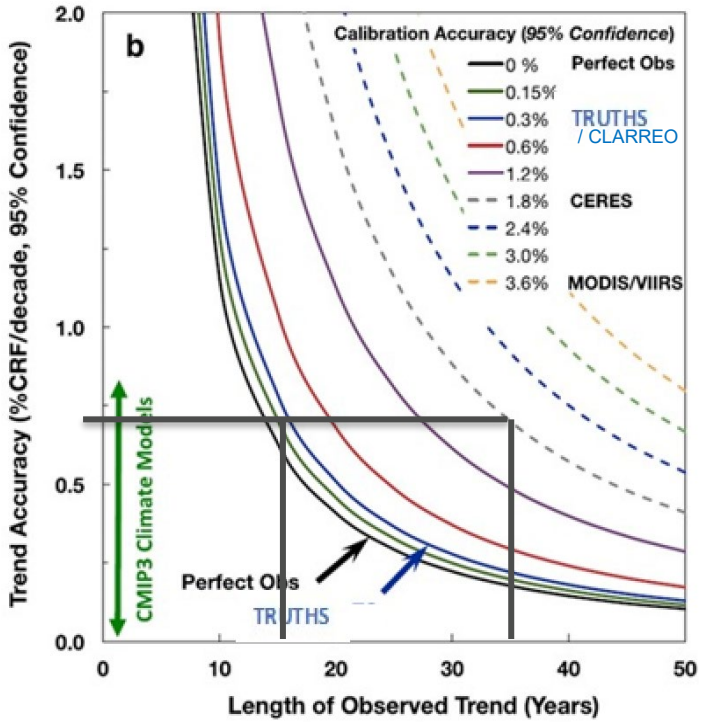
Climate: Systematic Uc dominate

- **Very small signals require decades to become large enough to detect with confidence from unpredictable natural variability**
  - **Robust accurate reference (benchmark) from which to detect change**
  - **Consistent measurements/instruments over time**
  - **Coherent- independent of techniques**



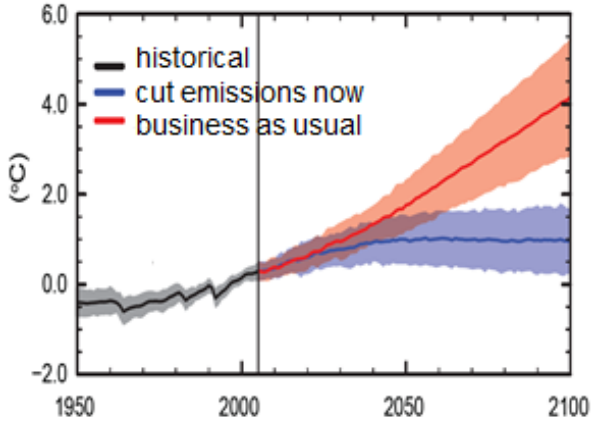
As spatial and temporal scales increase, systematic uncertainties dominate

From Wielicki (NASA)



Time to detect trend based on Uncertainty of sensor

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



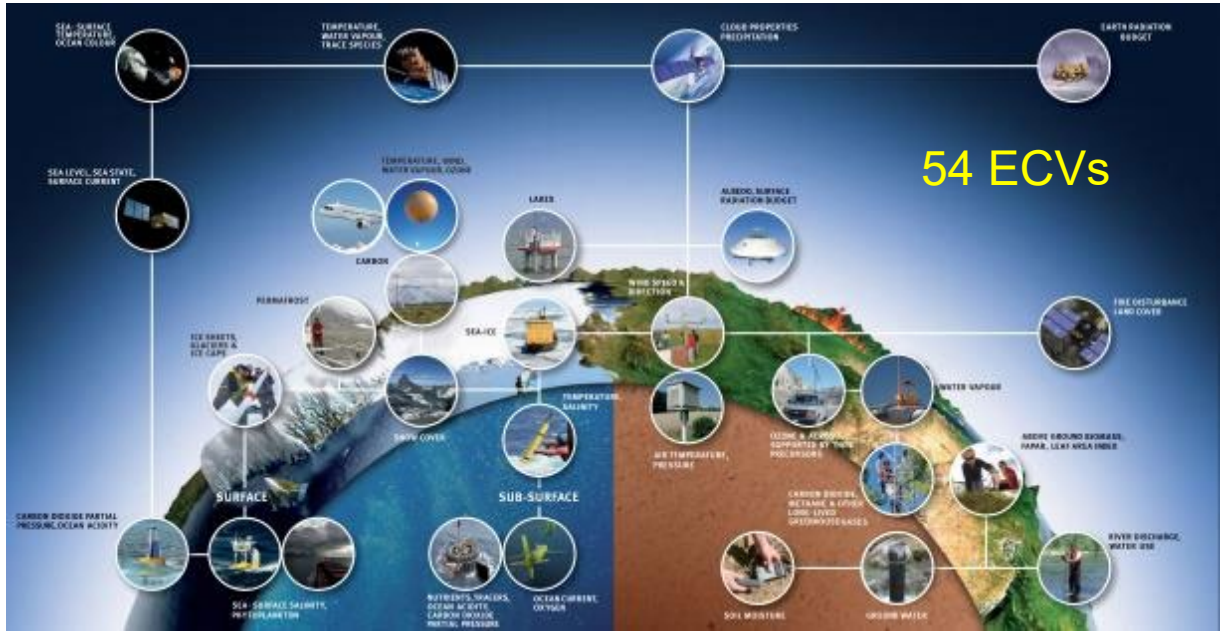
Many satellites but need to work together as a global integrated EO system together with in-situ

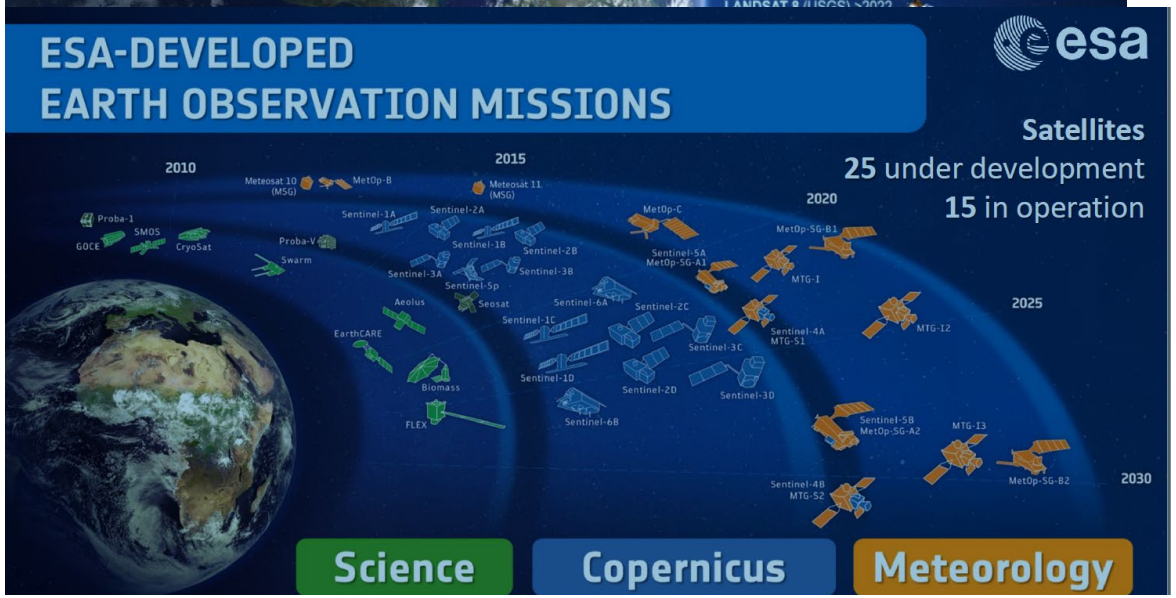
GEO GROUP ON EARTH OBSERVATIONS

CEOS

WMO

GSICS Global Space-based Inter-Calibration System



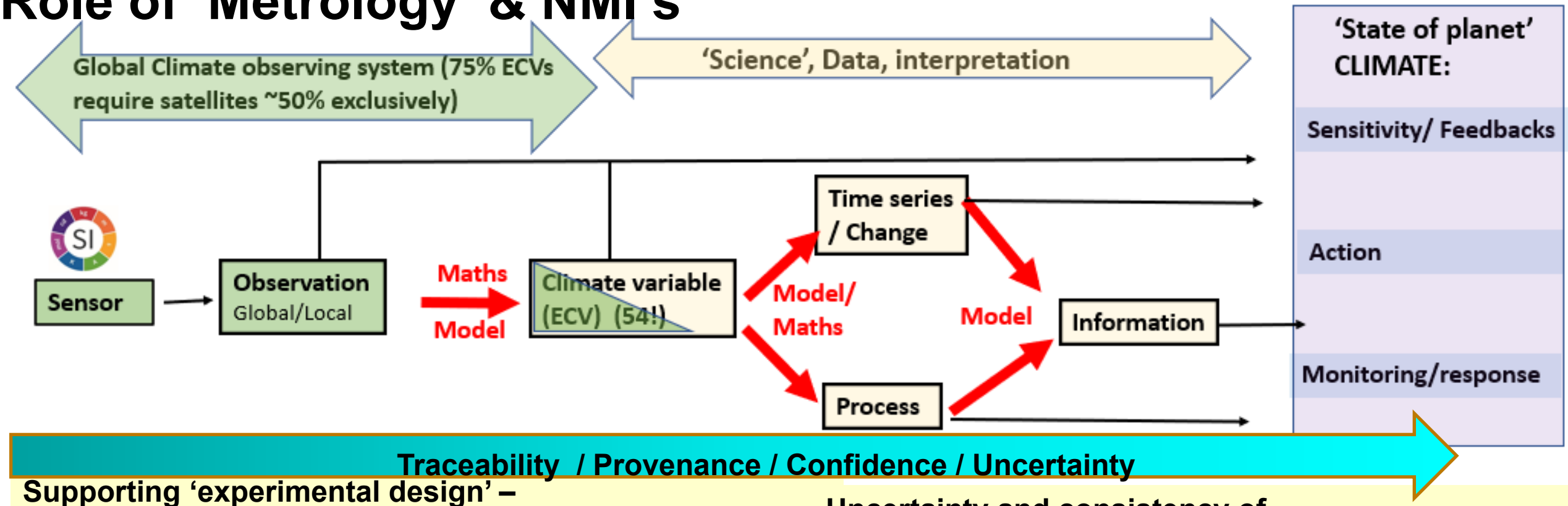


75% of ECV's require space observations (50% exclusively)

Satellites suffer biases and degradation in performance due to launch and harshness of space.

Dedicated SI-Traceable Satellites (SITSats) offer prospect of new epoch of an interoperable Climate observing system

Role of ‘Metrology’ & NMI’s



Supporting ‘experimental design’ –

- uncertainty of instrument from science requirement
- Measurement equation / sensor model / means to calibrate

Calibration pre-deployment

Calibration post-deployment/operational environment

Validation of measurements (Fiducial Reference Measurements, FRM)

- uncertainty & representativeness
- international consistency

Uncertainty and consistency of Retrieval/transformation algorithms

Harmonisation with other similar observations (current, future and historic)

Integration with other observations/information

Reporting/interpretation of uncertainty and QA from sensor to information

Validation ('Fiducial Reference Measurements'):'Real' bio-geophysical properties metrologically traceable

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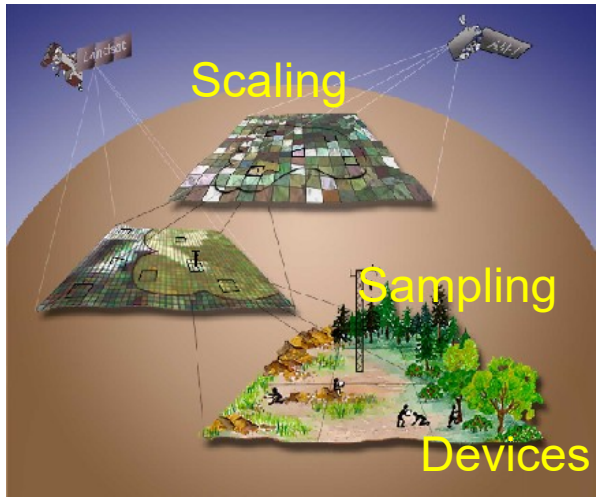
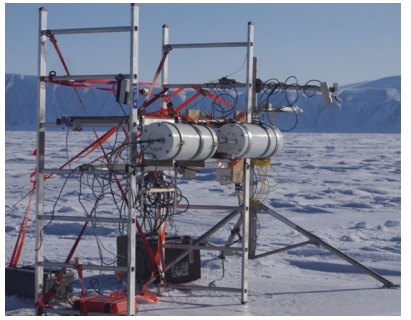
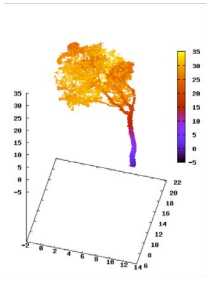
Developing Wytham woods as UK (CEOS) Validation Test-site): emphasis on carbon- biomass, vegetation/land cover …

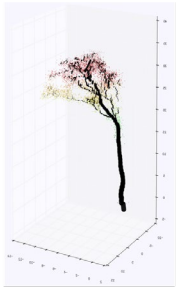




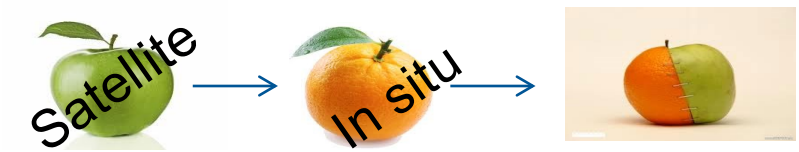
Polar regions

Oceans:
Temp / Biology





Building a virtual Forest for Uc evaluation



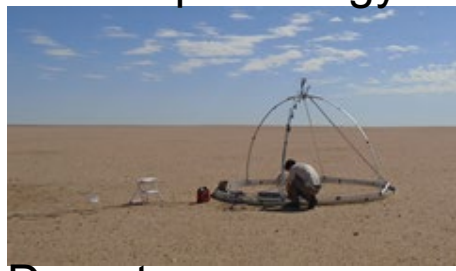
Role of Metrology

- Developing community Good practice's
- Establishing Uc of sensor, individual observation and 'representativeness' (temporal and spatial)
- Uc in linking to satellite (BoA to ToA) & retrieval of 'parameter'/ECV

Comparisons

- For consistency
- Uc confidence
- Learning
- 'Traceability'

e.g. http://www.frm4sts.org/



Deserts
Reflectance / Temp

Communicating uncertainty and data/information Quality Assurance/Confidence

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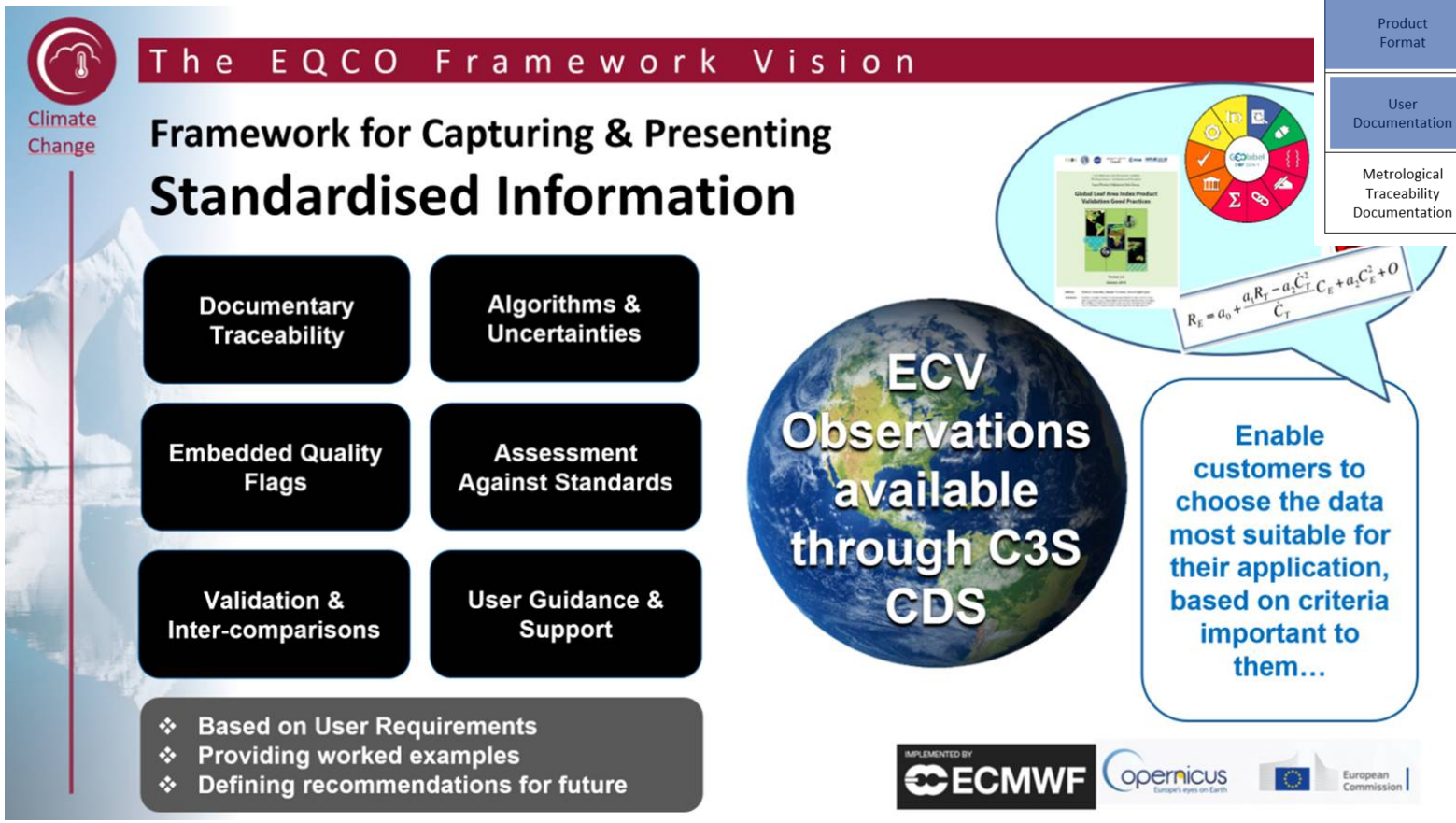
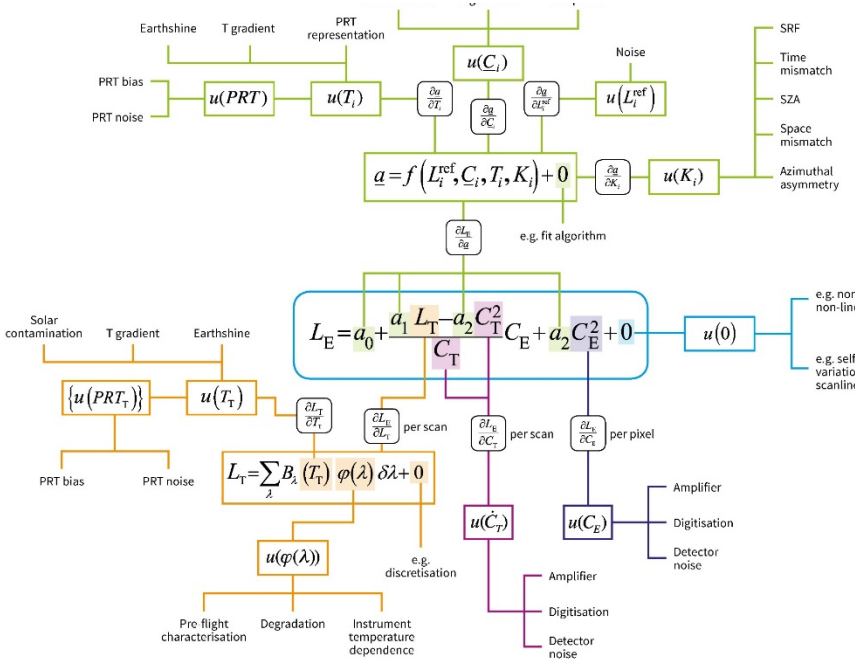
- Graphical Matrix to present summary information
- Rigorous end to end Uc analysis for traceability

Product Details	Product Generation	Ancillary Information	Uncertainty Characterisation	Validation
Product Information	Sensor Calibration & Characterisation Pre-Flight	Product Flags	Uncertainty Characterisation Method	Reference Data Representativeness
Product Availability & Accessibility	Sensor Calibration & Characterisation Post-Launch	Ancillary Data	Uncertainty Sources Included	Reference Data Quality
Product Format	Retrieval Algorithm Method	If target mission data product is Level 2	Uncertainty Values Provided	Validation Method
User Documentation	Retrieval Algorithm Tuning		Geolocation Uncertainty	Validation Results
Metrological Traceability Documentation	Additional Processing			

Key
Not Assessed
Not Assessable
Basic
Intermediate
Good
Excellent





Pre-flight SI-traceability for optical EO space instruments

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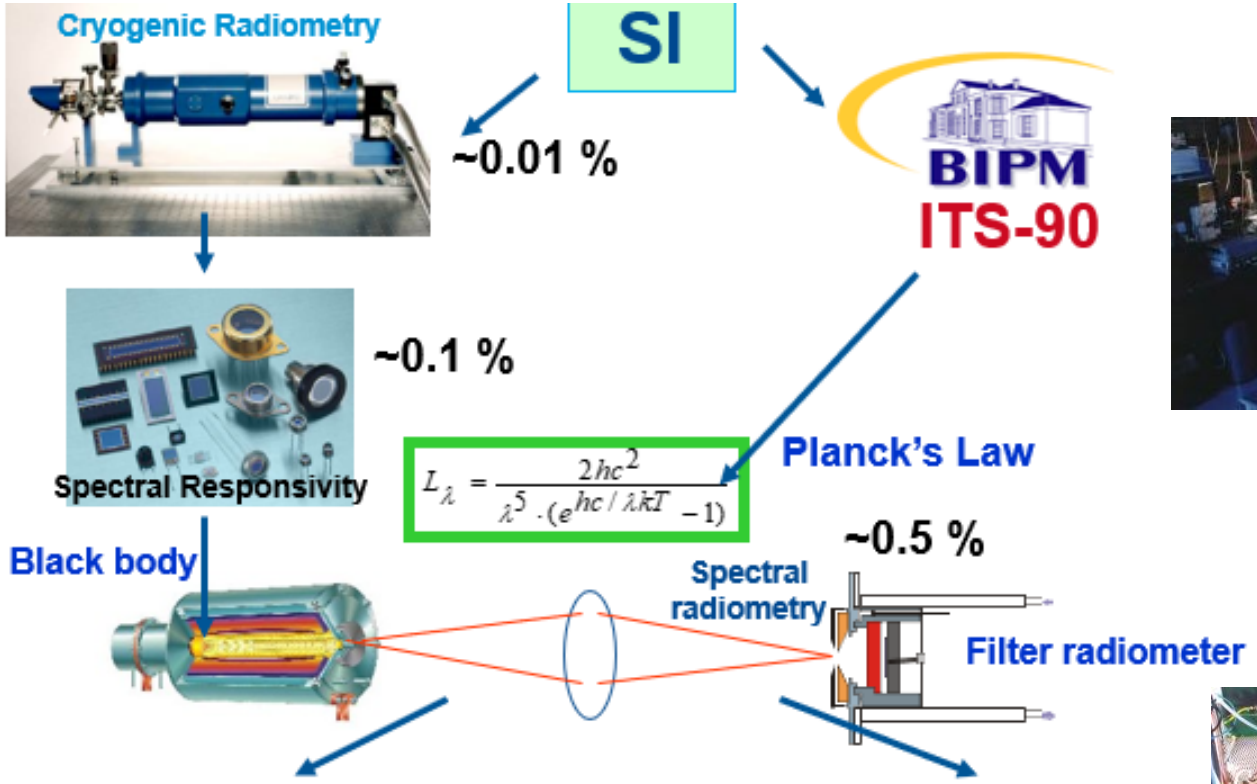
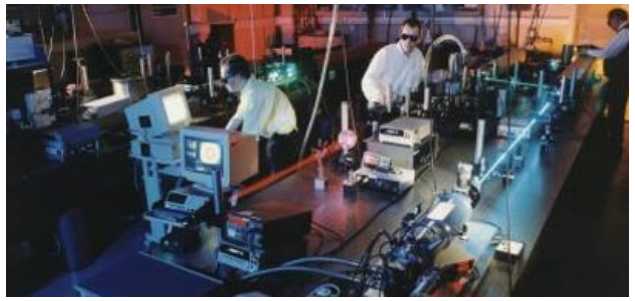
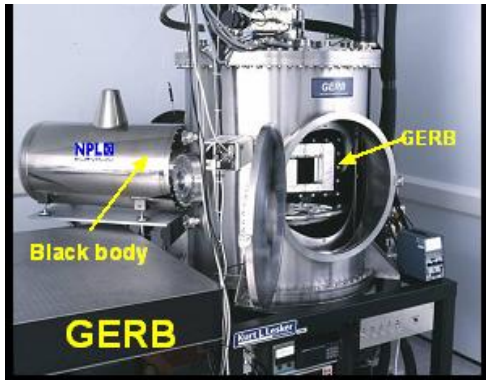
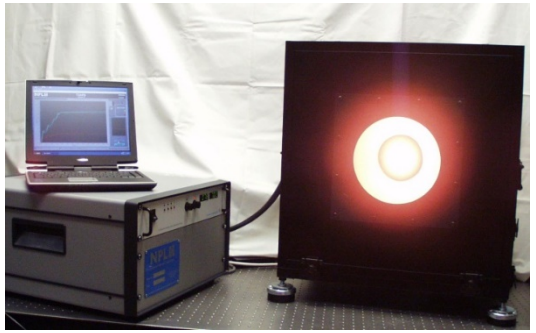
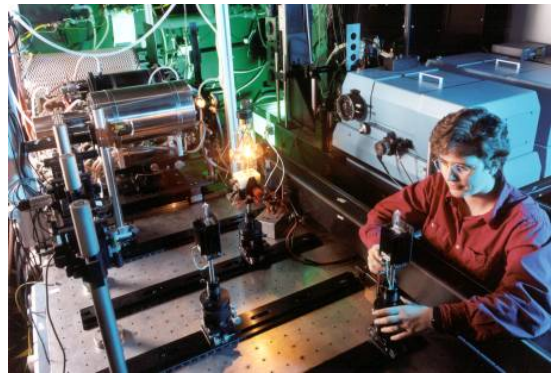
Space Instruments

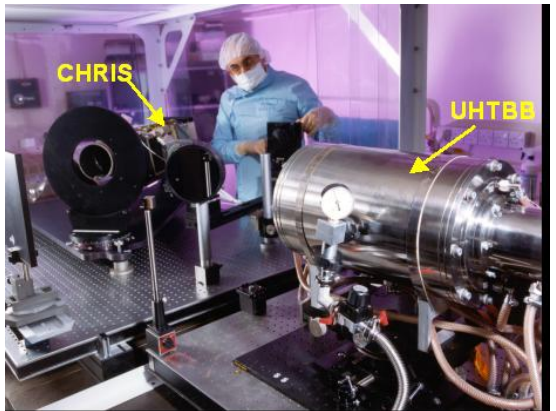




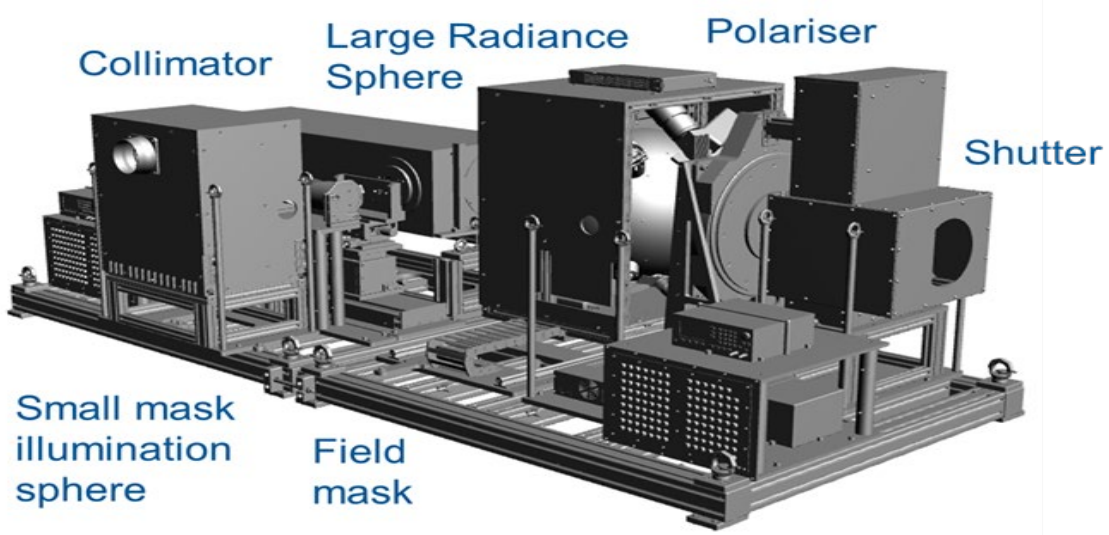


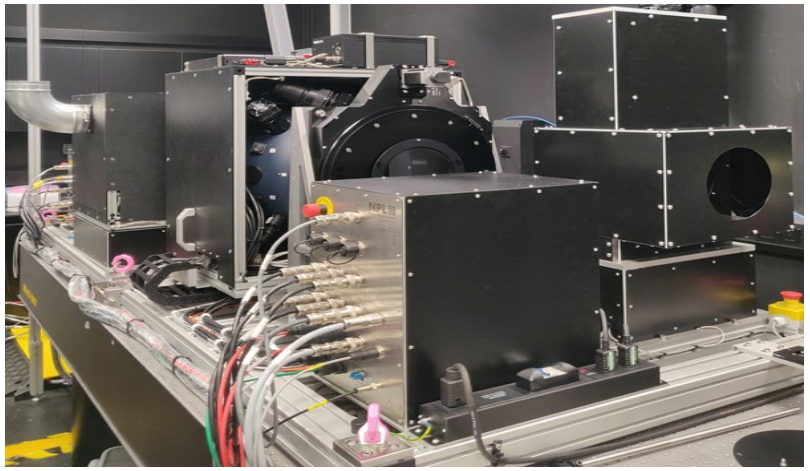






Taking the NMI to the customer



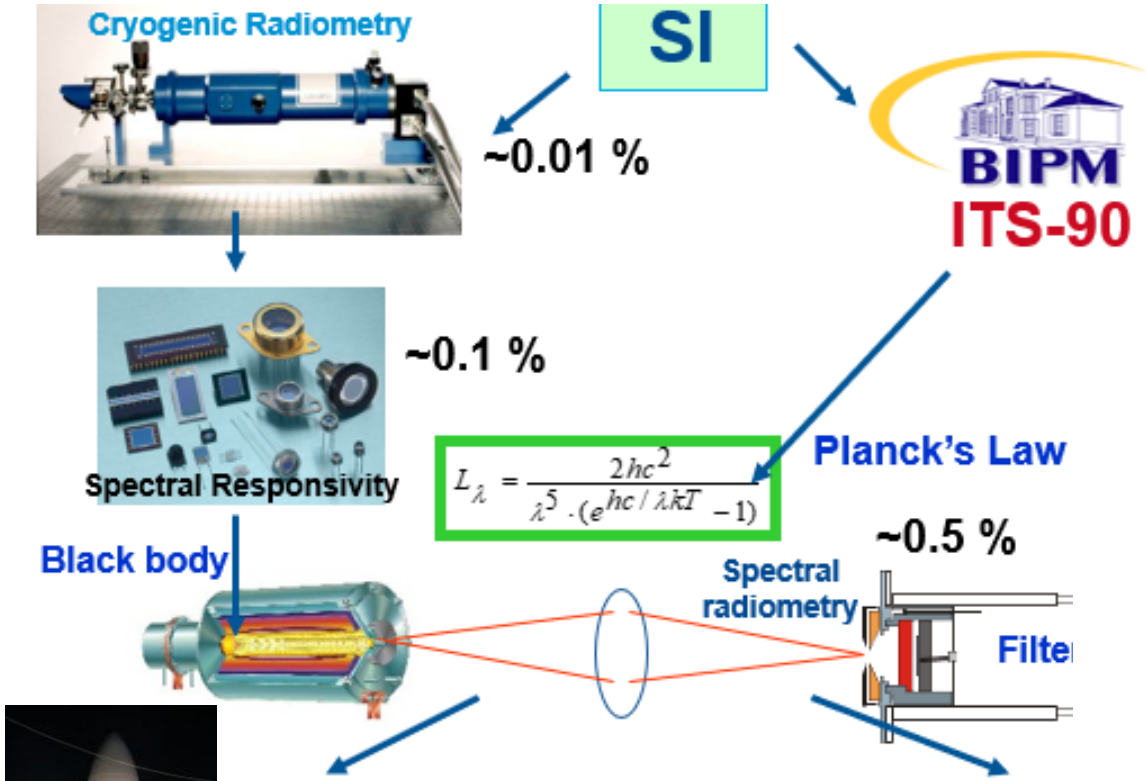


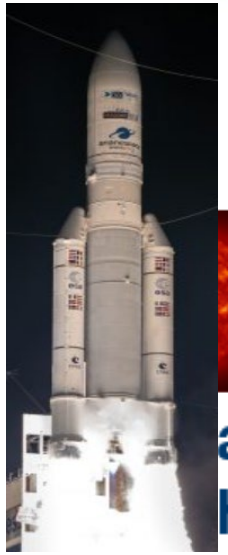
Spectroscopically Tuneable Absolute Radiometric - calibration & characterisation - Optical Ground Support Equipment (STAR-cc-OGSE)

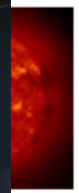
- Transported and operated in clean room of customer
- Turn-key automated tuneable CW laser (260 nm to 2600 nm)
- Collimator and integrating sphere (200 mm diameter) illumination
- Spectral bandwidth 0.1 pm (@ pm steps) to continuum (lamp)
- Spectral Radiance uncertainty target < 0.1%
- Radiance, bandwidth/line shape, linearity, stray-light, polarisation, image quality….

First customer: Airbus France for GHG satellite sensor: MicroCARB

SI-traceability for EO space instruments after launch







adiances achievable
hallenging !

TRUTHS replicates Lab capabilities in space

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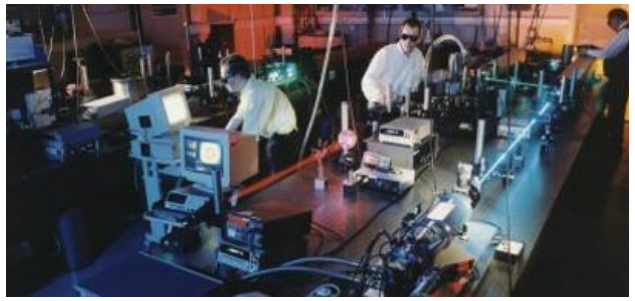
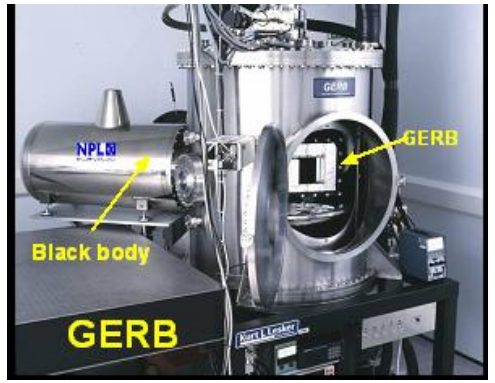
Space Instruments





- Shock
- Vibration
- Vacuum
- Radiation

- Calibration ? Traceability ?

TRUTHS: Mission Objectives

TRUTHS is a UK led **operational climate mission**, implemented by ESA Earthwatch aiming to:`

A Metrology lab in orbit:
on-board replica of on-ground methods, using a cryogenic absolute radiometer as primary standard

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 and reference calibration.

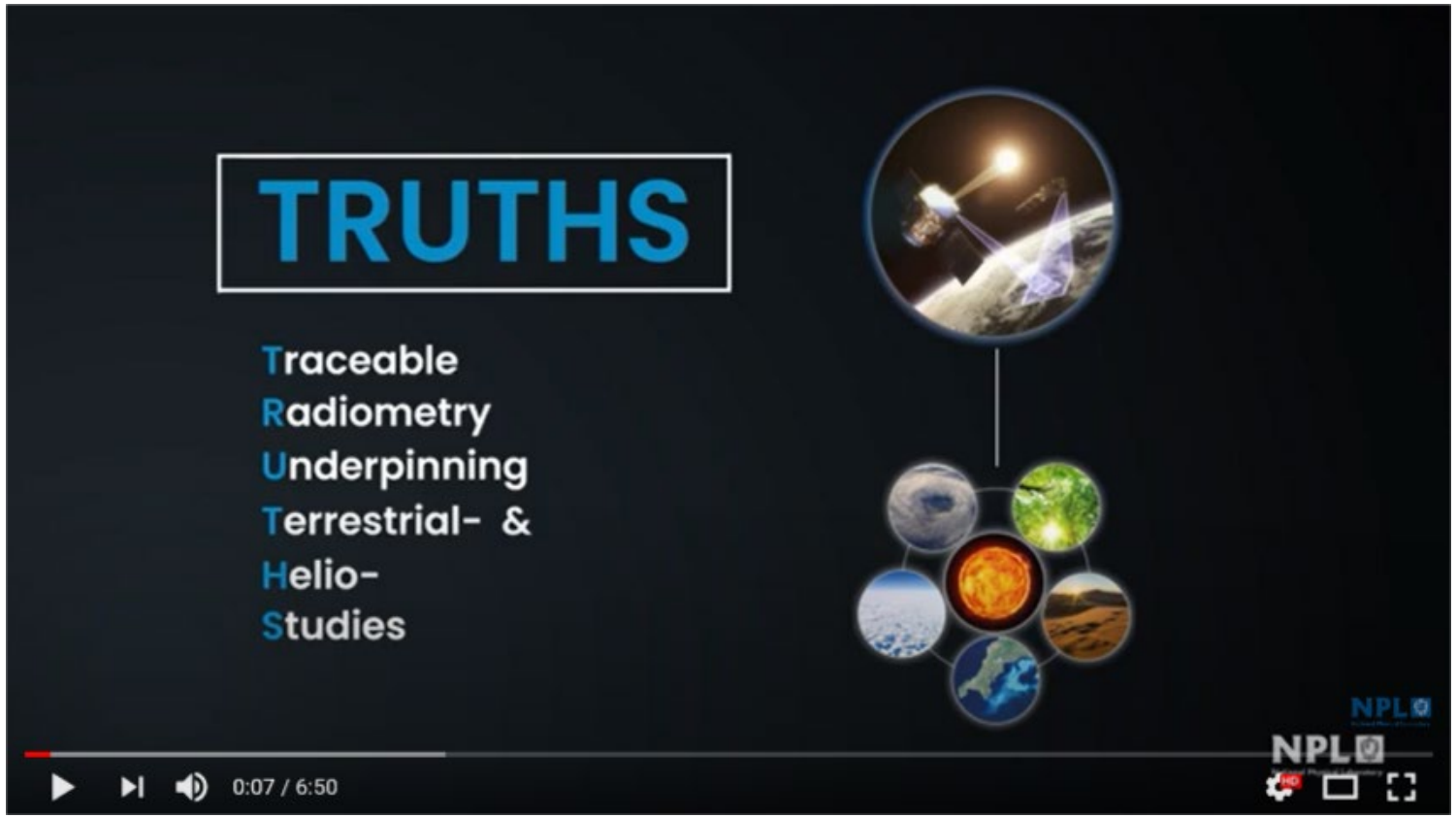
2. **Satellite cross-calibration:** establish a 'metrology laboratory in space' to create a fiducial reference data set to cross-calibrate other sensors and improve the quality and interoperability of their data, and

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

Mission Drivers:

- **Climate** application drives the stringent **Radiometric accuracy (0.3% G - 1%T)**
  ➔ *Payload & calibration System design* *(Factor of ~10X improvement)*
- **Cross-calibration** application leads to a **non-SSO orbit** ➔ *50-100 m GSD, 4 – 8 nm spectral resolution*
- **Solar/Earth/Moon observations in a large spectral range**: *UV to SWIR (320-2400 nm)* ***Total Solar Irradiance @ 0.02 % accuracy***

How the TRUTHS on-board calibration system works?



https://youtu.be/aX82kyPKFIA

‘Gold standard’ Reference Calibration

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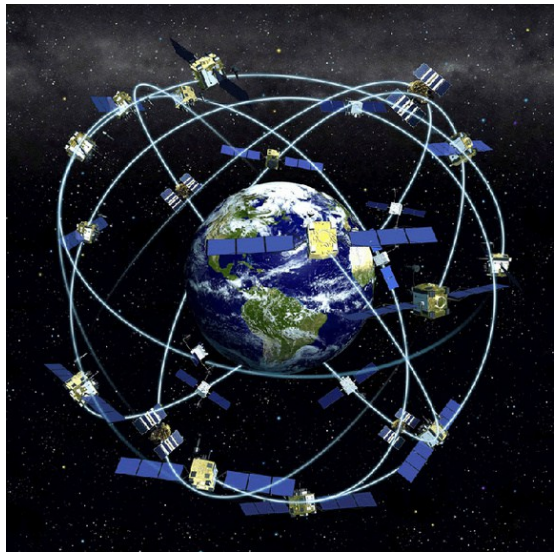
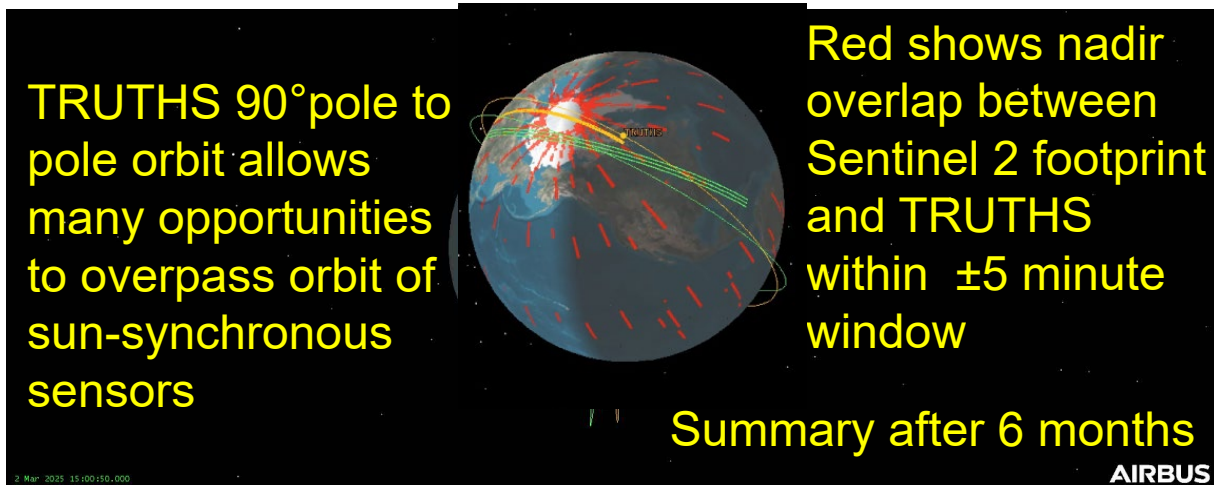
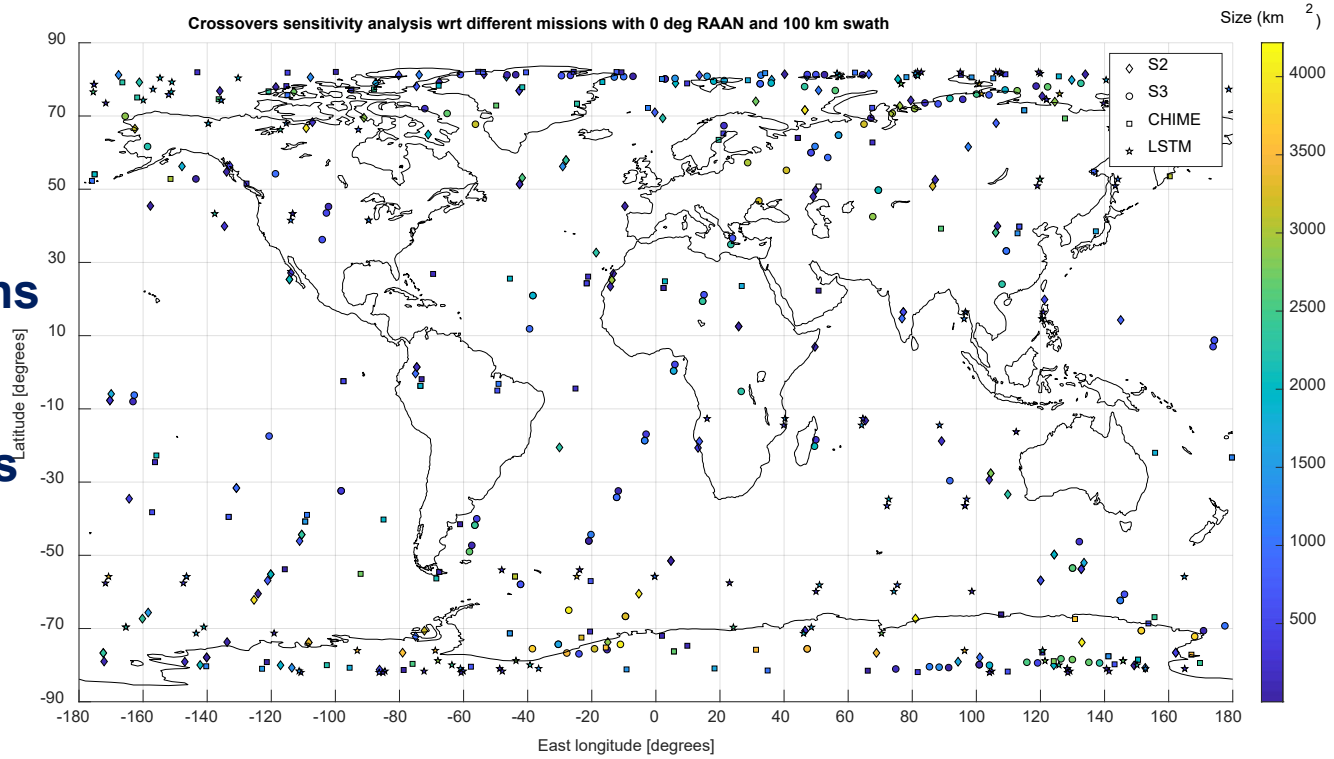
- **Enables interoperability & Harmonisation**
  - **Prospect of ‘certified calibration’**



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





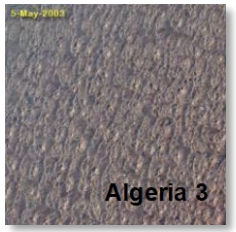
1 year of near perfect nadir overlaps for TRUTHS & satellite under test

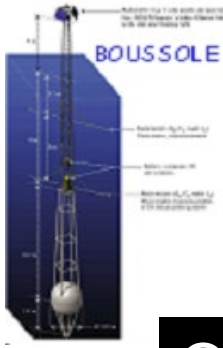
(<1° (no pointing) <30 s time differen

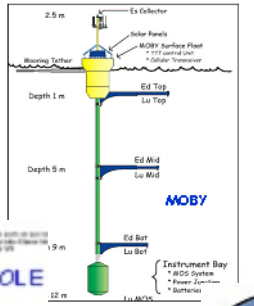
SI-Traceability to Cal/Val infrastructure

NPL

PICS

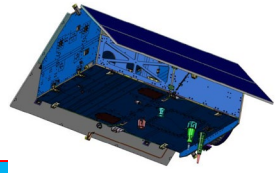






Ocean Colour

CEOS

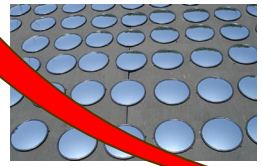


TRUTHS

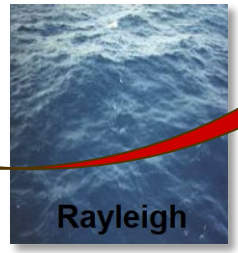
RadCalNet

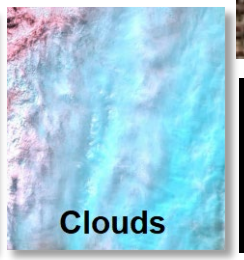
SI

SI



FLARE

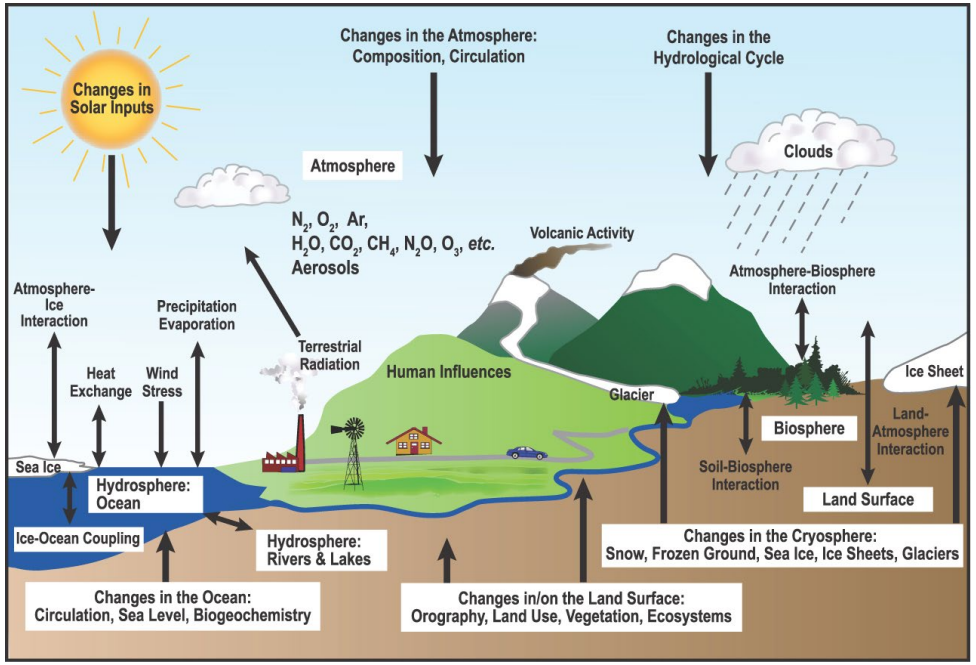


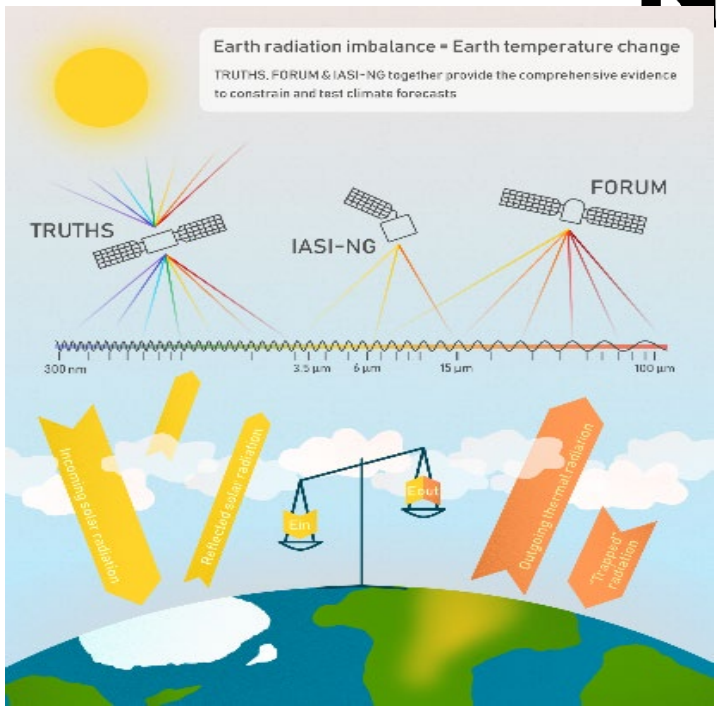


Natural Phenomena

Land/Vegetation Products

Key questions: Carbon & Radiation imbalance





TRUTHS data will help understand status and effectiveness of natural sinks of Carbon dioxide (forests and oceans) and support monitoring of land use change and agriculture amongst many others primarily by reference calibration

- **Also Cal for GHG sensors**
- **An SI-traceable anchor for the 'stocktake'**

TRUTHS is complementary to other satellite-based missions - helping to determine the Earth's radiation imbalance which drives global warming

- **Attribution of causes and feedbacks:**
  Solar, Cloud, Aerosol, Albedo, Water Vapour

Together with IASI-NG and FORUM it will provide a comprehensive spectral radiation observing system.

- **Spanning UV to Far-Infrared**

SUMMARY

NPL

- Climate action & a successful response to ‘net zero’ requires robust unequivocal observations from space of sufficient accuracy to allow ‘quantities’ & trends to be detected in as short at time as possible.
  - Creating a trustable benchmark reference of the ‘state of the planet’
  - Enabling local and planetary scale models and sensitivities to be initialised, tested and quantified
- Society needs to utilise all available data, space & in-situ (appropriately weighted) to facilitate comprehensive understanding
- Metrology needs to be embedded end-to-end in the creation and delivery of climate information
  - Not only NMIs but achieved in partnership with domain science and metrology experts
  - NMIs to evolve from a laboratory calibration of an instrument to the uncertainty of the measurement at location of observation and ultimately the uncertainty/confidence of the information
- SI-Traceable Satellites (SITSats) such as TRUTHS can help create a new epoch for EO with the prospect of an integrated global climate observing system delivering SI-traceable data
  - facilitating trust in EO to underpin regulation, litigation and international treaties

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THANKYOU!

For more info: nigel.fox@npl.co.uk