CEOI 5th and 6th Open Calls
Final Review

TRUTHS – A Mission to Provide Observational Climate Data to Enable the Unequivocal Detection of Climate Change

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Project Introduction

- Introduction
  - TRUTHS is a climate-benchmarking satellite mission proposal which was submitted to the ESA EE8 call, although not selected for phase-A, it was highly recommended by ESAC and has strong support from CEOS, WMO, GEO & NASA, reflecting the strong scientific justification & momentum emerging from the proposed US CLARREO mission.
  - Principle aim of the project to evolve the project concept by:
    - Reviewing the key science drivers & refine the mission technical specification.
    - Determine whether current or planned sensors could be ‘upgraded’ to meet these required specifications.
    - Revise the implementation options, to determine a low technical risk solution - reducing the number of mechanisms and identifying opportunities for a de-scoped ‘TRUTHS-light’ or ‘tech-demosat’ for early implementation.
    - Produce a draft mission requirements document (MRD) for the full TRUTHS mission and a principle de-scoped option.

Project Partners

- National Physical Laboratory (NPL)
  - Lead partner, TRUTHS mission PI institution.
  - Nigel Fox (PI), Paul Green & Emma Woolliams
- Imperial College London (IC)
  - NASA CLARREO science definition team members.
  - Helen Brindley, Jacqui Russell & Richard Bantges
- Surrey Satellite Technology Limited (SSTL)
  - EO instrumentation design & construction
  - Andy Barnes, Dan Lobb & Mike Cutter
- STFC-RAL
  - Calibration, vicarious calibration & operation of satellite systems
  - Dave Smith

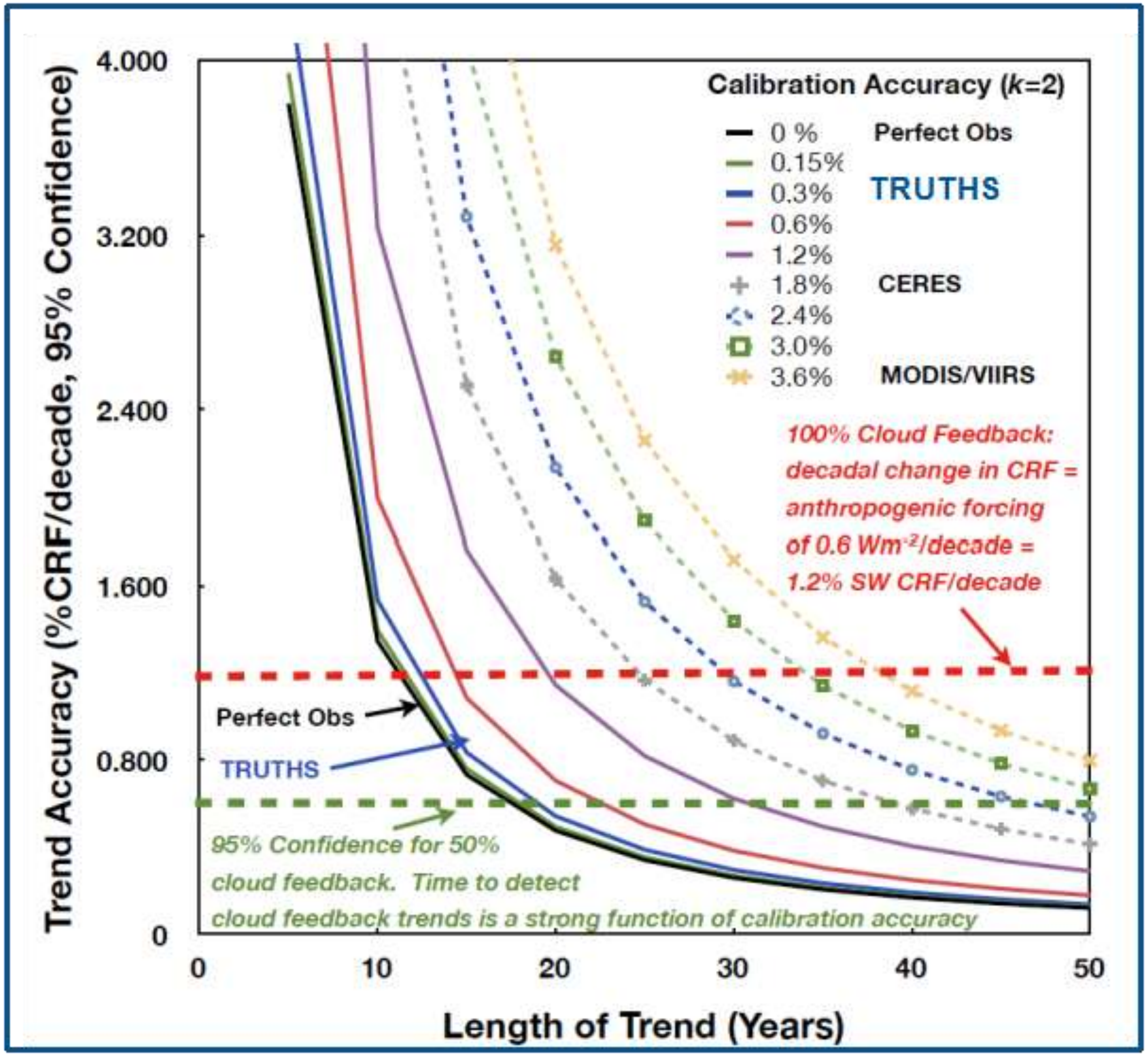
Science case for TRUTHS

- 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 mission concepts proposed to address this exacting issue.

Time to detect Cloud Radiative Forcing (CRF) from natural variability



Wielicki et al 2010

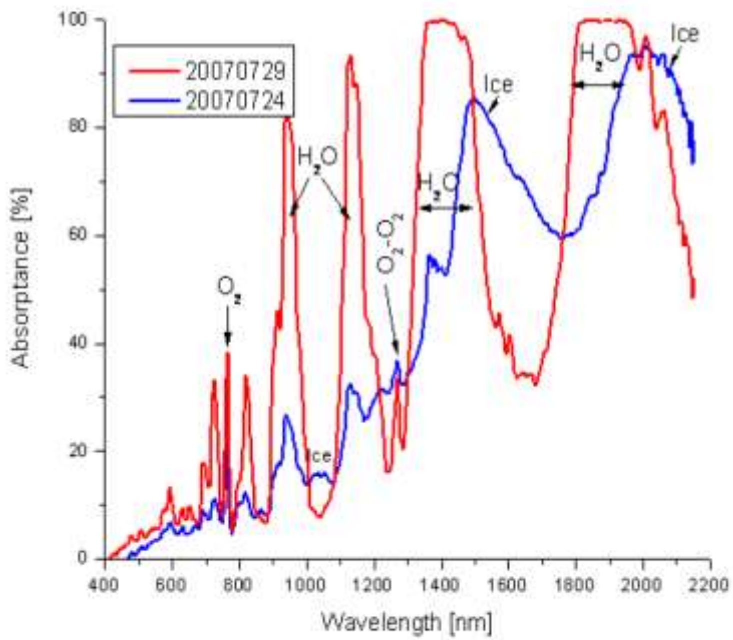
TRUTHS or (CLARREO) (proposed satellites) accuracy (0.3% k=2) near optimum to the perfect observing system

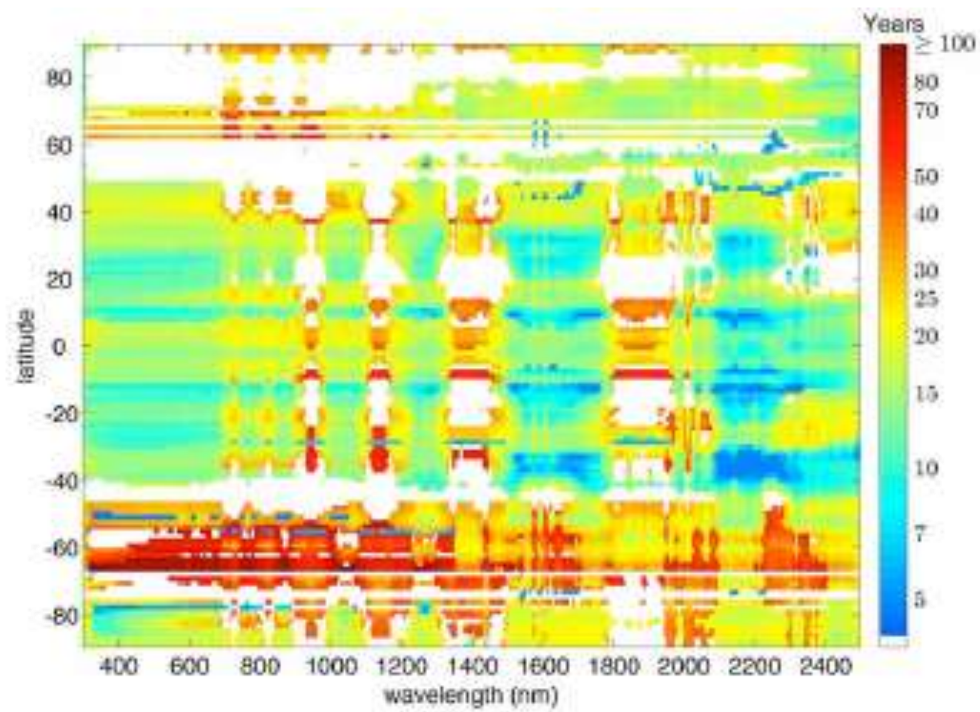
for 100% cloud feedback
TRUTHS ~ 12 yrs
CERES ~ 25 yrs
MODIS ~ 40 yrs

For 50% difference > 20 yrs

Key Science Drivers

- Reflected solar radiation from the Earth-Atmosphere system is a strong forcing.
- Benchmarking provides a measure of the current climate state.
- Require zonally-averaged TOA spectrally-resolved spectra to compare with model.
- Climate feedback are main uncertainties in model predictions (cloud, water vapour lapse rate & surface albedo)
- Some signals are broadband – but accurate attribution needs spectral resolution across full UV-VIS-NIR bands.





Feldman, D. R., et al. *JGR 116* (D24) 1-18
doi:10.1029/2011JD016407

Technical specification

Benchmarking Level	Requirement
Level 1	**All-sky climate benchmark** Spectral range: 320/400-2300 nm, resolution: 8-25 nm Accuracy: broadband 0.3%(k=2), spectral 0.3%-1%(k=2) for sampling: zonal average (30-60° longitude res.)
Level 2	**Clear-sky/cloudy & land/ocean climate benchmark** As level 1 but with higher instantaneous accuracy (reduced averaging) and smaller spatial sampling (≤250m). Improved spectral accuracy in some bands, e.g. 0.5%(k=2) in 600-700 nm spectral region.
Level 3	**Improved cloud-type determination climate benchmark & on-orbit reference calibration sensor.** As level 2 but with higher instantaneous accuracy (reduced averaging) improved spatial resolution & platform pointing.

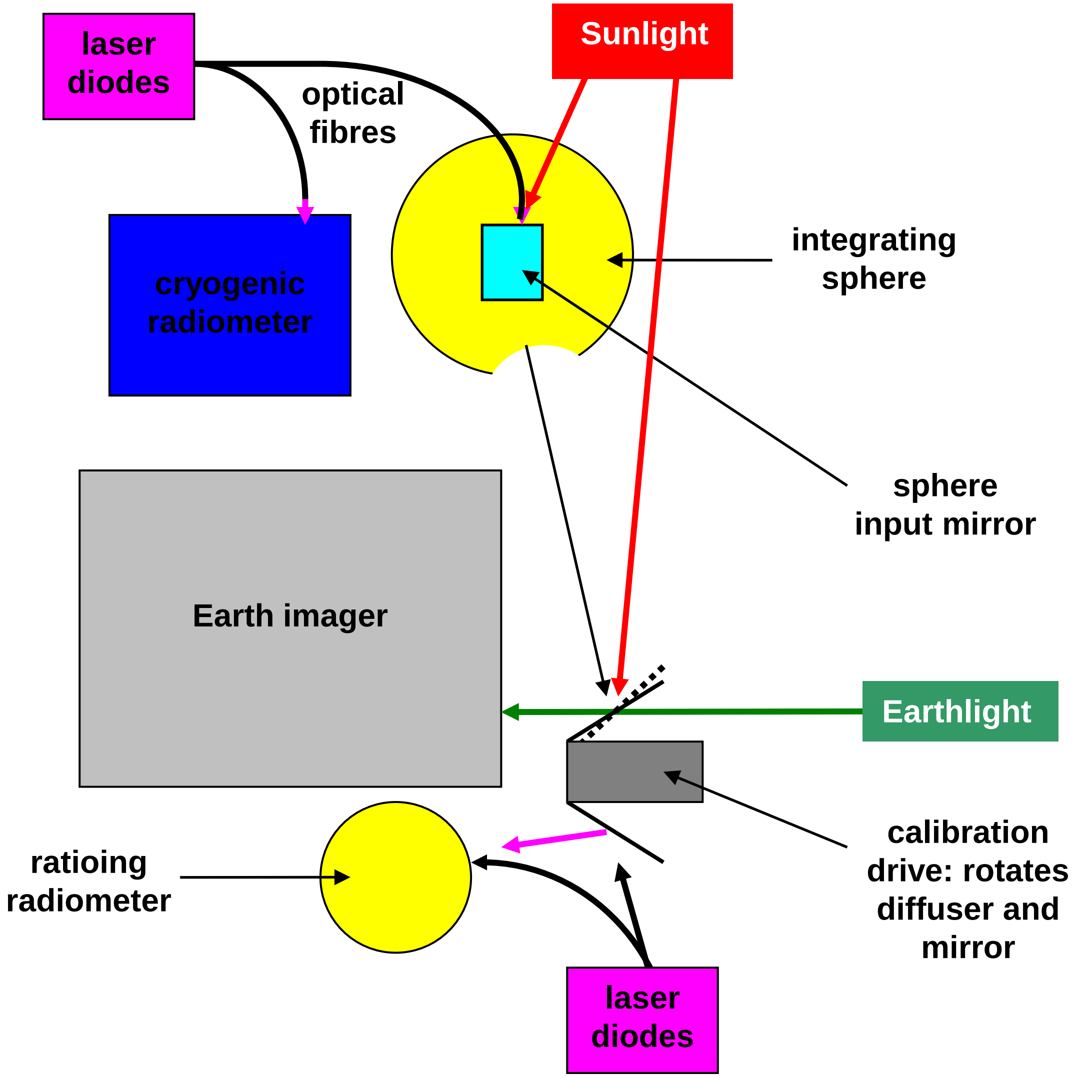
Development options of current/planned sensors

- Of 399 current and planned sensors, only 7 capable of climate benchmarking – but on-board calibration accuracy the limiting factor.
- Many current sensors have design goal accuracies of 1%, but few achieve this in practice at the start of life, let alone at end of mission.
- Typical pre-launch accuracy is 2-5% degrading over mission lifetime.
- Common on-orbit calibration sources are lamps & diffuser and although short-term stability is good, but long-term degradation behaviour assumed and not accurately monitored. Detector non-linearity and polarisation, for instance, usually assumed to remain constant over mission lifetime.
- Vicarious calibration to stable ground sites are limited by long term stability and atmospheric correction uncertainties. Typically limited to 2-3% accuracy

Current calibration methodologies are unable to achieve the required accuracies for climate benchmarking through upgrading or iterative improvement. For the 10 times accuracy improvement needed, a different methodology is needed.

The Cryogenic Solar Absolute Radiometer (CSAR) at the core of the TRUTHS concept is fundamental to providing high accuracy SI traceability on-orbit.

TRUTHS layout concept



TRUTHS operation concept

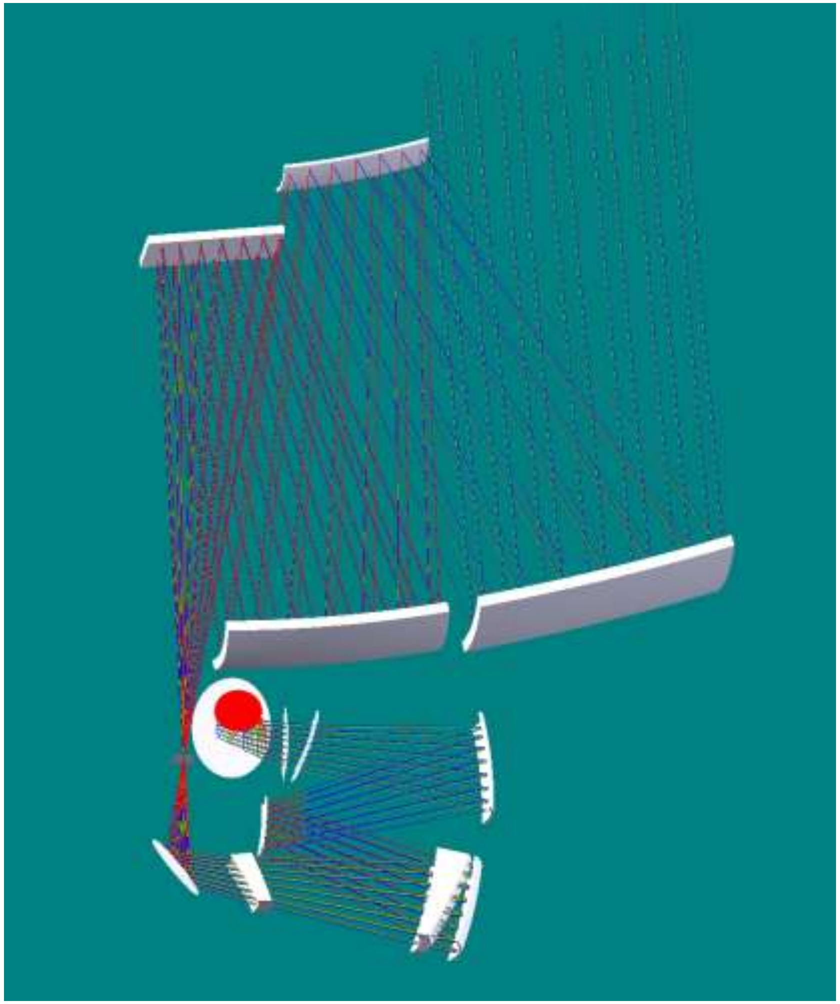
- 1st laser diodes cover the TRUTHS spectral range at intervals
- Optical fibres (movement 1) carry the same power
  - To cryogenic radiometer for absolute measurement
  - To integrating sphere input mirror
- Sphere input mirror alternately reflects sunlight into the sphere
- Calibration drive (movement 2)
  - 1st position: mirror reflects light from sphere to Earth imager
  - ➢ Ratio of sun/laser signals gives absolute solar spectral irradiance, interpolated using lamps in the sphere
  - 2nd position: diffuser reflects direct sunlight to Earth imager
  - 3rd position for Earth imaging and diffuser calibration
- Fibre guides from 2nd laser diodes (movement 3)
  - Send light alternately to diffuser and reflection-radiometer
  - Measures diffuser reflectance at laser wavelengths
  - ➢ Provides calibration for Earth reflectance + hence radiance

Earth Imager development

- Earth imager requirements
  - wide spectral range – ideally from UV to 2300nm
  - fine spectral resolution – possibly 5-10nm but ideally 2nm
- The SWIR range will require a cooled detector
  - May use common cooling with cryogenic radiometer
- Difficult to cover wide spectral ranges
  - Prism dispersion for single optics channel,
    - E.g. CHRIS, EnMap
    - Gives resolution typically 10nm to 20nm
  - Wide band systems with resolution down to 1nm or less
    - E.g. Sentinel 5 options
    - Typically require 5-7 separate grating channels
  - We need to find a creative compromise

CHRIS 2 design form as starting-point

- Mirror telescope
- Spectrometer
  - Prism dispersion
  - Spherical mirrors
- Split between 2 detectors
  - Si CCD for visible/NIR
  - MCT for short-wave IR – cooled
- CHRIS 2 specification
  - GSD = 19m
  - SNR >100:1 (all bands)
  - Spectral range 400 -2500nm
  - Spectral resolution <10nm to 20nm
- EnMap specification is similar
- Adjustments
  - Much smaller telescope at 100m
  - Relaxed aperture for spectrometer
  - 5-10nm resolution may be achieved



Achievements

A significant step forward in the development of the TRUTHS mission concepts, building on an already well supported project called for by the international climate science community.

- Evolution and refinement of the science case – making use of many of the studies developed for CLARREO.
- Enhanced technical specification defined on a 3-level structure, from threshold to maximum benchmarking utility.
- Development of advanced considerations, e.g. a trade-off between UV spectral coverage extent and accuracy requirements.

- Survey of current and future planned mission 'upgrade' implementations proven to be insufficient for benchmarking mission goals.

- New, simpler calibration chain methodologies developed that both reduce platform complexity (less mechanisms) and also allows de-scoped 'light' and 'tech demosat' options.
- EI spectrometer defined at a high level against current instruments.
- A draft MRD that can be taken forward to a fuller phase-A study.

Roadmap

The TRUTHS mission is gaining momentum and has strong support from CEOS, WMO, GEO & NASA. To take the project to the next logical step requires funding for a phase-A study.

- Future steps
  - The majority of technologies are high TRL, the innovation is in their combined use.
  - The CSAR cryogenic radiometer has been demonstrated on-ground and is being used at the WRR in Davos, Switzerland to measure TSI.
  - Demonstration of some of the calibration linkages is underway.
  - Some aspects require advancement to space-qualification.
  - Possible tech demosat option for the CSAR reference instrument.

- Publications
  - ‘Monitoring the Climate system from space: progress, pitfalls and possibilities’ - Grantham Institute briefing paper http://www3.imperial.ac.uk/climatechange/publications/