Determining Global Radiation Balance Measurements for Assessing Climate Change (Synergies among HyspIRI, CLARREO, and TRUTHS)

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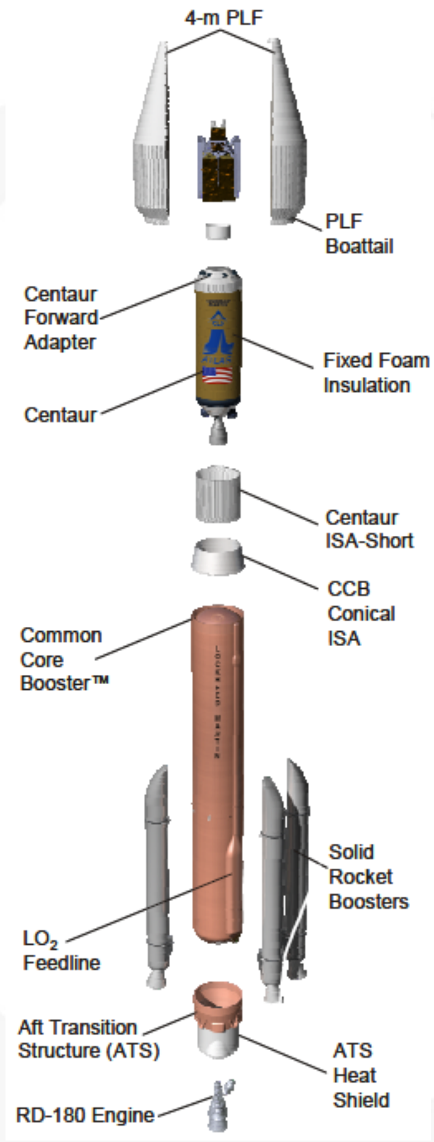
Purpose of Mission

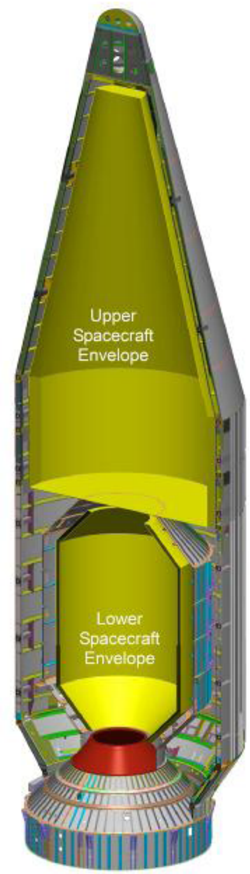
- The 3 laws of climate data: Calibrate. Calibrate. Calibrate.
- Provide reference instruments with on-orbit SI traceable calibration
- Provide accurate climate records to detect decadal changes
- How CLARREO differs from traditional Earth Science missions:
    - instruments focused on SI traceable absolute calibration at decadal change signal accuracy
    - larger spatial scales, not smaller
    - longer time scales (decadal), not shorter
    - high spectral resolution across full solar reflected and thermal emitted spectrum
    - orbits selected to minimize aliasing errors in decadal change (diurnal cycles)
    - orbits selected to optimize inter-calibration with other sensors
    - CLARREO provides SI traceable transfer radiometer in orbit to calibrate other sensors key to climate change observations: CERES, CrIS, IASI, VIIRS

Initial Mission Concept Architecture

- Two identical observatories
- 600 km polar orbits (90º inclination)
- Orbital planes separated by 90º
- Orbital maintenance
  - ± 200 meter altitude
  - ± 0.01º inclination angle
- Co-manifested on an Atlas V vehicle with Dual Satellite System (DSS) to provide the orbital plane change
- 3-year design life with spacecraft consumables to extend to a 5-year mission (design life trade study pending)
- Provisions for disposal within 25 years
- X-band and S-band communications



Atlas V Launch Vehicle



Initial Mission Concept Summary

- Two identical observatories
- Infrared Measurements:
  - *One infrared interferometer*
  - *Primary measurement is nadir benchmarking*
  - *Intercalibration at nadir only*
  - *0.1 K, 3σ; 100 km FOV*
- Reflected Solar Measurements:
  - *One suite of grating spectrometers*
  - *Nadir benchmarking ~95% of duty cycle*
  - *Sun and lunar views for calibration*
  - *Intercalibration requires off-axis pointing*
  - *0.3%, 2σ; 100 km swath; 0.5 km IFOV*
- GNSS Radio Occultation (RO):
  - *One GNSS-RO system*
  - *Fore and aft occultation antennas*

CLARREO Initial Mission Concept

Observatory Features

Instrument	Observatory I	Observatory II
Orbit	600 km polar	600 km polar
Orbit Maintenance	± 200 m Altitude ± 0.1° Inclination	± 200 m Altitude ± 0.1° Inclination
Attitude Control	LVLH 3-axis	LVLH 3-axis
Active Pointing	0.1° to 1.0° (TBR)	0.1° to 1.0° (TBR)

Payload Suite

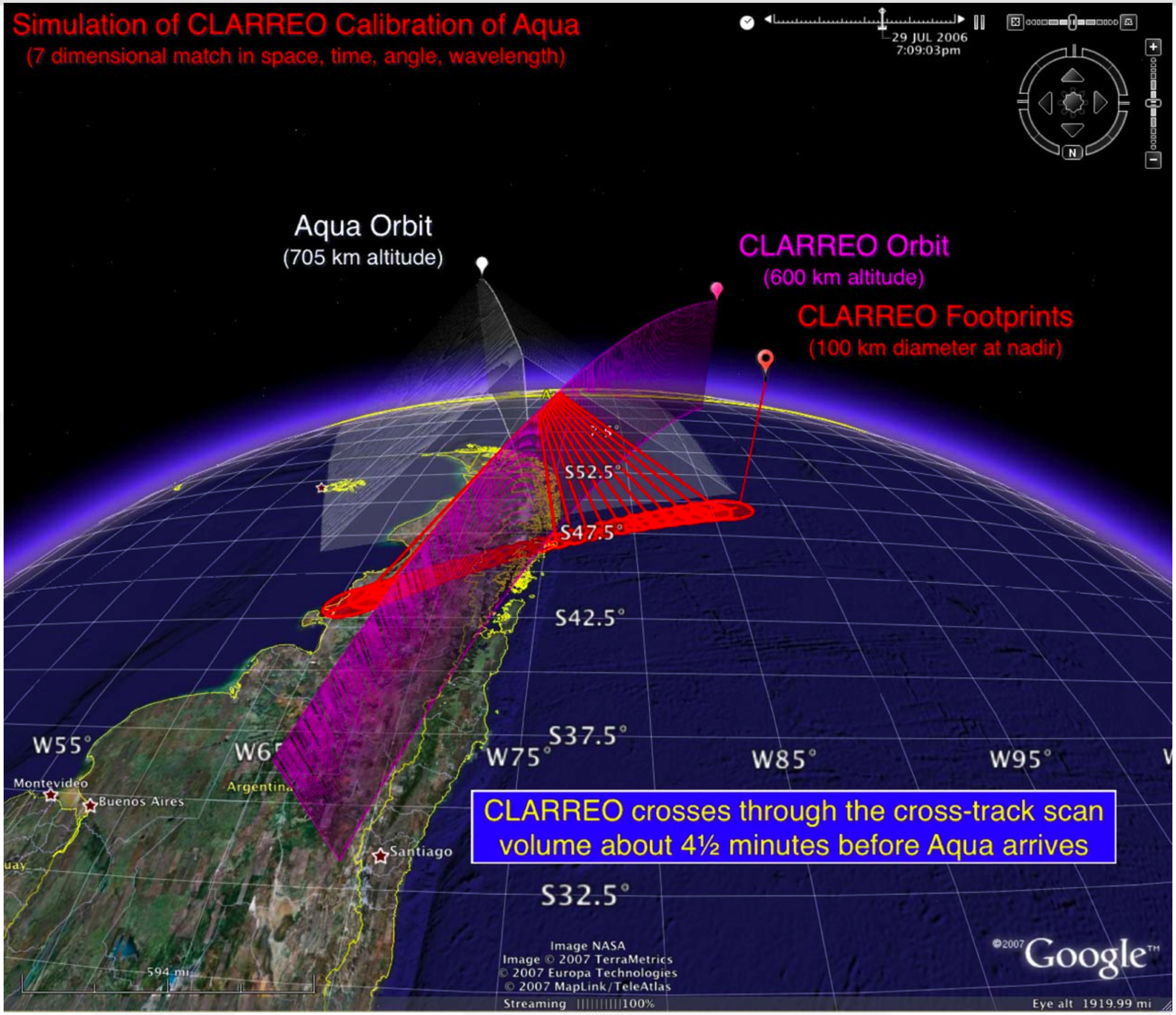
Instrument	Observatory I	Observatory II
Infrared Spectrometer	FTS	FTS
	5 to 50 micron	5 to 50 micron
	Nadir	Nadir
Reflected Solar Spectrometer 1	Grating	Grating
	320-640 nm	320-640 nm
	Gimbal-mounted	Gimbal-mounted
Reflected Solar Spectrometer 2	Grating	Grating
	600-1200 nm	600-1200 nm
	Gimbal -mounted	Gimbal -mounted
Reflected Solar Spectrometer 3	Grating	Grating
	1150-2300 nm	1150-2300 nm
	Gimbal -mounted	Gimbal -mounted
GNSS Radio Occultation System	POD	POD
	1 Receiver	1 Receiver
	3 Antennas	3 Antennas

Science Data Products

Level	Description
0	Raw instrument data
1	Navigated emitted spectral longwave and reflected spectral solar radiances, GNSS-RO time delays
2	Instantaneous retrieved geophysical parameters - aerosol if APS selected (TBR) - scene identification & cloud mask (TBR) - GNSS-RO refractivity and temperature profiles
3	Decadal change space & time averaged benchmarking products (1° zones)
3	Decadal change space & time averaged retrieval products (1° zones)
4	Decadal change CLARREO calibration of other sensors (monthly to annual) - LW calibration of CrIS/IASI/AIRS*/CERES - SW calibration of CERES/VIIRS#/AVHRR/MODIS*/Landsat/geo imagers#

** MODIS and AIRS are on Terra, Aqua only: may not overlap with CLARREO mission; the remaining sensors are all planned for missions in the CLARREO time period*
 # For LW, CLARREO calibrates CrIS, IASI which in turn calibrate leo and geo imager infrared channels.

Inter-Calibration



Inter-Calibration Use Case

- *Complex planning to select and execute IC events*
- *Coordination with all CLARREO ground systems, flight software, and external data systems*
- *Instrument pointing control for coincident co-aligned samples*
- *Weekly payload command uplinks to schedule IC events*
- *463 IC events/year/satellite for 9 satellites in various orbits (sunsync and geostationary); 4,167 events/year/satellite; 5-10 TB/year*
- *5 % duty cycle available for IC sampling, 1-2 IC events/orbit*
- *Concurrent instrument IC collection and science processing sessions*
- ***Requires automated access to external instrument data***
- ***Requires automated distributed operations** – IC planning, payload command generation, data acquisition, science processing*

National Physical Laboratory

TRUTHS:

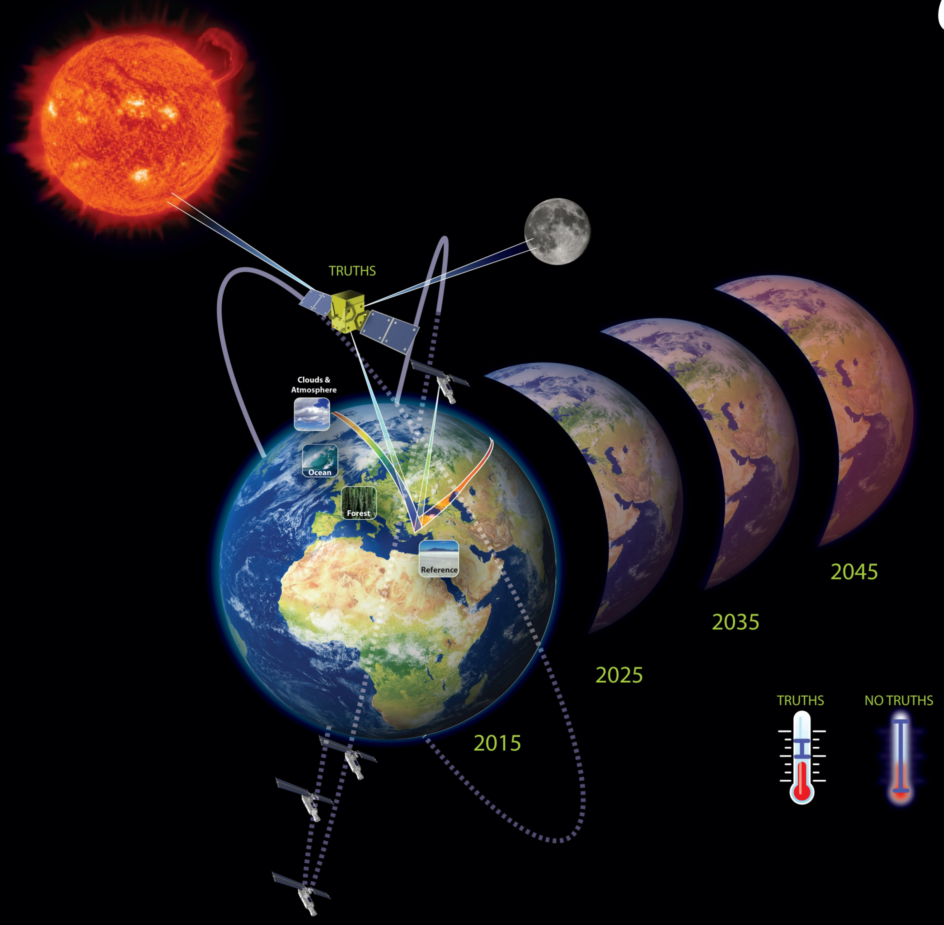
Traceable **R**adiometry **U**nderpinning **T**errestrial- and **H**elio- **S**tudies

A Benchmark Mission for Climate Change and GMES

Proposal for

ESA Earth Explorer-8

Ref: CRM329



Motivation for TRUTHS

Observing the changing Earth is at the heart of ESA's Living Planet Program. Measurements made in support of this program must be universally accepted, robust and of sufficient accuracy to ensure long-term stable records. TRUTHS can provide this missing assurance by directly anchoring the space-based Earth Observing systems to the internationally accepted physical standards of the SI measurement system, thus guaranteeing the temporal consistency of data, even beyond the lifetime of individual systems. This will enhance performance and ensure consistency of data from the instruments on- board the Sentinels and allow the upgrade of GMES to create a foundation for an "operational climate observing system"

TRUTHS Addresses Climate Change

The IPCC concludes that the mix of natural variability and anthropogenic effects on decadal timescales is far from fully understood or measured, requiring significant improvements in accuracy. Unequivocal attribution and quantification of subtle fingerprint indicators from this noisy background are fundamental to our ability to reliably predict climate and use appropriate mitigation/adaptation strategies. The uncertainty in climate prediction lies in the complexity of the models, our inadequate understanding of the Earth system and its feedback mechanisms and the relatively poor quality of available data against which to test predictions on the necessary decadal timescales. **TRUTHS** accuracy has been optimized so that it is within 20 % of the perfect observing system to detect trends in Cloud Radiative Forcing, the dominant and most uncertain climate feedback allowing detection in half the time of other sensors.

TRUTHS will address this challenge through two complimentary but distinct approaches:

- **Direct sampling of climate signals by TRUTHS' sensors.**
- **Improving performance in other observing systems through reference calibrations**.

What Does TRUTHS Measure?

TRUTHS will provide the following level 1 products, which will be available for subsequent processing into a range of level 2 products by the community. The baseline level 2 climate products: global, zonal, annual mean radiances will be automatically delivered with others to be prioritized during mission development.

Parameter	Spectral range /μm	Spectral resolution / nm	Max GIFOV / m	Swath / km	Sampling	Uncertainty / % (2σ)
Earth Radiance	0.32 to 2.45	~5 to 10 some polarised	40	40	Global nadir + multi-angle	0.3
Total Solar Irradiance	0.2 to 35	NA	NA	NA	Daily	0.02
Solar spectral Irradiance	0.2 to 2.5	0.5 to 10	NA	NA	Daily	0.2

These 2σ uncertainties, while challenging, are achievable and are essential to detect long-term changes in key climate variables. TRUTHS addresses cause and feedback of low-level cloud trends by observing reflected cloud property trends and relating these to the Earth radiation budget, which is of fundamental importance to improve climate modelling. The accuracy of TRUTHS will allow progress in cause attribution of the observed trends in the Earth radiation budget, and is vital for determining the long-term change in land surface variables (vegetation, snow/ice albedo), ocean colour, and atmospheric key parameters (aerosols, ozone, column water vapor). A 90° precessing polar orbit at altitude of 609 km allows two full diurnal cycles to be observed per annum. It also provides the opportunity for multiple near simultaneous overpasses with, and thus high accuracy “reference calibration” of, other Earth Observing sensors flying in the more common Sun-synchronous or Geo-Stationary orbits

How HyspIRI Can Contribute to the CLARREO/TRUTHS End-game

- Both CLARREO and TRUTHS can independently meet their stated mission objectives.
- By coordinating activities, they can provide greater validation to the climate science community.
- HyspIRI adds additional unique information through its combination of global coverage and higher resolution IFOV.
- Although the main approach to climate studies currently proposed for HyspIRI VSWIR involves generation of surface reflectance by the project and higher level products by investigators, the level 1R data can be used to generate a global high spectral and spatial set of exoatmospheric RS radiance at 19 day intervals.
- By coordinating observing strategies all three missions can enhance the success of meeting the common goals of: (1) direct detection of climate signals and (2) improving performance in other observing systems through reference calibration.