UKSA lead: Beth Greenaway
PI: Nigel Fox, NPL

TRUTHS in the Earth Watch context – a proposal by UKSA

What is the TRUTHS mission?

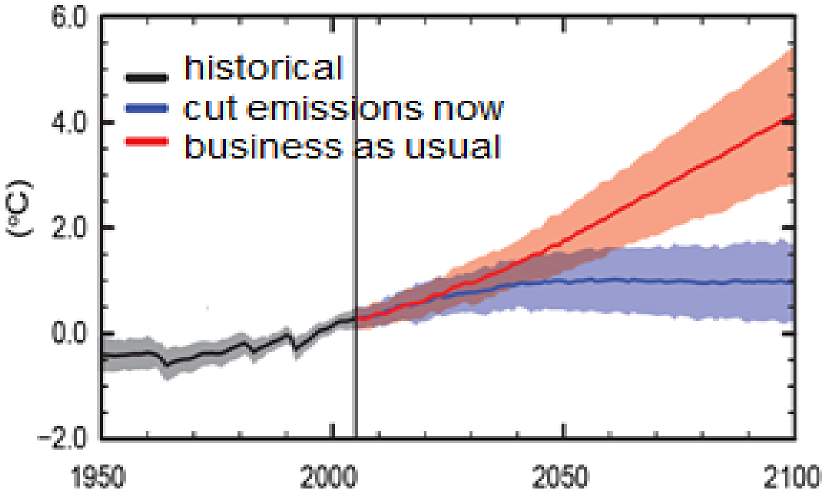
TRUTHS stands for '*Traceable Radiometry Underpinning Terrestrial- & Helio- Studies*'

- 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.

- The datasets needed to meet this objective have many secondary applications.
  - Operational products for removing radiometric biases in other satellite instruments by cross-calibration with TRUTHS data, improving accuracy & enabling inter-operability.
  - SI traceable measurements of the solar spectrum to address direct science questions.

The Climate Challenge

- Climate policies are driven by complex theoretical climate predictions that struggle to stand out from more immediate political drivers
  - Governments struggling to reconcile need to cut emissions with business as usual priorities
- Greater accuracy of climate observations enables more critical testing of climate models
  - Opportunity for a step-change in the political credibility of climate predictions, to unlock the barriers to transition
- TRUTHS delivers that opportunity by detecting the signal of climate change (above natural variability) in the shortest possible timeframe
- TRUTHS will accurately benchmark the start of the climate system now
  - The proposed mission is nominally 5-7yrs.
  - Repeat mission(s) will provide data on the 10-20 year timescale required to observationally detect climate trends.



User demand for TRUTHS for Climate

- Copernicus Climate Change Service:

  “The proposed mission will greatly enhance our ability to estimate the radiative imbalance underlying climate change. It will generate a fundamental benchmark dataset useful for many applications as a baseline for climate monitoring. It will additionally serve as a reference dataset for calibration of other sensors planned within the Copernicus programme.”

  Dr Dick Dee

- UK Met Office:

  “For our weather prediction models the radiances have to be bias corrected before being assimilated and a better knowledge of the cause of these biases would improve our forward modelling of the various instruments used to define our atmospheric and surface analyses and thus improve confidence in our forecasts.”

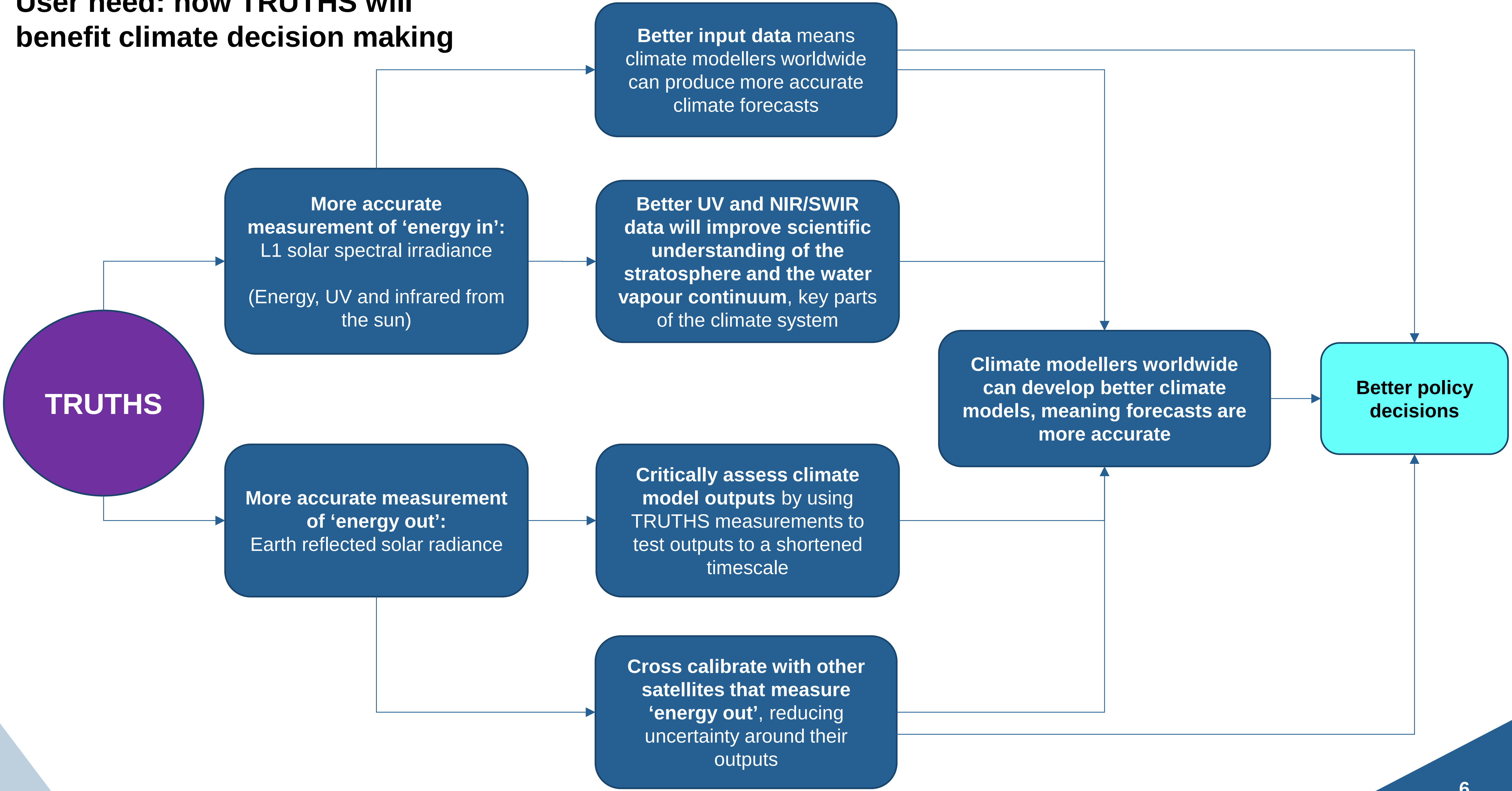
  Professor Julia Slingo

- BEIS Science and Innovation for Climate and Energy, and the UK Environment Agency have all expressed similar support for TRUTHS

TRUTHS Earth Watch proposal perimeter

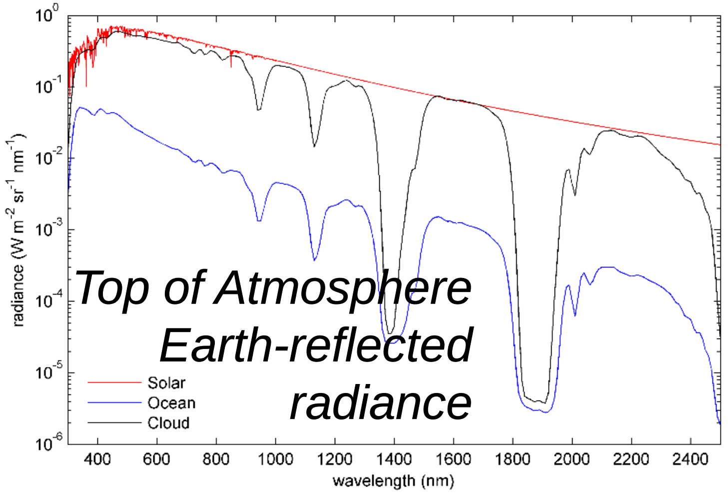
- 5-7yr mission S/M platform [P/L Mass ~ 150 kg, Power ~ 280 W, Data ~ 4500 Gb per day]
- Hyperspectral imaging spectrometer payload, measuring the Earth, Moon & Sun.
- On-orbit SI-traceable calibration that provides 10x improved accuracy to current sensors.
- 90deg precessing orbit to provide true diurnal cycle sampling & optimised cross-cal match-ups
- Data Products
    - L1 Earth-reflected spectral radiance (320nm to 2450nm)
    - Total Solar Irradiance (0.2um to 30um, integrated)
    - L1 Solar spectral irradiance (320nm to 2450nm)
    - L1 Lunar spectral irradiance (320nm to 2450nm)
    - Inter-calibration coefficients & match-up products.
    - L2 spectral surface reflectance (320nm to 2450nm)
- Sole-use Vega-C launch.
- Ground segment (FOS & PDGS) – download at Svalbard

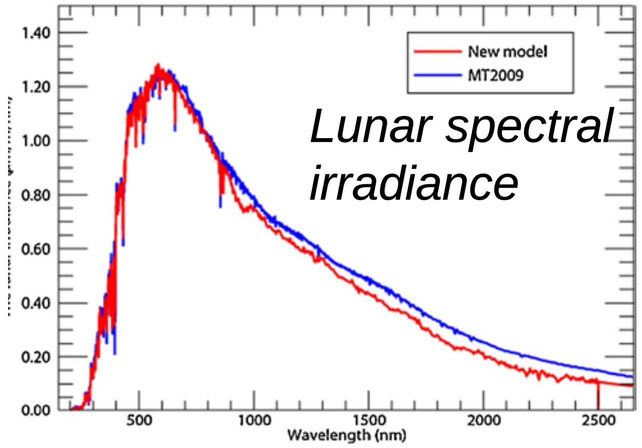
User need: how TRUTHS will benefit climate decision making

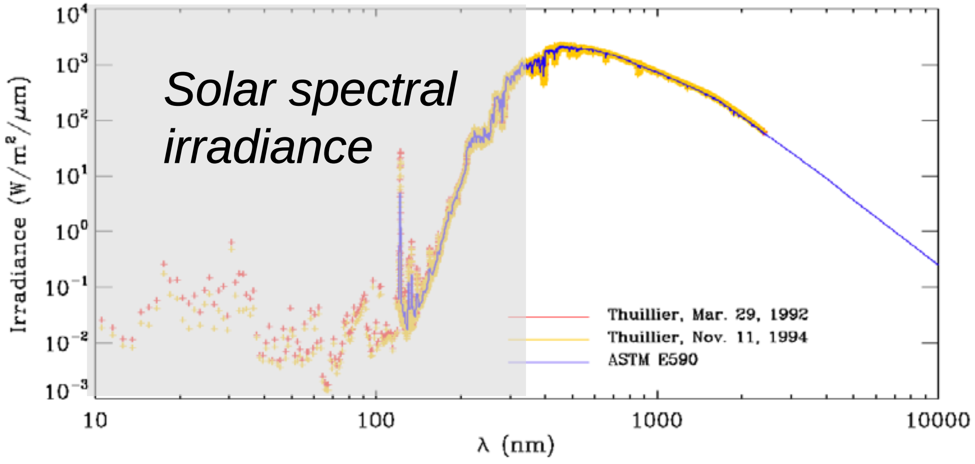


What does TRUTHS measure?

- TRUTHS provides an accurately, continuously calibrated hyperspectral dataset of solar and lunar irradiance and Top of Atmosphere Earth-reflected radiance in the Visible/NIR/SWIR waveband.



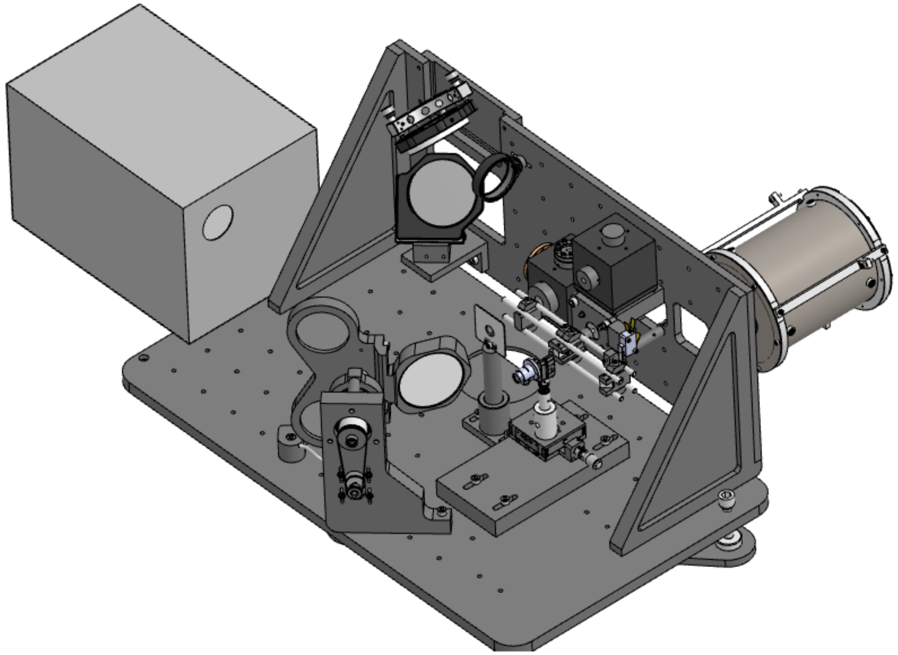




- The design of the TRUTHS payload is driven by the radiometric demands of the climate application whilst the design of the mission orbit allows optimal sampling to quantify the climate and facilitate match-ups with many other sensors for cross-calibration by TRUTHS data.

What makes TRUTHS different to other hyperspectral missions?

- TRUTHS includes an on-board calibration system, that replicates the SI-traceable calibration chain employed in NMIs globally.
  - No reliance on assuming maintenance of pre-flight performance, or modelled degradation.
  - No reliance on a contiguous overlapping mission series.
  - Not limited to Sun diffuser method accuracies (2-5%)
- The differentiator is the continuous (daily) re-calibration maintaining the TRUTHS HIS calibration to SI.
  - That mitigates internal components (diffuser, mirrors etc.) degradation – this is unavoidable.



How TRUTHS on-board Cal System works

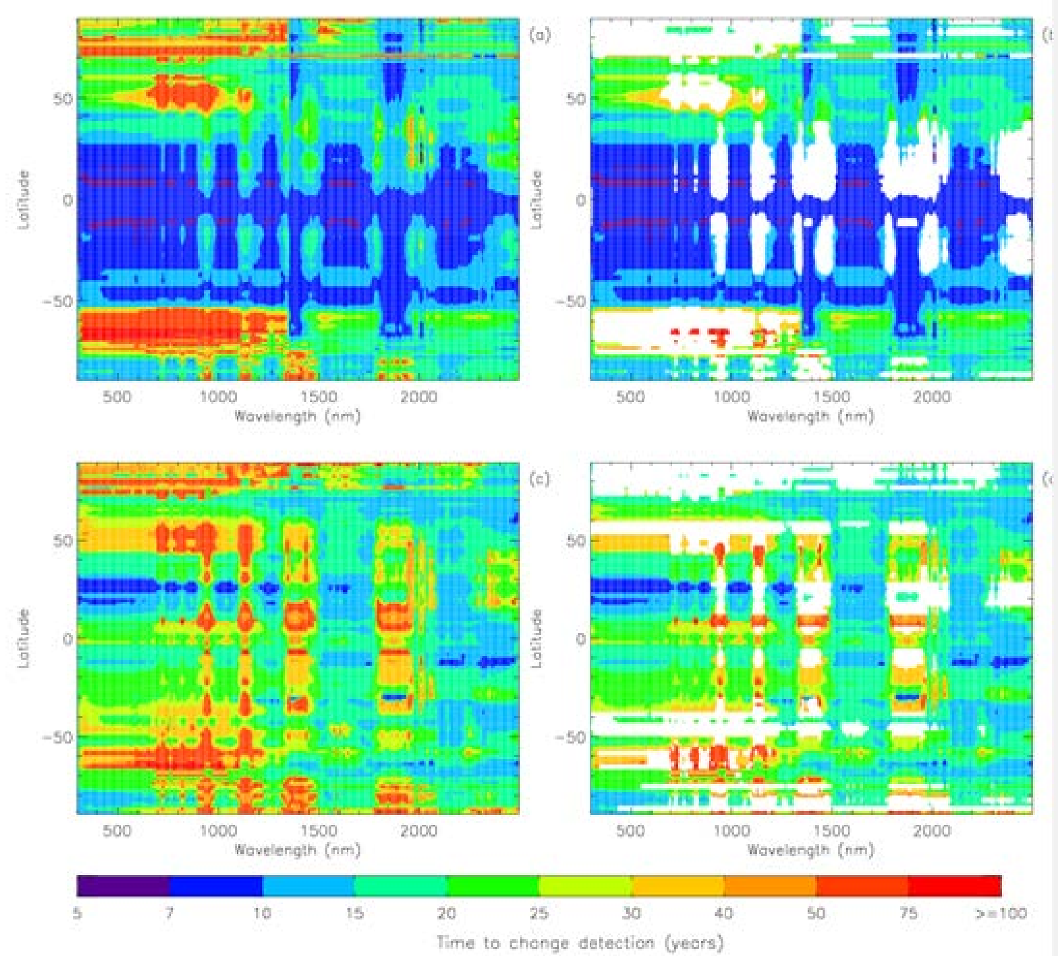
https://www.npl.co.uk/earth-observation/truths

Climate User Requirements

The climate benchmark operational requirements derive from the need to measure:

- Albedo to an accuracy of 0.001 -> 0.3% (k=2) spectral accuracy requirement. (Wielicki 2013)
- Over >96% of the solar spectral extent 320-2450 nm
- Contiguous spectral fingerprinting information -> <=10nm bandwidth (Huang 2010 & Feldman 2015)
- SNR ~300 (higher in the blue for Ocean Colour apps.)
- An orbit that samples the full diurnal cycle.

Level 1 products	Mission Requirement				
	Spectral range (nm)	Bandwidth (nm)	Uncertainty (%) (k=2)	SNR	GIFOV (m)
Earth/lunar spectral radiance	320-2450	8 – 25 nm	0.3	~300 (Vis-NIR) >1000 (blue)	250
Solar Spectral Irradiance	<320 – 2450	1 (<400), 5 (<1000), 10 (<2350)	0.3	300	NA
Total Solar Irradiance	Total	200-30000	<0.02	<500	NA



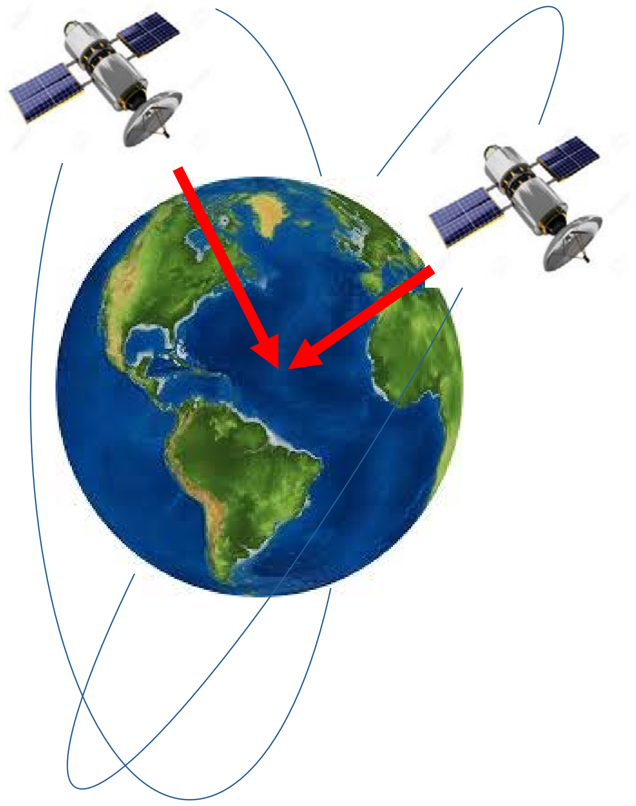
Feldman 2015

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.

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

- 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.
- TRUTHS can back correct the satellites already launched – improving the quality of their data and letting us make the most of our existing investments.



Inter-calibration uncertainty drivers

- 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
- Each inter-comparison component (μ) has a typical magnitude of 0.1% - 0.5% (k=1) compared to the current reference sensor (2%).

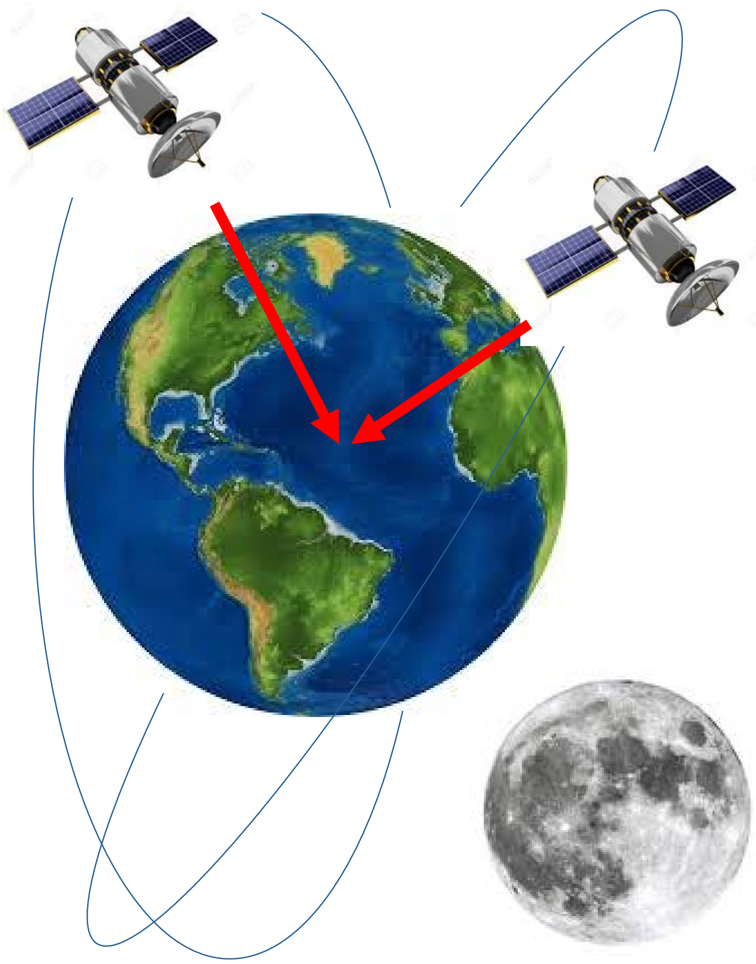
$$\sigma_{inter} \sim \sqrt{\sigma_{ref}^2 + \mu^2} \sim \sqrt{1.0^2 + (5 \times 0.3^2)} = 1.2\%$$

- The reference sensor requirement is of the order of ≤1%.

Inter-calibration user requirements

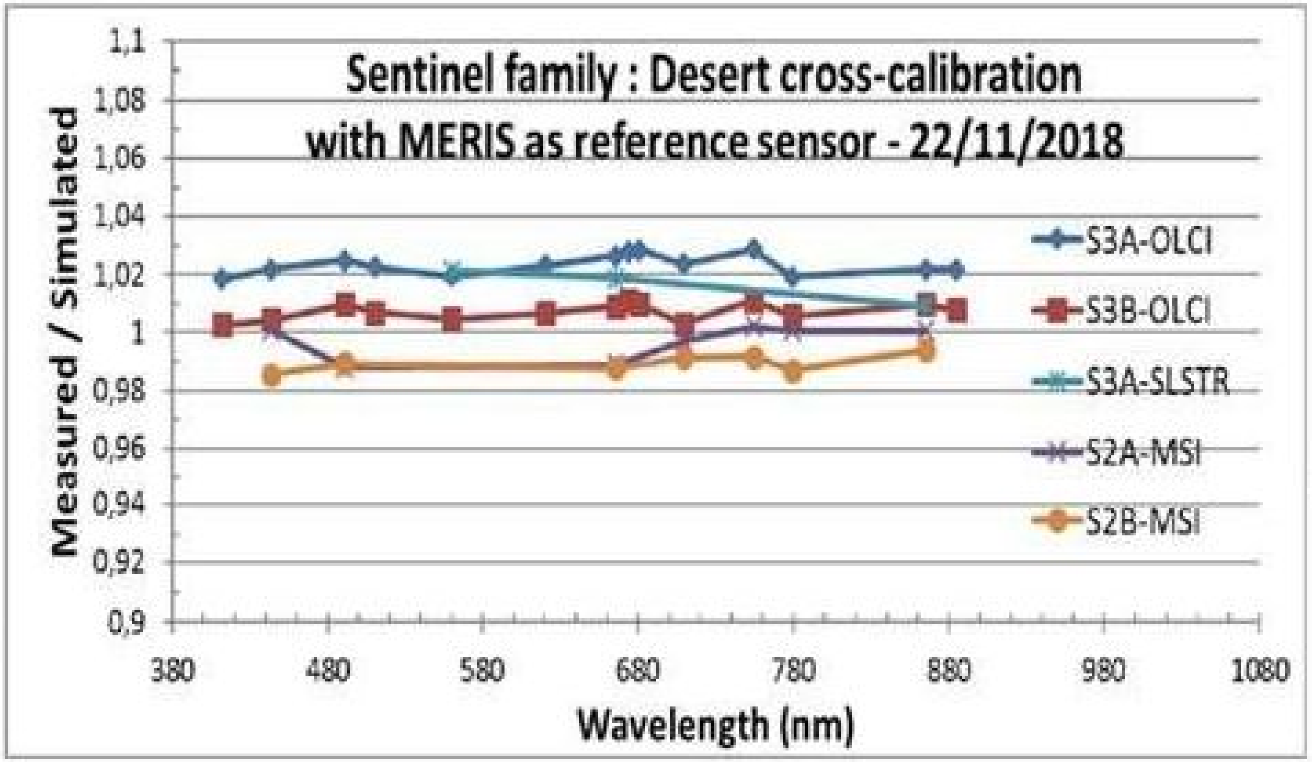
The inter-calibration requirements derive from the need to measure:

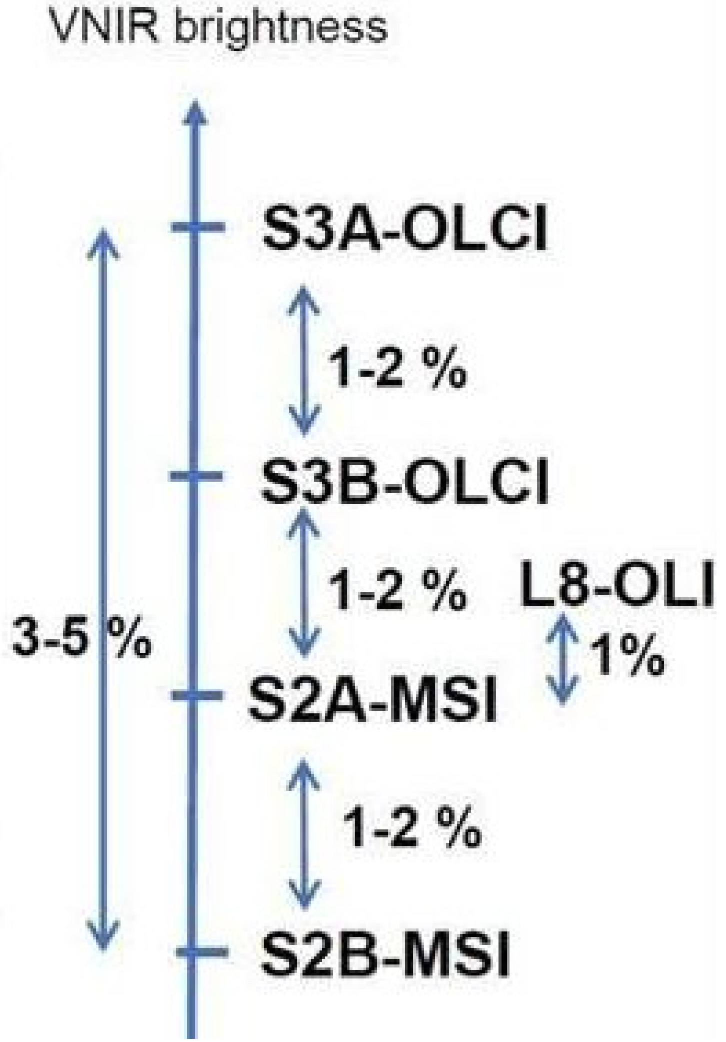
- Spectral rad. accuracy <1% (k=1).
- Over the same spectral extent as the target sensor.
- 5-10nm bandwidth to minimise spectral rep. error.
- SNR ~300 (higher in the blue for Ocean Colour apps.)
- GIFOV to match/exceed target sensor spatial resolution.
- An orbit that maximises match-ups.



Level 1 products	Mission Requirement				
	Spectral range (nm)	Bandwidth (nm)	Uncertainty (%) (k=2)	SNR	GIFOV (m)
Earth/lunar spectral radiance	320-2450	<5 for < 1000 nm <10 for >1000 nm	<1.0	~300 (Vis-NIR) >2000 (blue)	50 250
Solar Spectral Irradiance	NA	NA	NA	NA	NA
Total Solar Irradiance	NA	NA	NA	NA	NA

Cross-calibration user need example





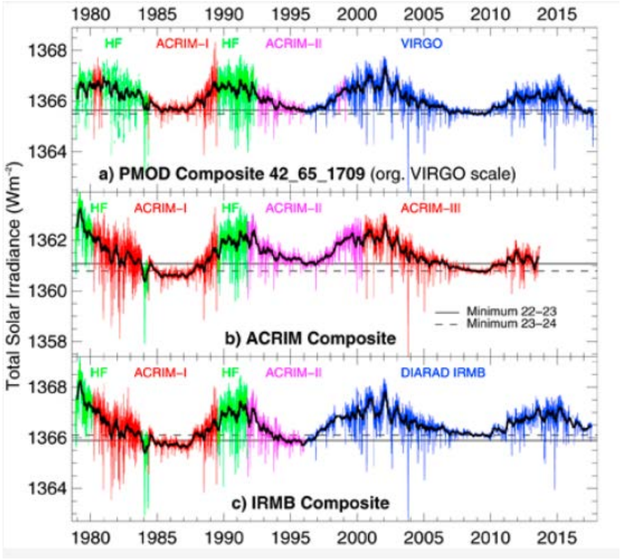
A Meygret (CNES)

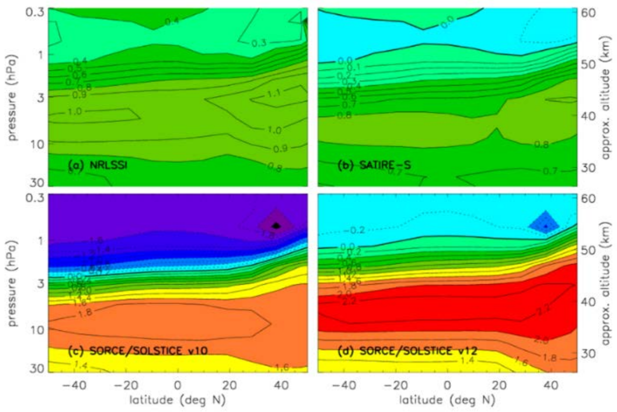
TRUTHS for actionable EO data

- A high accuracy L1 nadir-looking hyperspectral Earth-reflected radiance product will have direct uses:
  - Land surface reflectance products
  - Vegetation products, such as, Photochemical Reflectance Index
  - Address atmospheric correction issues for multiple ECVs
- The L2+ products derived (by third parties) from the direct TRUTHS products or through the improved radiometric calibration of other sensors after inter-calibration include:
  - Improved GHG retrievals [1% rad acc. = 0.1 ppm error]
  - Enhanced information content in Ocean Colour products [0.5% TOA rad. acc. Needed for 5% WLR target.]
  - Fusion data products across Space Agency assets
  - Provide calibration of commercial CubeSat constellations

TRUTHS for Solar Impacts on Earth

- The evidence for solar influence on climate is growing. Over recent cycles the 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.
- To best serve long term records an accuracy of 0.01% (k=1) is needed in TSI.
- Spectrally, the solar output is more variable. With significantly more variation in the near-UV and near-IR that have an impact on stratospheric processes, and the influences of these processes global scale oscillations and surface weather phenomena.
- The user requirement on SSI is derived from the climate objective on albedo known to an accuracy of 0.001. Resulting in a need to measure the SSI to the same accuracy as the Earth-reflected solar radiance.

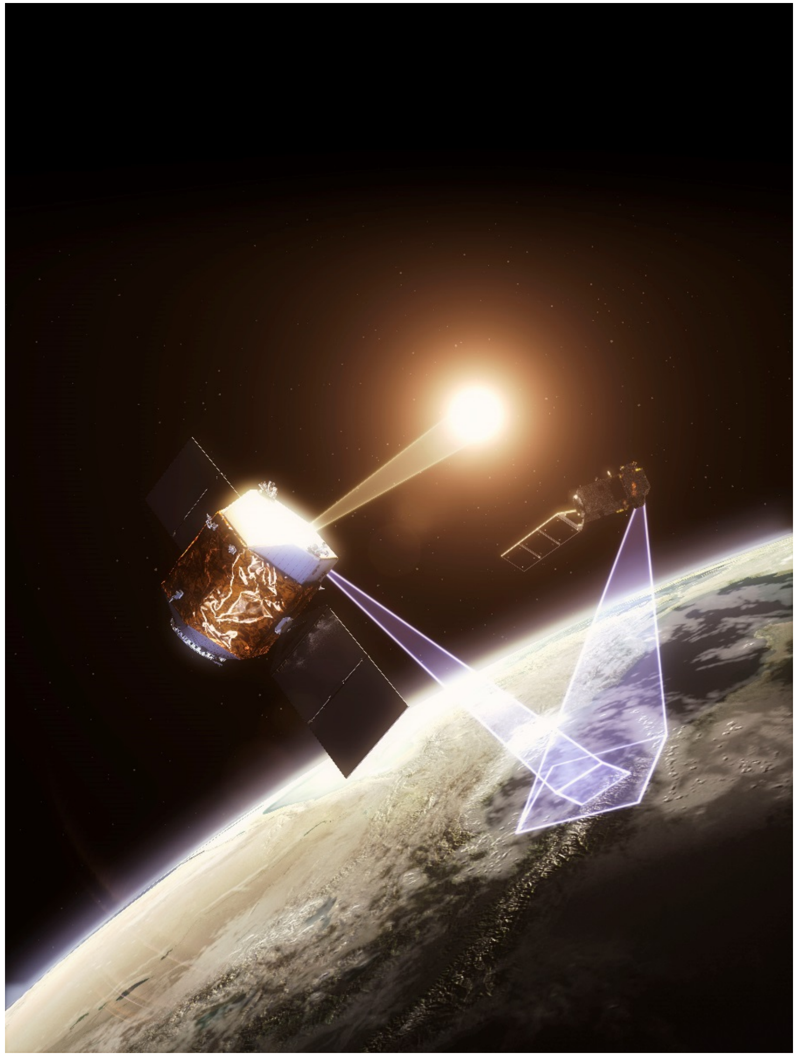




Change in stratospheric ozone between 2003 and 2008 from solar spectral irradiance (SSI) variations

Mission Products

- The operational products from the TRUTHS mission are;
  - L1 Earth-reflected spectral radiance (320nm to 2450nm)
  - Total Solar Irradiance (0.2um to 30um, integrated)
  - L1 Solar spectral irradiance (320nm to 2450nm)
  - L1 Lunar spectral irradiance (320nm to 2450nm)
  - Inter-calibration coefficients & match-up products.
  - L2 spectral surface reflectance (320nm to 2450nm)
- All other L2+ & inter-calibration products are not part of the standard data products produced by the ground segment.
- The breadth of possible L2+ products is too extensive to be the responsibility of the mission.
- Example L2 requirements
  - OCO – 1% abs. rad. cal. in O2 A-band is 0.1 ppm error in XCO2, for low AOD & surface albedo values. Reduces spatially-dependant biases & random errors.
  - Ocean colour, to meet GCOS specified ECV uncertainty, need 0.5% abs. rad. Cal at ToA – currently rely on indirect methods via system vicarious calibration using ocean Buoys.



Uncertainty budget propagation

CSAR (On-board SI Traceability primary standard) → HIS (On board calibration system) → SNO inter-calibration between 2 satellites → L2+ application product

Element	Uc (%)
Measurement of electrical power	0.010
Cavity absorptance	0.010
Scattered light	0.004
Random noise	0.06
TOTAL	**0.02-0.07**

Element	Uc (%)
CSAR	<0.06
Prism arm	< 0.01
Transfer radiometer	0.03
External aperture	0.02
Traceability	0.08
HIS thermal control (1K)	0.01-0.20
HIS SNR	0.03
TOTAL	**0.16-0.26**

Element	Uc (%)
TRUTHS HIS	0.16-0.26
Spectral mismatch	0.1-0.2
Spatial mismatch	0.1
View Angle	0.1-0.2
Atmos. corr.	0.1-0.3
BRDF	0.1
TOTAL	**0.4-0.7**

Element	Uc (%)
GHG retrievals	1% = 0.1ppm
Ocean Colour	0.5% = 5% WLR
Cloud Radiative Forcing	0.3%

TRUTHS helps us get data from satellites when we need it and where we need it

“Analysis Ready Data” and Environmental Information Services are being built to give everyone access to easy-to-use satellite data.

The public and private sectors are beginning to use this information for everything from farming to disaster monitoring, from fishing to flood predictions.

These services rely on data from lots of different satellites: government and commercial from around the world.

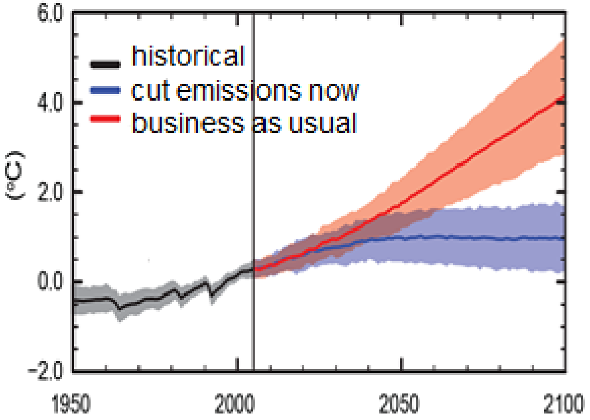
TRUTHS will help us see and correct for differences between those satellites – giving a seamless service to users.

TRUTHS helps us understand the climate

Climate models predict future warming, and make better predictions when based on accurate observations

This helps politicians and businesses plan better for the future with increased confidence. They will be able to invest in the things we need at the right time because they’ll get trustable information more quickly.

TRUTHS halves the time (from more than 30 years to ~15 years) needed to see climate trends in the observation data.



We’ve invested in the satellites that are up there and they are giving us useful information

TRUTHS back corrects the satellites we’ve already launched – improving the quality of their data and letting us make the most of our existing investments

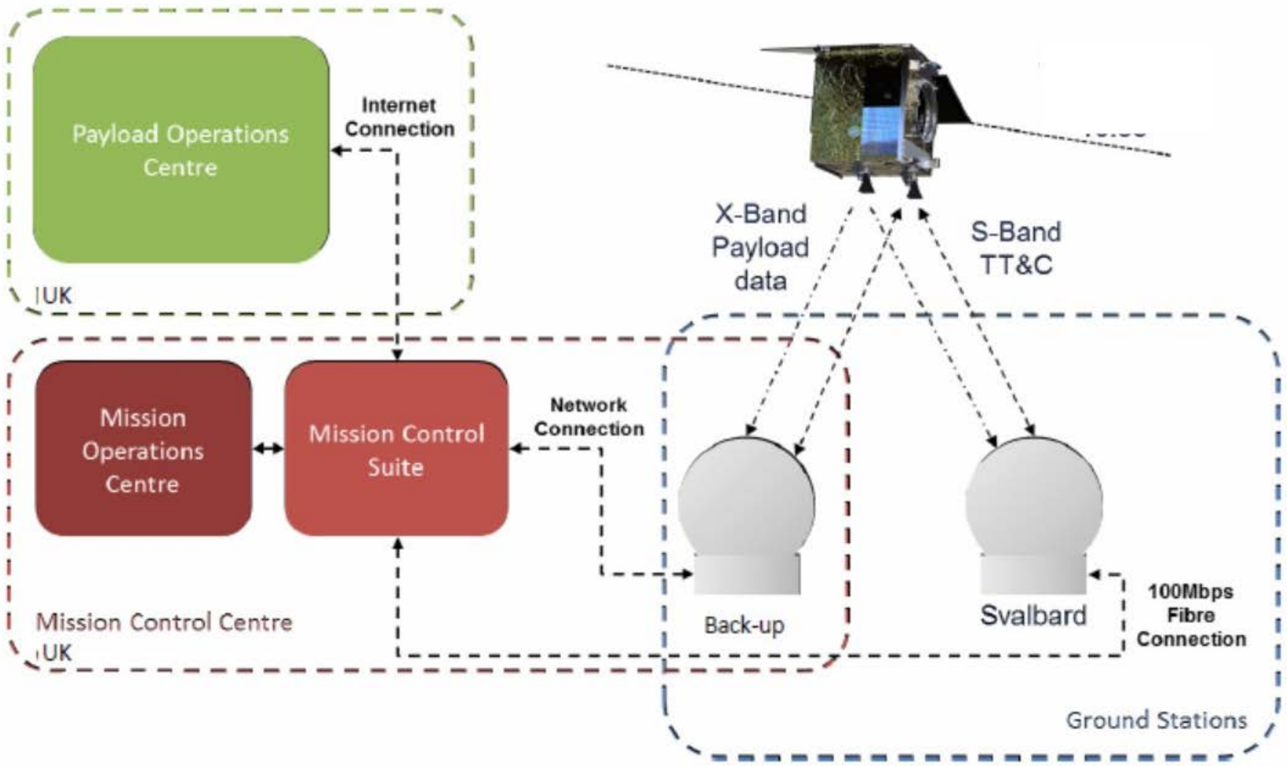
TRUTHS increases confidence and Trust in satellite data

TRUTHS makes the most of our investments in satellites

Mission Management and Flight Operations

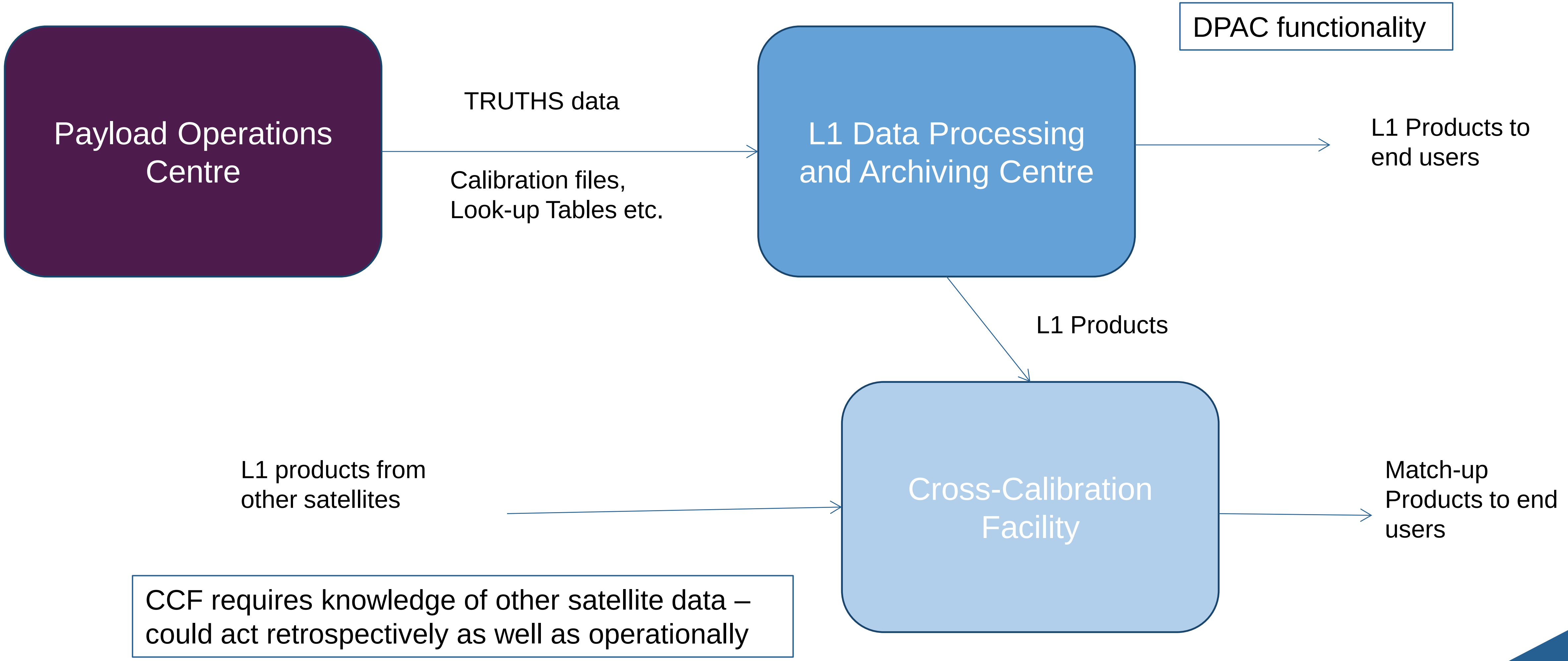
POC monitors instrument health and plans payload operations.

MOC monitors satellite health and executes platform and payload operations.



TTC ground station at high latitude provides contact with the spacecraft.

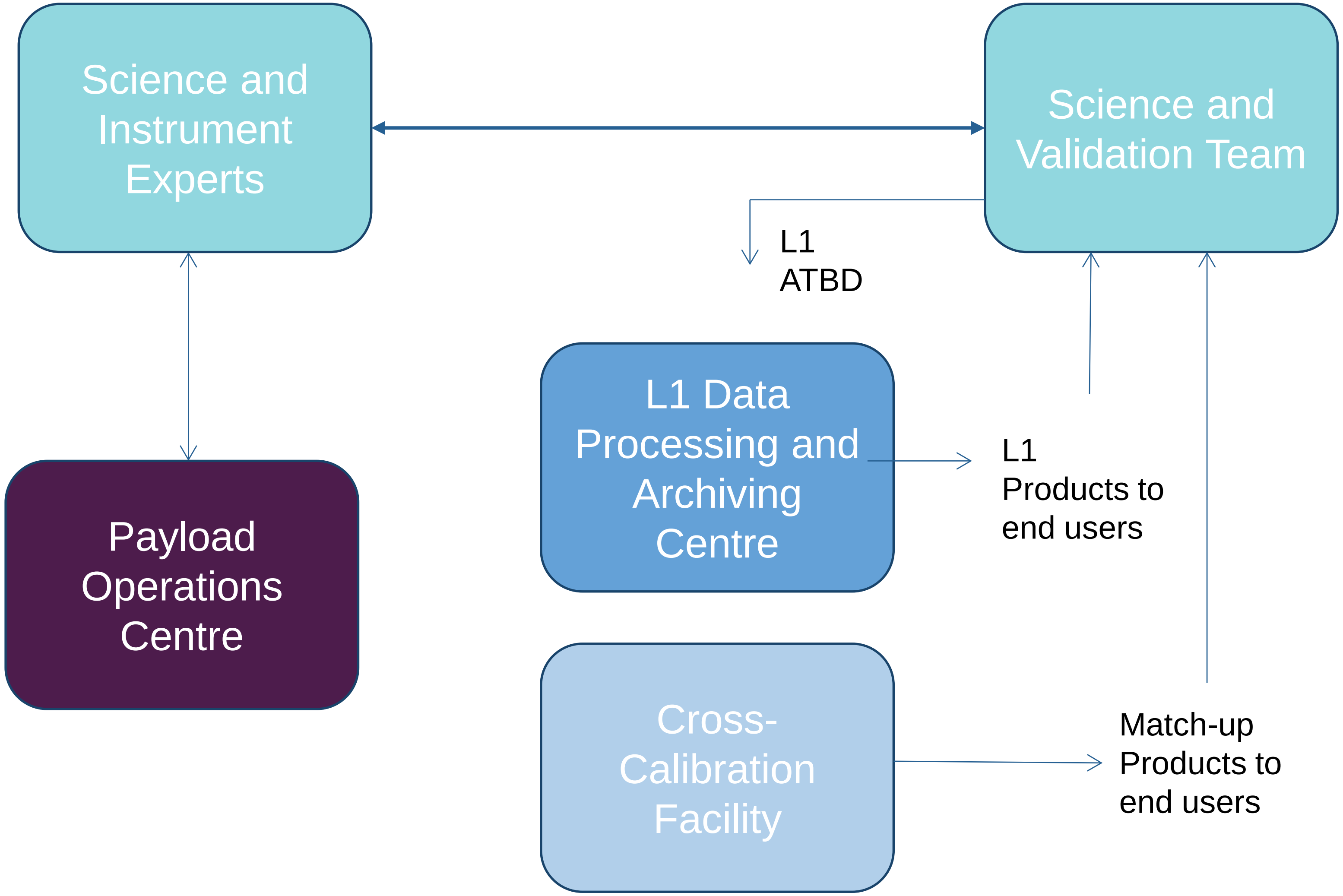
Payload Data Processing and Archiving



Science and Validation

Science and Validation experts would be drawn from the global science community.

Science and instrument experts would support the POC to assure the quality of the TRUTHS data and instrument health.



Validation experts would analyse the TRUTHS L1 product and Cross-Calibration files to confirm the performance of TRUTHS as a reference instrument..

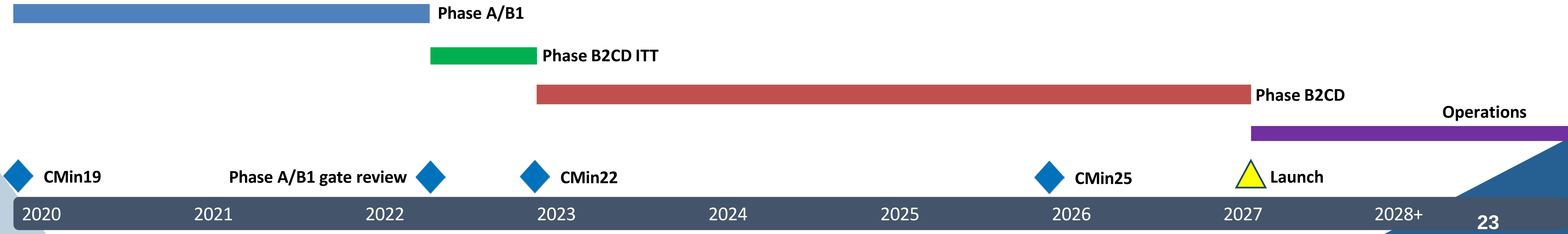
Mission programmatic

Overview

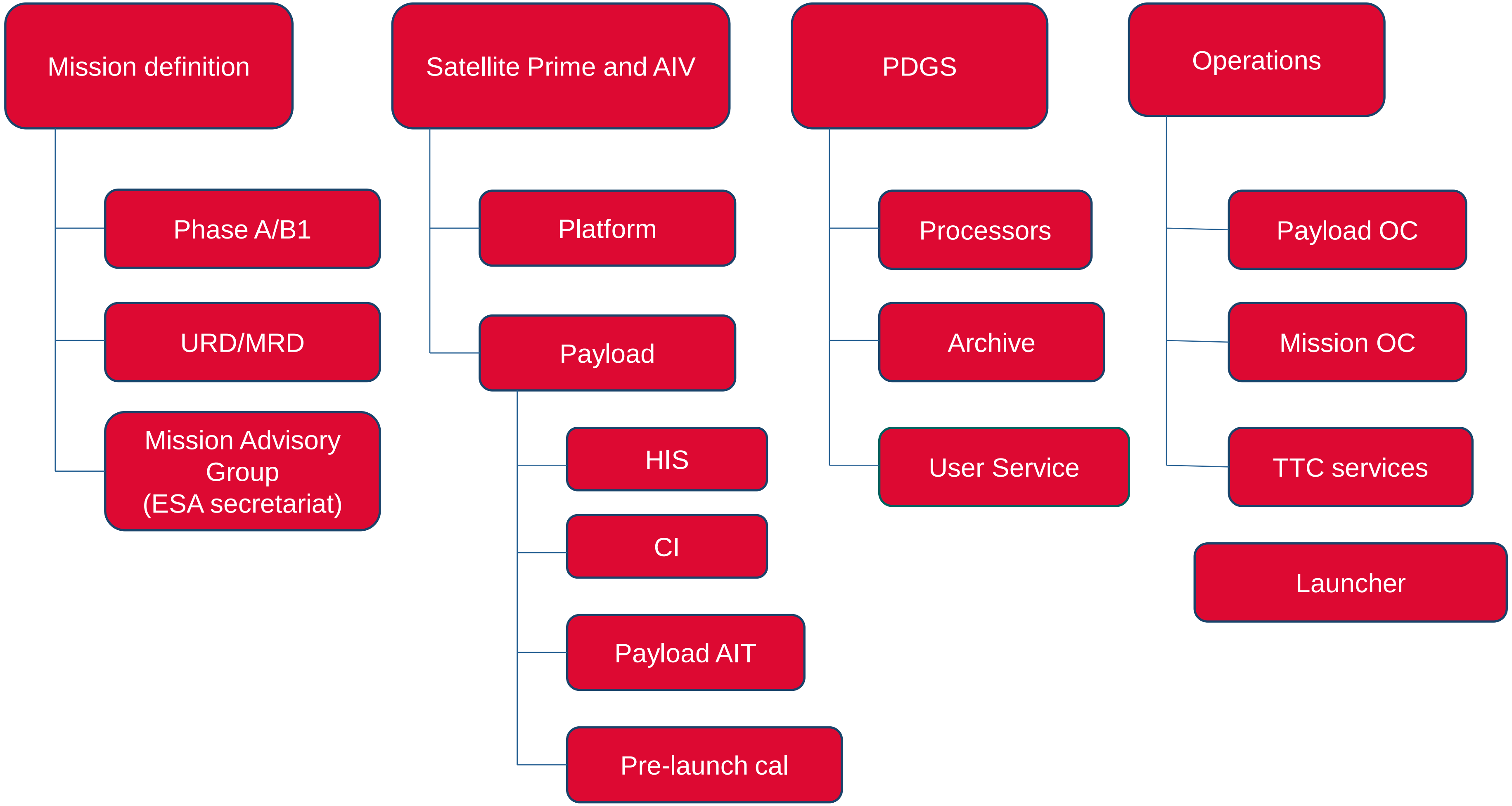
- **Total mission costs are estimated at between €230m and €360M**. This will include development, launch and operations.
- TRUTHS is expected to be flight ready between 2026 and 2028.

Phasing

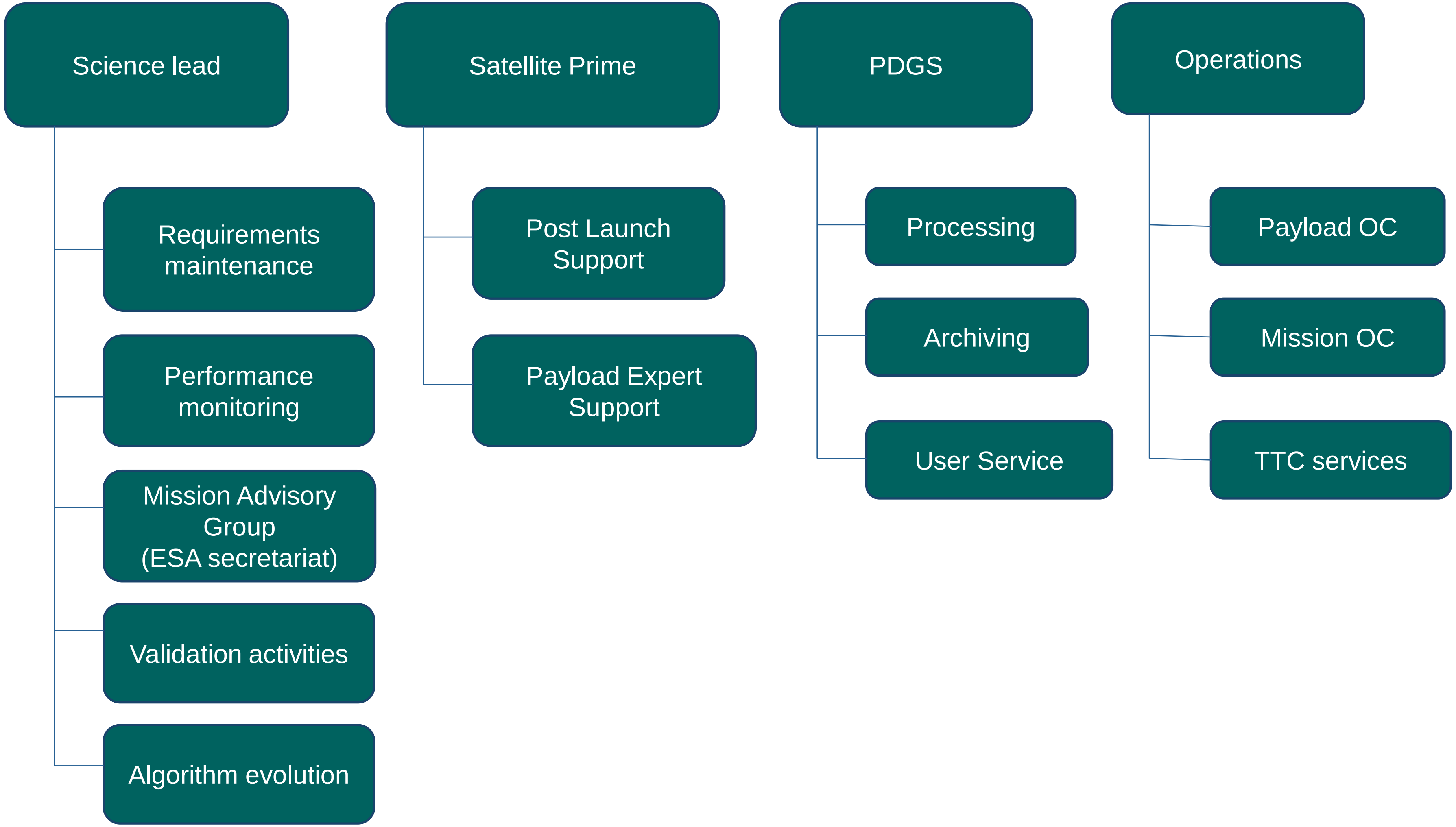
- **CMin19 will seek a financial envelope of €32m to fund phase A/B1**, which will confirm the total mission costs.
- Phase A/B1 will take 21 months, and will be followed by a decision point in early 2022 on whether to proceed.
- Following a positive decision, further funds will then be sought at CMin22 to cover Phase B2CD, with Launch Services and Phase E1and E2 available for subscription at CM25.
- Following a positive decision, the tendering process for Phase B2/C/D will be started in early 2022, leading to the start of activities after CM22 once funding is secured.



TRUTHS Development (Phases B2/C/D/E1)



TRUTHS Operations (Phase E2)



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