TRUTHS

esa

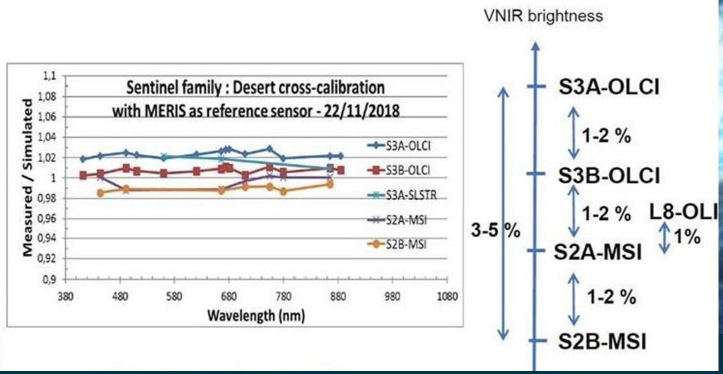
'Traceable Radiometry Underpinning Terrestrial- and Helio-Studies'

- Optical mission for measuring incoming solar and outgoing reflected radiation
- A Metrology lab in orbit: flying a primary calibration standard enabling traceable to SI Units a 'SITSat'

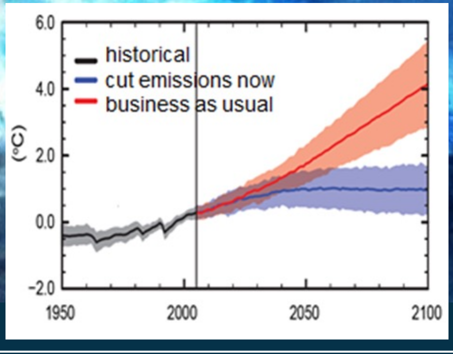
provide **SI-traceable measurements of the solar spectrum** to address direct science questions.

Satellites cross-calibration: Establish a 'metrology laboratory in space' to create a fiducial reference data set to cross-calibrate other sensors and improve the quality of their data

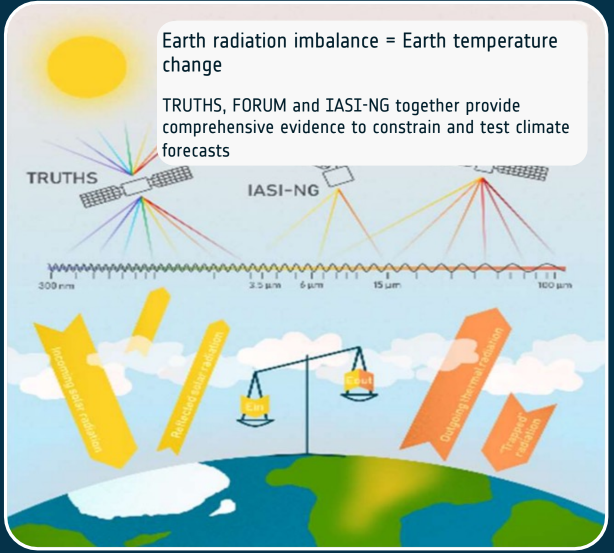
TRUTHS cross-calibration: bias removal, improving accuracy of other sensors, Datasets re-calibration



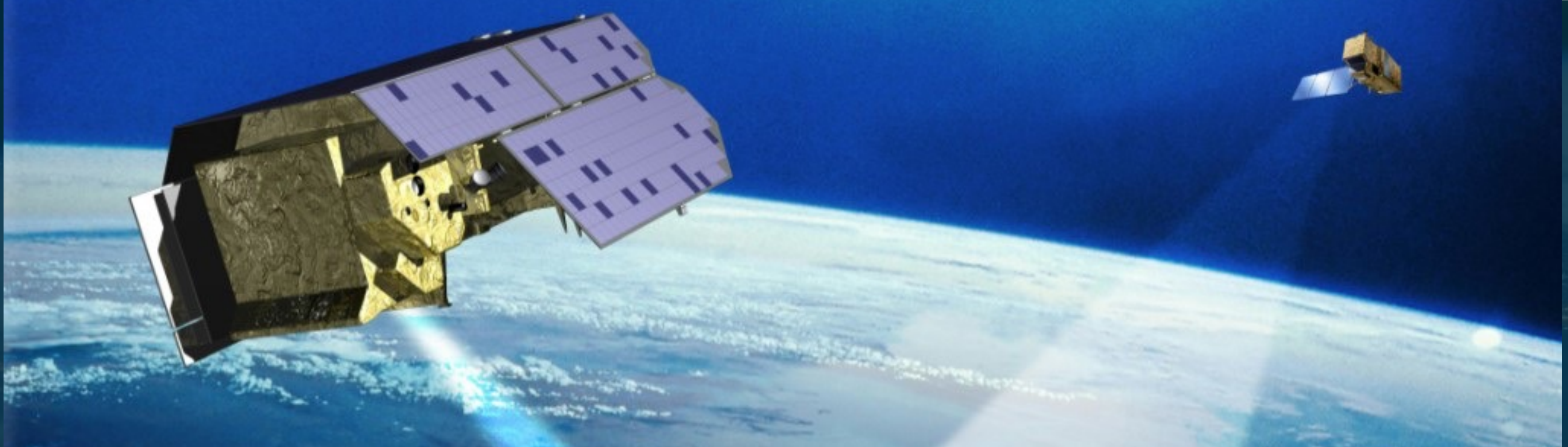
TRUTHS climate Benchmarking: more precise predictions



Climate benchmarking: enhance by up to an order-of-magnitude our ability to estimate the **Earth Radiation Budget** through direct measurements of incoming & outgoing energy



TRUTHS mission in a nutshell



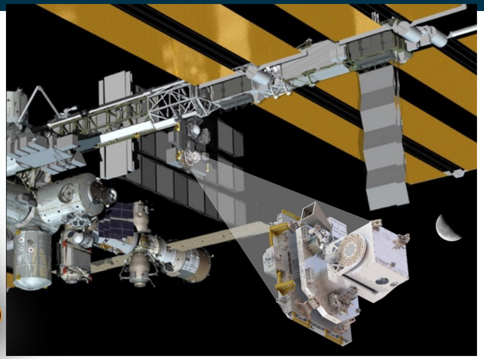
- Target launch Q1/2030; 5 yrs lifetime (+3 yrsext)
- Satellite flying at 611 km in polar non-sunsynchronous orbit, 61 days repeat cycle
- Payload composed of three elements:
  - HIS (Hyperspectral Imaging Spectrometer) – **UV to SWIR**, single detector, 50 m resolution, 100 km swath
  - CSAR (Cryogenic Solar Absolute Radiometer) – operated at 60 K ,the “absolute radiometric reference”
  - OBCS (On-Board Calibration System) –) transferring the CSAR solar absolute measurement to the HIS
- Absolute radiometric accuracy < 1% (Threshold), <0.3% (goal)
- Sampling 300/100 m SSD (land-ocean – 50 m S2SC

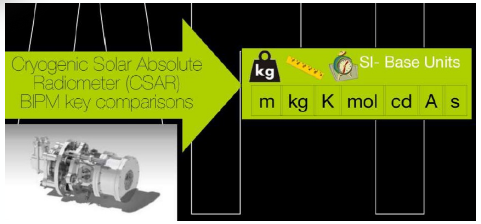
Ground Segment and operations

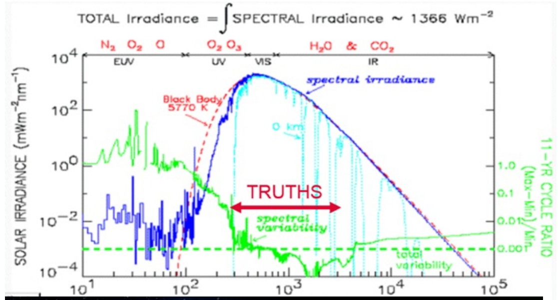
- Data downlink at 822 Mbps X-band VCM; lossless compression baselined
- 1 polar Ground Station baselined and 1 high-latitude TT&C G/S; mid-lat (UK) additional G/S TBC
- LEOP/early commissioning @ ESOC
- Routine FOS in UK (Flight control centre hand-over before IOCR)
- PDGS in UK, data access supervised by ESA
- (ESA open data access policy)
- Priority to science and institutional users

TRUTHS mission assets and perspectives

- **World-class observations for climate science**
  - International committees (CEOS) expressed the need for trustworthy observation from Space based on metrological rigor and traceability to SI units: **SITSats** (SI Traceable Satellites able to retrieve of climate variables with a set of trustable harmonized time series. TRUTHS to become a 'Gold Standard Reference' with free and open 'analysis ready' data, for climate modelling international communities (ECMWF, Eumetsat, C3S)
- **An international climate Observatory**
  - The need to cover long time series and many solar cycles calls for long-term operation. Once TRUTHS will be operational it is expected that NASA CLARREO program will be initiated and that international cooperation and data interoperability among different missions worldwide (Australia, China) will be implemented.
- **An operational service for institutional and commercial satellites**
  - The capability to cross-calibrate other satellites opens up to an operational service for improving the quality of other optical satellites, either institutional (e.g. Copernicus and Eumetsat satellites) and commercial (new space). The traceability to SI units and rigorous uncertainty tracing makes the measurements unambiguous and trustworthy
- **A new concept for next generation optical missions**
  - Once proven, TRUTHS unique calibration system might be optimized / miniaturized and become a novel package for optical instruments calibration. In alternative, smaller satellites might opt to fully rely on calibration from TRUTHS data service and optical payload can be conceived lighter and simpler,
- **A step towards a System of Systems**
  - TRUTHS opens up to an efficient use of space and data assets: one satellite improves the performance of many others and the TRUTHS data on calibration sites permit to improve new and existing datasets, even taken in the past. TRUTHS concepts fits in the strategic view of making space assets interconnected and result of a distributed effort







Mission Products

L1: Earth-reflected Spectral Radiance (ToA), Solar Spectral Irradiance, Lunar Spectral Irradiance – all in the range <320nm to ~2400nm; across Earth diurnal and lunar cycles

L1: Total Solar Irradiance integrated in the range 200nm to 30000nm;

→ **Climate benchmark, solar measurement, lunar calibration**

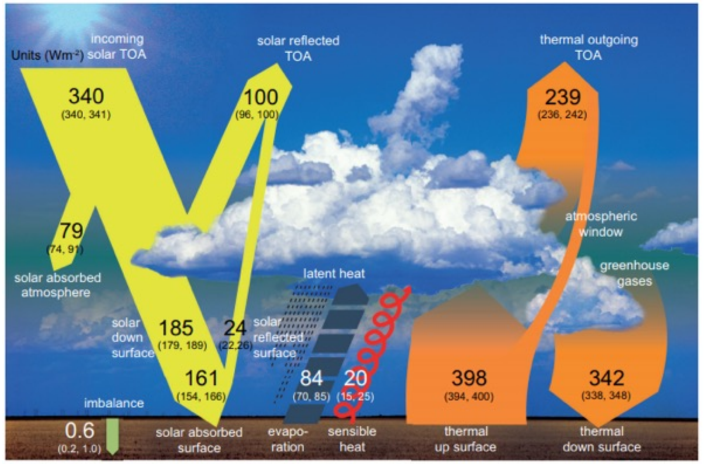
L2: Spectral Surface Reflectance, at ground level (~400nm to ~2400nm); primarily as reference

→ **Earth science**

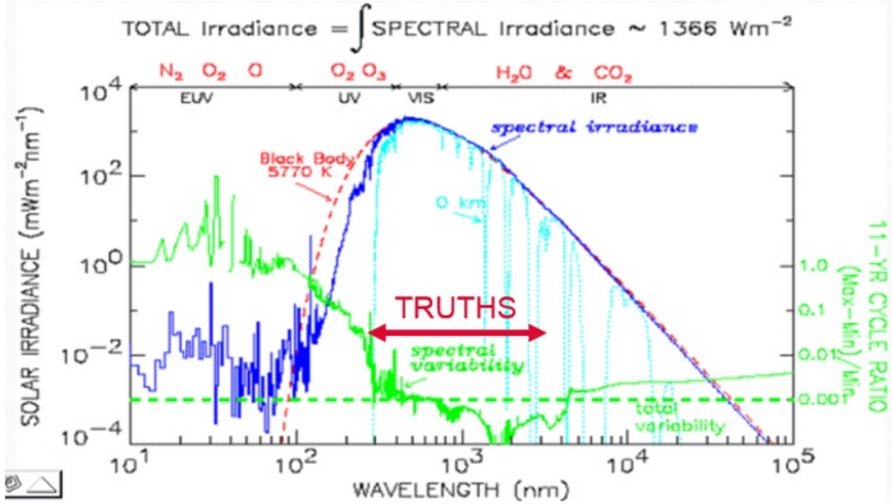
Calibration coefficients & match-up products to determine biases for other sensors over Multi-scene types and view angles (climate sensors & geo-spatial).

→ **Cross-calibration**

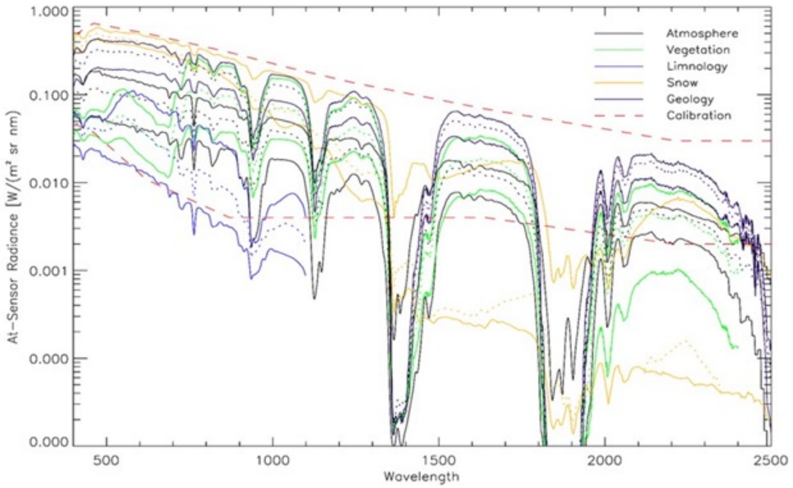
- **Algorithm maturity**: prototyping in OPSI/E2E simulator in A/B1 –TMAC support on L2 – continuation in B1 extension, focus also in early B2 (calibration algorithms, S2SC, Metrology simulator (FIDUCEO methodology)



Radiation balance



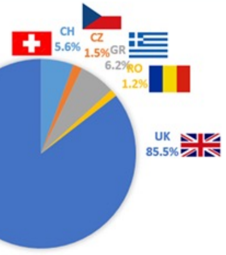
Solar spectral irradiance



Surface reflectance

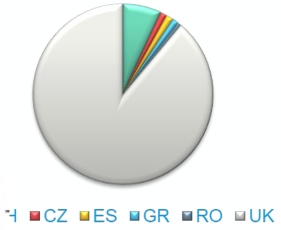
TRUTHS Program context and current status

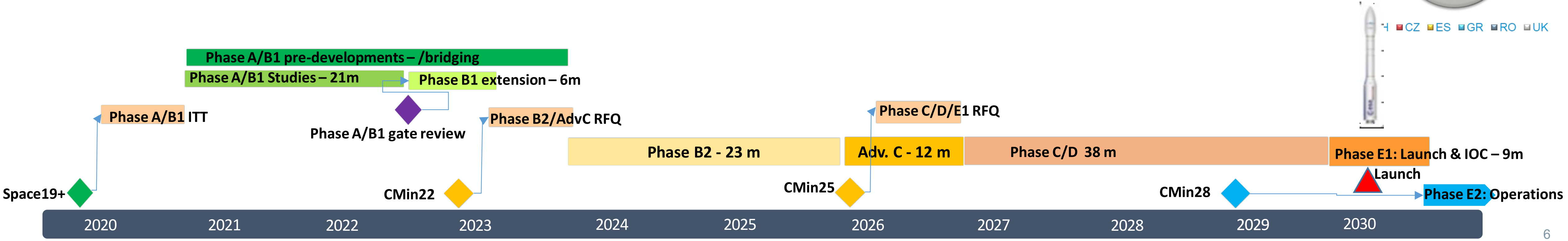
- TRUTHS was proposed by UKSA in May 2019 as a new **Earth Watch (EW) Element**.
- TRUTHS Phase A/B1 has been fully subscribed at CM-19 by 5 Participating Countries: **UK, GR , CH, CZ and RO**
  - Steering Board established to inform delegations of the Participating States.19 meetings held to Oct-23
- Industrial Phase A/B1 system studies and technology predevelopments completed with successful ISRR.
- Science study (TMAC) held in parallel to support mission consolidation; **Bridging study and Ph.B2 continuation**
- Mission Advisory Group (MAG) 12 scientists + obs. Eumetsat, NASA, C3S; 13 meetings held
- Independent Science review held in Jun-22- successful, SRL-5 achieved
- Programmatic **"Gate Review":** go/no-go decision, passed in July-22, to submit program to CM-22
- Phase B2/C/D/E1 to be funded at CM-22/-25. CM-22 UK+ CH, CZ,ES, GR, RO **subscribed TRUTHS Implementation Phase 1 (B2/Adv.C)**
  - **Kick-off of Phase B2 held on 2-3 November**
  - **Consolidation studies for GS on-going till end 2023**
  - **Science studies for Phase B2/Advance C to be initated in early 2024**



TRUTHS A/B1 SUBSCRIPTION - @SPACE19+

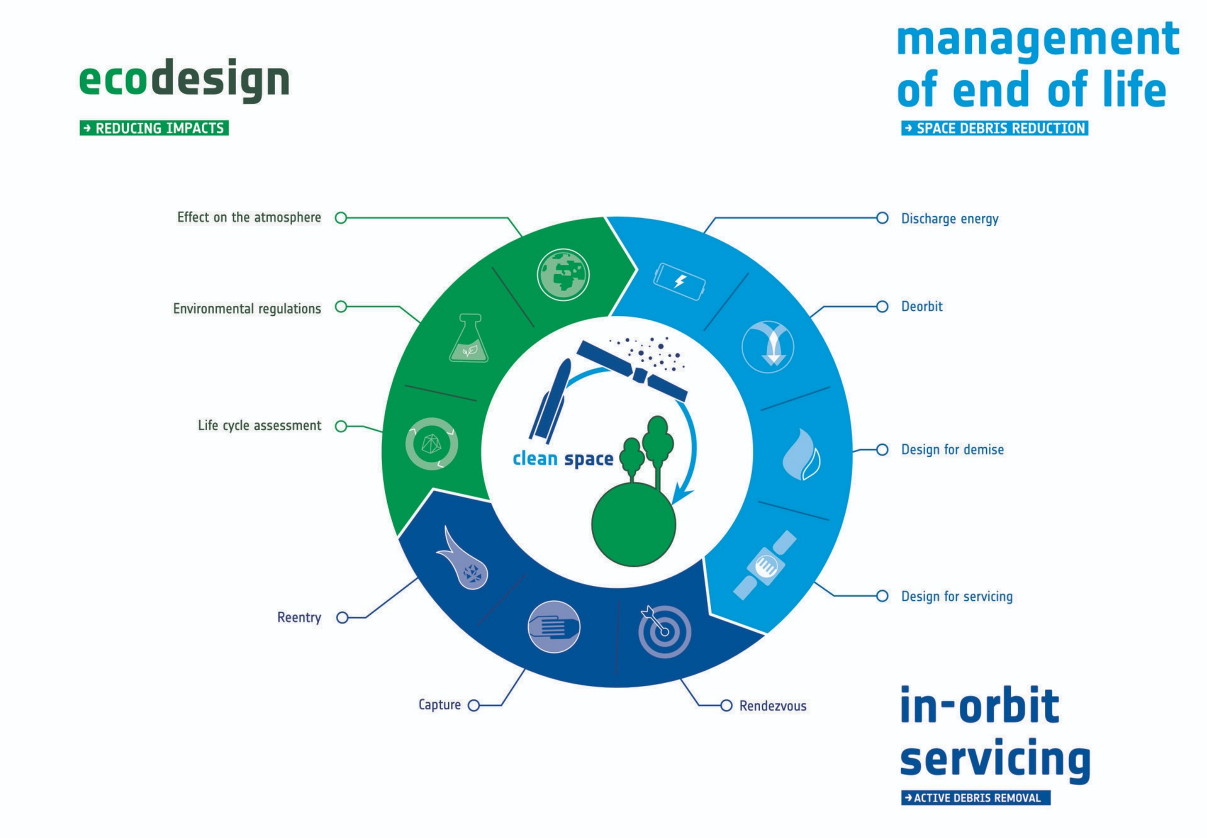
Geo-return TRUTHS B2/Adv.C

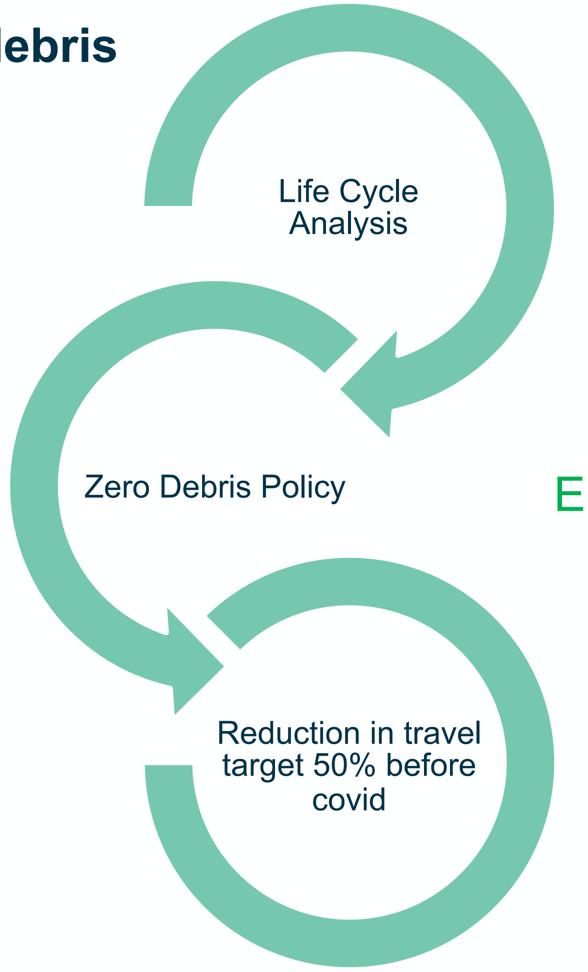




TRUTHS GOES GREEN

- TRUTHS shall contribute to the **CLIMATE** benchmarking
- Several initiatives to **reduce carbon footprint** and minimize **debris**





ESSB-HB-U-005

ESSB-HB-U-002

SITSats and TRUTHS Mission Objectives

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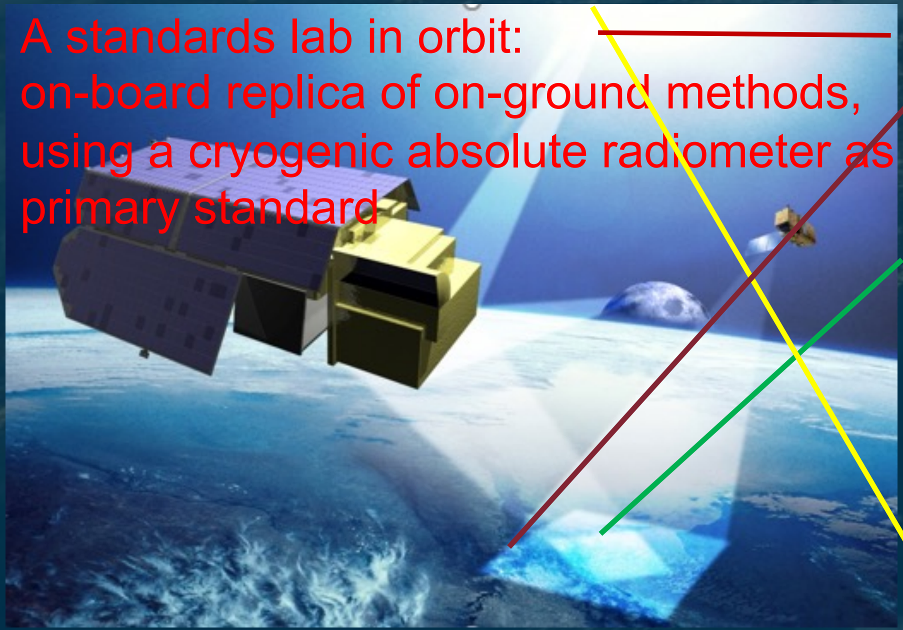
*What is a SITSat?: ‘Space borne missions specifically designed, characterised and documented to provide **high accuracy SI-Traceable** ‘Fiducial reference’ measurements (FRM).’ (Evidencing comprehensive uncertainty to SI, at time and location of measurement i.e. ‘in-space’, of all contributors to observations made from the satellite)*

TRUTHS is an **operational climate mission**, aiming to provide and support:`



1. **Climate benchmarking:** enhance our ability to estimate the **Earth Radiation Budget** (and attributions) through direct measurements of incoming & outgoing energy and reference calibration of other ERB & similar missions. Creating a comprehensive FDR for many applications.
2. **Satellite cross-calibration:** establish a ‘standards laboratory in space’
   1. to create a ‘**gold standard’** reference data set to cross-calibrate other sensors and improve the quality and interoperability of their data through simultaneous observations, surface reference sites & the moon. Upgrading historical data, facilitating harmonization of (F)CDR & mitigagtion of data gaps.
3. SI-traceable measurements of the **solar spectrum (incoming & reflected)** to address its impact on climate and interactions with the atmosphere and surface including Earth system cycles.

*A **benchmark measurement** is one with characteristics (documentation, SI-Traceable uncertainty, representative sampling) that allows it to be unequivocally considered a ‘reference’ of the specified measurand against which future measurements of the same measurand, can be compared. Can be from a single instrument or derived from a synergistic combination of others.*

What does TRUTHS do?

Measures incoming & Earth/Moon reflected radiation from the Sun

- 320 to 2400 nm @ ~4-6 nm BW (1 nm for solar UV)
- Global nadir @ 50 m ground resolution (capability) with 100 km swath
- Target uncertainty of 0.3% (k=2) (spectral radiance/irradiance)
  0.02% (k=2) (Total Solar Irradiance)

Establishing a benchmark of the radiation state of the planet at ToA (radiance/reflectance) & BoA surf reflectance to help enable:

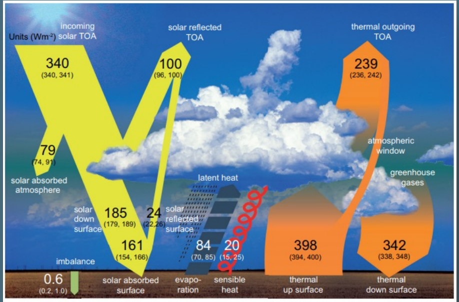
Observations

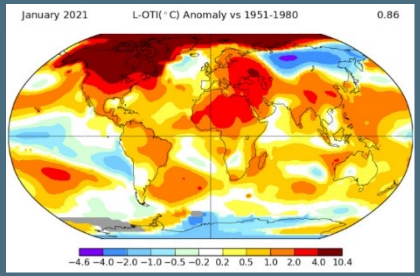
- Benchmark
- monitoring
- Litigation
- algorithm improvement

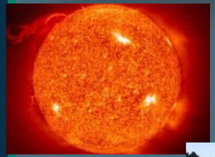
Calibration

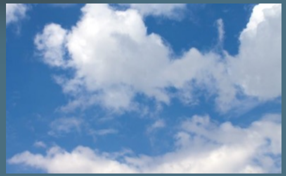
- Interoperability
- data-gaps
- performance
- Utility

Climate sensitivity/response

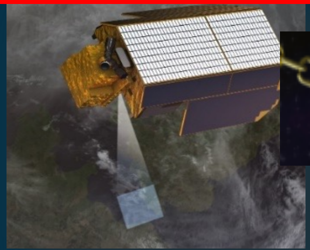
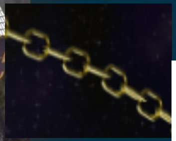








Climate action: Supporting 'Net Zero'

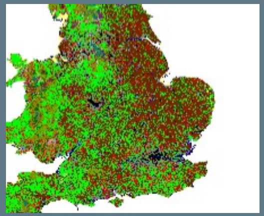
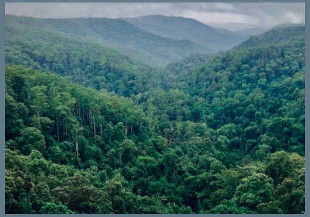




Adaptation/sustainability



Climate action/mitigation



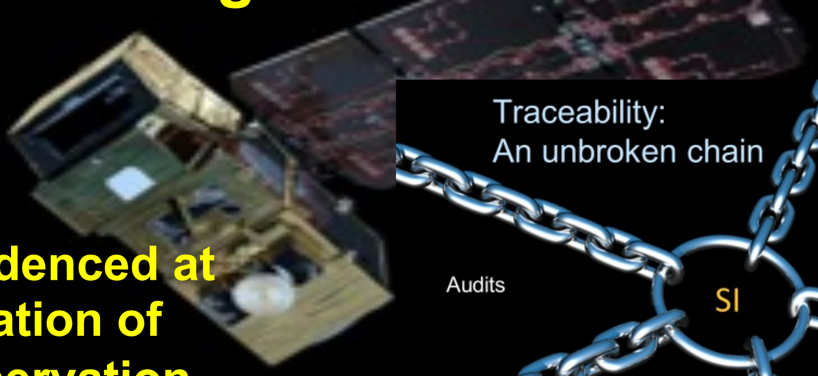




Long-time-base & societal/economic critical applications like Climate require robust 'trustworthy' data:

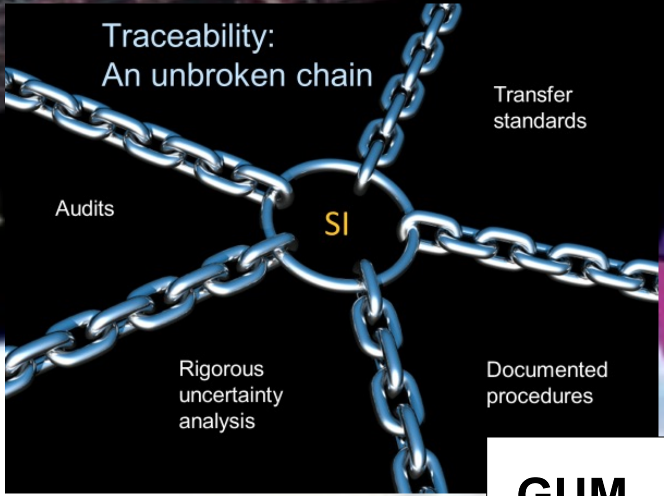
e.g detection of small signals of change out of a noisy background of nat variability

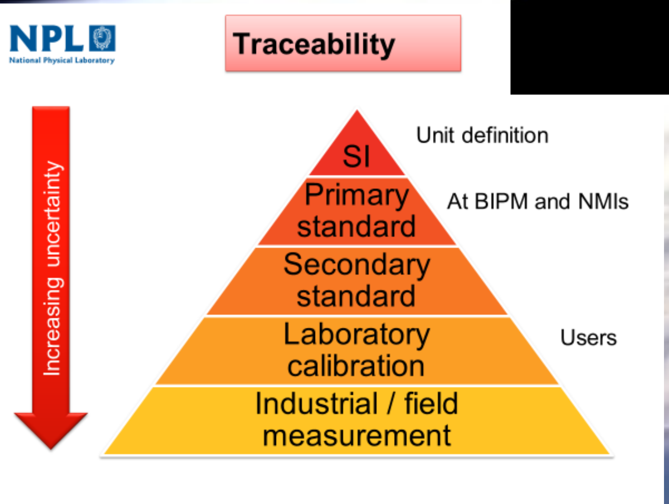
- Small 'trends' generally need decades of observation 'stability' to be large enough to detect – How to trust stability?

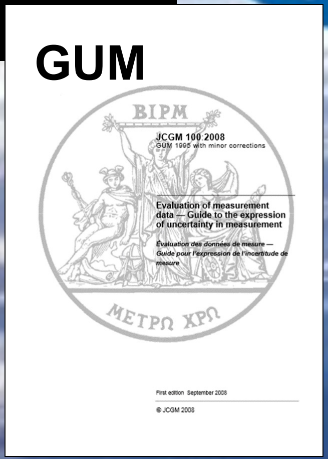
- Interoperable
- Century-long stability
- Coherence
- Absolute accuracy



Evidenced at location of observation

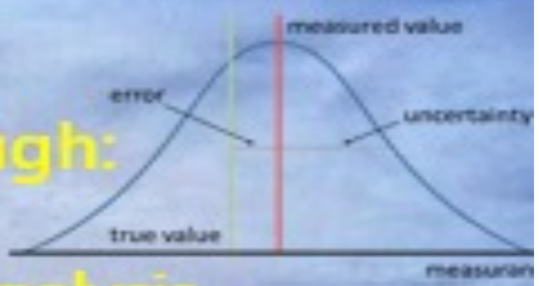






Achieved through:
- Traceability
- Uncertainty Analysis
- Comparison

All documented and accessible



CEOS QA4EO A QUALITY ASSURANCE FRAMEWORK FOR EARTH OBSERVATION

A 'metrology lab in space' - Open access data with full transparency of uncertainties and traceability

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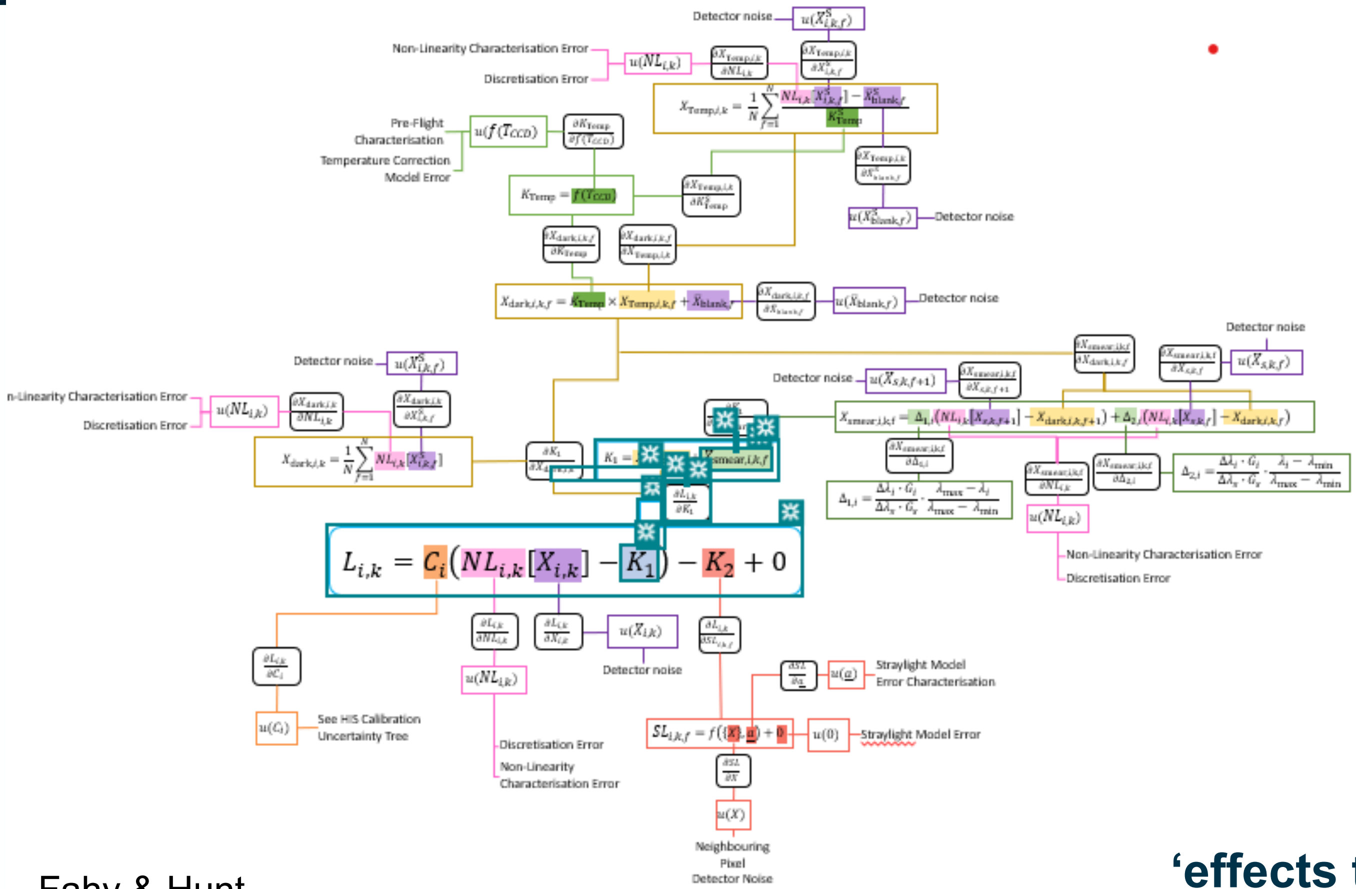


Fahy & Hunt

TRUTHS Earth Radiance Uc tree

CSAR power correction						
Name of effect		Cavity temperature characterisation error (Shuttered)	Cavity temperature characterisation error (open)	Sensor reference resistor voltage fluctuation error	Reference resistor characterisation error	Cavity sensitivity characterisation error
Affected term in measurement function		$T_{cav,\,c}$	$T_{cav,\,i}$	$V_{r\_cav,i}$	$R_{r\_h\_cav}$	S_{cav}
Image error-correlation type, form and scale	Across track (k)	Systematic	Systematic	Random	Systematic	Systematic
	Along track (f)	Systematic	Systematic	Systematic	Systematic	Systematic
	Between spectral pixels (i)	Systematic	Systematic	Systematic	Systematic	Systematic
Uncertainty	PDF shape	Rectangular	Rectangular	Gaussian	Rectangular	Rectangular
	units	K	K	V	Ω	KV^{-1}
	magnitude	TBD	TBD	TBD	TBD	TBD
Source						
Sensitivity coefficient		$\frac{\partial L_{i,k}}{\partial T_{cav,\,c}}$	$\frac{\partial L_{i,k}}{\partial T_{cav,\,i}}$	$\frac{\partial L_{i,k}}{\partial V_{r\_cav,i}}$	$\frac{\partial L_{i,k}}{\partial R_{r\_h\_cav}}$	$\frac{\partial L_{i,k}}{\partial S_{cav}}$

'effects table' for each error source including correlations

Fiduceo like analysis of end to end traceability and uncertainties – an exemplar for other missions

From - Mittaz, J et al (2019) , Metrologia, 56 (3). ISSN 00261394 doi: https://doi.org/10.1088/16817575/ab1705

Interoperable observing system

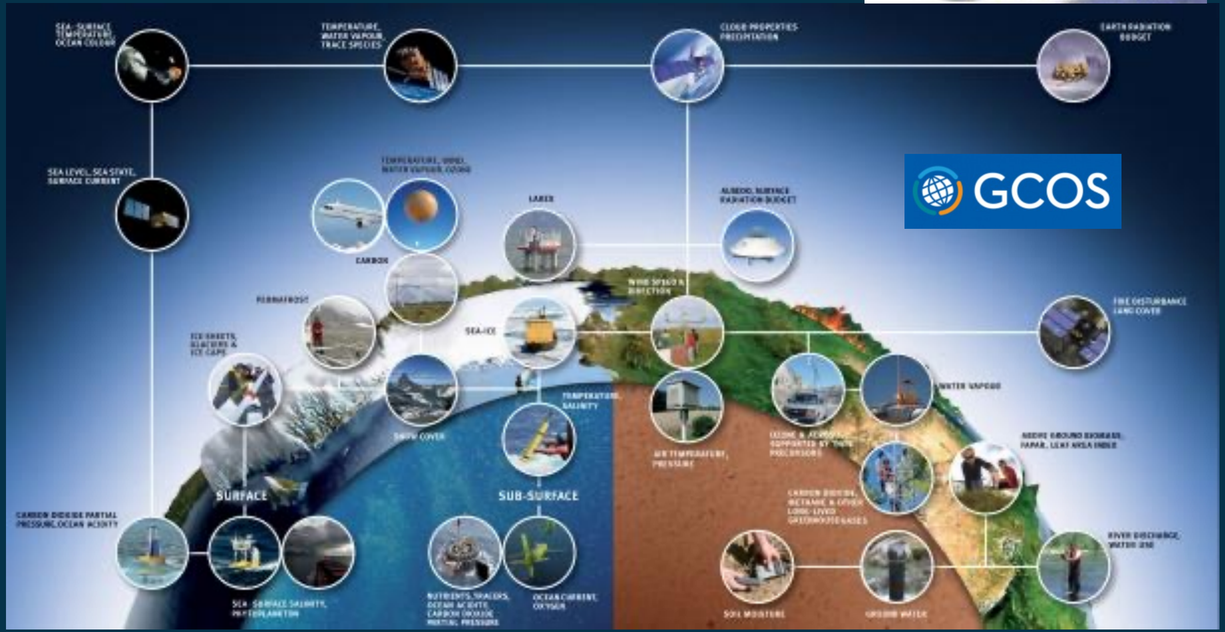
GROUP ON EARTH OBSERVATIONS

CEOS

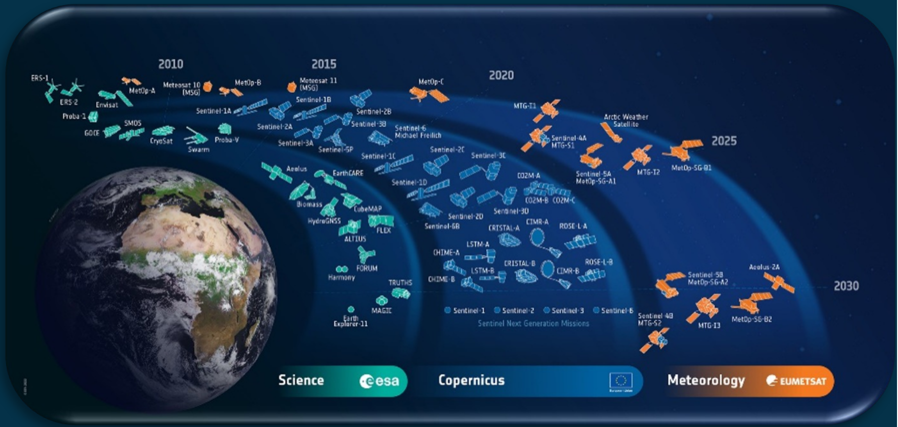
WMO

GSICS Global Space-based Inter-Calibration System

QA4EO

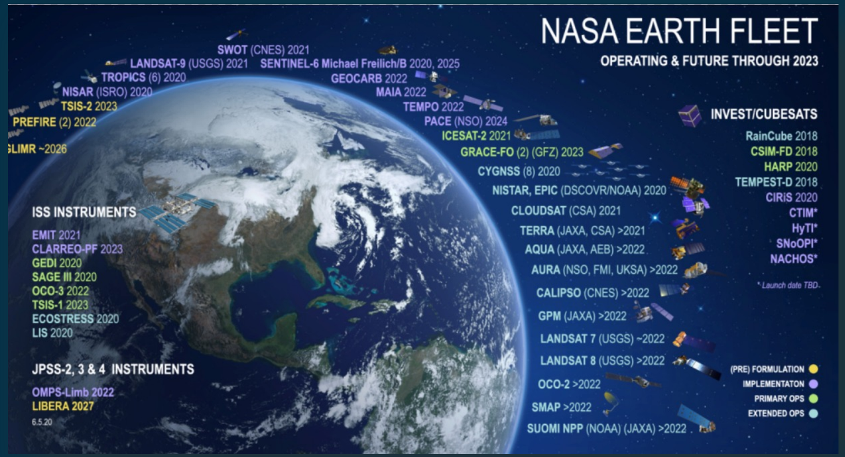


ESA Developed Earth Observation Satellites



New Space!

Maximise utility of data

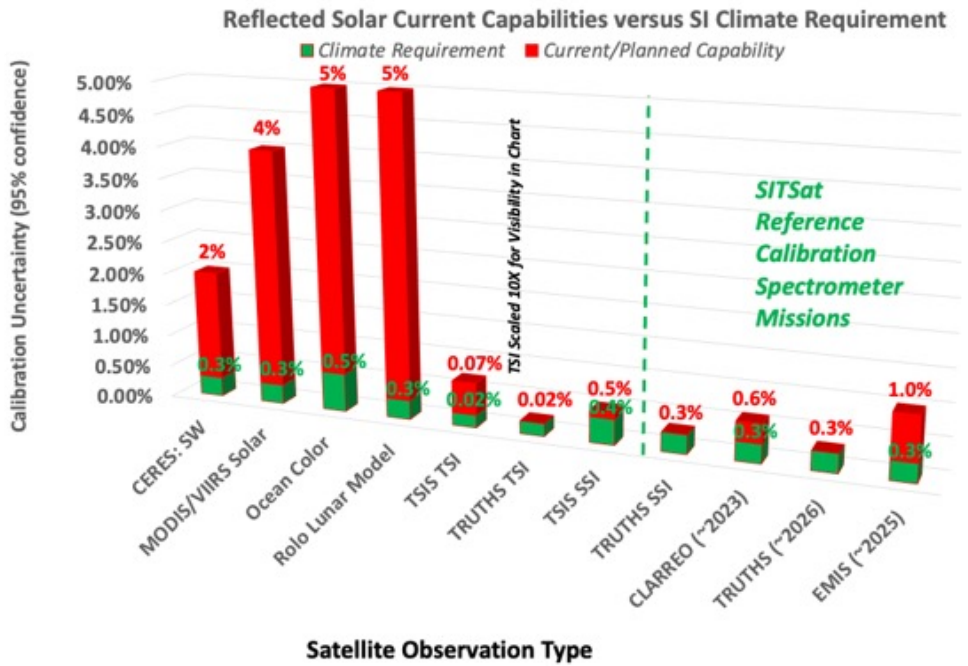


>60% of ECVs requires space observations
(TRUTHS can support ~>1/2 of these)

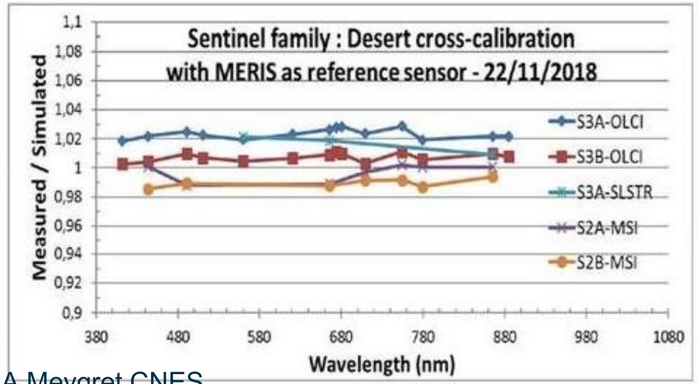
Satellites can suffer biases and degradation in performance due to launch and harshness of space.

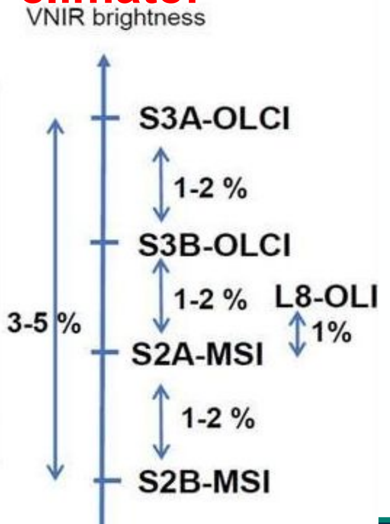
SITSats such as TRUTHS can help enable a new epoch for space-based Earth Observation

Climate Need & observation challenges



Most satellites not designed for climate: performance to suit application

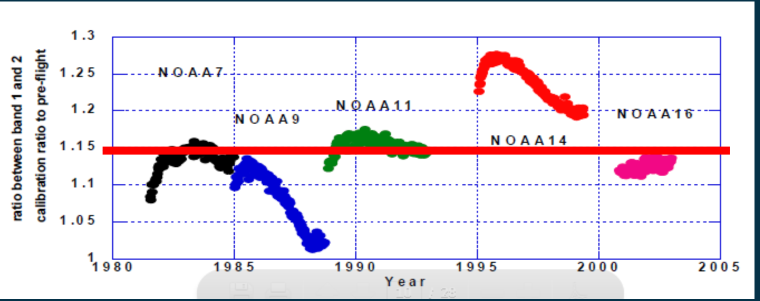




A Meygret CNES

What is the Truth?

Libya 4, a CEOS PICS site is a desert with a stable long-term reflectance. Vegetation index measured below should be horizontal red line i.e. none!



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

https://doi.org/10.47120/npl.9319

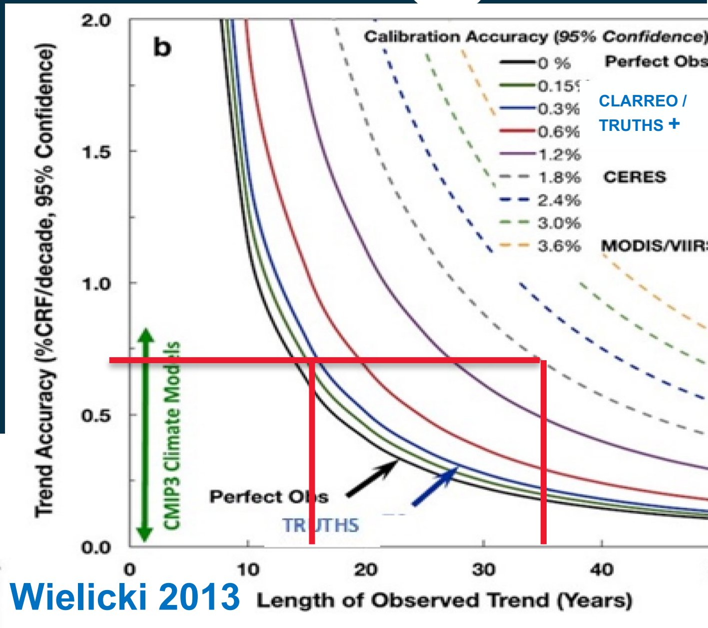
Trustable harmonised time series require stable/understood sensors anchored to invariant references

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

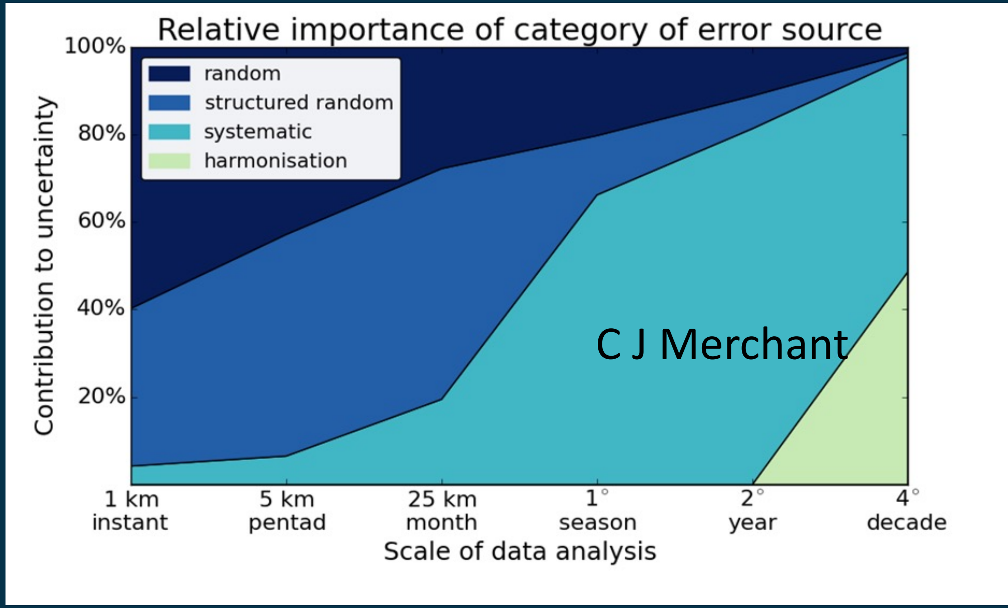
https://doi.org/10.47120/npl.9319

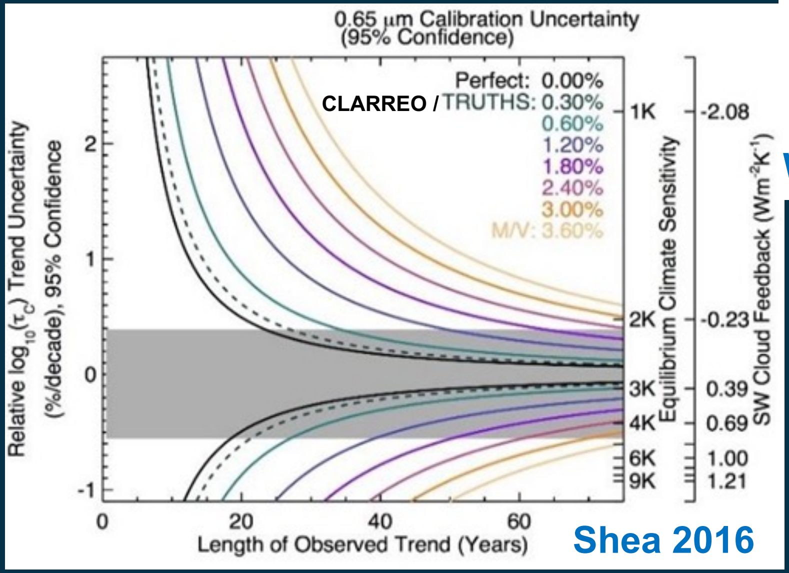
For Climate: Systematic Uncertainties dominate

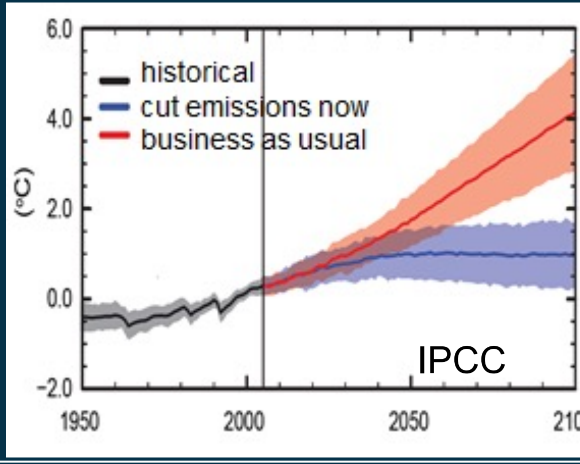
- **Very small signals 'trends' require decades to become large enough to detect with confidence from 'noisy' unpredictable natural variability**
  - Robust accurate reference (benchmark) from which to detect change
  - Consistent measurements/ stable instruments over time
  - Reduce critical dependency on sensor overlaps to remove biases and data gaps for (F)CDRs



Time to detect trend based on Uncertainty of sensor







As spatial and temporal scales increase, systematic uncertainties dominate

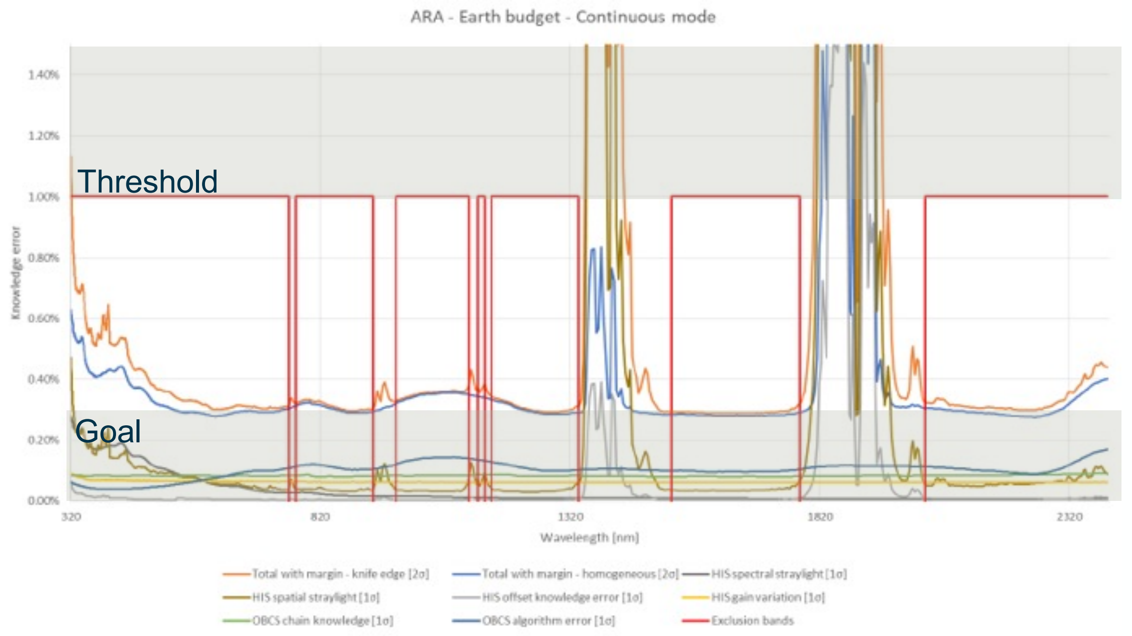
Need to test & constrain variance in climate model forecasts (IPCC)

‘Systematic’ Radiometric Uncertainty of HIS measurements (current assessment with ~ 20 % margin)

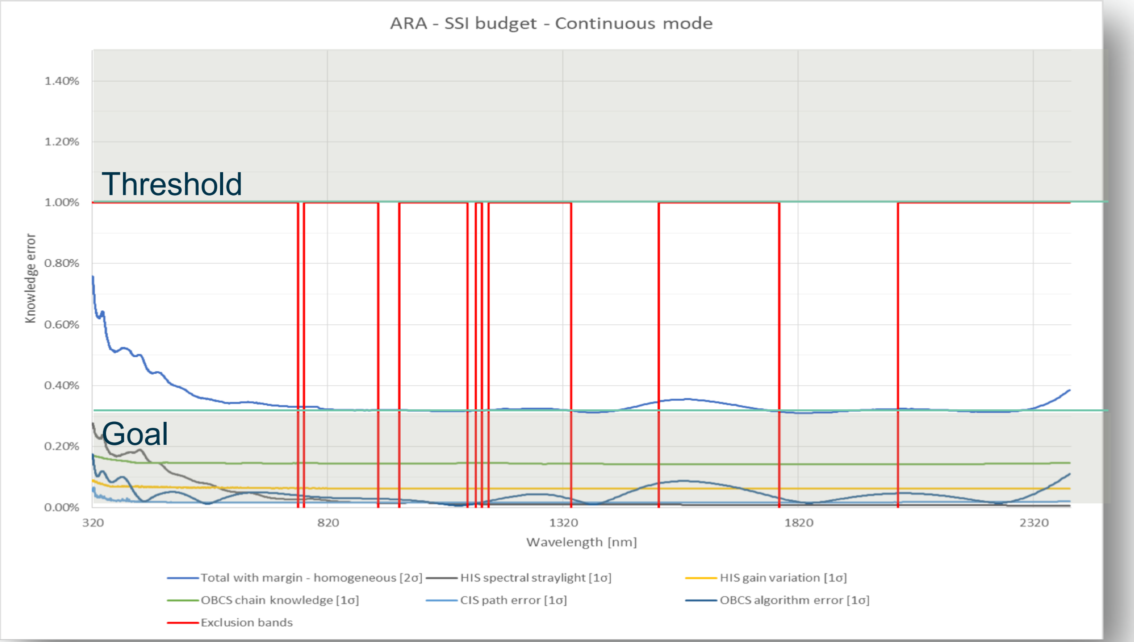
Mission requirement:

MRD-ID	Type	Value
MRD-OBS-310	ERU ERSR, SSI, LSI	The Expanded Radiometric Uncertainty for ERSR, SSI and LSI measurements shall be better than 0.3% (G) / 1% (T).

Earth Reflected Solar Radiance



Spectral Solar Irradiance



~ <400 nm Uncertainty increases to ~ 0.4% (k=2). Largely Knowledge of uncorrected spectral stray light

TRUTHS Standard Product specifications: summary
Launch Q1 2030 lifetime 5 – 8 yr

- **Earth ToA Spectral Radiance/Reflectance – Spectrally & Spatially continuous**
  - 90 Deg non-sun-synchronous orbit - spans 2 diurnal cycles pa
  - 320 – 2400 nm @ 4 – 8 nm spectral sampling interval and bandwidth
  - GSD (global) 100 m (min), 100 km Swath @ nadir (50 m + angles special)
  - Operational with summary Uncertainty info - full correlations on demand
  - Typically 100 X 100 km fixed geo grid (Land/Ocean mask) (download or analysis platform)
  - Level 1C climate grid (spatial/spectral TBD)
- **Solar BoA spectral Reflectance – Spectrally & Spatially continuous**
  - As above
  - Also AOD & TCWV (by-product of retrieval)
- **Solar/Lunar Spectral Irradiance – Spectrally continuous, Daily**
  - 320 – 2400 nm @ 1 – 8 nm (sun) (~20 nm moon) sampling and bandwidth
- **Total Solar Irradiance – Different instrument, Daily**

TRUTHS utility for climate applications?: observations

Benchmark (against which future 'decadal' change can be assessed)

- Total Solar Irradiance (accounting for solar cycle)
- Solar Spectral Irradiance (accounting for solar cycle)
- Earth (annual, seasonal, Zonal) cf similar future observations/sampling
- Initialising models (radiances, parameters (vegetation?, land cover type?, ….)
- Spectrally resolved observational reference for future model sensitivity comparisons
  - Feedbacks
  - Spectral signatures
- Radiation imbalance trends and attribution
- Earth (multi-temporal/spatial scales) (Hyperspectral) (not necessarily decadal change)
- Various ECVs (Trends, algorithm improvement, interdependency)

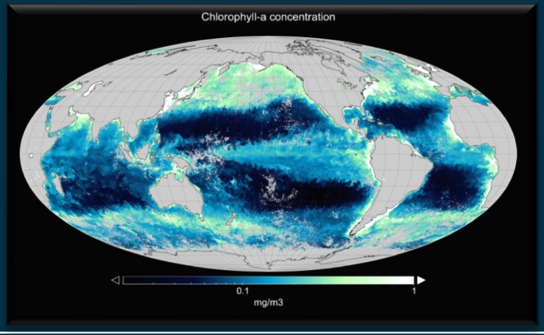
Above addressed by TRUTHS own data (sampling constraint). However combined with other observations to improve sampling (TRUTHS brings added fidelity: spectral, spatial, uncertainty)

TRUTHS: Underpinning operational ECV retrievals for climate monitoring, data set harmonisation, data-gap risk mitgation and model improvement

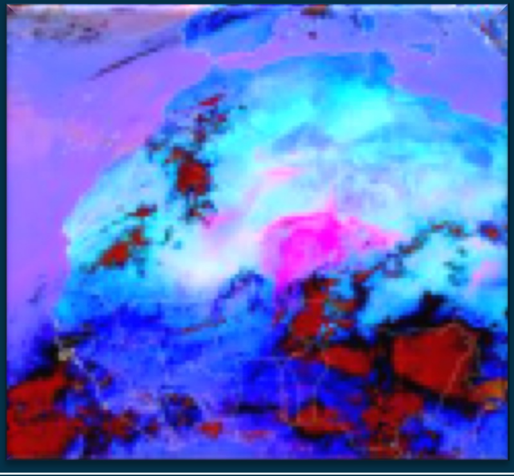
TRUTHS contributions	Climate data records
Provides reference calibration	Cloud properties, ozone, aerosol optical depth, greenhouse gases
Provides reference calibration AND direct observation	Solar irradiance, Earth radiation budget, surface albedo, cloud cover, cloud particle size, water vapour, ocean colour, ice and snow cover, vegetation indices such as leaf area index, land cover …..

- **Ocean colour:** direct TOA calibration of sensors to absolute radiometric accuracy of ~0.5%, **many locations** meeting GCOS requirements

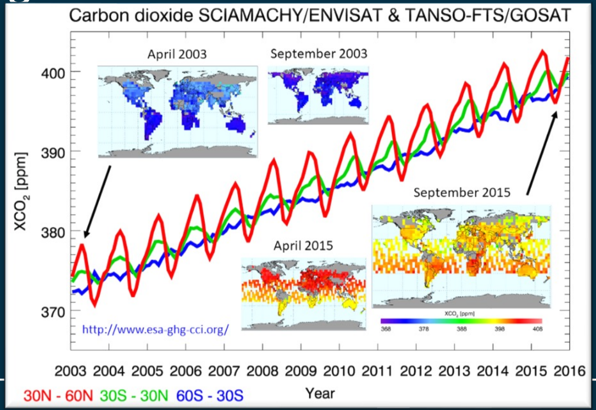
– global 200 m observations but limited temporal coverage



Aerosols: "Climate closure points" unifying ground networks and multiple optical sensors through the TRUTHS FCDR.



- **GHG:** Referencing Copernicus and multi-agency CO_2 constellations at 0.5-1.0% radiometry through cross-calibration (albedo/aerosol corrections in retrievals).
- Large scale CH4 emmisions detection

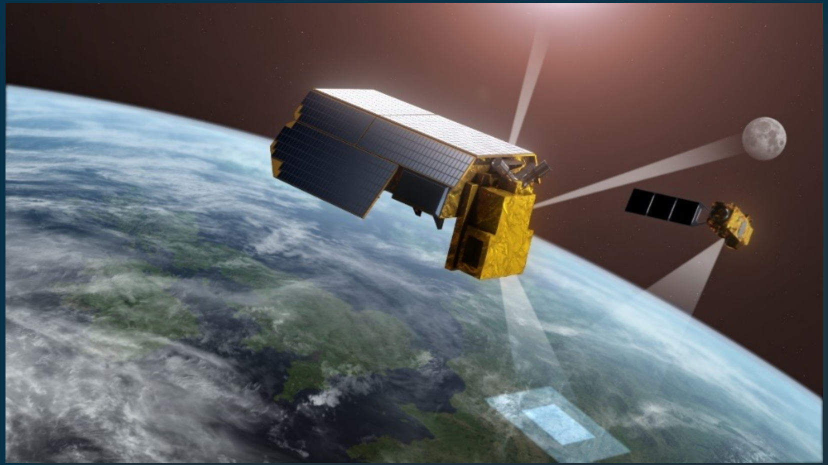


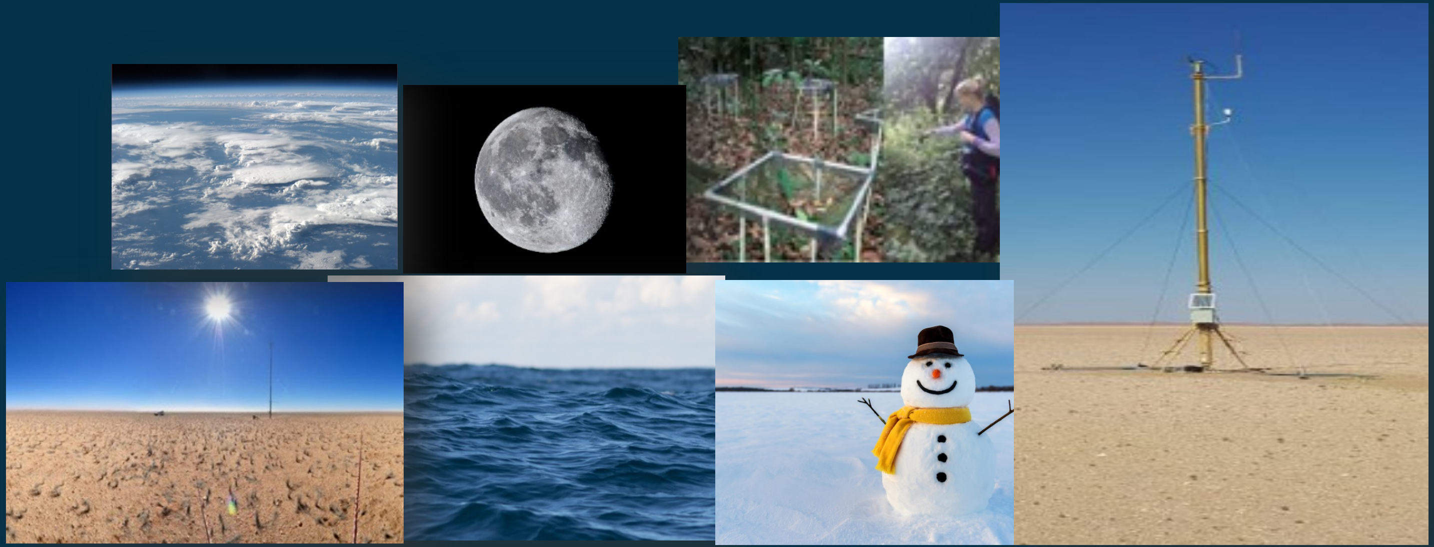
Gold Standard for Satellites observing the Earth, Moon & Sun

TRUTHS will:

- become a ‘**Gold Standard Reference**’ with spectral/spatial & orbital properties to match other sensors
- **Assess and remove biases of** other satellites improving their performance (L1 & L2) e.g. improve albedo/aerosol correction of GHG satellites
- characterize special sites on Earth (inc BRDF), the moon and the sun’s radiation, viewed by other satellites and new-space to **assess and improve their data quality** without direct overpass of TRUTHS.

TRUTHS will help harmonise and improve the uncertainty of data and confidence in derived information from the world’s current, historic and future satellites, enabling improved ‘time-series’ of Essential Climate Variables.

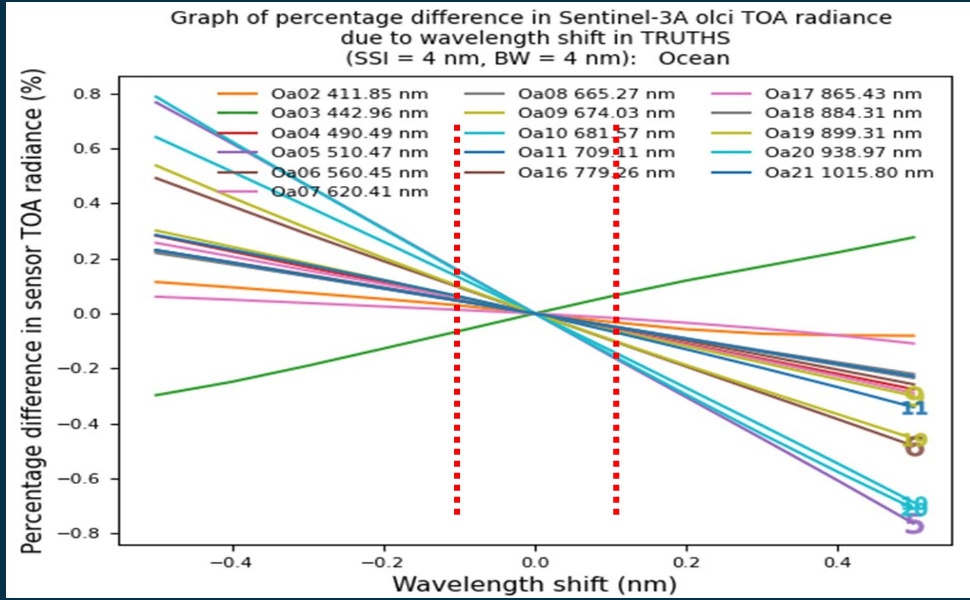


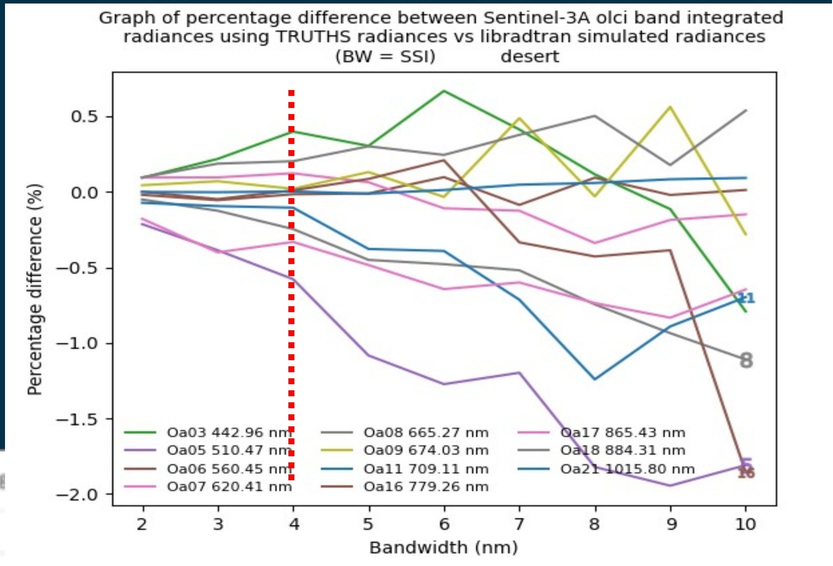


TRUTHS observational characteristics

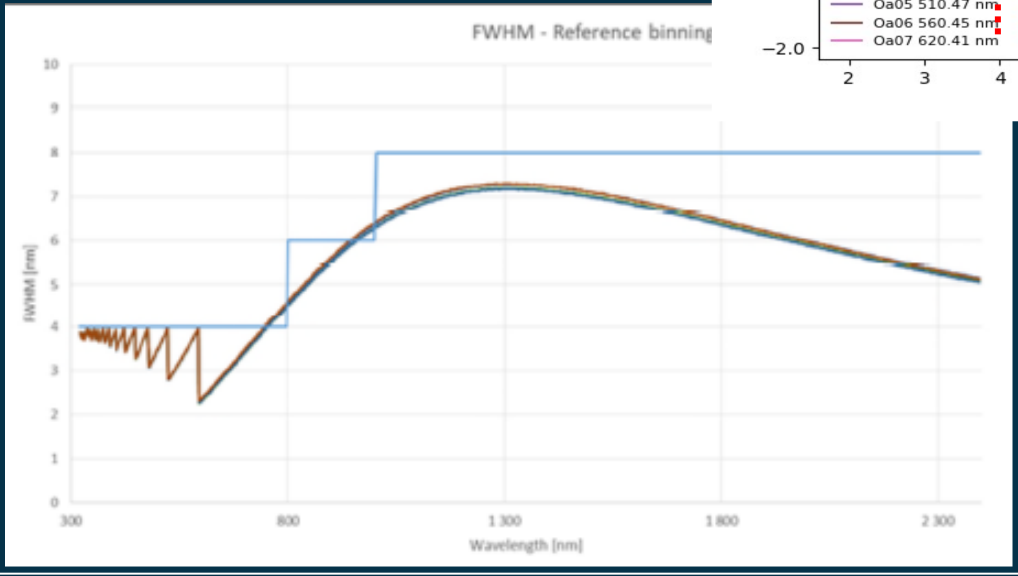
Spectral Knowledge: Primarily impact on matching response of another sensor for reference calibration & harmonisation of (F)CDR

Other than spectroscopy (atmospheric signatures), most spectrally demanding applications are biological particularly Ocean colour in terms of overall uncertainty





TRUTHS' spectral BW < specification. Mostly 2-3 nm in Vis and 5-6 nm in SWIR

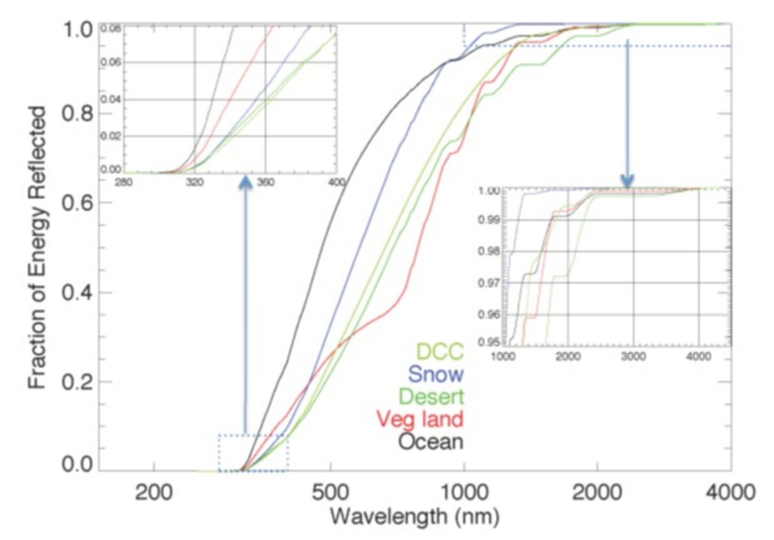


<0.1 nm wavelength accuracy results in < 0.1% impact when spectrally matching and calibrating S3-OLCI sensor for one of most demanding ECVs Ocean Colour

<4 nm BW & SSI also allows matching to S3-OLCI at <~ 0.3% for all critical bands

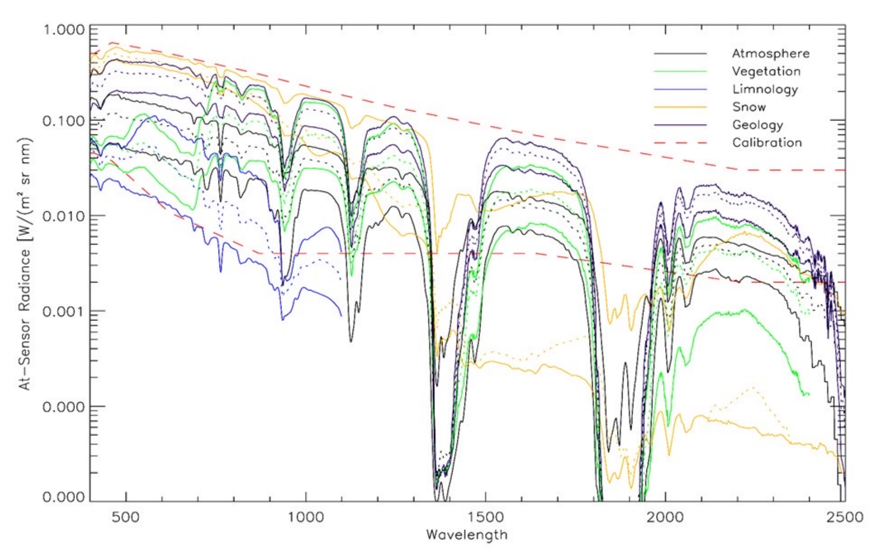
Spectral properties: 320 – 2400 nm

Spectrally continuous Hyperspectral data meets radiation imbalance and attributions/feedbacks as well as supporting many other applications & retrievals in the solar reflective domain e.g. biosphere, carbon/water cycle

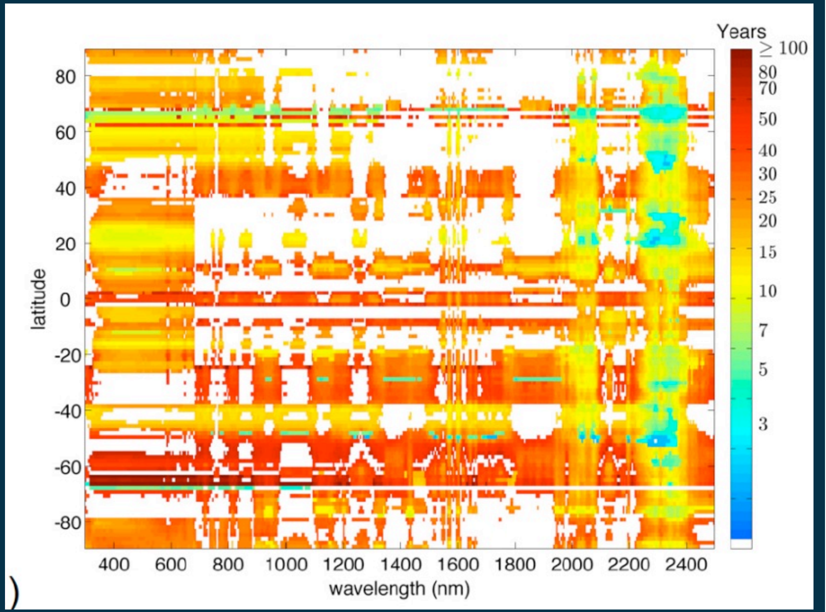


Spectral range more than adequate to account for short-Wave radiation. Uncertainties at spectral extremes can be relaxed without impact.

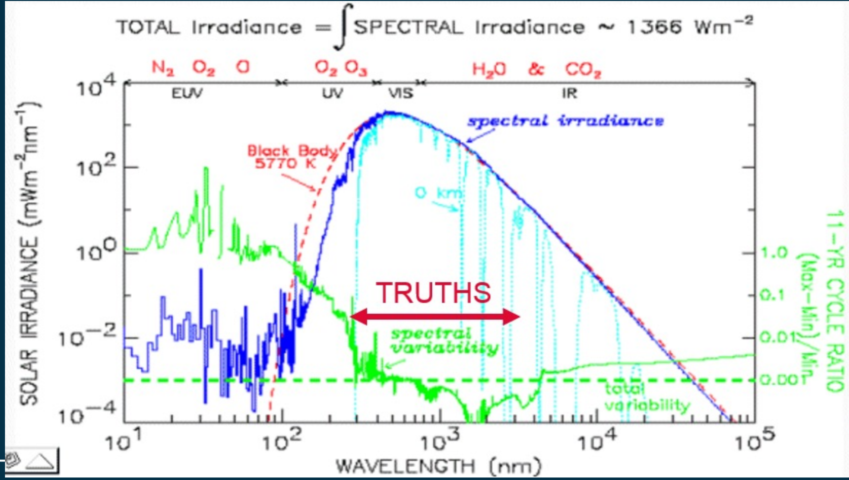
Scene Type	320 – 2300 nm	320 – 2400 nm
Global	0.09%	0.07%
All-sky Ocean	0.10%	0.08%
All-sky Land	0.08%	0.06%
Clear Ocean	0.16%	0.15%
Clear Desert	0.10%	0.07%



Spectral detail unravels Earth system complexity.



Spectral signature in Climate system response can lead to insight and improved temporal visibility cf broadband (Feldman 2011 + others)

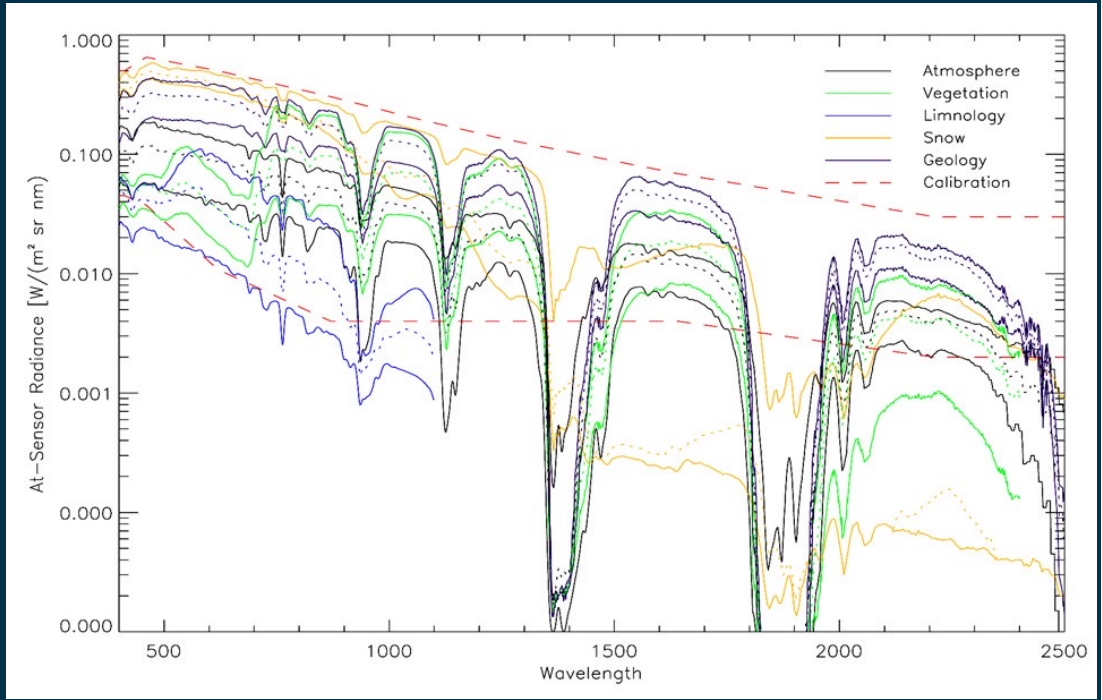


TRUTHS covers significant part of solar variability impacting Earth system

Hyper-spectral applications: e.g. 'Analysis Ready' (ARD) Surface reflectance

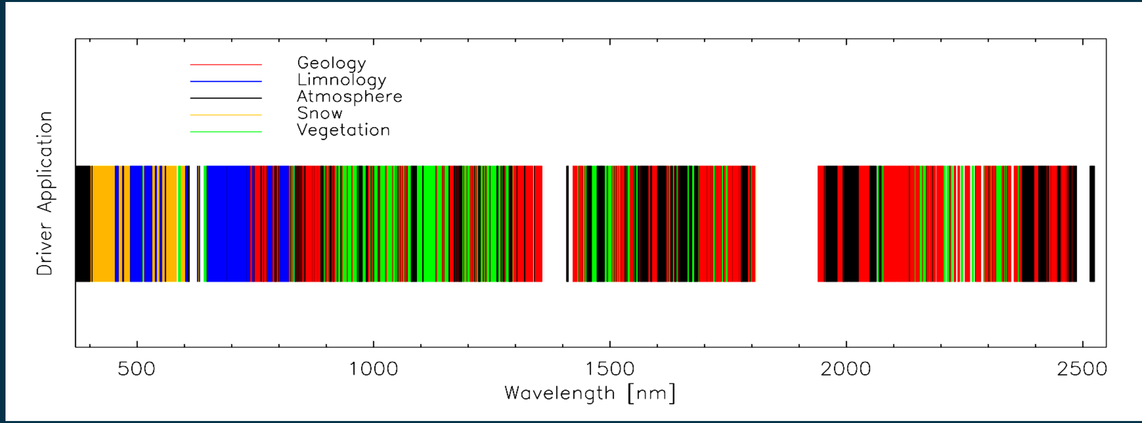
Hyperspectral data can be convolved for many applications enabling an earth system science approach (not temporally critical applications (61 day repeat)

- **Directly**
- **Upgrading other sensors**
- **Test & Improve retrieval algorithms**
- **Validation establishing references surface reflectance e.g. Fluxnet**



Complementary to EnMAP, PRISMA, CHIME ….

- Land-cover change
- Forest
- Surface Albedo
- Agriculture
- Pollution
- Resource prospecting
- …….



Ground sampling spatial grid / SNR:

Native GSD of TRUTHS is 50 m square with a Swath of 100 km i.e. 2000 pixels across-track.

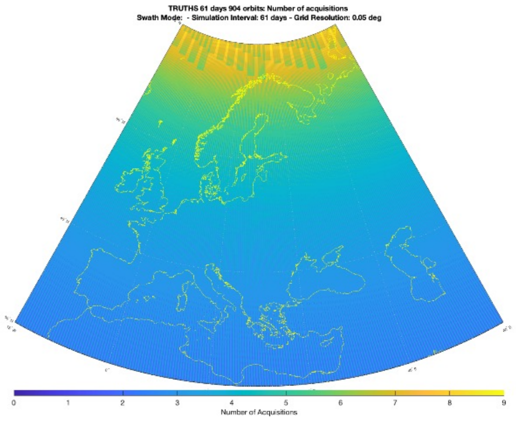
Due to data transmission limitations this is normally binned on-board to 100 m for Land and 200 m for Ocean (with a bias to Land e.g. Mediterranean sea is considered land). 50 m can and is downloaded on-demand for special applications e.g. Sensor 2 Sensor calibration mode.

Spatial and/or spectral binning increases SNR performance. For many climate applications native spatial and spectral resolutions are not required (except perhaps for cloud or land class identification)

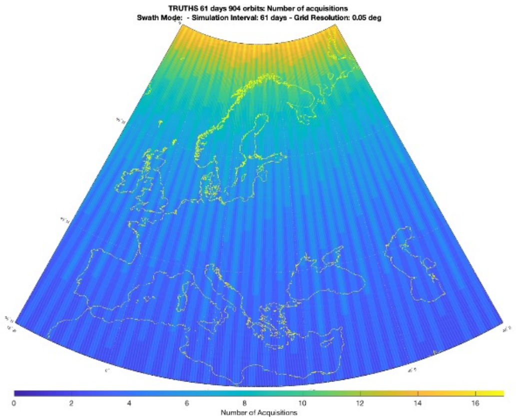
Spectral Range / nm	@ Ground Processor			Climate grid? (BW as native)		
	GSD / m	SNR BW ~2–6 nm	Typ/exp	GSD / m	SNR (For climate BW ~ 15 nm	Typ/exp SNR X 2)
Land (0.2 albedo)						
(Lref) <350	100	>40	**>120**	400 / 1000	>290 / >400	**>580 / >800**
<380	100	>70	**>350**	400 / 1000	>475 / >670	**>950 / >1600**
<1950	100	>280	**>420**	400 / 1000	>1900 / >2700	**>3800 / >5400**
<2400	100	>140	**>140**	400 / 1000	>950 / >1350	**>1900 / >2700**
Ocean (0.03 albedo)						
(Lmin) <350	200	>120	**>240**	400 / 1000	>335 / >675	**>670 / >1350**
<400	200	>200	**>600**	400 / 1000	>560 / >1125	**>1120 / >2250**
<1000	200	>320	**>500**	400 / 1000	>900 / >1800	**>1800 / >3600**
<2200	200	>160	**>240**	400 / 1000	>450 / >900	**>900 / >1800**
<2400	200	>120	**>120**	400 / 1000	>335 / >675	**>670 / >1350**

Number of Acquisitions (Europe, 0.05 deg grid)

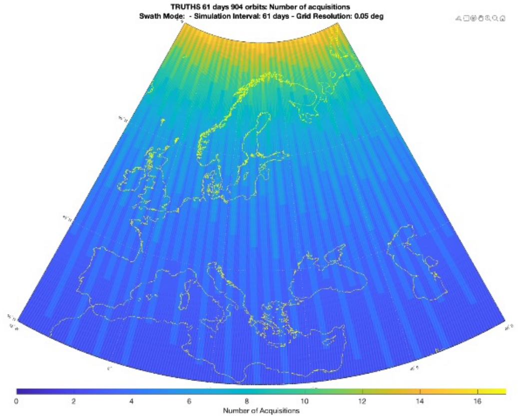
Coverage ≈ Lat > ± 75 deg ≈ 5-10 days (sun-lit) Lat > ± 45 deg ≈ 10-20 days Lat > ± 30 deg ≈ 11-50 days



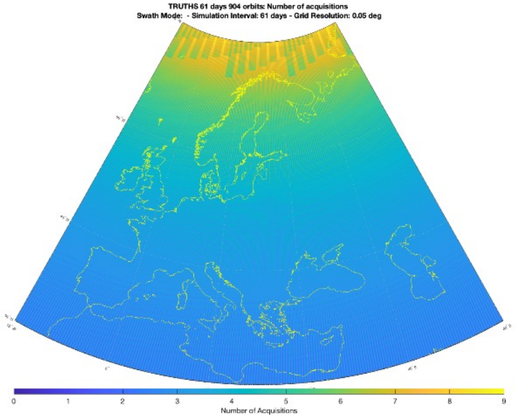
Cycle 19 Feb – 21 Apr



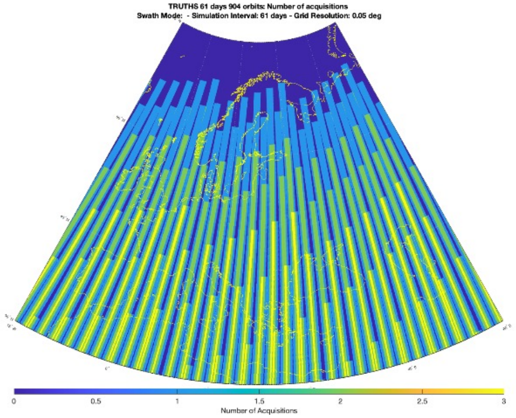
Cycle 21 Apr – 21 Jun



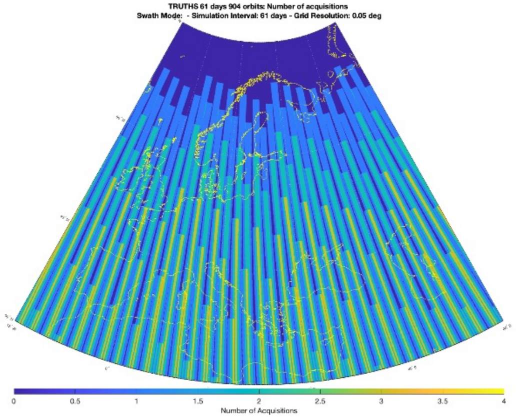
Cycle 21 Jun – 21 Aug



Cycle 21 Aug – 21 Oct

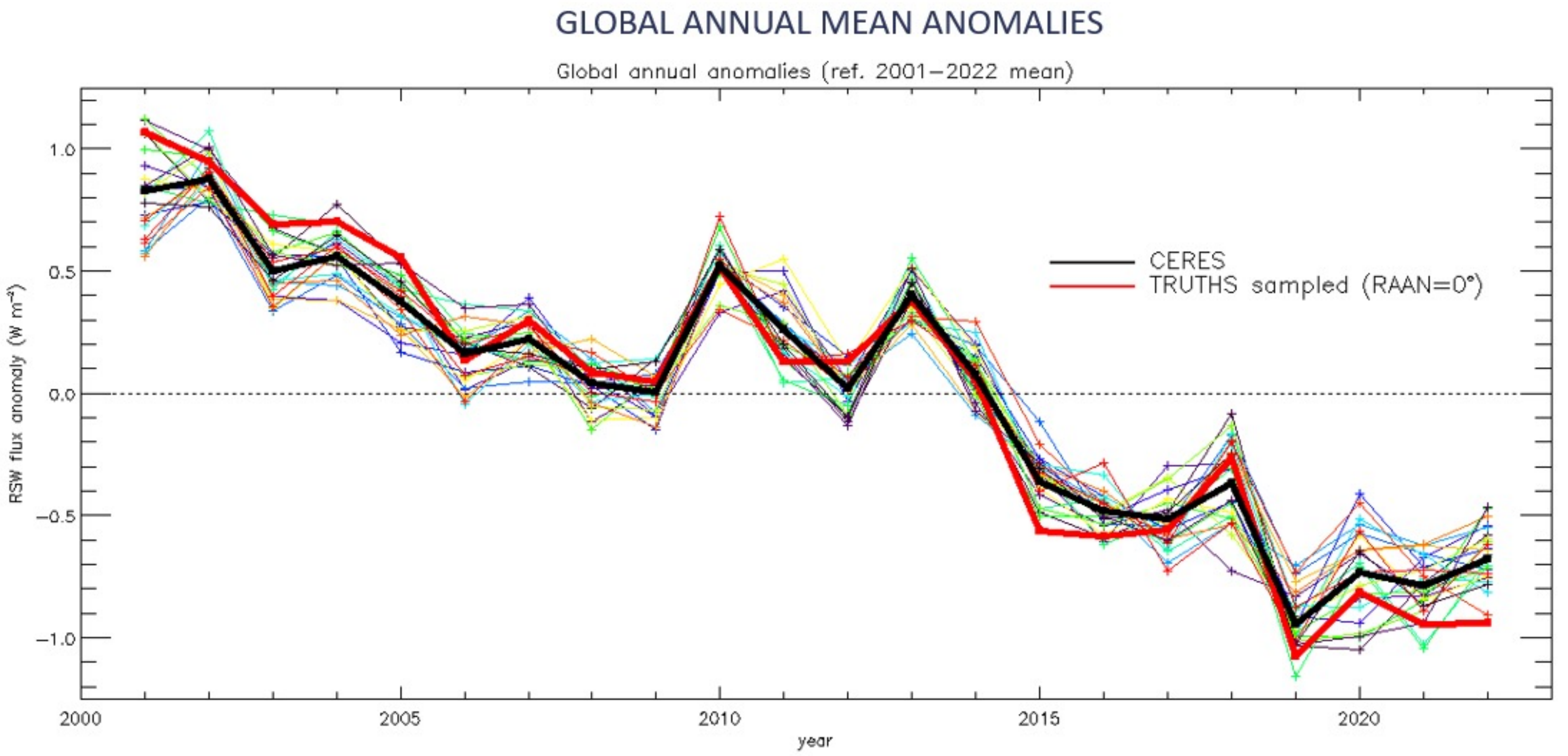


Cycle 21 Oct – 21 Dec



Cycle 21 Dec – 19 Feb

Potential for Trend detection from sub-sampled (TRUTHS sampling) from CERES 1 deg Syn data set



National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

Richard Bantges | r.bantges@imperial.ac.uk | Imperial College London / NCEO

UKRI Natural Environment Research Council

International Climate & Calibration Observatory

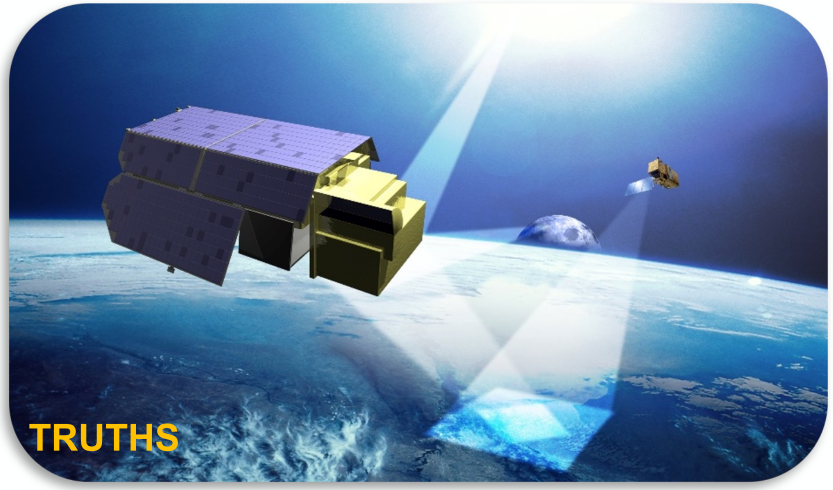
TRUTHS ~ 2030 will help initiate a sustainable long-term international climate & calibration observatory as direct response to international requests

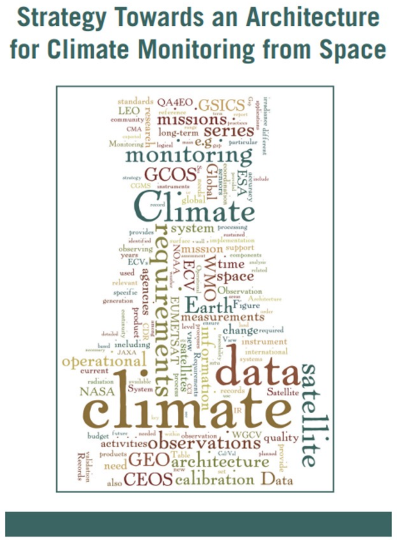
NASA CLARREO-Pathfinder 'sister mission' which will be launched to the ISS in 2026!.

- Hope for overlap!
- Also potential overlap with Chinese Mission

Guaranteeing the future of space activities by protecting the environment

TRUTHS & CPF SITSats will provide unique and critical information for understanding and monitoring Climate and environmental change from space and support climate action



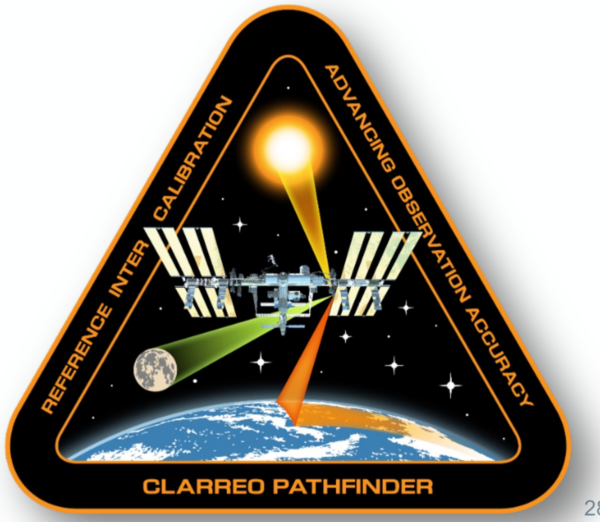



CEOS

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



How can TRUTHS help? (noting 2030 timeframe)

1) At what scales will TRUTHS deliver a useful climate benchmark record? (e.g. spatial, temporal and spectral) and for what ‘applications’
   - independently? Or in combination with another sensor (which are priorities?)
   - Simulations to assess (data/models/expertise)
   - Can observational benchmarks provide utility for model comparisons

2) How will TRUTHS help to constrain climate sensitivity? (e.g. enhance/develop climate model ability/capability, Observational benchmark to CF against in future

3) Enable enhanced ECVs - which ones, and what are the key observational requirements?

4) Optimise products for maximal utility

June 24 plan to host community workshop at ECSAT To explore opportunities

TRUTHS team keen to open dialogue: Nigel.Fox@npl.co.uk, Thorsten.Fehr@ESA.int

Reserve slides

TRUTHS MAIN PRODUCTS – L1B

PRODUCT ID	Name of product	Level	Uncertainty requirement	Coverage	SSD [ACT] [m]	Number of Spectral samples	Format	End-to-End Availabilit y	Timeliness [DAYS]	Frequency	Processing
ERSR-LAND/COAST	TOA Earth-Reflected Spectral Radiance (Normal spatial resolution mode for Land+ Coast) +uncertainties per pixel	Level 1b	0.3% (G)/1%(T)	SZA<83 deg, 100 km x 100 km	100	328	NetCDF	95%	5 (G) 7 (T)	Every orbit	Systematic
ERSR-OCEAN	TOA Earth Reflected Spectral Radiance (Normal spatial resolution mode for Ocean) +uncertainties per pixel	Level 1b	0.3% (G)/1%(T)	SZA<83 deg, 100 km x 100 km	200	328	NetCDF	95%	5 (G) 7 (T)	Every orbit	Systematic
ERSRE-LAND/COAST	TOA Earth Reflected Spectral Reflectance for LAND +uncertainties per pixel	Level 1b	0.3% (G)/1%(T)	SZA<83 deg, 100 km x 100 km	100	328	NetCDF	95%	5 (G) 7 (T)	Every orbit	Systematic
ERSRE-OCEAN	TOA Earth Reflected Spectral Reflectance for OCEAN + uncertainties per pixel	Level 1b	0.3% (G)/1%(T)	SZA<83 deg, 100 km x 100 km	200	328	NetCDF	95%	5 (G) 7 (T)	Every orbit	Systematic
ERSR-TARGET-NADIR (TBC)	TOA Earth Reflected Spectral Radiance - nadir over PICS for BRDF characterisation	Level 1b	0.3% (G)/1%(T)	Nadir	50	328	NetCDF	95%	5 (G) 7 (T)	Every orbit	Systematic
ERSR-TARGET	Viewing of Calibration site non -nadir e.g. RADCALNET/PICS	Level 1b	0.3% (G)/1%(T)	[-40 deg, +40 deg] (G) [-20 deg, +20 deg] (T)	50	328	NetCDF	95%	5 (G) 7 (T)	TBC	On demand
SSI	Solar Spectral Irradiance (SSI) +uncertainties per pixel	Level 1b	0.3% (G)/1%(T)	Sun	NATIVE	388	NetCDF	95%	5 (G) 7 (T)	Every day	Systematic
LSI	Lunar Spectral Irradiance (LSI) +uncertainties per pixel	Level 1b	0.3% (G)/1%(T)	Moon disc	NATIVE	205	NetCDF	95%	5 (G) 7 (T)	Every 3 days	Systematic
TSI	Total Solar Irradiance (Integrated over 300 nm to 30 000 nm)+ uncertainty	Level 1b	(0.02% (G) / 0.05% (T))	Sun	NATIVE	TBC	NetCDF	95%	5 (G) 7 (T)	Every Day	Systematic
S2SC	Sensor to sensor intercalibration coefficients for a group of sensors (S-2, S-3, CHIME, LSTM, METOP-SG, CO2M)	Level 1b	0.3% (G)/1%(T)	[-40 deg, +40 deg] (G) [-20 deg, +20 deg] (T)	50	TBC	NetCDF	95%	5 (G) 7 (T)	less then 1 per orbit	On demand
S2SC-3PARTY (TBC)	Intercalibration coefficients with a Third Party mission	Level 1b	0.3% (G)/1%(T)	[-40 deg, +40 deg] (G) [-20 deg, +20 deg] (T)	50	TBC	NetCDF	95%	5 (G) 7 (T)	less then 1 per orbit	On Request Pending TRUTHS operations

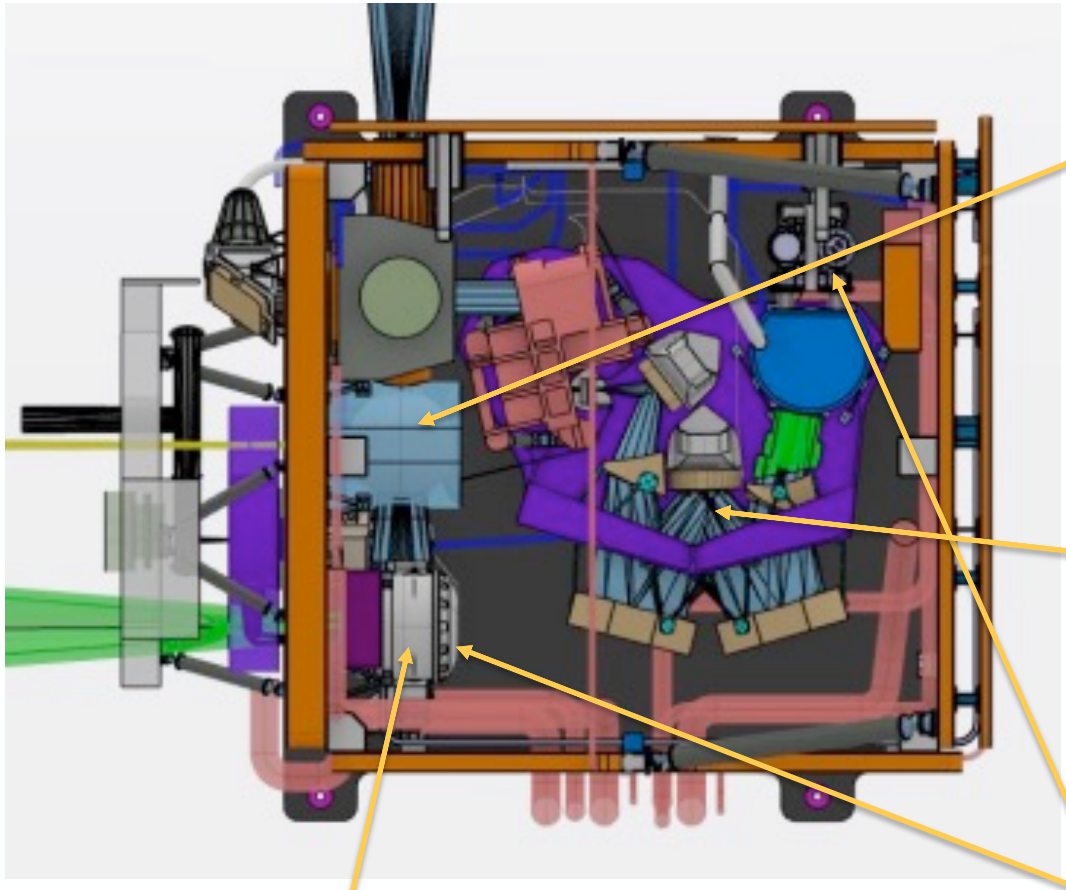
TRUTHS MAIN PRODUCTS – L1C

PRODUCT ID	Name of product	Level	Uncertainty requirement	Coverage	SSD [ACT] [m]	Number of Spectral samples	Format	End-to-End Availability	Timeliness [DAYS]	Frequency	Processing
ERSR-LAND/COAST -	TOA Earth-Reflected Spectral Radiance (Normal spatial resolution mode for Land+ Coast) +uncertainties	Level 1c	0.3% (G)/1%(T)	SZA<83 deg, 100 km x 100 km	100	328	NetCDF	95%	5 (G) 7 (T)	Every orbit	Systematic
ERSRE-LAND/COAST	TOA Earth Reflected Spectral Reflectance (Normal spatial resolution mode for Land+ Coast) + uncertainties	Level 1c	0.3% (G)/1%(T)	SZA<83 deg, 100 km x 100 km	100	328	NetCDF	95%	5 (G) 7 (T)	Every orbit	Systematic
ERSR-OCEAN	TOA Earth Reflected Spectral Radiance (Normal spatial resolution mode for Ocean) +uncertainties	Level 1c	0.3% (G)/1%(T)	SZA<83 deg, 100 km x 100 km	200	328	NetCDF	95%	5 (G) 7 (T)	Every orbit	Systematic
ERSRE-OCEAN	TOA Earth Reflected Spectral Reflectance (Normal spatial resolution mode for Ocean) + uncertainties	Level 1c	0.3% (G)/1%(T)	SZA<83 deg, 100 km x 100 km	200	328	NetCDF	95%	5 (G) 7 (T)	Every orbit	Systematic
ERSR-PICS	TOA Earth Reflected Spectral Radiance - nadir over PICS	Level 1c	0.3% (G)/1%(T)	PICS/RADCAL sites	50	TBVC	NetCDF	95%	5 (G) 7 (T)	TBC	Systematic
ERSR-TARGET	TOA Radiance High spatial resolution mode for PICS/S2SC +uncertainties	Level 1c	0.3% (G)/1%(T)	[-40 deg, +40 deg] (G) [-20 deg, +20 deg] (T)	50	TBC	NetCDF	95%	5 (G) 7 (T)	TBC	On-demand
LSI	Lunar Spectral Irradiance (LSI) +uncertainties per pixel	Level 1c	0.3% (G)/1%(T)	Moon disc	NATIVE SSD	205	NetCDF	95%	5 (G) 7 (T)	Every 3 days	Systematic
SSI	Solar Spectral Irradiance (SSI) +uncertainties per pixel	Level 1c	0.3% (G)/1%(T)	Sun	NATIVE SSD	388	NetCDF	95%	5 (G) 7 (T)	Every day	Systematic

TRUTHS MAIN PRODUCTS –L2

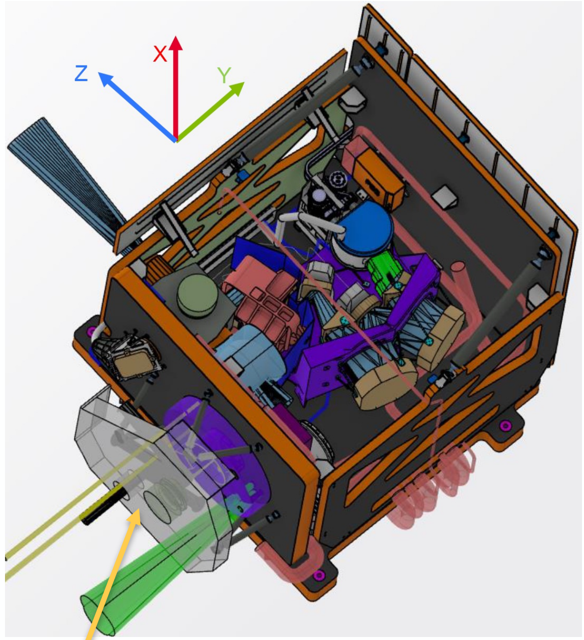
PRODUCT ID	Name of product	Level	Uncertainty requirement	Coverage	SSD [ACT] [m]	Number of Spectral samples	Format	End-to-End Availability	Timeliness [DAYS]	Frequency	Processing (data driven or user driven)
SRR-LAND	BOA Spectral Surface Reflectance - Land + uncertainties	Level 2	(reflectance ρ shall be <1% (G), 3% (T) for SZA ≤ 60 and AOT at 550 nm ≤ 0.6)	SZA<83 deg, 100 km x 100 km	100	TBC	NetCDF	97%	5 (G) 7(T)	TBC	On demand
SRR-OCEAN	BOA Spectral Surface Reflectance - Ocean + uncertainties	Level 2	(reflectance ρ shall be <1% (G), 3% (T) for SZA ≤ 60 and AOT at 550 nm ≤ 0.6)	SZA<83 deg, 100 km x 100 km	200	TBC	NetCDF	97%	5 (G) 7(T)	TBC	On demand
SRR-LAND	BOA Spectral Surface Reflectance Resampled - Land + uncertainties	Level 2	(reflectance ρ shall be <1% (G), 3% (T) for SZA ≤ 60 and AOT at 550 nm ≤ 0.6)	SZA<83 deg, 100 km x 100 km	100	TBC	NetCDF	97%	5 (G) 7(T)	TBC	On demand
SRR-OCEAN	BOA Spectral Surface Reflectance Resampled - Ocean + uncertainties	Level 2	(reflectance ρ shall be <1% (G), 3% (T) for SZA ≤ 60 and AOT at 550 nm ≤ 0.6)	SZA<83 deg, 100 km x 100 km	200	TBC	NetCDF	97%	5 (G) 7(T)	TBC	On demand
SRR-PICS	BOA Spectral Surface Reflectance over PICS sites + uncertainties	Level 2	(reflectance ρ shall be <1% (G), 3% (T) for SZA ≤ 60 and AOT at 550 nm ≤ 0.6)	TBD	50	TBC	NetCDF	97%	5 (G) 7(T)	TBC	On demand

Payload overview



DISA:
- Fibre bundle + relay optics connects DISA to HIS
- Uniformity and characterisation requirements under assessment

HIS:
- Telescope optical design optimised (stop added after M3)
- Preliminary STOP analysis done
- Detector contamination baffling introduced
- Detector actively cooled @150K (same cryocooler type as CSAR)



SPC (Solar PolyChromator):
- Generates ref wavelengths
- Step/continuous scan

CSAR:
- Cavity manufacture trials
- Continuous mode validation test specification (baseline mode)

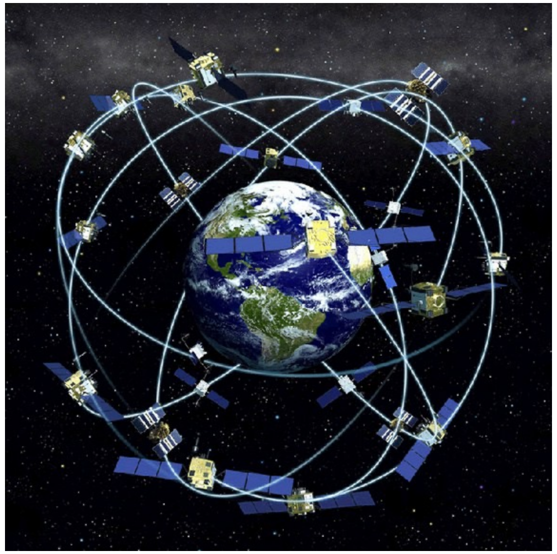
Cryocooler:
- LPT6510 fully redundant baseline @ 60K nom (hot redundancy)
- 65K in failure mode (1 cooler off)

Other:
- Need of purging confirmed (DISA, Cryostats, HIS)
- Routing of heat pipes

Novel/challenging 90 deg polar orbit Facilitates S2S Calibration & diurnal globalsampling for climate

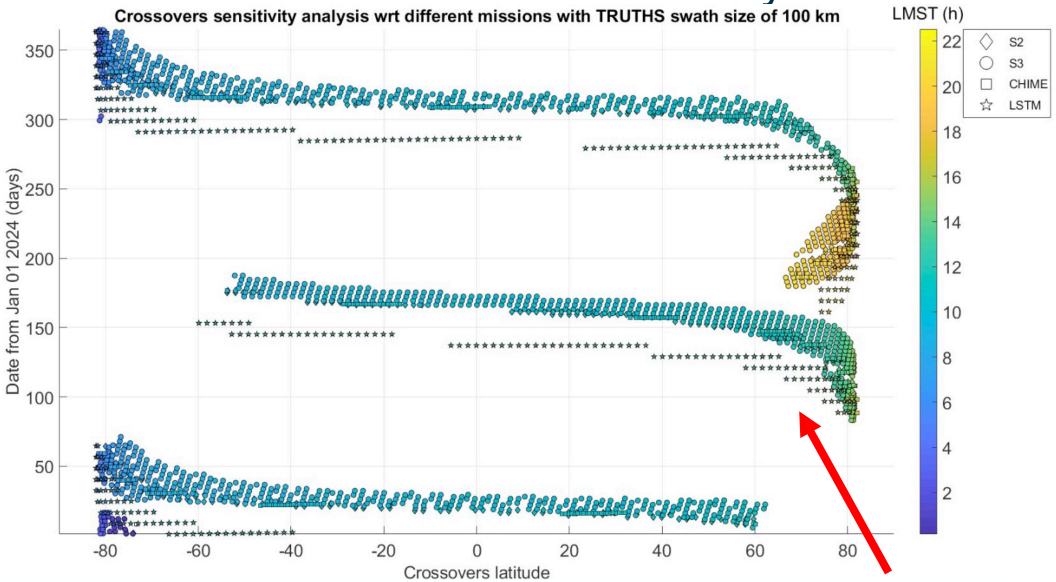
esa

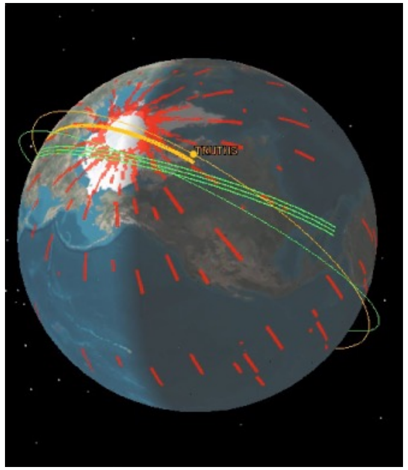
- **Enables interoperability & Harmonisation**
  - **Prospect of 'certified calibration'**



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

TRUTHS 90°pole to pole orbit, observing through the diurnal cycle, allows many opportunities to overpass orbit of sun-synchronous sensors



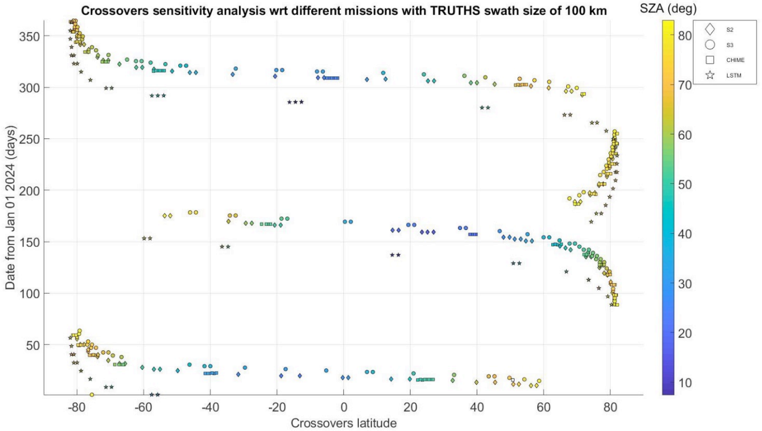


<30 s time difference Swath overlap

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

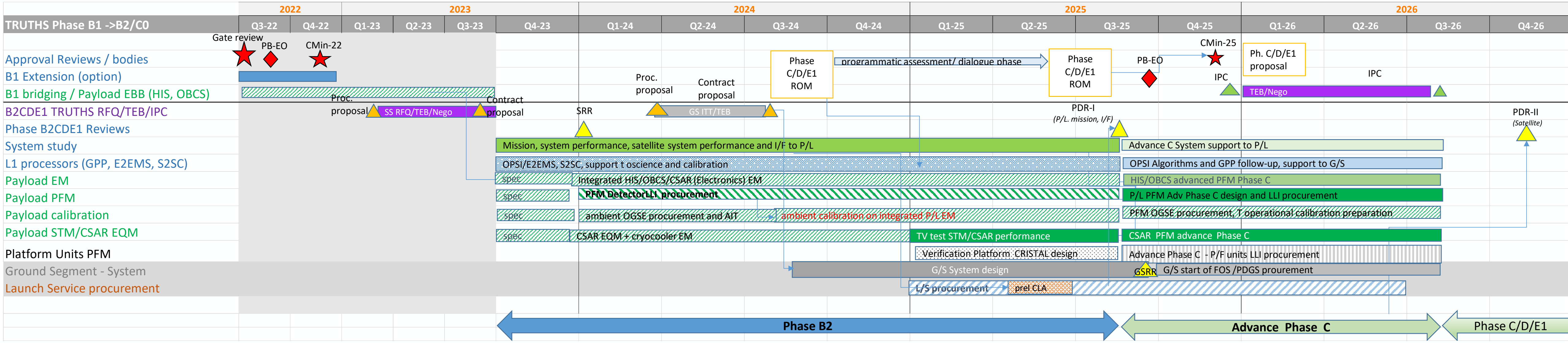
(<1° (no pointing) <30 s time difference

Summary after 6 months



Phase B2/Advance C Schedule - Objectives

esa



- Phase B2 key objectives:
  - De-risk the Payload by extensive EBB/EM work and achieve TRL-6 by PDR-I
  - Achieve PDR Part-I (no platform) by mid-2025
  - Stabilise the industrial cost by reducing risks and adopting cost-reduction options to prepare for CM-25
  - Initiate GS and Launch Services activities
  - Implement science studies
- Advance Phase C objectives:
  - Continue P/L development (critical path) in parallel to contracting of phase C/D/E1
  - Continue support simulation and performance analysis,
  - Start key LLI procurement for Payload and Platform (TBC) PFM to secure schedule