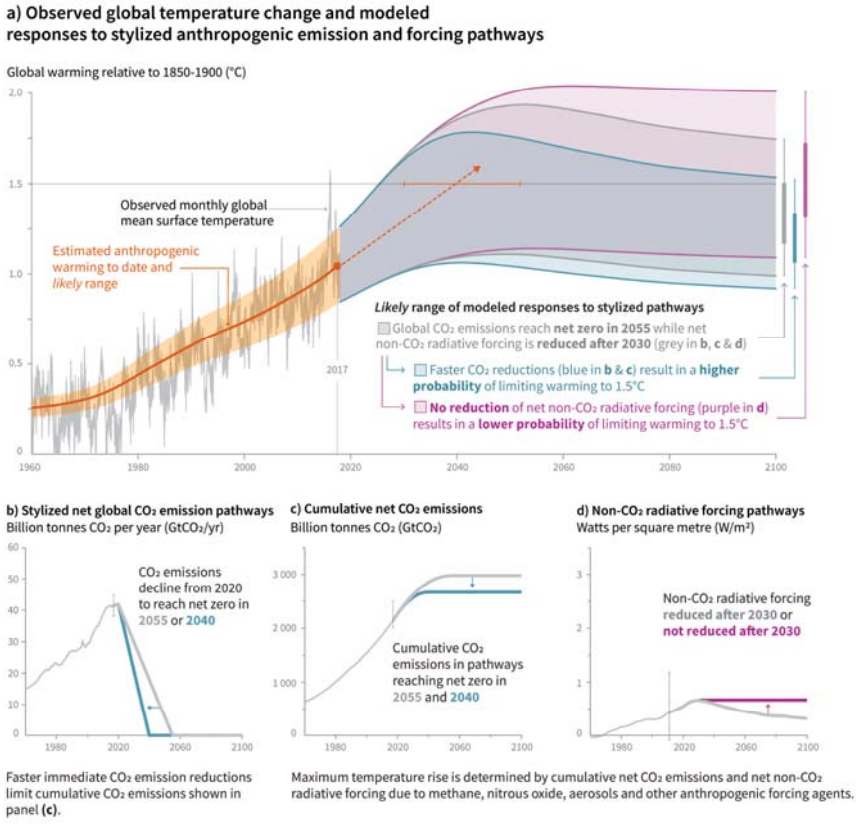
Tropical Carbon Mission (TCM)

Quantifying tropical carbon fluxes from space using high-resolution, multi-view SWIR spectroscopy and aerosol retrievals

Prepared by Paul Palmer, Hartmut Bösch, Hugh Kelliher

Mitigating worst climate impacts: achieving 1.5°C and 2°C demands progressive CO_2 emission cuts

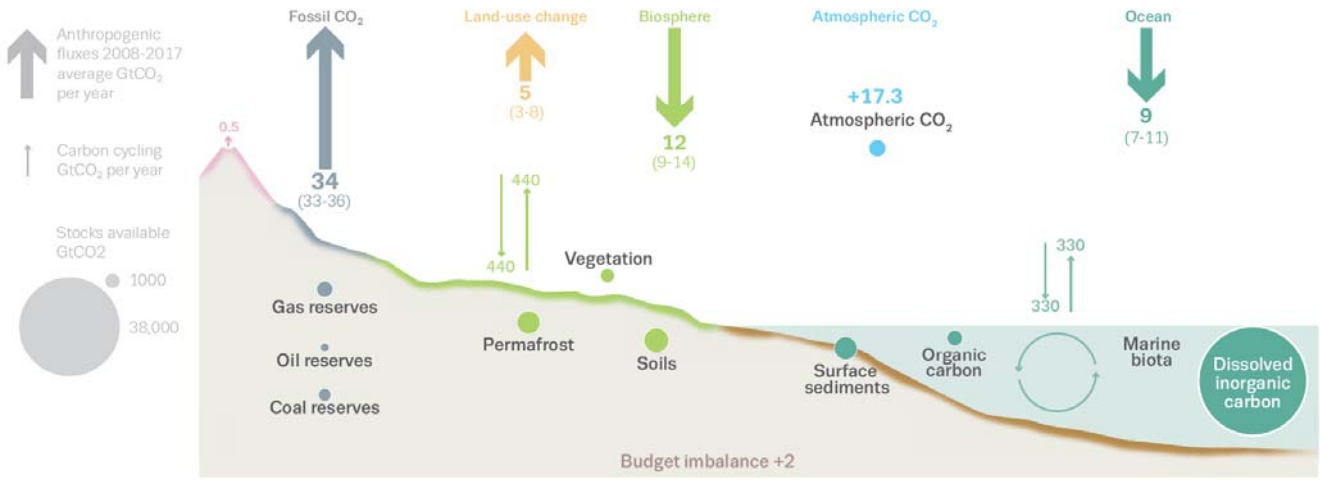


The Paris Agreement will use 5-year global stocktakes as a mechanism to assess CO_2 cuts

Reducing emissions; maintaining/enhancing sinks

There is an appetite to pursue bottom-up and top-down methods to estimate emissions

Land biosphere is a large source of uncertainty



With ground-based data we are largely blind to the tropical ecosystems and how they respond to change in climate

GLOBAL CARBON project

TCM addresses fundamental gaps in knowledge

Primary mission objective: reduce uncertainties in the magnitude and distribution of tropical CO_2 fluxes to determine the sign and magnitude of the net carbon balance of the tropics every four weeks.

Secondary science objectives: a) reduce the uncertainties in CO and CH_4 fluxes, and b) improve source attribution of observed variations in atmospheric CO_2.

Complements CO_2 measurements from LEO instruments by improving their ability to infer extra-tropical fluxes.

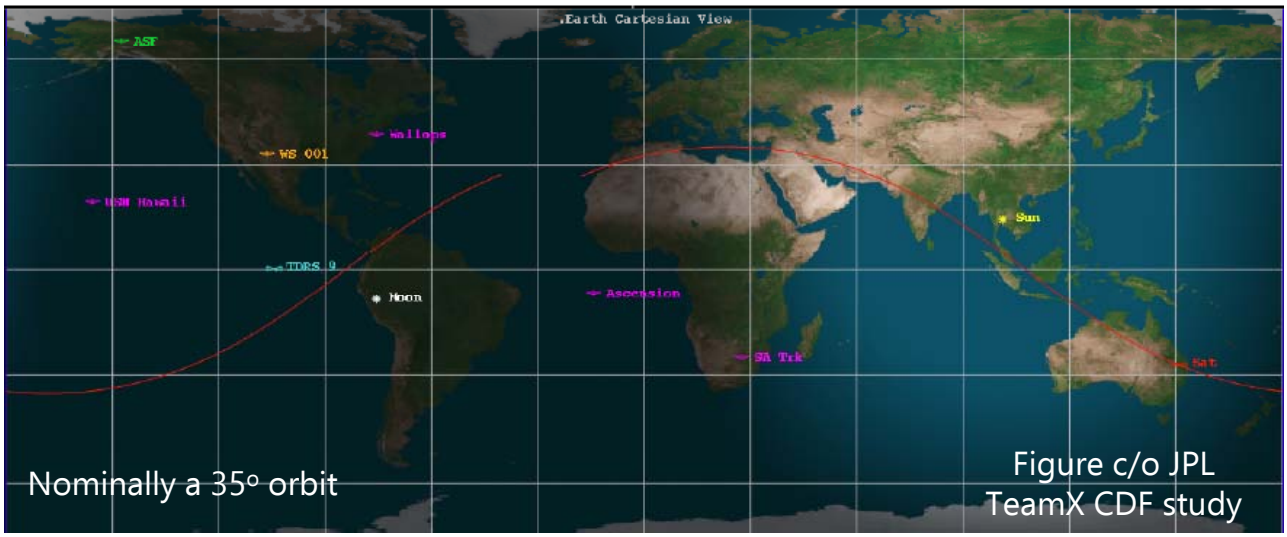
TCM payload: innovative high TRL technologies

TCM comprises 3 instruments building on current technology:

1) short-wave IR (**SWIR**) **multi-view** spectrometer that will measure **CO_2**, **CH_4**, **CO**, and **O_2**;
2) co-boresighted aerosol imager; and
3) wide-view cloud imager

- The **SWIR spectrometer** is based on the existing prototype, GHOST
- An **aerosol imager** will improve the characterization of atmospheric aerosols and cirrus clouds prevalent over tropical latitudes. It builds on technology and techniques developed for MISR, POLDER and (A)ATSR.
- A **cloud imager** can be used to help intelligent pointing and post-processing of data

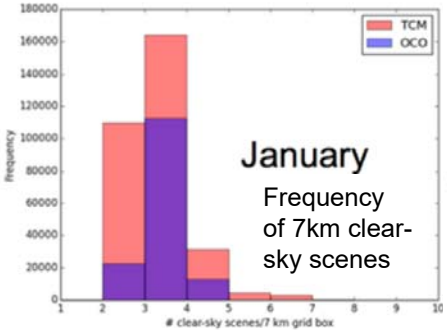
TCM uses a low-inclination orbit to maximize tropical sampling

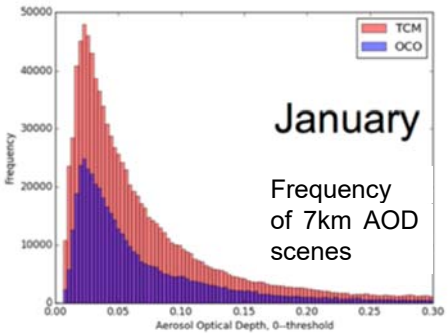


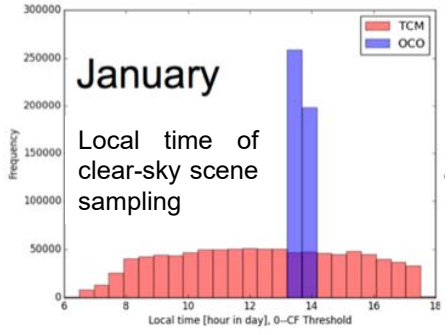
Orbit used successfully by the NASA Tropical Rainfall Monitoring Mission

Compared to a LEO, tropical orbit results in more clear-sky scenes and more uniform temporal sampling

We use a unique 7 km NASA chemistry-climate model to study LEO and TCM orbits





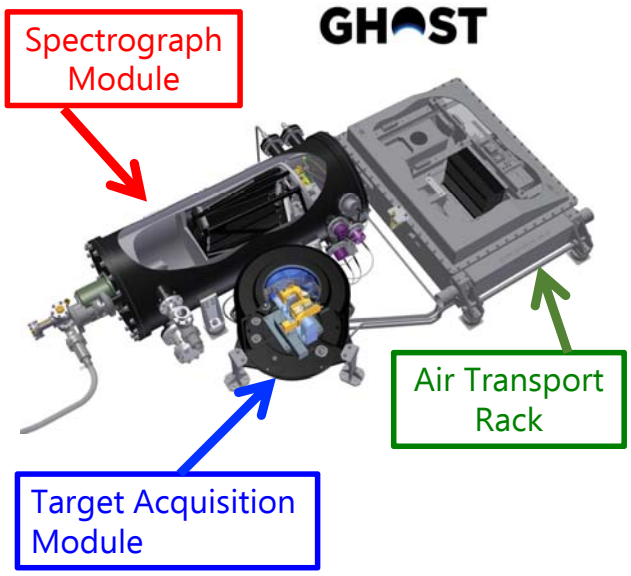


Take home message

TCM has more clear-sky data with less gaps than OCO-2 and no temporal bias. This will result in more robust CO_2 fluxes

TCM: high TRL through proven heritage

Merging astronomy and EO designs.

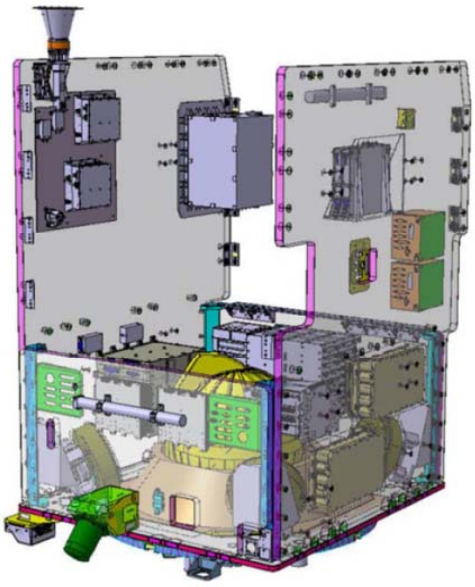


Innovative instrument design

Minimize moving parts, size, mass while maximizing S/N: one grating and two detectors

Design fits available bus platforms

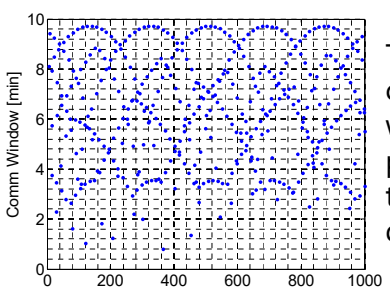
Power, size, mass fit within available launch vehicles, e.g. Vega C



Shown: Airbus Astrobus S

Existing downlink stations address TCM needs

Using 8PSK modulation scheme (470Mbps) at Kourou and Maspalomas



The total communication window length per orbit using the two downlink sites.

TCM: uniqueness and benefits to the UK

Main unique selling points:

1) Addresses compelling science and policy challenges
2) Low risk concept that uses technology with heritage and a proven orbit
3) Relies on UK science and engineering expertise

Benefits of TCM for the UK

1) propel the UK to the forefront of carbon cycle EO science within 5 years
2) promote UKSA within the international arena
3) support UK industry in technology development
4) demonstrate clear economic and environmental leadership
5) inspire new generations of UK scientists
6) develop existing UK expertise in science and engineering

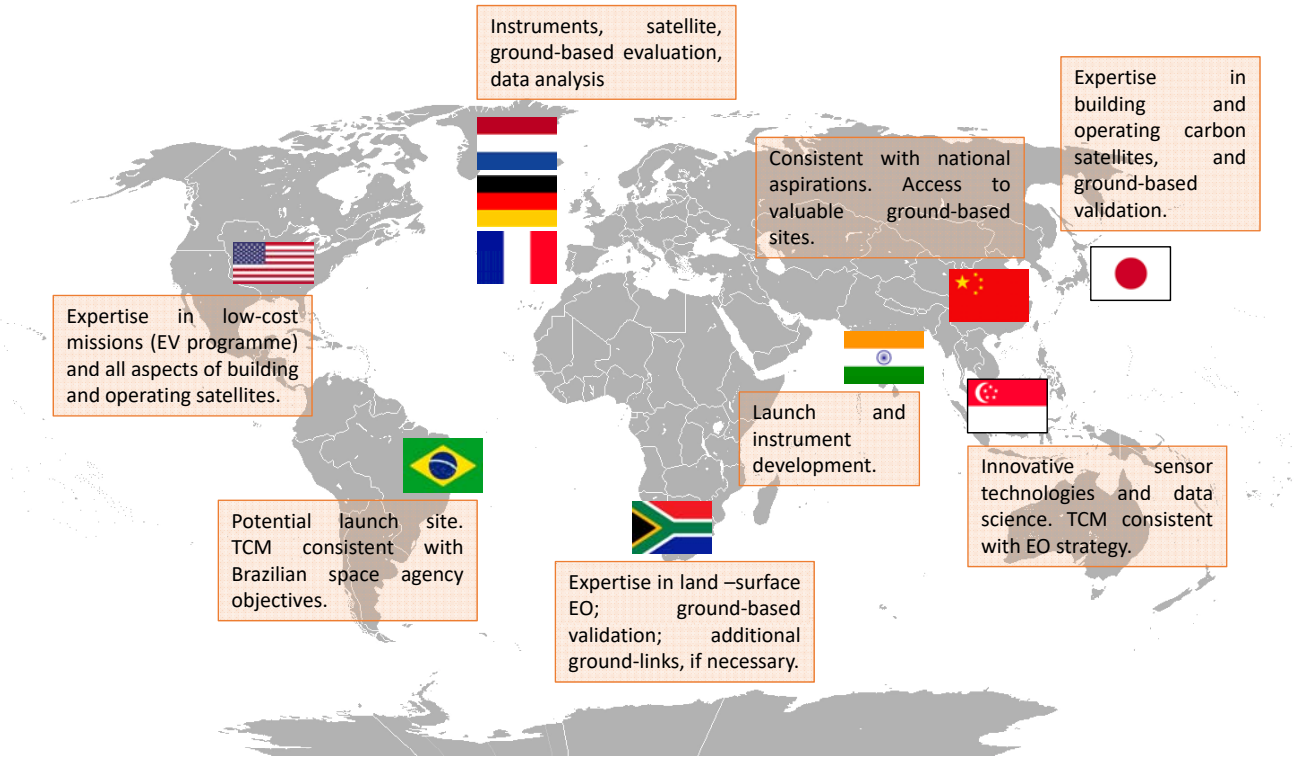
TCM: synergy with existing and planned CO_2 missions

All current missions use LEO

1) TCM has massive scientific advantage over LEO sensors re sampling clear-sky and temporal bias (see previous slides)
2) LEO instruments are complementary to TCM, providing information about midlatitude and high latitudes CO_2 fluxes
3) OCO-3 (launch in mid-2019) provides a useful testbed for TCM

Instrument	Dates	Data products	Orbit/local eq. Overpass time	Nadir dimension of data product
OCO-3	~2019	Column CO_2	Drifting on ISS	1.6 km x 2.2 km
MicroCarb	~2021	Column CO_2	SS	~5 km
Sentinel-5	~2021	Column CO, CH_4	SS	7.5 km x 7.5 km
GeoCarb	~2021	Column CO_2, CH_4, CO	G over Americas	3 km x 6 km
Copernicus CO_2 service constellation	~2025	Column CO_2, CH_4	SS constellation	4 km^2
TCM	~2025	Column CO_2, CH_4	Low inclination, drifting between ±30° latitude	Similar to OCO-3

TCM: assessment of potential partners



Fundamental gap in science knowledge of the tropical C cycle:

- Land biosphere
- Fires
- Wetlands

Compelling societal challenges

- Management of the Earth's resources and energy
- Health of the planet and humankind
- Climate change

TCM

High TRL via heritage of innovative instrument design

High SRL building on NASA, Japanese and ESA proof-of-concept missions

Exploiting European scientific and engineering leadership

The Business Case

- The intention is to develop TCM as a UK-led bilateral or multilateral mission, which requires UKSA financial support (as TCM is a science mission, commercial support is not available).
- The high level requirements for the UK to fund TCM are assumed to be:
  - Mission implementation is low risk, with Technology Readiness Level (TRL) and Science Readiness Level (TRL) of at least 3.
  - The total mission cost, including launch and operations will require less than £280M of UK government funding as of 2019.
  - That the mission will keep UK EO technology at the leading edge.
  - That the mission could be attractive to other ESA member states and potential partners overseas.

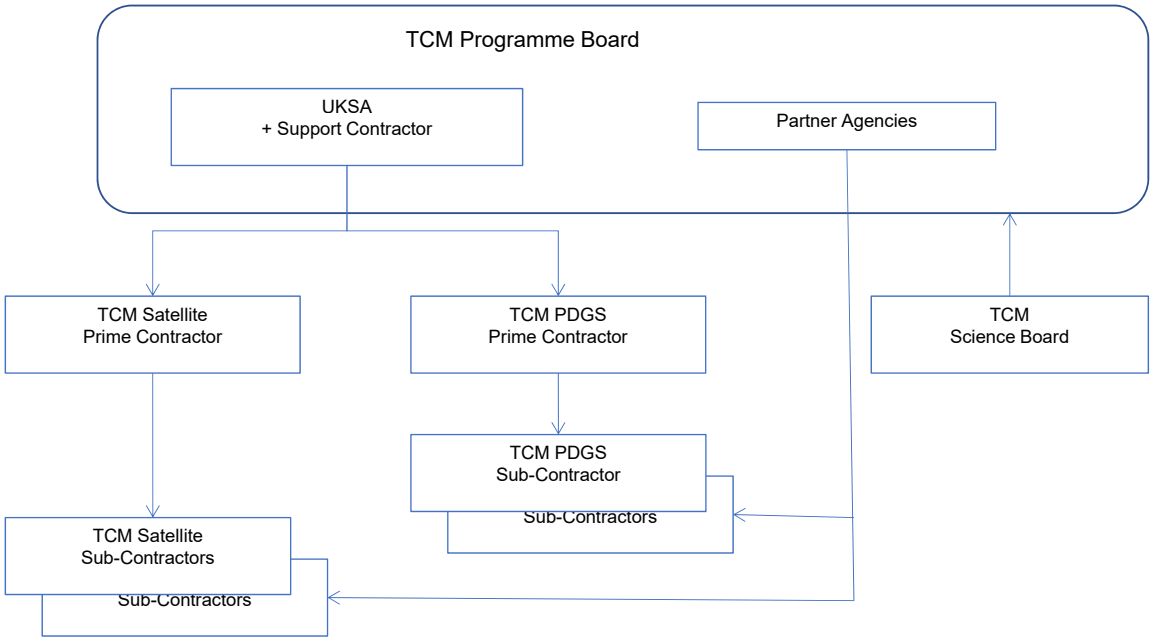
Fit to UKSA Policy Strategy

- The proposal addresses elements of the UKSA's *Earth Observation Strategic Implementation Plan 2015-2017*, and Defra's *A Green Future: Our 25 Year Plan to Improve the Environment*, in particular the critical area of climate change science and services.
- It is also relevant to the UK government's commitment to the Paris Agreement, which addresses the need for sustained carbon monitoring, including from space. This cross-cutting area is of concern to several government departments and agencies, including UKSA, BEIS, Defra, the Met Office and NERC.
- In the framework of the UKSA strategic implementation plan, the following actions are most relevant:
  - A1, to "ensure that the UK is proactive in Europe and policy lines are reflected in ... new European EO programmes ..."
  - C1, to "position the UK at the leading edge for exploitation of climate services from space".
  - D3, regarding "coordinated international activities".

Economic Case

- The mission would bring about important benefits through enhanced knowledge in technology and industrial expertise, as well as wider benefits to society.
- There are two major outcomes for the project:
  - The data provided by TCM will lead to a better understanding of carbon emissions and sinks in the Tropics and will help improve the accuracy and prediction of climate models. The goal of improved climate models is to better mitigate the effects of climate change on the UK and globally.
  - The mission will help build a National Space Programme that will develop UK capabilities in the upstream and downstream sectors of the space industry, with a goal of developing space industry exports.

Project Management Framework



Key roles and responsibilities (1 of 3)

- UKSA
  - Business Case for TCM
  - Procurement of spacecraft and flight operations
  - Procurement of PDGS
  - Negotiation of MOUs with partners
  - Oversee science programme
  - Chair TCM Programme Board
- UKSA Support Contractor
  - Prepare documents for procurement ITTs
  - Manage contracts on behalf of UKSA
  - Support negotiation of MOUs with partners
  - Provide Secretariat for TCM Programme Board

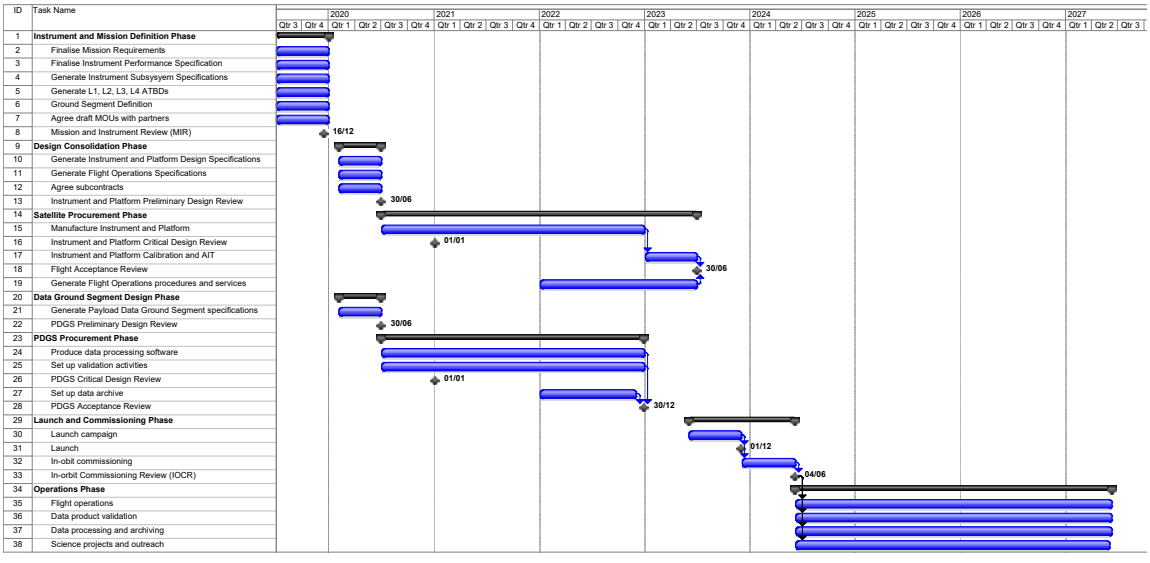
Key roles and responsibilities (2 of 3)

- Partner Agencies
  - Support procurement of spacecraft and flight operations subsystems
  - Support procurement of PDGS subsystems
  - Support science and validation programme
  - Participate in TCM Programme Board
- TCM Science Board
  - Chaired by a Principal Investigator who will report to, and represent the TCM Science Board on, the TCM Programme Board.
  - Produce and maintain TCM Science Requirements and TCM Instrument Performance Requirements
  - Review documents and participate in procurement contract review meetings from a scientific point of view.
  - Advise the UKSA and partners on TCM science matters.
  - Define and co-ordinate TCM science and validation programme
  - Support the use of TCM data in the science community and organise meetings to facilitate the sharing of science results etc.

Key roles and responsibilities (3 of 3)

- TCM Satellite Prime Contractor
  - Procurement of spacecraft and flight operations subsystems
  - Production and delivery of calibrated instrument and spacecraft
  - Launch campaign and In-orbit commissioning
  - Spacecraft flight operations
- TCM Satellite Sub-contractors
  - Production and delivery of instrument and spacecraft subsystems
  - Production and delivery of spacecraft control centre
  - Support, as appropriate, launch, commissioning and flight operations
- TCM PDGS Contractor
  - Procurement of data processing and archiving systems
  - Provide data to users
  - Procurement of validation activities
- TCM PDGS Sub-contractors
  - Production and delivery of data processing and archiving systems
  - Operation of data service to users
  - Conduct validation activities

Preliminary schedule



Expected benefits

- The benefits will accrue to the UK industrial and academic participants initially. Once data are available, government departments, including BEIS and Defra, should benefit from the increased knowledge of the carbon cycle that should follow from the improvement in climate models.
- The TCM mission will contribute to the UK National Space Programme by:
  - Creating an end-to-end Earth Observation mission that is led by the UK, including manufacture, assembly and test of the instrument and spacecraft, and its operation from a UK-based control centre.
  - Expanding the calibration and validation activities in the UK.
  - Developing scientific expertise in the handling and analysis of carbon data.
  - Providing a leading role in carbon monitoring, both for operational application and climate change monitoring.

Appendix – Work share options

Satellite platform and payload options (1 of 2)

Option	Possible UK contributions	Benefits to UK
Spacecraft Platform	The TCM instrument would fit on an Airbus DS Astrobus S platform, which is compatible with a Vega C launcher. An alternative option, if more power is required, is the Astrobus M. SSTL platforms are also an option.	Employment for highly-skilled workforce in platform design and manufacture, and in adjacent industries and supplier organizations Increasing the proportion of upstream space business in the UK Maintains and grows UK satellite manufacturing capability.
Spectrometer	The spectrometer is based on GHOST.	Extends UK capability in designing and building spectrometers. Maintains UK competitiveness in this area.
Detector	The HgCdTe detectors are being developed by Leonardo for ESA and ESO projects. Teledyne-e2v is an alternative UK provider of their US detectors.	Extends UK capability in designing and building detectors. Maintains UK competitiveness in this area.
Instrument Control Unit (ICU)	UK companies have a long history in supplying ICU for spacecraft. In addition to the primes, several smaller companies across the UK are capable of delivering an ICU.	Exploits existing UK expertise.

Satellite platform and payload options (2 of 2)

Option	Possible UK contributions	Benefits to UK
Calibration source	STFC have a long history of providing calibration sources.	Exploits existing UK expertise.
Cooler	The baseline cooler is the Small Scale Cooler (SSC) manufactured by STFC.	Exploits technology developed with UKSA funding.
Assembly, Integration and Test (AIT)	AIT could be performed by Airbus, TAS-UK or SSTL.	Exploits existing expertise in this area and maintains UK capabilities. Could make use of new spacecraft AIT facilities in Harwell.

Satellite ground segment options (1 of 2)

Option	Possible UK contributions	Benefits to UK
Spacecraft Control Centre	Spacecraft Control Centres (SCCs) exist at Satellite Applications Catapult, Airbus or SSTL. Scope of this activity could be scaled depending on the interface with the satellite manufacturer but would include implementation of the SCC software. Several UK companies have also designed SCCs and software for ESA, Eumetsat, Inmarsat, Paradigm etc.	Employment for highly-skilled STEM workforce in satellite ground system design and procurement, software development and in adjacent industries and supplier organizations Increasing the proportion of upstream space business in the UK Grows UK ground infrastructure. Fills a gap in the UK's EO end-to-end capability.
TTC Ground Station	UK could provide use of a 13m or 7.6m antenna, depending on requirements. Two ground stations are required about 180 degrees apart in the tropics.	Use of a UK Telemetry, Tracking and Command (TTC) ground station would build UK capability in satellite mission support. It would exploit UKSA-funded work on CCSDS protocols and demonstrate cross support capability between UKSA and CNES. Fills a gap in the UK's EO end-to-end capability.

Satellite ground segment options (2 of 2)

Option	Possible UK contributions	Benefits to UK
Spacecraft Simulator	UK companies have a long history in supplying simulators for ESA so this would exploit existing UK capabilities. A version with RF or IF hardware could be used to test the interfaces between the ground station and SCC.	Exploits existing UK expertise.
System Tests	This covers (scalable) end-to-end testing of the ground segment, using a spacecraft simulator.	Exploits existing expertise in this area. Goes with the provision of the SCC and TTC ground station.

Algorithm Development and Data Processing options

Option	Possible UK contributions	Benefits to UK
L2 and L4 Algorithm Development	UK science groups have world-class expertise in translating retrieved XCO2 and XCH4 column data into regional estimates of surface fluxes. An existing algorithm could be developed to help underpin the delivery of CO_2 fluxes inferred from TCM data.	This would leverage the strong capabilities of UK science groups from the universities of Leicester and Edinburgh and others (e.g. NCEO). It would position UK players in the frame for a future ESA CO_2 mission. Fundamental to the UK's aim to support carbon monitoring for climate and possible operational applications in the longer term.
L0-L1, L1-L2 and L2-L4 Processing	Several companies in the UK have expertise in the development of L0-L1, L1-L2 and L2-L4 processing software. Software could be run at JASMIN-CEMS.	Generation of L2 products is a key element that feeds directly into downstream exploitation, climate data initiatives and can make use of previous investments at CEMS etc. This role could secure similar roles for future missions. UK L4 expertise would help position the UK to exploit CO_2 data from the Copernicus service. Fundamental to the UK's aim to support carbon monitoring for climate and possible operational applications in the longer term.

Calibration and Validation options

Option	Possible UK contributions	Benefits to UK
Pre-launch Calibration	UK has substantial expertise and facilities for pre-launch calibration of EO instruments. Requires an excellent understanding of the instrument characteristics.	Builds on existing UK expertise in calibration activities and positions the UK for more work in this area. Very important for assuring climate quality data.
Post-launch radiometric (L1) vicarious calibration	There is extensive UK expertise in vicarious calibration of EO mission data.	Vicarious (radiometric) calibration is a key post-launch activity especially for missions in the climate domain. Builds on existing UK expertise. Very important for assuring climate quality data.
Validation (including vicarious)	The UK has extensive experience in the validation of EO instrument data products. The activities could include the use of the GHOST instrument as an airborne validation facility.	Validation is a key activity post-launch especially for missions in the climate domain. Builds on existing UK expertise. Very important for assuring climate quality data.