The Tropical Carbon Mission (TCM): quantifying tropical carbon fluxes from space

A proposed bilateral mission between the UK Space Agency and NASA

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Abstract

We present an overview of the Tropical Carbon Mission (**TCM**), a proposed bilateral Earth Observation mission between the UK and US space agencies, for launch in 2015/2016. TCM will measure columns of CO_2, CH_4 and CO over the tropics to a precision sufficient to infer the underlying emission and uptake of CO_2 from natural and anthropogenic activities. We present the TCM mission objectives and how they address current and future science and political issues related to the release and uptake of CO_2. We also discuss how funding TCM will benefit UK science and industry sectors.

Scientific and Political Impetus for TCM

The importance of CO_2 and CH_4 in climate is well established. There is broad scientific consensus that human activities are the main driver for increasing concentrations of these greenhouse gases (**GHGs**), particularly over the past century (Denman et al, 2007). Based on accurate surface measurements we know that on average less than half of the CO_2 emitted by human activities remain in the atmosphere. The net balance is apparently being taken up by global oceans, terrestrial vegetation and soils (Canadell et al, 2007). However, there are substantial uncertainties associated with the location, strength and durability of these natural components of the carbon cycle (Le Quere et al, 2009). There is a similar underlying story about tropical and boreal emissions of CH_4 from wetlands (Heimann, 2010). Without proper characterisation of these natural fluxes we cannot obtain reliable predictions of future climate and it will be impossible to move far forward with establishing a robust emission verification scheme that is critical in reducing global GHG emissions.

The tropics and sub-tropics are regions of key importance for the global carbon cycle. They are characterized by a high ecosystem diversity and productivity, with large spatial and temporal variability of natural and anthropogenic carbon release and uptake. These ecosystems are subject to rapid environmental change due to extensive deforestation and urbanisation, with consequent changes in hydrology and regional carbon balance. The existing network of surface measurements (flasks, continuous sensors, tall towers and aircraft flights) provides an excellent measure of the temporal, seasonal, and latitudinal variations of global carbon fluxes. However, these measurements are mostly located in maritime locations within Europe and North America whereas key regions such as the tropics or southern-hemispheric sub-Tropics are essentially unobserved. Consequently, the tropics and sub-tropics remain poorly characterized compared to other ecosystems on the planet and dense and frequent observations as obtained by TCM are urgently needed to improve our understanding of the tropical carbon cycle.

Anthropogenic GHG emissions are receiving increased attention from the international policy communities, such as the United Nations Framework Convention on Climate Change, and from the financial sector, as carbon trading becomes more prevalent. A key challenge for monitoring anthropogenic emissions is that these emissions to the atmosphere are embedded within a dynamic, natural carbon cycle with much larger fluxes into and out of the atmosphere. Measurements of anthropogenic contributions with the precision and frequency likely to be required by policy makers and carbon markets is an unmet technical challenge, which can be addressed with precise and reliable measurements from space, such as those made by TCM.

TCM Mission Objectives

TCM is a GHG monitoring mission that will measure CO_2, CH_4 and CO columns over the tropics to a precision sufficient to infer the underlying emission and uptake of CO_2 from natural and anthropogenic activities.

The primary science and economic objectives of TCM are to reduce overall uncertainties in the magnitude and distribution of tropical CO_2 fluxes, and to improve our understanding of the tropical carbon cycle. These will result in more reliable climate change forecasts and contribute to the verification of anthropogenic emissions as part of international treaty agreements. By better estimating tropical fluxes, we also improve the efficacy of existing surface measurement networks to help estimate extratropical CO_2 fluxes.

The secondary science objectives of TCM are: 1) to reduce the uncertainties in the magnitude and distribution of CO and CH_4; and 2) use concurrent measurements of CO and CH_4 to improve source attribution of observed variations in CO_2.

The tertiary science objective of TCM is to complement global survey CO_2 measurements from the NASA OCO-2 instrument, which will be launched in a sun-synchronous orbit in 2013.

TCM Mission Overview

TCM will be in a low Earth orbit of 430 km altitude and an inclination of 35^o. The orbit inclination has been selected to enhance coverage over the tropics (Figure 1), where there are currently large uncertainties in the magnitude and distribution in the release and uptake of GHGs. TCM is expected to reduce these uncertainties to levels commensurate with those in the developed world. The TCM orbit precesses with a repeat time of 48 days so that successive measurements provide some information on the temporal variability of emissions.

TCM carries two mature instruments: (1) a copy of the visible/short-wave IR (**SWIR**) spectrometer that the NASA/Jet Propulsion Laboratory (**JPL**) has developed for the Orbiting Carbon Observatory (**OCO**) missions (Crisp et al, 2004); and (2) a version of the SWIR instrument developed in the UK for the ESA Sentinel-5 precursor, the Carbon Monoxide and Methane Spectrometer (**CMS**), which will be co-boresighted with the OCO instrument. The maturity of the instruments minimises the overall risk to the mission (Appendix A).

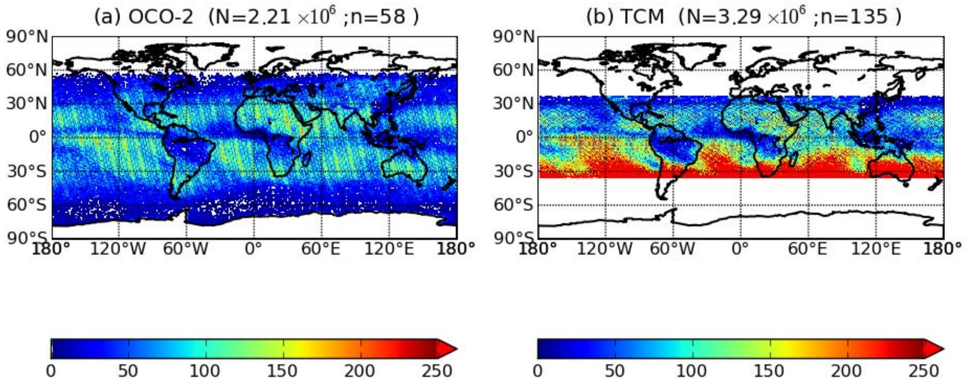

Figure 1: The number of cloud- and aerosol- clear scenes for January 2003 averaged on a uniform 1 degree grid for OCO-2 and for TCM. N denotes the monthly global total clear-sky measurements, and n denotes the mean number of clear-sky measurements for each grid box with measurements.

The combined instrumentation will measure atmospheric concentrations of CO_2, CH_4 and carbon monoxide (CO). CO is an excellent atmospheric tracer of incomplete combustion that will be used to identify the burning of biomass, which is extensive over the tropics. Concurrent measurements of CO and CO_2 will be used to distinguish between the release and uptake of CO_2 from combustion and natural sources (e.g., Palmer et al, 2006). Our calculations show that even including realistic levels of instrument noise CO_2 measurements from TCM will be sufficient to produce independent estimates of the release and uptake of CO_2 over finer spatial resolutions achievable using OCO-2 (Figure 2). By using TCM in conjunction with OCO-2 we improve the spatial resolution by an addition 33%.

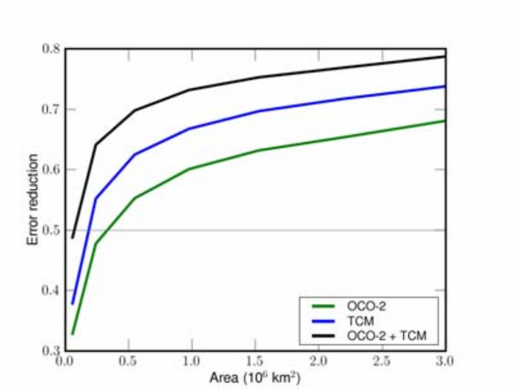

Figure 2: The fractional error reduction of estimated surface CO_2 fluxes over South America (15°S—15°N) during January 2003 as a function of spatial resolution achieved by using measurements from OCO-2 and TCM, and the combination of the two instruments. The horizontal line (the error reduction=0.5), indicates the level above which the error reduction is driven mostly by the measurements.

TCM has been designed with the SSTL600 spacecraft bus developed by Surrey Space Technologies Limited (**SSTL**). The preferred launch vehicle is the Space-X Falcon-1e, which can be launched out of the Vandenburg launch site in Central California. Flight system integration and testing will take place at JPL.

Post-launch mission operations would be primarily conducted from the UK, with data downlinked through commercially available ground stations. Raw data from each instrument will be processed separately at science data processing centres at JPL and in the UK. Processed data products will be combined to develop higher-order products, such as tropical GHG flux maps. We will take advantage of mature production algorithms developed for the OCO-2 missions (Bösch et al, 2006), which will save time and money for TCM.

The TCM science team will be led by leading UK and US scientists, with wider participation from the science community in both countries. Participation from scientists in countries located in tropical regions, particularly with regard to validation of TCM results, will be encouraged.

Mission Opportunity

NASA will release a new Venture call for proposals in 2011: officially scheduled for June with a September submission deadline. The total amount of the call is $150M, which is roughly half the cost of comparable predecessor missions NASA has flown, e.g. Cloudsat and OCO. NASA envisages the launch of the first Venture mission in 2015/2016. NASA has requested "imaginative" ways to fit within the cost envelope, including bilateral missions, which is also consistent with the recent Joint Statement of Interest between NASA and the UK Space Agency supports this interpretation.

Relevant Experience

TCM will be an equal partnership between the UK and NASA/JPL, with each partner contributing the best of their capabilities. Both have world-class atmospheric science and climate science communities, as well as leading edge developers of Earth Observation instruments. SSTL is seen as a world leader in cost-effective small satellites. The UK also has a venerable history of key contributions to ESA's Earth Observation programme. NASA/JPL has a long history of success in executing space missions, and currently contributes more than half of the observations in NASA's Earth Observation fleet. The US has extensive experience in launching satellites, which is now being augmented by new low-cost commercial ventures, which are strongly supported by NASA.

What are the Unique Selling Points of TCM?

1) TCM is a focused mission concept with low risk that uses technology that already exists, and an orbit similar to one that has been used previously by the NASA Tropical Rainfall Monitoring Mission satellite.

2) TCM directly addresses compelling science, political and economic challenges that will only become more pressing with time.

3) For a modest investment, the UK Space Agency can take advantage of substantial NASA infrastructure to launch a cutting-edge instrument and to greatly enhance the science return.

What are the benefits of TCM for the UK?

There are a number of compelling reasons why the UK should invest in TCM. TCM will

1) <u>propel the UK Space Agency</u> to the forefront of current EO technology and carbon cycle science within 5 years;

2) <u>promote UK science and technology leadership</u> within the international space agency arena;

3) <u>support UK industry</u> with UK investment in bus and spectrometer technology returned to UK-based companies;

4) demonstrate clear economic leadership to help verify greenhouse gas emissions to support international climate agreement;

5) inspire upcoming generations of UK scientists through target outreach material;

6) utilize existing UK expertise in science and engineering, which saves money because there is no need to develop new facilities to initiate the project;

7) meet the objectives expressed in the recently agreed Joint Statement of Interest between the UK Minister of Science and the head of NASA by forging a partnership in Earth observation between leading UK entities and the Jet Propulsion Laboratory, a leading NASA science centre; and

8) represent a stepping-stone to an operational carbon monitoring system.

References

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Appendix A: Details of OCO-3 and CMS

The TCM instruments include: the NASA Orbiting Carbon Observatory (OCO-3) instrument measuring CO_2 and the UK Carbon Monoxide and Methane Spectrometer (CMS), to measure CH_4 and CO (see Table 1 for a summary of the observation parameters).

Table 1: Overview of instruments onboard TCM. Note that the swath width and size of spatial samples is for an orbit altitude of 760 km. For a 430 km orbit altitude, they will be reduced to ~57% of the given values.

Instrument	**OCO-3**			**CMS**
Spectral band	757 - 772 nm	1590 - 1620 nm	2040 - 2080 nm	2305 - 2385 nm
Spectral resolution (FWHM)	<0.05 nm	<0.08 nm	<0.1 nm	0.25 nm
Swath width	10 km	10 km	10 km	2600 km
Spatial samples	3 km^2	3 km^2	3 km^2	7 x 7 km^2
Main Function	Cloud and aerosol, surface pressure	CO_2 columns	CO_2 columns, cloud and aerosol	CO and CH_4 columns

The OCO-3 instrument is effectively a copy of the OCO-2 instrument, scheduled to fly in 2013. The OCO-3 instrument is designed to measure the absorption of reflected and scattered sunlight by CO_2 and molecular oxygen (O_2) at near-IR/SWIR wavelengths. Consequently, measurements of CO_2 in these spectral bands are sensitive to near-surface quantities of CO_2 where atmospheric variability of CO_2 is largest due to uptake by vegetation or release through transpiration or combustion. The spectral resolution and signal-to-noise of this instrument is sufficient to resolve the CO_2 absorption lines in this spectral region, thus reducing uncertainties from interfering species and surface albedo. The OCO instrument measures the O_2-A band to provide a reference O_2 column to help reduce systematic errors from uncertainties in H_2O, surface pressure, and unresolved clouds. Combining measurements of the O_2-A band and the 2040-2080 nm CO_2 band will also be used to characterize aerosols, a key interferent that can greatly increase the bias error in the estimated CO_2 columns if not accounted properly in the CO_2 estimate. To obtain dense coverage, OCO employs two science observation modes. In the nadir mode, the instrument points toward the local nadir and achieves the highest spatial resolution and is expected to provide the most reliable data over bright land surfaces and in regions with patchy clouds. In glint mode, the instrument points at the glint spot, where sunlight is specularly reflected from the surface. The sunglint mode is expected to yield more reliable data over water surfaces, which are relatively dark at SWIR wavelengths. Finally, the OCO footprint, approximately 3km^2 (at 760 km altitude), is designed to increase the number of clear-sky scenes because already relatively thin clouds (with optical depth of more than 0.3) can make the estimation of CO_2 from near IR radiances impractical.

The Carbon Monoxide and Methane Spectrometer (CMS) is based on the SSTL design for the GMES Sentinel 5 Precursor SWIR module, utilising an immersed grating spectrometer to minimise the mass and volume of the instrument. This instrument will provide 7 km spatial sampling with a swath width of 2600 km. The spectral range covered by the instrument is 2314 to 2842 nm and is designed to provide a resolution of approximately 0.25mn. For TCM, CMS and OCO will be co-aligned to minimize coincident sampling error. The sampling strategy between the two instruments will be reviewed at a later stage.