GHG White Paper

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CEOS AC-VC
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Chapters

Contributions from participants at the CGMS and CEOS AC-VC meeting were incorporated into the White Paper structure:

Executive Summary

1: Introduction

2: **Using atmospheric GHG measurements to improve inventories**

3: Space-based GHG measurement capabilities and near term plans

4: Lessons Learned from SCIAMACHY, GOSAT and OCO-2

5: Integrating GHG Satellites into Operational Constellations

6: Towards an operational constellation measuring anthropogenic CO₂ emissions

7: **The Transition from Science to Operations**

8: Conclusions
Past and Present GHG Satellites

- **SCIAMACHY (2002-2012)** – First sensor to measure \( \text{O}_2 \), \( \text{CO}_2 \), and \( \text{CH}_4 \) using reflected NIR/SWIR sunlight
  - Regional-scale maps of \( X_{\text{CO}_2} \) and \( X_{\text{CH}_4} \) over continents

- **GOSAT (2009 …)** – First Japanese GHG satellite
  - FTS optimized for high spectral resolution over broad spectral range, yielding \( \text{CO}_2 \), \( \text{CH}_4 \), and chlorophyll fluorescence (SIF)

- **OCO-2 (2014 …)** – First NASA satellite to measure \( \text{O}_2 \) and \( \text{CO}_2 \) with high sensitivity, resolution, and coverage
  - High resolution imaging grating spectrometer small (< 3 km\(^2\)) footprint and rapid sampling (10\(^6\) samples/day)

- **TanSat (2016 …)** - First Chinese GHG satellite
  - Imaging grating spectrometer for \( \text{O}_2 \) and \( \text{CO}_2 \) bands and cloud & aerosol Imager
  - In-orbit checkout formally complete in August 2017
In orbit Checkout

• **Feng Yun 3D (2017)** – Chinese GHG satellite on an operational meteorological bus
  - GAS FTS for $O_2$, $CO_2$, $CH_4$, $CO$, $N_2O$, $H_2O$

• **Sentinel 5p (2017)** - Copernicus pre-operational Satellite
  - TROPOMI measures $O_2$, $CH_4$ (1%), $CO$ (10%), $NO_2$, SIF
  - Imaging at 7 km x 7 km resolution, daily global coverage

• **Gaofen 5 (2018)** - 2nd Chinese GHG Satellite
  - Spatial heterodyne spectrometer for $O_2$, $CO_2$, and $CH_4$

• **GOSAT-2 (2018)** – Japanese 2nd generation satellite
  - CO as well as $CO_2$, $CH_4$, with improved precision (0.125%), and active pointing to increase number of cloud free observation

• **OCO-3 (2019*)** – NASA OCO-2 spare instrument, on ISS
  - First $CO_2$ sensor to fly in a low inclination, precessing orbit

The Next Generation
Future GHG Satellites (2)

- **CNES/UK MicroCarb (2021+)** – compact, high sensitivity
  - Imaging grating spectrometer for $O_2 A$, $O_2 ^1\Delta_g$, and $CO_2$
  - $\sim 1/2$ of the size, mass of OCO-2, with 4.5 km x 9 km footprints

- **CNES/DLR MERLIN (2021+)** - First CH$_4$ LIDAR (IPDA)
  - Precise (1-2%) $X_{CH4}$ retrievals for studies of wetland emissions, inter-hemispheric gradients and continental scale annual CH$_4$ budgets

- **NASA GeoCarb (2022*)** – First GEO GHG satellite
  - Imaging spectrometer for $X_{CO2}$, $X_{CH4}$, $X_{CO}$ and SIF
  - Stationed above 85° W for North/South America

- **Sentinel 5A,5B,5C (2022)** - Copernicus operational services for air quality and CH$_4$
  - Daily global maps of XCO and XCH4 at $< 8$ km x 8 km
• A broad range of GHG missions will be flown over the next decade.

• Most are “science” missions, designed to identify optimal methods for measuring CO₂ and CH₄, not “operational” missions designed to deliver policy relevant GHG products focused on anthropogenic emissions.
GCOS CO₂ and CH₄ Requirements.

The CO₂ and CH₄ measurement requirements in the 2011 update for the Global Climate Observing System (GCOS) Systematic Observation Requirements for Satellite-Based Data Products for Climate (GCOS, 2011) and GCOS 2016 Implementation Plan (GCOS, 2016) were adopted as targets for a future GHG constellation.

<table>
<thead>
<tr>
<th>Variable / Parameter</th>
<th>Horizontal Resolution</th>
<th>Vertical Resolution</th>
<th>Temporal Resolution</th>
<th>Accuracy</th>
<th>Stability/Decade*</th>
<th>Stability/Decade**</th>
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</thead>
<tbody>
<tr>
<td>Tropospheric CO₂ column</td>
<td>5-10km</td>
<td>N/A</td>
<td>4 h</td>
<td>1 ppm</td>
<td>0.2 ppm</td>
<td>1.5 ppm</td>
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<tr>
<td>Tropospheric CH₄ column</td>
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<td>4 h</td>
<td>10 ppb</td>
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<tr>
<td>Tropospheric CH₄</td>
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<td>10 ppb</td>
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<td>0.7 ppb</td>
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<tr>
<td>Stratospheric CH₄</td>
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<td>2 km</td>
<td>Daily</td>
<td>5%</td>
<td>0.30%</td>
<td>0.30%</td>
</tr>
</tbody>
</table>

* from GCOS 2011
** from GCOS 2016
Timely inputs to policy makers

Paris Agreement

CO₂ Task Force

2015 2017 2021

Global Stock Take 1
using inventories of 2021 2023

2026 2028

Global Stock Take 2
using inventories of 2026

Initial system capacity built up
Launch target for Copernicus S-7 constellation

Mission Requirement Document

CO₂ Follow-up Report
The coverage, resolution, and precision requirements could be achieved with a constellation that incorporates

- A constellation of 3 (or more) satellites in LEO with
  - A broad (> 200) km swath with a mean footprint size < 4 km²
  - A single sounding random error near 0.5 ppm, and vanishing small regional scale bias (< 0.1 ppm) over > 80% of the sunlit hemisphere
  - One (or more) satellites carrying ancillary sensors (CO, NO₂, CO₂ and/or CH₄ Lidar)

- A constellation with 3 (or more) GEO satellites
  - Monitor diurnally varying processes (e.g. rush hours, diurnal variations in the biosphere)
  - Stationed over Europe/Africa, North/South America, and East Asia

- This constellation could be augmented with one or more HEO satellites to monitor carbon cycle changes in the high arctic
Future LEO GHG Constellations in the Planning Stages

- **Copernicus Sentinel CO₂ (2025+)**
  - 3 or 4 LEO satellites in an operational GHG constellation
  - Primary instruments measure O₂ (0.76 µm A-band), CO₂ (1.61 and 2.06 µm), and NO₂ (0.450 µm) at a spatial resolution of 2 km x 2 km along a broad (200-300 km) swath
  - A dedicated cloud/aerosol instrument is also under consideration

- **TanSat-2 Constellation**
  - 6 satellites, with 3 flying in morning sun-synchronous orbits and 3 flying in afternoon sun-synchronous orbits
  - Primary GHG instrument on each satellite with measure CO₂ (1.61 and 2.06 µm), CH₄ and CO (2.3 µm) as well as the O₂ A-band (0.76 µm) across a 100-km cross-track swath
• Because of the unprecedented requirements for precision and accuracy, the space based elements of the an operational GHG constellation architecture must be accompanied by
  o Rigorous pre-launch and on-orbit measurement calibration and product validation methods that evolve to meet emerging needs
  o Continuous refinements in remote sensing retrieval and flux inversion modeling methods that improve the products over time
• CEOS could play an essential role in coordinating these activities among its partner agencies
• Any operational architecture will also have to address
  o orbit and mission coordination, data distribution, data exchange, and data format requirements
  o Training and capacity building and public outreach will be needed to fully exploit the value of the space based GHG measurements
• CEOS should collaborate with CGMS and other operational organizations to foster the development of these capabilities
On “placing the space segment in the broader context of a fully sustained system for CO2 monitoring”

The EC proposes to organise a dedicated discussion workshop:
• Bringing together these different stakeholders to define best practices and synergies
• Exploring possibilities for common approaches to some of the system development.
• This would also require the strong engagement of CGMS as well as CEOS Associate members such as the WMO.

June 18-19th European Commission – JRC, Ispra (IT)
• 9 CEOS Agencies confirmed attendance 2-4 people each, 3 CEOS associates – around 40 attendees in total
CEOS Chair GHG Workshop

Monday 18th June

Introduction & Objectives

International Programmes:
WMO, GCOS, GEO

Ongoing Activities:
AC-VC Whitepaper, Inversion Modelling Workshop, IPCC TFI, Copernicus…

Agencies Perspectives:
CNES, CSA, CMA, DLR, NOAA, NASA, JAXA, EU (EC, ESA, EUM), UKSA

General & Crosscutting Aspects:
discussion on issues such as terminology
System defn., needs and requirements

Tuesday 19th June

Review of Previous Day

Break out Groups:
Space-Modelling, Space-In-situ, Space-Inventory

Reports from Breakout Groups

Consolidation of Recommendations and Identified Best Practices

Conclusion and Follow-up
Overview of the Core Elements of the Copernicus CO$_2$ Emission Monitoring & Verification Support capacity