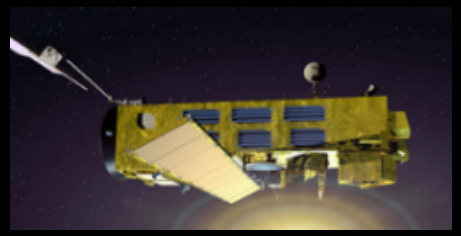
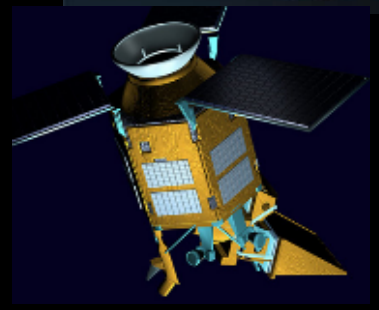
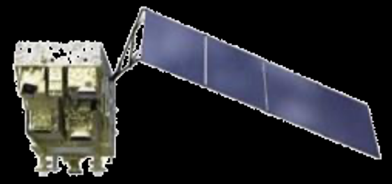
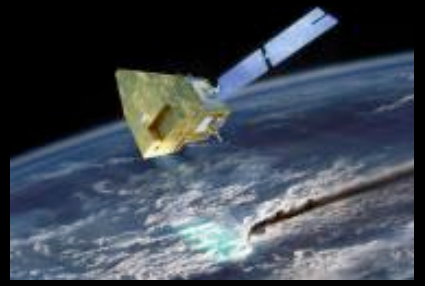
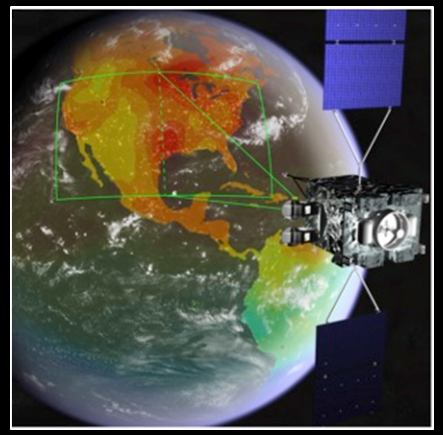
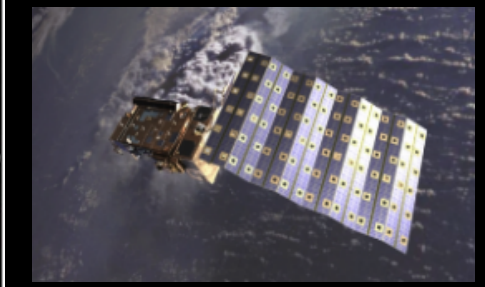
The Evolving Space-based Greenhouse Gas Measurement Fleet



David Crisp (Jet Propulsion Laboratory, California Institute of Technology)

for the CEOS AC-VC Greenhouse Gas Team, 4 June, 2019

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The Evolving GHG Constellation

- Space agencies are deploying a growing fleet of space-based sensors designed to collect high-resolution spectra within CO_2 and CH_4 bands at shortwave infrared (SWIR) wavelengths.
- These sensors are well suited for monitoring surface CO_2 and CH_4 fluxes because estimates of their column averaged dry air mole fractions (XCO_2 and XCH_4) are most sensitive to changes in the concentration these gases in the lower troposphere.
- Recent efforts to analyze the data from these sensors have demonstrated the precision (~0.125%) and accuracy (~0.25%) needed to resolve both anthropogenic and natural fluxes of CO_2 and CH_4 on spatial scales spanning individual power plants to regional scales.
- These systems still do not have the spatial or temporal resolution and coverage needed to provide timely, quantified guidance on natural and anthropogenic fluxes at urban to national scales.
- One way to address this challenge would be to would be to integrate the available space-based sensors into a virtual constellation, and harmonize their data products so that their XCO_2 and XCH_4 estimates can be combined and assimilated into atmospheric inversion models.

Updating the GCOS CO_2 and CH_4 Requirements

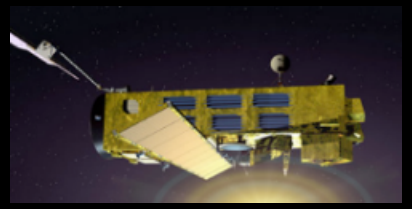
The CO_2 and CH_4 measurement requirements in the 2011 update for the Global Climate Observing System (GCOS) Systematic Observation Requirements for Satellite-Based Data Products for Climate (GCOS, 2011) were adopted as targets for a future GHG constellation.

Variable / Parameter	Horizontal Resolution	Vertical Resolution	Temporal Resolution	Accuracy	Stability/ Decade*
Tropospheric CO_2 column	5-10km	N/A	4 h	1 ppm	0.2 ppm
Tropospheric CO_2	5-10 km	5 km	4 h	1 ppm	0.2 ppm
Tropospheric CH_4 column	5-10 km	N/A	4 h	10 ppb	2 ppb
Tropospheric CH_4	5-10 km	5 km	4 h	10 ppb	2 ppb
Stratospheric CH_4	100-200 km	2 km	Daily	5%	0.30%

We are currently working with GCOS to refine these requirements

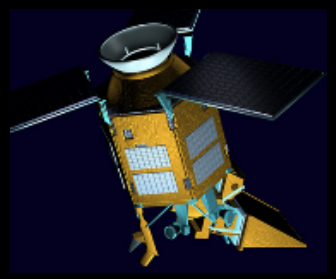
The Pioneers

- **ENVISAT SCIAMACHY (2002-2012)** – First NIR/SWIR sensor for O_2, CO_2, and CH_4
  - XCO_2 and XCH_4 over continents
- **GOSAT (2009 …)** – First Japanese GHG satellite
  - TANSO-FTS optimized for high spectral resolution over broad spectral range, yielding CO_2, CH_4, and chlorophyll fluorescence (SIF)
- **OCO-2 (2014 …)** – First NASA satellite to measure O_2 and 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 O_2 and CO_2 bands and cloud & aerosol Imager



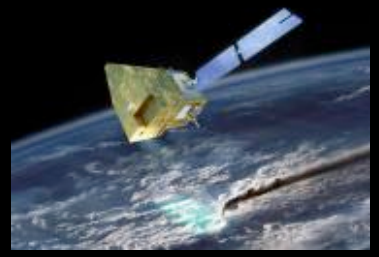
The Next Generation

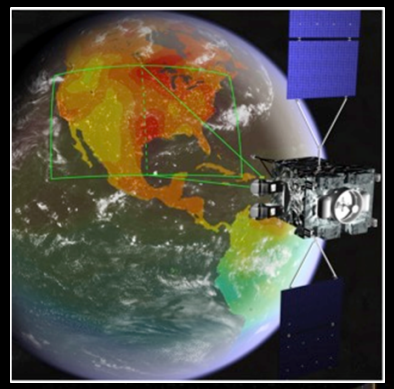
- **Feng Yun 3D (2017)** – Chinese GHG satellite on an operational meteorological bus
  - GAS FTS for O_2, CO_2, CH_4, CO, N_2O, H_2O
- **Sentinel 5p (2017)** - Copernicus pre-operational Satellite
  - TROPOMI measures O_2, CH_4 (1%), CO (10%), NO_2, SIF
  - Imaging at 7 km x 7 km resolution, daily global 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 Near Future

- **CNES MicroCarb (2021+)** – compact, high sensitivity
  - Imaging grating spectrometer for O_2 A, O_2 $^1\Delta_g$, and CO_2
  - ~1/2 of the size, mass of OCO-2, with 4.5 km x 9 km footprints
- **Sentinel 5A,5B,5C (2022) - Copernicus operational services**
  - Daily global maps of XCO and XCH4 at < 8 km x 8 km
- **NASA GeoCarb (2023*) – First GEO GHG satellite**
  - Imaging spectrometer for X_{CO2}, X_{CH4}, X_{CO} and SIF
  - Stationed above ~103° W to view North/South America
- **CNES/DLR MERLIN (2024)** - 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

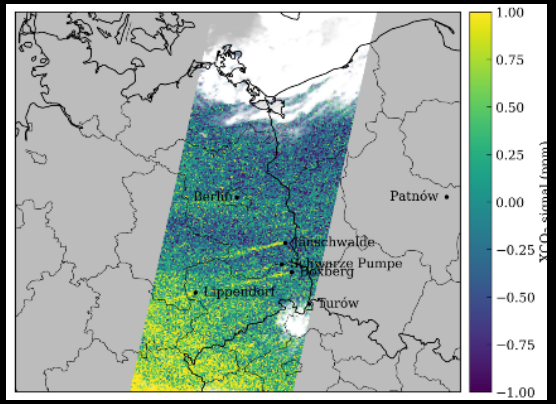


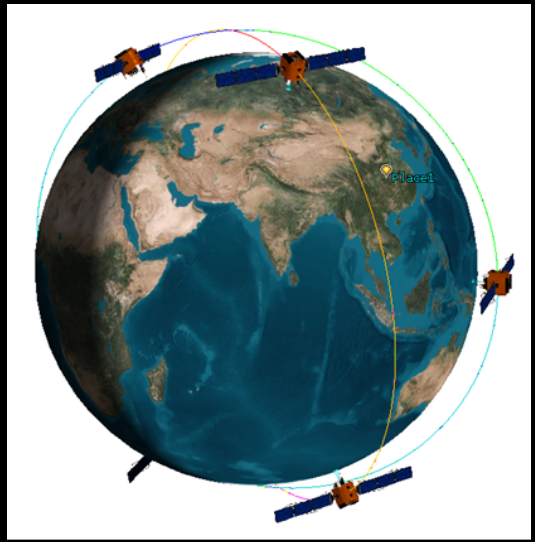


“ Pre-Decisional Information -- For Planning and Discussion Purposes Only

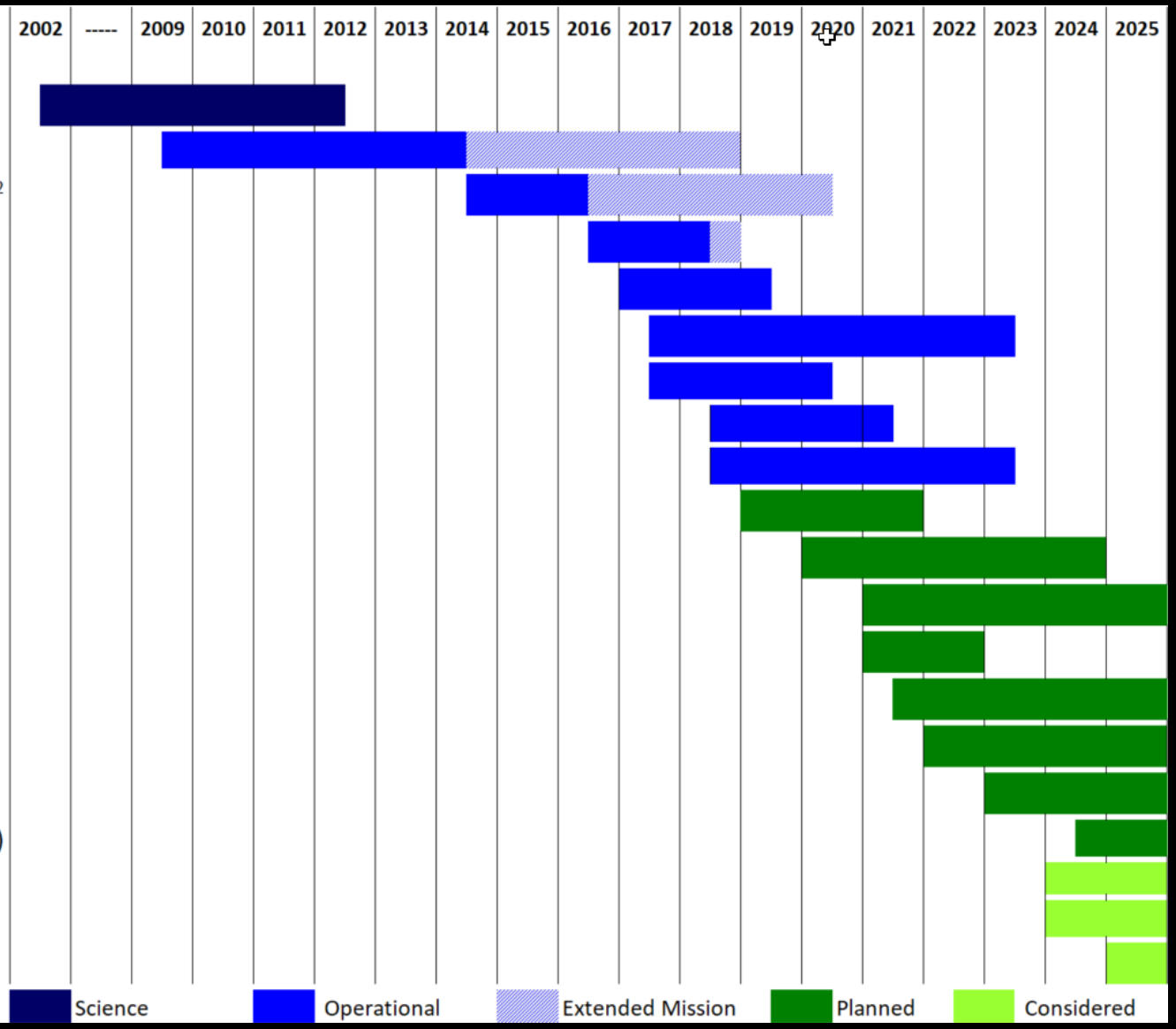
Future Operational LEO GHG Constellations in Planning Stages

- **Copernicus CO_2 Sentinel (2025+)**
  - 3 or 4 LEO satellites in an operational GHG constellation
  - Primary spectrometer measures O_2 (0.76 μm A-band), CO_2 (1.61 and 2.06 μm), CH4 (1.67 μm)
  - Ancillary instrument include
    - NO_2 (0.450 μm) at a spatial resolution of 2 km x 2 km along a 200-300 km swath for plumes
    - A cloud/aerosol multi-angle polarimeter
- **TanSat-2 Constellation**
  - 6 satellites, with 3 flying in morning and 3 flying in afternoon sun-synchronous orbits
  - primary GHG instrument on each satellite measures CO_2 (1.61 and 2.06 μm), CH_4 and CO (2.3 μm) as well as the O_2 A-band (0.76 μm) across a 100-km cross-track swath





TanSat Constellation

The GHG Mission Timeline

Satellite, Instrument (Agencies)	CO_2	CH_4	Swath	Sample
ENVISAT SCIAMACHY (ESA)	●	●	960 km	30x60 km^2
GOSAT TANSO-FTS (JAXA-NIES-MOE)	●	●	3 pts	10.5 km (d)
OCO-2 (NASA)	●		10.6 km	1.3x2.3 km^2
GHGSat (Claire)		●	12 km	0.0004 km^2
TanSAT (CAS-MOST-CMA)	●		20 km	1x2 km^2
Sentinel 5P TROPOMI (ESA)		●	2600 km	7x7 km^2
Feng Yun 3D GAS (CMA)	●	●	7 pts	10 km (d)
GaoFen-5 GMI	●	●	5-9 pts	10 km (d)
GOSAT-2 TANSO-FTS (JAXA-MOE-NIES)	●	●	5 pts	10.5 km (d)
OCO-3 (NASA)	●		11 km	4 km^2
Bluefield Technologies		●	25x20 km	0.0004 km^2
MicroCarb (CNES)	●		13.5 km	40 km^2
MethaneSAT (EDF)		●	200 km	1 km^2
MetOp Sentinel-5 series (Copernicus)		●	2670 km	7x7 km^2
Feng Yun 3G (CMA)	●	●	100 km	< 3 km^2
GEOCARB (NASA)	●	●	2800 km	4x4 km^2
MERLIN (DLR-CNES)		●	100 m	0.14 km (w)
TanSat-2 Constellation	●	●	3x100 km	2x2 km^2
GOSAT-3 (JAXA-MOE-NIES)	●	●	TBD	TBD
CO2 Sentinel (Copernicus)	●	●	3x250 km	2x2 km^2