WGClimate
The joint CEOS/CGMS Working Group on Climate

D. Crisp[1], M. Dowell[2], R. Husband[3], A. von Bargen[4] and J. Schulz[3] for the CEOS/CGMS WGClimate GHG Task Team

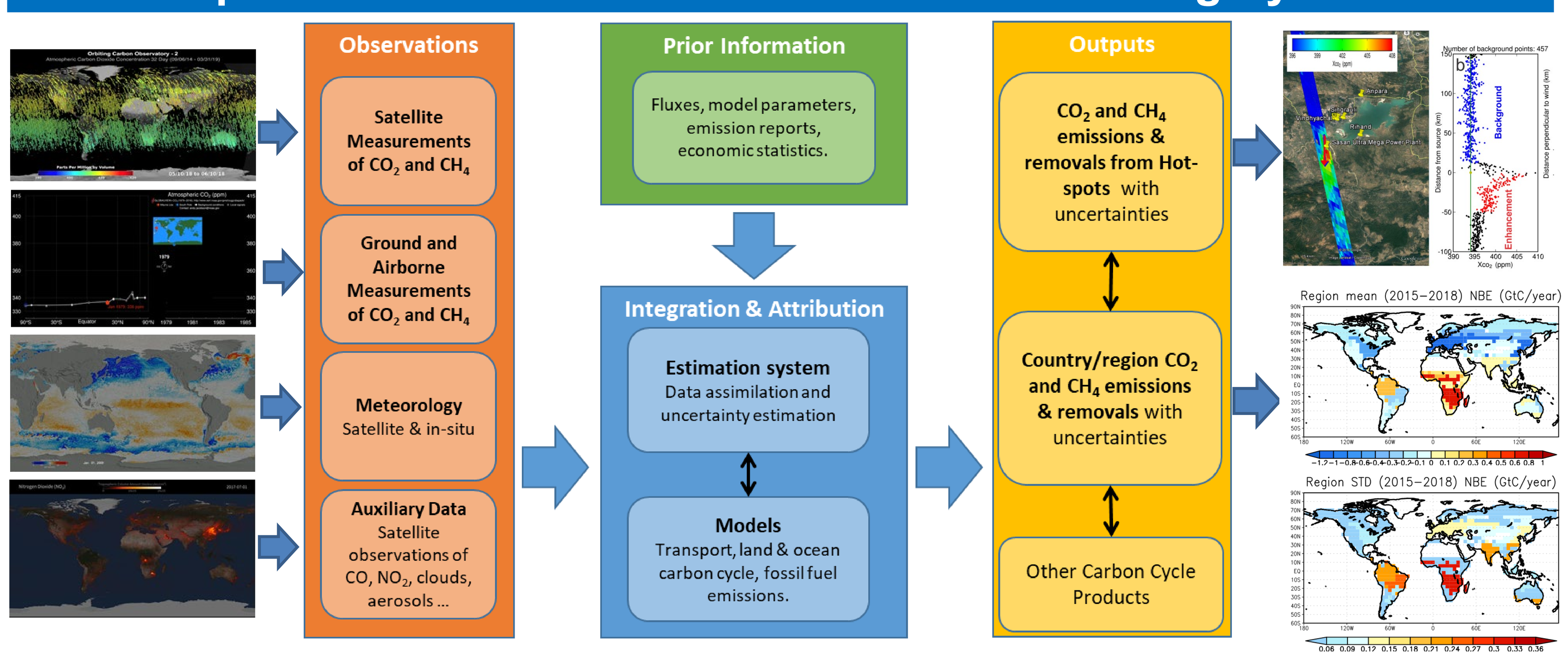
[1] Jet Propulsion Laboratory, California Institute of Technology
[2] European Commission, Joint Research Centre
[3] European Organisation for the Exploitation of Meteorological Satellites, EUMETSAT
[4] Deutsches Zentrum für Luft- und Raumfahrt; DLR

A Constellation Architecture for Space-based Observations of Greenhouse Gases: Measurement approaches, datasets, and models in support of the Global Stocktake

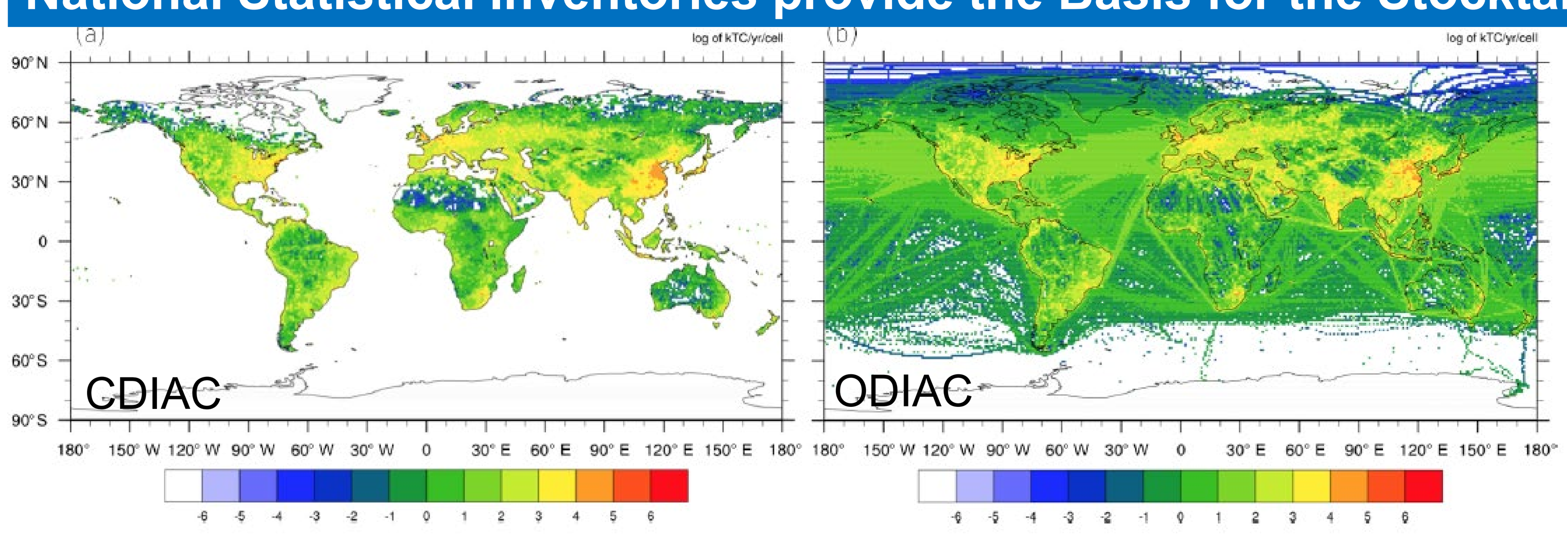
Abstract: Atmospheric carbon dioxide (CO_2) and methane CH_4 measurements complement bottom-up greenhouse gas (GHG) inventories by providing an integrated constraint on the exchanges of these gases between land and ocean surfaces and the atmosphere (including anthropogenic emissions) and their trends over time. While CO_2 and CH_4 fluxes inferred from atmospheric measurements are not as source-specific as the data sources typically used in inventories, they include contributions from sources that are often omitted or poorly quantified by bottom-up inventory methods. At global scales, atmospheric concentrations of CO_2, CH_4 and other well-mixed GHGs are well characterized by precise, ground-based *in situ* measurements from surface and airborne systems. Recent advances in space-based remote sensing methods are providing new opportunities to augment the resolution and coverage of the ground and airborne measurements with estimates of the column-averaged CO_2 and CH_4 dry air mole fractions (XCO_2 and XCH_4). These ground-based, airborne, and space-based atmospheric CO_2 and CH_4 estimates are now being assimilated into atmospheric transport models to estimate CO_2 and CH_4 fluxes on scales spanning individual large power plants to nations. The long-term objective of these efforts is to develop top-down global inventories that:

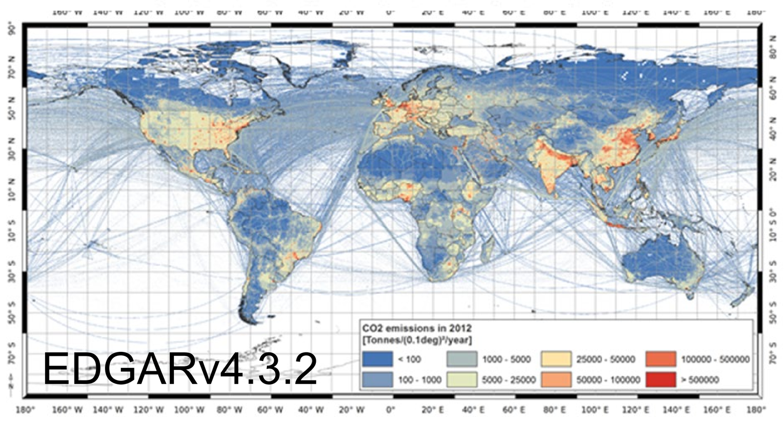
(i) reduce uncertainties in national emission inventory reports,
(ii) identify additional emission reduction opportunities
(iii) provide nations with timely and quantified guidance on progress towards their emission reduction targets and pledges (Nationally Determined Contributions, NDCs), and
(iv) track changes in the natural carbon cycle caused by human activities (deforestation, degradation of ecosystems, fire) and climate change.

A System Approach that Integrates Available Methods is Needed to Implement a Global Greenhouse Gas Monitoring System



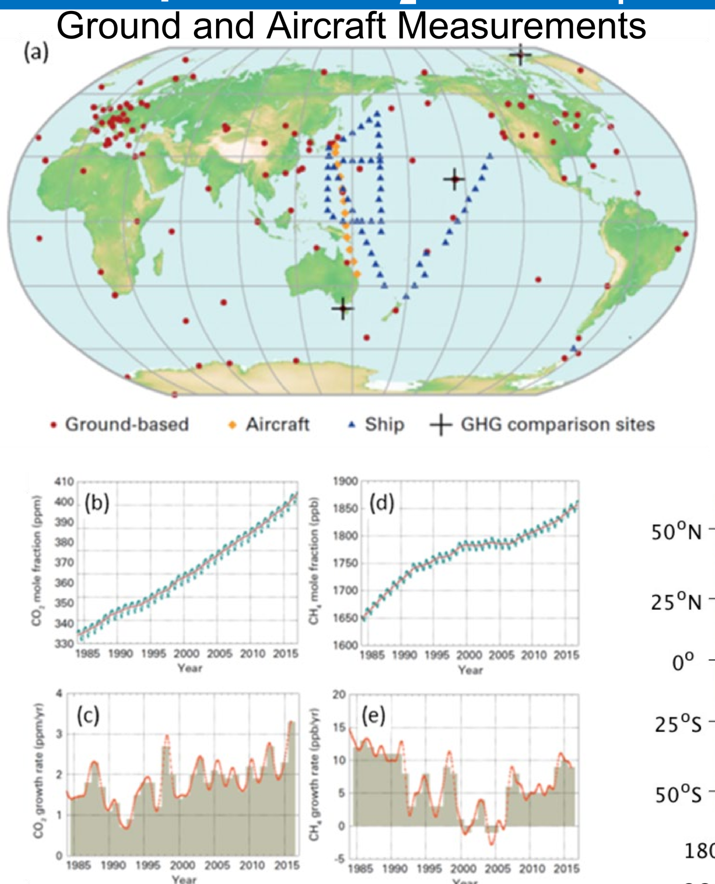
National Statistical Inventories provide the Basis for the Stocktakes

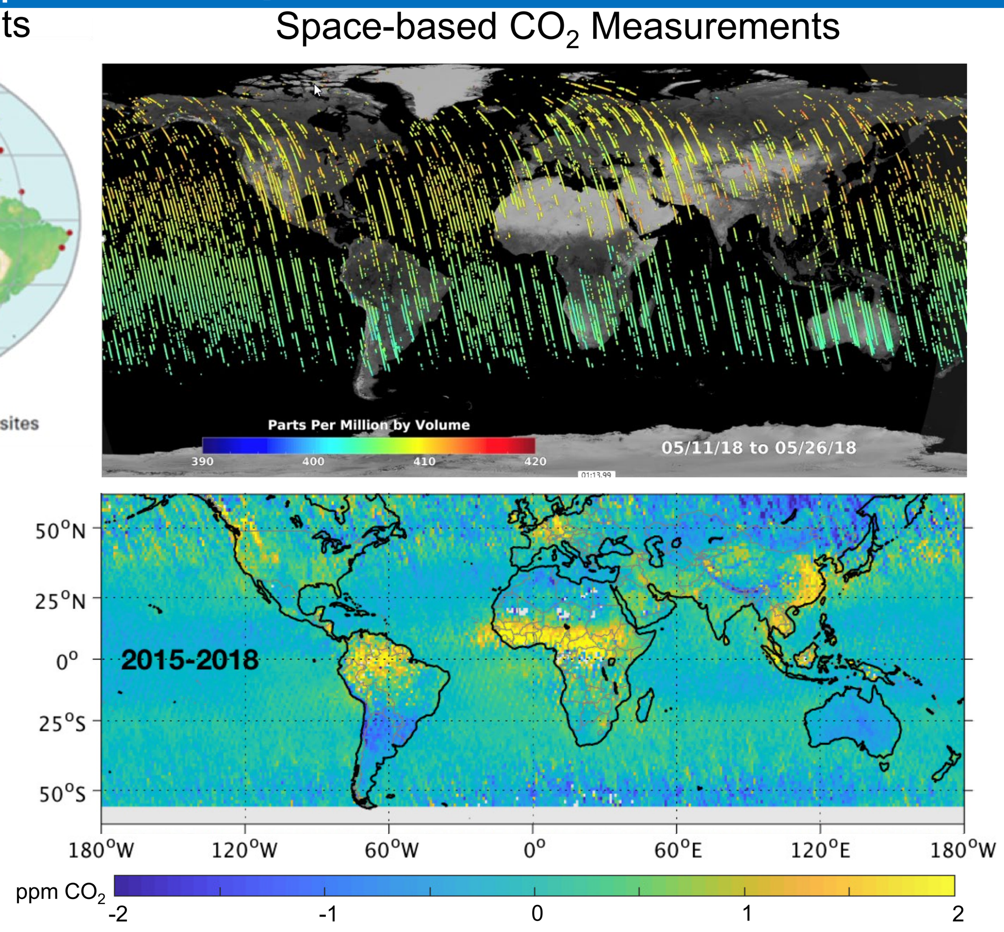




National statistical and scientific inventories provide source-specific estimates CO_2 and CH_4 emissions into the atmosphere for most, but not all anthropogenic sources. They provide less insight into the natural carbon cycle or its changes due to anthropogenic activities and climate change.

Atmospheric CO_2 and CH_4 Data Complements Statistical Inventories





Ground and space-based atmospheric measurements of CO_2 and CH_4 complement Statistical Inventory methods by providing a spatially- and temporally resolved integral constraint on the net amount of these gases that are added to or removed from the atmosphere by all processes. Ground-based measurements from the WMO Global Atmospheric Watch (GAW) Network (left panel) and its partners provide the most accurate available estimates of atmospheric CO_2 and CH_4 concentrations and their trends on global scales, but their spatial coverage and resolution are limited. Space-based CO_2 and CH_4 measurements like those from the NASA Orbiting Carbon Observatory-2 (OCO-2, right panel) are less precise and accurate but provide high spatial and temporal resolution and greater coverage of the globe.

Collecting GHG Measurements from Space: the Evolving Fleet

Space agencies have supported several pioneering space-based GHG sensors:

- German-Dutch-Belgian SCIAMACHY on ESA's ENVISAT
- Japan's GOSAT TANSO-FTS, NASA's OCO-2, China's TanSat AGCS, Feng Yun-3D GAS and Gaofen-5 GMI, Copernicus Sentinel 5 Precursor TROPOMI.

Other sensors just added to the fleet:

- Japan's GOSAT-2 TANSO-FTS-2 and NASA's ISS OCO-3

Others are under development:

- CNES MicroCarb, CNES/DLR MERLIN, NASA's GeoCarb, Japan's GOSAT Follow-on, and the Copernicus CO2M

These spacecraft demonstrate the measurement approach, but more resolution, coverage, and resiliency are needed for an operational system.

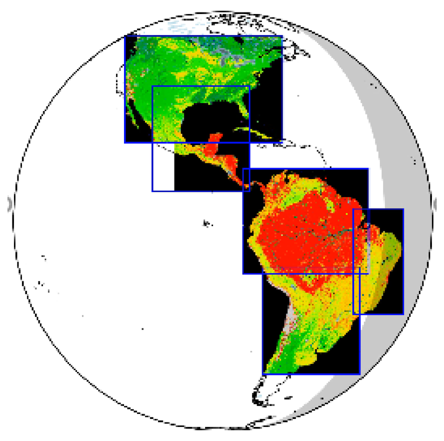
COP-23/SBSTA-47

9. The SBSTA recognized the progress made by the satellite community (see para. 4(e) above), in close collaboration with GCOS, in the development of the essential climate variable inventory.[16] It noted the usefulness of the essential climate variable inventory for climate services. It invited CEOS and CGMS to report on progress at future sessions of the SBSTA, as appropriate.

A Candidate Operational CO_2 and CH_4 Constellation Architecture

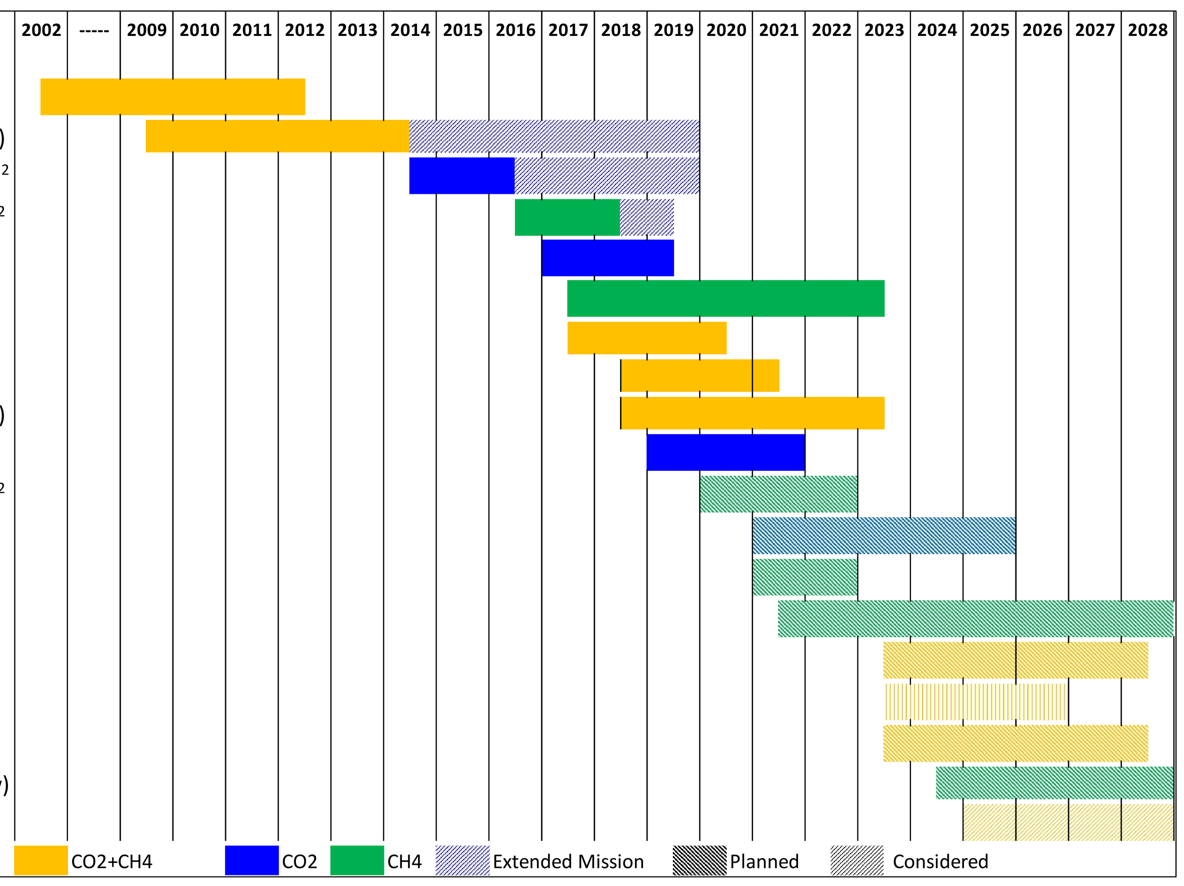
The coverage, resolution, and repeat frequency requirements could be achieved with a constellation that incorporates:

- A constellation of 3 (or more) satellites in LEO with
  - Broad (> 300 km) swaths with a footprint size < 4 km²
  - Single sounding random errors< 0.5 ppm
  - Vanishing small regional scale bias (< 0.1 ppm)
  - Ancillary sensors to identify plumes (CO, satellites NO_2)
  - The Copernicus CO2M mission addresses these requirements
- A constellation with 3 (or more) GEO satellites
  - Stationed over Europe/Africa, Americas, and East Asia
  - NASA's GeoCarb provides a pathfinder for this capability
- Possible augmentations include:
  - Active (lidar) satellites in LEO for night-time/polar night coverage
  - Satellites in HEO for improved high latitude coverage



The Timeline for CO_2 and CH_4 Monitoring Missions

Satellite, Instrument (Agencies)	CO_2	CH_4	Swath	Sample
ENVISAT SCIAMACHY (ESA)	●	●	960 km	30x60 km²
GOSAT TANSO-FTS (JAXA-NIES-MOE)	●	●	3 pts	10.5 km (d)
OCO-2 (NASA)	●		10.6 km	1.3x2.3 km²
GHGSat (Claire)		●	12 km	0.0004 km²
TanSAT (CAS-MOST-CMA)	●		20 km	1x2 km²
Sentinel 5P TROPOMI (ESA)		●	2600 km	7x7 km²
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 km²
Bluefield Technologies		●	25x20 km	0.0004 km²
MicroCarb (CNES)	●		13.5 km	40 km²
MethaneSAT (EDF)		●	200 km	1 km²
MetOp Sentinel-5 series (Copernicus)		●	2670 km	50 km²
Feng Yun 3G (CMA)	●	●	100 km	< 3 km²
GEOCARB (NASA)	●	●	2800 km	20 km²
GOSAT Follow-on (JAXA-MOE-NIES)	●	●	400 km	4 km²
MERLIN (DLR-CNES)		●	100 m	0.14 km (w)
CO2 Sentinel (Copernicus)	●	●	3x250 km	2x2 km²



Implementing an Atmospheric GHG Constellation for Informing Stocktakes

1. Refine requirements and implementation plans for atmospheric flux inventories
   Foster collaboration between the space-based and ground-based GHG measurement and modeling communities and the bottom-up inventory and policy communities
2. Produce a prototype atmospheric CO2 and CH4 flux inventory that is available in time to inform the bottom-up inventories for the 2023 global Stocktake
   Exploit capabilities of CEOS), Coordination Group on Meteorological Satellites (CGMS) and the WMO Integrated Global Greenhouse Gas Information System (IG3IS)
3. Use lessons learned from the prototype flux product to refine requirements for a future, purpose-built, operational, atmospheric constellation that better addresses the inventory process in time to support the 2028 global Stocktake.