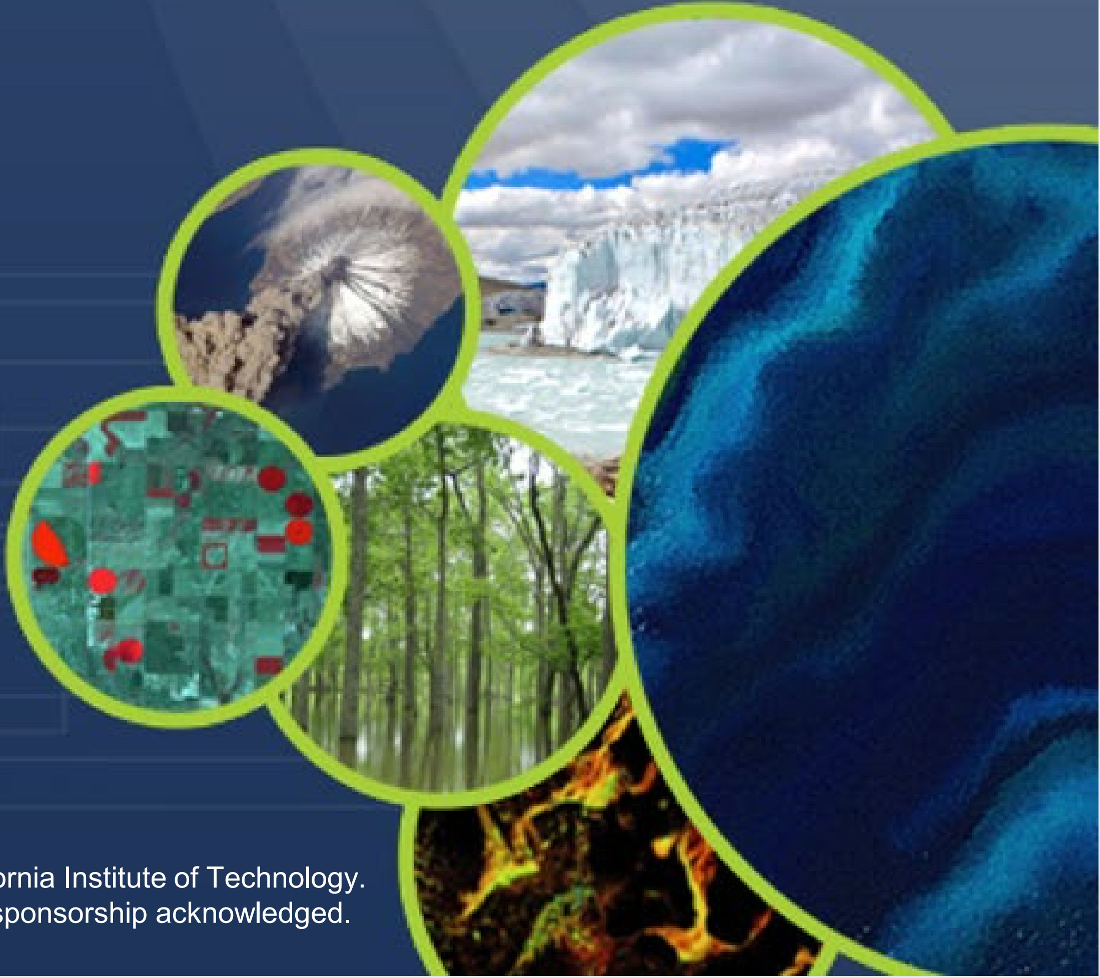
Committee on Earth Observation Satellites

The CEOS AC-VC GHG Initiative

David Crisp (Jet Propulsion Laboratory, California Institute of Technology, CEOS AC-VC GHG Lead) for the CEOS AC-VC Greenhouse Gas Team

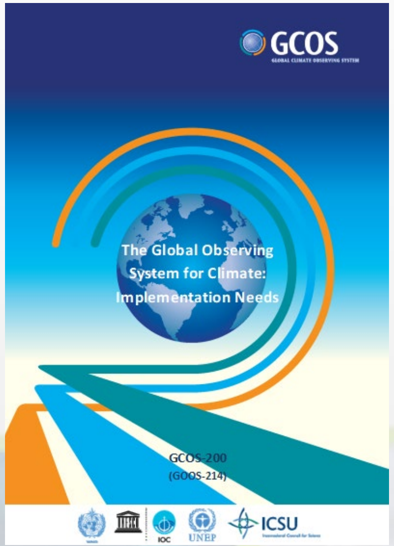


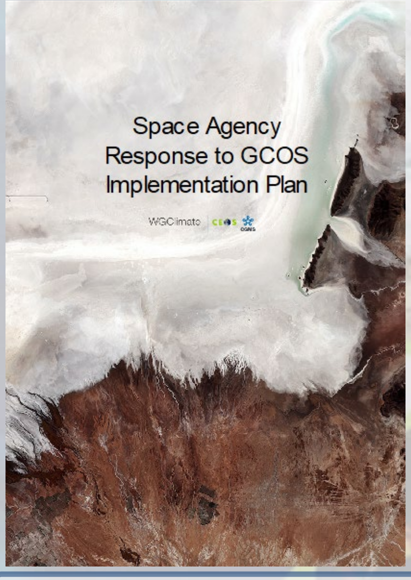
June 10, 2019

Objectives

- Background and international Context
- An architecture for GHG observations
- Role of atmospheric CO_2 and CH_4 inventories in the Paris Agreement
- Prototype atmospheric CO_2 and CH_4 inventory to support the Stocktakes
- Developing a GHG Roadmap

Background
Action T71 from GCOS IP 2016





Action T71:	**Prepare for a carbon-monitoring system**
Action	Preparatory work to develop a carbon monitoring system to be operational by 2035; Development development of comprehensive monitoring systems of measurements of atmospheric concentrations and of emission fluxes from anthropogenic area and point sources to include space-based monitoring, in situ flask and flux tower measurements and the necessary transport and assimilation models
Benefit	Improved estimates of national emissions and removals
Time frame	Initial demonstration results by 2023 – complete systems unlikely before 2030
Who	Space agencies
Performance indicator	Published results
Annual cost	US$ 10–100 billion

- CEOS and CGMS will define an architecture of space component elements to address the requirements of a CO_2 and GHG monitoring system , …

United Nations FCCC/SBSTA/2017/L.21

Framework Convention on Climate Change

Distr.: Limited
12 November 2017

Original: English

Subsidiary Body for Scientific and Technological Advice
Forty-seventh session
Bonn, 6–15 November 2017

Agenda item 8
Research and systematic observation

Research and systematic observation

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.

10. The SBSTA noted with appreciation the information provided in the submission referred to in paragraph 4(a) above on the Global Framework for Climate Services (GFCS).[17] It invited WMO to report on progress in implementing the GFCS at future sessions of the SBSTA, as appropriate.

11. The SBSTA invited the UNFCCC secretariat to communicate with the WMO secretariat, including with regional centres, to inform work on climate services.

12. The SBSTA noted the increasing capability to systematically monitor greenhouse gas concentrations and emissions, through in situ as well as satellite observations, and its relevance in support of the Paris Agreement.[18]

Objectives of the AC-VC GHG White Paper

- The CEOS Chair commissioned the Atmospheric Composition Virtual Constellation (AC-VC) to write a white paper that defines the key characteristics of a global architecture for monitoring atmospheric CO_2 and CH_4 concentrations and their natural and anthropogenic fluxes from instruments on space-based platforms to:
  - reduce uncertainty of national emission inventory reporting;
  - identify additional emission reduction opportunities
  - provide nations with timely and quantified guidance on progress towards their emission reduction strategies and pledges (Nationally Determined Contributions, NDCs); and,
  - track changes in the natural carbon cycle caused by human activities (deforestation, degradation of ecosystems, fire) and climate change

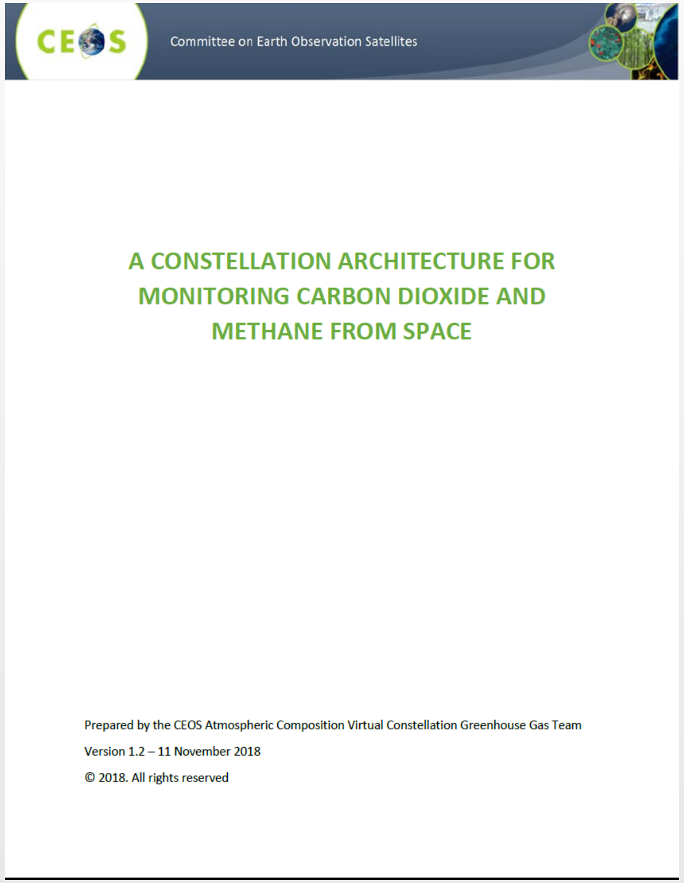
Atmospheric Inventories in the Context of the Paris Agreement

- Atmospheric measurements of CO_2 and CH_4 from ground-, airborne- and space-based sensors could reduce uncertainty in national emission inventory reports by:
  - providing nations with timely, quantified guidance on progress towards their emission reduction strategies and pledges (NDCs)
  - identifying additional emission reduction opportunities;
  - tracking changes in the natural carbon cycle caused by human activities (deforestation, degradation of ecosystems, fire) and climate change
  - Helping to close the carbon budget by providing measurements over ocean and over land areas with poor data coverage (tropical forests, polar regions)

The CEOS Architecture for Monitoring Atmospheric CO_2 and CH_4 Concentrations

The Committee on Earth Observations Satellites (CEOS) commissioned the Atmospheric Composition Virtual Constellation (AC-VC) team to write a white paper defining a global architecture for monitoring atmospheric CO_2 and CH_4 concentrations from instruments on space-based platforms

- 166-page document, 88 authors from 47 organizations
- Executive Summary (2 pages)
- Body of report (75 pages)
- Technical Appendices (42 pages)


Committee on Earth Observation Satellites

A CONSTELLATION ARCHITECTURE FOR MONITORING CARBON DIOXIDE AND METHANE FROM SPACE

Prepared by the CEOS Atmospheric Composition Virtual Constellation Greenhouse Gas Team

Version 1.2 – 11 November 2018

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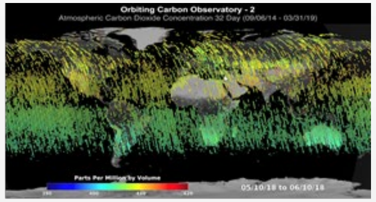
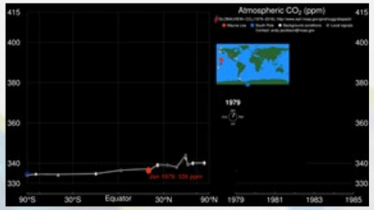
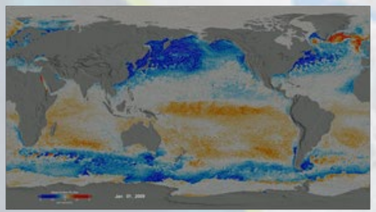
http://ceos.org/document_management/Virtual_Constellations/ACC/Documents/CEOS_AC-VC_GHG_White_Paper_Publication_Draft2_20181111.pdf

Space-based Measurements: Only One Component of an Atmospheric GHG Inventory System







Observations

Satellite Measurements of CO_2 and CH_4

Ground and Airborne Measurements of CO_2 and CH_4

Meteorology
Satellite & in-situ

Auxiliary Data
Satellite observations of CO, NO_2, clouds, aerosols ...

Prior Information

Fluxes, model parameters, emission reports, economic statistics.

Integration & Attribution

Estimation system
Data assimilation and uncertainty estimation

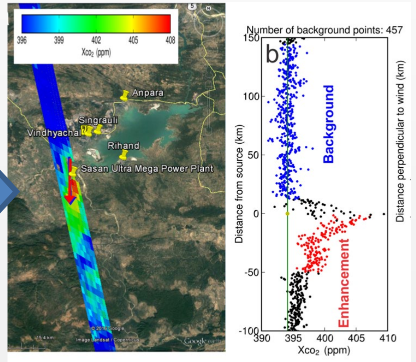
Models
Transport, land & ocean carbon cycle, fossil fuel emissions.

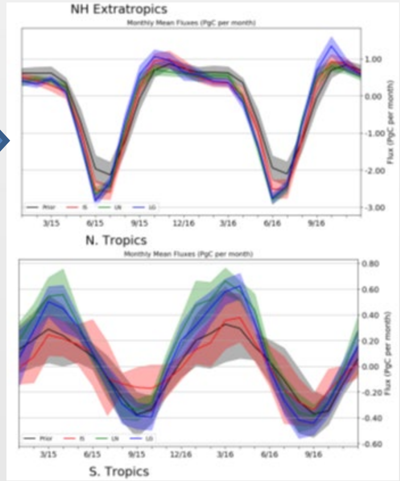
Outputs

CO_2 and CH_4 emissions & removals from Hot-spots with uncertainties

Country/region CO_2 and CH_4 emissions & removals with uncertainties

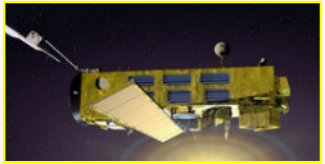
Other Carbon Cycle Products



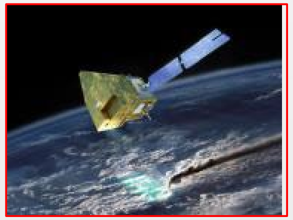


Collecting GHG Observations from Space: The Evolving Fleet

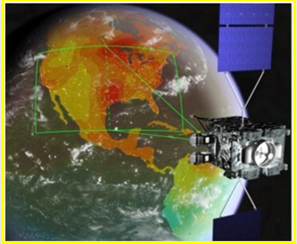
- **Space agencies have supported several pioneering space-based GHG sensors :**
  - **ESA's ENVISAT SCIAMACHY,**
  - **Japan's GOSAT TANSO-FTS, NASA's OCO-2, China's TanSat AGCS, Feng Yun-3D GAS and Gaofen-5 GMI, Copernicus Sentinel 5 Precursor TROPOMI.**
- **Other sensors just added to the fleet:**
  - **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**





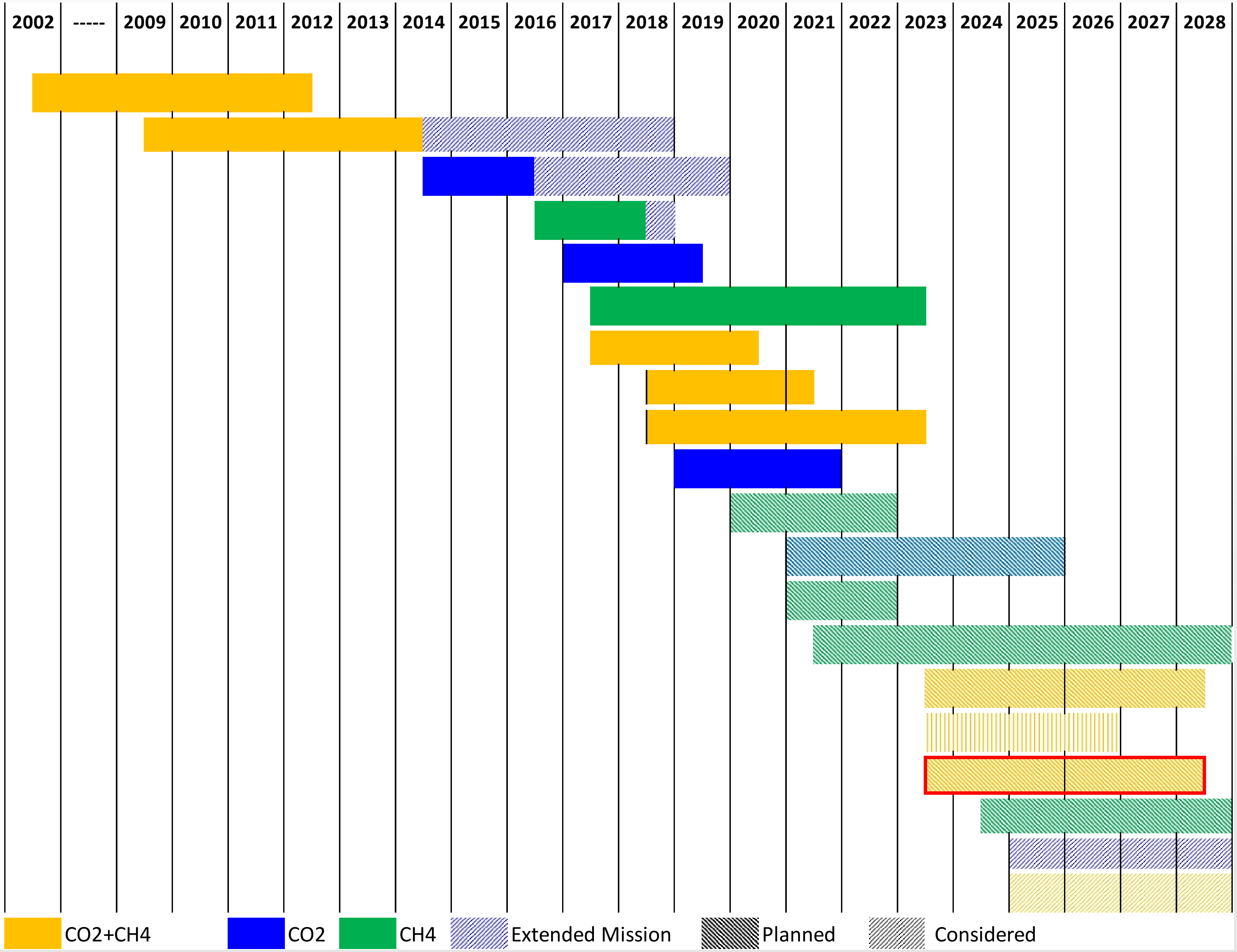



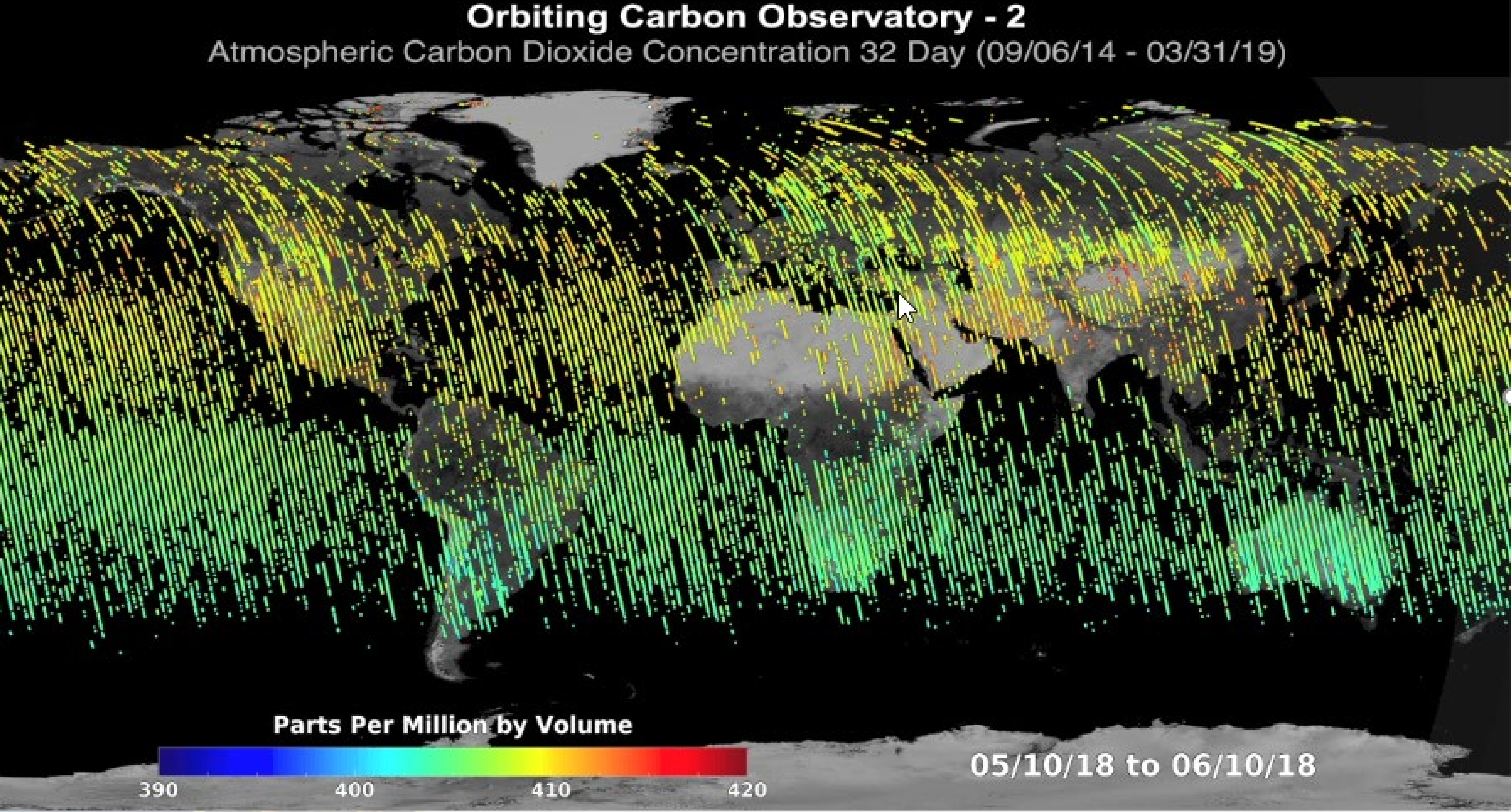




The GHG Constellation Time Line

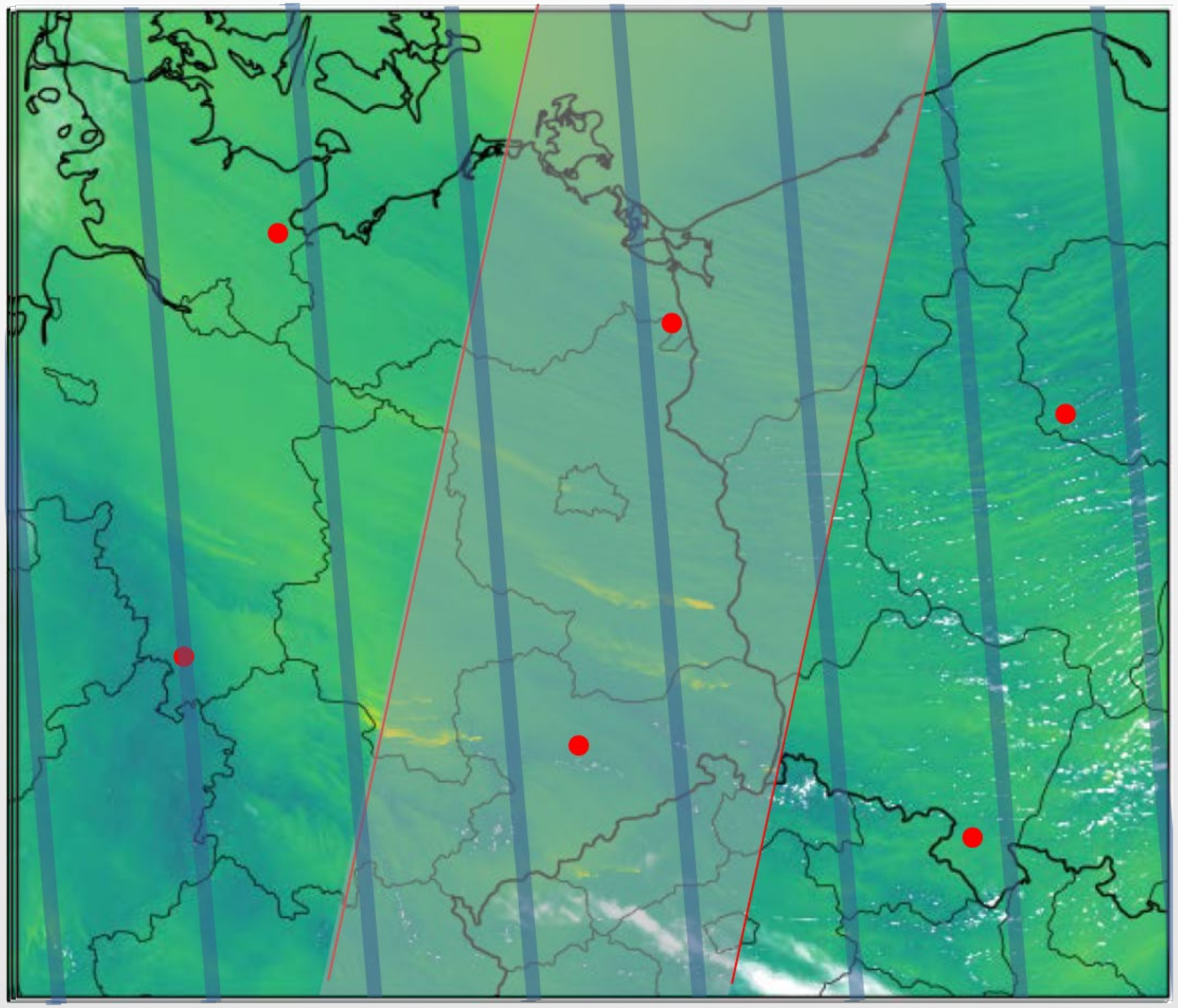
Satellite, Instrument (Agencies)	CO_2	CH_4	Swath	Sample
ENVISAT SCIAMACHY (ESA)	●	●	960 km	30x60 km^2
GOSAT TANSO-FTS (JAXA-NIES-MOE)	●	●	3 pts	10.5 km (d)
OCO-2 (NASA)	●		10.6 km	1.3x2.3 km^2
GHGSat (Claire)		●	12 km	0.0004 km^2
TanSAT (CAS-MOST-CMA)	●		20 km	1x2 km^2
Sentinel 5P TROPOMI (ESA)		●	2600 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	3x6 km^2
GOSAT-3 (JAXA-MOE-NIES)	●	●	TBD	TBD
MERLIN (DLR-CNES)		●	100 m	0.14 km (w)
TanSat-2 Constellation	●	●	3x100 km	2x2 km^2
CO2 Sentinel (Copernicus)	●	●	3x250 km	2x2 km^2




Orbiting Carbon Observatory - 2
Atmospheric Carbon Dioxide Concentration 32 Day (09/06/14 - 03/31/19)
Parts Per Million by Volume
390
400
410
420
05/10/18 to 06/10/18

Next Steps: Operational LEO GHG Constellations

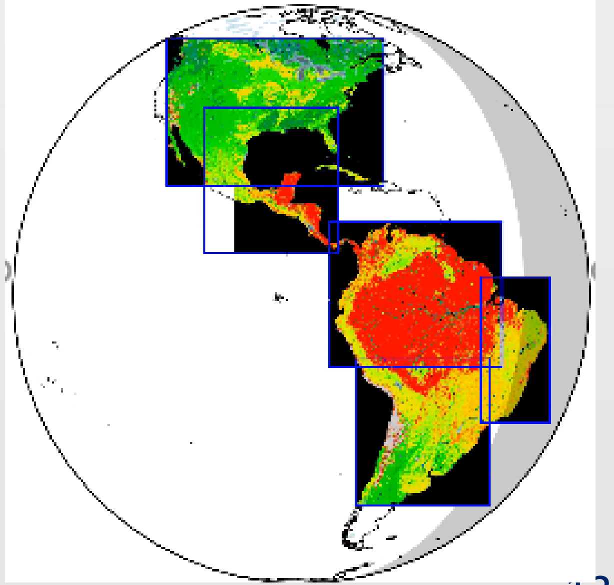
- **Copernicus CO_2 Sentinel (2025+)**
  - **3 or 4 LEO satellites in an operational GHG constellation**
  - **Primary spectrometer measures O_2 (0.76 μm A-band), CO_2 (1.61 and 2.06 μm), CH4 (1.67 μm)**
  - **Ancillary instrument include**
    - **NO_2 (0.450 μm) at a spatial resolution of 2 km x 2 km along a 200-300 km swath for plumes**
    - **A cloud/aerosol multi-angle polarimeter**



A Candidate Operational CO_2/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**
  - **A broad (> 250 km) swath with a footprint size < 4 km^2**
  - **A single sounding random error near 0.5 ppm, and vanishing small regional scale bias (< 0.1 ppm)**
  - **Ancillary sensors to identify plumes (CO, satellites NO_2)**
- **A constellation with 3 (or more) GEO satellites**
  - **Stationed over Europe/Africa, Americas, and East Asia**
  - **Monitor diurnally varying processes (e.g. rush hours, diurnal variations in the biosphere)**



Developing Atmospheric GHG Inventories

The CEOS AC-VC GHG White Paper recommends the following approach:

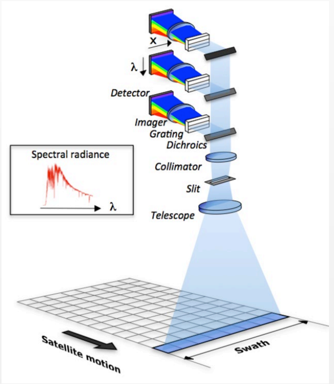
1. Refine requirements and implementation plans for atmospheric flux inventories
   - Foster collaboration between the space-based and ground-based GHG measurement and modeling communities and the bottom-up inventory and policy communities
2. Produce a prototype atmospheric CO_2 and CH_4 flux inventory 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 the lessons learned from this prototype flux product to refine the requirements for a future, purpose-built, operational, atmospheric inventory system
   - more completely addresses the inventory process in time to support the 2028 global Stocktake.

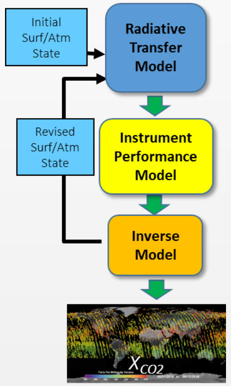
Endorsement and Next Steps

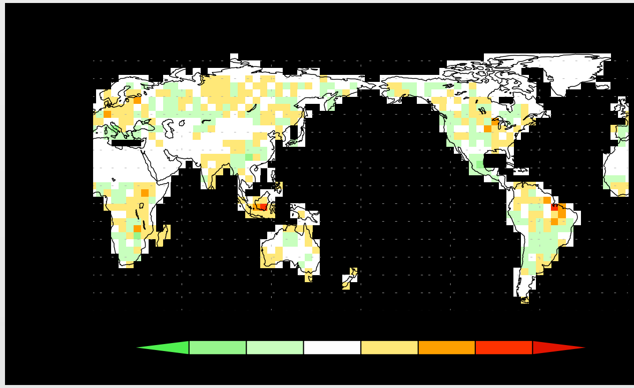
- The 2018 CEOS Plenary endorsed the AC-VC GHG White Paper
  - The Plenary confirmed CEOS interest in continuing collaboration with CGMS through a specific task in WGClimate on GHG monitoring, with dedicated resources and activities based on the mapping table of the actions identified in the Way Forward chapter of the report
    - The 3-point plan and activities are interpreted as recommendations to the CEOS Agencies
    - Plenary also endorsed the revision of the Terms of Reference of the WGClimate to accommodate these changes
  - AC-VC will support GHG constellation development and synergistic GHG and atmospheric composition observations and modelling efforts
  - WGCV and GSICS will support the definition of the calibration and validation needs
  - The CEOS SIT Chair encouraged the publication of the white paper to facilitate citations and efforts to build on its content
    - WMO and Copernicus have agreed to jointly publish the white paper
    - Publication date ~June 2019

Tools Needed to Meet New Requirements

- Sensors: improved precision, spatial resolution, and coverage
  - Accuracy/Precision: Improved calibration accuracy and stability
  - Resolution/Coverage: Dedicated LEO and Geo GHG constellations
- Improved remote sensing retrieval algorithms
  - Optical properties: gas absorption and aerosol scattering
  - Retrieval methods: Optimized to exploit information from solar spectra
- Better coordination with ground-based/aircraft networks
  - Validation: TCCON, EM27-Sun, AirCore, Aircraft
  - Complementary coverage: polar regions, persistently cloud regions
- Improved atmospheric inversion models
  - Transport: Higher spatial resolution to resolve mesoscale transport
  - Assimilation techniques: for ground-, aircraft-, and space-based data
- Methods to validate fluxes on local to national/regional scales







Calibration Advances Needed

- Space based sensors for CO_2 and CH_4 must be
  - calibrated to unprecedented levels of accuracy to detect and quantify the small XCO_2 and XCH_4 changes associated with surface fluxes
  - cross-calibrated against internationally-accepted standards prior to launch and in orbit so that their measurements can be integrated into a harmonized data product that meets the accuracy, precision, resolution, and coverage requirements for CO_2 and CH_4
- Efforts by the ACOS and GHG-CCI teams have demonstrated the feasibility of this approach for SCIAMACHY, GOSAT, and OCO-2
  - Rigorous pre-launch and in-orbit calibration methods demonstrated
- Working actively with CEOS WGCV and GSICS to meet the much more demanding requirements of anthropogenic emissions monitoring
  - Cross-calibrating a more diverse range of spacecraft sensors
  - Reducing calibration-related biases across multiple spacecraft

Data Analysis Tools Needed

- Remote sensing retrieval algorithms used to estimate the XCO_2 and XCH_4 from space based observations
  - These methods are now being successfully used to study emission hot spots and regional-scale natural CO_2 sources and sinks
  - Additional advances needed to accurately quantify anthropogenic sources

- Atmospheric inversion models used to estimate the surface fluxes of CO2 and CH4 from XCO_2 and XCH_4 distributions in the presence of the prevailing winds field
  - A substantial amount of additional development is needed to support applications as demanding and diverse as
    - o supporting urban- to national-scale GHG emission inventories
    - o monitoring the natural carbon cycle response to climate change

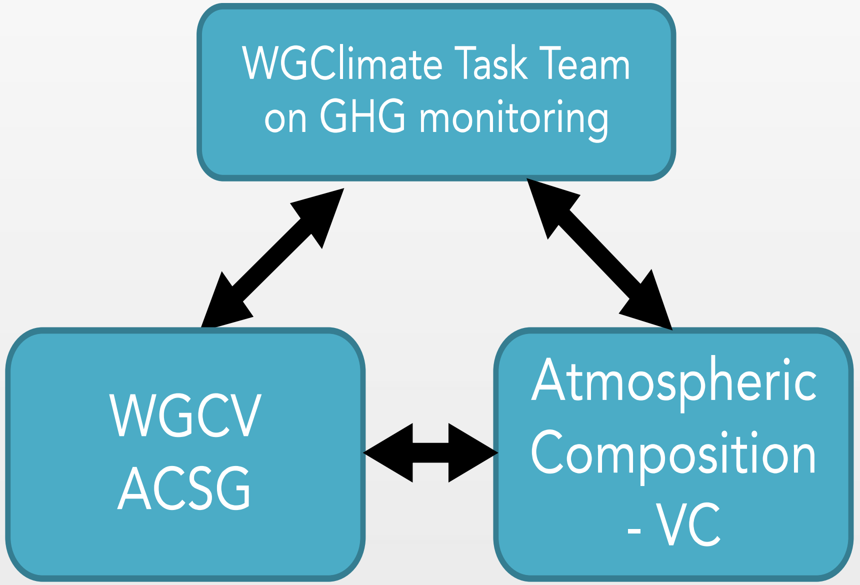
Validation Advances Needed

XCO_2 and XCH_4 estimates across the constellation must be cross validated against internationally-recognized standards to yield a harmonized integrated product that meets the demanding precision, accuracy, resolution, and coverage requirements

- The Total Carbon Column Observing Network (TCCON) currently serves a critical transfer standard between the space based measurements and the *in situ* standard maintained by WMO GAW
- TCCON must be maintained and expanded meet the much greater demands of anthropogenic emissions monitoring on national scales
  - Very little coverage over tropics and central Asia
  - Biases must be reduced by a factor of 5-10 from 0.25% on regional scales to < 0.025 to 0.05% to improve inventories
- Innovative methods must be developed to validate emissions estimates on scales ranging from that of individual large power plants to that of a nation.

CEOS/CGMS GHG Roadmap

1. Coordination mechanism proposed and endorsed by CEOS and CGMS Plenaries
2. Contributions from multiple CEOS & CGMS entities (WGClimate GHG Task Team, AC-VC, WGCV/ACSG & GSICS)
3. Addressing Actions on two different time horizons i)Prototype products: 2021 for 2023 Global Stocktake and ii)Pre-operational: 2026 for 2028 Global Stocktake
4. Roadmap meeting in Tokyo (09/06) draft roadmap by CEOS SIT TW in September 2019 present to CEOS 33rd Plenary (October 2019), and send to CGMS, for written endorsement



GSICS Global Space-based Inter-Calibration System

With CGMS Agency involvement

CEOS/CGMS GHG Roadmap Report Outline

1 SCOPE AND OBJECTIVE OF ROADMAP

2 CONTEXT

3 APPROACH

4 CEOS AND CGMS IMPLEMENTATION ENTITIES AND THEIR ROLES

- 4.1 Role of Joint WGClimate GHG Task Team
- 4.2 Role of Atmospheric Composition – Virtual Constellation
- 4.3 Role of WGCV/ACSG and GSICS
- 4.4 Role of other entities in CEOS and CGMS

5 ROADMAP ACTIONS TO 2021 AND 2025

- 5.1 Actions for Joint WGClimate GHG Task Team
- 5.2 Actions for Atmospheric Composition – Virtual Constellation
- 5.3 Actions for WGCV/ACSG and GSICS

6 EXPECTED OUTCOMES

7 RESOURCE IMPLICATIONS

8 HIGH-LEVEL TIMELINE

The roadmap document will be complemented by a representation of the roadmap in a project planning tool that is maintained by the WGClimate Task Team. This allows a close follow up of achievements and emerging risks during implementation.

CEOS/CGMS GHG Roadmap - Tokyo Working Meeting (9th June)

1. Reviewed proposed objectives for way forward identified in Whitepaper, and known “boundary conditions”, in formulating Roadmap
2. Discussed approach for implementation of roadmap: iterative versioned approach – with defined iteration cycle
3. Reviewed sequences of necessary timeline elements (2019-2023…2026…) with activities from different CEOS and CGMS entities
   - Key sub-iterations of prototype products to critical friends/beta-testers from Inventory Community in 2019-2021 period
4. Discussed additional resources needed to accomplish work (agency staff, scientific experts, workshops, research needs) to formulate request to CEOS & CGMS Principals

Community Interactions

- Existing scientific conferences and workshops are being exploited to encourage interactions among the measurement, modeling, and inventory communities
  - **17-20 Sept 2018: IG^{3}IS/TRANSCOM** – GHG measurement, flux modeling, and inventory communities
  - **26-29 Nov 2018: ESA ATMOS** – Current/future space based measurements
  - **10-14 Dec 2018: AGU** - Ground and space-based measurement, flux modeling, and inventory communities
  - **4-8 Mar: GSICS** – Calibration and operational satellite communities
  - **12-14 Mar: CHE/VERIFY** - GHG Measurement, flux modeling and national inventory communities
  - **18-22 Mar: GCOS/WCRP WGClimate** – Next steps in CEOS/CGMS interactions (CEOS-32-05)
  - **25-29 Mar: CEOS WGCV IVOS 31** – CEOS WGCV community
  - **3-6 Jun: IWGGMS-15** – space-based GHG community
  - **10-13 Jun: CEOS AC-VC Annual Meeting** – CEOS atmospheric composition and GHG communities
  - **17-20 Jun: CALCON Technical Meeting –**Instrument Radiometric Calibration community
  - **26-29 Aug: Chapman Conference, Understanding Carbon Climate Feedback** – flux modeling
  - **6-8 Nov: 19th GEIA: Global Emissions InitiAtive (GEIA) Conference** – national inventory community