Committee on Earth Observation Satellites

Progress Toward Atmospheric CO_2 and CH_4 Inventories

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CEOS AC-VC 2020

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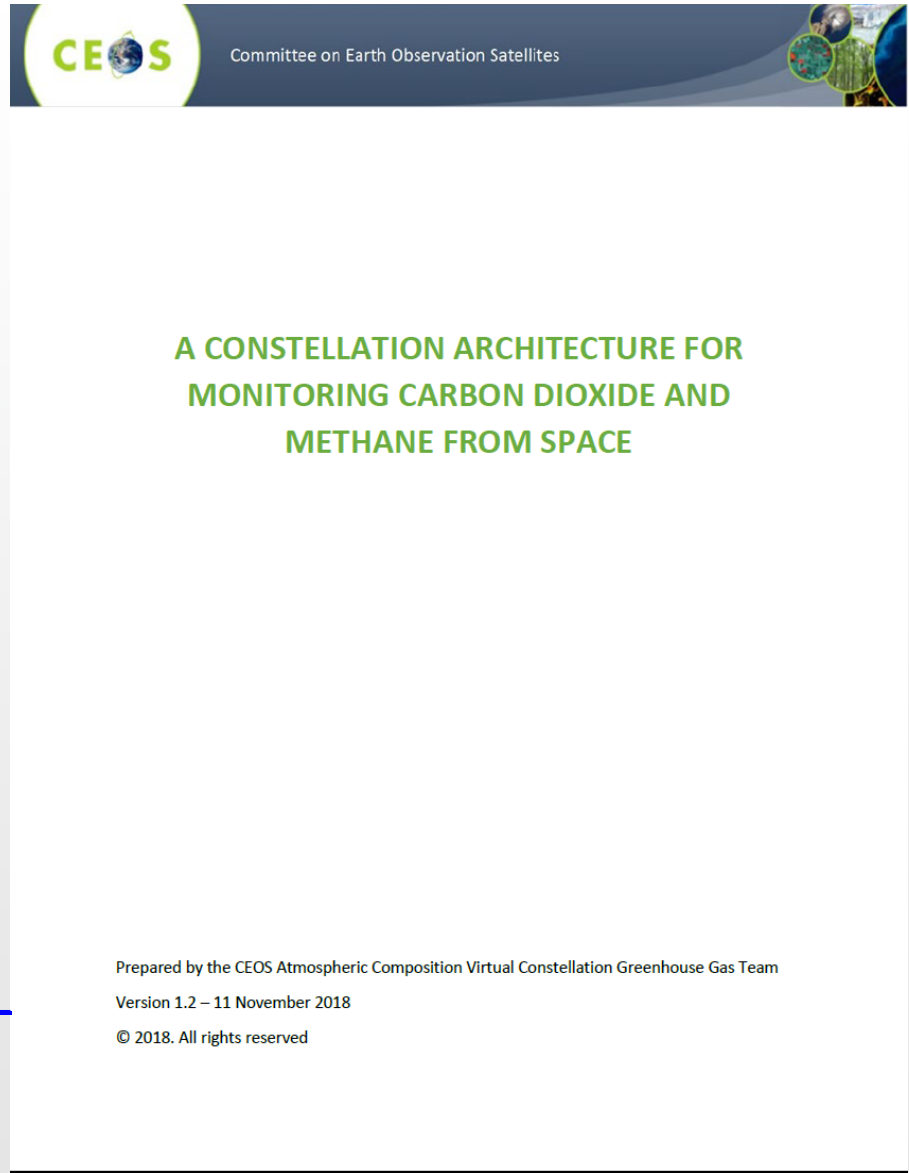
The CEOS Architecture for Monitoring Atmospheric CO_2 and CH_4 Concentrations

The CEOS Atmospheric Composition Virtual Constellation (AC-VC) white paper defines 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)



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

A Role for Atmospheric CO_2 and CH_4 Inventories

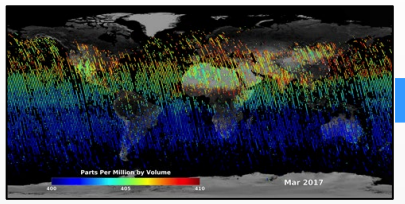
Bottom-up National statistical emission inventories

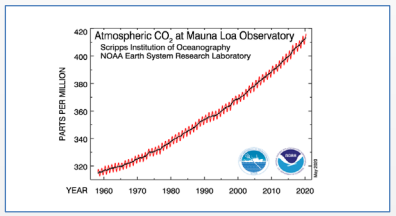
- Provide source-specific estimates of CO_2 and CH_4 emissions for most human activities
- Describe emissions at national scales at 1-5 year intervals
- Form the basis for Global Stock Takes (GSTs) that provide nations with guidance on progress towards their emission reduction targets and pledges (NDCs)

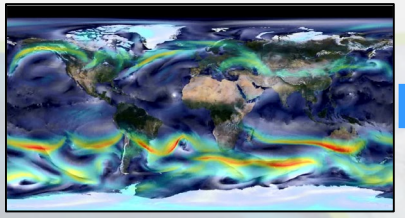
Top-down atmospheric inventories derived from direct measurements of CO_2 and CH_4 concentrations complement these efforts by:

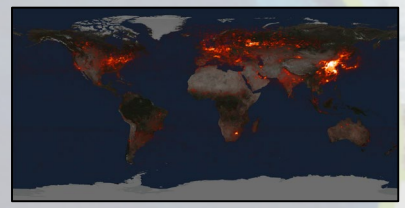
- Providing an integral constraint on the total amount of CO_2 and CH_4 added to or removed from the atmosphere by all natural and anthropogenic processes
- Tracking emission hot spots and identifying emerging emission reduction opportunities
- Detecting changes in the natural carbon cycle caused by human activities (deforestation, degradation of ecosystems, fire) and climate change

A System Approach to Deliver Atmospheric CO_2 and CH_4 Inventories









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

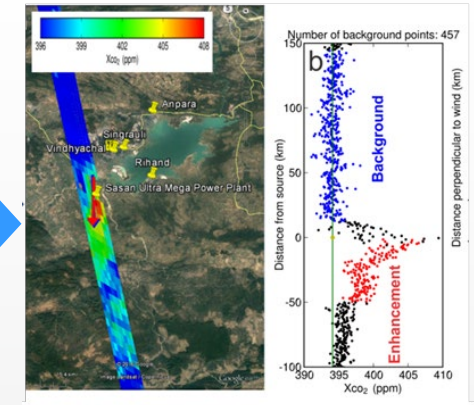
Fluxes, model parameters, emission reports, economic statistics.

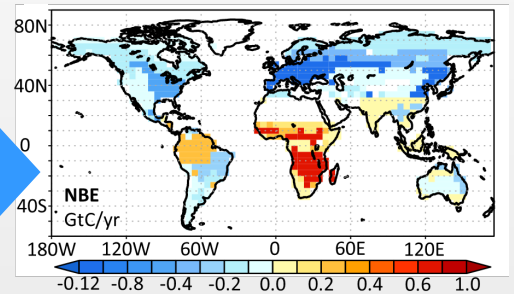
Integration & Attribution

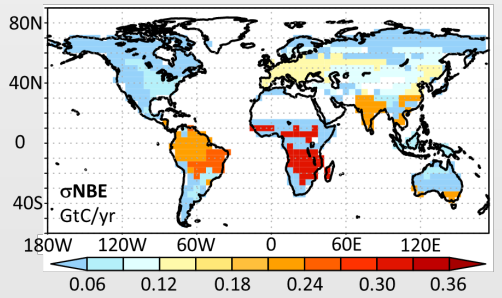
- **Estimation system** Data assimilation and uncertainty estimation
- **Models** Transport, land & ocean carbon cycle, fossil fuel emissions.

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

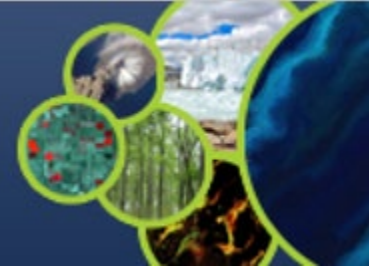






Measurements Models Products

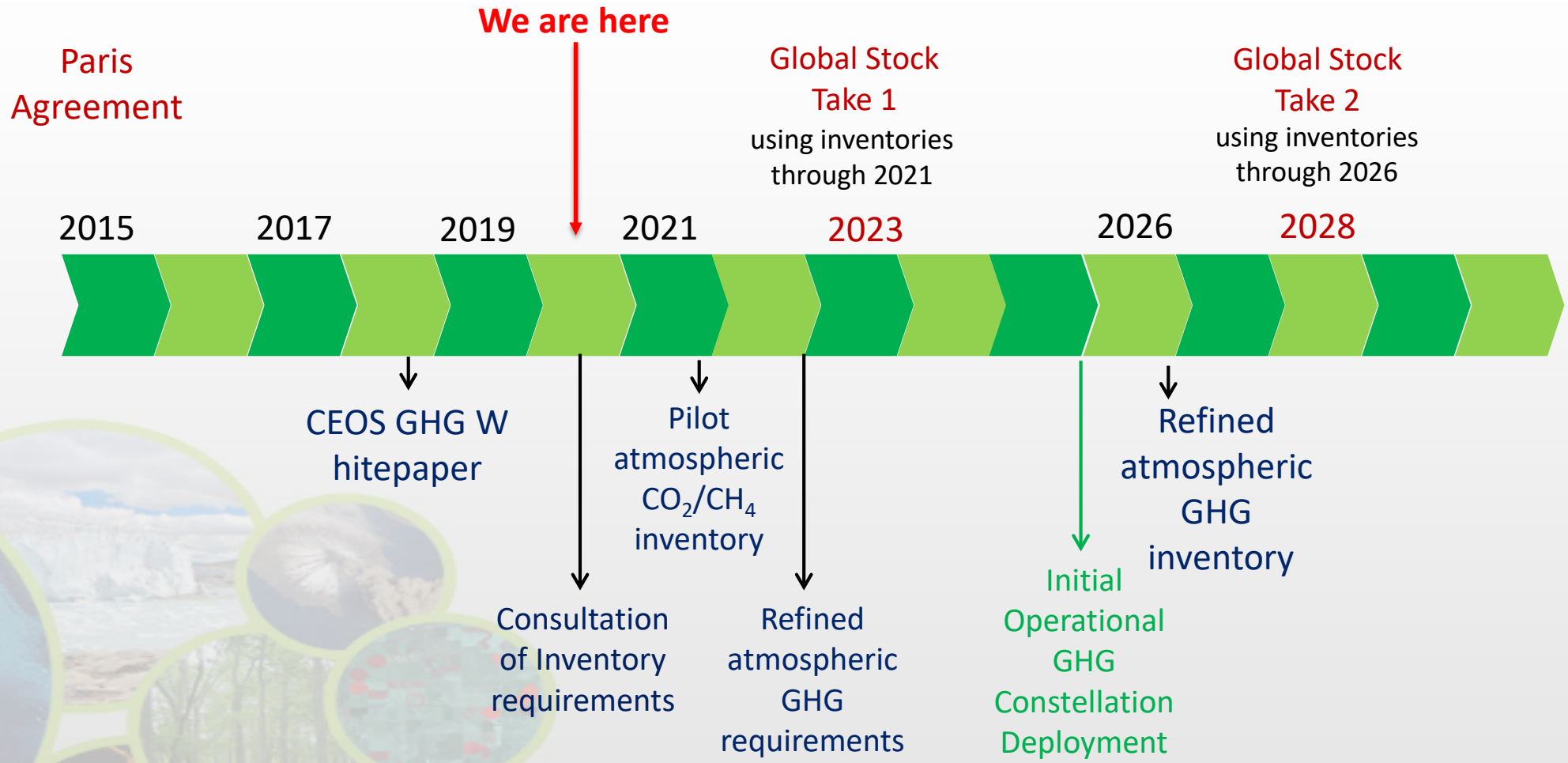
Developing the Space-based Systems Needed to Compile Atmospheric CO_2 and CH_4 Inventories



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

1. **Refine requirements and implementation plans for atmospheric flux inventories**
   - Foster collaboration between space-based and ground-based GHG measurement and modeling communities and the bottom-up inventory and policy communities
   - Deliver preliminary requirements by end of 2020
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 Stock Take (GST)**
   - Exploit capabilities of CEOS), Coordination Group on Meteorological Satellites (CGMS) and WMO Integrated Global Greenhouse Gas Information System (IG3IS)
   - Deliver a prototype global atmospheric CO_2 and CH_4 flux inventories by 2021
3. **Use lessons learned from this prototype flux product to refine requirements for a future, purpose-built, operational, atmospheric inventory system**
   - more completely address the inventory process in time to support the GST in 2028 and beyond

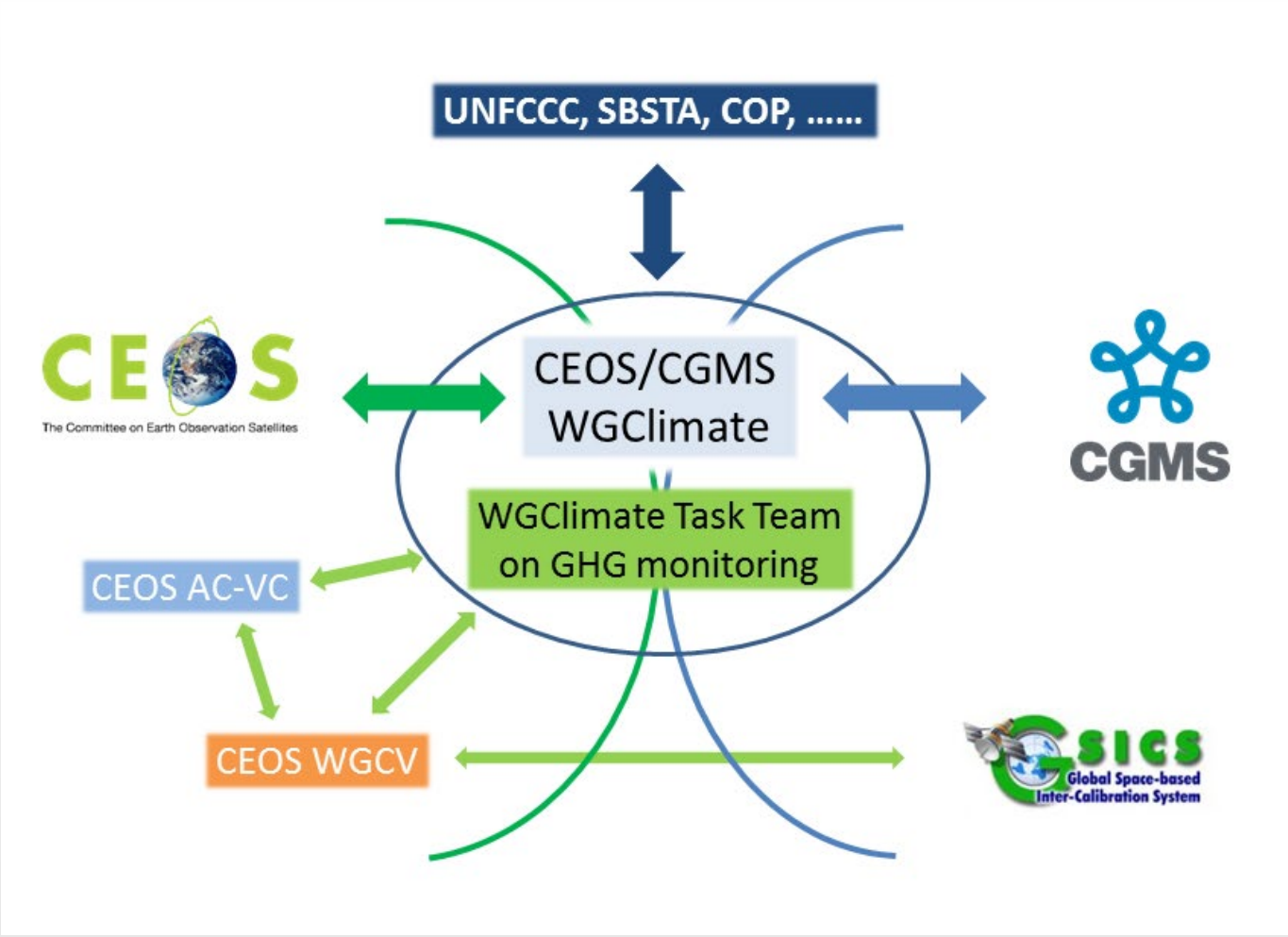
GHG Roadmap Timeline



The GHG Task Team and Roadmap

In response to the AC-VC GHG White Paper, CEOS established a GHG Task Team in WGClimate to:

- Create and maintain roadmap to implement actions proposed in the AC-VC white paper
- Establish primary user interface to Users (Inventory and Policy) and ensure feedback on prototype products
- Provide a system overview and track requirements, capabilities, and deliverables
- Identify additional resource needs and relevant CEOS/CGMS Agencies to dedicate appropriate resources



GHG Roadmap Table of Contents

Primary Roles

- **WGClimate GHG Task Team**
  - Create and maintain a roadmap to implement actions proposed in the AC-VC white paper
  - Establish primary user interface to Users (Inventory and Policy) and ensure feedback on prototype products
  - Provide a system engineering overview and track requirements, capabilities, and deliverables
  - Identify additional resource needs and relevant CEOS Agencies to dedicate appropriate resources
- **WGCV ACSG**
  - Identify best practices for prelaunch calibration of CO_2 and CH_4 concentration sensors and facilitate the exchange and harmonization of approaches and reference standards
  - Identify best practices for on-orbit calibration of GHG sensors and disseminate standards including solar, lunar, and surface vicarious validation sites
- **AC-VC GHG Team**
  - Coordinate ongoing agency activities to implement a prototype atmospheric GHG inventory system that incorporates products from a virtual constellation of sensors by 2021
  - Coordinate efforts to trade studies on constellation architecture
  - Coordinate development of a more complete atmospheric GHG inventory for the 2028 Stocktake

AC-VC Contributions to the WGClimate GHG Task Team

- Work with stakeholders (i.e. UNFCCC, IPCC) and users (national inventory community) and partner organizations (WMO GCOS and IG3IS) to define the requirements for space-based atmospheric CO_2 and CH_4 inventories that are used as part of a GHG emission inventory system
- Coordinate CO_2 and CH_4 flux inversion efforts by CEOS agencies to implement a pilot atmospheric GHG inventory in time to support the 2023 Global Stocktake
- Work with WGCV ACSG and GSICS to define best practices and facilitate exchange and harmonization of approaches for instrument cross-calibration
- Coordinate Observation System Simulation experiments (OSSEs) among CEOS agencies to support trade studies on constellation architecture
- Coordinate discussions of auxiliary observations enhancing data quality (e.g., aerosol properties, NO_2 for plume detection)
- Work with WGClimate to identify gaps in space-based GHG sensors and climate data records
- Refine requirements for space based CO_2 and CH_4 measurements to support a more complete atmospheric GHG inventory for the 2028 Global Stocktake

Interactions with Stakeholder, Science Communities and User communities

- **Supported COP-21 Earth Information Day with talks and posters**
  - *Schulz, J., Crisp, D., Dowell, M. and von Bargen, A.: Space-based observation for supporting Nationally determined contributions (NDCs), national inventories and the global stocktake*
  - *Crisp, D., Dowell, M., Husband, R., and von Bargen, A.: A constellation architecture for space-based observations of greenhouse gases: measurement approaches, datasets, and models in support of the global stocktake*
  - *Crisp, D., and Dolman, H.: The carbon cycle and the climate: an evolving system?*
- **Hosted a WGClimate Task Team workshop in conjunction with the American Geophysical Union meeting in San Francisco, CA USA**
  - Described GHG Roadmap objectives, deliverables and schedule
  - Solicited inputs and contributions from members of the ground-based and space based measurement communities and the atmospheric GHG flux inversion modeling communities
- **Fostering engagement with the user community by participating in the 2020 GEIA meeting (6/23-24)**
  - Expected to provide opportunities for interactions with the national statistical emission inventory community

The Growing Fleet of CO_2 and CH_4 Satellites

- **Space agencies have supported several pioneering space-based GHG sensors**
  - 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, Japan's GOSAT-2 TANSO-FTS-2 NASA's ISS OCO-3 and the commercial GHGSat
- **Others are under development**
  - CNES MicroCarb, CNES/DLR MERLIN
- **Others are in the formulation stages***
  - NASA's GeoCarb, Japan's GOSAT-GW, Copernicus CO2M
- **Commercial entities and NGO's (EDF) are developing high-resolution sensors that complement these efforts**

**** Approved since last AC-VC meeting***

Progress in Atmospheric Inventory Development

AC-VC is tracking and attempting to coordinate agency activities to implement a prototype atmospheric GHG inventory to support the 2023 Global Stocktake

- **New CO_2 and CH_4 Data Sets**
  - OCO-2/ACOS team reprocessed the decade-long GOSAT TANSO-FTS XCO_2 record using the Version 9 ACOS/GOSAT algorithm https://disc.gsfc.nasa.gov/datasets?keywords=acos%20gosat&page=1
  - OCO-2 team updated the retrieval algorithm (Version 10) and reprocessed the entire 5.5 year XCO_2 data record with increased accuracy https://disc.gsfc.nasa.gov/datasets?keywords=oco-2%20b10&page=1
  - Significant progress in bias correction in S5p TROPOMI CH_4
  - Beginning to assess GOSAT-2 TANSO-FTS-2 CO_2, CH_4, and CO, and OCO-3 CO_2
- **New Flux Inversion Models**
  - Copernicus Climate Monitoring System (CAMS) is using GOSAT and OCO-2 XCO_2 estimates and *in situ* data to create global CO_2 flux maps (Chevallier et al., ACP, 2019; https://atmosphere.copernicus.eu/new-high-quality-cams-maps-carbon-dioxide-surface-fluxes-obtained-satellite-observations)
  - OCO-2 Project is conducting a Flux Multi-Model Intercomparison Project (MMIP) to assess the relative roles of these factors on atmospheric flux uncertainties (Crowell et al. ACP, 2019; https://www.esrl.noaa.gov/gmd/ccgg/OCO2/)

Progress and Near-Term Plans

- **Ground-based, airborne and space-based CO_2 and CH_4 sensors with increasing accuracy, precision, resolution, and coverage are being deployed**
  - Japan's GOSAT/GOSAT-2, NASA's OCO-2/OCO-3, China's TanSat, & Copernicus S5p in operation
  - NASA's GeoCarb, Japan's GOSAT-GW and Copernicus CO2M approved for development
- **Scientists in the US, Europe, China and Japan are using ground- and space-based CO_2 and CH_4 data to produce atmospheric flux estimates – yielding prototype inventories**
  - Most global flux efforts focus on land biospheric fluxes (fossil fuels are prescribed)
  - Local source methods describe emissions from large urban areas and power plants
  - Improvements expected as the length and quality of the XCO_2 and XCH_4 records improve
- **CEOS/CGMS WGClimate GHG Task Team is completing a Roadmap to implement the space-based sensors and modeling capabilities needed for emission inventories**
  - Soliciting input from the science, stakeholder and national inventory development communities
    - UNFCCC, IPCC, GCOS, WMO IG3IS, and the GEIA community are being engaged for input