WGCV support to the CEOS strategy for the Global Stocktake of the UNFCCC Paris Agreement Report

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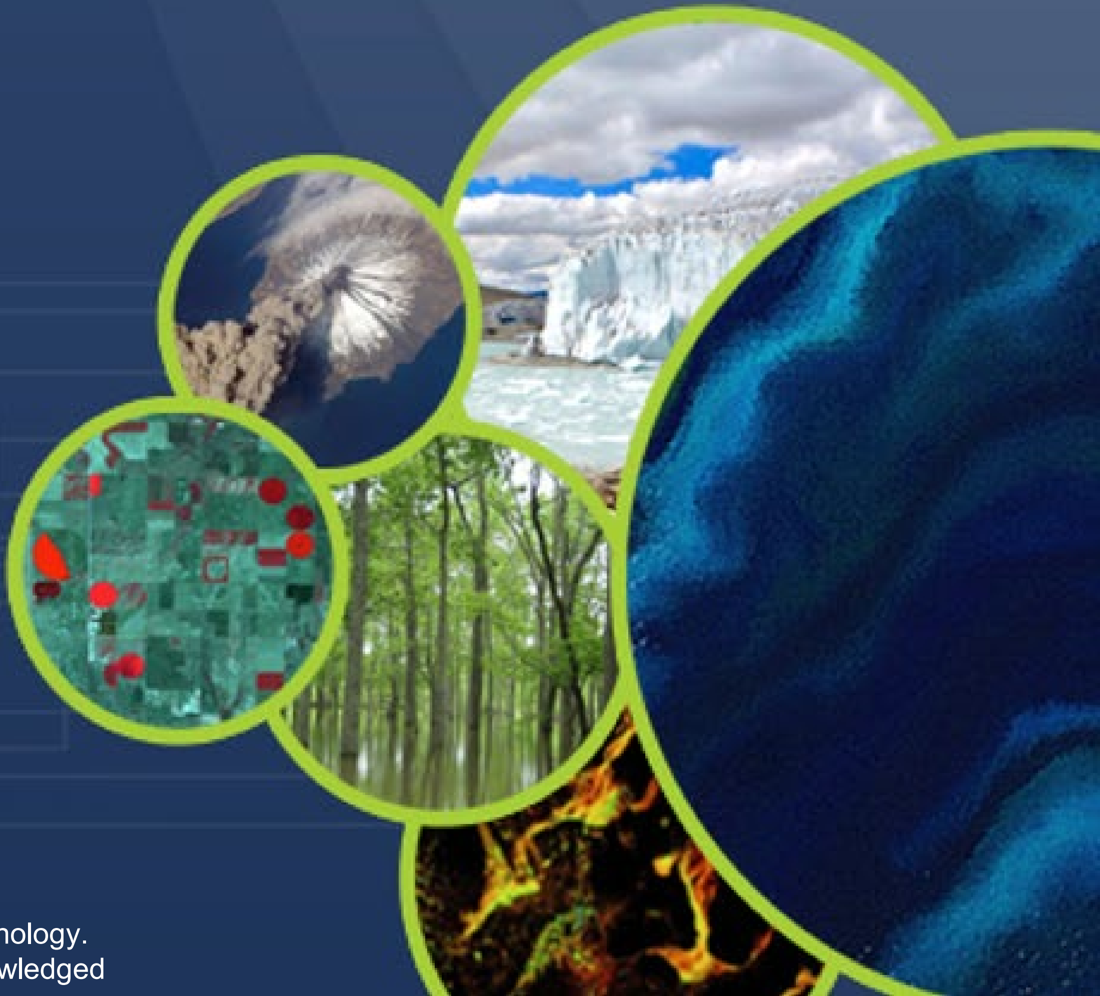
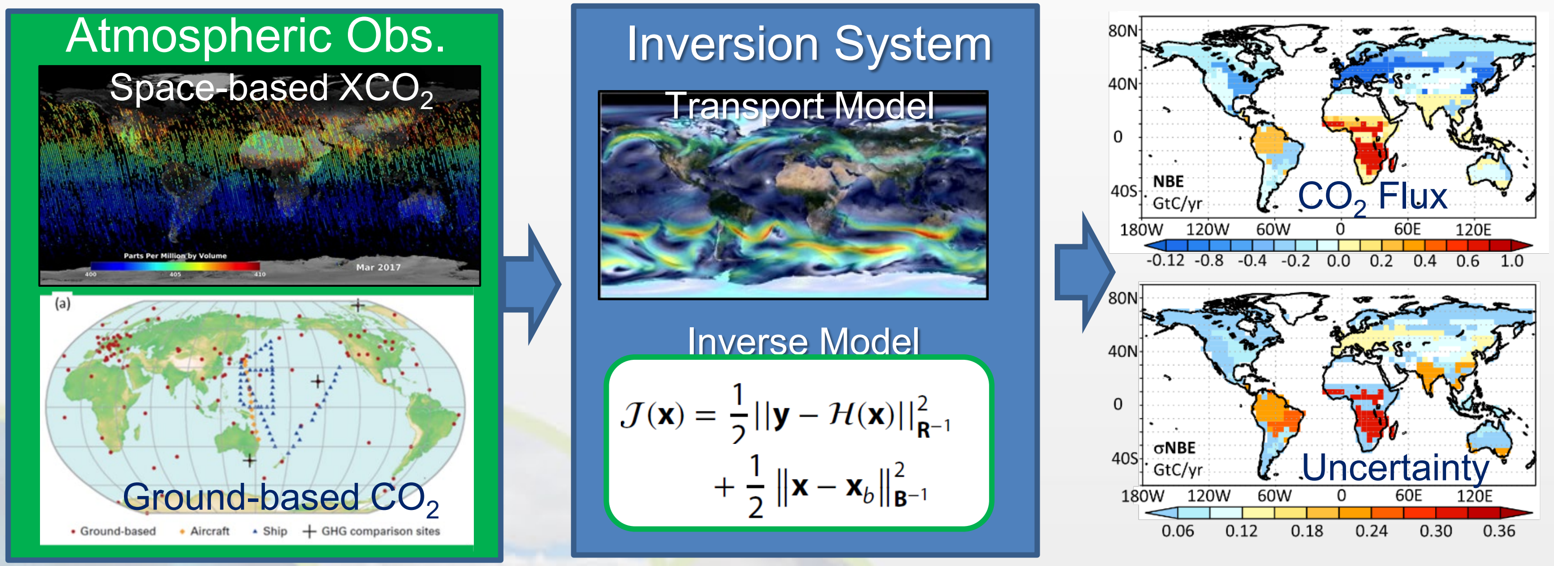
CEOS WGCV-49

July 2, 2021



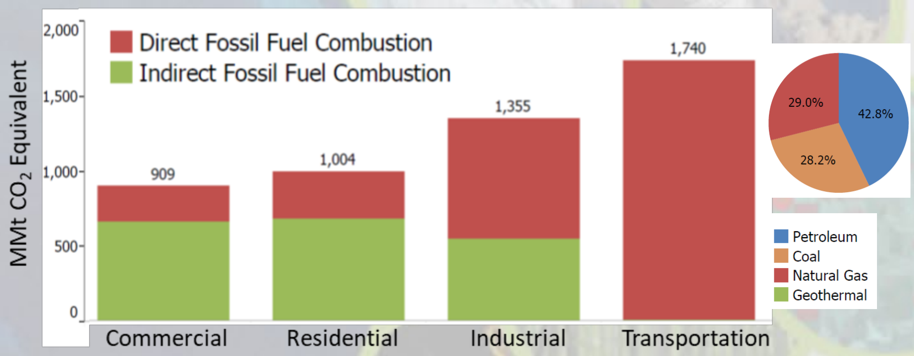
Combining Bottom-up and Top-down Inventories to Support the Global Stocktake



Top-Down Inventories

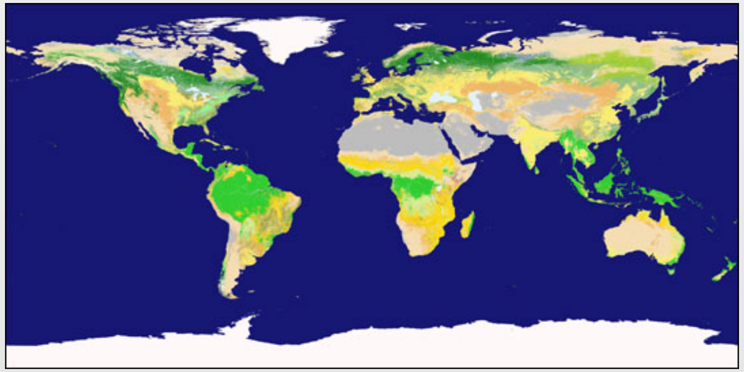
Observations of atmospheric CO_2 and CH_4 provide an integral constraint on emissions and removals to

- Track emission hot spots and rapid changes
- Detect emission changes from the natural carbon cycle caused by human activities and climate change



Bottom-Up Inventories

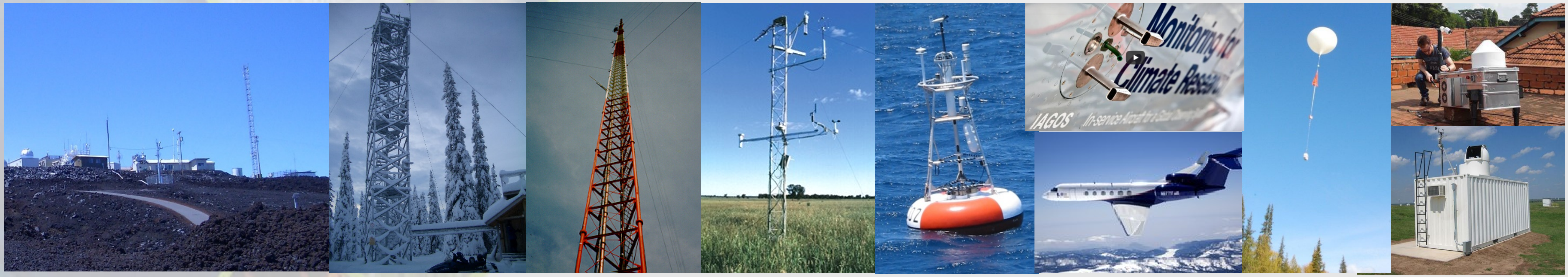
- Provide sector-specific estimates of emissions from known sources.
- Earth Observations play a critical role for tracking land use change.



Growing Capabilities in Ground-based and Space-based Atmospheric GHG Measurements

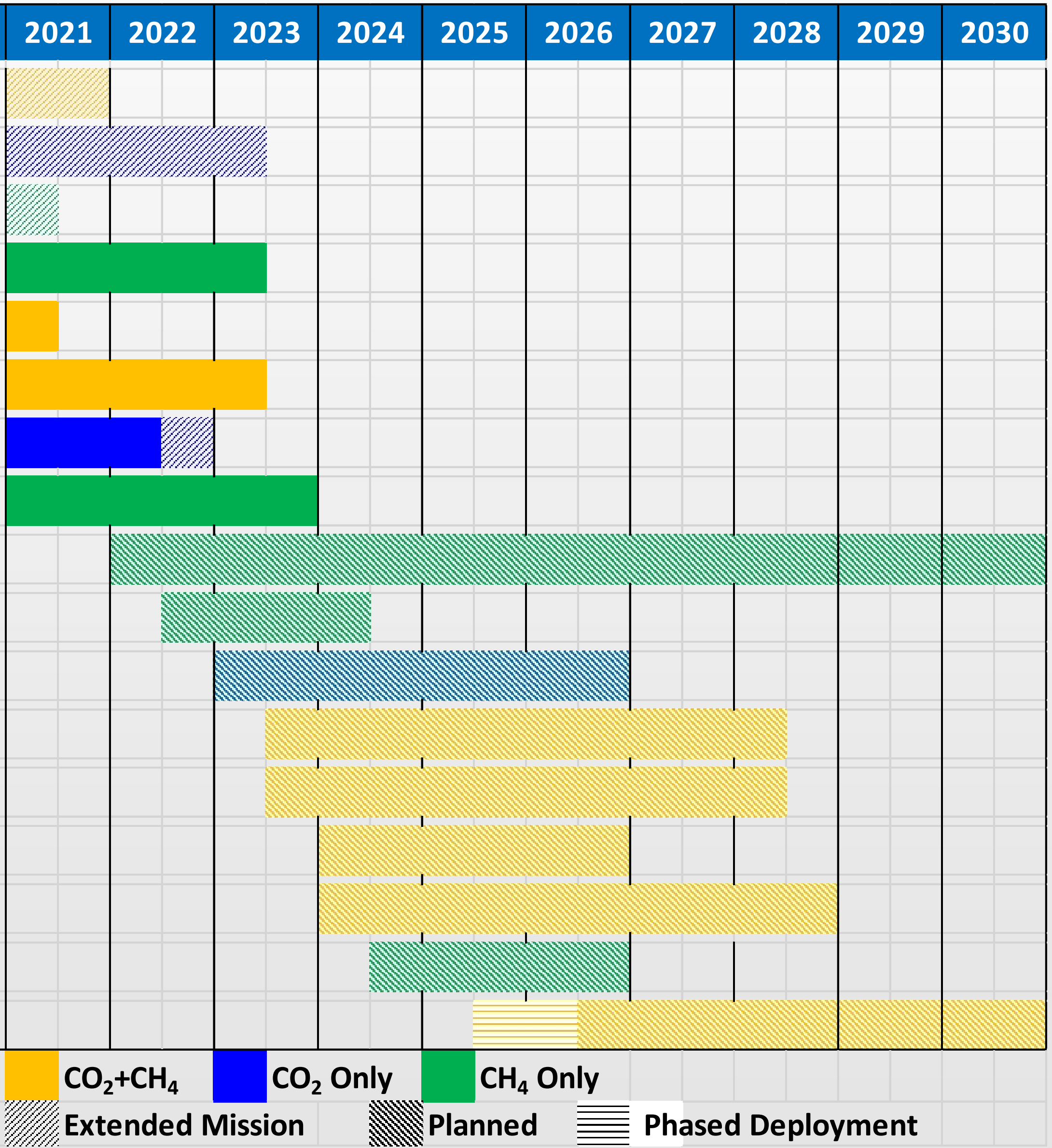
Space-based measurements of CO_2 and CH_4 from a growing fleet of satellites are less precise and accurate but provide high spatial and temporal resolution and greater coverage of the globe.

Ground-based measurements from the WMO Global Atmospheric Watch (GAW) Network and its partners provide accurate estimates of atmospheric GHG concentrations and their trends on local and global scales.



Several GHG Satellites are Coming on Line

Satellite, Instrument	Agency/Origin	CO_2	CH_4	Public	Private
GOSAT TANSO-FTS	JAXA-NIES-MOE/Japan	●	●	●	
OCO-2	NASA/USA	●		●	
GHGSat-D - Claire	GHGSat/Canada		●		●
Sentinel 5P TROPOMI	ESA/Europe		●	●	
GaoFen-5 GMI	CHEOS/China	●	●	●	
GOSAT-2 TANSO-FTS-2	JAXA-NIES-MOE/Japan	●	●	●	
OCO-3	NASA/USA	●			
GHGSat C1/C2 - Iris, Hugo	GHGSat/Canada		●		●
MetOp Sentinel-5 series	EC Copernicus/Europe		●	●	
MethaneSAT	EDF/USA		●		●
MicroCarb	CNES/France	●		●	
Feng Yun 3G (CMA)	CMA-NMSC/China	●	●	●	
Carbon Mapper[1]	Carbon Mapper LLC/USA	●	●	●	●
GeoCarb	NASA/USA	●	●	●	
GOSAT-GW	JAXA-NIES-MOE/Japan	●	●	●	
MERLIN	DLR/Germany-CNES/France		●	●	
CO2M	EC Copernicus/Europe	●	●	●	



Pilot Global Top-Down Inventory Products

Global, Top-down CO_2 Budgets

- Pilot global CO_2 inventory products will be derived from flux products being developed by the OCO-2 Flux Multi-model Intercomparison Project (OCO-2 Flux MIP)
- Combine in situ CO_2 measurements with space-based estimates of the column-averaged CO_2 dry air mole fraction (XCO_2) from OCO-2 v10 product to predict fluxes and stock changes

Global, Top-down CH_4 Budgets

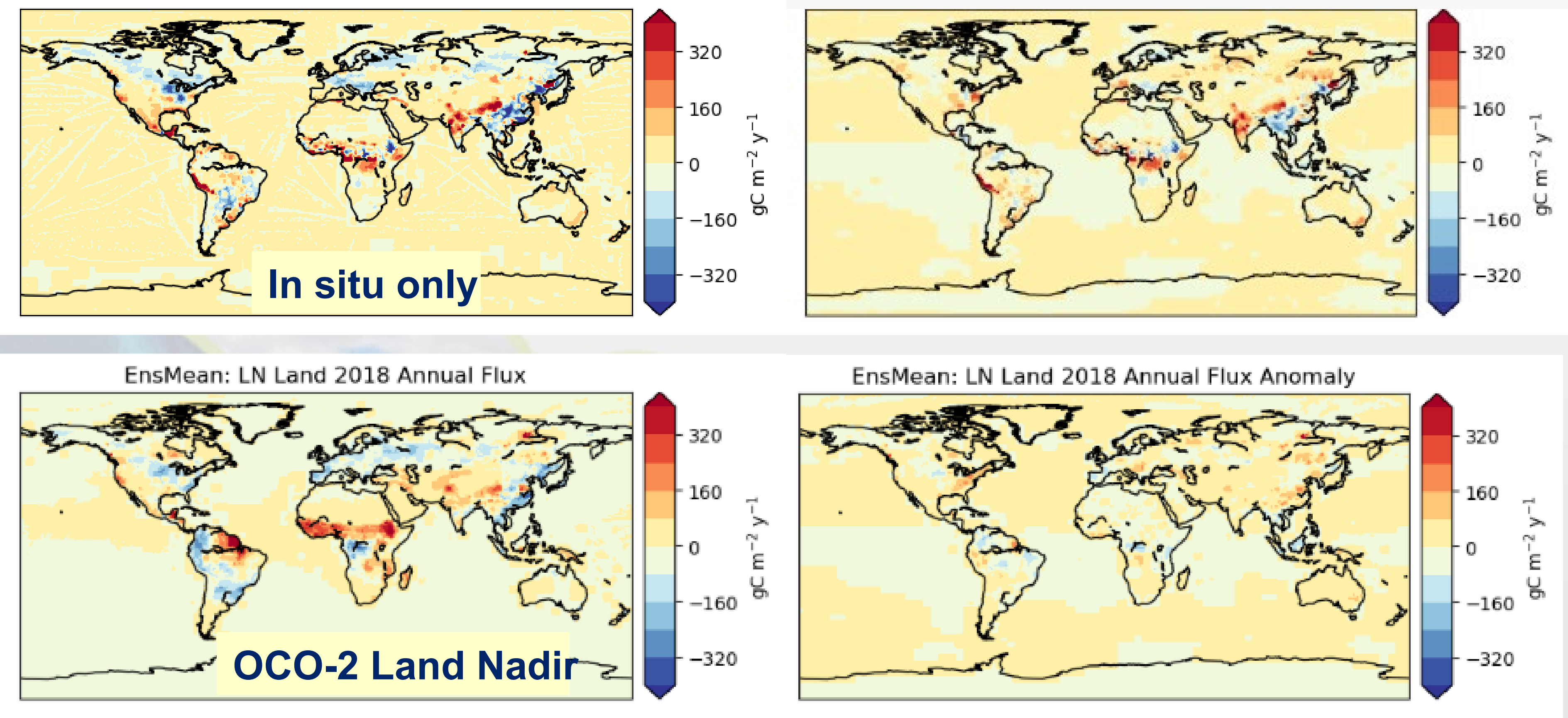
- Pilot global CH_4 inventory products will be derived from flux products being developed by the NASA Carbon Monitoring System Flux (CMS-Flux) team
- Combine in situ CH_4 measurements with GOSAT and TROPOMI products

Local Source Inventory Products

- Urban-scale emission products from OCO-2, GOSAT, and TROPOMI teams are being solicited from individual PIs

Example: Regional-scale Global Maps of Annual Mean Non-Fossil Fuel CO_2 Fluxes

2018 non Fossil Fuel Fluxes | **Flux Uncertainties**



OCO-2 Flux MIP Team

Non-fossil fuel fluxes (left column) and uncertainties (right column) based on in situ CO_2 and OCO-2 version 9 (v9) XCO_2 products from the v9 MIP.

- 10 different inverse models used to assess impact of transport and model architecture.
- Experiments using only *in situ* CO_2 or observations for specific space-based datasets show impact of accuracy and coverage on fluxes and uncertainties.

Tracking Emissions from Localized Hot Spots

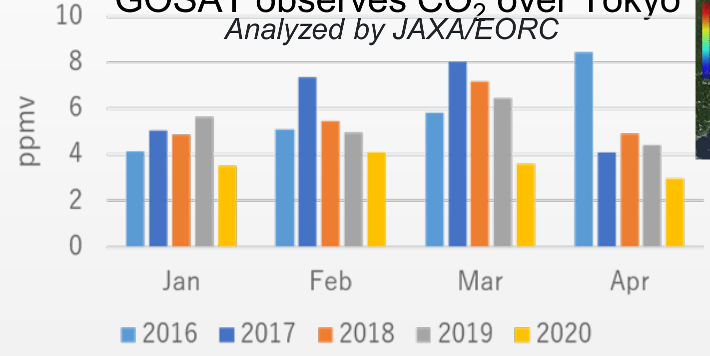
Pilot products are also being developed to track emissions from localized sources including large urban areas, power plants and oil fields

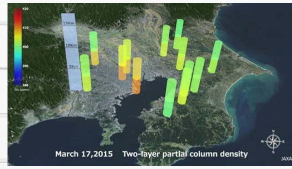
- The GOSAT team accelerated the development of an upper/lower tropospheric product to track effects of COVID-19 lockdowns on emissions from large urban areas
- The OCO-2 and TROPOMI teams are combining CO_2 and NO_2 to quantify emissions from powerplants and large urban areas
- The TROPOMI team is tracking methane emissions from fossil fuel extraction, and collaborating with the GHGSat team to track intense plumes

Existing capabilities do not have the resolution or coverage needed to track all local sources, but can illustrate methods for tracking emissions from hot spots for future GST's

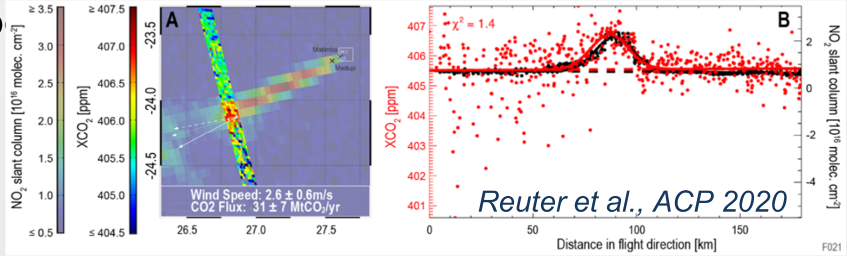
GOSAT observes CO_2 over Tokyo

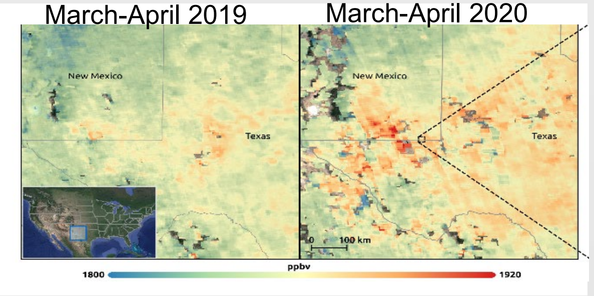
Analyzed by JAXA/EORC





OCO-2 XCO_2 and TROPOMI NO_2 combined to quantify CO_2 emission by large South African p

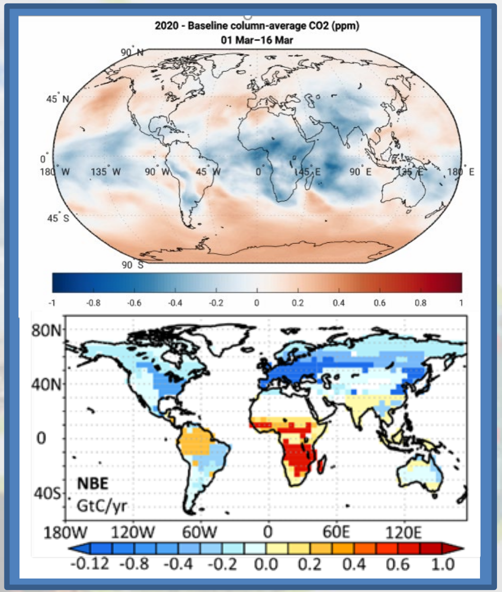


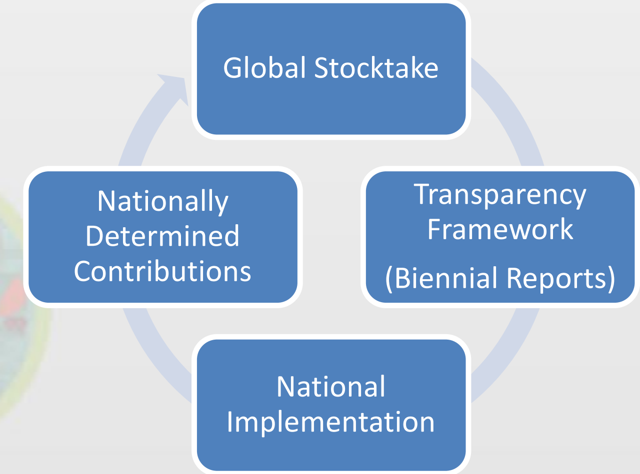


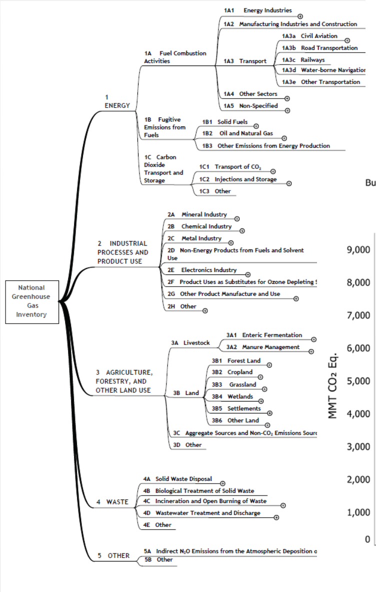
TROPOMI observes CH_4 emissions changes over Texas oil fields

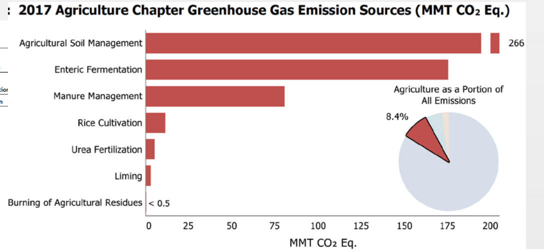
Creating Interfaces and Capacity Building for Future Global Stocktakes

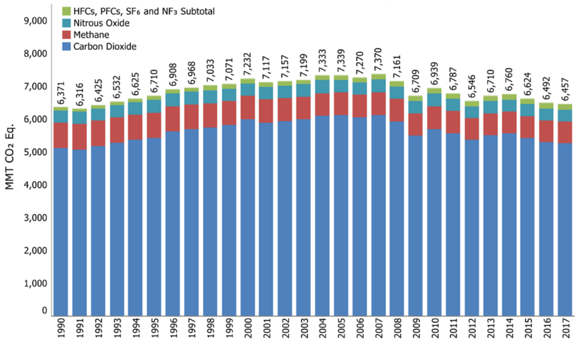
The primary objective of this pilot inventory activity is to provide a product that starts a conversation with the national inventory agencies, the UNFCCC, and other relevant players (IG^3IS, GCOS, IPCC) to establish the utility and best practices for the use of top-down atmospheric inventories in future Global Stocktakes











Interoperability is Critical for Measurements and Derived Products

Harmonizing measurements from different satellites

- Improve resolution and coverage and to provide redundancy
- Extend the science data record as new systems come on line
- Encourage their use by multiple teams to generate GHG products
- **This requires cross calibration of the satellite observations against internationally recognized standards**

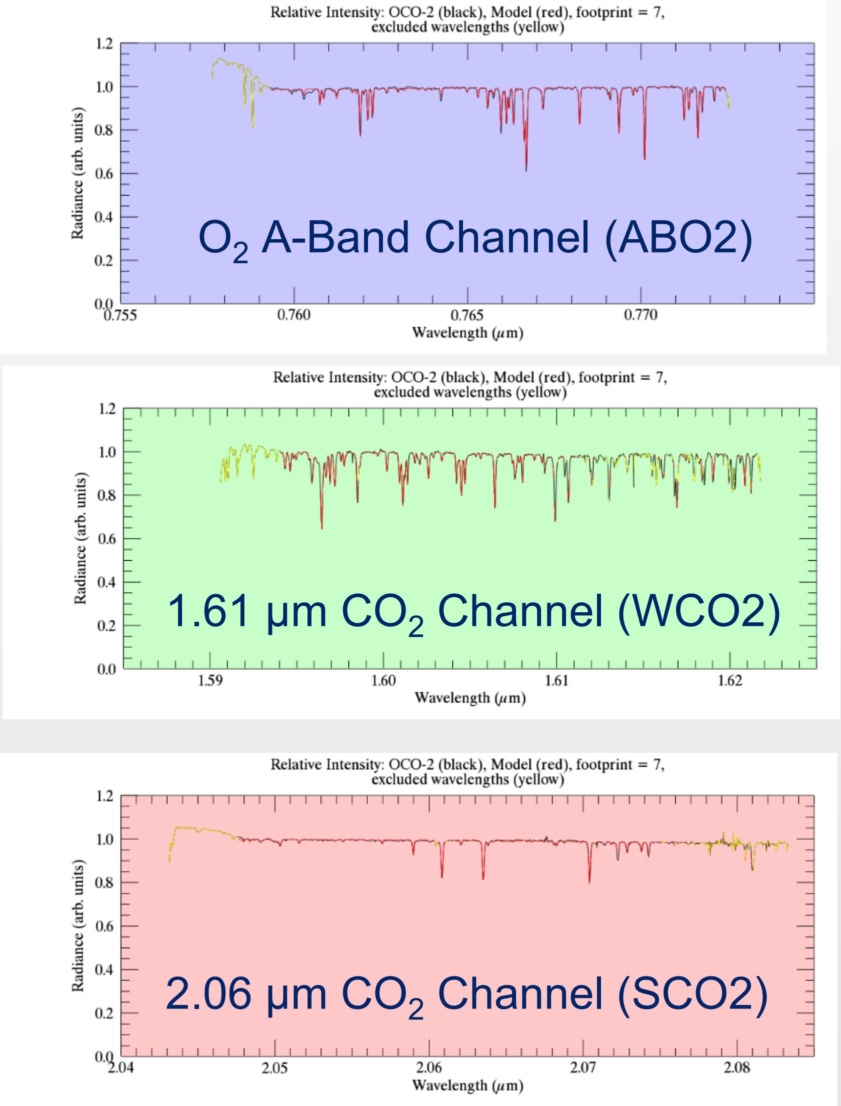
Harmonizing retrieval model results is also critical for the same reasons

- This requires cross-validation of their GHG estimates products against internationally recognized standards

WGCV is playing an important role in all of these activities

Solar Radiometric Calibration – an OCO-2 Example

- **Routine observations of diffuse sunlight are used to track changes in the radiometric calibration**
- **Observations of diffuse sunlight collected across the full day-side orbit has also been used to track changes in the instrument line shape (ILS)**
  - This approach yields thousands of observations with Doppler shifts varying from +/- 7 km/sec
- **High accuracy solar reference spectra (i.e. TSIS SIM HSRS) are critical for interpreting these measurements**

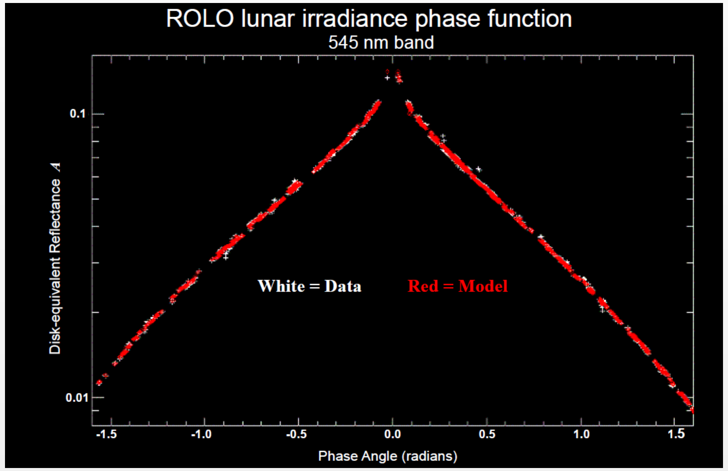


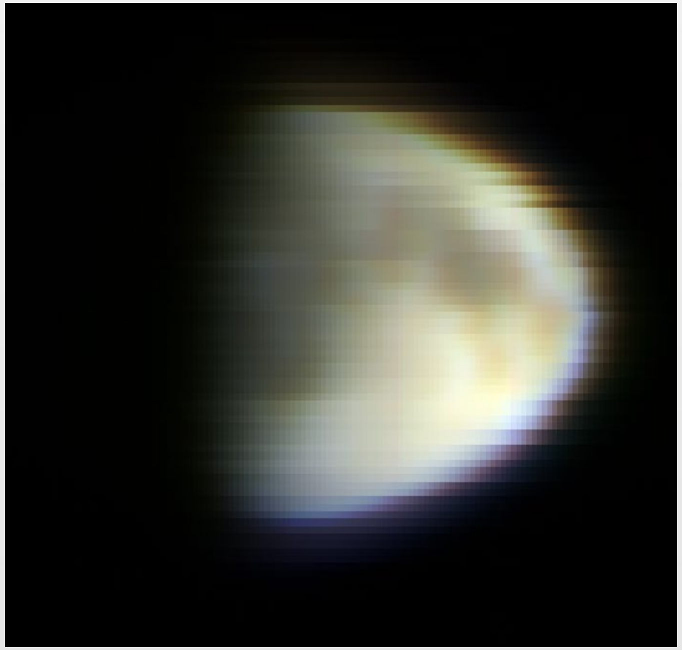
Typical Examples of OCO-2 solar spectra

Lunar Radiometric Calibration – an OCO-2 Example

- **Observations of the Moon are acquired monthly to support relative radiometric calibration**
  - Trending the throughput of the science data path (with no diffusers or attenuators) and trending the performance of the solar calibration diffuser
  - ROLO database essential for interpreting lunar measurements

- **OCO-2 observes the Moon at ¾ gibbous phase (and near full earlier in mission)**
  - Both gibbous and full phases yield useful calibration data, but gibbous phase is more highly polarized
  - Observations of the full moon were lost after gyro failed because the Earth's disk obscures the star tracker for these observations

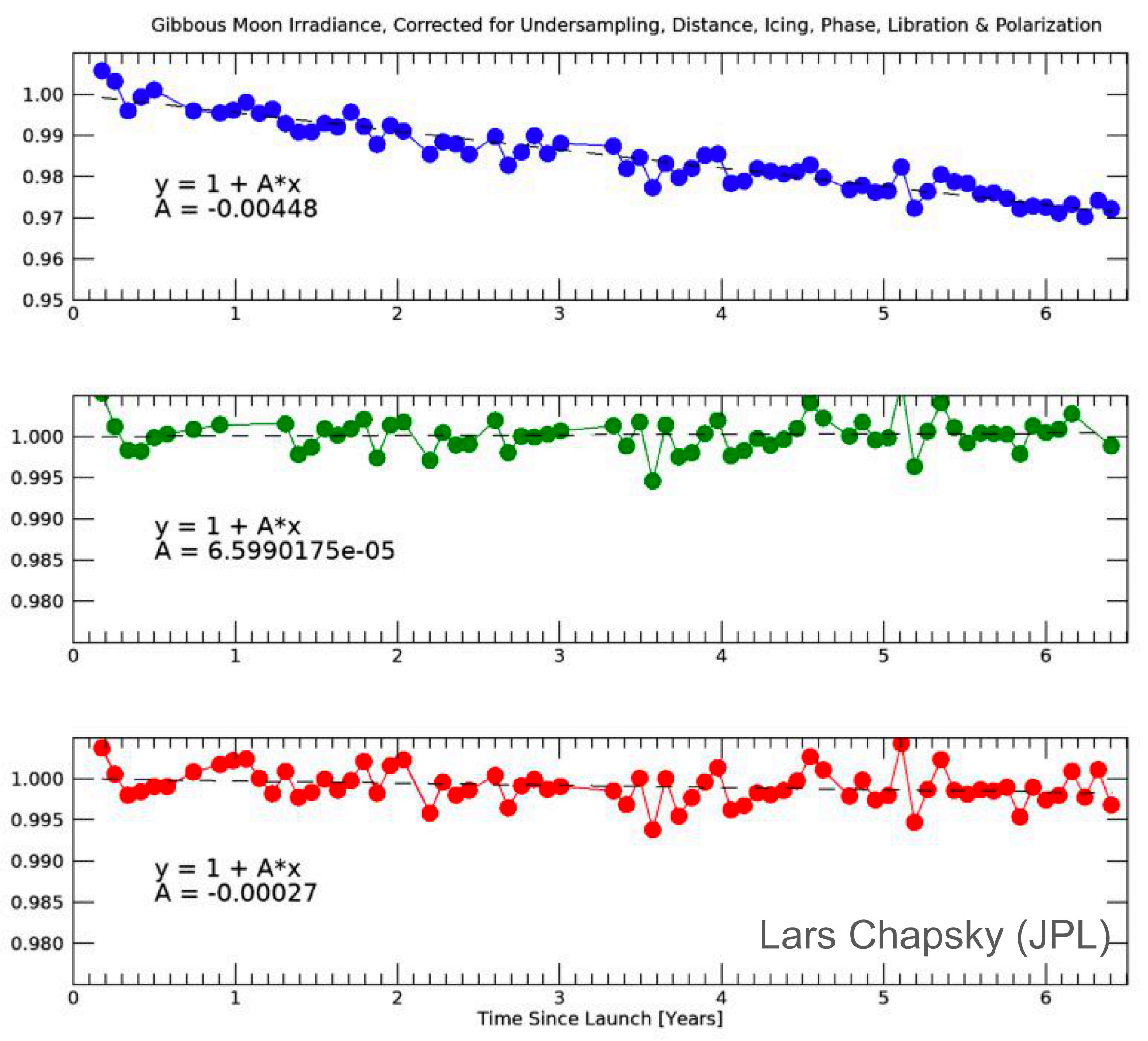




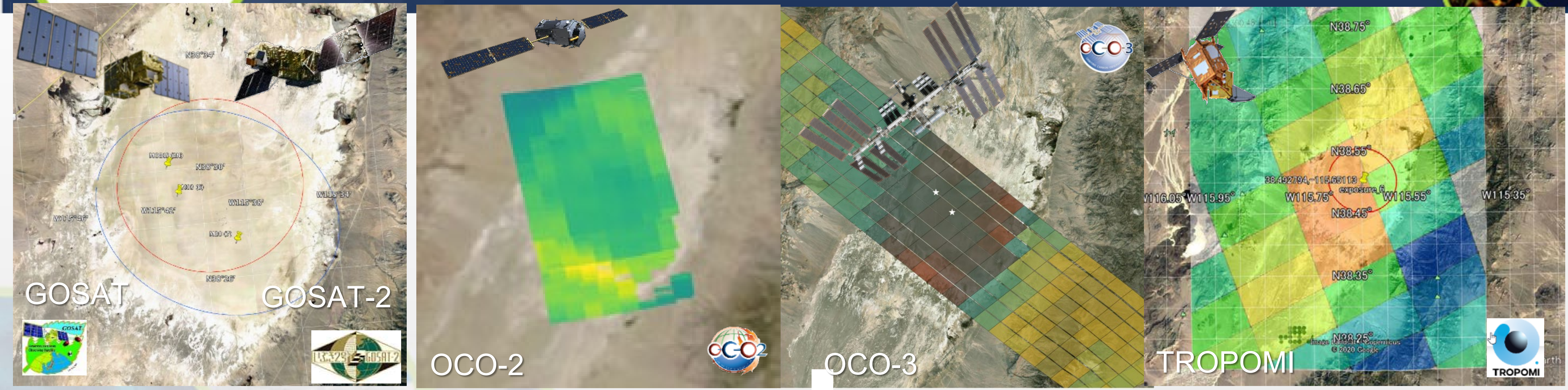
Lunar Calibration Tracks Science Throughput

Observations of the 75% gibbous phase are used to track changes in the throughput of the optical system

- Provide direct measurements of degradation of science optical path
- Also used to trend the long-term degradation of the solar calibration diffuser.
  - The largest changes in the science optical path (~3% over 6 years) are seen in the 765 nm ABO2 channel.
  - Changes in the CO_2 channels at 1610 and 2060 nm are < 1%
- **In principle, lunar reflectance estimates could also be combined with a calibrated solar spectrum (TSIS SIM HSRS) to yield an absolute radiometric calibration**



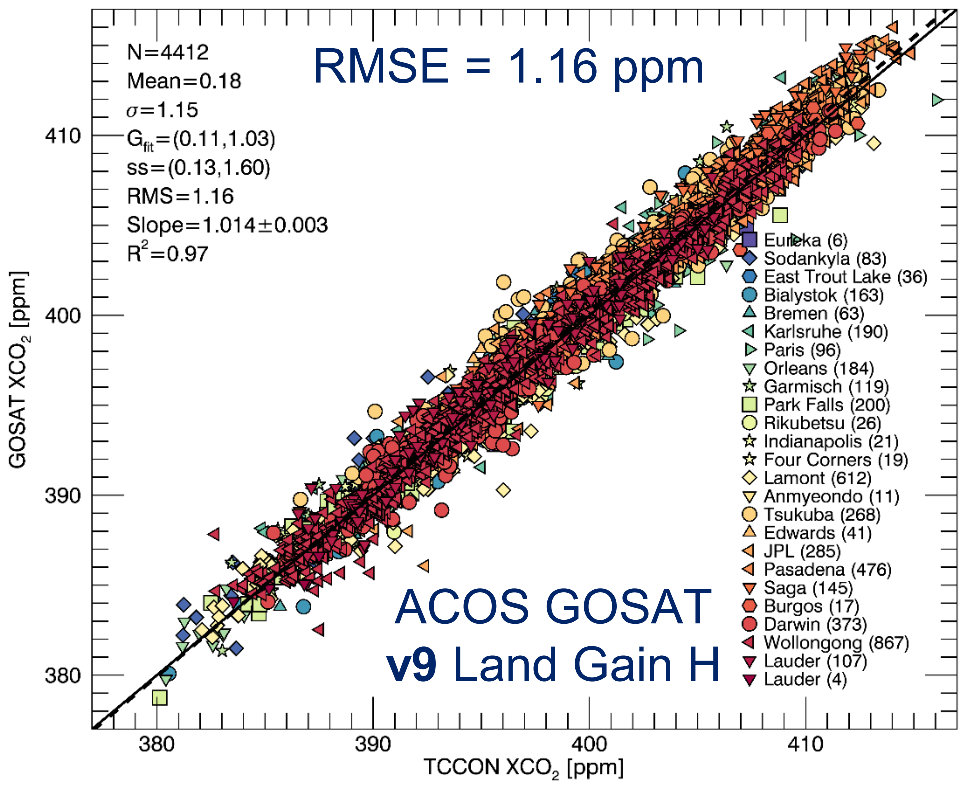
2020 Railroad Valley Calibration Campaigns

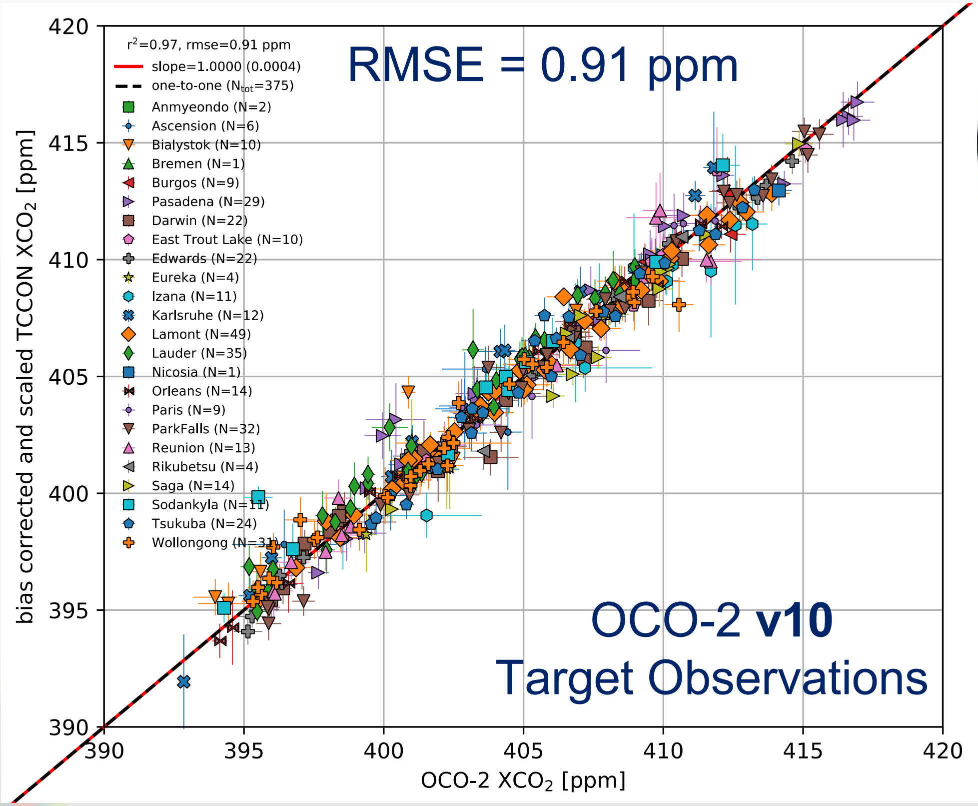


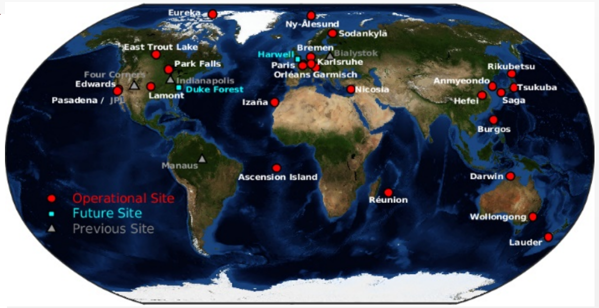
Railroad Valley, Nevada, USA is the primary vicarious calibration site used to cross-calibrate the current fleet of GHG Sensors

- In 2020 and 2021, GOSAT, GOSAT-2, OCO-2, OCO-3 the European Copernicus Sentinel 5 Precursor TROPOMI missions cross-calibrated their sensors in the campaign.
- The OCO team deployed “socially-distanced” field teams to Railroad Valley in 2020 and 2021 to collect ground-based data in support of the calibration campaigns.

XCO_2 Precision and Accuracy Validated Though Comparisons with TCCON and Other Standards







TCCON Sites

Lamont, Ok. TCCON

Estimates of XCO_2 derived from GOSAT and OCO-2 data are validated against estimates derived from the Total Carbon Column Observing Network, TCCON to quantify their uncertainties.

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Cal/Val Activities Identified in the CEOS/CGMS WGClimate GHG Roadmap

Sens-3: Sens-3: Define best practices and facilitate exchange and harmonization of approaches for instrument cross-calibration in coordination.

CV-2: Identify the current shortcomings/gaps/sustainability in GHG calibration and validation capabilities, and formulate recommendations on the medium- to long-term way forward, that is with a specific focus on GHG Fiducial Reference Measurement (FRM).

CV-3: Identify gaps and suggest improvements in the inter-calibration of a future LEO/GEO constellation of GHG sensors

CV-4: Define protocols for comparing and validating GHG retrieval algorithms

CV-5: Identify gaps and suggest improvements in ground-based and airborne validation infrastructure

CV-6: Work towards an operational reporting on the quality of space-borne GHG measurements and the underlying calibration and validation infrastructure.

CV-7: Identify a repository for hosting quality-controlled CO_2 and CH_4 products

Contributors

- **Joint Committee on Earth Observation Satellites (CEOS) / Coordination Group on Meteorological Satellites (CGMS) Working Group on Climate (WGClimate) Greenhouse Gas Task Team**
- **CEOS Atmospheric Composition Virtual Constellation (AC-VC)**
- **CEOS Working Group in Calibration and Validation (WGCV)**
- **CEOS Agriculture, Forestry, and Other Land Use (AFOLU) Team**
- **World Meteorological Organization (WMO) Integrated Global Greenhouse Gas Information System (IG3IS)**
- **European Space Agency (ESA) TROPOMI Team**
- **Japan Aerospace Exploration Agency (JAXA) GOSAT and GOSAT-2 Missions**
- **European Centre for Medium-Range Weather Forecasts (ECMWF)**
- **Copernicus Atmospheric Monitoring Service (CAMS)**
- **H2020 CoCO2 project**
- **NASA Carbon Monitoring System (CMS)**
- **OCO-2 Flux MIP Team**
    - Laboratoire des sciences du climat et de l'environnement
    - NOAA Global Monitoring Laboratory
    - NASA Ames Research Center
    - NASA Carbon Monitoring System Flux Team
    - NASA Goddard Space Flight Center Global Modeling and Assimilation Office
    - NASA Jet Propulsion Laboratory, California Institute of Technology
    - Colorado State University
    - University of Colorado
    - University of Maryland
    - University of Oklahoma
    - University of Toronto

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