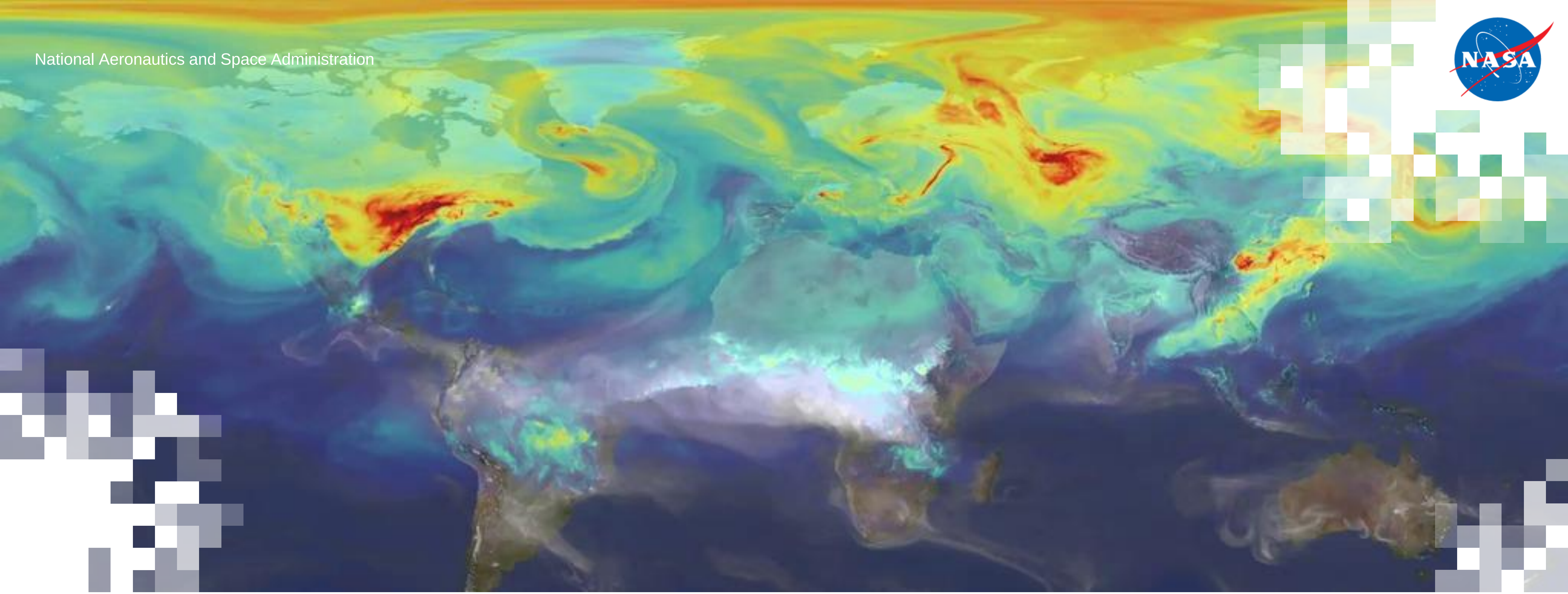


Atmospheric CO_2 and CH_4 Budgets to Support the Global Stocktake

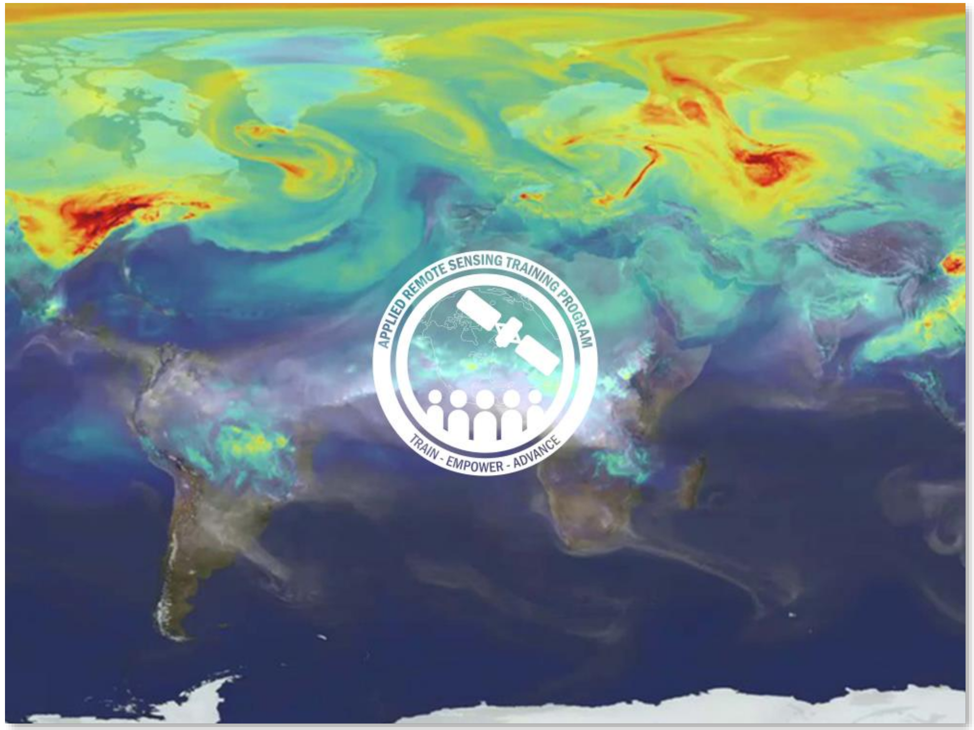
Part 1: Tracking Greenhouse Gases

David Crisp, Sean McCartney

May 11, 2022

Course Materials and Q&A

- Webinar recordings, PowerPoint presentations, and the homework assignment can be found after each session at:
    - https://appliedsciences.nasa.gov/join-mission/training/english/arset-atmospheric-co2-and-ch4-budgets-support-global-stocktake
- Q&A: Following each lecture and/or by email:
    - sean.mccartney@nasa.gov



Homework and Certificates

- **Homework:**
    - One homework assignment for the intermediate sessions submitted via Google Forms
        - Available on training website
- **Certificate of Completion**
    - Attend all three live introductory webinars
    - Complete the homework assignment by **Wednesday, June 8**
    - You will receive certificates approximately two months after completion of the course from: marines.martins@ssaihq.com

Webinar Agenda

Part 1. Wednesday, May 11, 2022

Tracking Greenhouse Gas Emissions and Removals – The Paris Agreement

- Tracking greenhouse gas emissions and removals to meet the Mitigation objectives of the Paris Agreement
- The need for transparent methods for tracking greenhouse gas emissions and removals at national scales
- National inventories and top-down atmospheric budgets for tracking greenhouse gases

Part 2. Wednesday, May 18, 2022

How do we create atmospheric budgets of carbon dioxide (CO_2) and methane (CH_4) on policy-relevant national to sub-national scales?

- What human activities and natural processes control emissions and removals of CO_2 and CH_4?
- How well can we measure CO_2 and CH_4 with existing ground-based, airborne, and space-based sensors?
- How are these data used to estimate emissions and removals of these gases on national scales?

Part 3. Wednesday, May 25, 2022

How can atmosphere CO_2 and CH_4 budgets be combined with inventories to support a more complete, accurate, and transparent global stocktake?

- Define best available products and best practices for combining these methods to develop national inventories and to assess the collective progress of those efforts towards the goals of the Paris Agreement
- Exploring "Use Cases" that illustrate the application of these methods

Audience

This ARSET training is intended for the following target audiences:

1. **Stakeholders** at local, regional, and national levels who are interested in reducing greenhouse gas emissions to meet the climate change mitigation goals of the Paris Agreement
2. **National inventory developers** responsible for producing the inventories of emissions and removals of greenhouse gases that are reported the United Nations Framework Convention on Climate Change (UNFCCC)
3. **UNFCCC bodies** responsible for assessing the effectiveness of the methods employed to reduce greenhouse gas emissions and our progress toward the goal of limiting global temperature increases to 2 °C
4. **Scientists** in the greenhouse gas measurement and modeling communities who are interested in developing atmospheric greenhouse gas budgets and working with the inventory development and assessment communities to support the global stocktake process

Part 1: Atmospheric Greenhouse Gas Measurements Supporting the Paris Agreement

At the end of today's webinar, the participants will understand:

- Key features of the United Nations Framework Convention on Climate Change (**UNFCCC**) Paris Agreement and key concepts, definitions, and acronyms used throughout the course
  - Focus of **Mitigation** Goals – Rapidly reducing greenhouse gas (**GHG**) emissions
  - **National GHG inventories** supporting the Enhanced Transparency Framework
  - Assessing progress through Global Stocktakes (**GSTs**)
- How systematic observations of atmospheric carbon dioxide (**CO_2**) and methane (**CH_4**) can support the Paris Agreement's Mitigation objectives as well as the Enhanced Transparency Framework and the GSTs

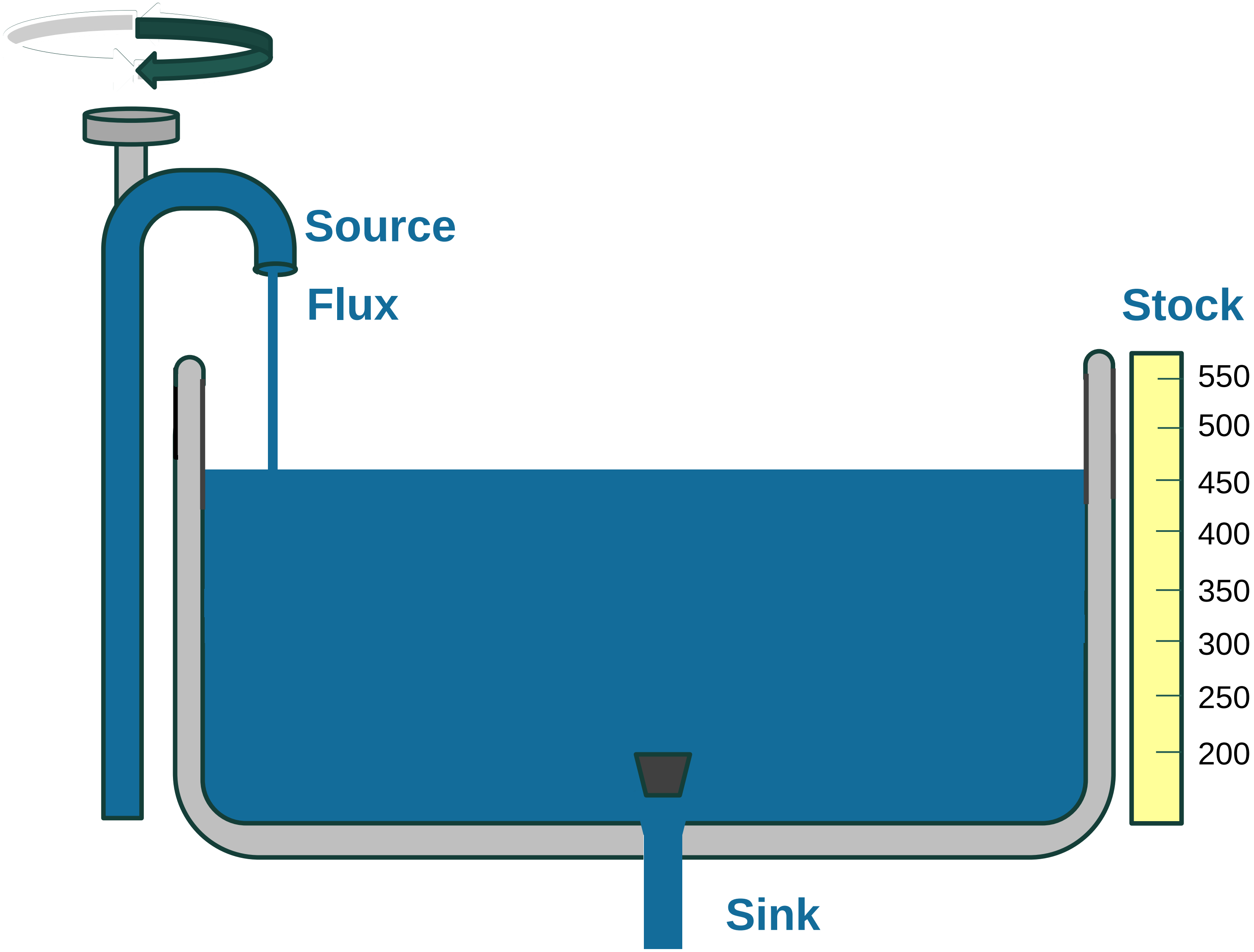
Carbon Dioxide (CO_2), Methane (CH_4), and Climate Change

- Fossil fuel combustion, land use change, and other human activities are now adding ~40 billion tonnes of carbon dioxide (**CO_2**) to the atmosphere each year, increasing the atmospheric CO_2 concentration by **~50%** over the industrial age.
  - These changes would have been much larger if natural ***sinks*** in the land biosphere and ocean hadn't absorbed **over half** of these emissions.
  - The identity & location of these natural sinks are not well understood.
- Over this same period, human activities have increased atmospheric methane (**CH_4**) concentrations by **~160%**, from **~0.72 ppm** to more than **1.88 ppm**.
  - Human activities are responsible for about 60% of the ~0.6 billion tonnes of CH_4 added to the atmosphere each year.
  - CH_4 is much less much abundant than CO_2, but it is a more potent greenhouse gas, with each molecule warming the atmosphere 28–36 times more efficiently than CO_2 on 100-year time scales.
- CO_2 and CH_4 account for **over 90%** of the present-day 1.1°C global warming.
  - Reducing these emissions is the major thrust of the Paris Agreement.

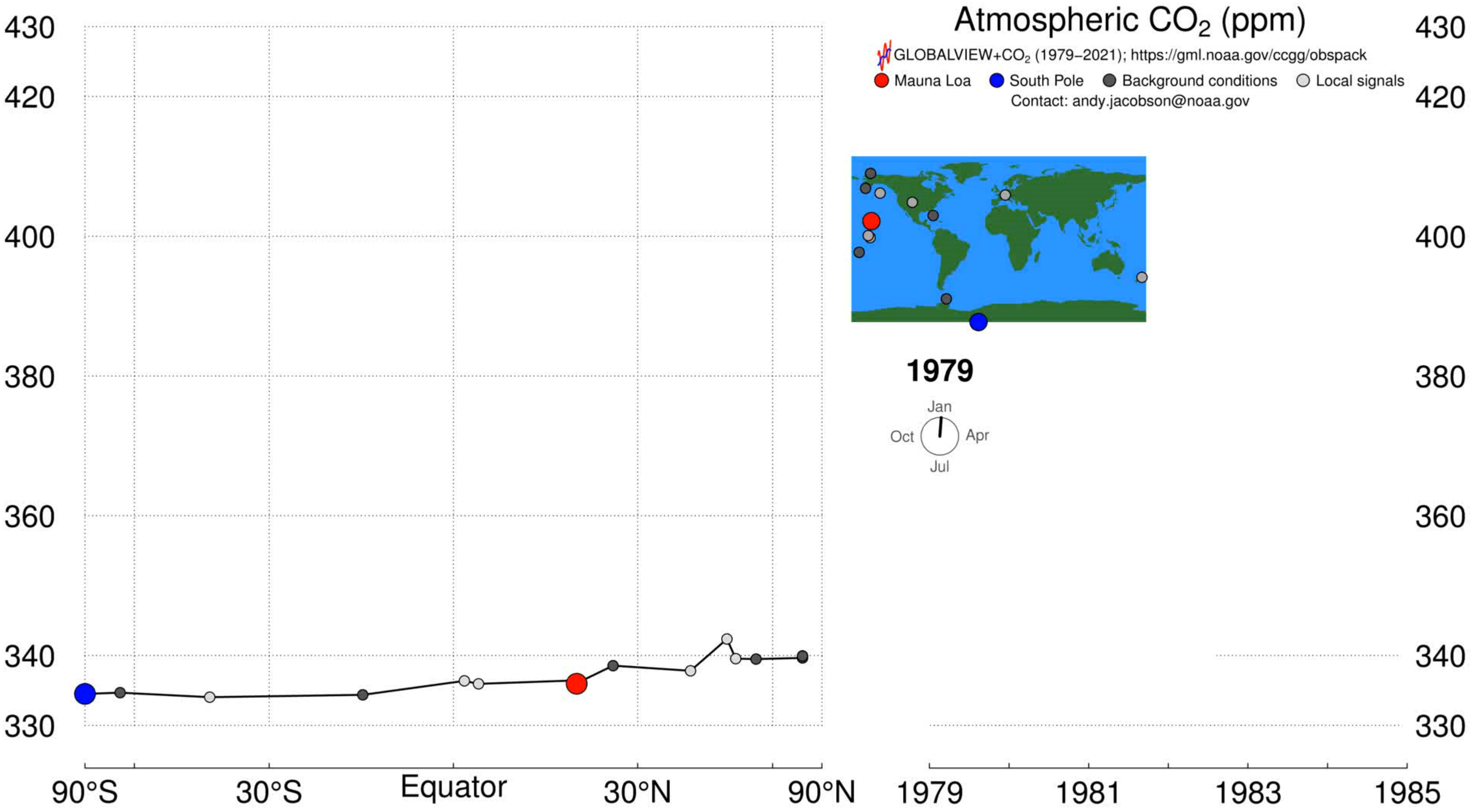
A Few Definitions: Stocks, Fluxes, Sources, and Sinks

Consider a basin with faucet and a plug at its bottom.

- The amount of water in the basin is a measure of its **stock**.
- A processes that adds water to the basin is called a **source**.
- A processes that removes water from the basin is called a **sink**.
- If the faucet is turned on, water accumulates in the basin, increasing the stock.
- The ***rate*** of increase of the stock in the basin is called the **flux.**
  - **Sources** yield ***positive*** fluxes.
  - **Sinks** yield ***negative*** fluxes.



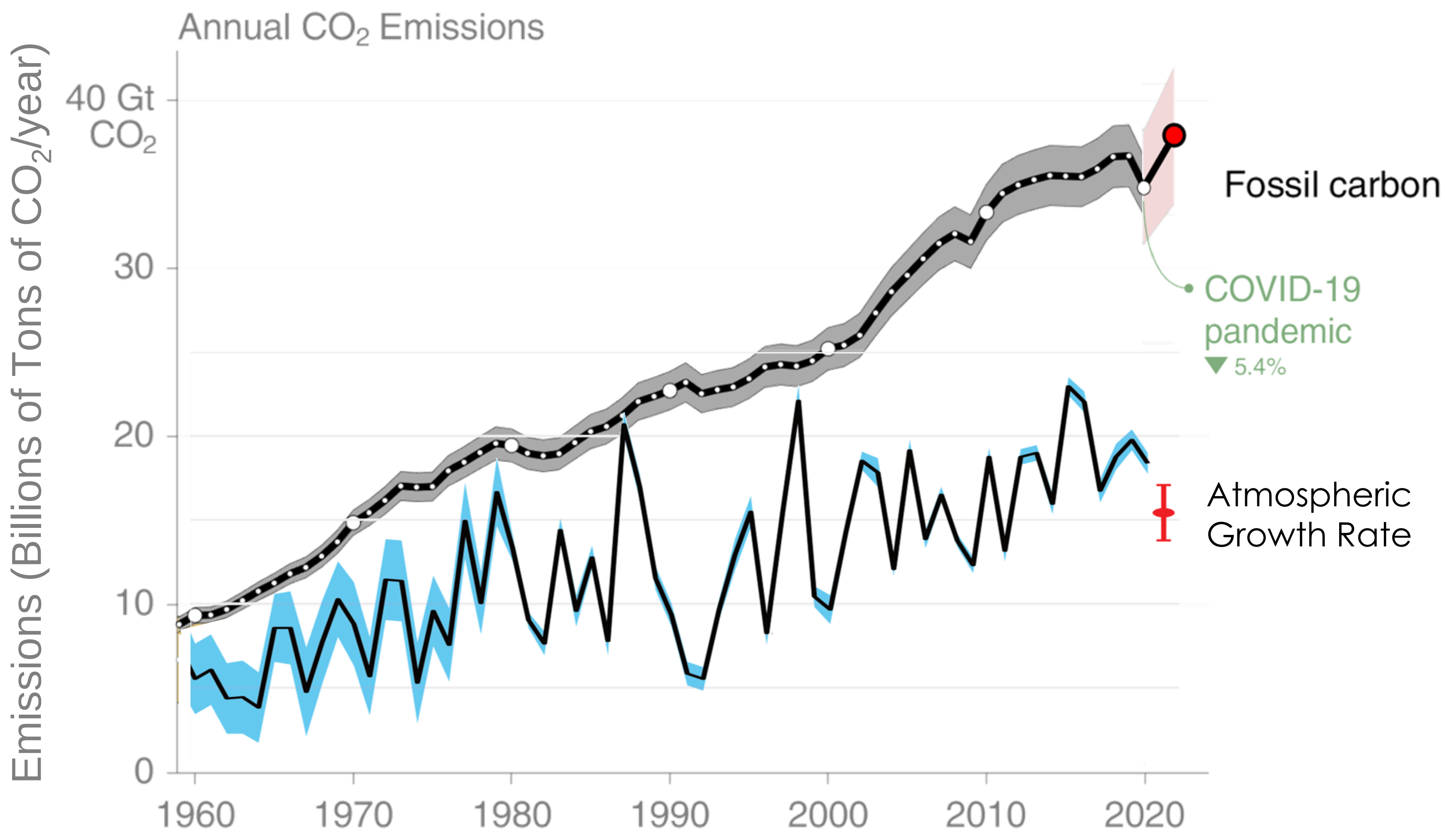
Atmospheric CO_2 Concentrations



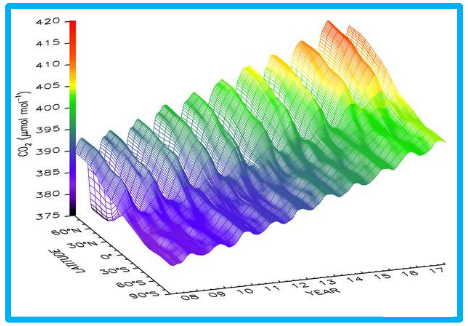
Global Monitoring Laboratory
Earth System Research Laboratories

https://gml.noaa.gov/ccgg/trends/history.html

Human Activities that Emit CO_2 Into the Atmosphere

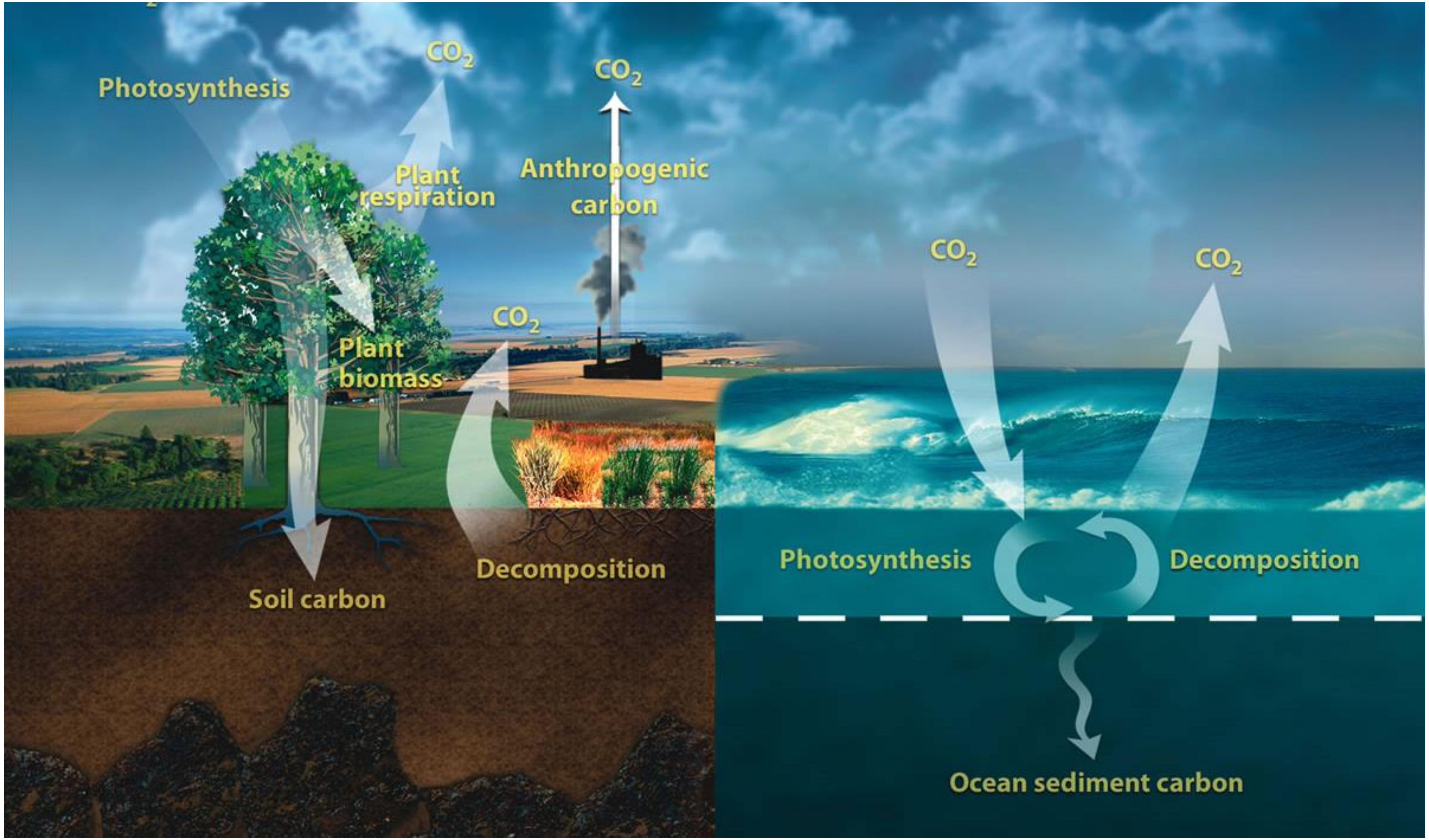


Global Carbon Project

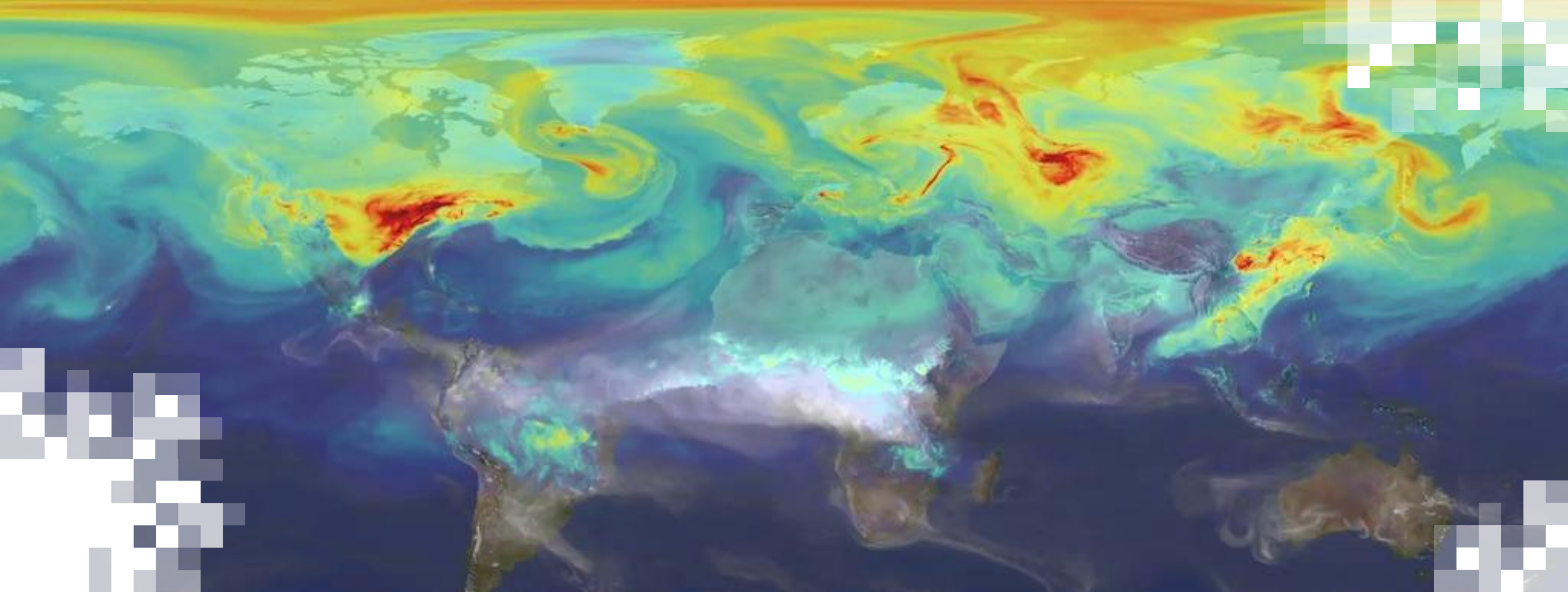


Adapted from Global Carbon Budget 2021

These human activities are a part of the Earth's carbon cycle.



https://public.ornl.gov/site/gallery/originals/CCycle_cover_image.jpg



Mitigating Climate Impacts by Reducing Greenhouse Gas Emissions – **The Paris Agreement**

Primary Objectives of the Paris Agreement

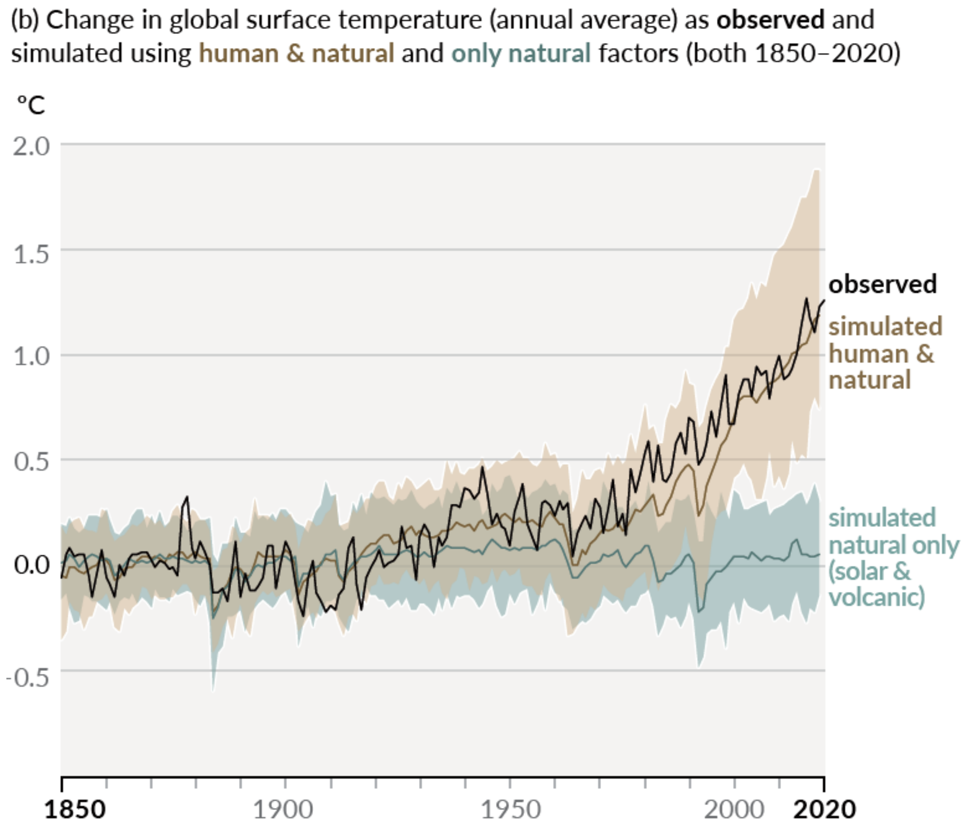
https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

To strengthen the global response to the threat of climate change, while encouraging sustainable development and efforts to reduce poverty, **Article 2** of the Paris Agreement identifies three objectives:

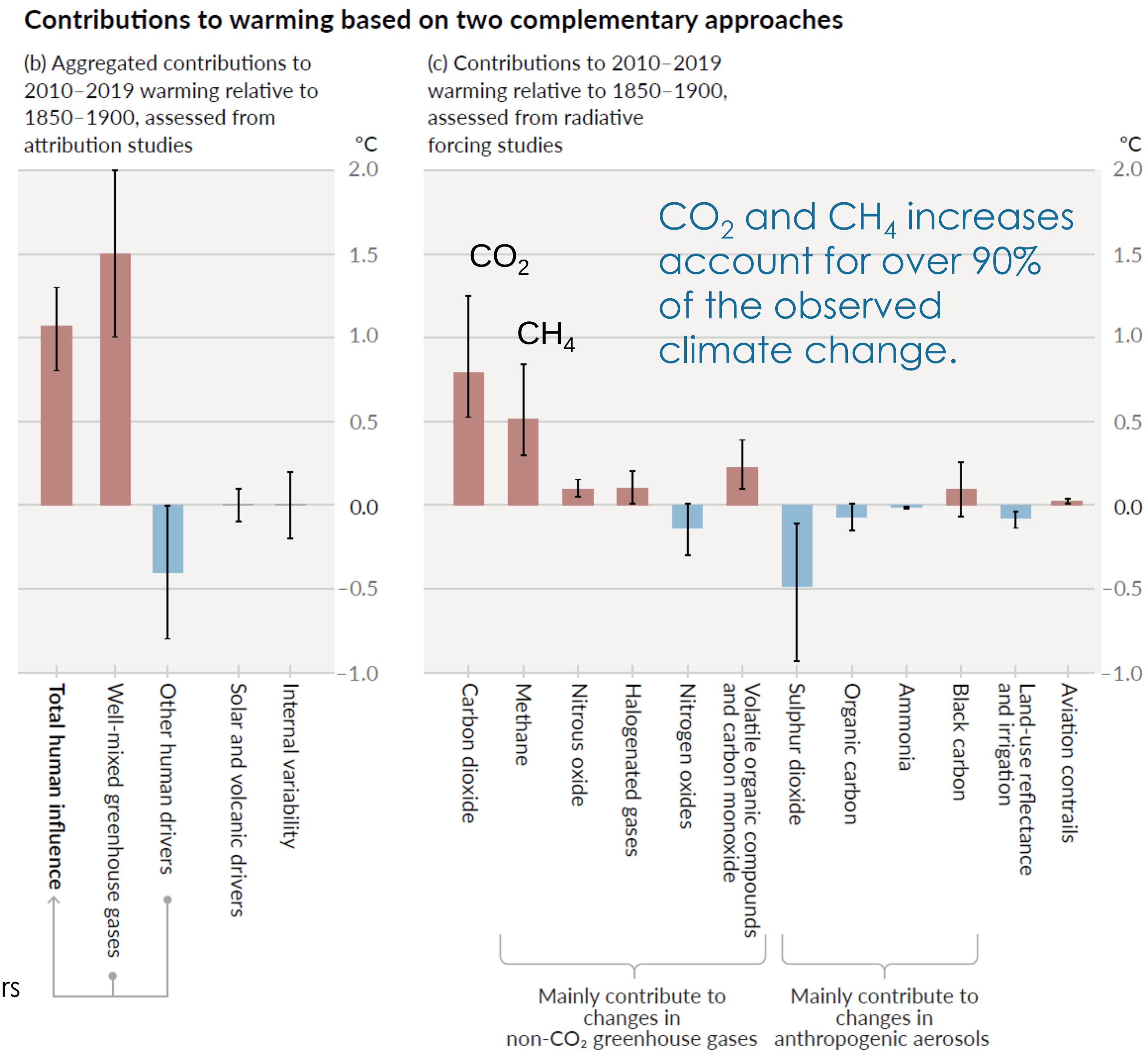
- **Mitigation:** Limit global average temperature increases to well below 2 °C above pre-industrial levels and pursue efforts to limit these increases to less than 1.5 °C to reduce the risks and impacts of climate change
- **Adaptation:** Increase the ability to adapt to the adverse impacts of climate change and foster climate resilience and low GHG emissions development, without threatening food production
- **Means of Implementation:** Align finance flows to encourage low GHG emissions and climate-resilient development

Here, we will focus primarily on the Mitigation goals.

Greenhouse Gas Emissions and Climate Change


(b) Change in global surface temperature (annual average) as **observed** and simulated using human & natural and only natural factors (both 1850–2020)

Climate models link greenhouse gas increase with the observed climate change.


Contributions to warming based on two complementary approaches

(b) Aggregated contributions to 2010–2019 warming relative to 1850–1900, assessed from attribution studies

(c) Contributions to 2010–2019 warming relative to 1850–1900, assessed from radiative forcing studies

CO_2 and CH_4 increases account for over 90% of the observed climate change.

Adapted from IPCC AR6 Summary for Policymakers

Mitigation Approach – Reducing Greenhouse Gas Emissions

Article 4 of the Paris Agreement requires Parties to:

- Undertake rapid reductions in GHG emissions in accordance with the **best available science**
- Prepare and communicate their successive nationally determined contributions (**NDCs**) to the global response to climate change at five-year intervals
  - NDCs are expected to reflect **greater ambition** over time and to report GHG emissions and removals in a way that promotes environmental integrity, transparency, accuracy, completeness, comparability, and consistency.

To build mutual trust and confidence and to promote effective implementation, Article 13 incorporates an Enhanced Transparency Framework (ETF)

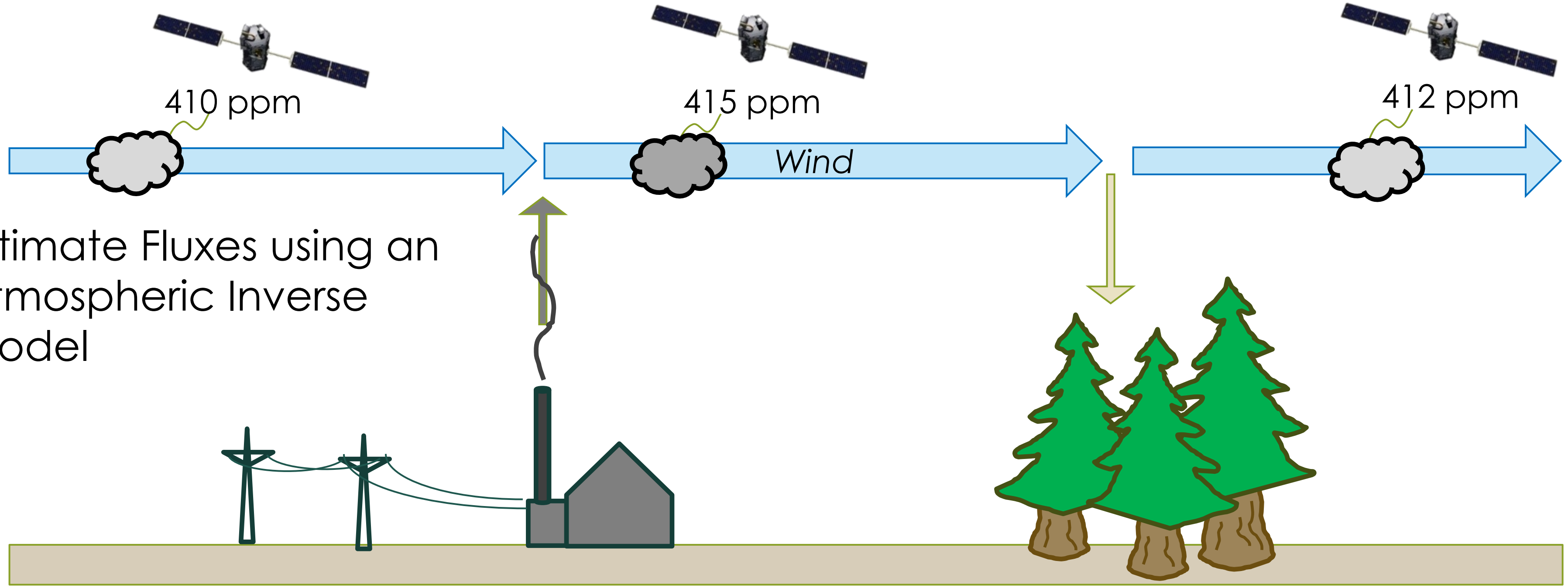
- To track progress toward their NDCs, each Party shall submit a Biennial Transparency Report (**BTR**), including **a national inventory of anthropogenic GHG emissions by sources and removals by sinks**.

Article 14 - Global Stocktakes

- The Conference of Parties (**COP**) shall periodically take stock of the implementation of the Paris Agreement to assess collective progress towards achieving its purpose and long-term goals.
    - It shall do so in a comprehensive and facilitative manner, considering mitigation, adaptation, and the means of implementation and support, and in the light of equity and the **best available science**.
- Global stocktakes (**GSTs**) are conducted at **five-year intervals**, starting in 2023.
- The outcome of each GST is then used to inform the parties of their progress towards achieving the long-term goals of the Agreement and to enhance international cooperation for climate action.

Tracking GHG Emissions:
Bottom-Up Inventories and *Top-Down* Atmospheric Budgets

Top-Down Atmospheric Budgets



Estimate Fluxes using an Atmospheric Inverse model

Bottom-Up National Inventories[1]

tCO_2/yr = PetaJoules/yr × tCO_2/PJ + Hectares Field-Forest × $tCO_2/hectare$ + …

Activity × Emission Factor + Activity × Emission Factor

[1] Prepared in accordance with the Intergovernmental Panel on Climate Change (**IPCC**) Guidelines for GHG inventories, as adopted by the Conference of Parties (**COP**).

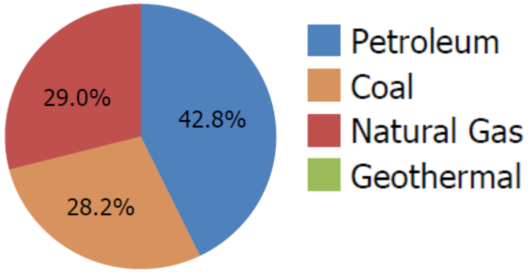
Sectors and Categories Tracked in National Inventories

The IPCC Guidelines for National Greenhouse Gas Inventories requires that parties track emissions from a series of sectors, including:

- **Energy** – largest source sector globally
  - Fuel combustion, Fugitive Emissions from Fuels, CO_2 Transport and Storage
- **Industrial Processes and Product Use**
  - Mineral, Chemical, Metal, Electronics, Non-Energy Products from Fuels and Solvents, Substitutes for Ozone Depleting Substances, Other Product Manufacture, Other
- **Agriculture, Forestry, and Other Land Use (AFOLU)** – 2nd largest, most uncertain sector (called Land Use and Land Use Change and Forestry (**LULUCF**) by UNFCCC)
  - Livestock, Land, Aggregate Sources & Non-CO_2 Emissions Sources on Land, Other
- **Waste**
  - Solid Waste Disposal, Biological Treatment, Incineration/Open Burning, Wastewater Treatment & Discharge, Other
- **Other**
  - Indirect N_2O Emissions from Atmospheric Deposition of NO_x and NH_3, Other

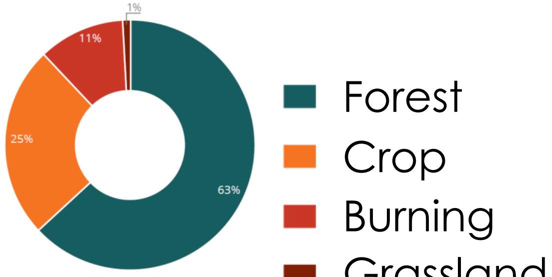
National GHG Inventories Supporting the Global Stocktakes

Energy
- Fuel Combustion
- Fugitive Emissions
- CO_2 Transport & Storage



Industry
- Mineral
- Chemical
- Metal
- Non-Energy Fuel/Solvent
- Electronics
- Other Products

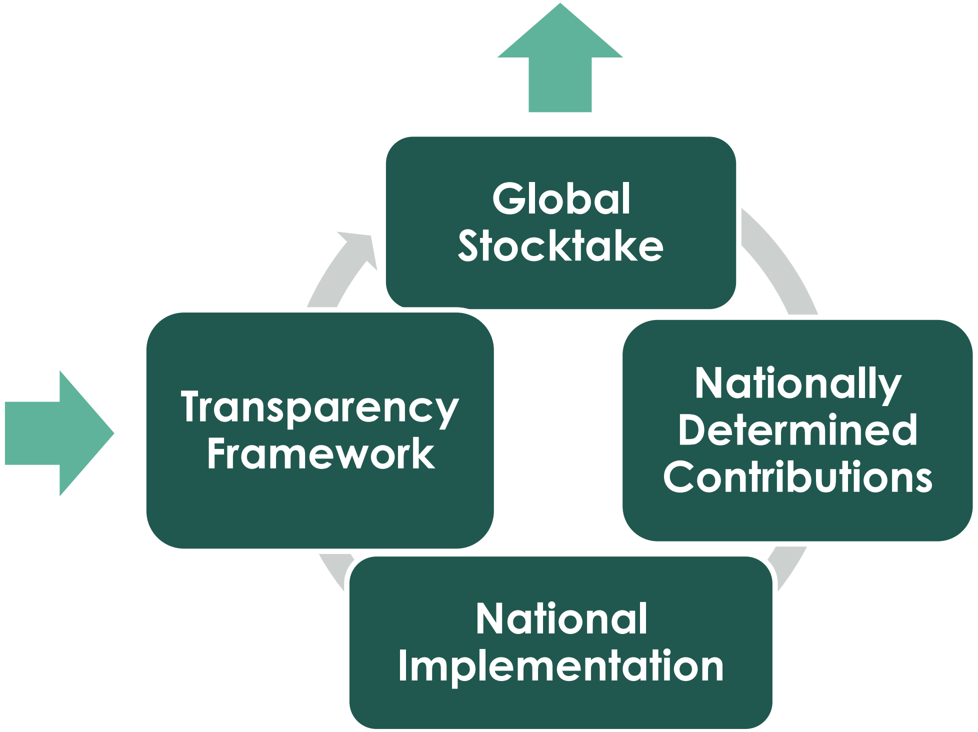
AFOLU
- Livestock
- Land
- Aggregated/Non-CO2 Land Sources



Waste
- Solid
- Biological
- Wastewater
- Other

National GHG Inventory

Biennial Transparency Report

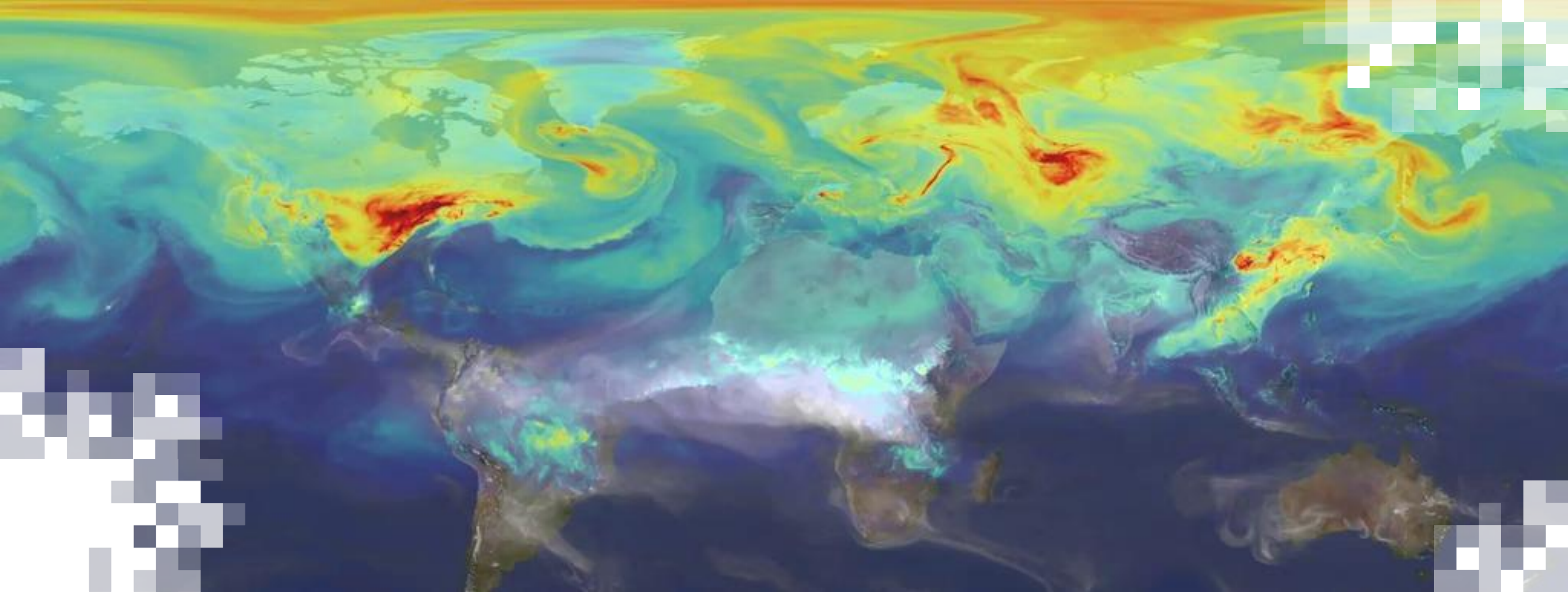


Global Stocktake

Nationally Determined Contributions

National Implementation

Transparency Framework



Atmospheric Greenhouse Gas Measurements Supporting the Global Stocktakes

A Role for Systematic Earth Observations

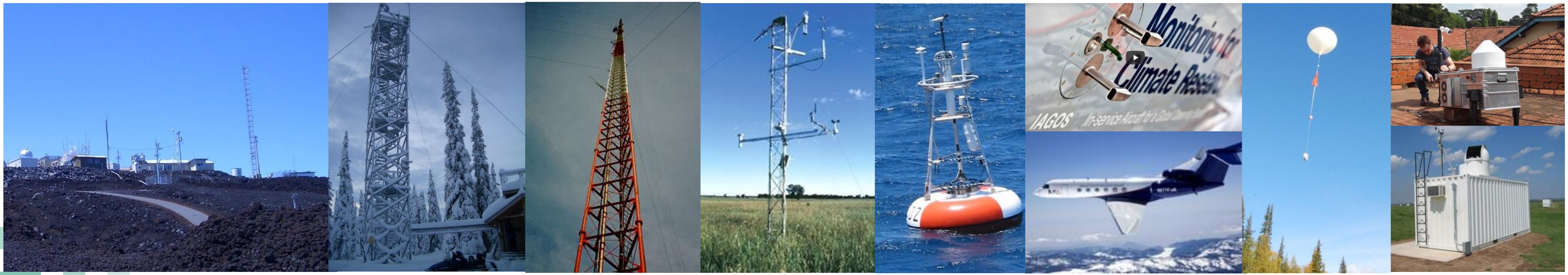
Systematic observations of the Earth's atmosphere and surface from ground-based, airborne, and space-based sensors can support the **Mitigation Objectives** of the Paris Agreement.

- **Direct measurements of atmospheric GHG concentrations** can be analyzed to track trends in GHG net emissions and removals on spatial scales spanning individual large power plants and urban areas, to nations and the planet.
- These measurements can be used to compile **top-down atmospheric budgets** of **net** CO_2 and CH_4 emissions and removals that can be used to assess the completeness and accuracy of the bottom-up methods used to compile BTRs.
- High spatial resolution observations of land cover type, above-ground biomass, and disturbances associated with fires, droughts, and severe weather can provide direct **support for the development of bottom-up emissions inventories for agriculture, forestry, and other land use (AFOLU)**.

Growing Capabilities in Atmospheric GHG Measurements

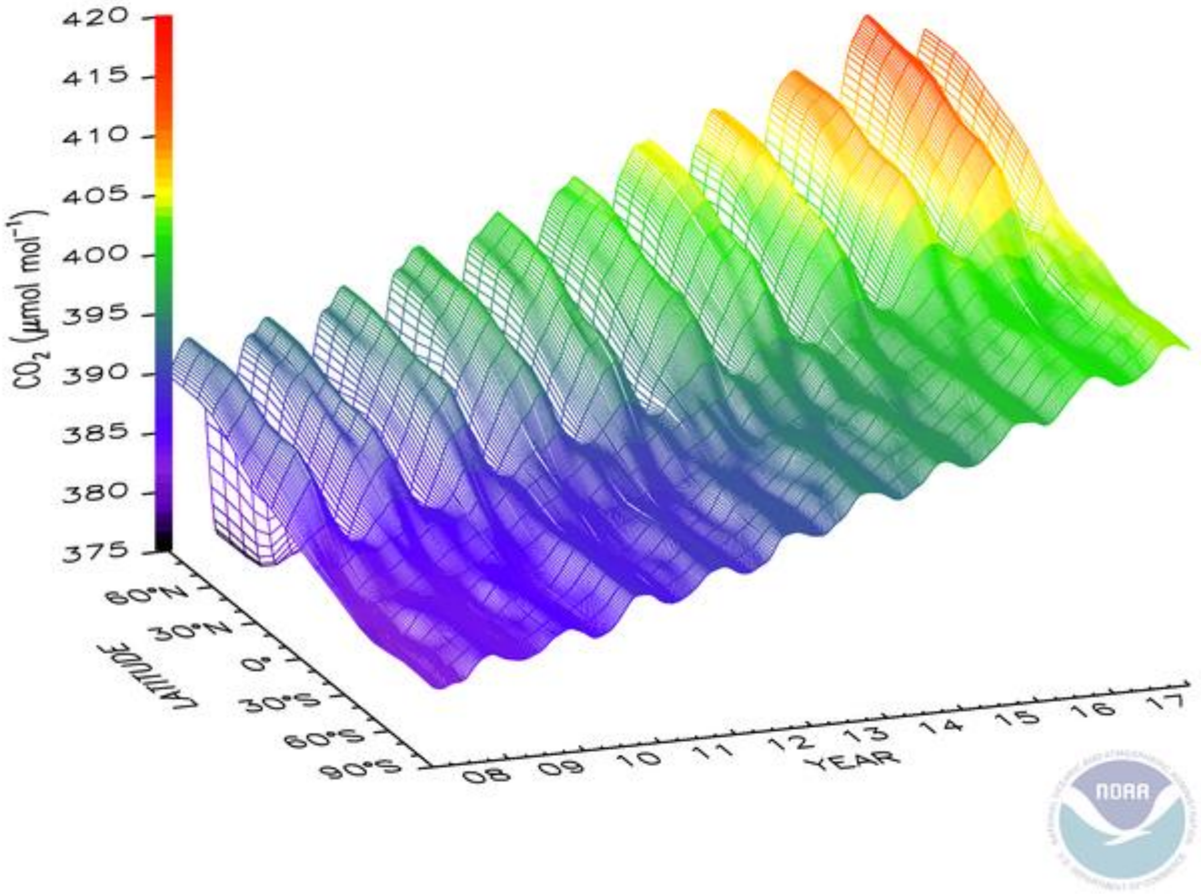
Space-based measurements of CO_2 and CH_4 from a growing fleet of satellites are less precise and accurate but provide high spatial and temporal resolution and greater coverage of the planet.

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 to global scales.

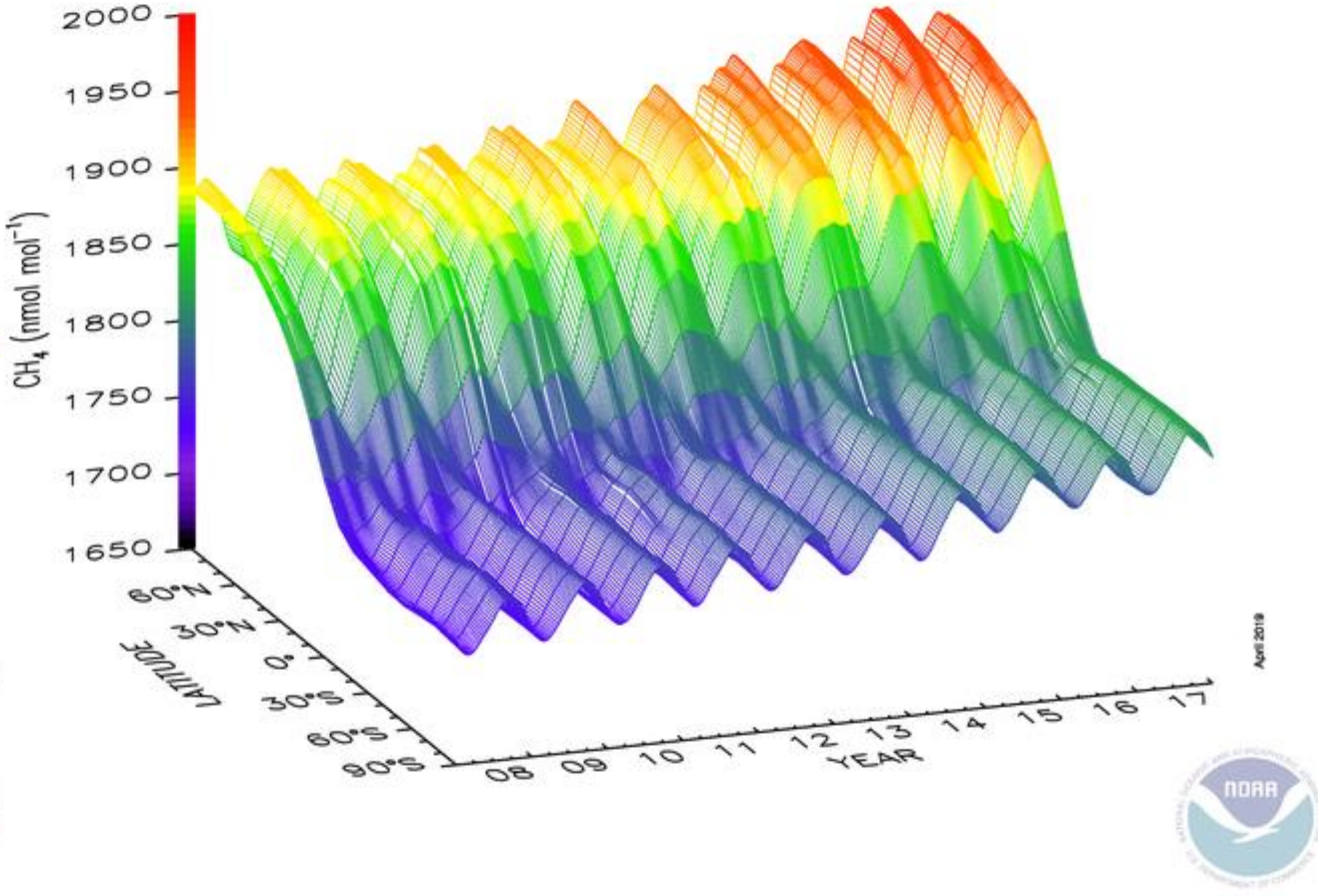


In Situ Atmospheric CO_2 and CH_4 Concentration Measurements

Carbon Dioxide



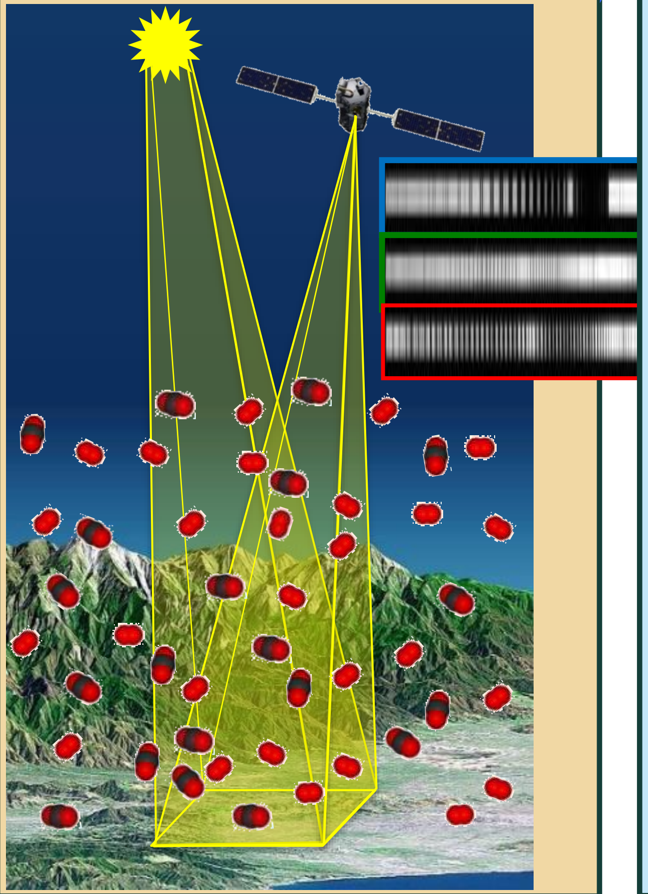
Methane



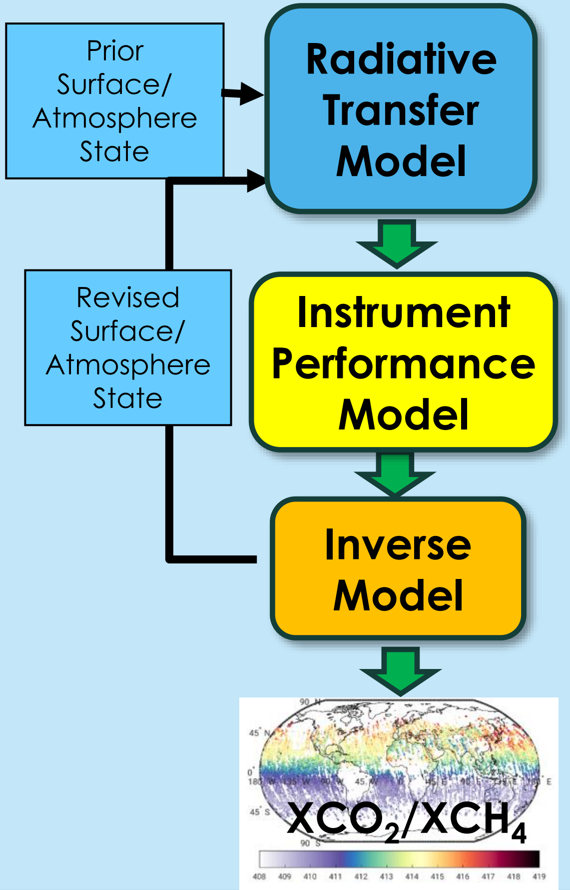
[NOAA Global Monitoring Laboratory](https://gml.noaa.gov/ccgg/figures/)
https://gml.noaa.gov/ccgg/figures/

Estimating CO_2 and CH_4 Fluxes from Space-Based Measurements

Record spectra of CO_2, CH_4, and O_2 absorption in reflected sunlight



Retrieve estimates of column-averaged dry air mole fraction (XCO_2/XCH_4)


Prior Surface/ Atmosphere State

Radiative Transfer Model

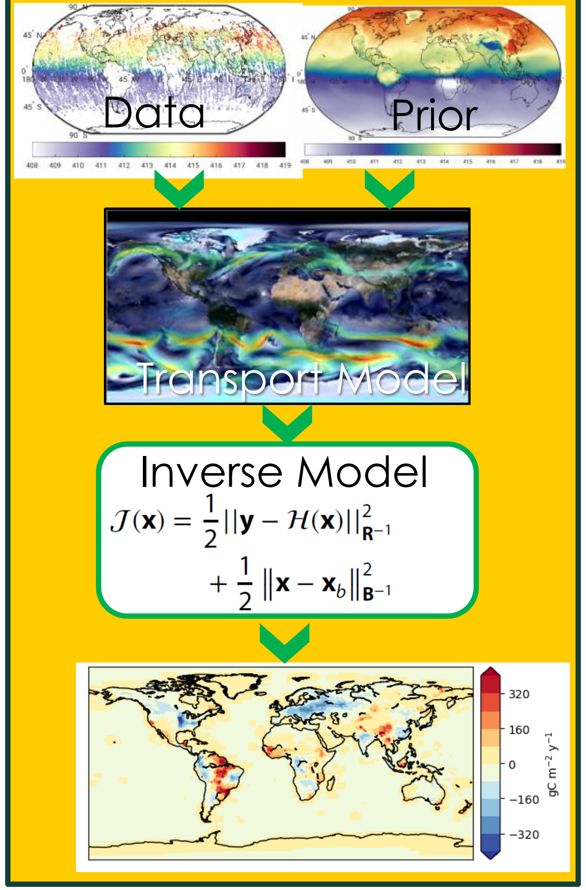
Revised Surface/ Atmosphere State

Instrument Performance Model

Inverse Model

Validate XCO_2/XCH_4 estimates to ensure accuracy (0.25%)

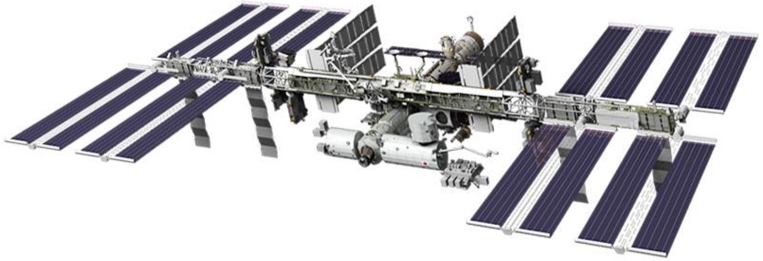
Assimilate into atmospheric inverse models to find fluxes

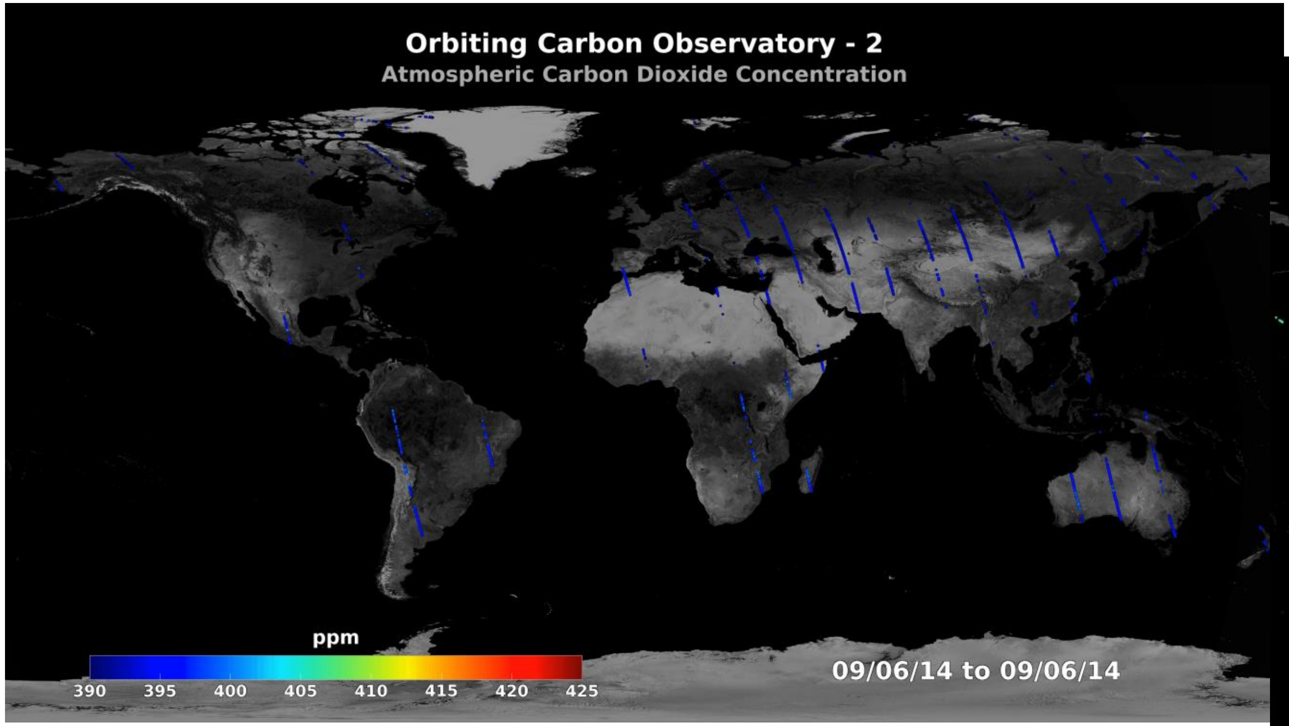


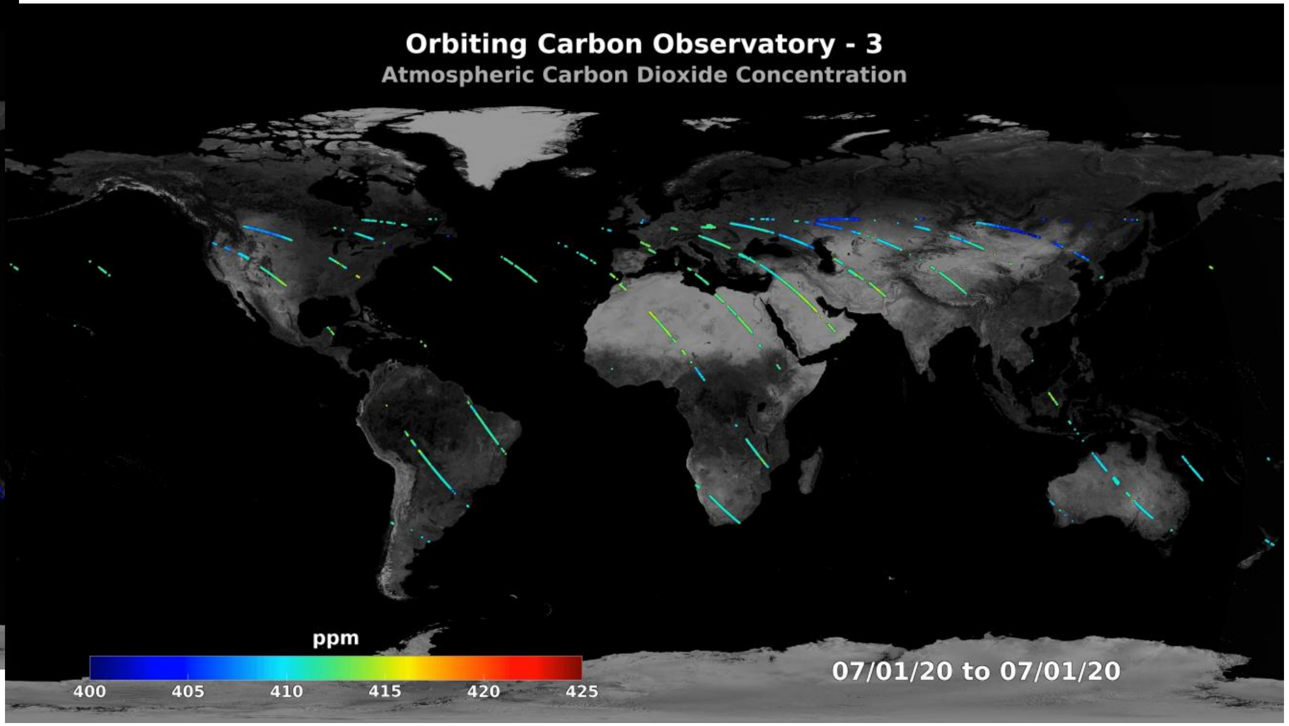
Inverse Model

$$\mathcal{J}(\mathbf{x}) = \frac{1}{2}||\mathbf{y} - \mathcal{H}(\mathbf{x})||^2_{\mathbf{R}^{-1}} + \frac{1}{2}||\mathbf{x} - \mathbf{x}_b||^2_{\mathbf{B}^{-1}}$$

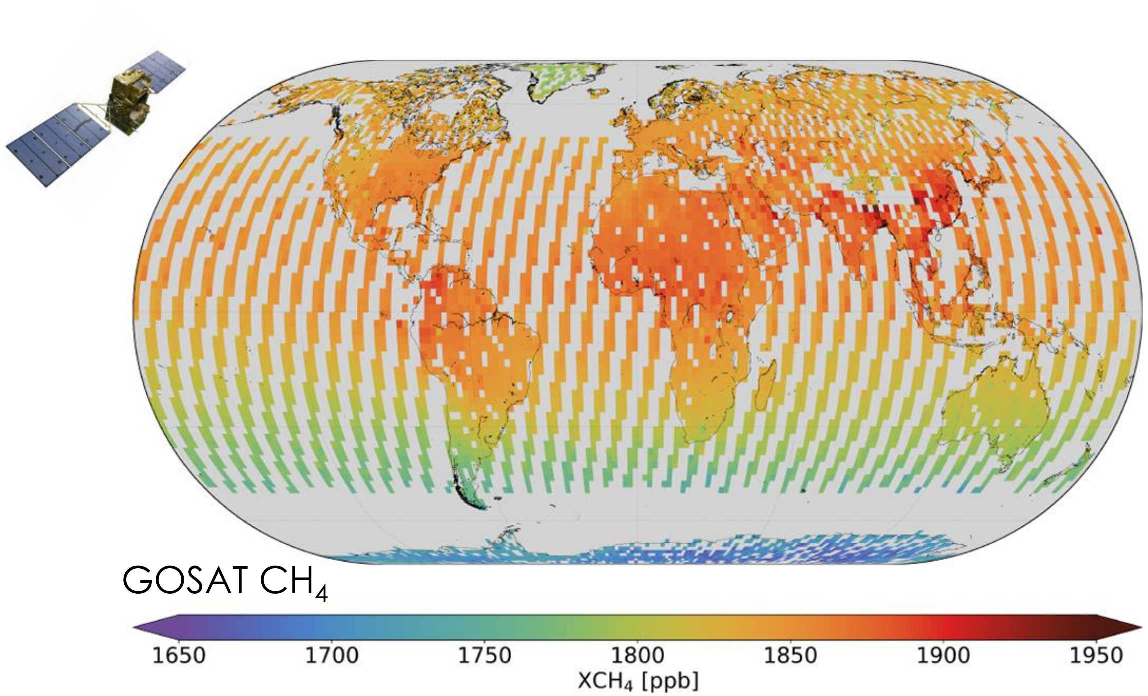
Space-Based Estimates of CO_2 from OCO-2 and OCO-3

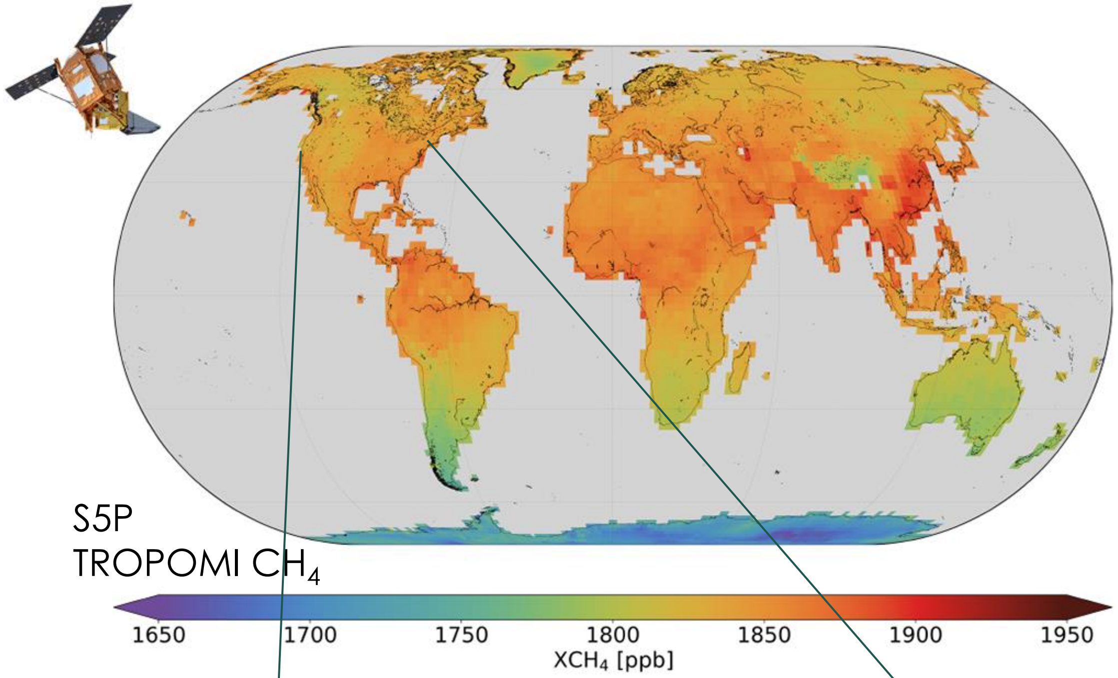


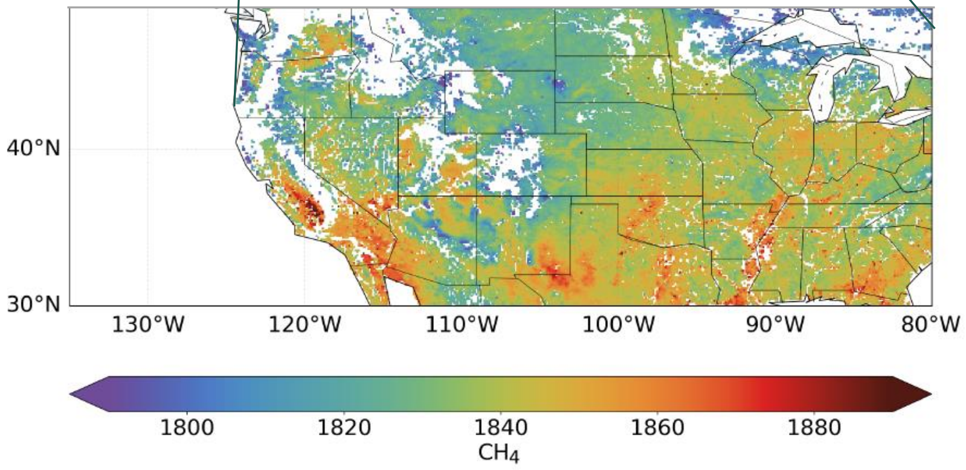




Space-Based Estimates of CH_4 from GOSAT and S5P


GOSAT CH_4


S5P
TROPOMI CH_4

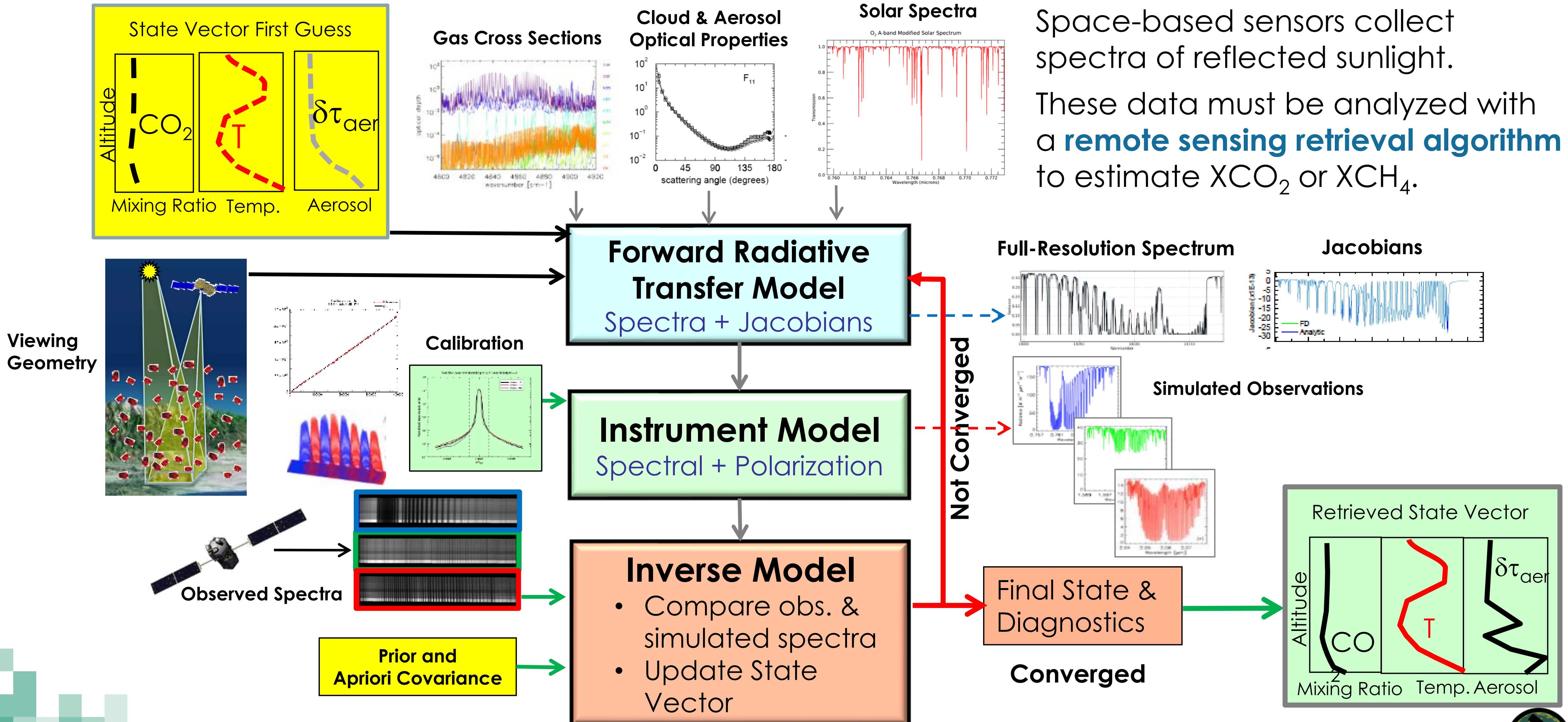


Near-global estimates of XCH_4 are now being retrieved by Japan's Greenhouse gases Observing SATellite (GOSAT) and by the European Copernicus Sentinel-5 Precursor (S5P) TROPOMI instruments. Here, results from both missions have been averaged over 2° × 2° bins for the two-year period from 1 January 2018 – 31 December 2019 (from Lorente et al. 2021, doi: 10.5194/amt-14-665-2021).

Estimating XCO_2 and XCH_4 from Space-Based Measurements

Space-based sensors collect spectra of reflected sunlight.

These data must be analyzed with a **remote sensing retrieval algorithm** to estimate XCO_2 or XCH_4.



State Vector First Guess

Gas Cross Sections

Cloud & Aerosol Optical Properties

Solar Spectra

Viewing Geometry

Calibration

Observed Spectra

Prior and Apriori Covariance

Forward Radiative Transfer Model
Spectra + Jacobians

Instrument Model
Spectral + Polarization

Inverse Model

- Compare obs. & simulated spectra
- Update State Vector

Not Converged

Full-Resolution Spectrum

Jacobians

Simulated Observations

Final State & Diagnostics

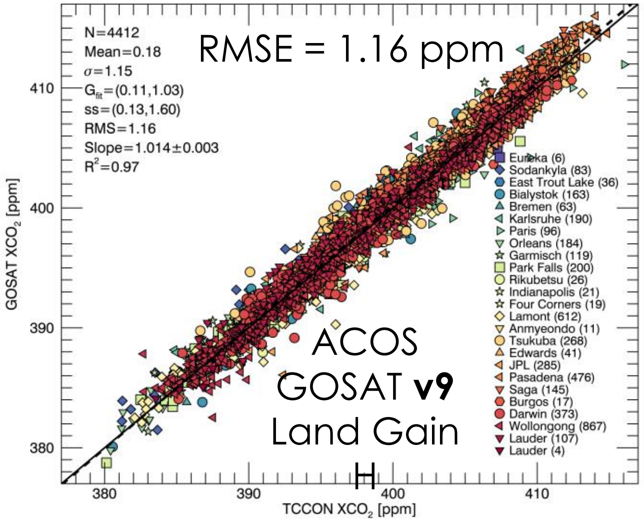
Converged

Retrieved State Vector

Validating Space-Based XCO_2 & XCH_4 Estimates through Comparisons with Ground-Based TCCON Standard

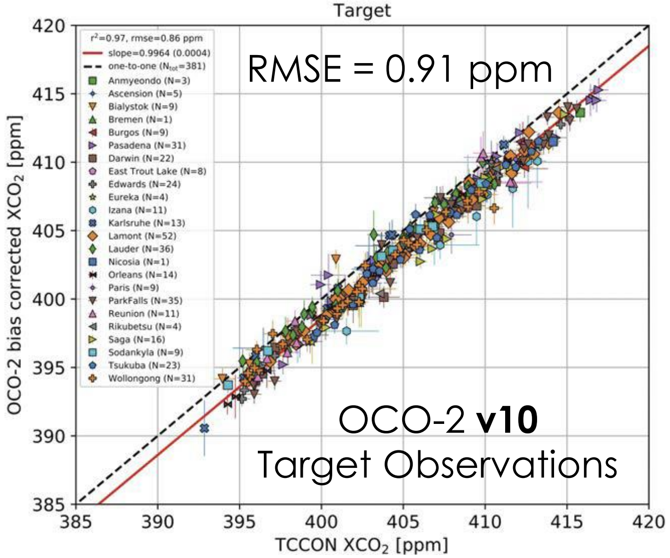
Estimates of XCO_2 and XCH_4 derived from GOSAT, OCO-2, OCO-3, and TROPOMI are validated against estimates derived from the ground-based **Total Carbon Column Observing Network, TCCON,** to quantify their uncertainties.

Lamont, Ok. TCCON station



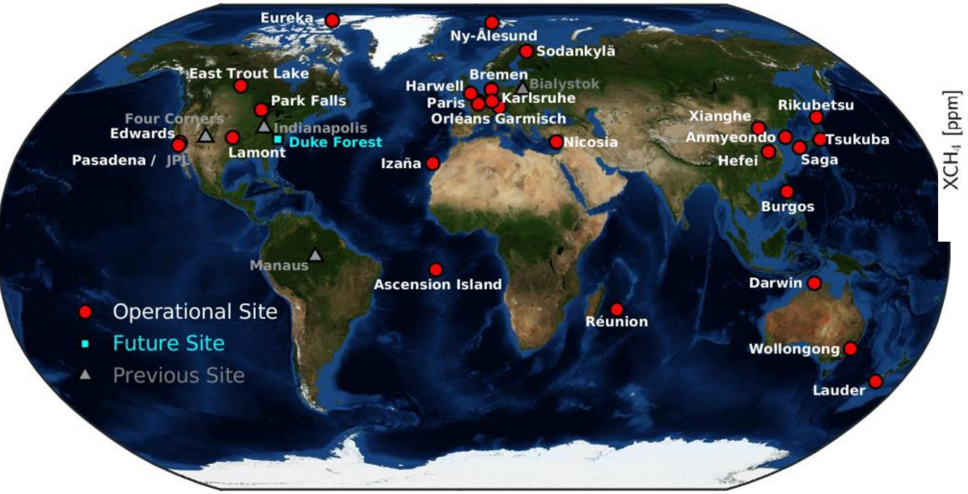
RMSE = 1.16 ppm

ACOS
GOSAT **v9**
Land Gain
H

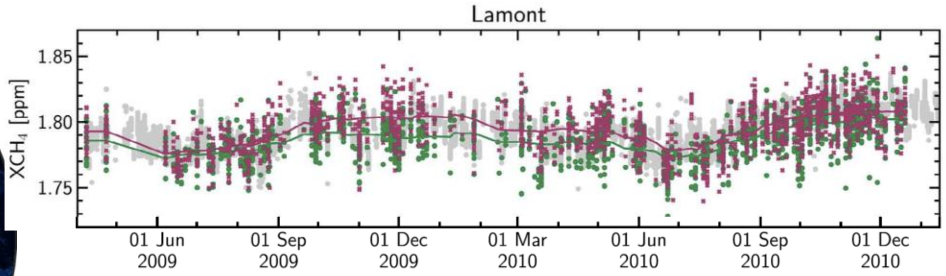


RMSE = 0.91 ppm

OCO-2 **v10**
Target Observations

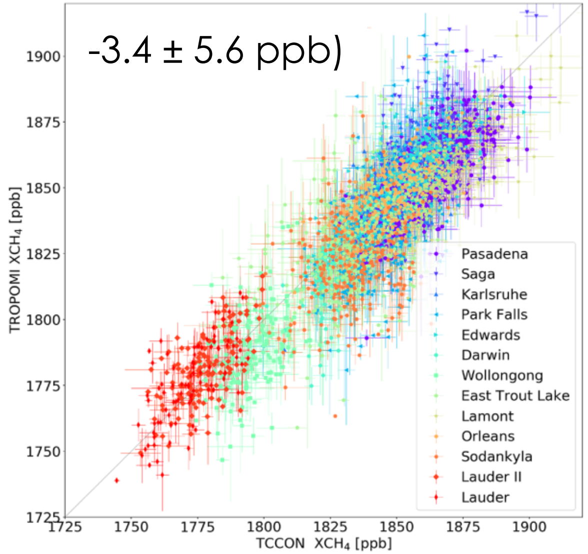


TCCON Network



GOSAT XCH_4 vs TCCON

Schepers et al. 2012, doi:10.1029/2012JD017549



TROPOMI XCH_4 vs TCCON

Lorente et al. 2021,
doi: 10.5194/amt-14-665-2021

TCCON
total carbon column observing network

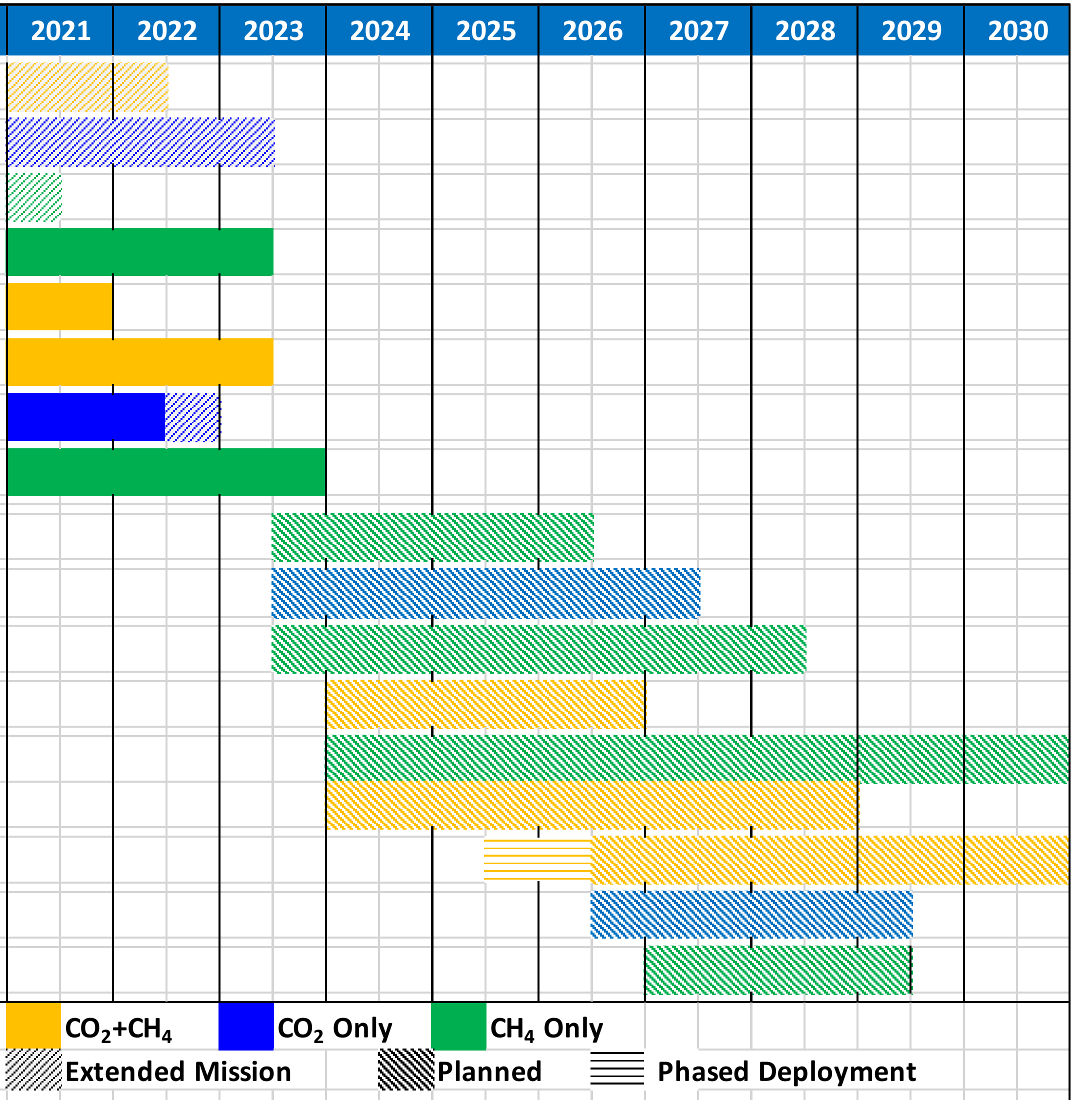
Measurement Requirements for Estimating CO_2 and CH_4 Emissions and removals from Space-Based Measurements

Space-based XCO_2 and XCH_4 estimates are retrieved using similar observing methods but pose unique challenges for estimating emissions.

- **Quantifying CO_2 fluxes requires very high precision and accuracy (< 0.25%).**
  - Anthropogenic CO_2 emissions must be quantified in the context of natural sources and sinks that are often co-located – **high spatial resolution & coverage are essential**.
  - Currently, only large, public-sector, high-resolution spectrometers meet these requirements.
- **Quantifying CH_4 fluxes from** a diverse range of sources
  - **The largest sources** are spatially-extensive, weakly-emitting wetlands and croplands.
    - Must be monitored using large, public-sector, high-resolution spectrometers
  - Super-emitters such as leaking extraction and storage systems and pipelines also contribute a substantial fraction of the total emissions in some regions.
    - Private-sector hyperspectral imaging satellites can play a role here.

The Growing Fleet of GHG Satellites

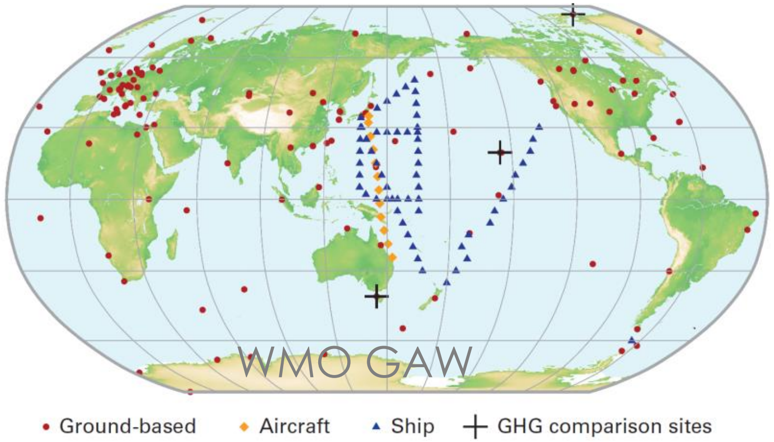
Satellite, Instrument	Agency/Origin	CO_2	CH_4	Public	Private
GOSAT TANSO-FTS	JAXA-NIES-MOE/Japan	●	●	●	
OCO-2	NASA/USA	●		●	
GHGSat-D - Claire	GHGSat/Canada		●		●
Sentinel 5P TROPOMI	ESA/Europe		●	●	
GaoFen-5 GMI	CHEOS/China	●	●	●	
GOSAT-2 TANSO-FTS-2	JAXA-NIES-MOE/Japan	●	●	●	
OCO-3	NASA/USA	●			
GHGSat C1/C2 - Iris, Hugo	GHGSat/Canada		●		●
MethaneSAT	EDF/USA	○	●		●
MicroCarb	CNES/France	●		●	
Carbon Mapper[1]	Carbon Mapper LLC/USA	○	●	○	○
GeoCarb	NASA/USA	●	●	●	
MetOp Sentinel-5 series	EC Copernicus/Europe		●	●	
GOSAT-GW	JAXA-NIES-MOE/Japan	●	●	●	
CO2M	EC Copernicus/Europe	●	●	●	
CO2Image	DLR/Germany	●		●	
MERLIN	DLR/Germany-CNES/France		●	●	



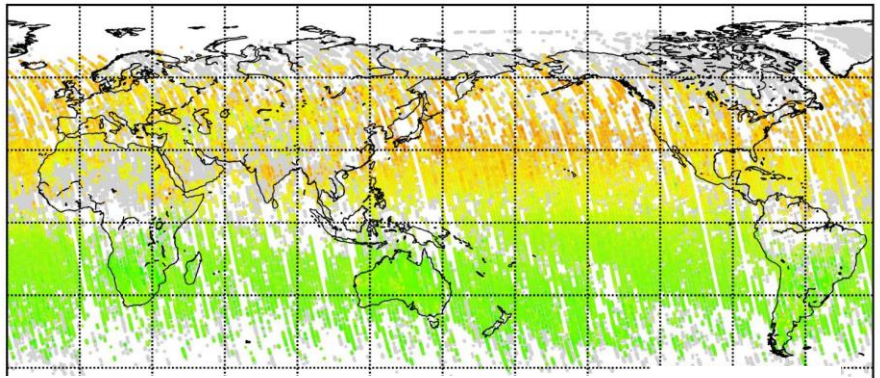
[1] Carbon Mapper is a public/private partnernship between California and Carbon Mapper LLC.

Combining Surface, Airborne, and Space-Based Measurements

WMO GAW Ground-Based/Airborne/Ship Network



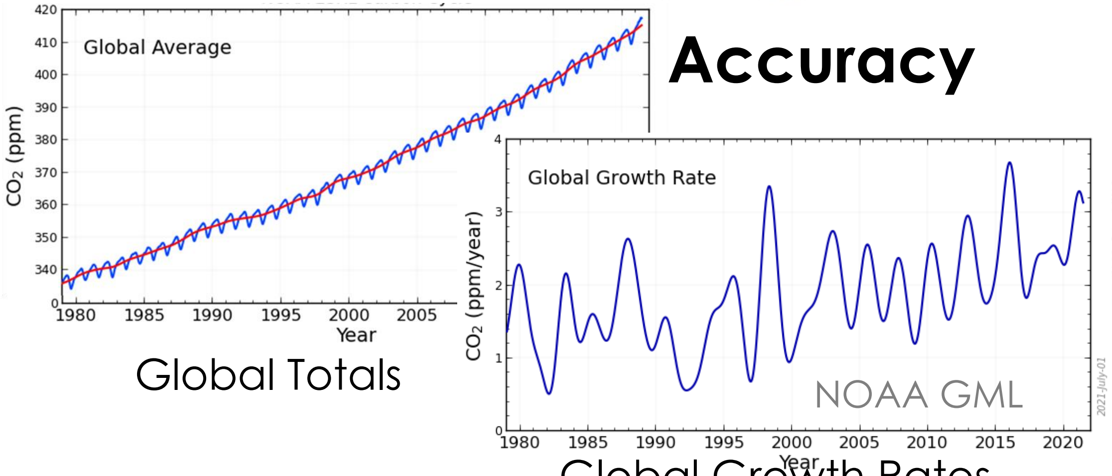
Space-Based Measurements



OCO-2 – 85,000 Soundings/Day

WDCGG

Accuracy

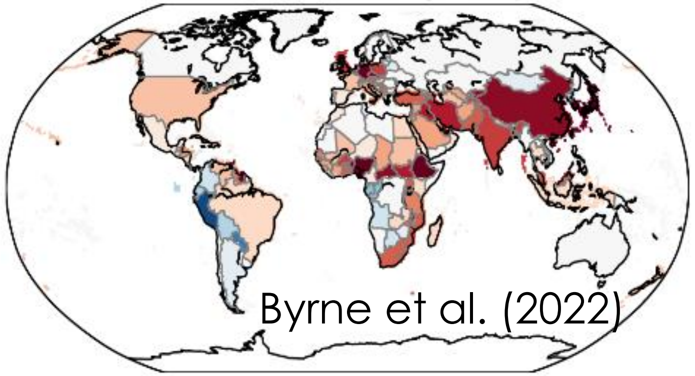


Global Totals

NOAA GML

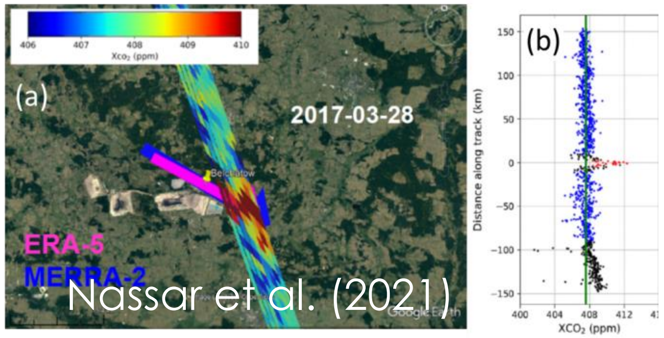
Global Growth Rates

Resolution/Coverage



Byrne et al. (2022)

Regional/National-Scale Fluxes



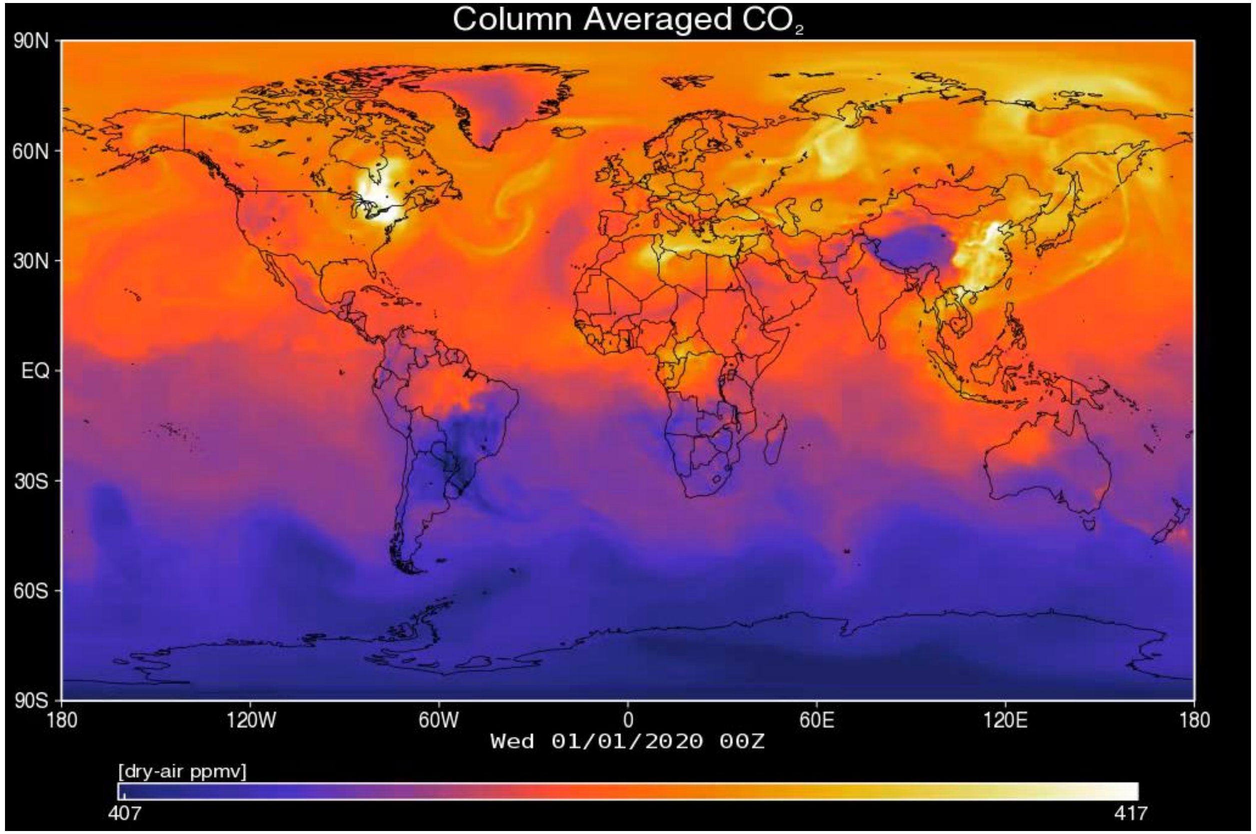
Nassar et al. (2021)

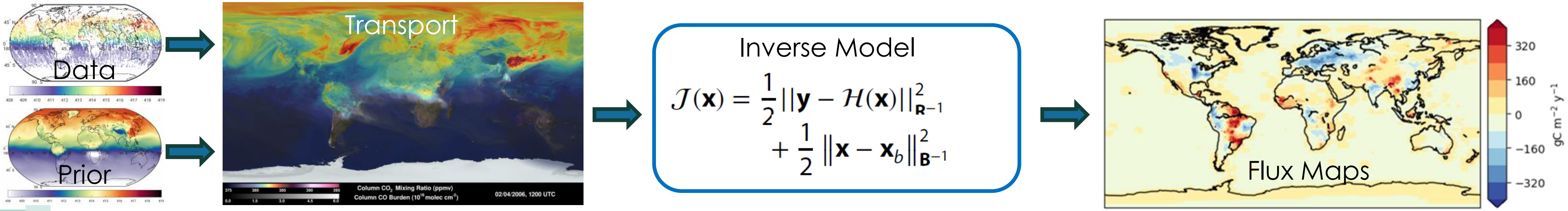
Emissions from Local Sources

Ground-based and airborne measurements provide accuracy. Space-based measurements complement these with increased resolution and coverage.

Estimating CO_2 and CH_4 Fluxes from Atmospheric Measurements with Atmospheric Inverse Models

- As CO_2, CH_4, and other GHGs are added or removed from the atmosphere by surface sources and sinks, the modified air masses are transported away by the winds.
- An **atmospheric inverse model** is used to estimate GHG in the presence of these winds.



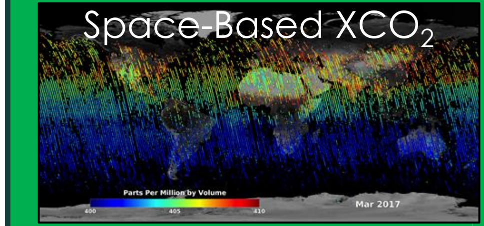


Inverse Model

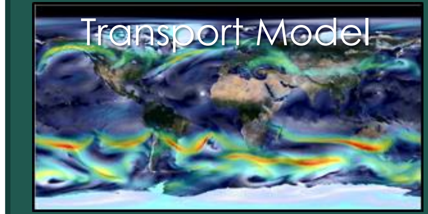
$$\mathcal{J}(\mathbf{x}) = \frac{1}{2}||\mathbf{y}-\mathcal{H}(\mathbf{x})||^2_{\mathbf{R}^{-1}} + \frac{1}{2}\left\|\mathbf{x}-\mathbf{x}_b\right\|^2_{\mathbf{B}^{-1}}$$

Combining Bottom-Up and Top-Down Inventories to Support the Global Stocktakes

Atmospheric Obs.

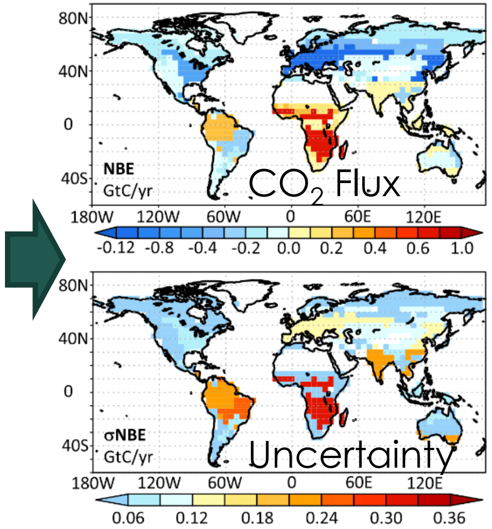


Inversion System



Inverse Model

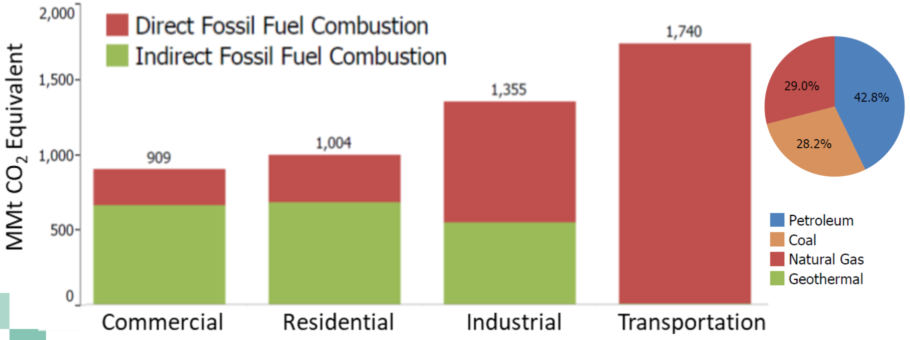
$$\mathcal{J}(\mathbf{x}) = \frac{1}{2}||\mathbf{y} - \mathcal{H}(\mathbf{x})||^2_{\mathbf{R}^{-1}} + \frac{1}{2}||\mathbf{x} - \mathbf{x}_b||^2_{\mathbf{B}^{-1}}$$



Top-Down Budgets

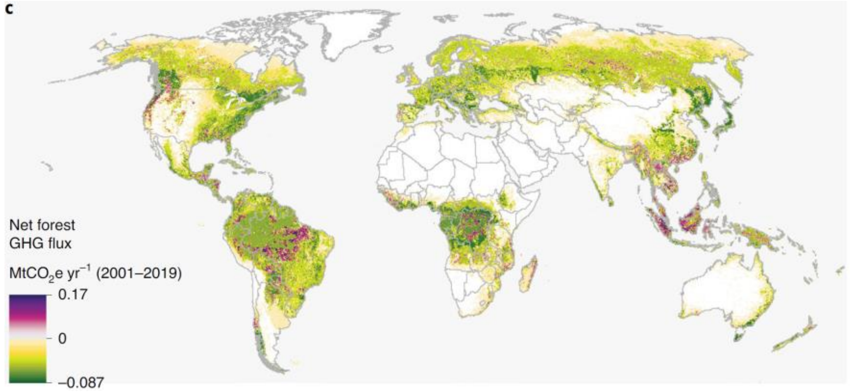
Observations of atmospheric CO_2 and CH_4 provide an integral constraint on emissions and removals to:

- 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

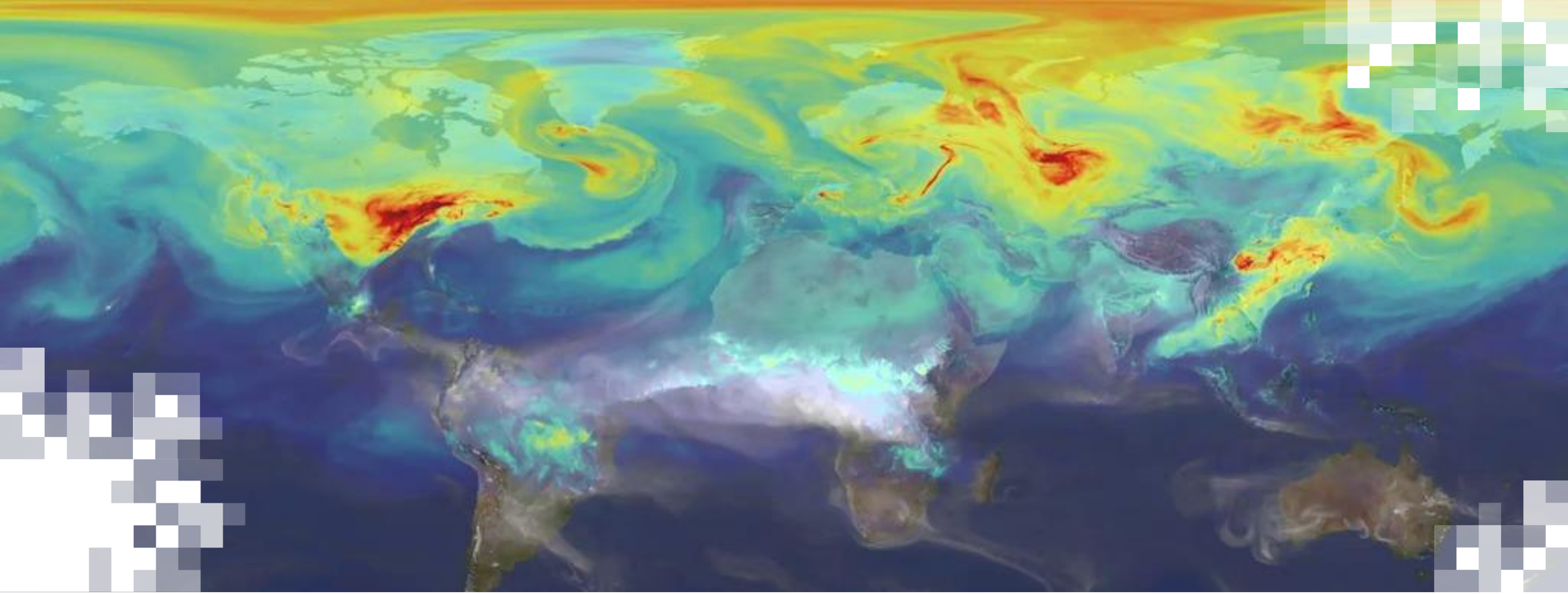
- Sector-specific estimates of emissions from known sources
- Earth observations play a critical role for tracking land use change.



Harris et al. Nature Climate Change, 2021

Key Takeaways – We can only manage what we can measure.

- The best way to **manage and regulate** greenhouse gas emissions is to compile and track **source-specific, bottom-up inventories** of their emissions and removals by human activities.
  - Inventories often provide the initial guess or “prior” for atmospheric inversions.
- The best way to **assess collective progress** toward the greenhouse gas emissions goals on national to continental scales is to create **top-down atmospheric greenhouse gas budgets** derived from spatially- and temporally-resolved measurements of their atmospheric concentrations that are analyzed with atmospheric inverse models.
  - Atmospheric CO_2 and CH_4 budgets can also facilitate the development and validation of bottom-up national inventories for larger countries.
- Both bottom-up inventories and top-down budgets are critical to the success of the Paris Agreement.



Examples of Top-Down Atmospheric CO_2 and CH_4 Budgets –

The CEOS Pilot Use Cases

How can top-down methods support the global stocktake?

Top-down atmospheric CO_2 & CH_4 budgets complement bottom-up inventories to support a more complete, accurate, & transparent global stocktake by:

- Providing a means of assessing the accuracy & completeness of emissions reports on regional, national, and local scales
- Facilitating development of bottom-up inventories, particularly for non-fossil fuel sectors
- Identifying opportunities for improving GHG inventories to support future GSTs

- To begin this conversation, the Committee on Earth Observation Satellites (**CEOS**), a group of 34 space agencies and 29 associate members, has compiled pilot, top-down budgets of CO_2 and CH_4 as "**Use Cases**" that illustrate the application of these methods.
  - These Use Cases are introduced here and described in greater detail in **Part 2**.
- CEOS is soliciting input from stakeholders (UNFCCC, IPCC) and members of the national inventory community to develop the requirements for more complete and relevant top-down GHG products to support future GSTs.

Pilot CO_2 and CH_4 Budgets for the First Global Stocktake

Global Top-down CO_2 Budgets

- Pilot global CO_2 budgets derived from flux products being developed by the OCO-2 Model Intercomparison Project (OCO-2 MIP)
  - Combine in situ CO_2 measurements and column-averaged CO_2 dry air mole fraction (XCO_2) estimates from OCO-2 to predict fluxes and stock changes

Global Top-down CH_4 Budgets

- Pilot global CH_4 budgets derived from flux products being developed by the NASA Carbon Monitoring System Flux (CMS-Flux) team
  - Based on GOSAT XCH_4 products

Local Source Emissions Supporting Bottom-up Inventories

- Urban-scale emission products from OCO-2, GOSAT, and TROPOMI teams are being considered for demonstration products
  - Products published by individual science teams are being used

Pilot CEOS GHG Products for the GST #1

The Primary Objective – To start a conversation with stakeholders and users

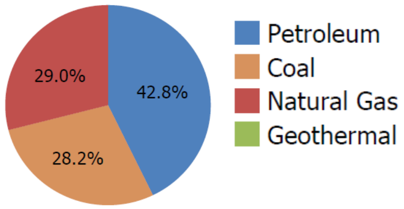
- Establish the utility and best practices for combining bottom-up and top-down methods to enable a more complete and transparent Global Stocktake

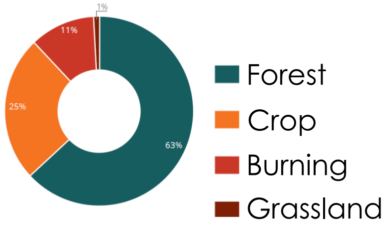
Energy
- Fuel Combustion
- Fugitive Emissions
- CO_2 Transport & Storage

Industry
- Mineral
- Chemical
- Metal
- Non-Energy Fuel/Solvent
- Electronics
- Other Products

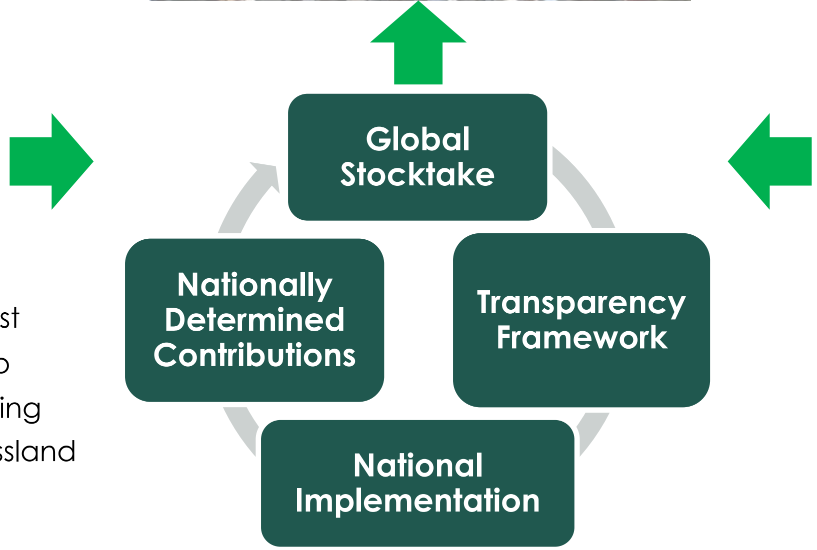
AFOLU
- Livestock
- Land
- Aggregated/Non-CO2 Land Sources

Waste
- Solid
- Biological
- Wastewater
- Other





National GHG Inventory



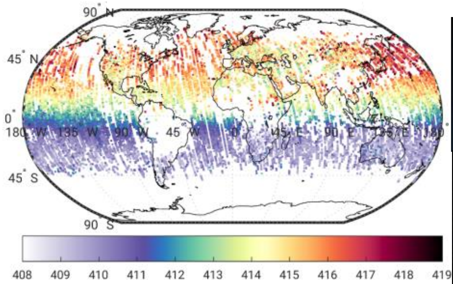
Global Stocktake

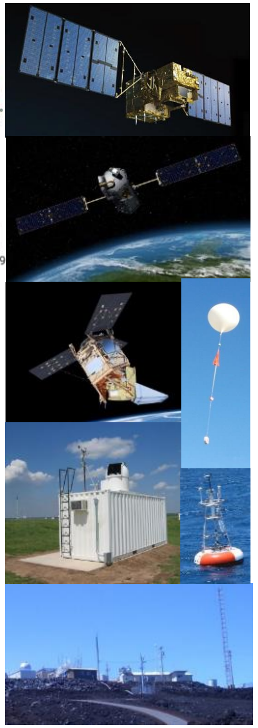
Nationally Determined Contributions

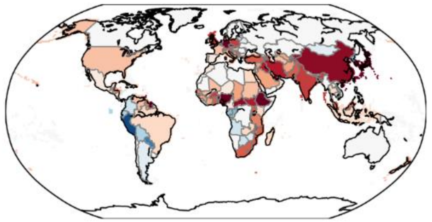
Transparency Framework

National Implementation

National GHG Budgets







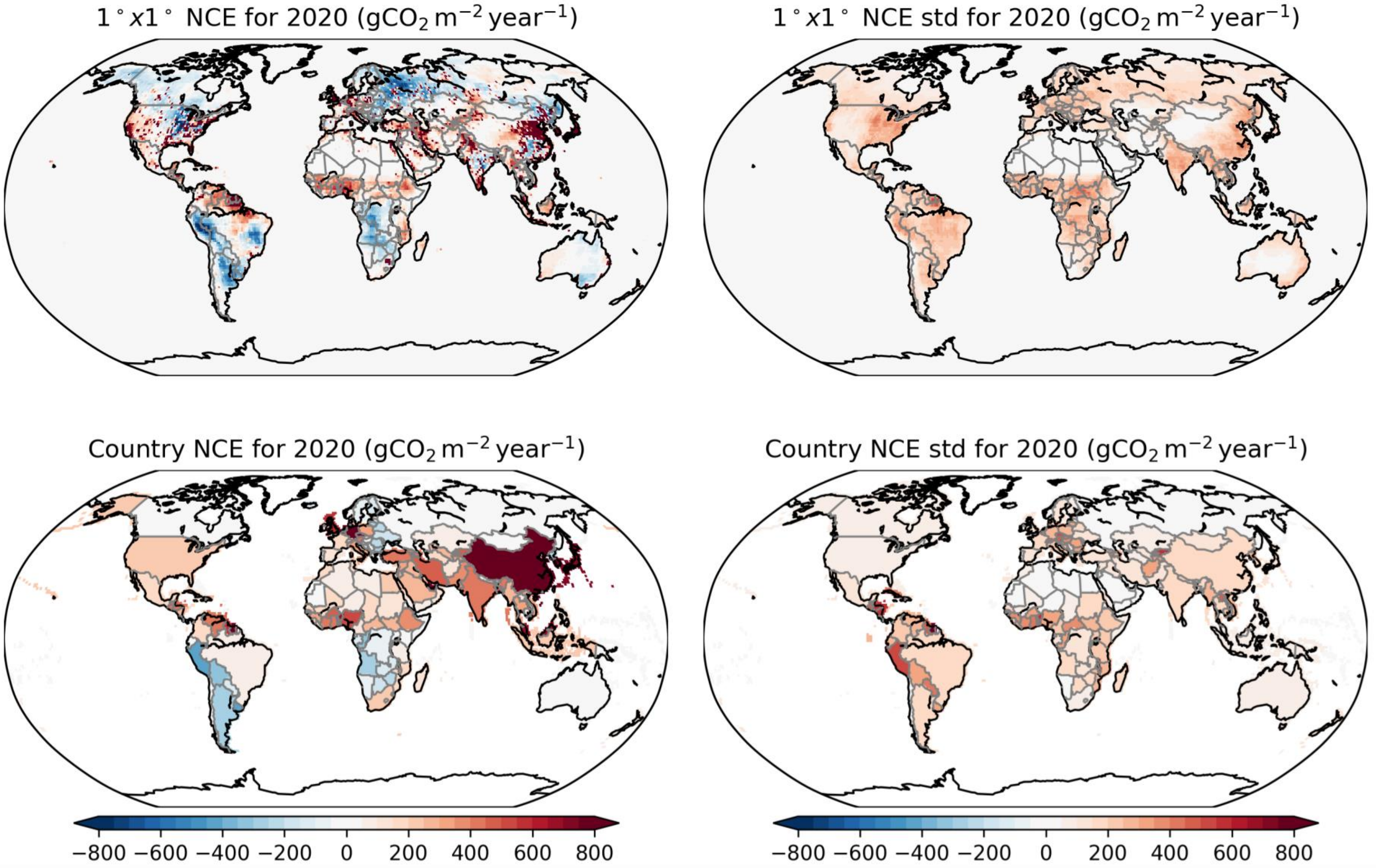
Bottom-Up GHG Inventories
- Sector-specific estimates of emissions from known sources

Top-Down GHG Budgets
- Integral constraint on emissions and removals from all processes

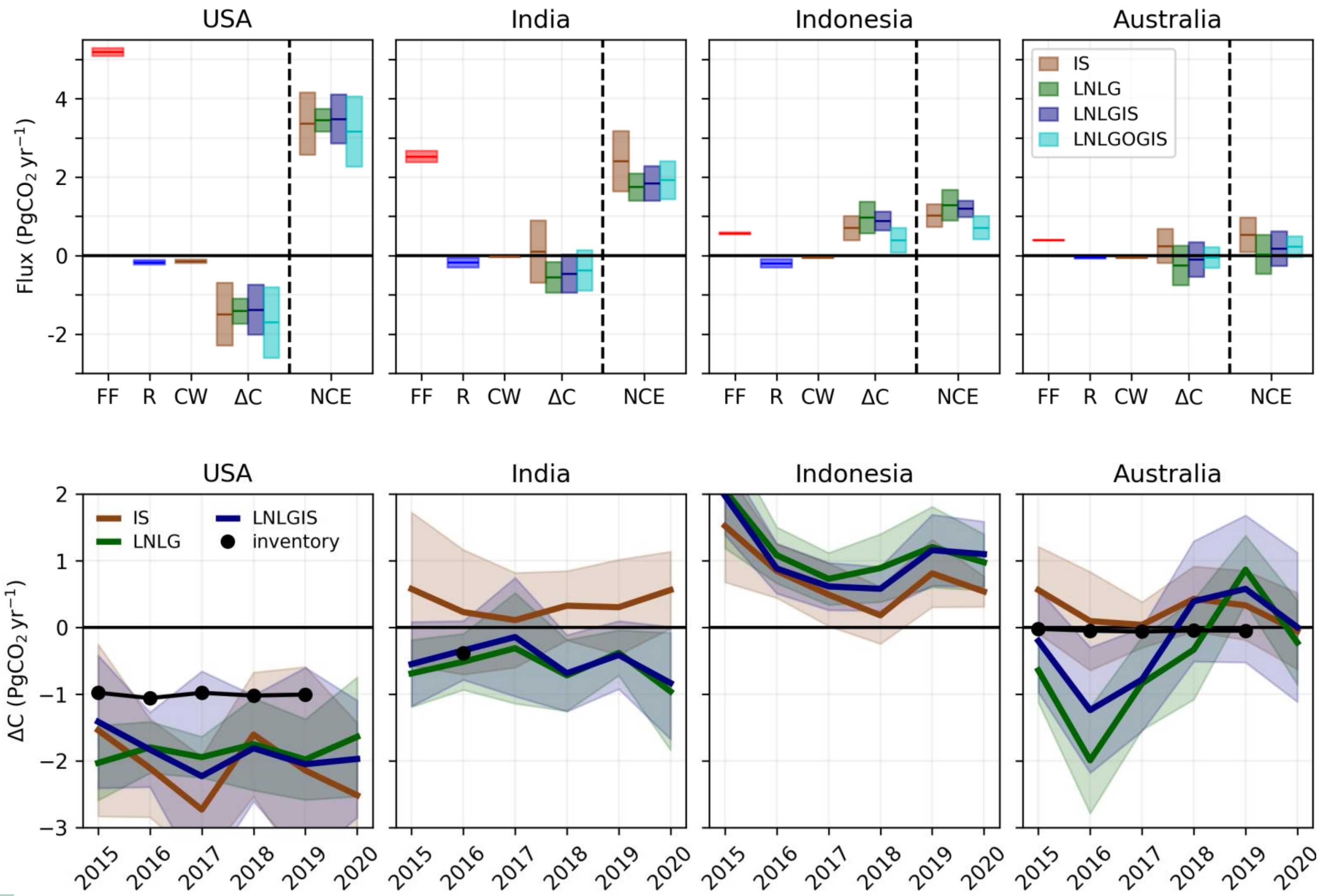
Use Case 1: Net CO_2 Emissions & Removals

CO_2 measurements can be analyzed with ***atmospheric inverse models*** to estimate the net carbon exchange (**NCE**), which is the net flux of CO_2 by all sources and sinks over land.

- Positive values (red) indicate a net CO_2 source.
- Negative values (blue) indicate a net CO_2 sink.



Carbon Stock Changes from CO_2 Emissions & Removals



Plots by Brendan Byrne (NASA/JPL) and the OCO-2 Flux MIP

Combining information from bottom-up inventories with estimates of NCE from atmospheric measurements, we can partition CO_2 emissions and removals by sector.

- Here, 2016–2020 averages for USA, India, Indonesia, and Australia

Trends in **land carbon loss, ΔC**, can be compared to bottom-up inventories from agriculture, forestry, and other land use (AFOLU; black dots).

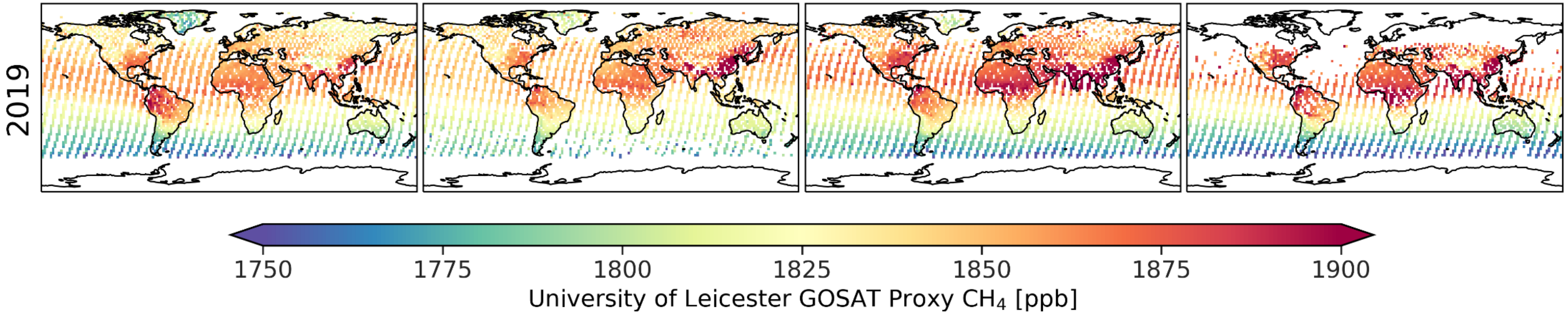
- Note: ΔC is for whole countries while AFOLU is only for managed lands.

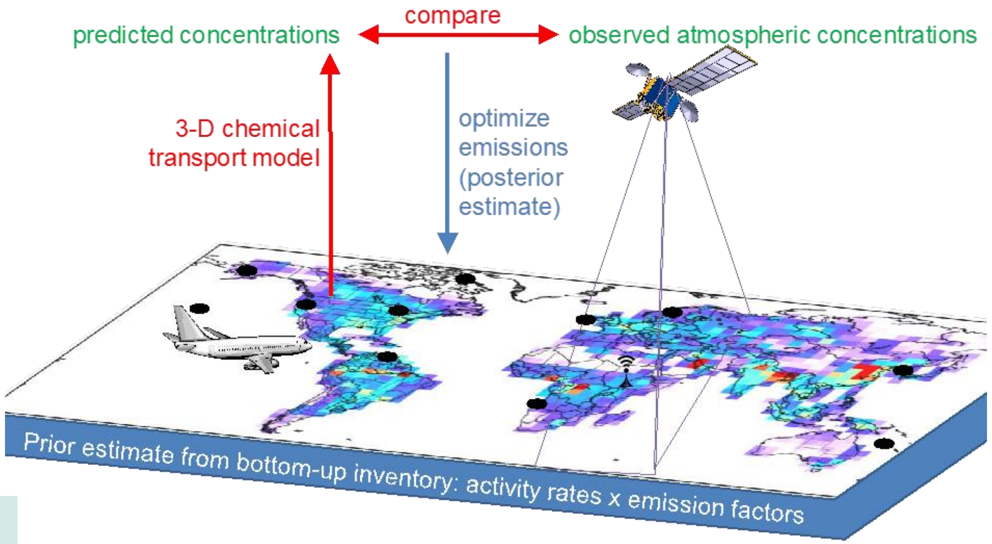
Use Case 2: CH_4 Emissions from Atmospheric Measurements

Methane is emitted into the atmosphere by a broad range of natural processes and human activities, many of which are difficult to measure with bottom-up inventories. Methane is removed primarily by atmospheric chemical reactions, which limit its atmospheric lifetime to 9.1 ± 0.9 years.

Deriving Top-Down CH_4 Emissions Estimates

- The NASA Carbon Monitoring System Flux (CMS-Flux) team analyzed remote sensing observations from Japan's GOSAT to produce national-scale CH_4 emission budgets.



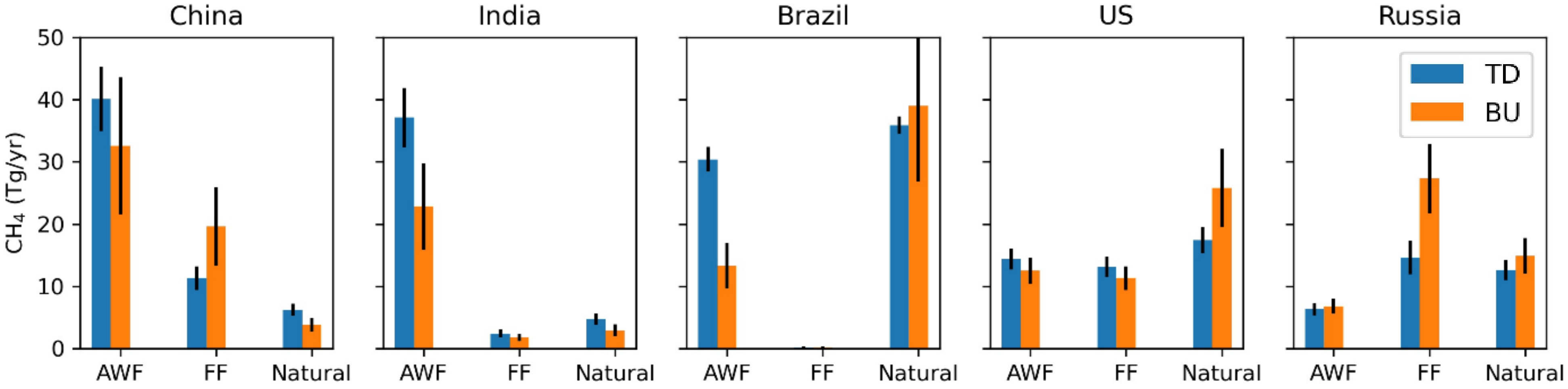


The GEOS-Chem global chemistry transport model was used to quantify emissions and their uncertainties at a spatial resolution of 1° by 1°. These value were then projected these to each country.

Plots by John Worden and the CMS-Flux Team (NASA/JPL)

CH_4 Emissions by Sector and Country

- GOSAT observations can yield top-down (**TD**) atmospheric CH_4 budgets for about 58 countries.
- The top 5 emitting countries emit about half of all anthropogenic CH_4 emissions.
  - Consistent with bottom-up (**BU**) inventory data
- Most emissions are from the agricultural sector (primarily livestock).
- Methane extraction, transport, and storage is another key source.



AWF = Agriculture, Waste, and Fires

FF = Fossil Fuels (Coal, Oil, Gas)

N = Natural (Wetlands and Seeps)

Plots by John Worden and the CMS-Flux Team (NASA/JPL)

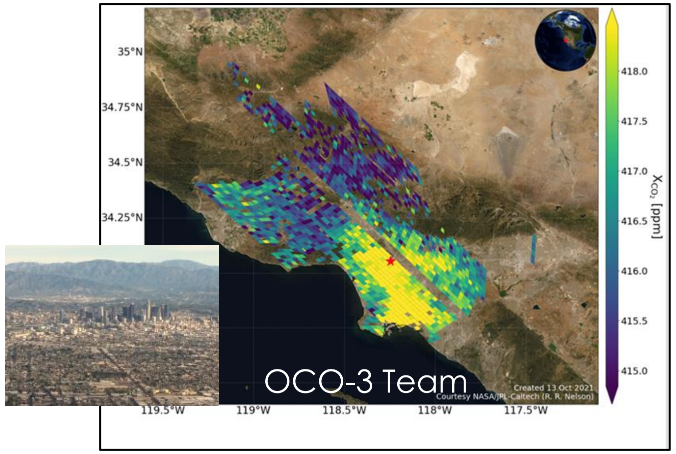
Tracking Emissions from Localized Hot Spots

Atmospheric GHG measurements are also being used to track emissions from compact sources including:

- Large urban areas
- Large coal- and gas-fired power plants
- Fossil fuel extraction, transport, and storage

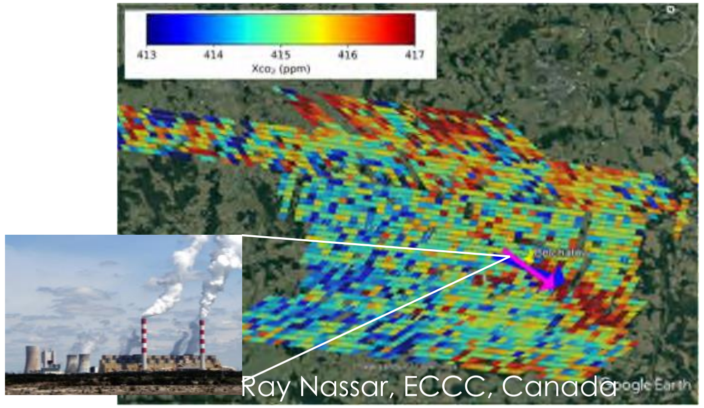
Existing atmospheric measurements and models do not yet have the resolution or coverage needed to track anything but the largest local sources, but they:

- Are adequate for demonstrating methods for tracking emissions from hot spots for future global stocktakes
- Are more source-specific than national-scale atmospheric GHG budgets, and could therefore contribute to bottom-up inventories



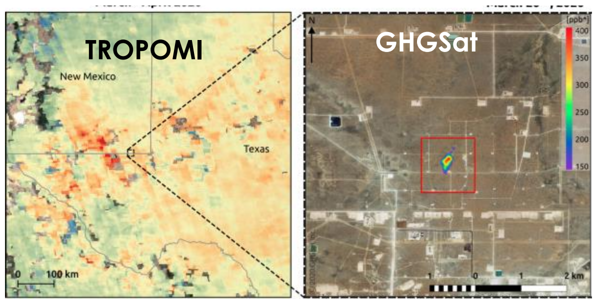
OCO-3 Team

OCO-3 XCO_2 estimates over Los Angeles, CA 19 Feb 2021



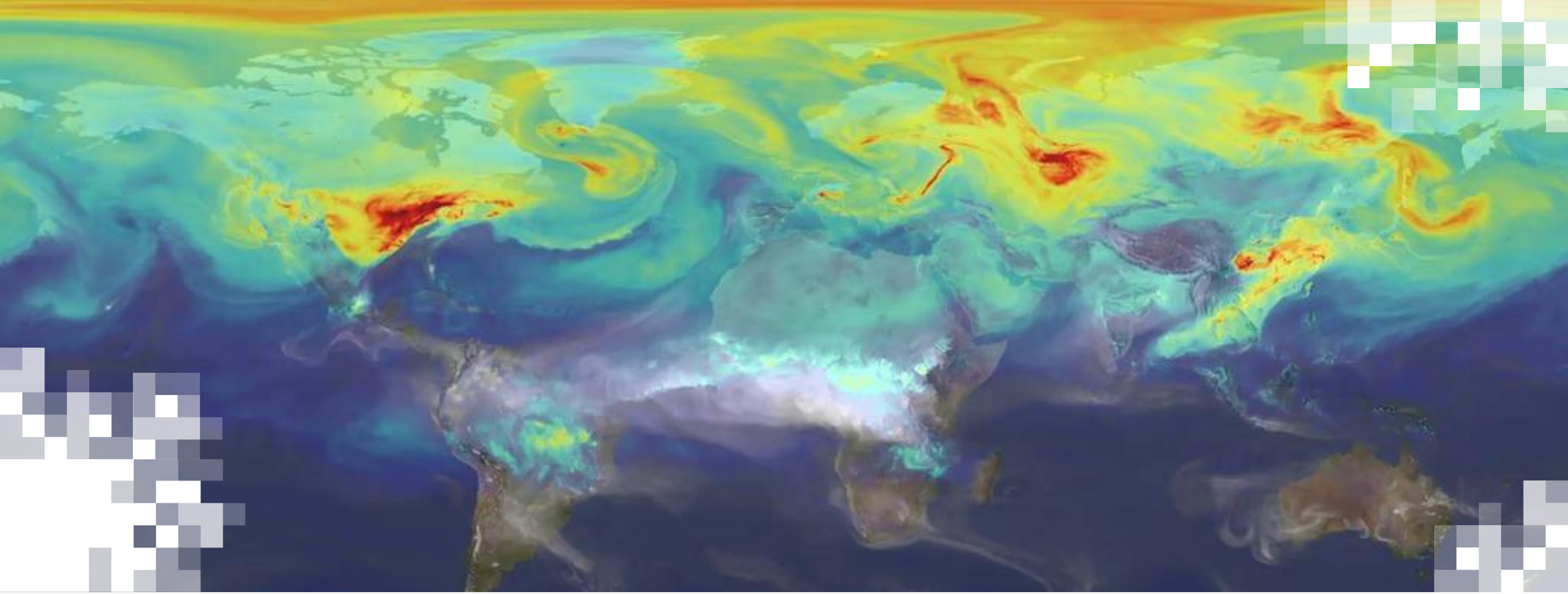
Ray Nassar, ECCC, Canada

OCO-3 XCO_2 estimates over Poland's Bełchatów Power Plant on 10 April 2020.



TROPOMI and GHGSat observe CH_4 emissions over Texas oil fields

Zehner et al. (IWGGMS-16, 2020)



Wrap-Up of Part 1: What have we learned?

Key Topics Covered

In this webinar, we:

- Summarized the impact of CO_2, CH_4, and other GHGs on the climate
- Introduced the United Nations Framework Convention on Climate Change and the primary objectives of the Paris Agreement
  - Reduce the net emissions of GHGs to mitigate their impact on the climate
- Reviewed the methods used to compile bottom-up inventories of GHGs
- Showed how top-down atmospheric budgets of CO_2 and CH_4 emissions and removals can be derived from atmospheric measurements using atmospheric inverse models to produce a transparent description of their emissions and removals on local, national, and global scales
- Introduced pilot top-down CO_2 and CH_4 budgets developed to encourage their use in the first global stocktake. These pilot products will be described in greater detail in Part 2.

Coming Attractions:

May 18 - Part 2:

How do we create top-down atmospheric budgets of carbon dioxide (CO_2) and methane (CH_4) on policy-relevant national to sub-national scales?

May 25 - Part 3:

How can top-down atmosphere CO_2 and CH_4 budgets be combined with bottom-up inventories to support a more complete, accurate, and transparent global stocktake?

Contacts

Follow us on Twitter
@NASAARSET

- Trainers:
  - David Crisp: dcrispjpl@gmail.com
  - Sean McCartney: sean.mccartney@nasa.gov
- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-atmospheric-co2-and-ch4-budgets-support-global-stocktake

Check out our sister programs:

DEVELOP

SERVIR


APPLIED REMOTE SENSING TRAINING PROGRAM
TRAIN - EMPOWER - ADVANCE

Thank You!

Additional Background Information

- A comprehensive description of a space-based architecture for measuring CO_2 and CH_4 is provided here:
  - https://ceos.org/document_management/Virtual_Constellations/ACC/Documents/CEOS_AC-VC_GHG_White_Paper_Version_1_20181009.pdf

- More information about the pilot, national-scale CO_2 and CH_4 budgets that CEOS is delivering to the UNFCCC to support the first global stocktake can be found here:
  - https://ceos.org/gst/ghg.html

- Greater insight into our current understanding of anthropogenic CO_2 and CH_4 emissions can be obtained from the annual reports of the **Global Carbon Project**.
  - For CO2: https://doi.org/10.5194/essd-12-3269-2020
  - For CH4: https://doi.org/10.5194/essd-12-1561-2020