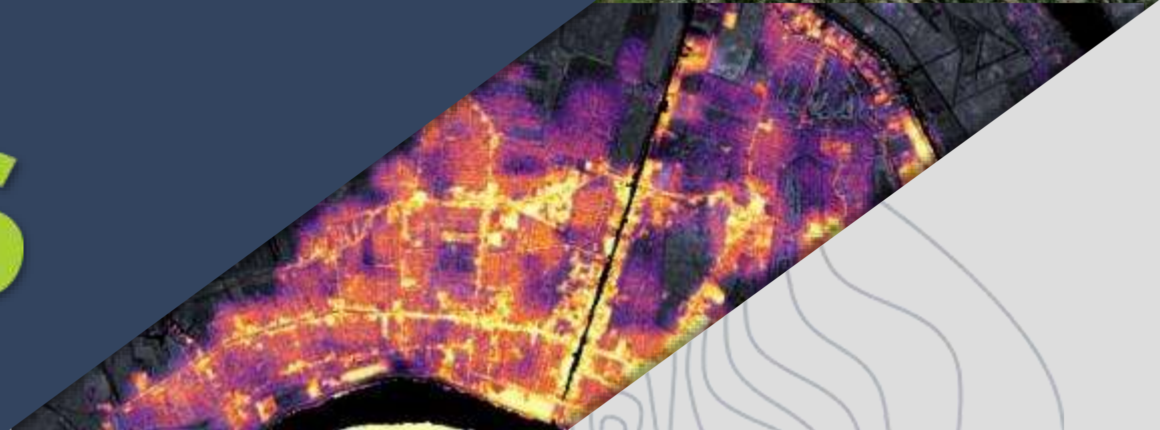
Enhancing the utility and adoption of space-based greenhouse gas observations by stakeholders in the inventory and policy communities



David Crisp

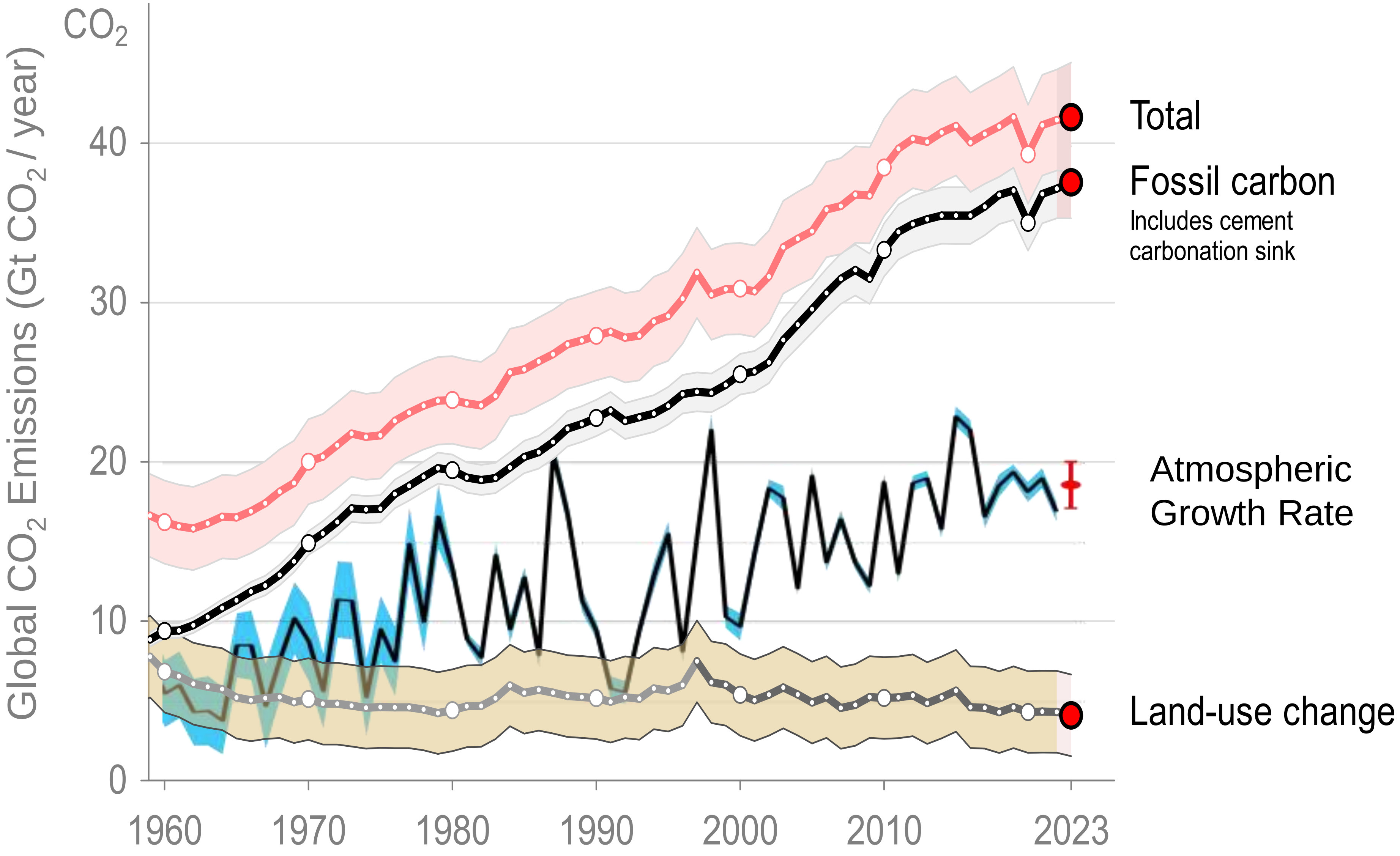
(JAXA, CEOS SIT Chair Team)

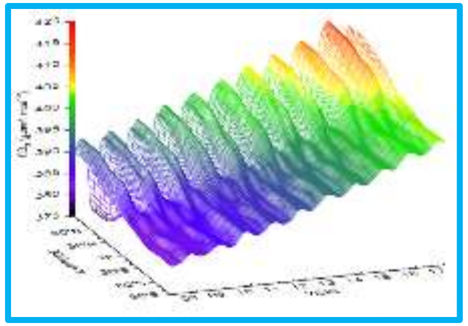
Vincent-Henri Peuch (ECMWF/ WGClimate), Yasjka Meijer (ESA/GHG-TT), Mark Dowell (EC/WGClimate), Wenying Su (WGClimate)

11 June 2025

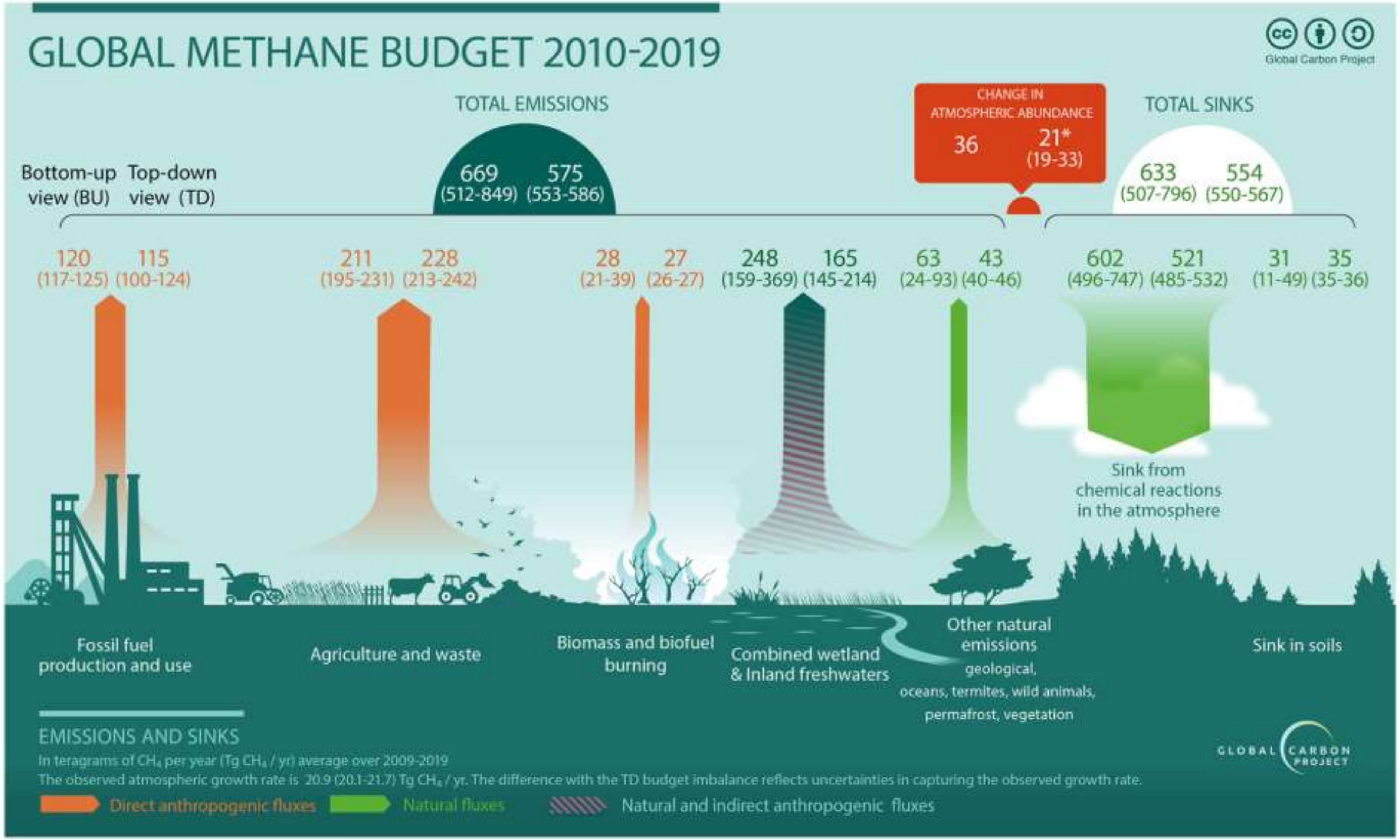
Committee on Earth Observation Satellites

Human activities that emit CO_2 into the atmosphere





Processes emitting CH_4 Into the atmosphere



Human activities add 300 to 400 million tons of methane (CH_4) to the atmosphere each year.

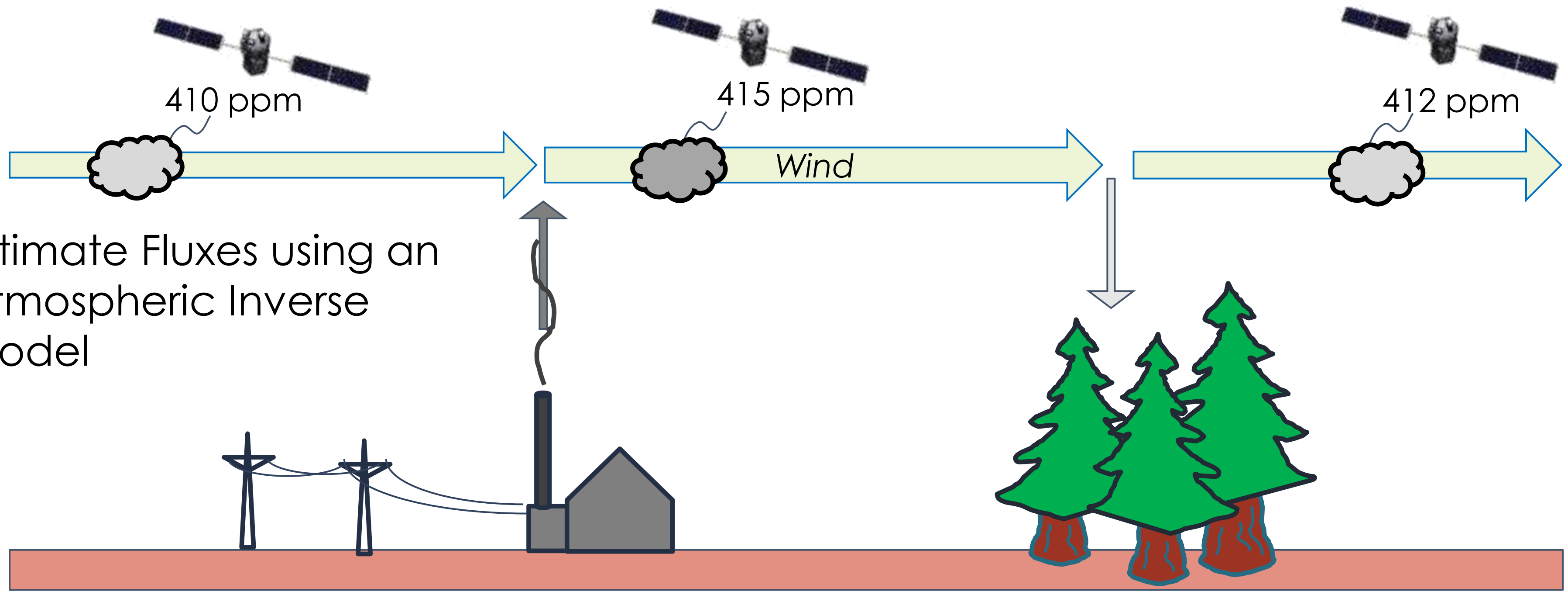
- Agriculture and waste
- Fossil fuel: CH_4 extraction & distribution

Natural wetlands and wildfires are the next largest emitters of CH_4

- **How will natural wetlands and permafrost respond to human activities and climate change?**

Tracking GHG emissions: Bottom-Up Inventories & Top-Down Atmospheric Budgets

Top-Down Atmospheric Budgets



Bottom-Up Inventories[1]

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

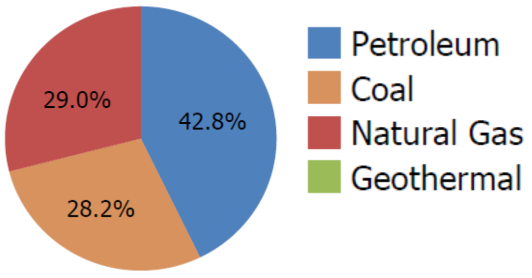
= Activity × Emission Factor + Activity × Emission Factor

[1]National inventories are prepared using bottom-up methods in accordance with the Intergovernmental Panel on Climate Change (**IPCC**) Guidelines for GHG inventories, as adopted by the Conference of Parties (**COP**).

National GHG Inventories Supporting the Global Stocktakes

Fuel Combustion
Fugitive Emissions
CO_2 Transport & Storage

Energy



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

Industry

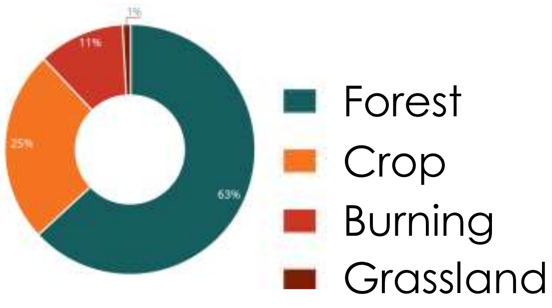
National GHG Inventory

Livestock
Land
Aggregated/Non-CO2 Land Sources

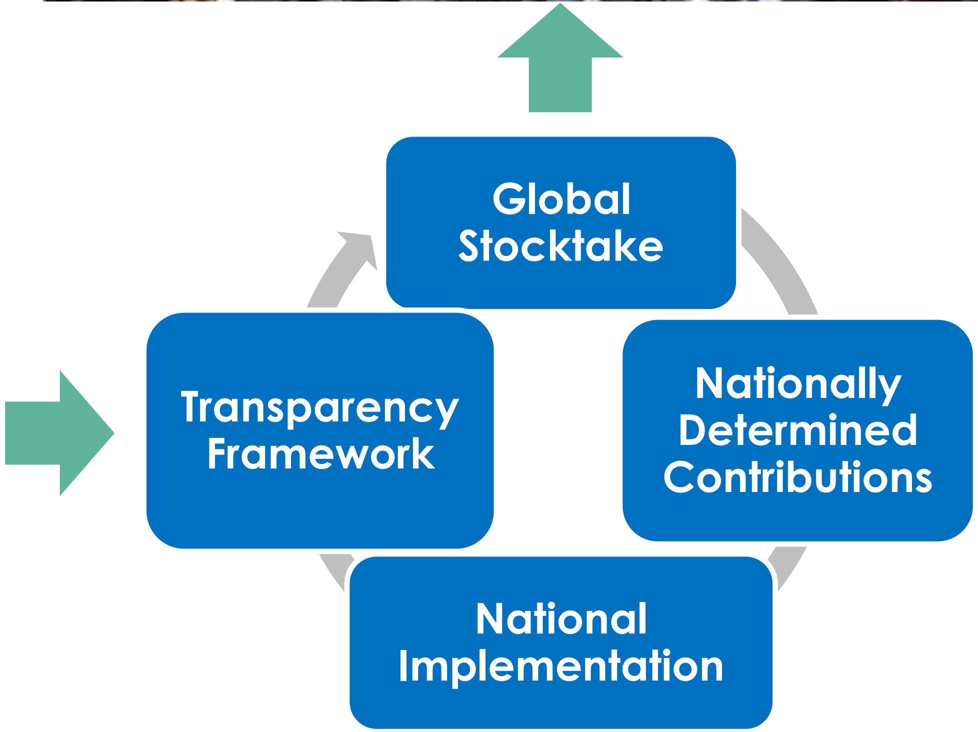
AFOLU

Solid
Biological
Wastewater
Other

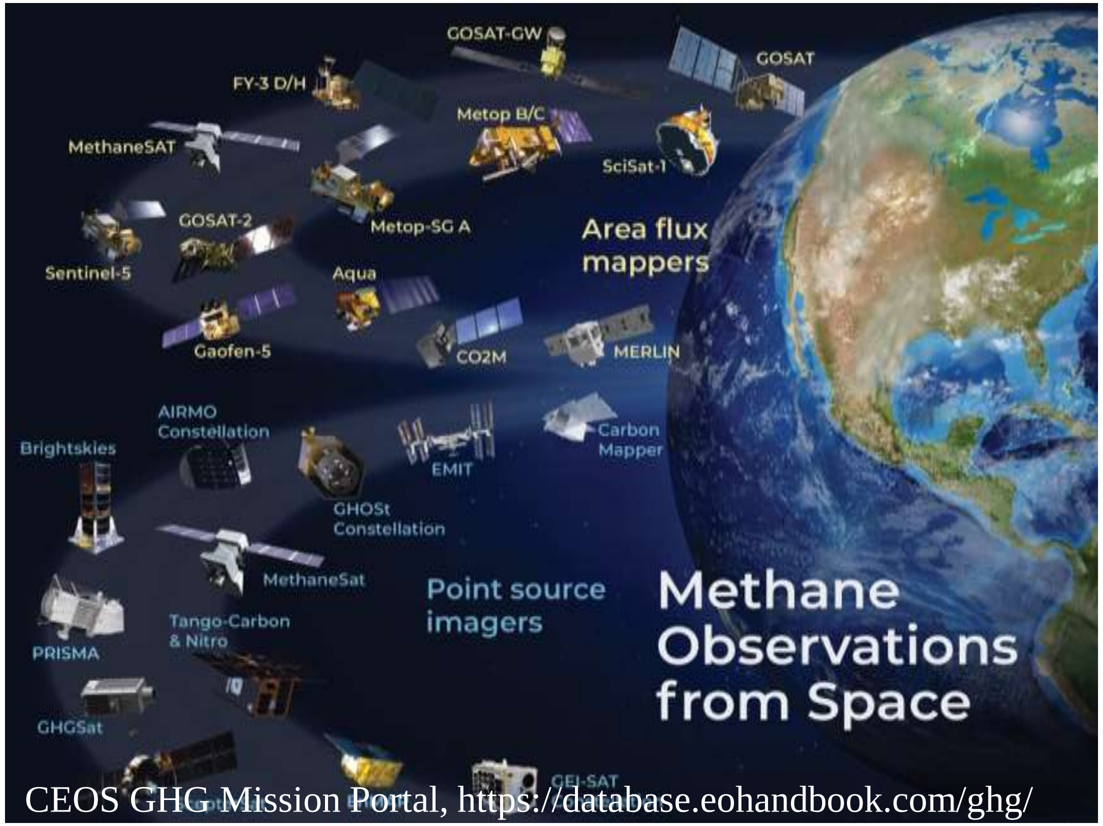
Waste



Transparency Reports



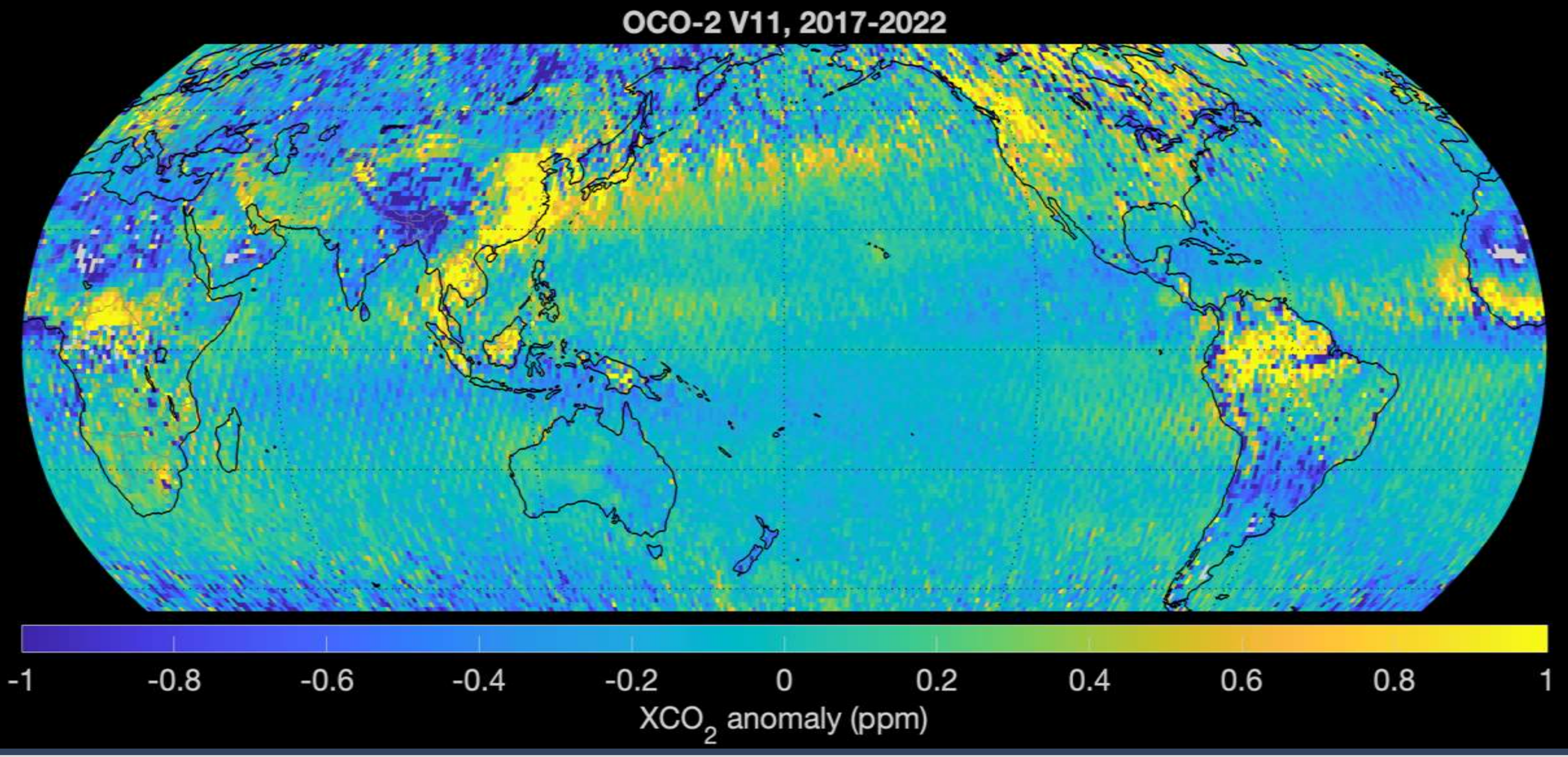
Existing and Planned GHG Missions



CEOS GHG Mission Portal, https://database.eohandbook.com/ghg/

- ❖ Operational sounders (e.g., AIRS, IASI, CrIS)
- ❖ Facility-scale missions (e.g., GHGSat, PRISMA, EMIT, MethaneSAT, Carbon Mapper)
- ❖ Global GHG mappers (e.g., GOSAT, OCO, TROPOMI, GOSAT-GW, MicroCarb, Sentinel 5, CO2M)

Space-based observations show persistent XCO_2 anomalies that provide insight Into fluxes

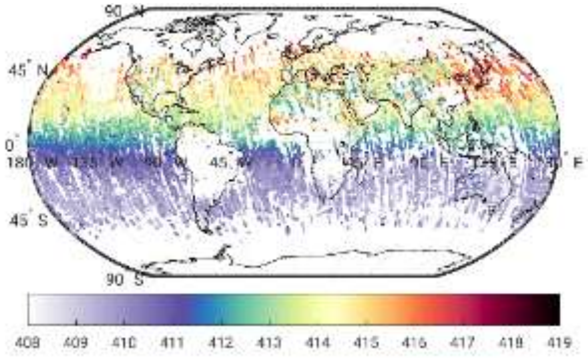


Estimating CO_2 and CH_4 emissions and removals from atmospheric measurements

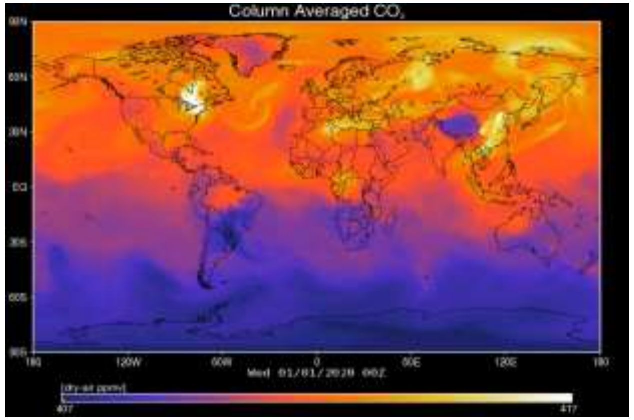
As CO_2, CH_4, and other GHGs are **added** or **removed** from the atmosphere by surface sources and sinks, the modified air masses are transported away by the winds.

Atmospheric inverse models assimilate GHG concentration measurements to estimate net GHG additions and removals (**fluxes**) in the presence of these winds.

GHG Data

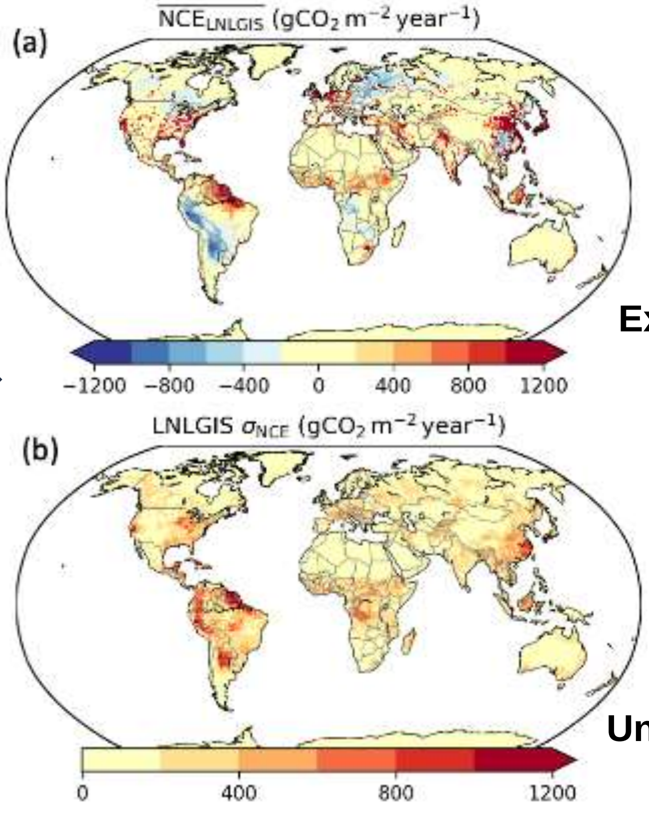


Transport



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

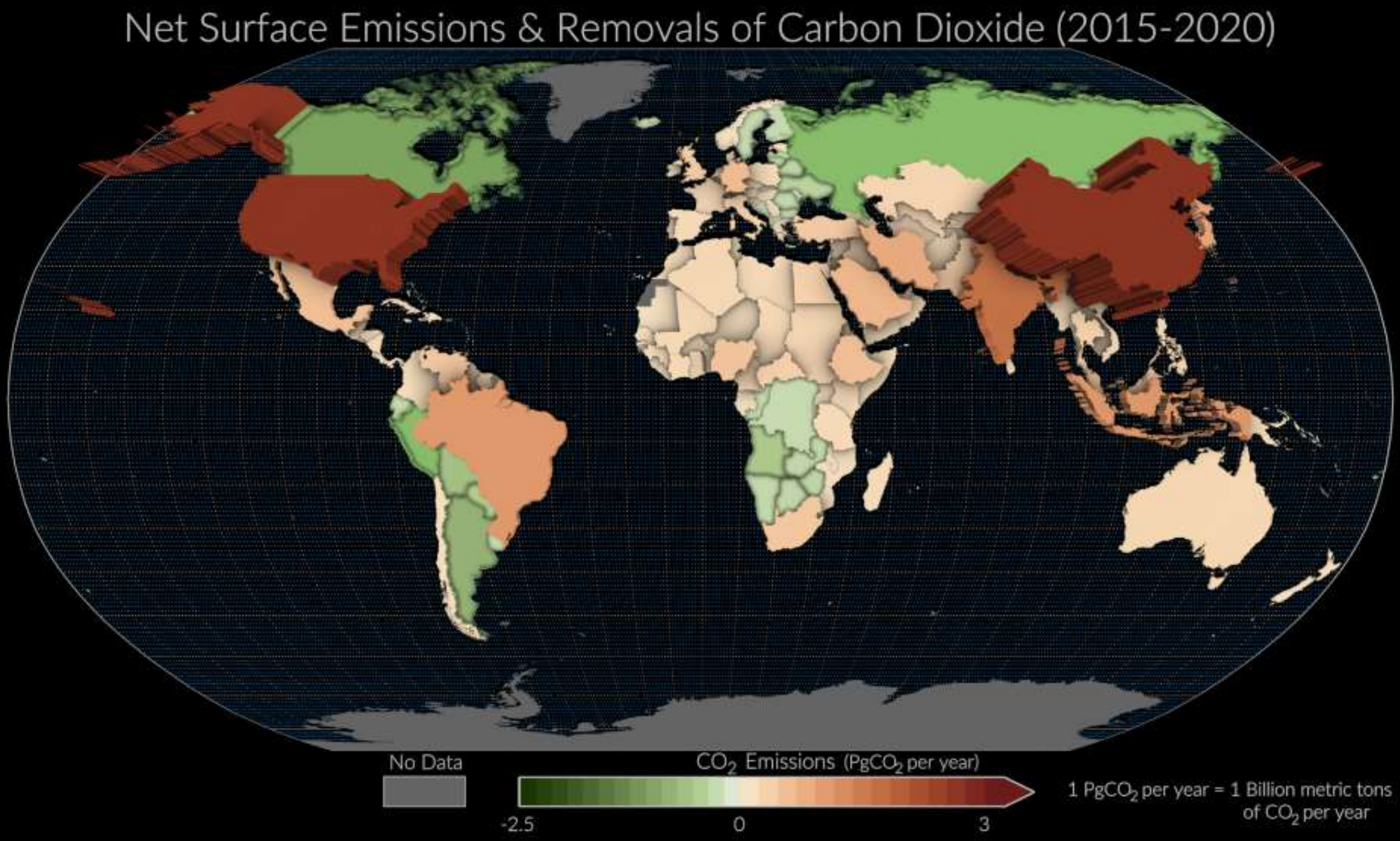
Inverse Algorithm



Net Carbon Exchange

Uncertainty

Pilot Top-down National CO_2 and CH_4 Budgets Supporting the First Global Stocktake



Bottom-up and Top-Down methods Provide Complementary Information

- **Bottom-Up Inventories of Greenhouse Gas Emissions and Removals**
  - Provide the best method for tracking emissions and removals by **known sources** with well-characterized ***activity data*** and ***emission factors***
  - Can yield direct insight into the **effectiveness of emissions reduction policies** for specific categories of specific sectors included in the inventory
  - Provide ***prior*** information needed for top-down atmospheric inversions
- **Top-Down Estimates of Net Greenhouse Gas Emissions and Removals**
  - Provide integrated estimates of **net GHG fluxes**, ideal for assessing **collective progress** toward the greenhouse gas emissions reduction targets
  - Offer a ***partially*** independent approach for assessing completeness of standard inventory methods based on activity data and emission factors
  - Can track emissions changes on **unmanaged lands** or **over ocean** associated with human activities or climate change, which are ***not included in inventories***
  - Improve traceability of emissions **policies**, to greenhouse gas **abundances** to **climate**

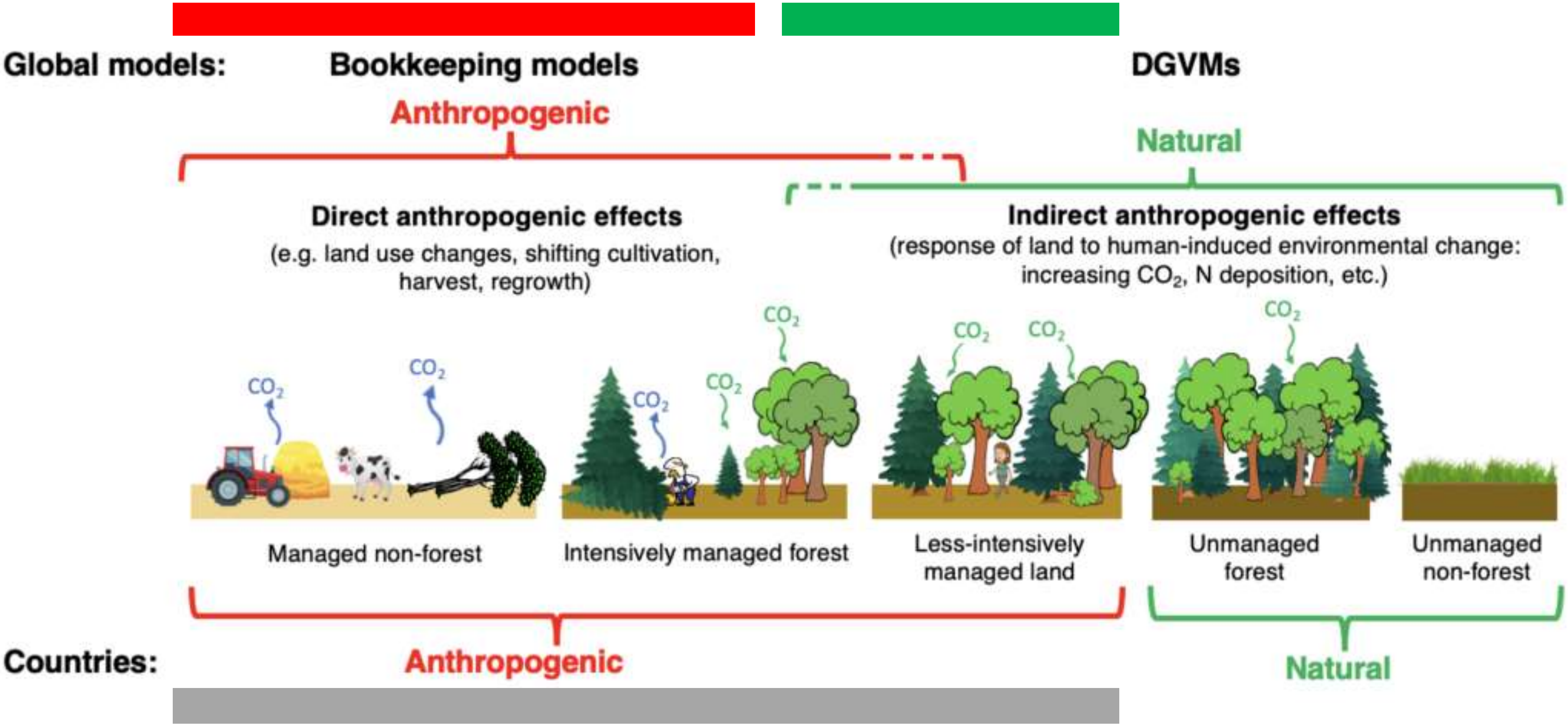
Key Lessons Learned from participation in the First Global Stocktake

- Scientific lessons learned
  - Top-down GHG products derived from existing space-based measurements provide
    - **Limited new information on fossil fuel emissions**, especially across the developed world
    - **Critical new insights** into GHG **emissions & removals** by the **land biosphere** associated with **human activities** (agriculture, forestry) and **climate change** across the entire globe
    - **Unique data** for quantifying the **collective progress** toward **GHG emissions reductions targets** on **regional scales**, especially across the developing world
- Lessons learned from stakeholder interactions
  - Few nations used the CEOS GHG products to **construct** or **validate** inventories
    - IPCC guidelines **discuss**, but **do not mandate** atmospheric data for inventory QA/QC
    - Most national inventory compilers **do not understand** top-down atmospheric GHG data
    - No "**champions**" were enlisted in the national inventory compiler or policy communities to encourage the use of these products for inventory development or QA/QC

Sources of Confusion – Different ways of Tracking Carbon

Carbon Cycle Scientists

Policy Makers (following IPCC-TFI guidelines)



Source: Friedlingstein et al 2024; Global Carbon Project 2024 - Figure from Grassi et al., ESSD 2023

Encouraging use of Space-based GHG Products by Policy Makers

- Establish broader and more continuous interactions with members of the **national inventory** and **policy** communities
  - Form partnerships to develop **transparent, purpose-built atmospheric GHG products**
  - Engage in **2-way capacity building** to improve understanding of **needs** and **information content** of space-based GHG products for inventory development & assessment
  - Identify "**champions**" in the inventory and policy communities who can demonstrate the use of space-based products in the development and QA/QC of national GHG inventories
- Foster stronger partnerships with UN Agencies
  - Provide the "space arm" of the **WMO Global Greenhouse Gas Watch** (G3W)
  - Work with UNEP International Methane Emissions Observatory (**IMEO**) to provide timely space-based observations to support its Methane Alert & Response System (**MARS**)
  - Work with **IPCC-TFI** to identify standard **tools** and **protocols** for using space-based GHG and AFOLU products for QA/QC of inventories and for evaluating the **collective progress** toward the mitigation goals of the Paris Agreement

Getting Involved

- Collaborate with **inventory developers** to build fit-for-purpose products supporting inventory development and assessment
  - Build tools to read space-based. high-resolution, time-resolved **land cover** and **above-ground biomass** maps to quantify **land use change activity** at sub-national to global scales
  - Combine **bottom-up scientific inventories**, **top-down GHG budgets** and space-based **activity data** to create regionally dependent **emission factor databases**
- Work with **IPCC-TFI** to develop tools & **protocols** for comparing space-based GHG products with bottom-up national inventories for QA/QC
- Work with the **UNFCCC** to define methods for using bottom-up scientific GHG inventories and top-down GHG budgets to assess **collective progress** toward the Paris Agreement’s mititation goals

Summary

- ❖ The science community is now developing a range of space-based GHG flux and AFOLU products that could support
  - GHG Inventory development and QA/QC
  - Assessments of collective progress toward GHG reduction goals
- ❖ So far, these tools have not been widely adopted
- ❖ To improve their utility & encourage their use, GHG scientists must
  - Co-develop products tools and services with the inventory and policy communities
  - Work with the IPCC-TFI and UNFCC to socialize their use in inventory development and QA/QC
  - Participate more broadly in outreach activities and capacity building targeting the broader inventory and policy communities

Other ideas and initiatives are welcome!!