# Linking Remote Sensing Estimates of $XCO_2$ and $XCH_4$ to Emissions

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## Abstract:

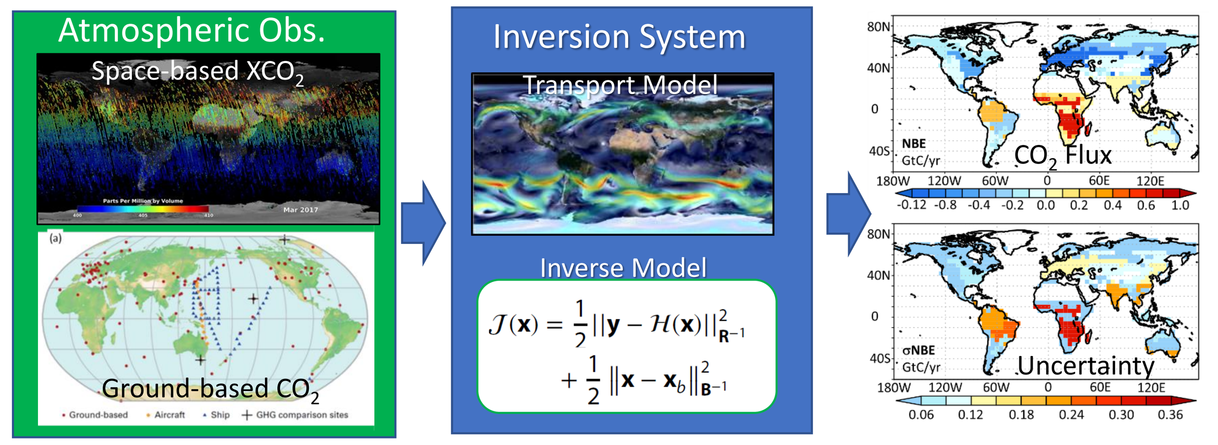
Space-based remote sensing observations are now providing the data needed to estimate the atmospheric column-averaged dry air mole fractions of carbon dioxide ($XCO_2$) and methane ($XCH_4$) with unprecedented precision, accuracy, resolution and coverage. These products are being analyzed with atmospheric inverse models to derive top-down estimates of atmospheric fluxes (emissions and removals) on spatial scales ranging from individual large fossil fuel-fired powerplants and large urban areas to nations and the globe.

In spite of their potential utility, these remote sensing products are not yet widely used by the greenhouse gas (GHG) inventory community. Often-cited obstacles include:

- Lingering concerns about the accuracy of remotely-sensed concentrations and fluxes;
- Top-down fluxes do not distinguish policy-relevant anthropogenic and natural processes; and
- Bottom-up inventory compilers do not yet understand the information content and limitations of these data.

We begin with a brief description of the evolving role of top-down atmospheric greenhouse gas estimates in national inventories. We then summarize the progress to date and near term plans to address these issues. We finish with a call for more collaboration between the atmospheric GHG community and the emissions inventory and policy communities.

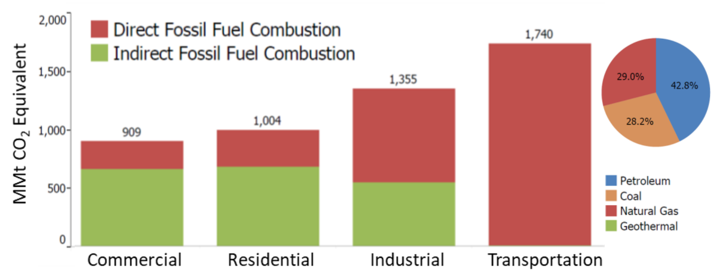

## Tracking $CO_2$ and $CH_4$ Emissions: Bottom-up Inventories and Top-down Budgets




### Top-Down Budgets

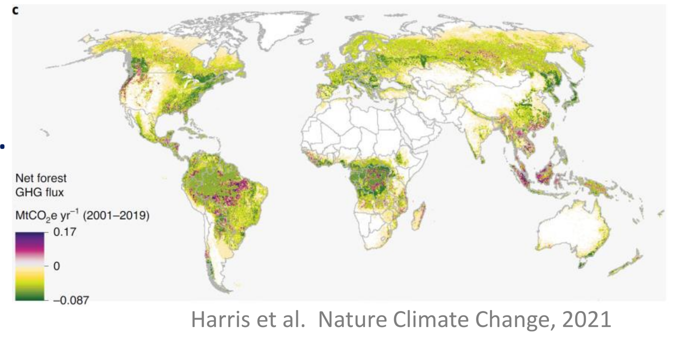
Observations of atmospheric $CO_2$ provide an integral constraint on emissions and removals to

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



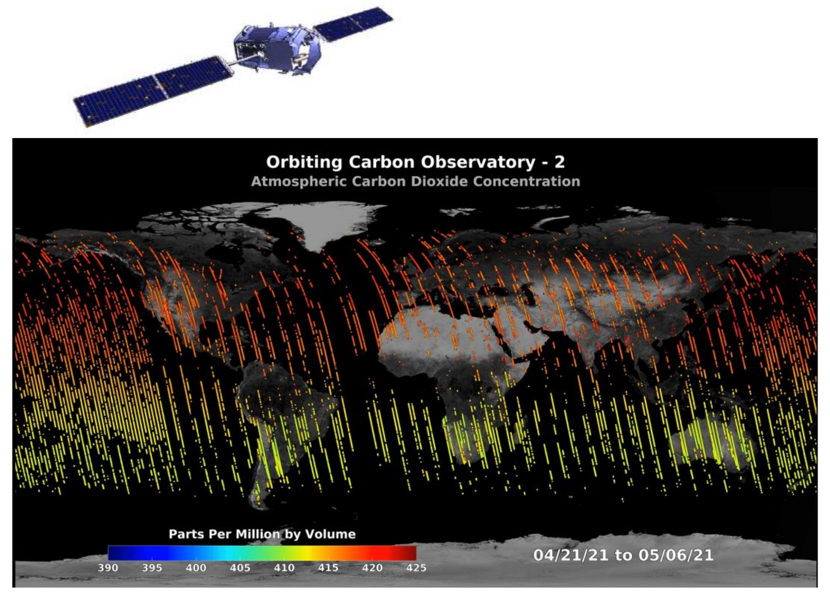

### Bottom-Up Inventories

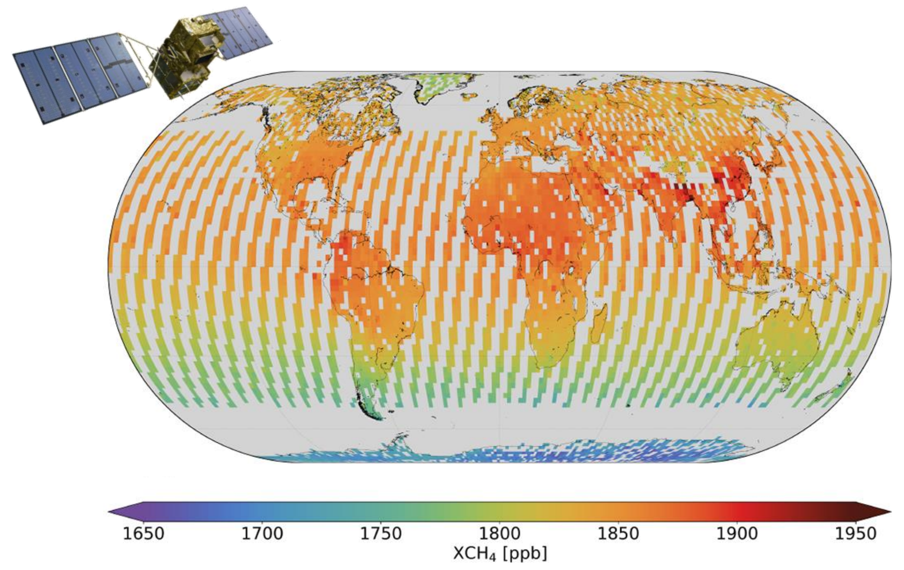
- Sector-specific estimates of emissions from known sources.
- Earth Observations play a critical role for tracking land use change.




Harris et al. Nature Climate Change, 2021

## Estimating $CO_2$ and $CH_4$ Concentrations from Space-based Measurements



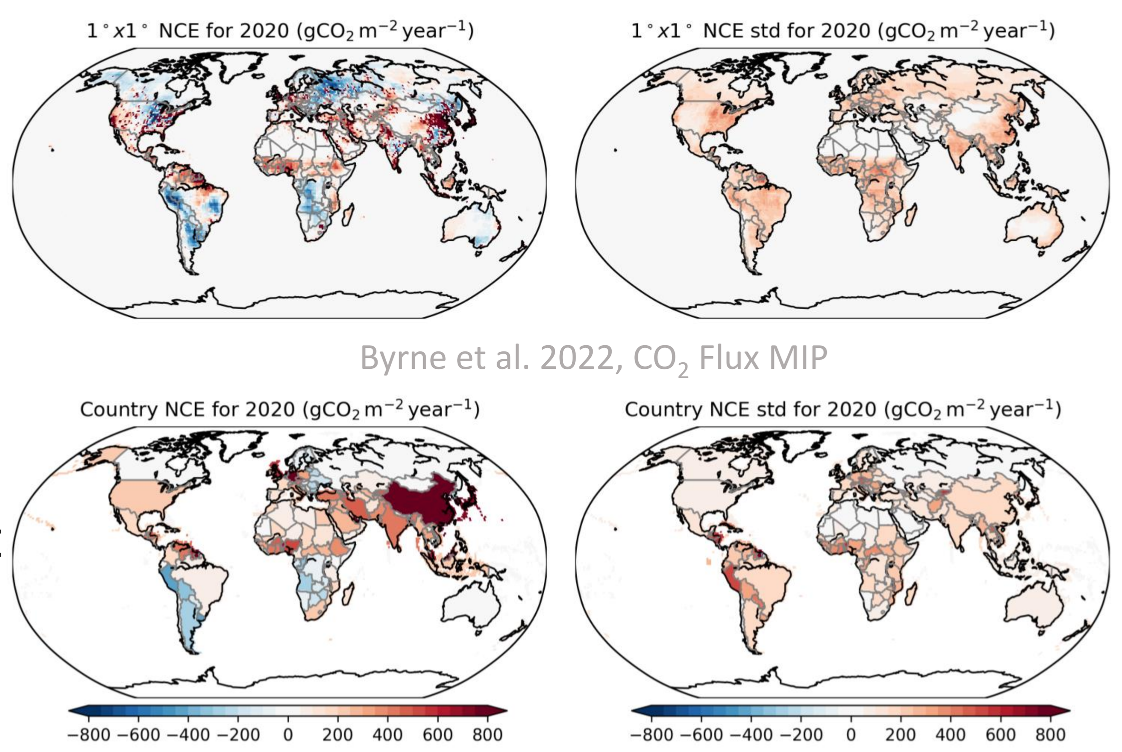




The $CO_2$ and $CH_4$ estimates derived from these space-based sensors are less precise and accurate than *in situ* data provided by ground-based GHG networks, but they provide the resolution and coverage needed to quantify emissions from intense point sources and place regional constraints on weak, spatially-extensive sources & sinks in the natural carbon cycle.

## Quantifying $CO_2$ and $CH_4$ Fluxes with Atmospheric inverse Models

*In situ* $CO_2$ and $CH_4$ measurements are now being combined with space-based $XCO_2$ and $XCH_4$ estimates in ***atmospheric inverse models*** to estimate $CO_2$ and $CH_4$ fluxes on regional scales over the globe.

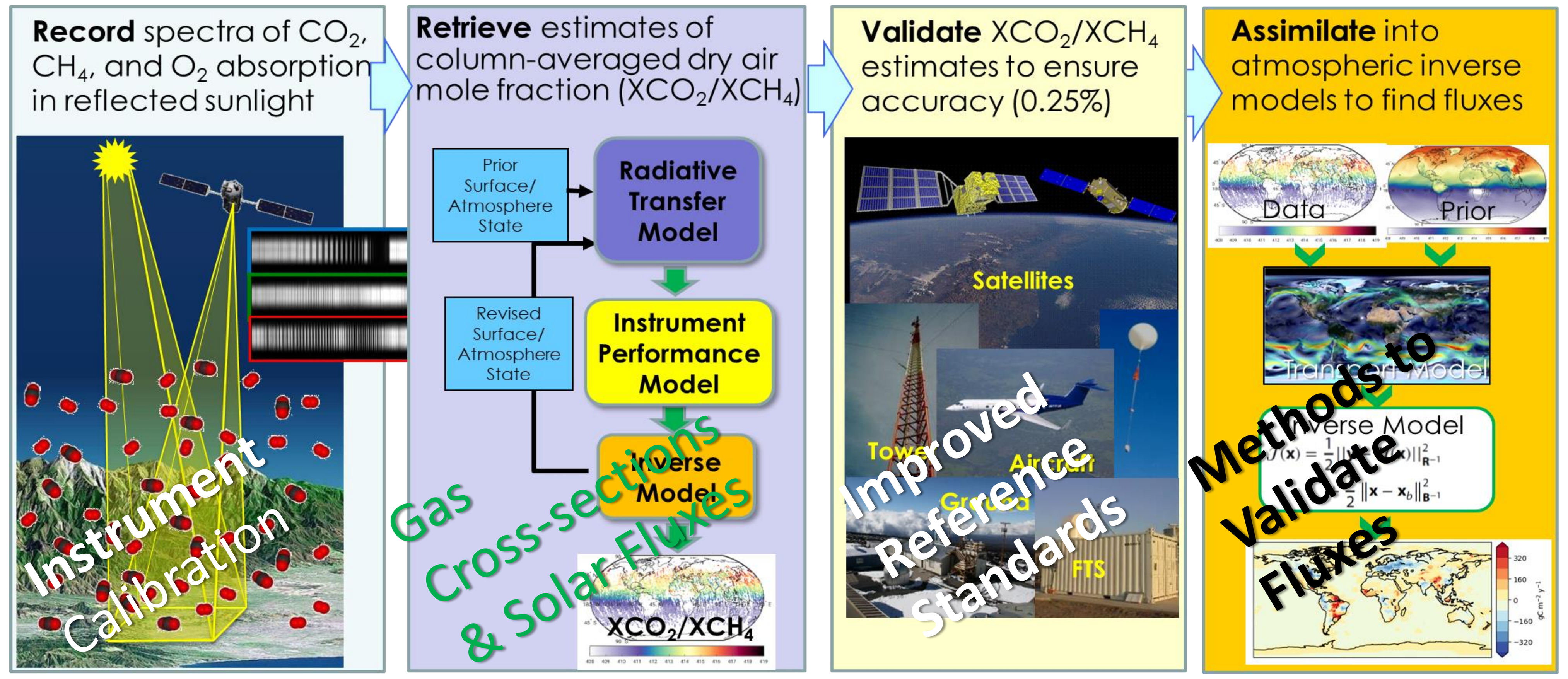
- Here we show the net carbon exchange (**NCE**), which is the net flux of $CO_2$ by all sources and sinks over land.
- A Country Mask can be applied to these mapped NCE values to derive national budgets




Byrne et al. 2022, $CO_2$ Flux MIP

- Positive values ⇒ a $CO_2$ source
- Negative values ⇒ a net $CO_2$ sink

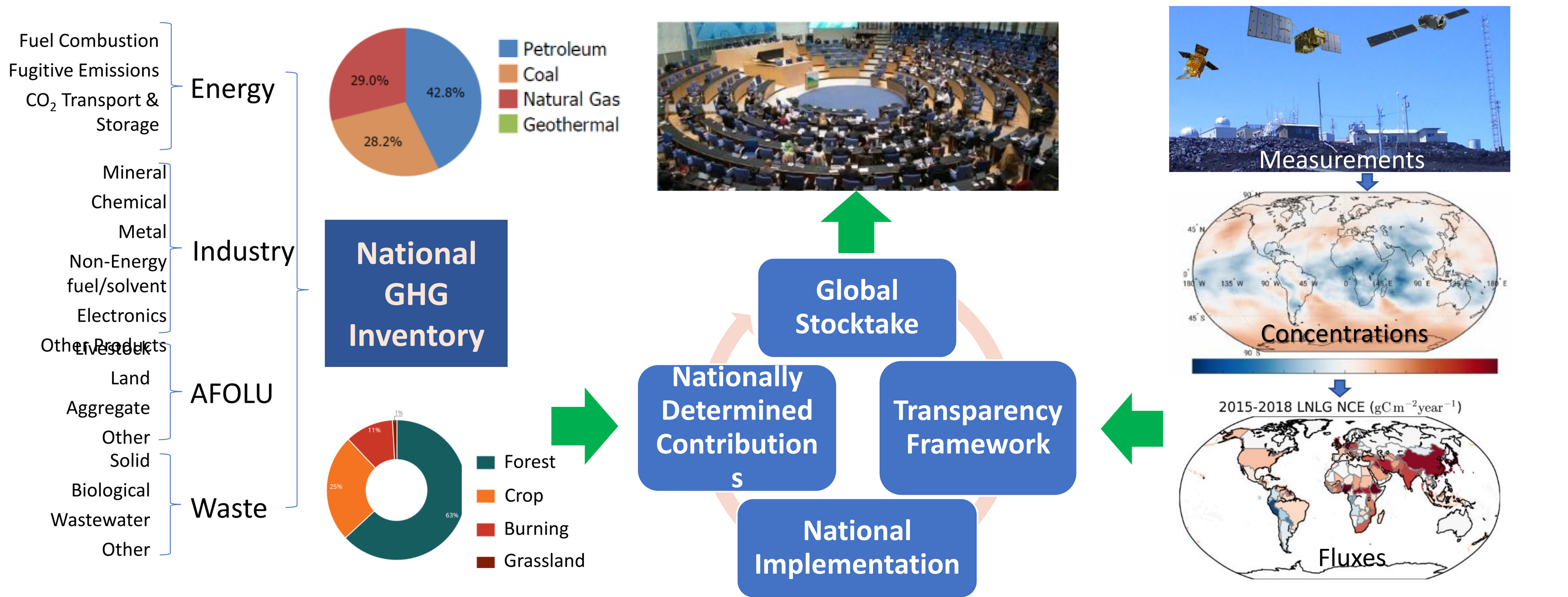
## Improvements in Metrology Needed to Encourage Acceptance of Atmospheric $CO_2$ and $CH_4$ Products




## Opportunities for Improving Carbon Flux Metrology

- **Advances in ground-based remote sensing** of $XCO_2$ and $XCH_4$ are providing better data for identifying and correcting biases in space-based estimates
- **Additional airborne *in situ* observations** of $CO_2$ profiles
  - Advances in AirCore, *in situ* sensors commercial aircraft, routine, operational GHG profile measurements across the tropics
- **Atmospheric inverse models** that better exploit high-density, moderate-accuracy space-based atmospheric $XCO_2$ and $XCH_4$ estimates
  - Collaboration through Multi-model Intercomparison Projects (MIPS)

## The Last Frontier – Collaboration and Capacity Building




Collaboration and capacity building are essential to facilitate the use of atmospheric $CO_2$ and $CH_4$ products by the inventory and policy communities

## Summary

- Showed how top-down atmospheric GHG estimates could be used in both the development and assessment national inventories
  - Provide an integral constraint on net emissions and uptake by all sources and sinks, including those not tracked in the inventories (oceans, unmanaged land)
  - Track evolving emission shot spots
- Reviewed technical progress to date and near-term plans for
  - Quantifying column-averaged atmospheric CO2 and CH4 dry air mole fractions ($XCO_2$, $XCH_4$)
  - Using these data to estimate $CO_2$ and $CH_4$ fluxes on local to regional/national scales
- Summarized improvements in metrology needed to encourage acceptance of atmospheric GHG products by the inventory development and policy communities
  - Improving the accuracy, resolution, coverage and traceability of the ground-based and airborne system for validating space-based estimates of concentrations
  - Addressing measurement gaps
- Reinforced the need for collaboration and capacity building with inventory development and policy communities

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