The Global Carbon Cycle – Insights from Space-based Observations of CO_2

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GLOBAL CLIMATE OBSERVING SYSTEM
KEEPING WATCH OVER OUR CLIMATE

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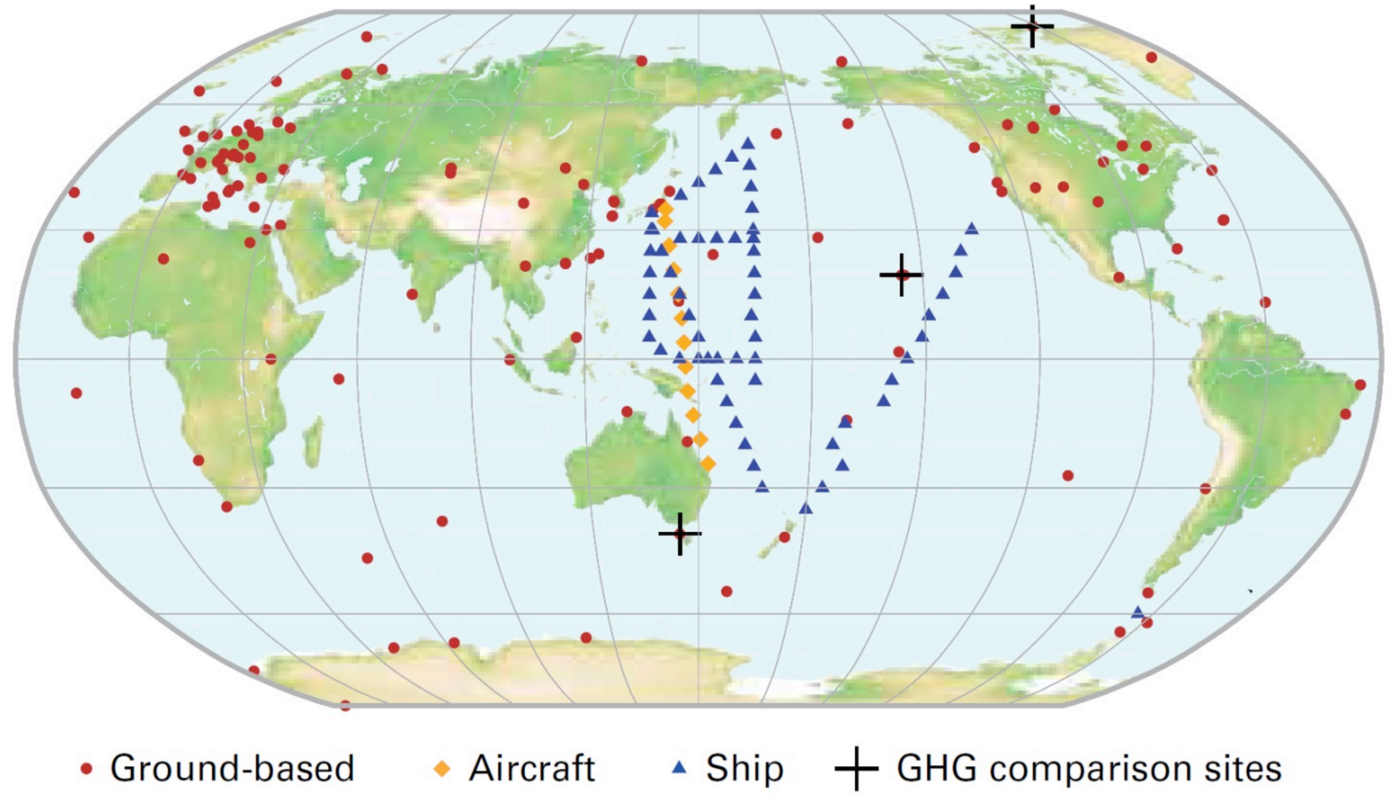
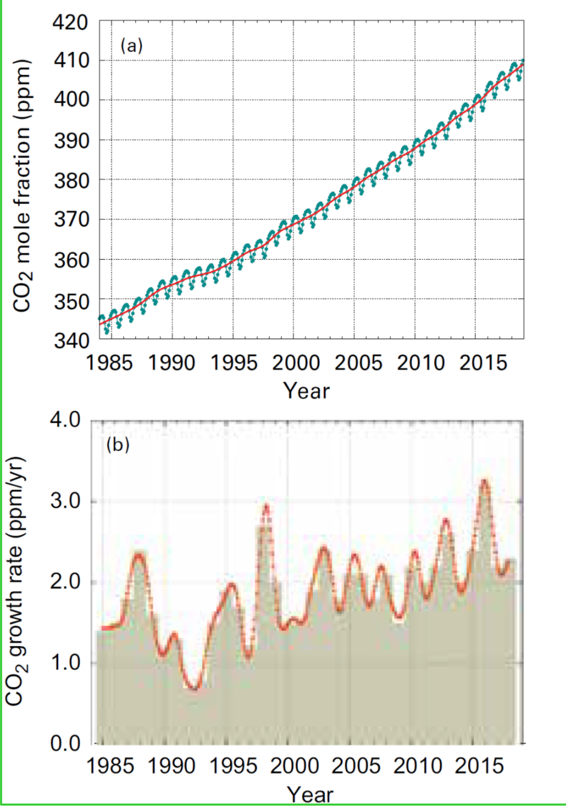
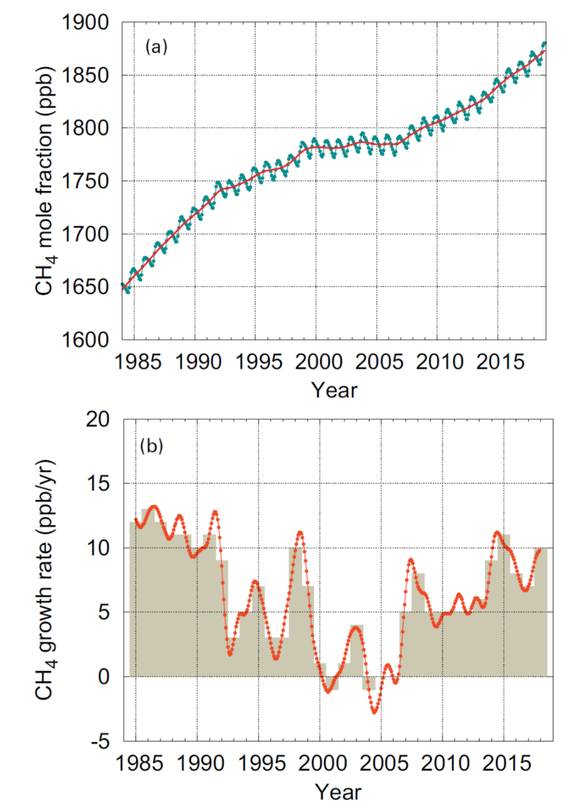
Overview

- Atmospheric CO_2 concentrations are controlled by both natural and anthropogenic processes
- An improved understanding of these processes is critical to
  - Our ability to predict the rate of increase in the CO_2 in the atmosphere
  - Our ability to anticipate the rate of CO_2-induced climate change.
- Until recently, most atmospheric CO_2 measurements were obtained from a global network of ground stations
- The resolution and coverage of these measurements are now being complemented by global space-based observations
- These new observations are providing new insights into both the natural and anthropogenic contributions to the carbon cycle

The Ground-based Greenhouse Gas Monitoring Network



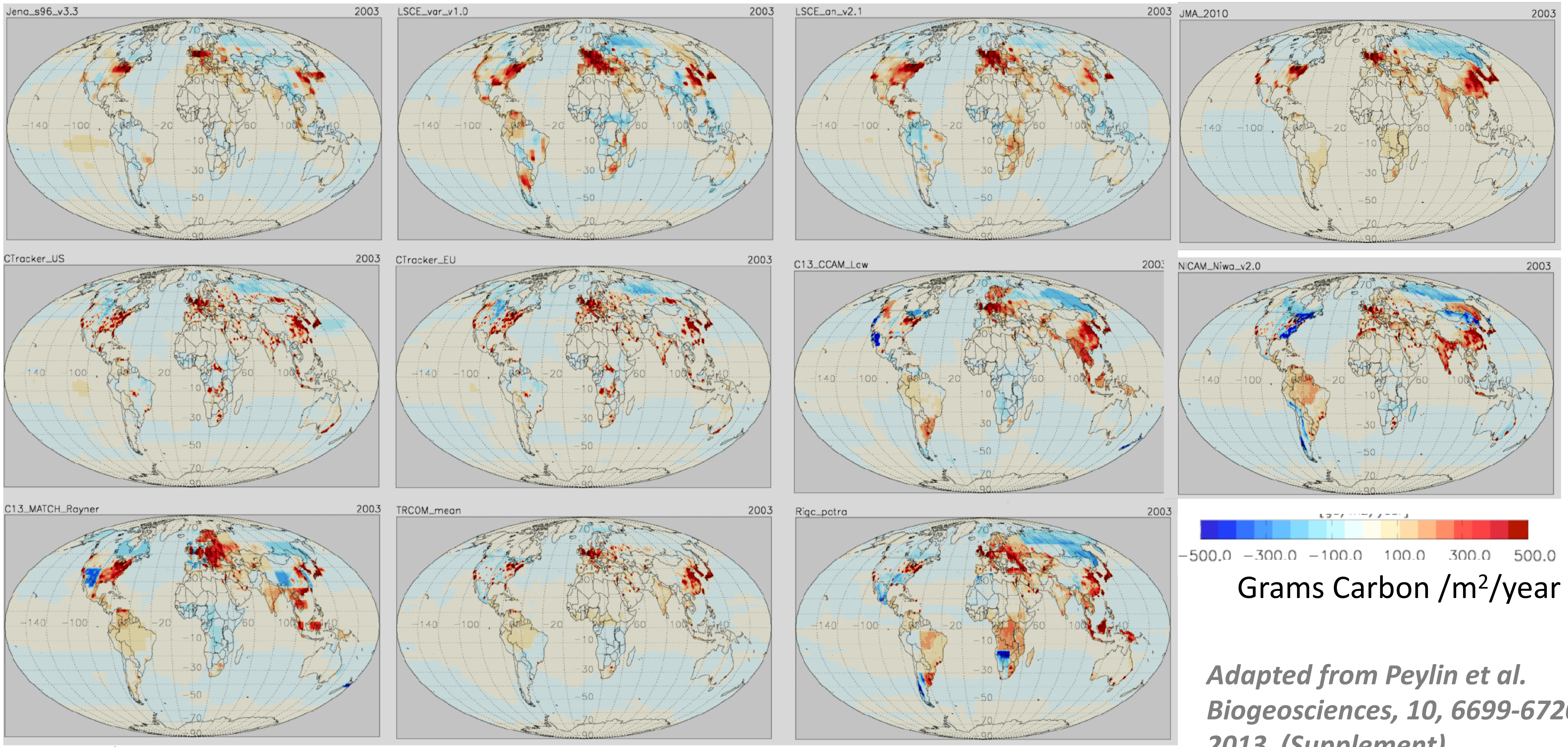




Ground-based *in situ* measurements from the WMO Global Atmospheric Watch (GAW) Network and its partners provide the most accurate available estimates of atmospheric concentrations of CO_2, CH_4 and other greenhouse gases and their trends on global scales, but the network's spatial coverage and resolution are limited.

Global Flux Inversion Models Constrained by in situ Data

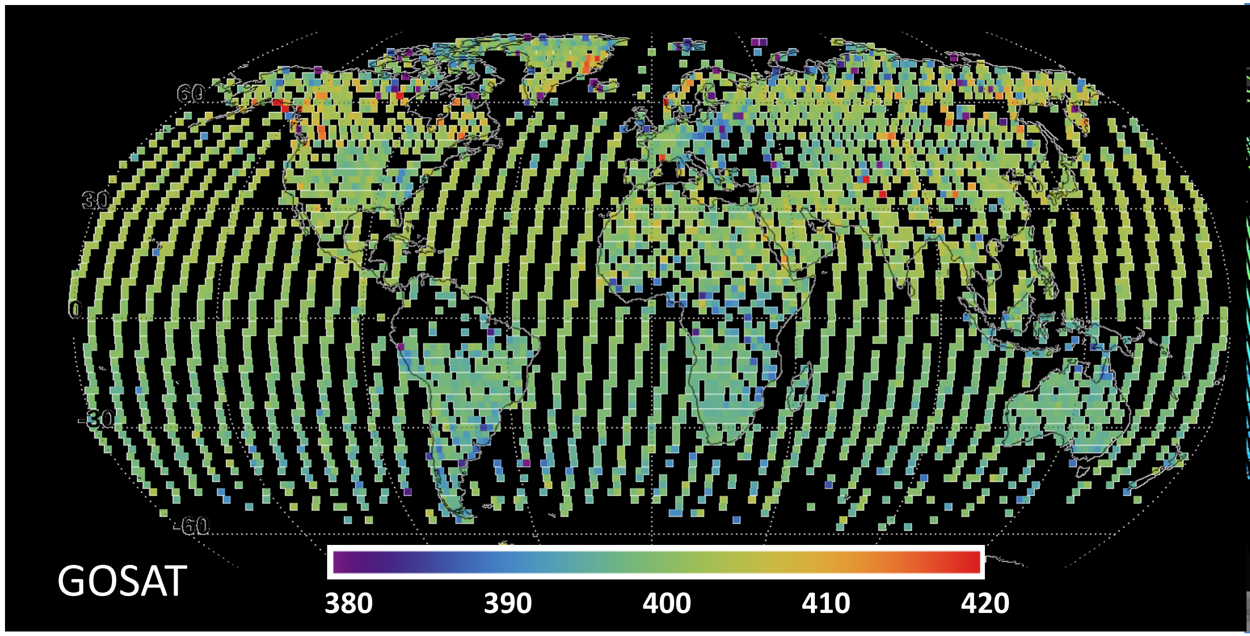
Flux inversion models constrained by in situ measurements show their largest signals where measurements are available.

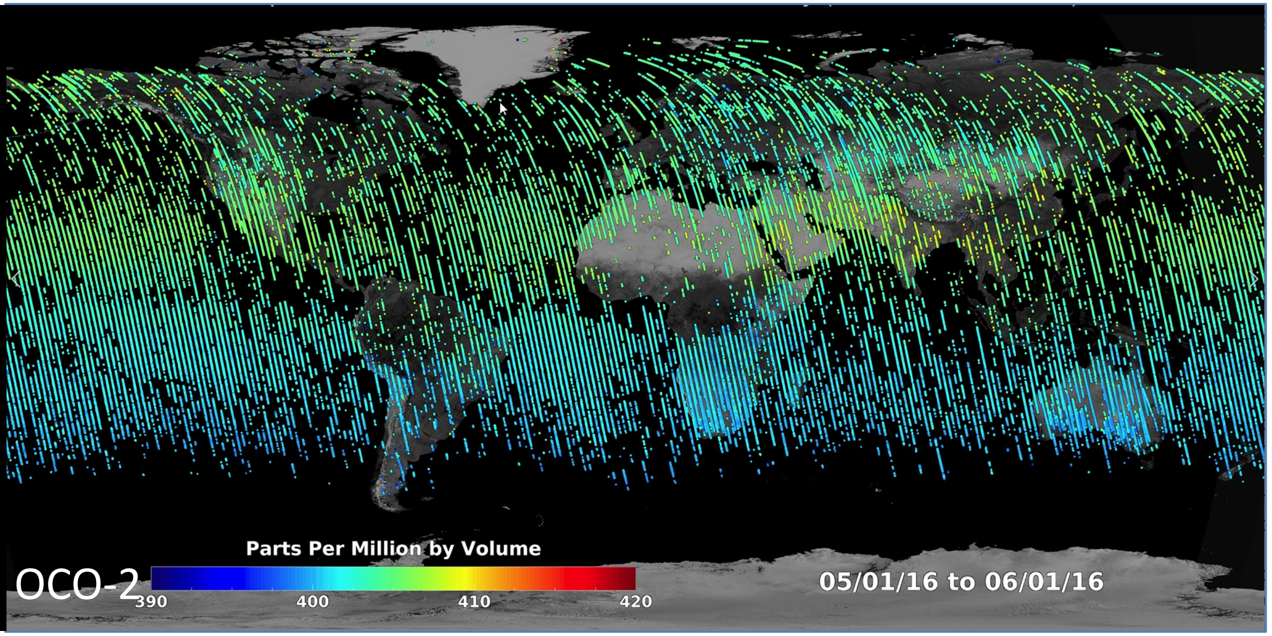


Grams Carbon /m^2/year

Adapted from Peylin et al. Biogeosciences, 10, 6699-6720, 2013 (Supplement).

Space-based CO_2 Estimates from GOSAT and OCO-2





Monthly estimates of the column-average CO_2 dry air mole fraction, XCO_2, from GOSAT (left) and OCO-2 (right) from May 2016.

- GOSAT collects 300-1000 full-column XCO_2 measurements each day.
- OCO-2 collects about 80,000 XCO_2 measurements each day.
- Clouds preclude observations in some regions, but these measurements still provide a high spatial resolution description of the atmospheric CO_2 concentration field.

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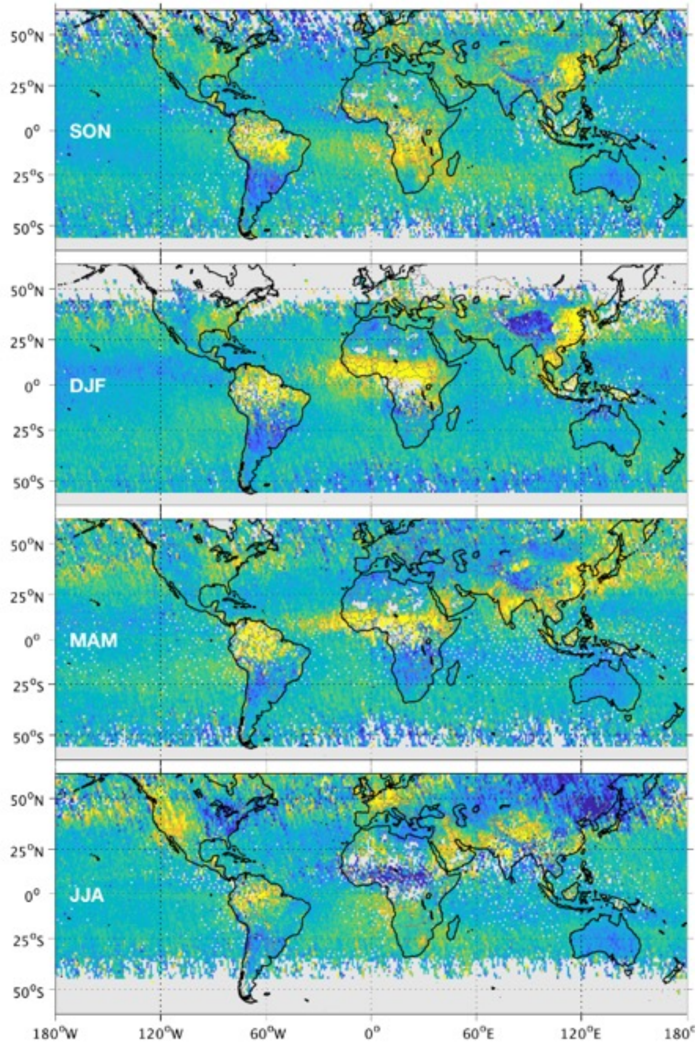
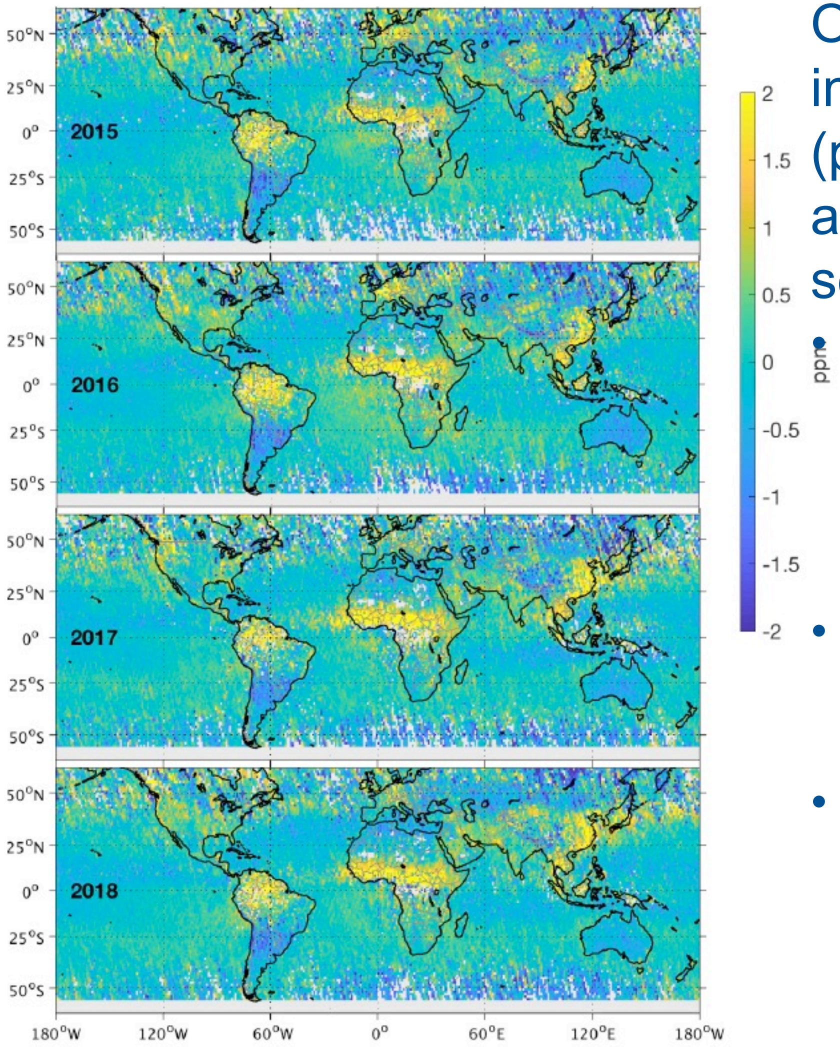
Persistent Spatial Anomalies in XCO_2

Seasonal Anomalies



Annual Anomalies



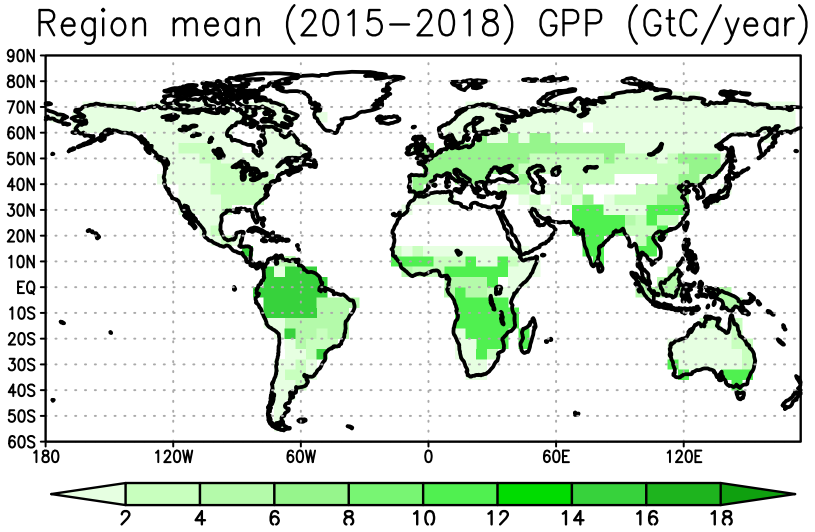
Hakkarainen et. al. Remote Sens. 11, 2019.

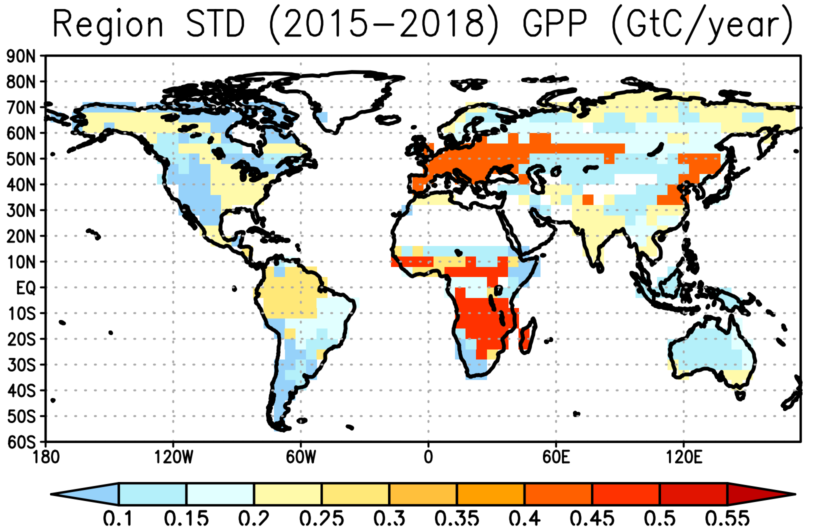
With the seasonal cycle removed, OCO-2 XCO_2 estimates (above) indicate that some regions have high (positive) or low (negative) XCO_2 anomalies that persist from season to season and from year to year.

- Tropical forests exhibit 1-2 ppm positive XCO_2 anomalies, indicating that they are net emitters of CO_2, rather than absorbers, in spite of their strong photosynthetic uptake.
- Tropical oceans have weak negative XCO_2 anomalies, indicating net CO_2 absorbers.
- Mid- and high latitudes show larger seasonal variations than expected, as well as large positive XCO_2 anomalies in regions with intense fossil fuel use (i.e. East Asia).

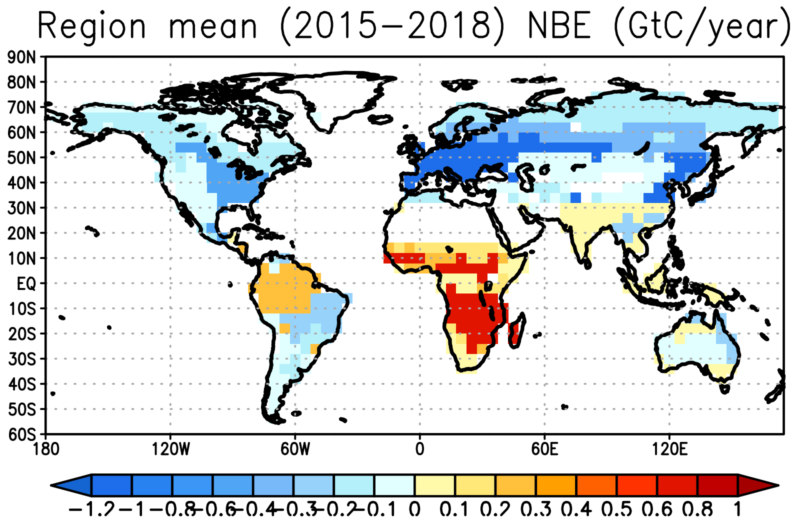
Flux Inversion Models Constrained by in Space-based Data

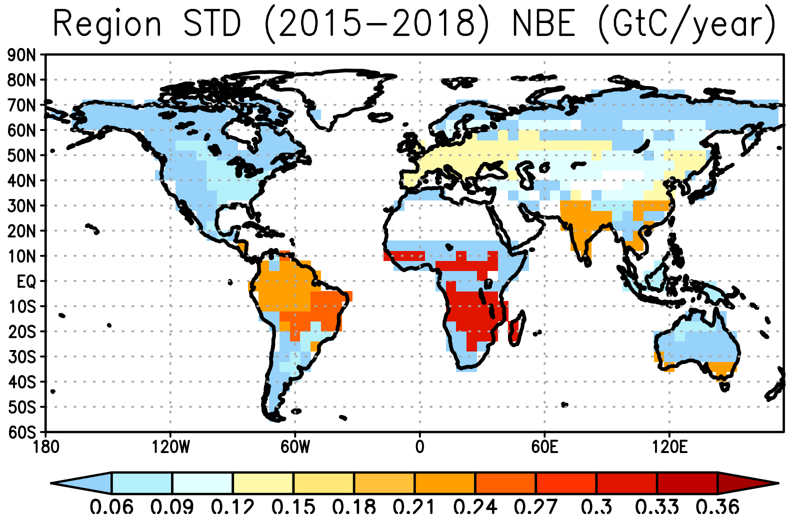
Gross Primary Production





Net Biospheric Exchange (NBE)





Flux Inversion models constrained by space-based CO_2 measurements as well as ground based *in situ* measurements show that some of the most biologically productive regions (high GPP), such as tropical forests, are net sources of atmospheric CO_2 emissions.

This represents a significant difference from earlier flux inversion experiments, constrained only by in situ data.

Liu et. al. CMS Flux, 2019.

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Possible Explanations for Regional Scale Differences

1. **Models constrained by *in situ* measurements, alone, tell an incomplete story.**
   - While ground-based and airborne data are more precise and accurate than the space based measurements, their spatial resolution and coverage is very sparse, especially in regions where the largest XCO_2 anomalies are seen by the space-based sensors. Flux inversion models yield unreliable results where there are no measurements.

2. **The space-based XCO_2 estimates still include regional biases.**
   - OCO-2 measurements have been validated against TCCON and other standards, but there are few validation sites in regions with the largest XCO_2 anomalies.
   - While tropical land anomalies appear to be robust to updates in retrieval algorithms, recent results suggest that the tropical ocean anomaly may be much weaker.

3. **The natural carbon cycle is evolving in response to climate change.**
   - There is increasing evidence from atmospheric CO_2 measurements and modeling studies that the carbon cycle is evolving rapidly in response to human activities (deforestation, biomass burning, land use change) and climate change.
   - Measurements and models based on earlier data may no longer describe this system.

Reconciling the in situ and Space-based Results

- **Additional ground-based and aircraft measurements are essential.**
  - New stations are needed to cover tropical land, topical ocean and Asia to identify mechanisms governing sources and sinks and to validate space based products.
- **Advances in space-based measurements and analysis methods are needed to further improve coverage and to identify and correct biases.**
  - Data quality, retrieval algorithms and flux inversion tools are improving rapidly.
- **Enhanced measurement and modeling capabilities are needed to detect and characterize the carbon cycle response to climate change**.
  - Critical to the development of improved models for predicting the carbon cycle evolution