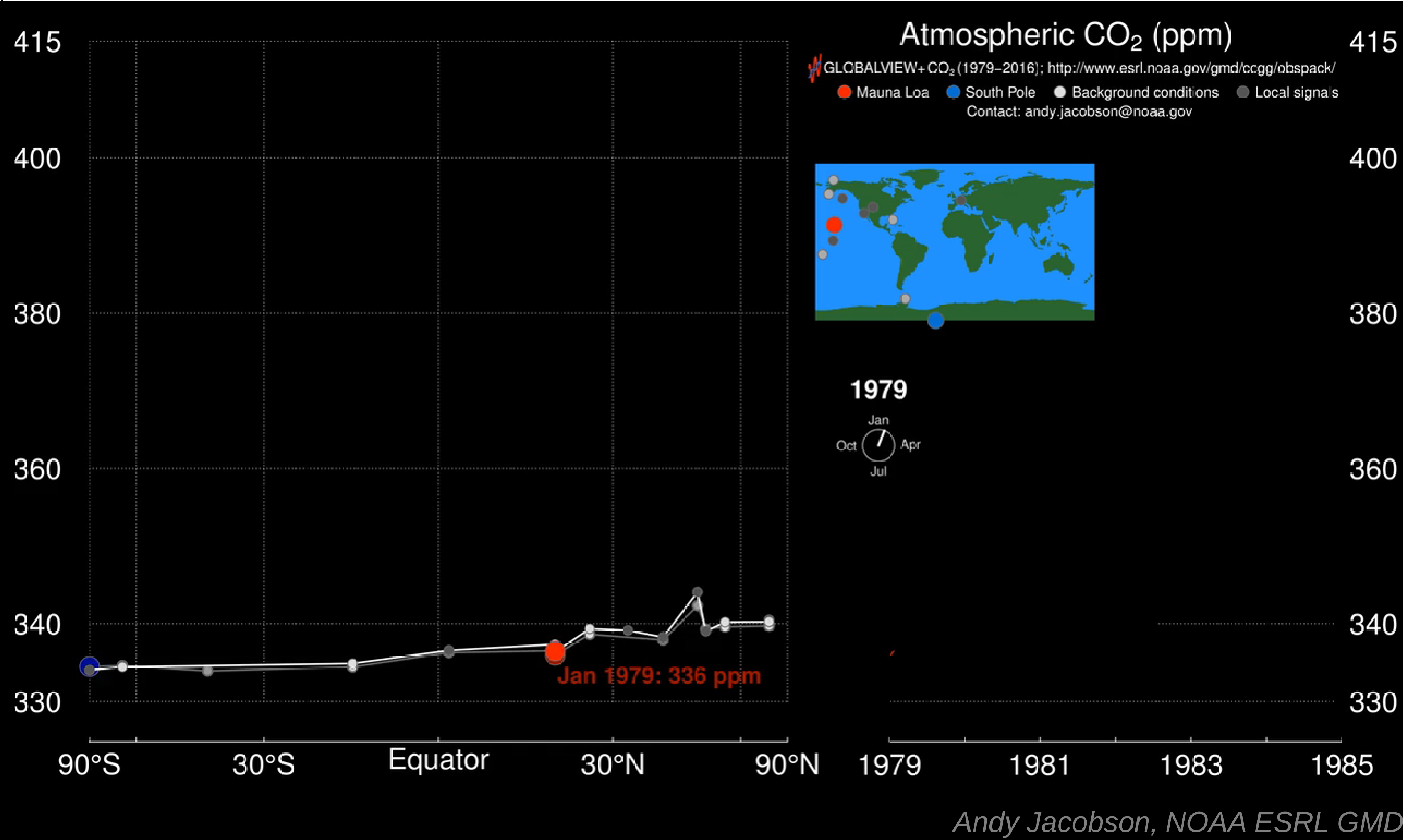
Measuring Atmospheric CO_2 with the NASA Orbiting Carbon Observatory-2 (OCO-2)

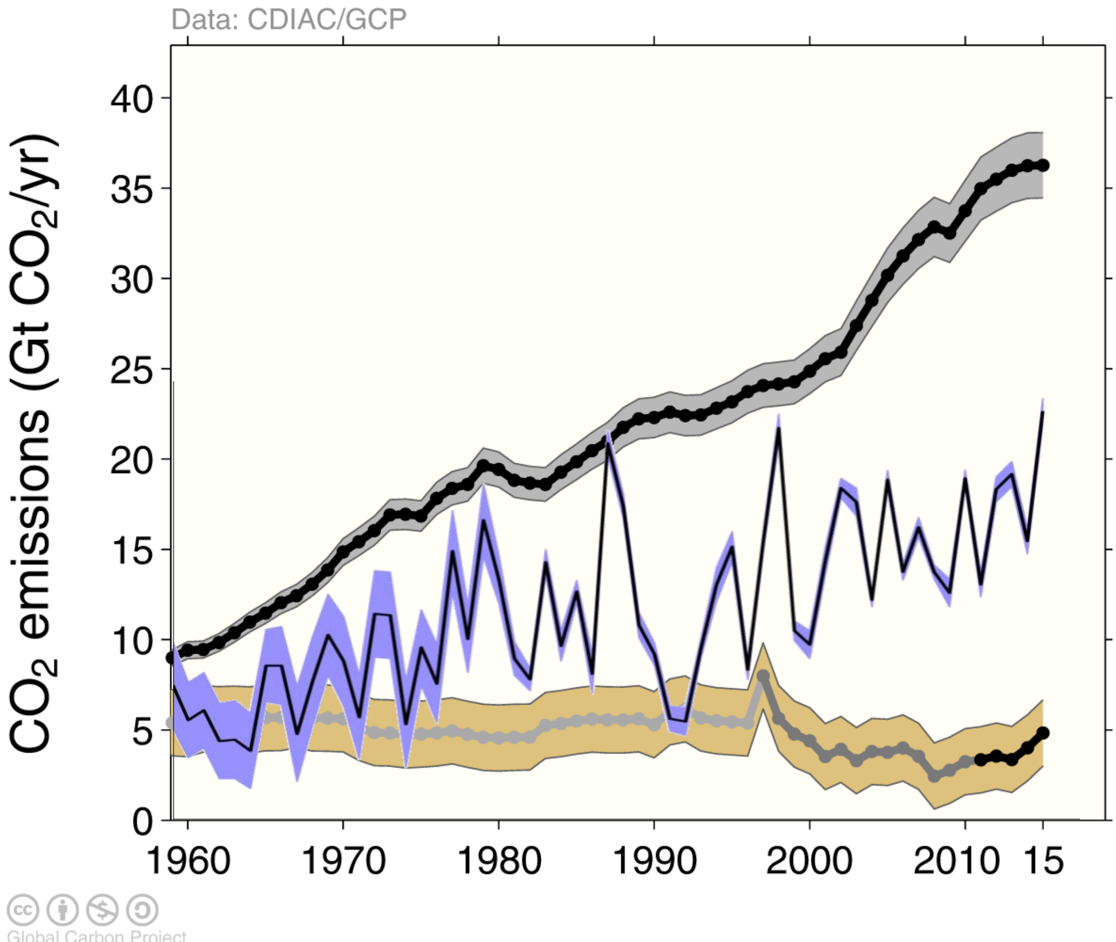
David Crisp, for the OCO-2 Science Team

Jet Propulsion Laboratory, California Institute of Technology

November 2017

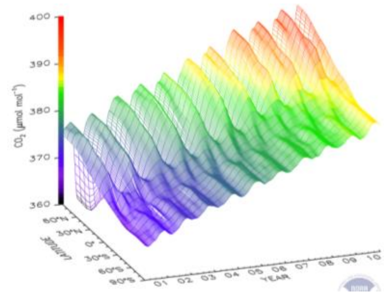

Atmospheric CO_2 (ppm)
GLOBALVIEW+CO_2 (1979–2016); http://www.esrl.noaa.gov/gmd/ccgg/obspack/
Mauna Loa
South Pole
Background conditions
Local signals
Contact: andy.jacobson@noaa.gov
415
400
380
360
340
330
90°S
30°S
Equator
30°N
90°N
1979
1981
1983
1985
1979
Jan
Apr
Jul
Oct
Jan 1979: 336 ppm
Andy Jacobson, NOAA ESRL GMD

What Processes Control CO_2?

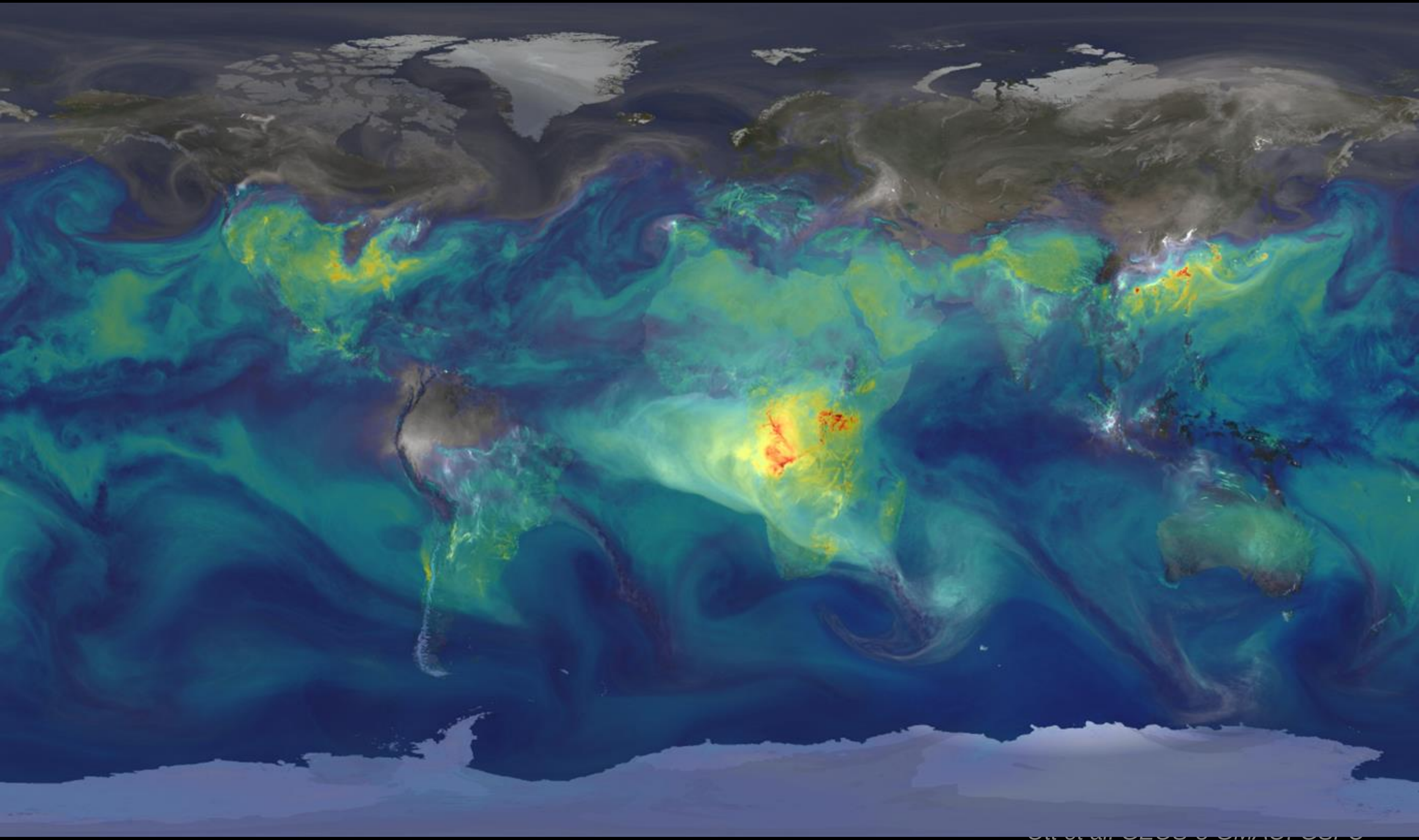


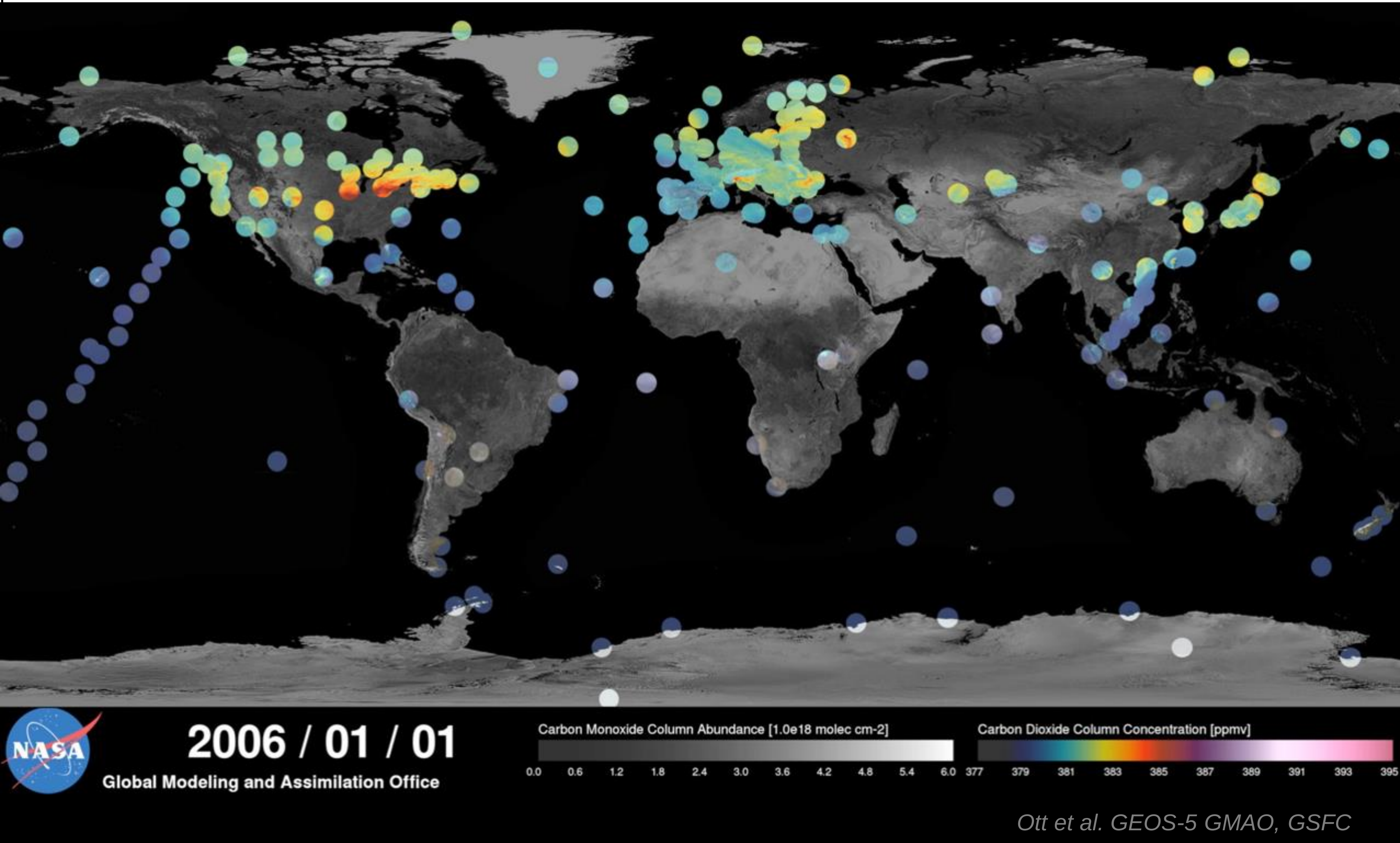
Fossil Fuel and Cement

Atmospheric growth rate



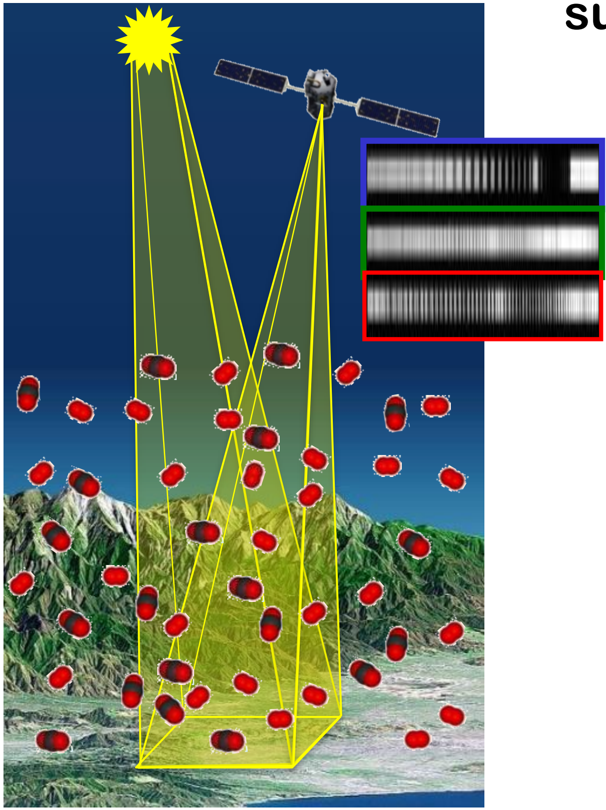
Land Use Change



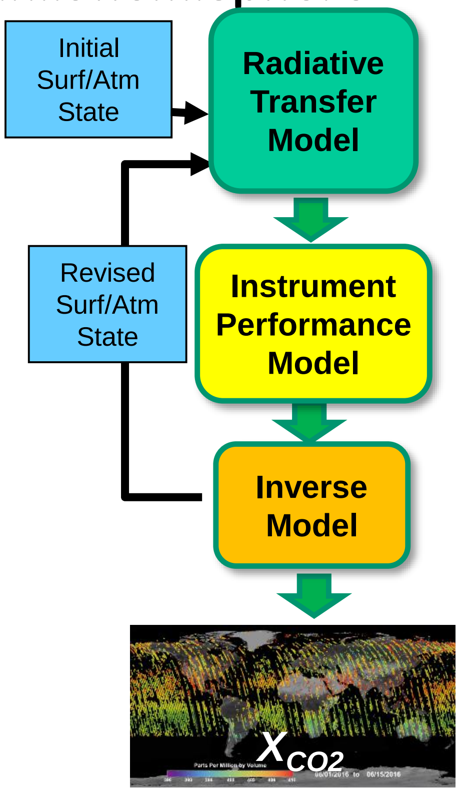

2006 / 01 / 01
Global Modeling and Assimilation Office
Carbon Monoxide Column Abundance [1.0e18 molec cm-2]
0.0 0.6 1.2 1.8 2.4 3.0 3.6 4.2 4.8 5.4 6.0
Carbon Dioxide Column Concentration [ppmv]
377 379 381 383 385 387 389 391 393 395
Ott et al. GEOS-5 GMAO, GSFC

Measuring CO_2 from Space

- **Record** spectra of CO_2 and O_2 absorption in reflected sunlight



Retrieve variations in the column averaged CO_2 dry air mole fraction, X_{CO2} over the sunlit hemisphere



Validate measurements to ensure X_{CO2} accuracy of 1 ppm (0.25%)

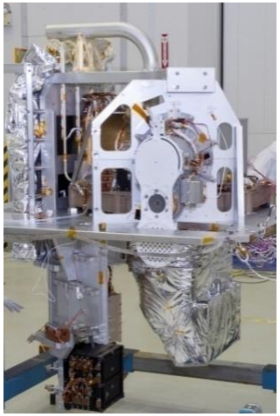
The Pioneers: GOSAT and OCO

GOSAT launched successfully on 23 January 2009

OCO was lost a month later when its launch system failed

Rebuilding the OCO-2 Mission

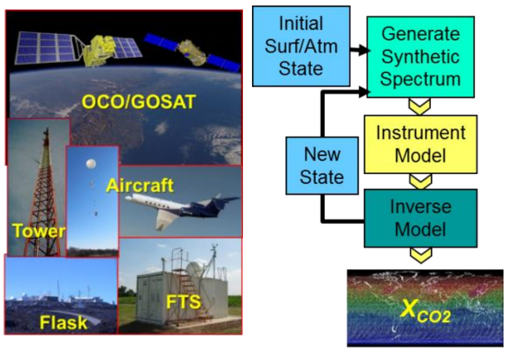
3-Channel Grating Spectrometer



Dedicated Spacecraft Bus

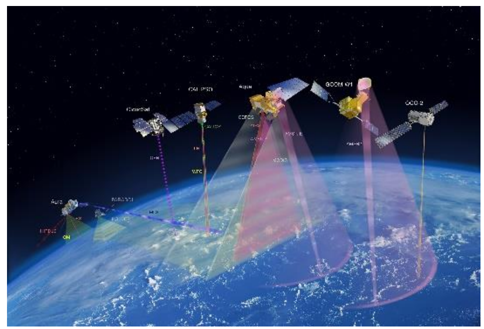
Delta-II Launch Vehicle

Data Product Generation

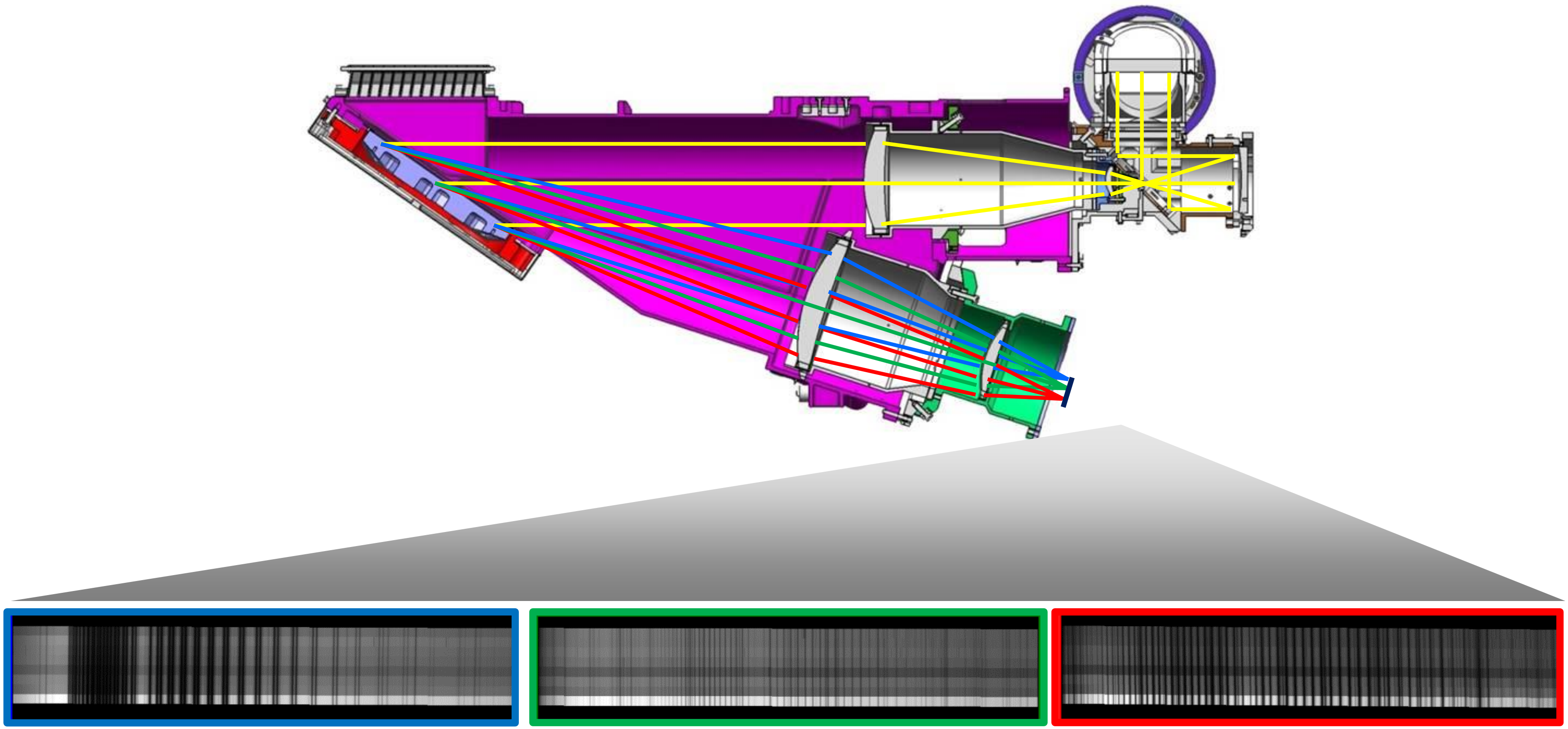


Data Transmitted to NASA NEN and SN

Formation Flying in the A-Train Constellation



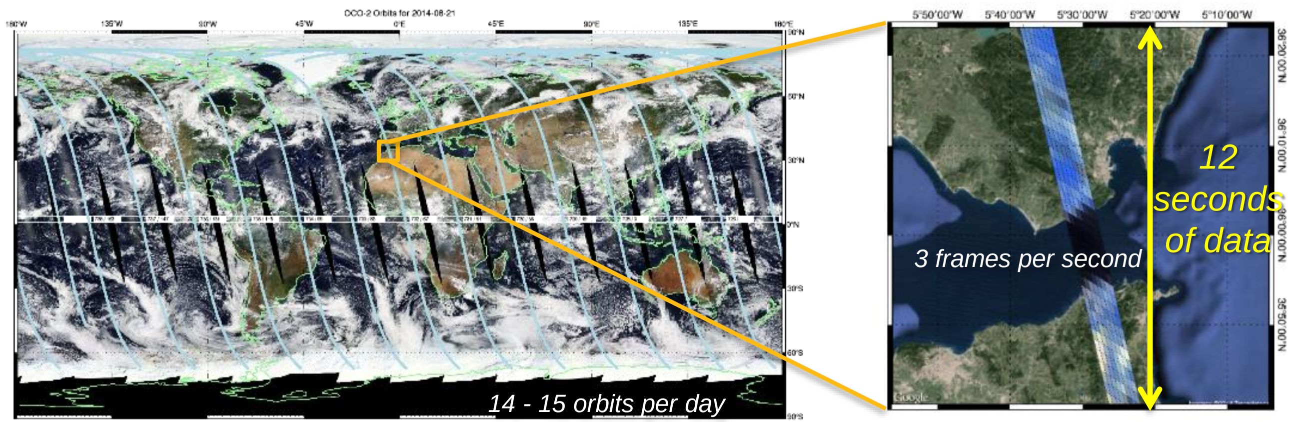
The OCO Instrument – Optimized for Sensitivity

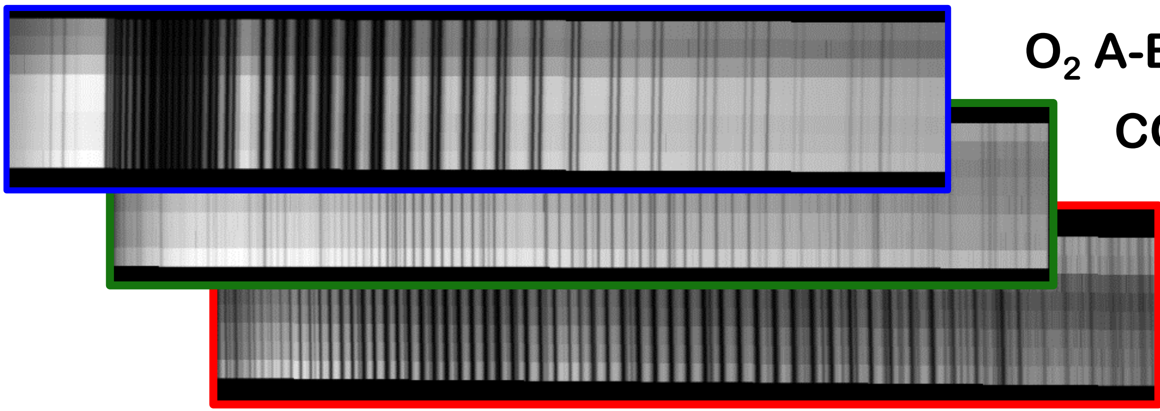


0.765μm O_2 A-Band | CO_2 1.61μm Band | CO_2 2.06 μm Band

Each 1/3 sec frame includes 8 spatial footprints with 1,016 wavelengths in 3 spectral channels.

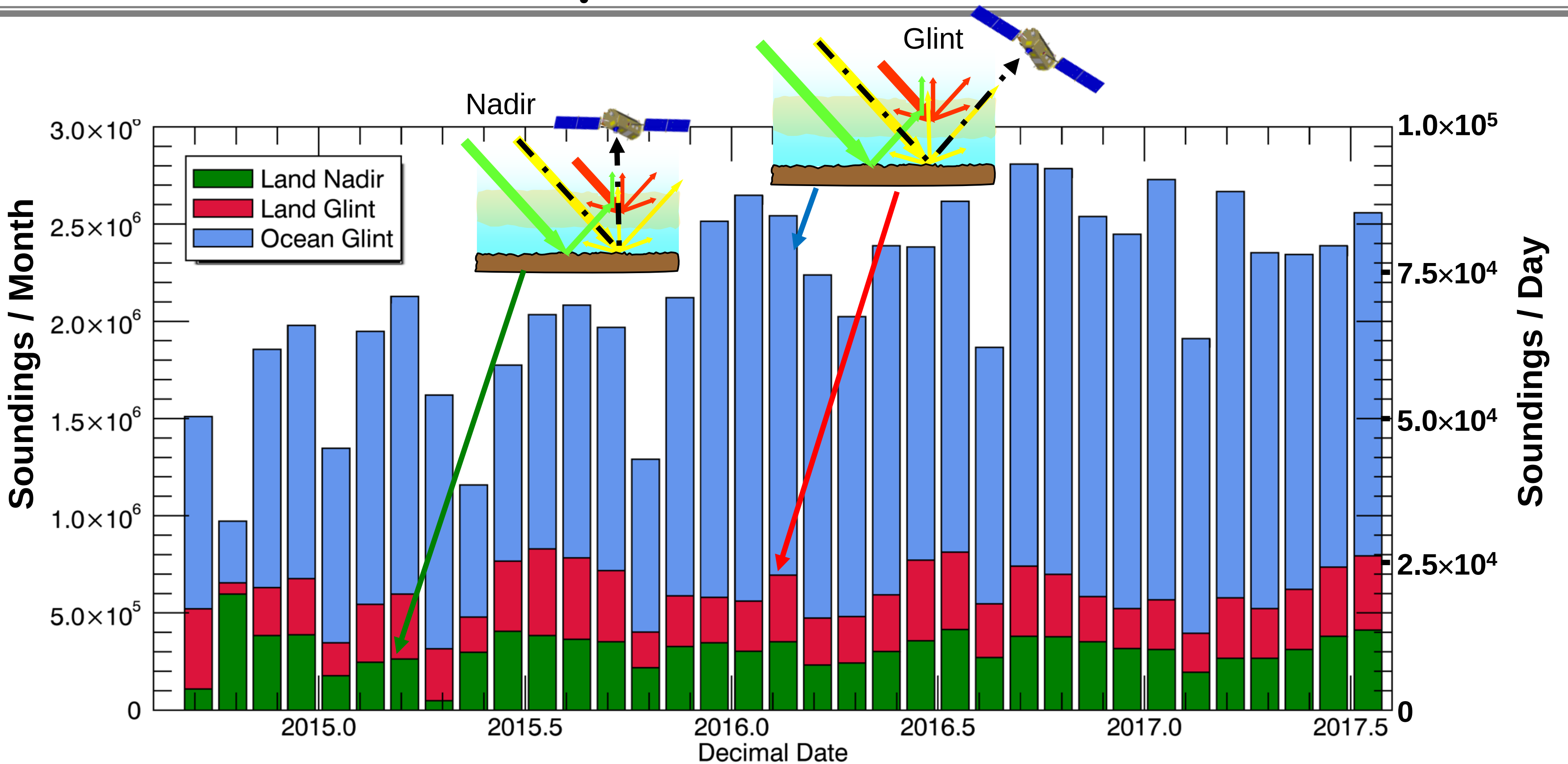
OCO-2 Sampling Approach





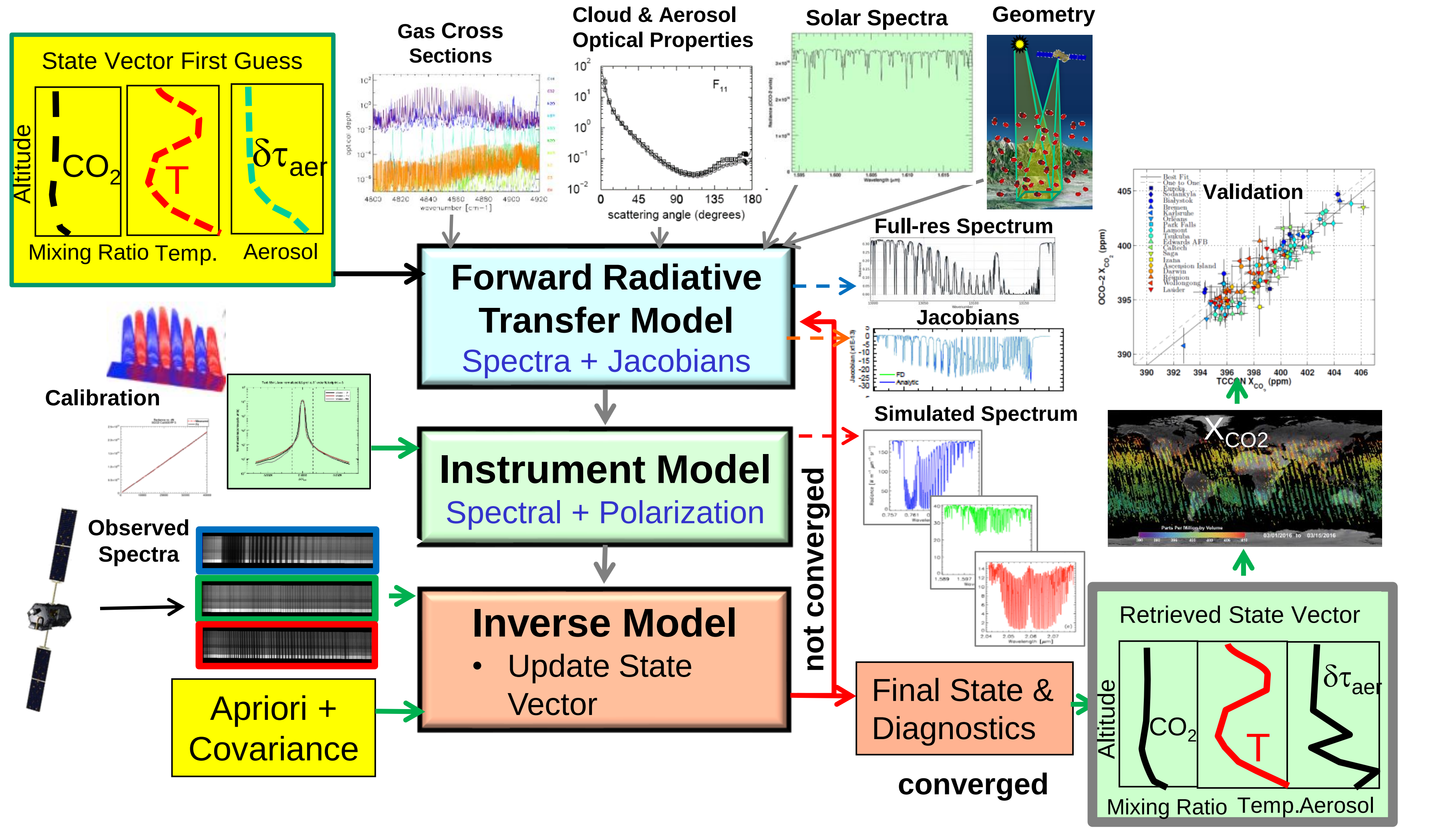
The OCO-2 instrument collects 24 soundings each second as it flies over the sunlit hemisphere of the Earth, yielding almost 1 million soundings each day

The Glint/Nadir Observing Strategy has been Optimized for Data Yield

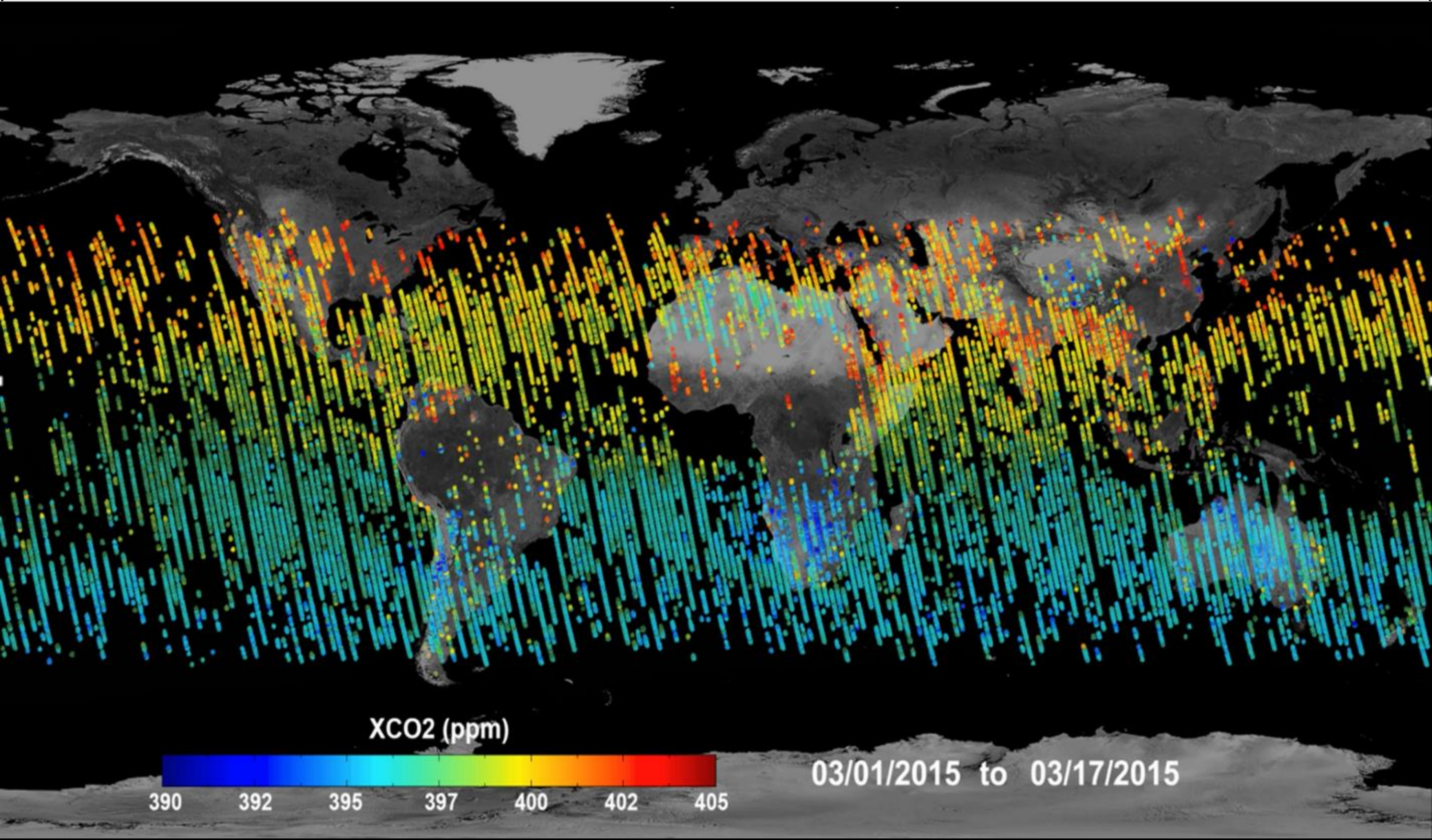


The glint/nadir observation strategy was refined to maximize the number of full-column X_{CO2} retrievals. The "optimal" strategy, implemented in November 2015 acquires ocean glint on orbits predominately over the Atlantic or Pacific Oceans.

The OCO-2 XCO2 Retrieval Algorithm

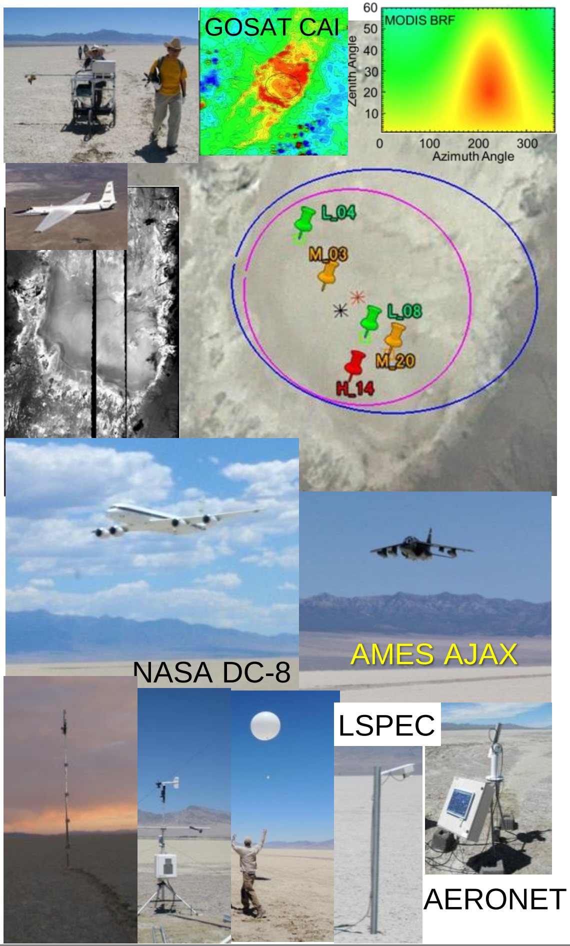


A Quick Look at the OCO-2 Prime Mission

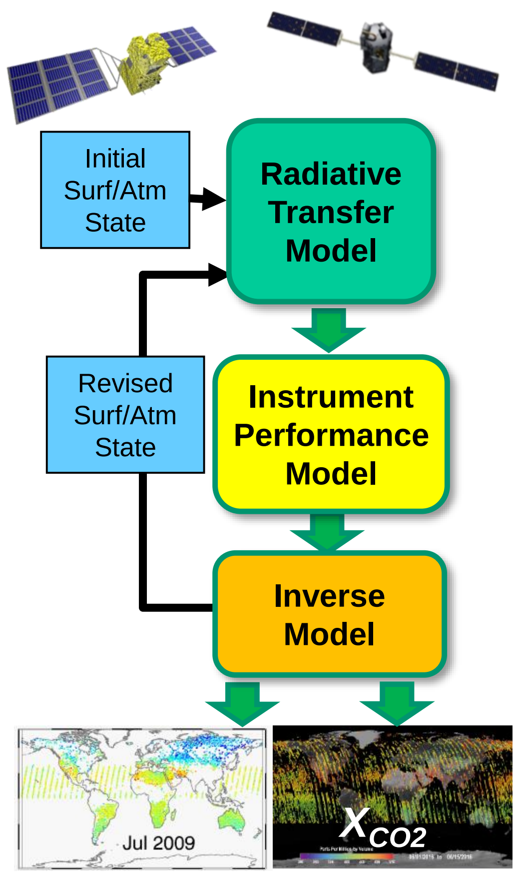


Measuring CO_2 from Space: the OCO-2/GOSAT Collaboration

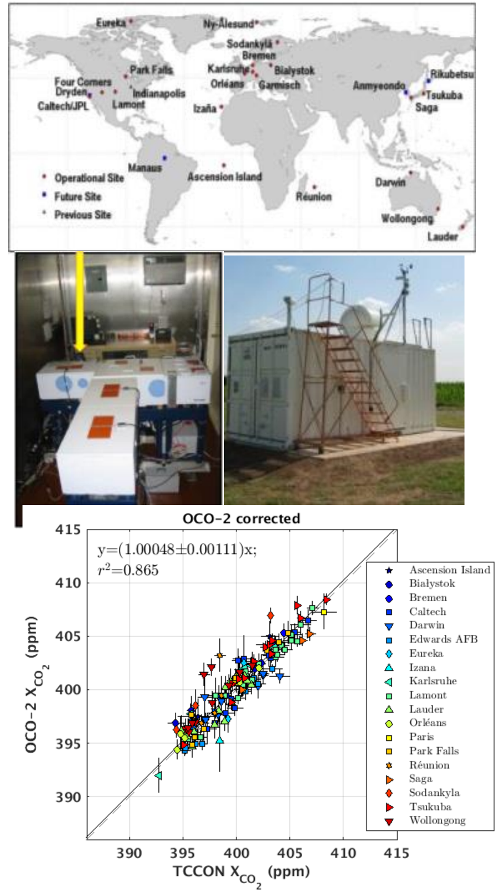
Vicarious Calibration



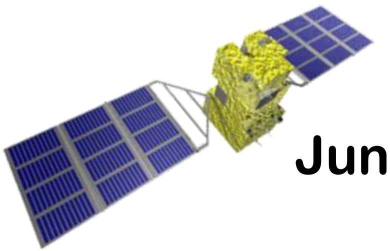
Retrieval Algorithm



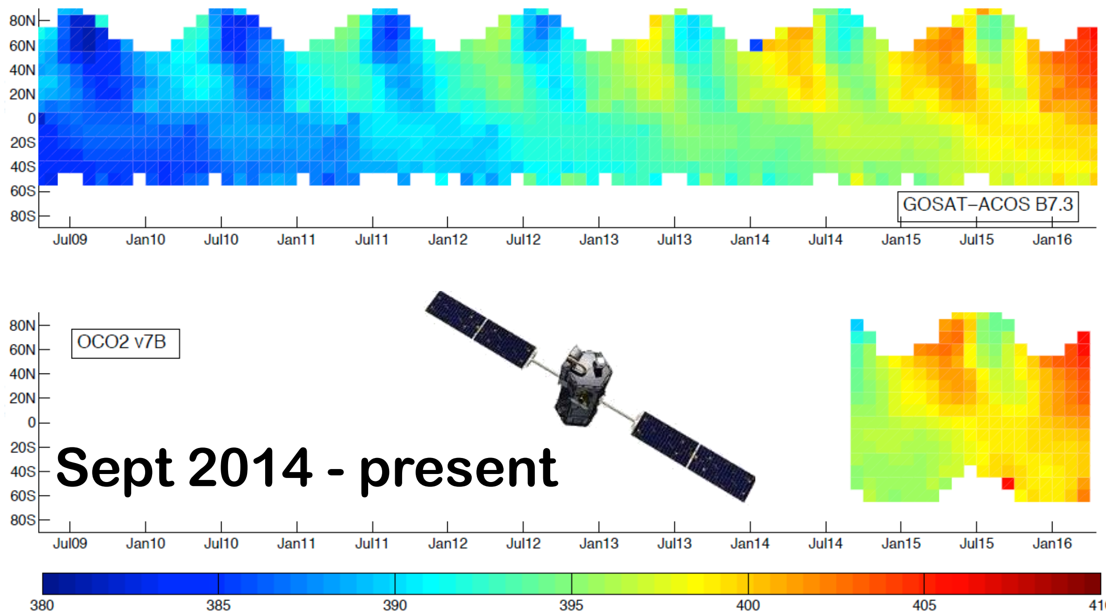
Validation



ACOS/GOSAT B7.3, and OCO-2 v7 XCO2



June 2009 - present

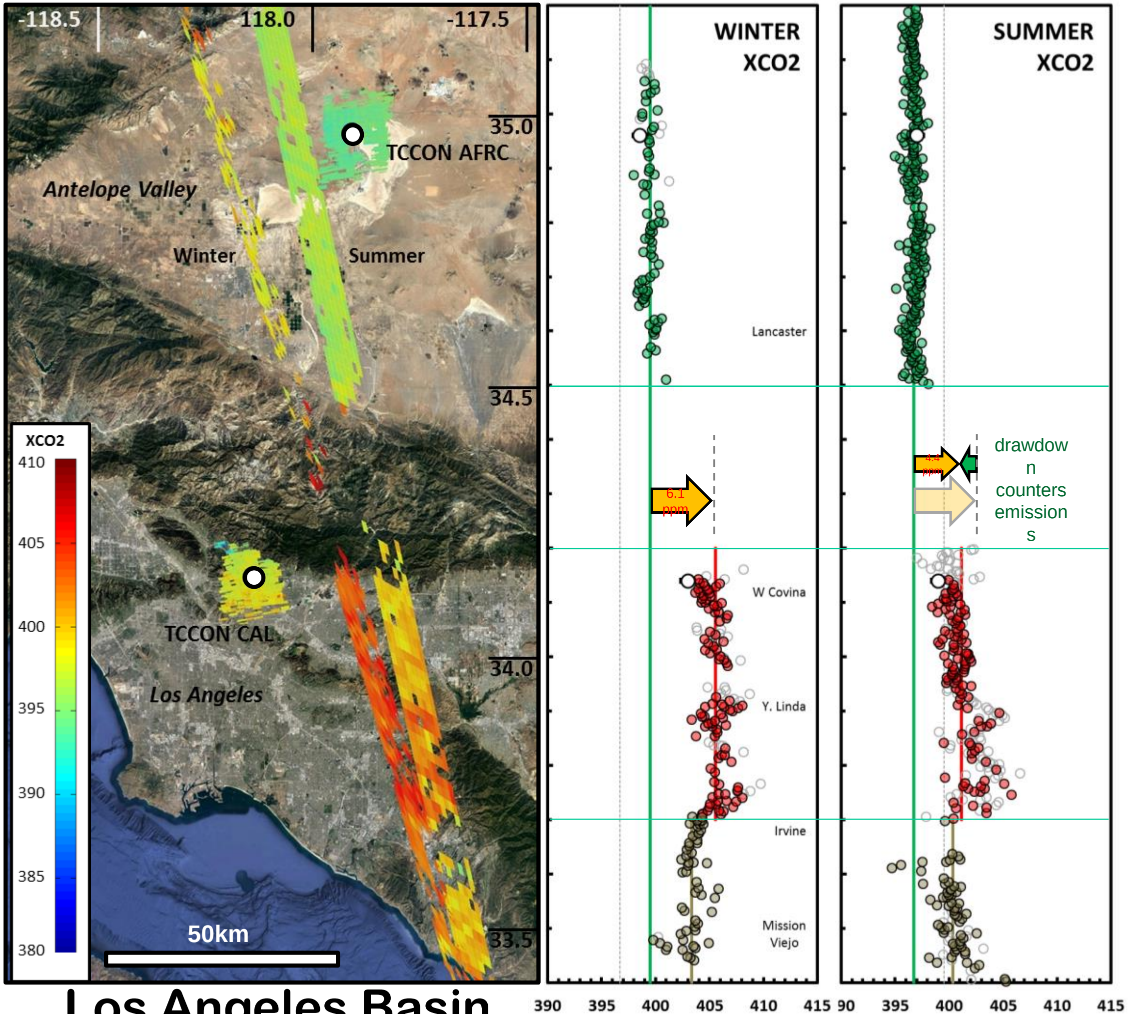


Sept 2014 - present

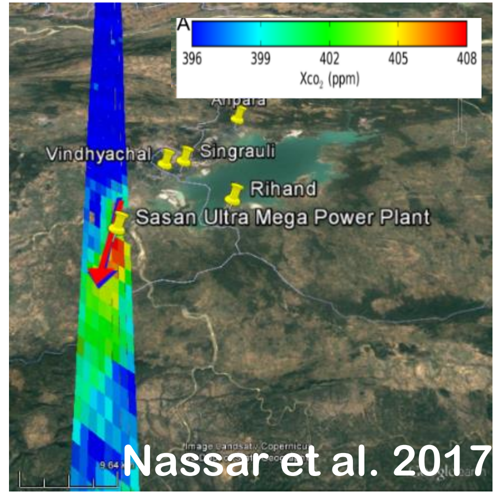
TCCON and other standards have been used to cross validate OCO-2 and GOSAT X_{CO2} to extend the climate data record

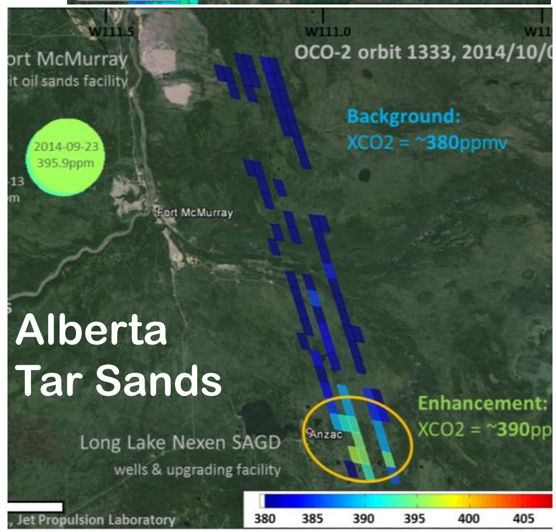
- The magnitude of differences between GOSAT-ACOS B7.3 and OCO2 v7r are within ±1 ppm for overlap regions

Localized Sources



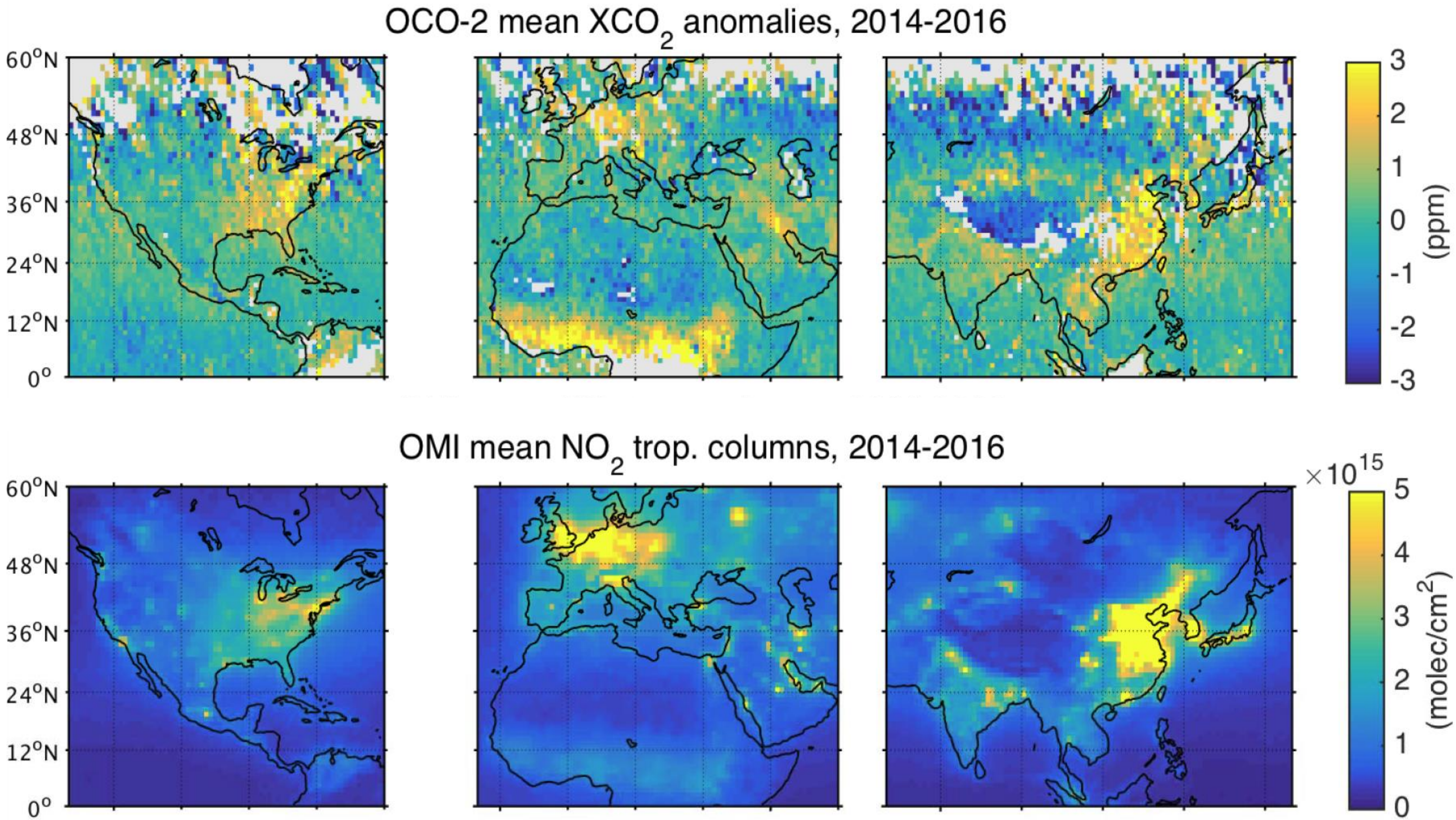
Los Angeles Basin





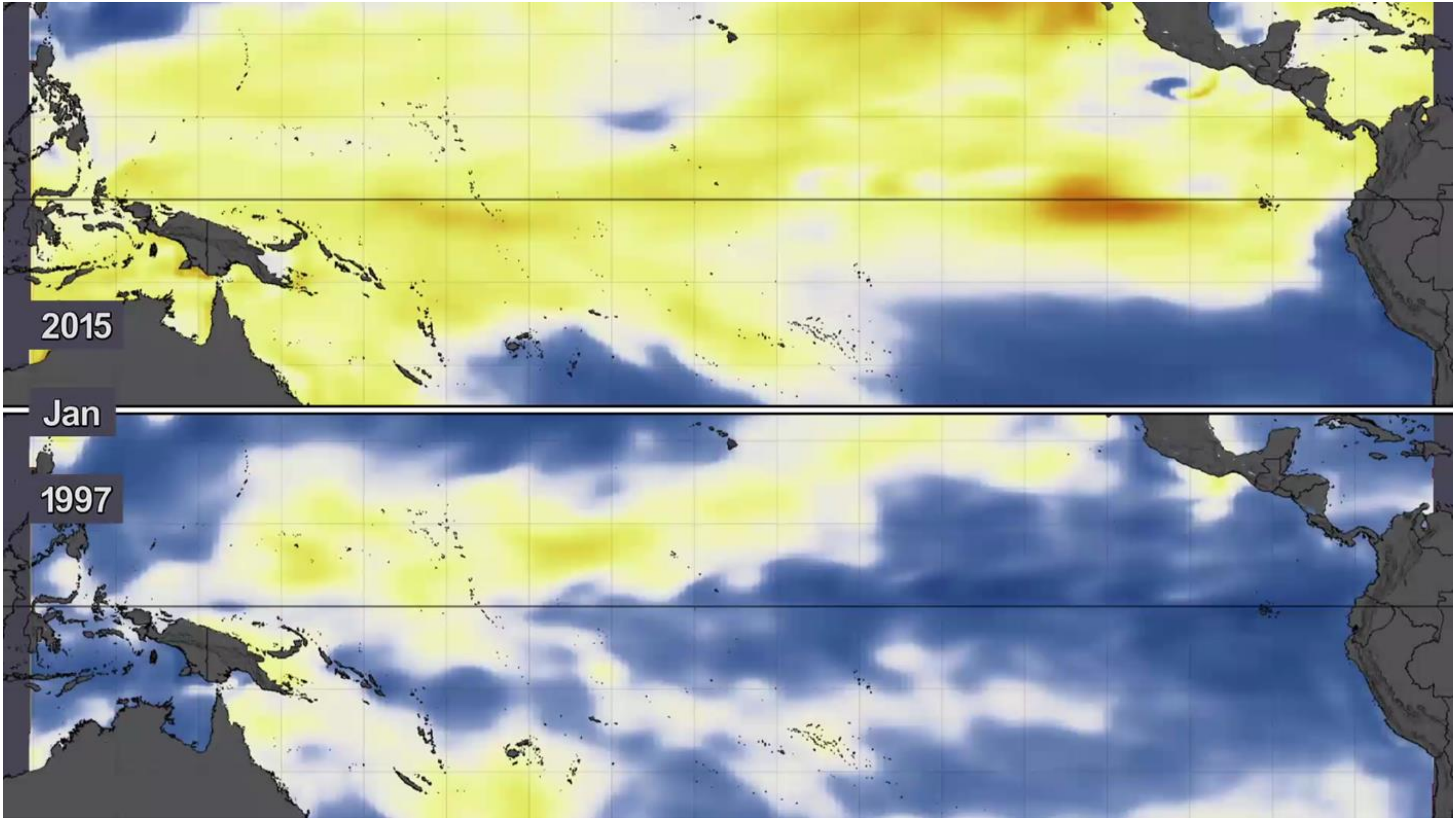
Florian Schwandner et al.(2017)

Anthropogenic Emissions



Janne Hakkarainen et al. GRL (2016)

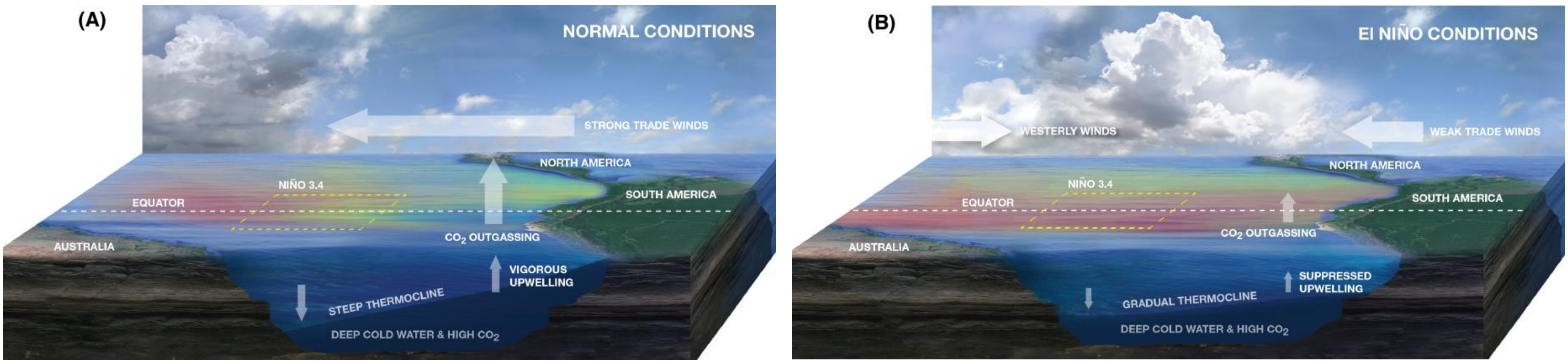
The 2015-2016 El Niño



How did the Carbon Cycle Respond to the 2015-2016 El Niño?

- OCO-2 was launched less than 9 months before the onset of the intense 2015-2016 El Niño
- During recent El Niños, the rate of CO_2 buildup has increased, but there are several unanswered questions:
  - What are the relative roles of the ocean and the atmosphere in the observed CO_2 increases?
  - What are the relative roles of drought, heat stress, and fire on the emissions of CO_2 from land during El Niño?
  - What are the implications of these changes for Climate/Carbon Cycle interactions as the climate warms?
- The unprecedented resolution and coverage provided by OCO-2 provides new ways to address these other questions about interactions between the climate and carbon cycle

Carbon system in the Tropical Pacific

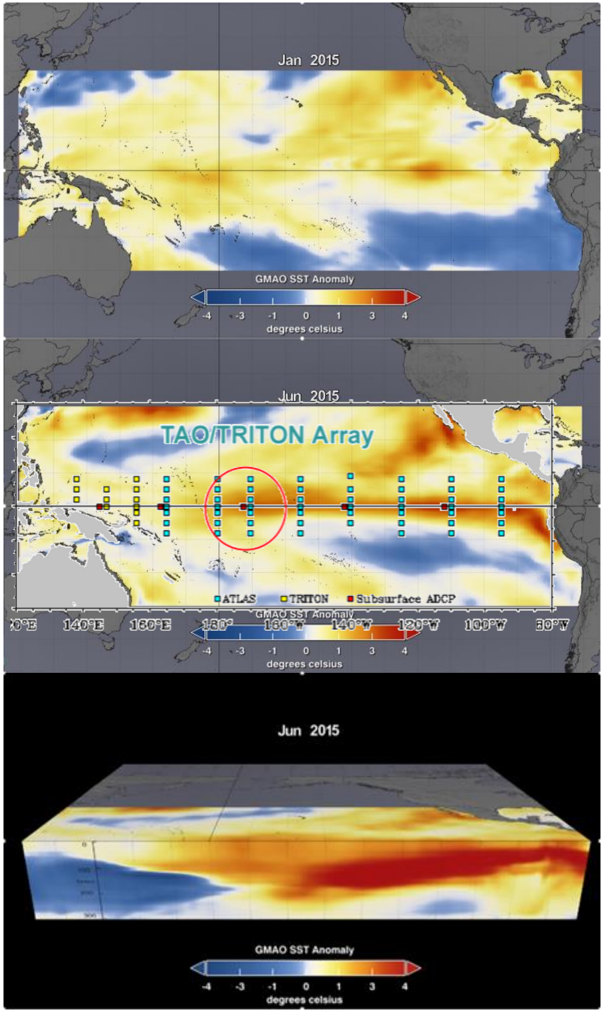


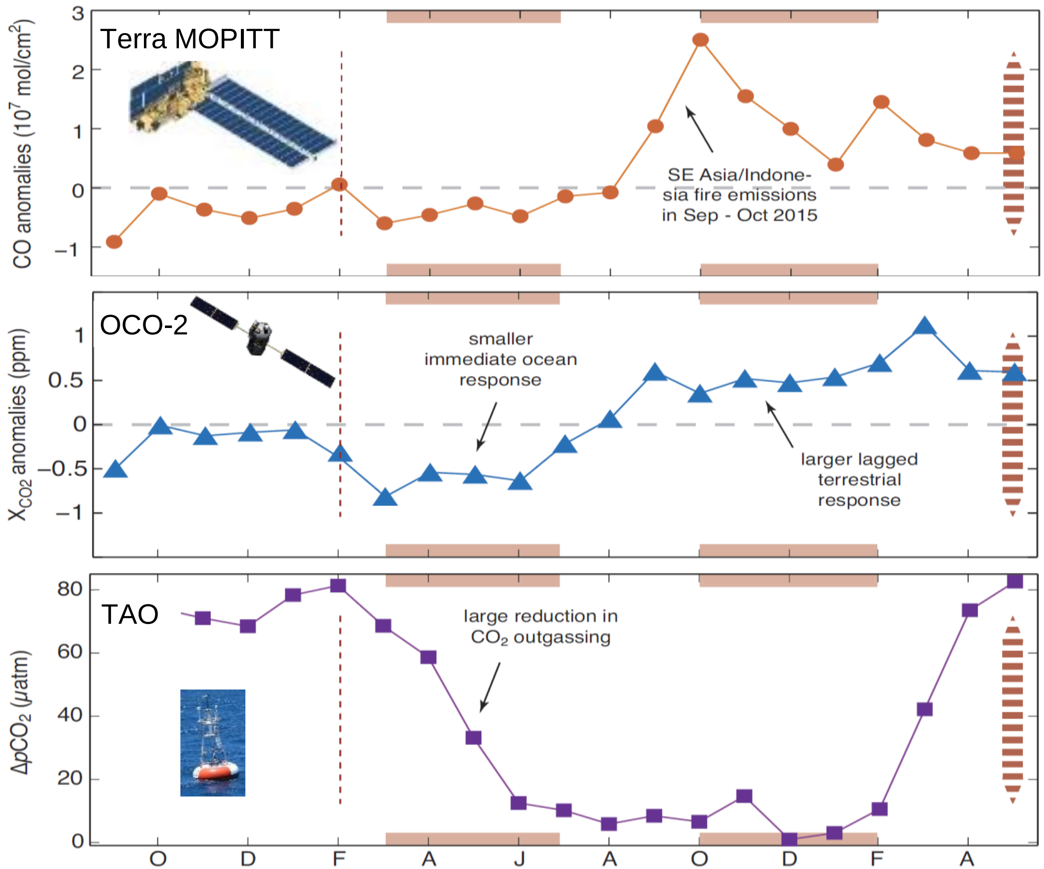
Dijkstra [2006]

- **Normal conditions: upwelling of cold subsurface waters that have high potential pCO_2 + inefficient biological pump → strong CO_2 outgassing**

- **El Niño conditions: deepening of thermocline, reduction in upwelling, weakening of trade winds + more efficient biological pump → decreases CO_2 outgassing by 40-60%**

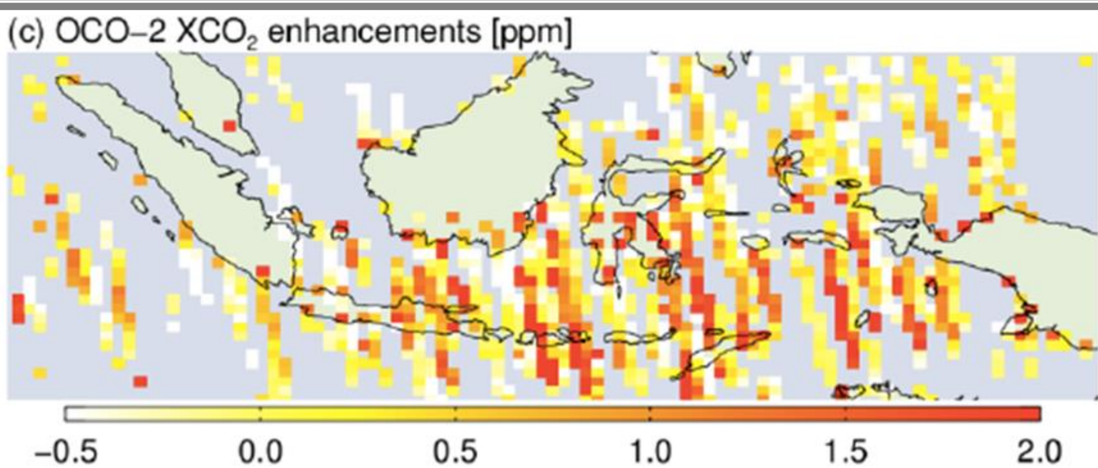
2015-2016 El Niño: Ocean Response

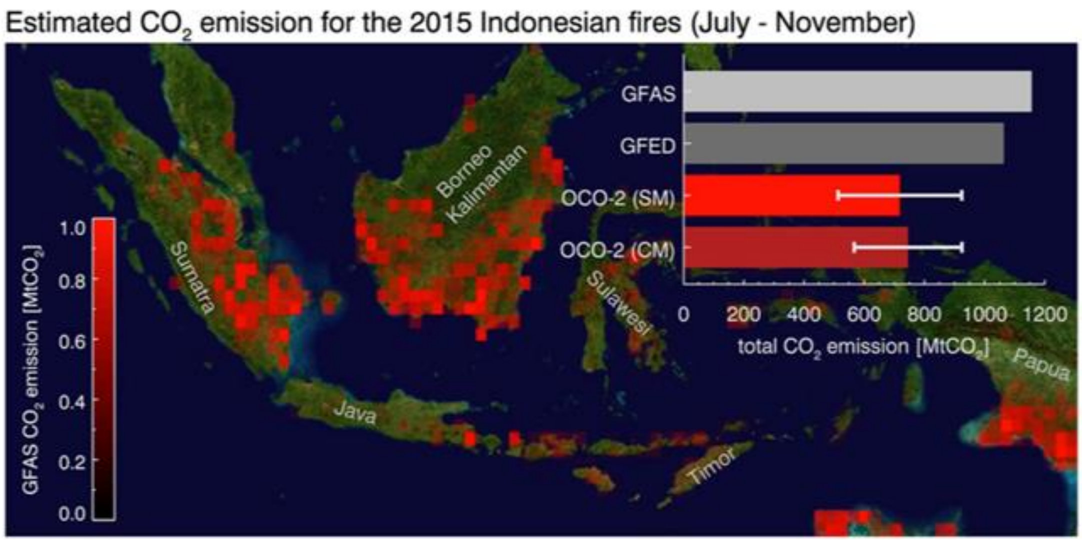




Abhishek Chatterjee et al. (2017)

2015-2016 El Niño: Fires



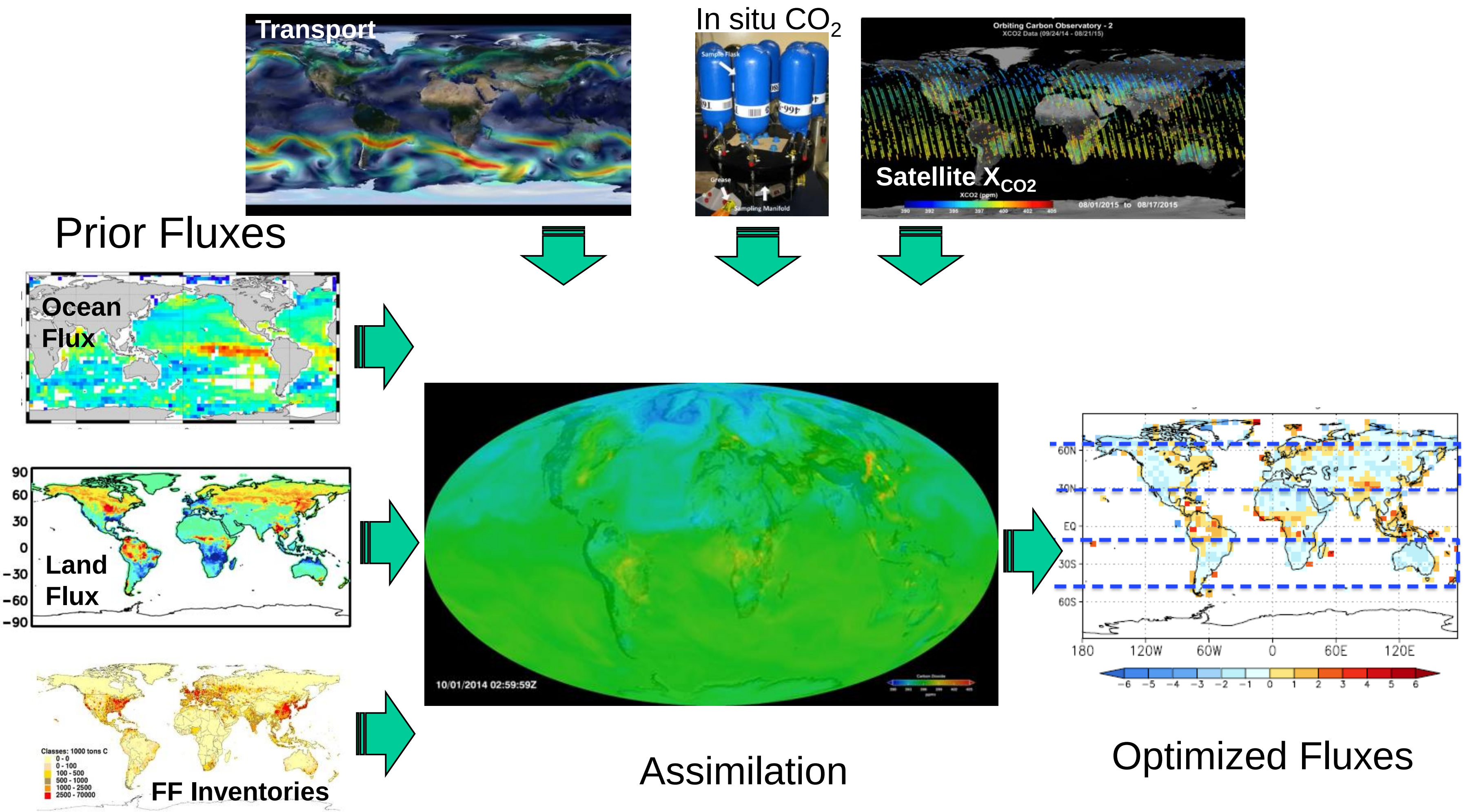


Jenns Heymann et al. (GRL, 2017)

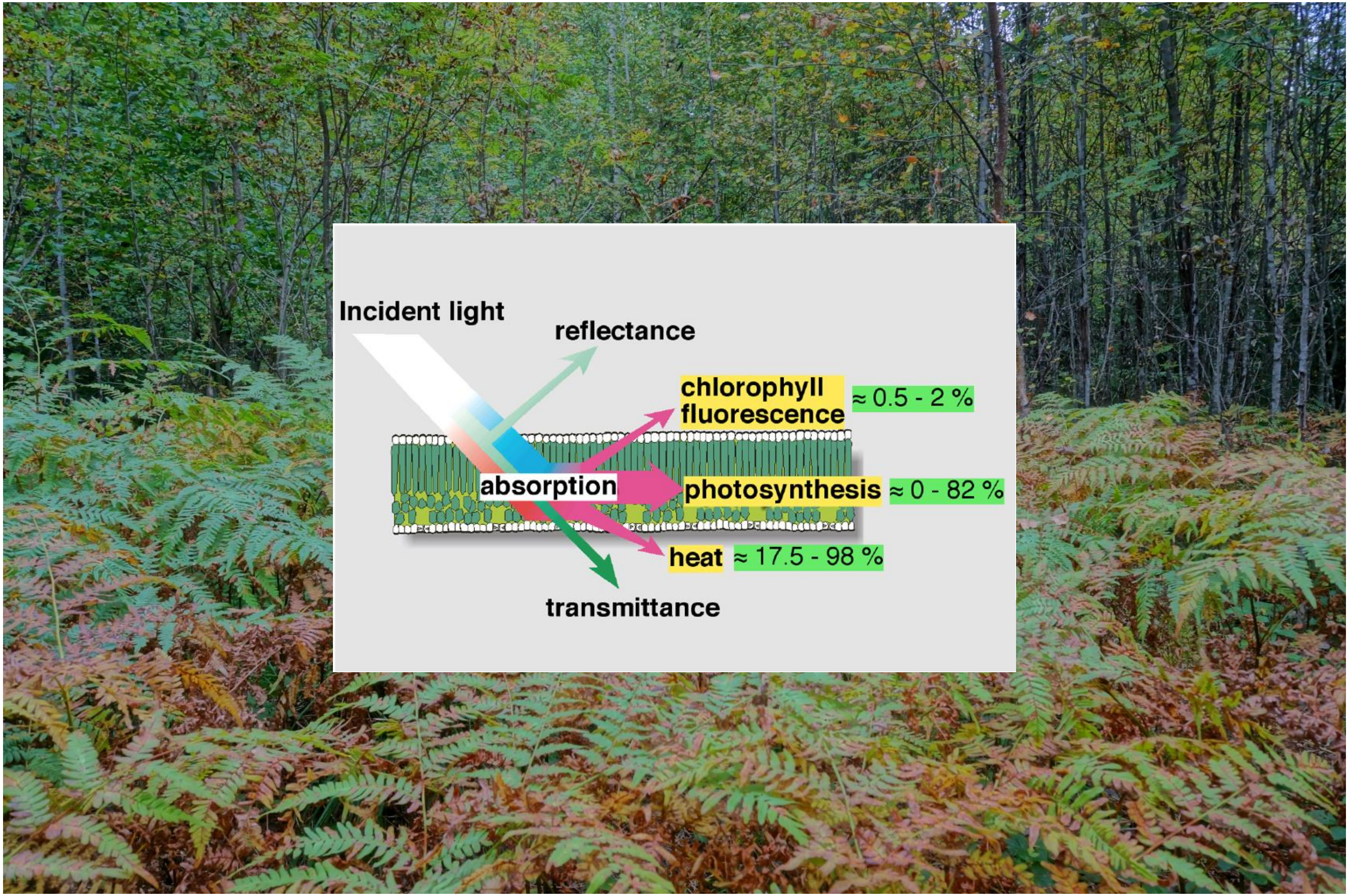
X_{CO2} enhancements over Indonesia observed by OCO-2 between July and November 2015.

Fire emissions estimates from the GFAS and GFED inventories to emission estimates obtained from OCO-2 data, using two analysis approaches. The OCO-2 estimates are less than 70% as large as those in the inventories.

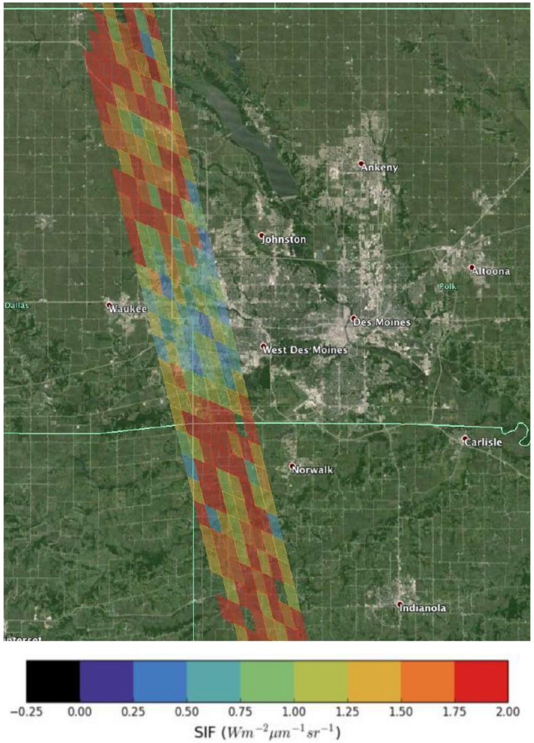
“Top-Down” Flux Inversion Estimates



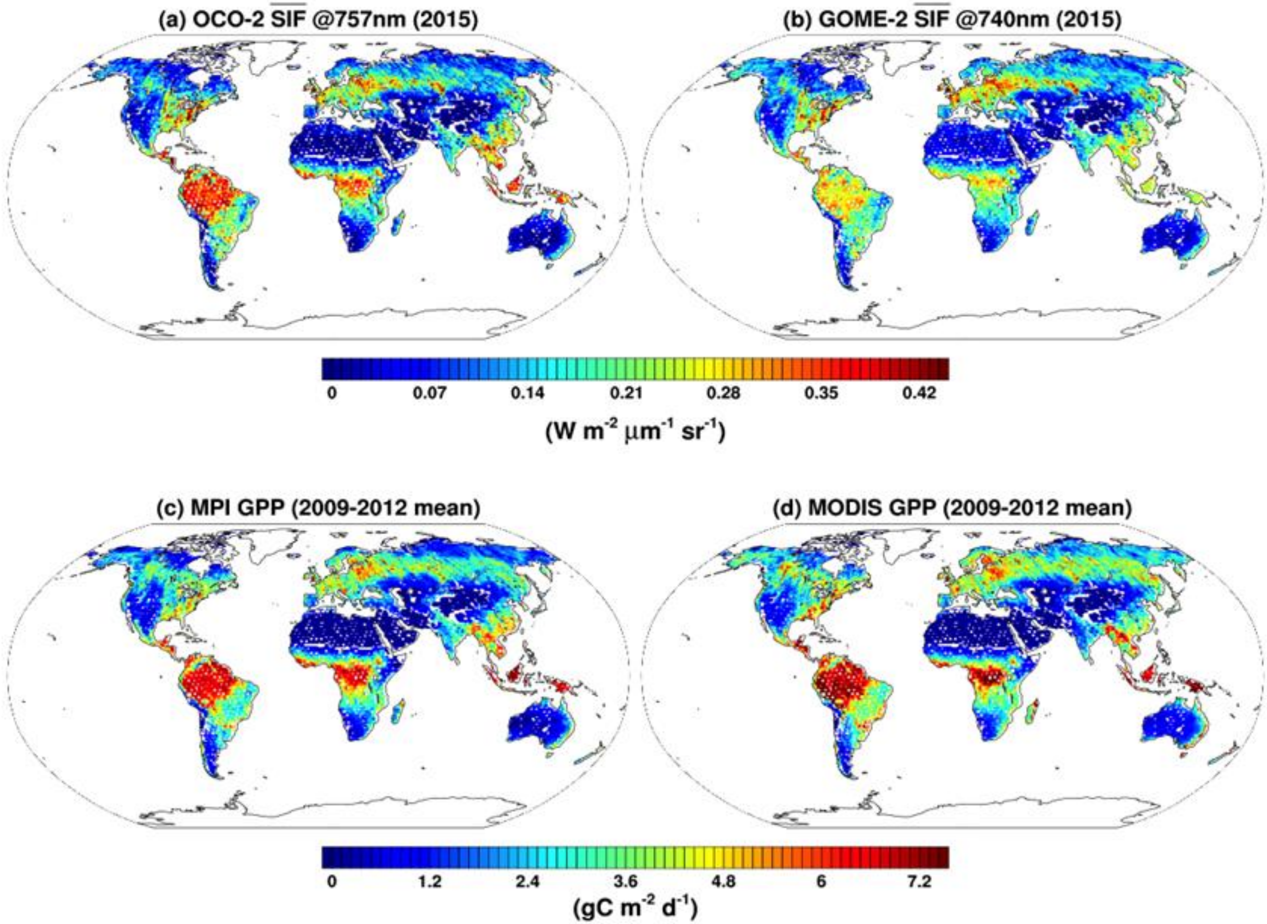
Solar-Induced Chlorophyll Fluorescence (SIF)



Solar Induced Chlorophyll Fluorescence (SIF)



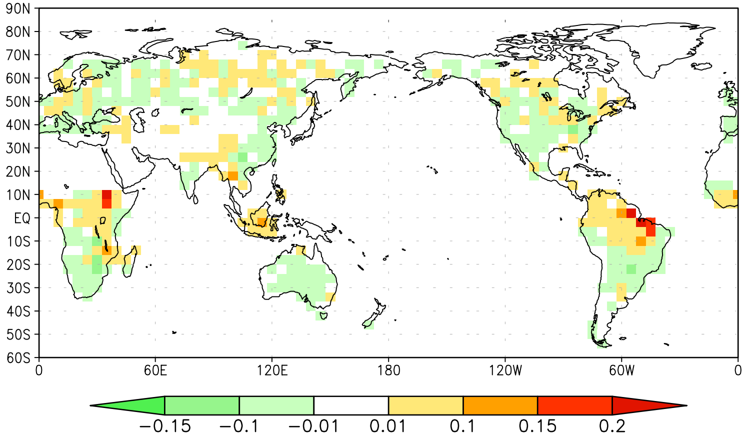
OCO-2 SIF over Des Moines, Idaho



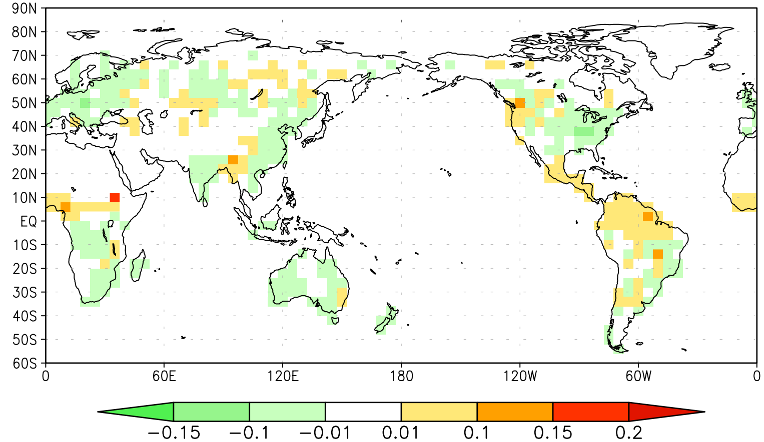
Ying Sun et al. (2017)

2015 El Niño and 2011 La Niña annual biosphere fluxes and their differences

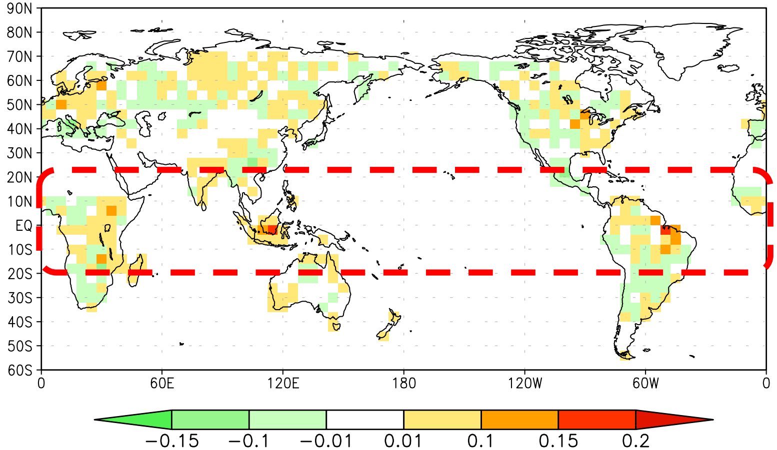
2015 (GtC/yr)



2011 (GtC/yr)



2015- 2011 (GtC/yr)



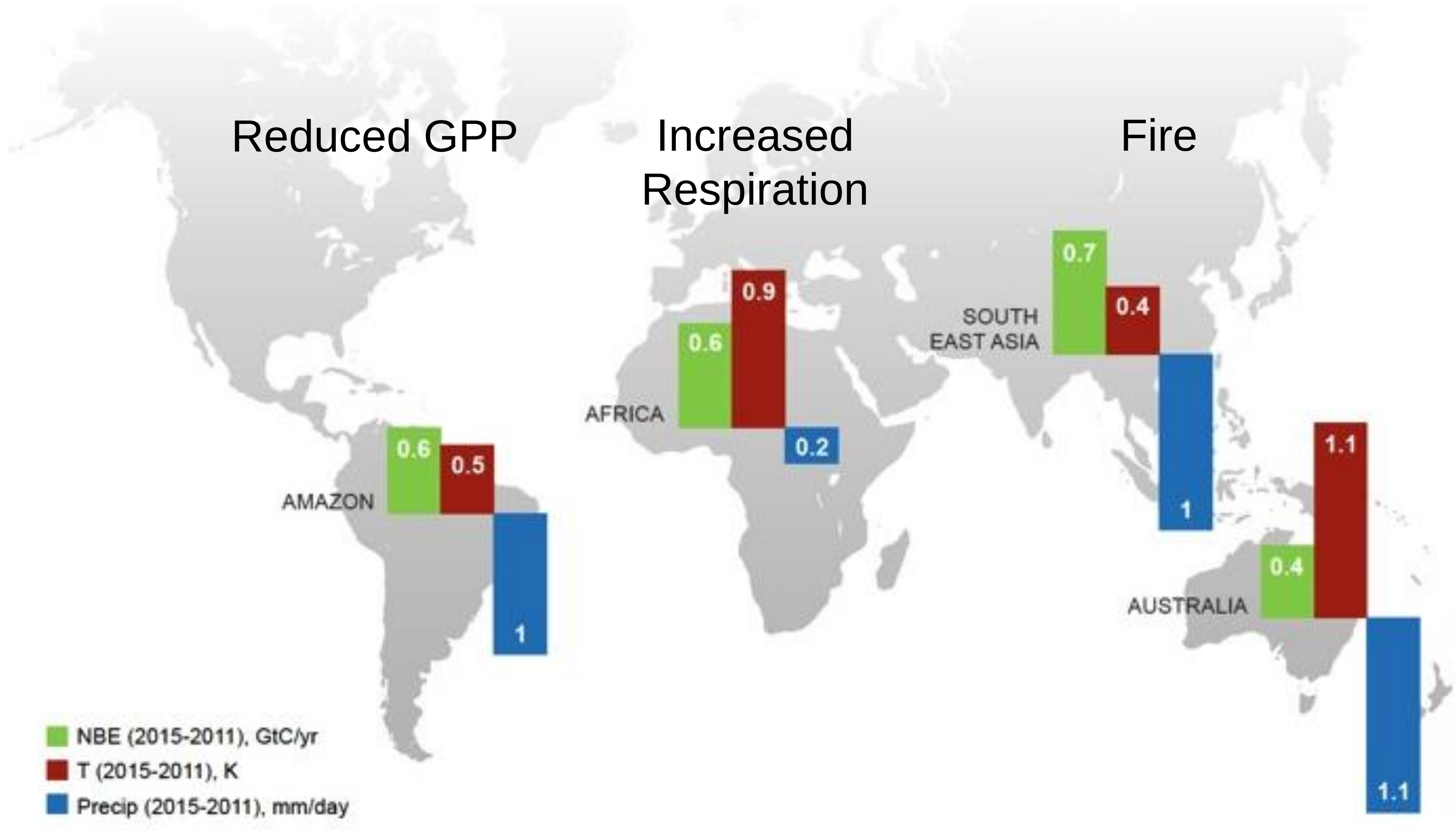
Red: release CO_2 into atmosphere

Green: absorb CO_2 from atmosphere

- **The most significant impact of 2015 El Niño on biosphere carbon fluxes is the increase of CO_2 release from the tropics**

Junjie Liu et al. (2017)

2015-2016 El Niño: 3 Continents, 3 Stories



Key Results

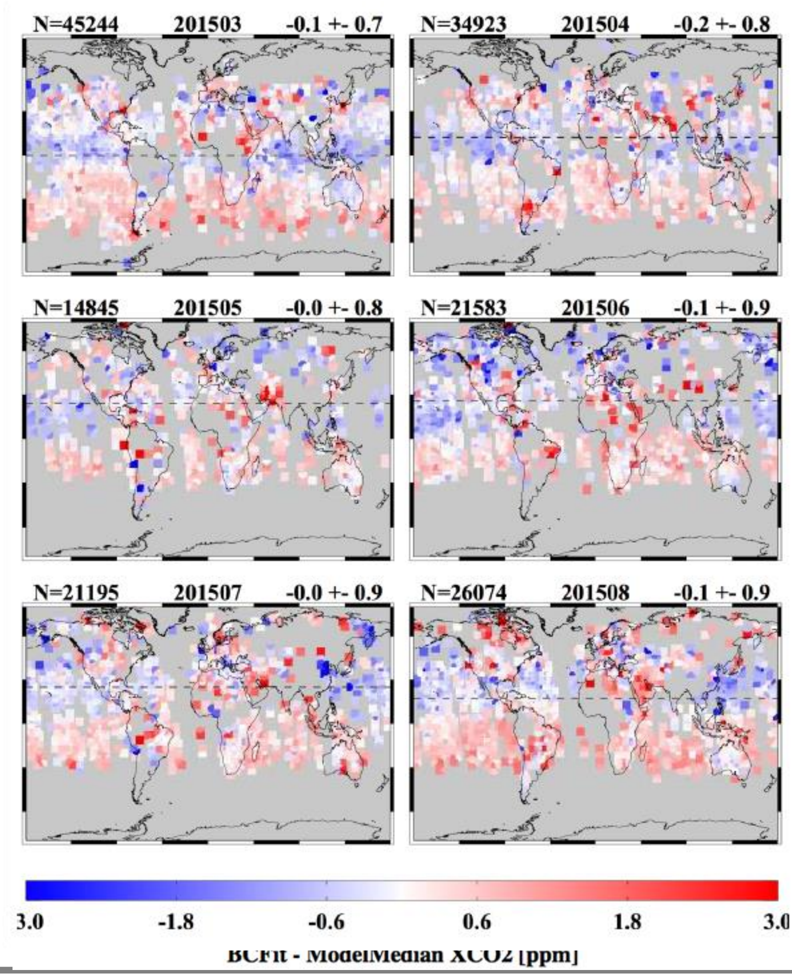

2018 AAAS ANNUAL MEETING Advancing Science: Discovery to Application
Science
$15
13 OCTOBER 2017
sciencemag.org
AAAS
EYE IN
THE SKY
Measuring carbon
from space p. 186

A New Data Product: OCO-2 Build 8

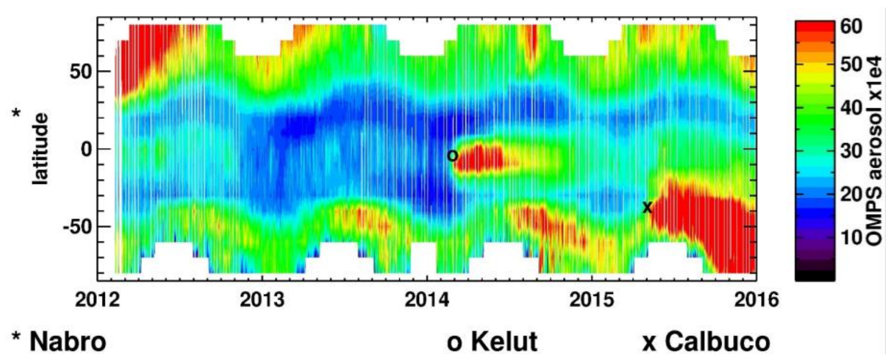
- Improved L1B Spectra
  - Fast (icing) and slow (solar diffuser) degradation corrected
  - Corrected zero level offset A-band detector
- Retrieval algorithm updates
  - Gas absorption cross sections (ABSCO 4.2 vs 5.0)
  - Added an optically-thin, stratospheric aerosol type
  - More realistic land surface reflectance model (soil BRDF)
  - Updated cloud screening, bias correction, and warn levels
  - Other small improvements
    - Changed prior meteorology from ECMWF → GEOS5 (FP-IT)
    - Revised X_{CO2} and Cirrus priors
    - Updated top of atmosphere solar spectrum

Tracking and Correcting Biases

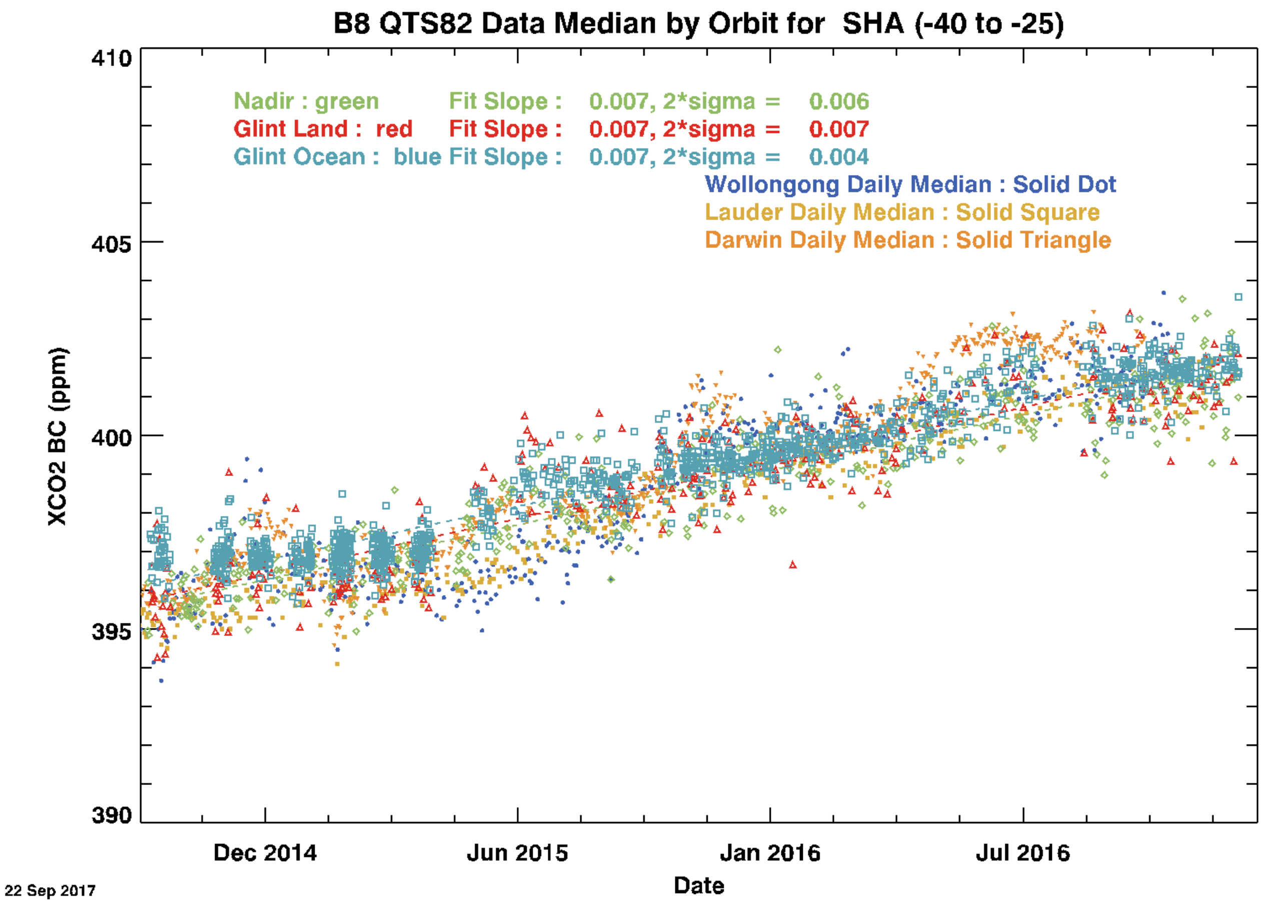
With Strat Aerosols



- **High bias seen over southern hemisphere oceans (glint) March-September, relative to models.**
- **Traced to Optically-thin stratospheric aerosol layers**
  - **The largest effects are seen at high latitudes over the ocean during the southern winter months**
  - **Effect was enhanced by volcanic activity (Wolf and Calbuco) which enhanced stratospheric aerosols**

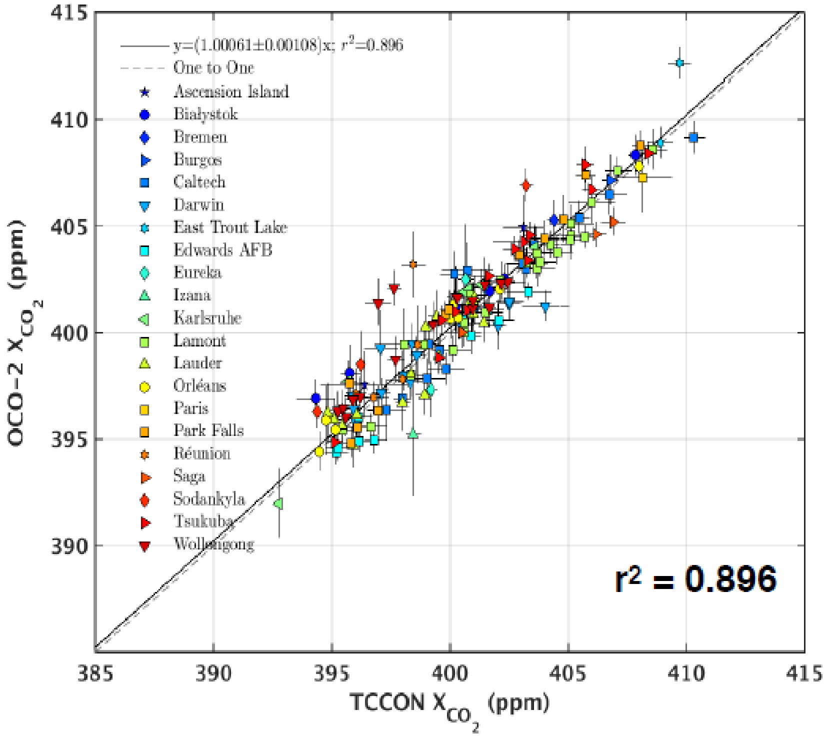


A Preview of the Version 8 Product

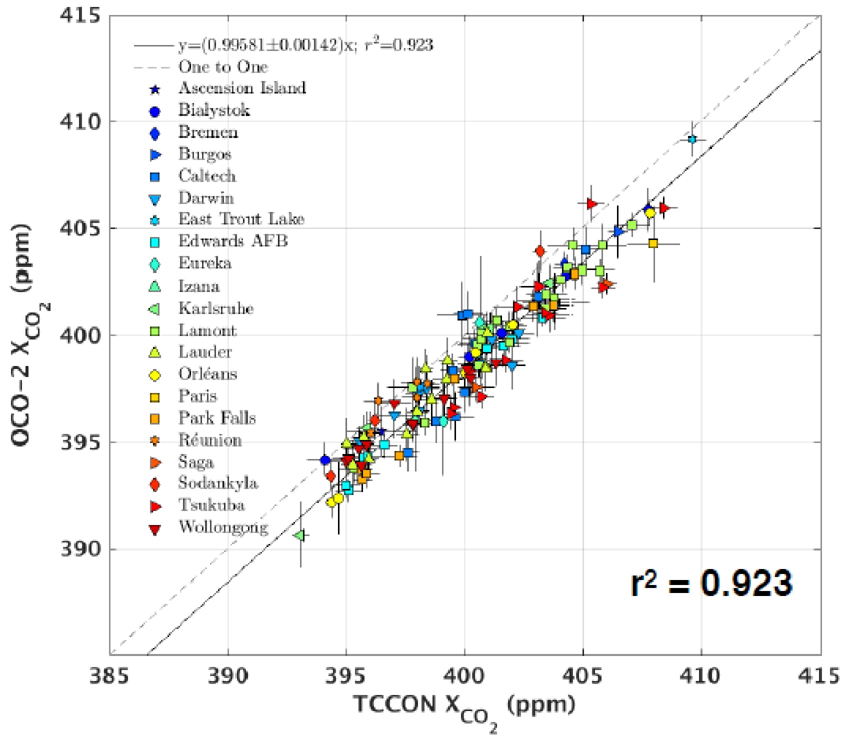


Comparisons to TCCON

V7



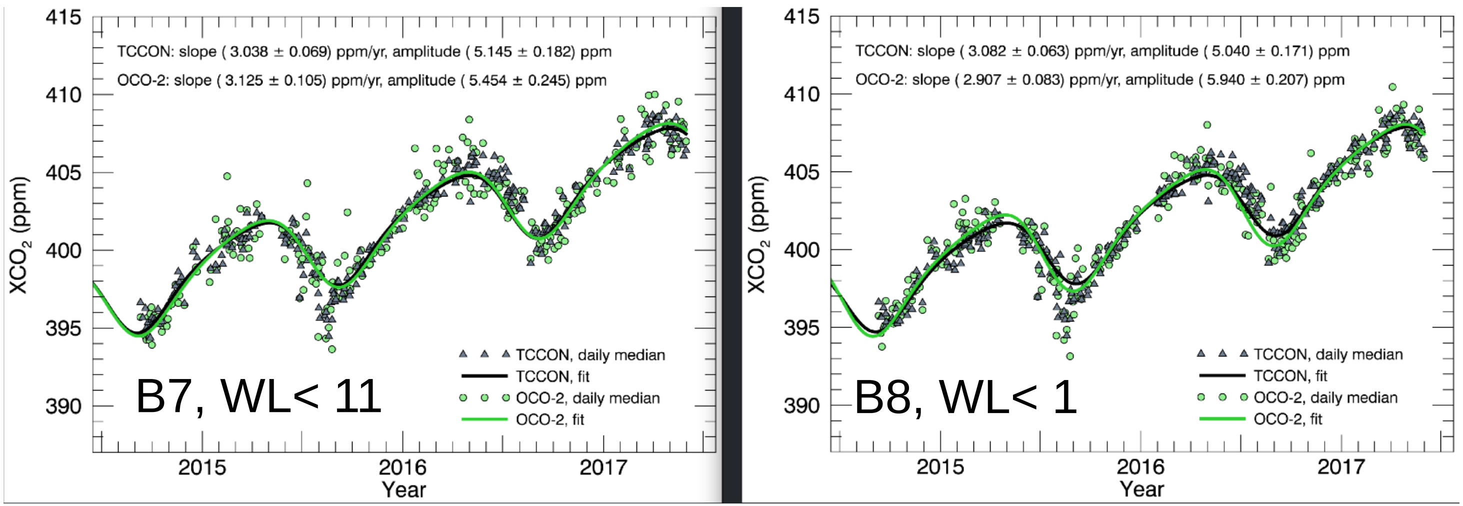
V8



(Kiel et al. 2017)

Validating Space-based Measurements against International Standards

- **GOSAT and OCO-2 data were validated against the Total Column Carbon Observing Network (TCCON)**
- **TCCON is validated against the WMO standards profiles from in situ instruments on aircraft**
- **Other standards, including aircraft campaigns (HIPPO, ACT-America, Atom) also used**
- **These validation methods must be maintained and expanded to support future observations from LEO, GEO and HEO platforms**

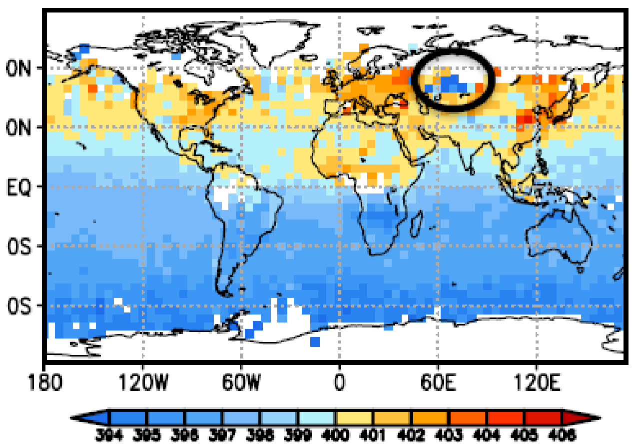


Time series of OCO-2 B7 (left) and B8 (right) X_{CO2} with the Lamont TCCON X_{CO2}

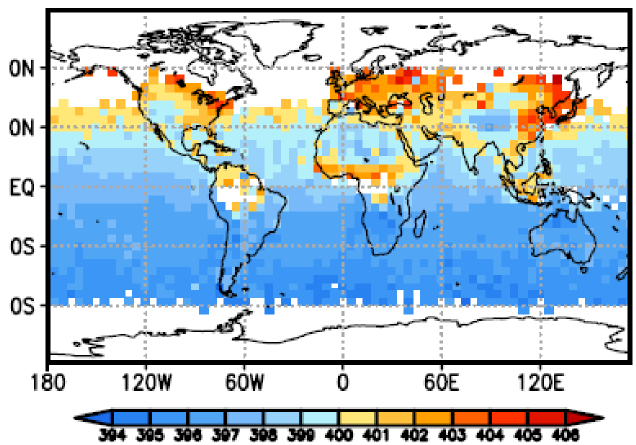
Lindqvist et al.

Differences in Coverage between B7 and B8

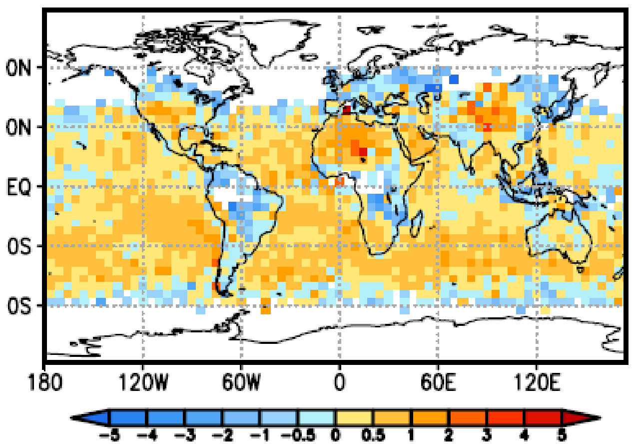
Jan-March, 2015, B8



Jan-March, 2015, B7



B8-B7, Jan-March, 2015



B8 has substantially more coverage than B7 at high latitudes in the winter hemisphere, but some of the results appear to be anomalous – such as the low values seen over central Asia

(Liu et al. 2017)

Summary of B8 – B7 Differences

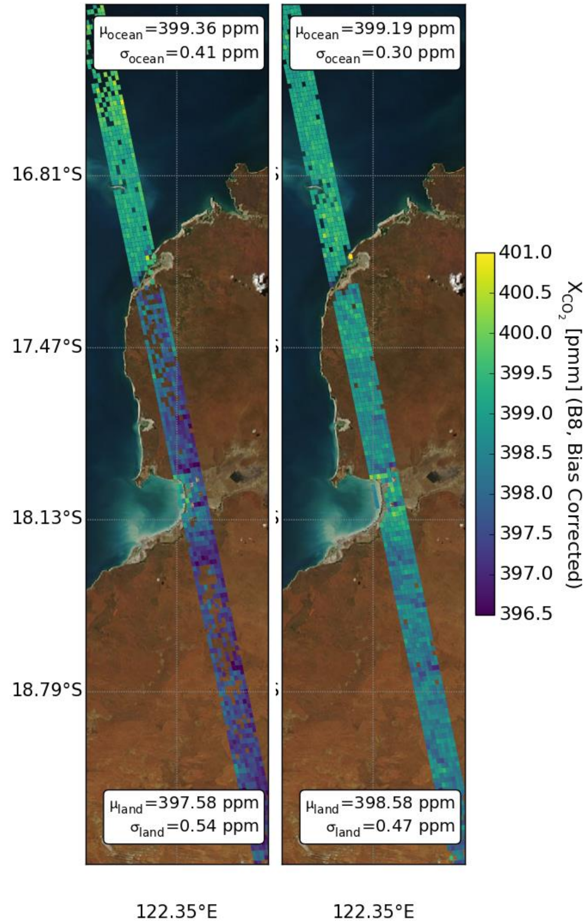
- The B8 product has a better overall agreement with TCCON and other truth metrics
- B8 X_{CO2} is lower than B7 X_{CO2} over tropical land, but higher over the tropical ocean;

  => Land-ocean gradient smaller in B8

- B8 X_{CO2} is lower than B7 X_{CO2} during summer, but higher during winter in the NH.

  => B8 has larger NH seasonal amplitude than B7

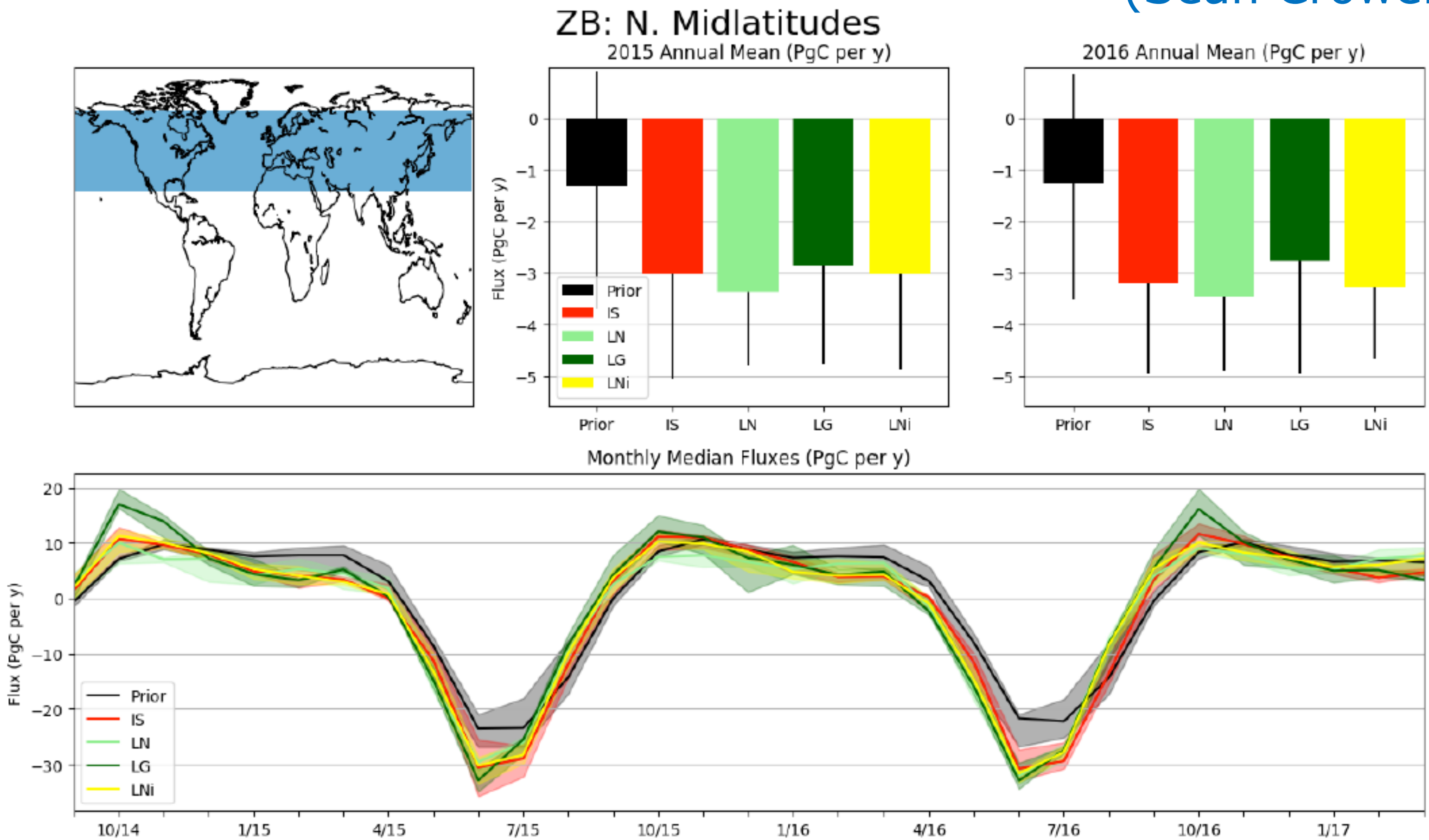
- B8 and B7 have large X_{CO2} differences over high topography and bright surfaces, such as desert.
- B8 X_{CO2} over land is lower than B7 X_{CO2} over land, and the difference becomes larger in 2016.



(Liu et al. 2017)

Preliminary Flux Inversion Results: Northern Mid-latitudes

(Sean Crowell et al.)



Inversions using OCO-2 XCO2 (B7) have a larger seasonal cycle than prior or simulations using only in situ observations. The phase is also shifted earlier.

Space-based GHG Measurement Capabilities are Advancing Rapidly

- TanSat Launched on 22 Dec 2016
- Sentinel 5p Launched on 13 Oct 2017
- NASA Earth Ventures GeoCarb Selected
- CNES MicroCarb Approved for Implementation

“ NEAR FUTURE and LATER Missions are Pre-Decisional Information -- For Planning and Discussion Purposes Only

Summary

- Space-based remote sensing observations hold substantial promise for future long-term monitoring of greenhouse gases
  - These data complement existing ground-based and aircraft based in situ data with increased coverage and sampling density
- The GOSAT and OCO-2 missions are beginning to demonstrate these capabilities
  - Their products have been cross-calibrated, cross validated and combined to produce an 8-year record that is now being used in studies of the global carbon cycle
- A new OCO-2 data product (B8) has been delivered to the Goddard Earth Science Data and Information Services Center (GES-DISC) for distribution to the science community:

https://disc.gsfc.nasa.gov/datasets?page=1&source=OCO-2%20OCO%20SPECTROMETERS

Thank You for Your Attention

Questions?