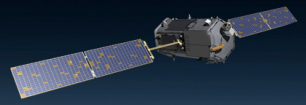
Measuring Atmospheric CO_2 with the NASA Orbiting Carbon Observatory-2 (OCO-2)



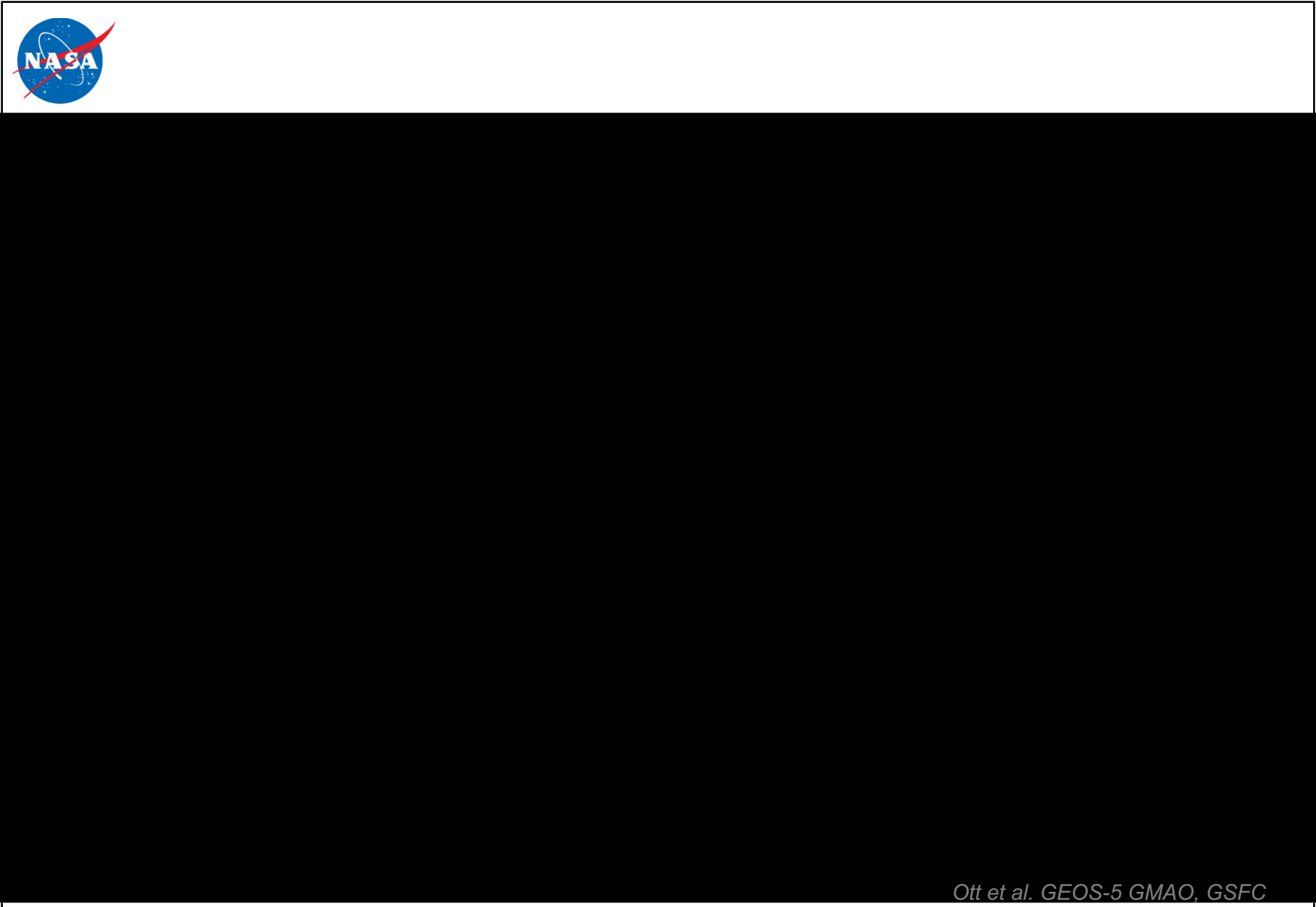
Los Angeles Basin

David Crisp, for the OCO-2 Science Team
Jet Propulsion Laboratory, California Institute of Technology

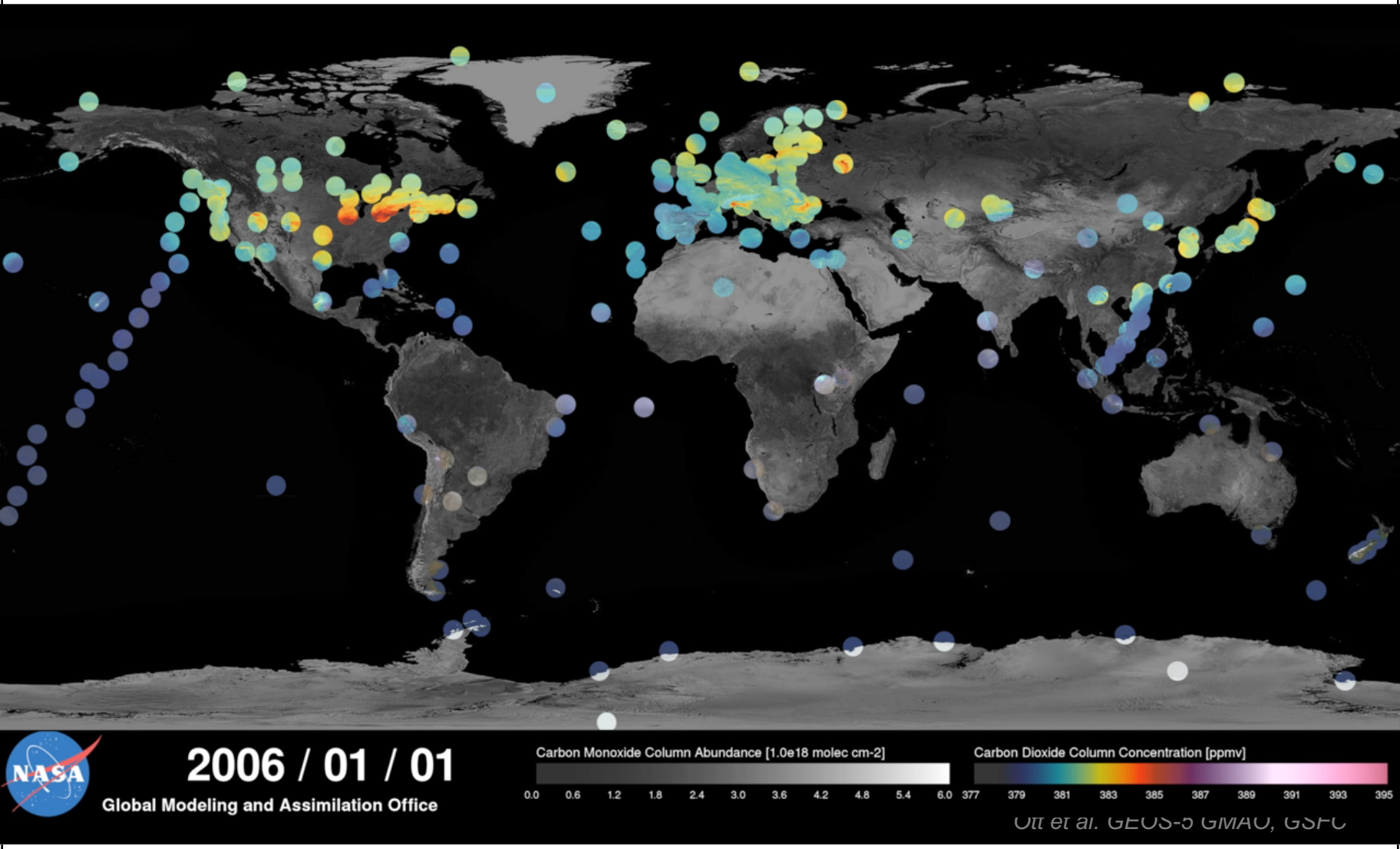
July 2017

Overview

- Observatory Status: Nominal
  - Drag Make-up Maneuver (DMUM) planned for July 20
- Instrument Status:
  - Last decontamination cycle completed on March 1, 2017
  - An instrument reset and decontamination cycle is currently being planned for July 30 – August 5
- Overview of ongoing science activities
  - Sneak Preview of the Science/GRL Special Collection
- Coming attractions: The Version 8 data product
  - A data product with updated calibration, retrieval algorithm and bias correction has been implemented
  - Level 2 B8r processing has begun



Ott et al. GEOS-5 GMAO, GSFC

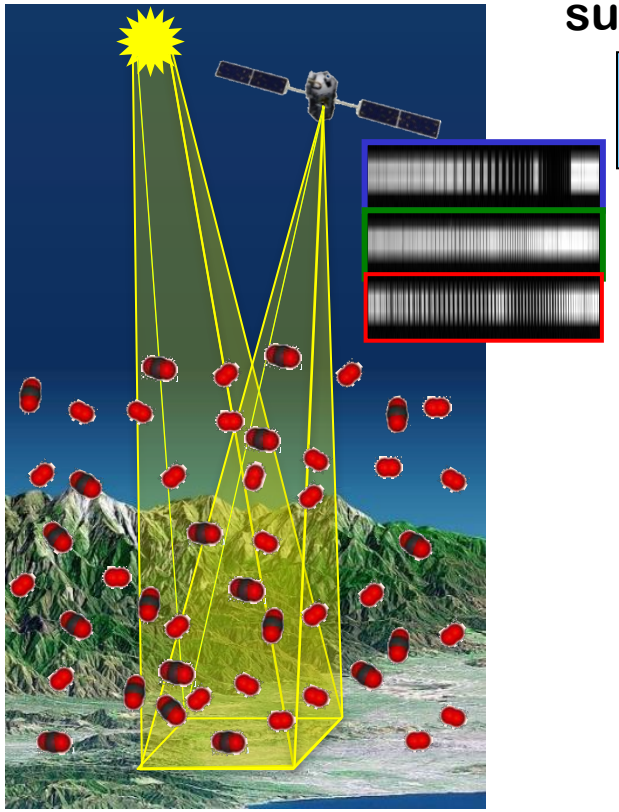

2006 / 01 / 01
Global Modeling and Assimilation Office
Carbon Monoxide Column Abundance [1.0e18 molec cm-2]
0.0 0.6 1.2 1.8 2.4 3.0 3.6 4.2 4.8 5.4 6.0
Carbon Dioxide Column Concentration [ppmv]
377 379 381 383 385 387 389 391 393 395
Ott et al. GEOS-5 GMAO, GSFC

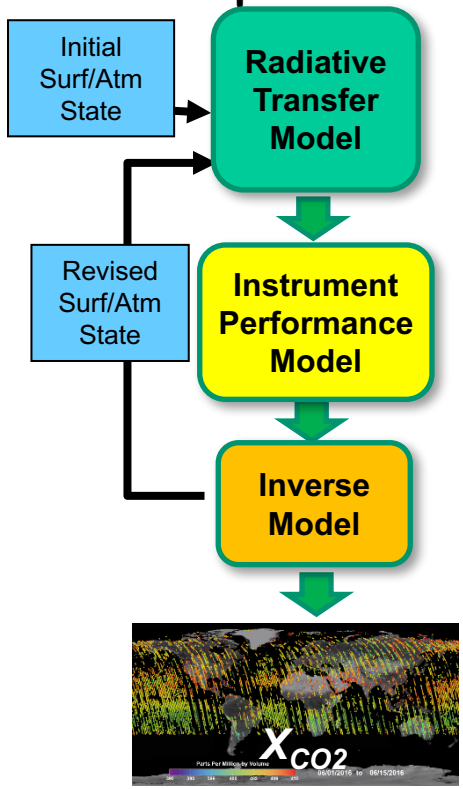
Measuring CO_2 from Space

- Record spectra of CO_2 and O_2 absorption in reflected sunlight

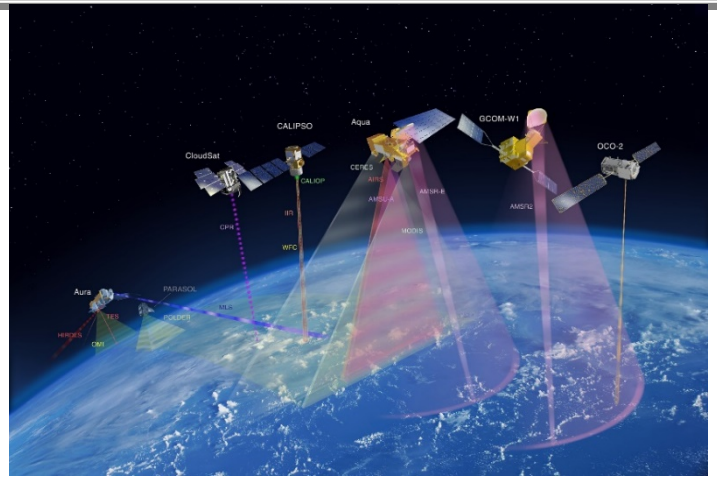
Retrieve variations in the column averaged CO_2 dry air mole fraction, X_{CO2} over the sunlit hemisphere

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





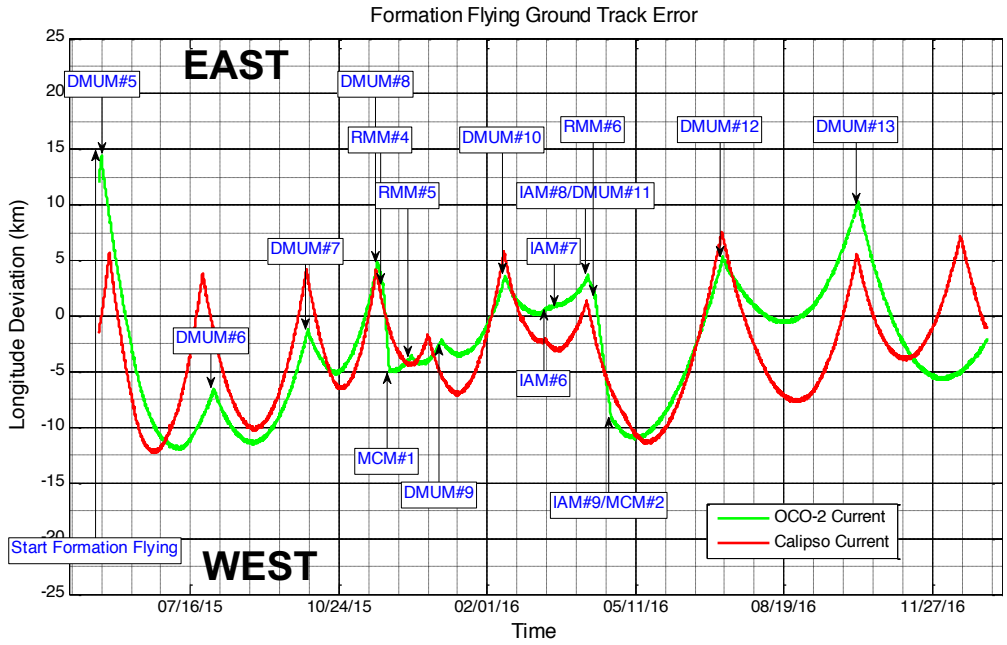
The OCO-2 Mission



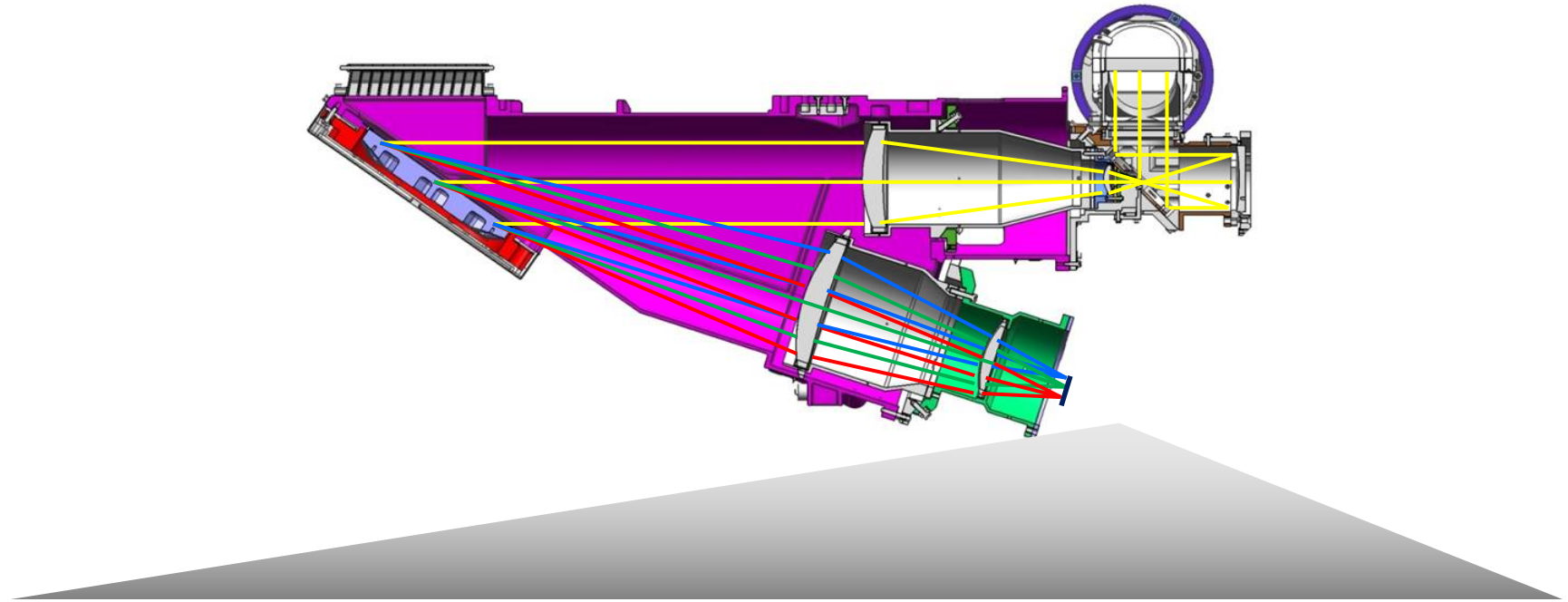
OCO-2 was launched on 2 July 2014, inserted at the head of the Afternoon Constellation (A-Train) on 3 August 2014. It completed its 2-year prime mission on 16 October 2016 and started its first extended mission with a healthy spacecraft and instrument

The OCO-2 orbit track is maintained so that its nadir observations overlap the CALIPSO and CloudSat ground tracks.

OCO-2 maintain this alignment until CALIPSO expends the rest of its fuel and leaves the A-Train



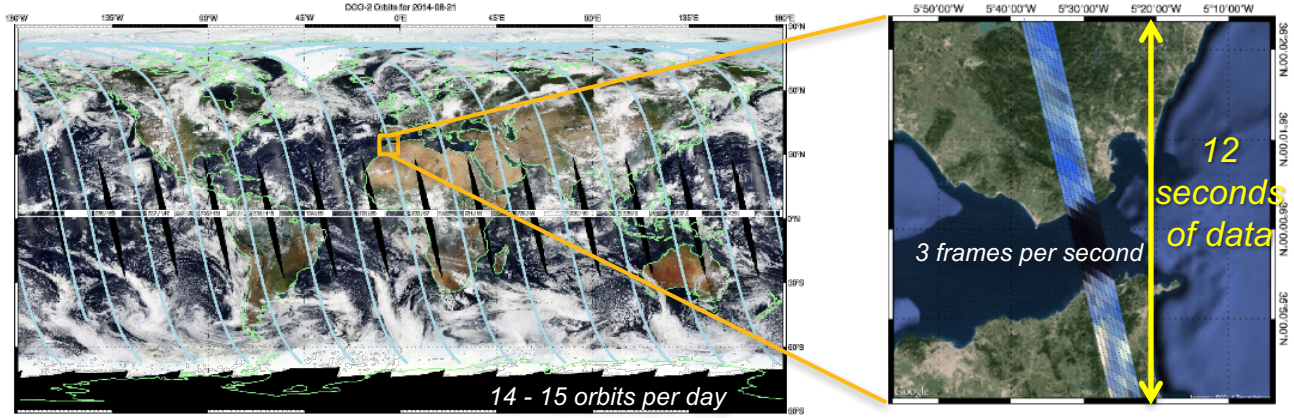
The OCO Instrument – Optimized for Sensitivity

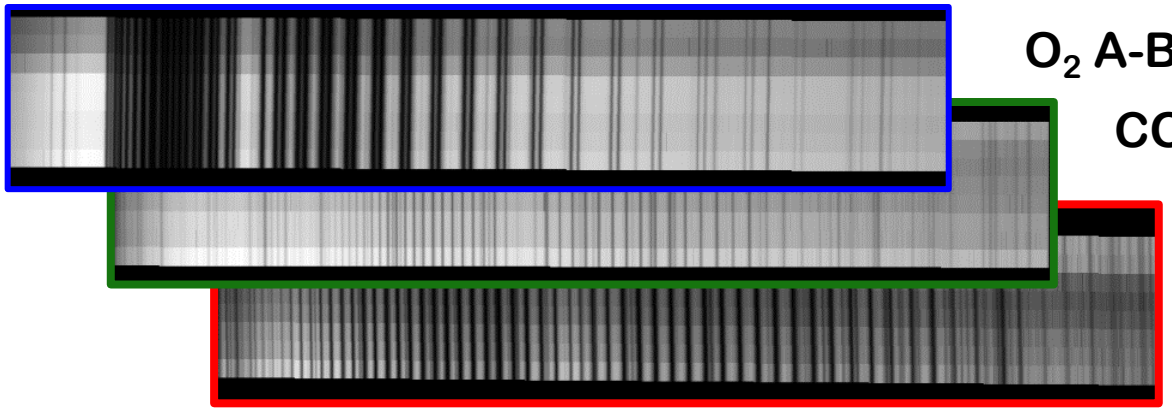


0.765µm O_2 A-Band | CO_2 1.61µm Band | CO_2 2.06 µm Band

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

OCO-2 Sampling Approach





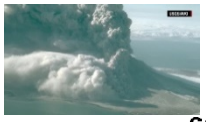
O_2 A-Band

CO_2 1.61 μm Band

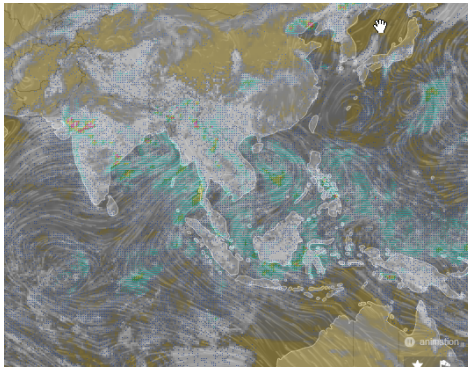
CO_2 2.06 μm Band

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

July X_{CO2} Data (forward stream)



Bogoslof



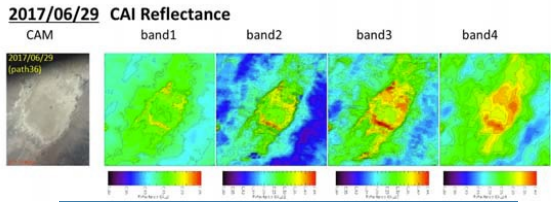
July 13 cloud forecast from www.windy.com

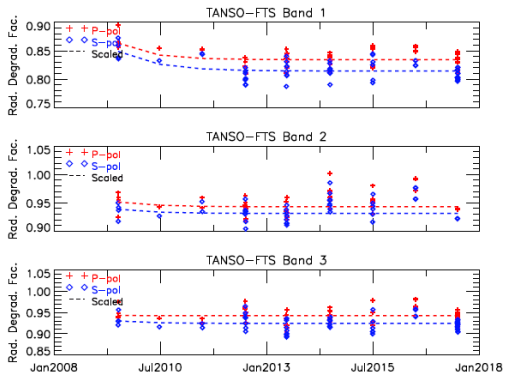
The first 2 weeks of July is looking as expected. Note the impact of the summer monsoon over Asia. High XCO2 values over Southern Ocean are under investigation.

This might be the LAST Version 7 Map that we distribute.

The 2017 Railroad Valley Campaign was a Success

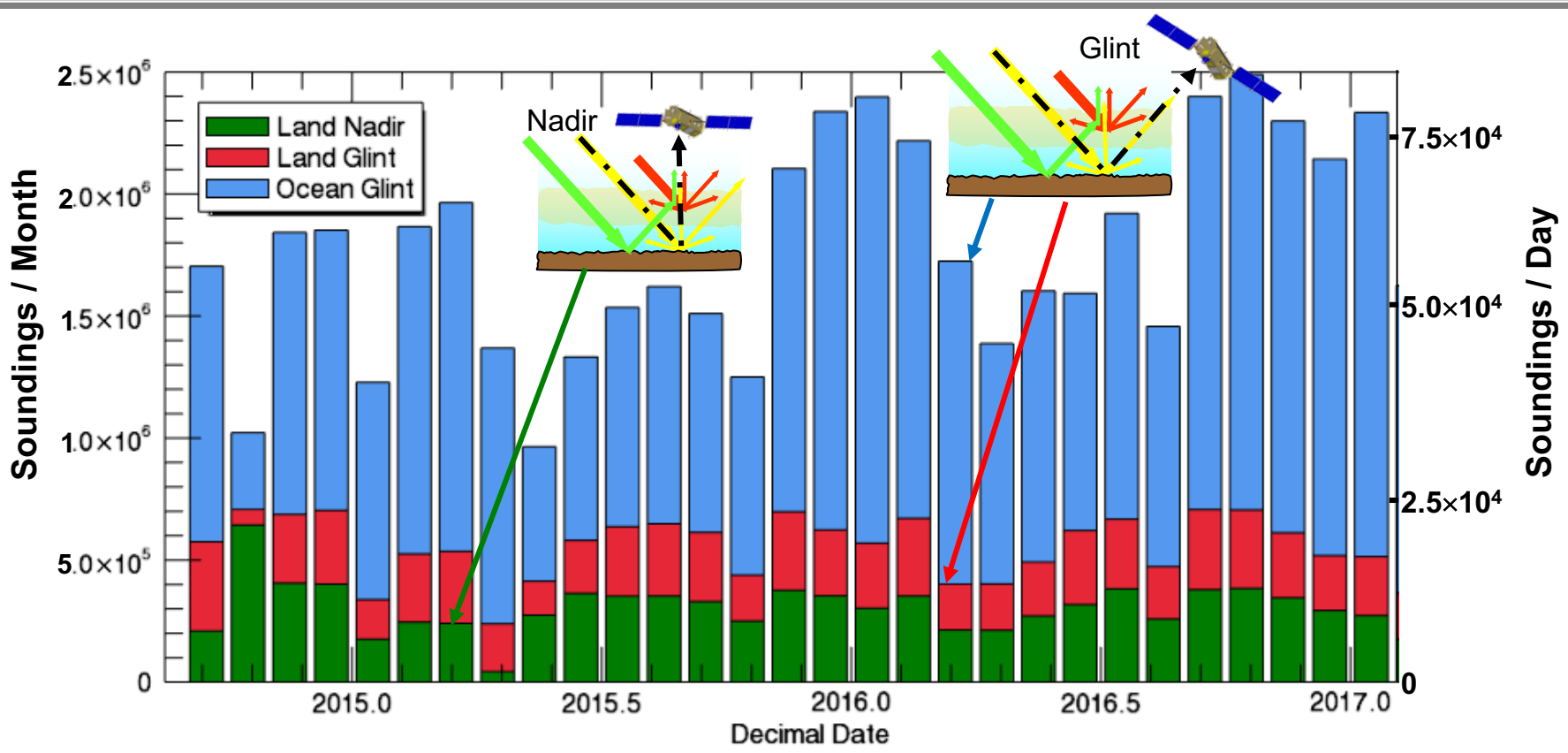
- Team deployed in RRV on 25-30 June
  - Ground based data collected on 25 (“training day”), 26, 27, 29 and 30 June
  - No rain and cloud-free skies on 25-23 June
    - Slightly hazy on 6/26
  - Alpha Jet not available
- OCO-2 Target Observations
  - 2017-06-25 14:05:28 PDT (2017-06-25 21:05:28 UTC)
  - 2017-06-27 13:53:08 PDT (2017-06-27 20:53:08 UTC)
  - 2017-06-29 13:41:00 PDT (2017-06-29 20:41:00 UTC)
- GOSAT Target Observations
  - Path 36 (east: forward scattering) on 2017-06-26 and 2017-06-29 (“Golden Day”)
  - Path 37 (west, backscattering)on 2017-06-27 (Silver day) and 2017-06-30 29
- Followed by a 1-day Salton Sea Campaign





Preliminary GOSAT Degradation

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

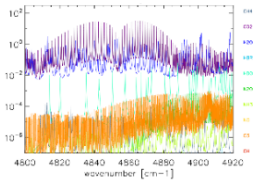
State Vector First Guess

Altitude

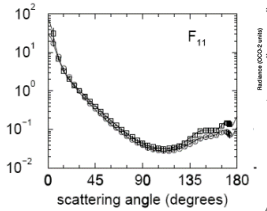
CO_2 T $\delta\tau_{aer}$

Mixing Ratio Temp. Aerosol

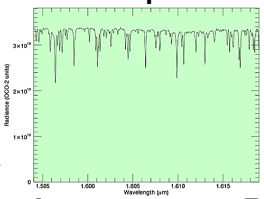
Gas Cross Sections



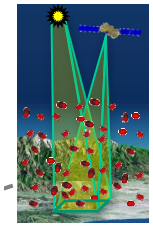
Cloud & Aerosol Optical Properties



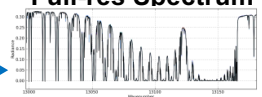
Solar Spectra



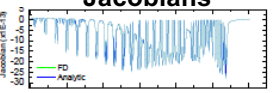
Geometry



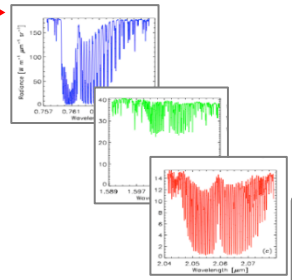
Full-res Spectrum



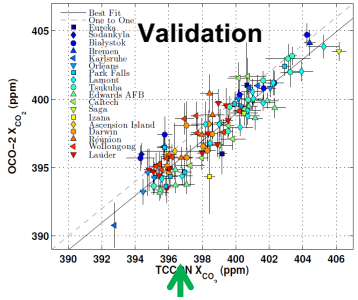
Jacobians



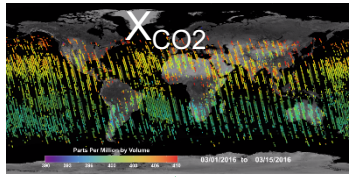
Simulated Spectrum



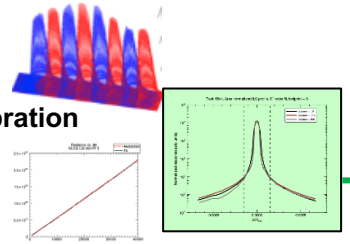
Validation



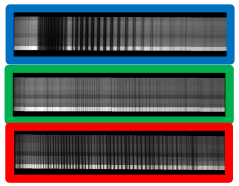
X_{CO2}



Calibration



Observed Spectra



Apriori + Covariance

Forward Radiative Transfer Model
Spectra + Jacobians

Instrument Model
Spectral + Polarization

Inverse Model
- Update State Vector

not converged

Final State & Diagnostics

converged

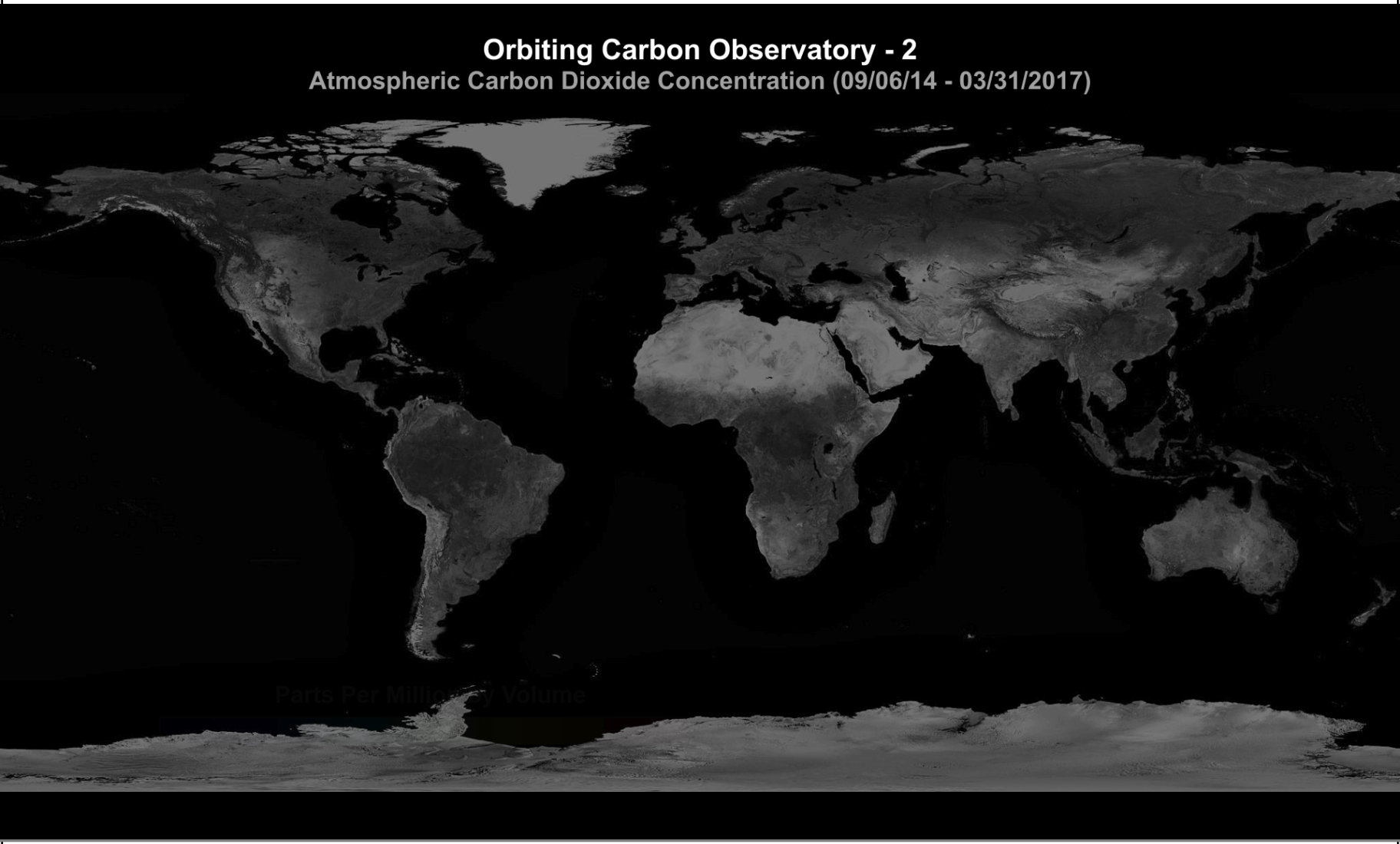
Retrieved State Vector

Altitude

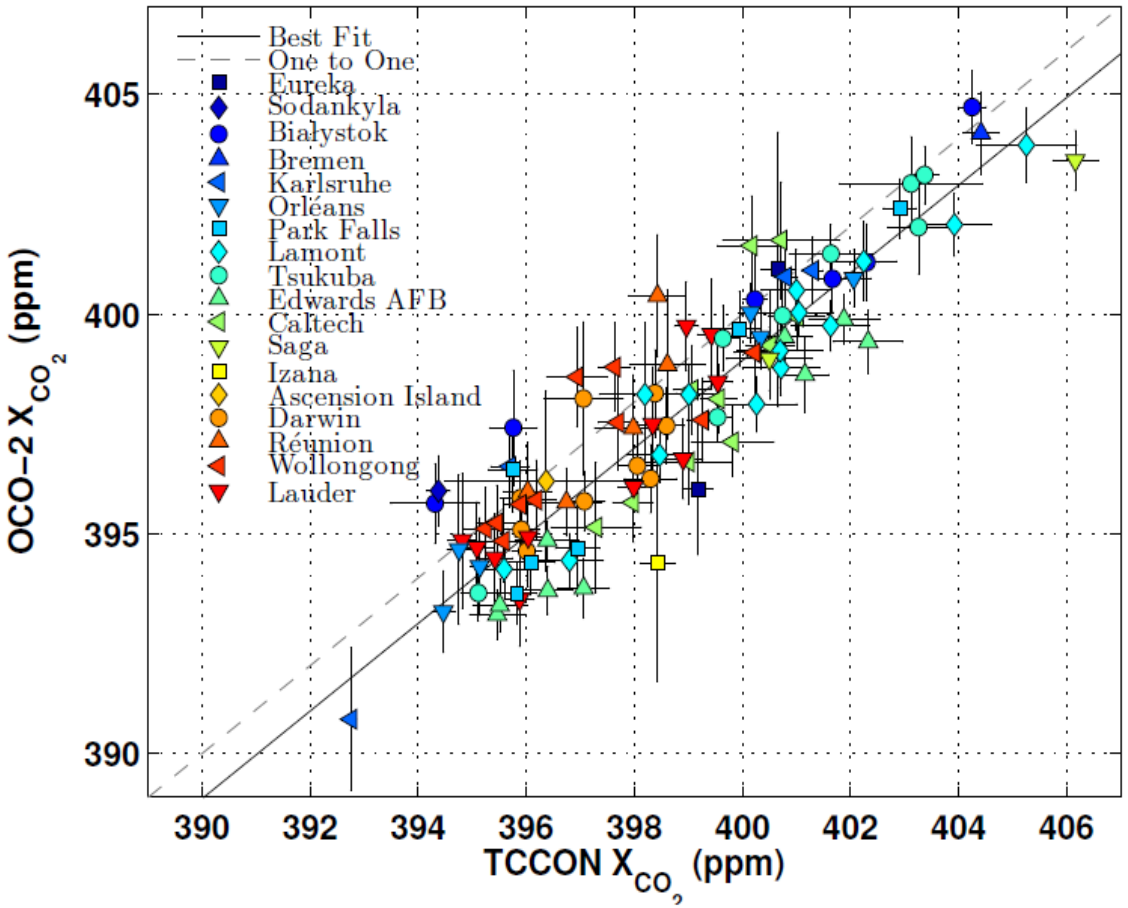
CO_2 T $\delta\tau_{aer}$

Mixing Ratio Temp. Aerosol

A Quick Look at the OCO-2 Prime Mission



Comparison of TCCON and OCO-2 X_{CO2}



Comparisons with the Total Carbon Column Observing Network (TCCON) stations are being used to identify and correct biases in target observations.

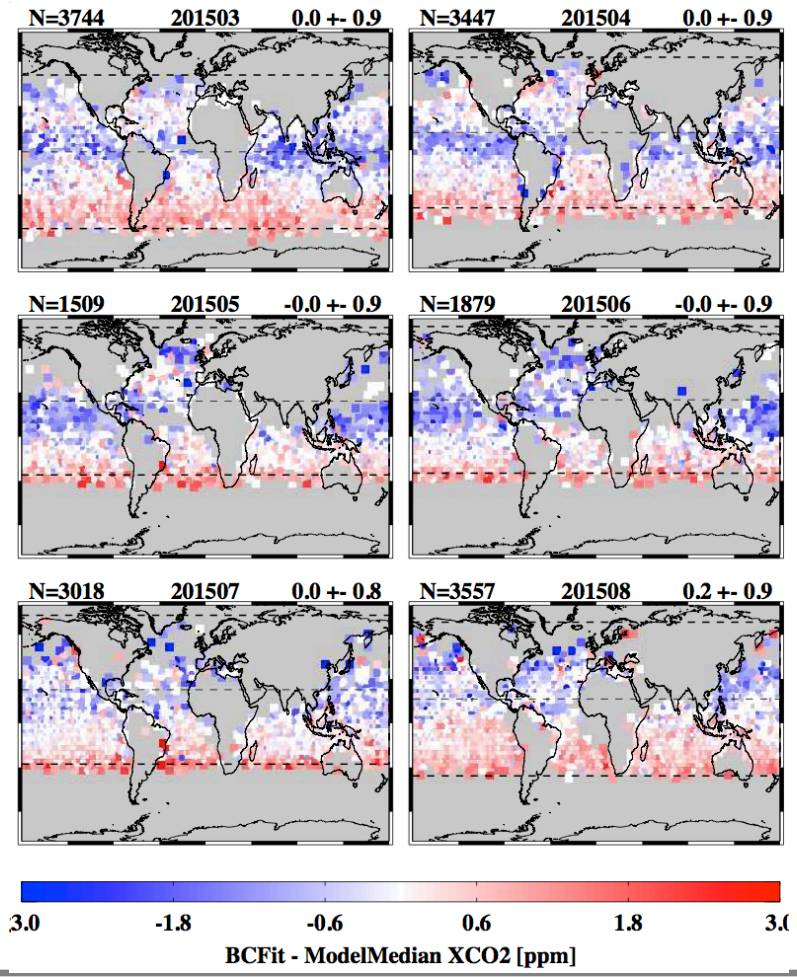
After applying a bias correction

- Global bias is reduced to < 1 ppm
- Station-to-station biases reduced to ~1.5 ppm

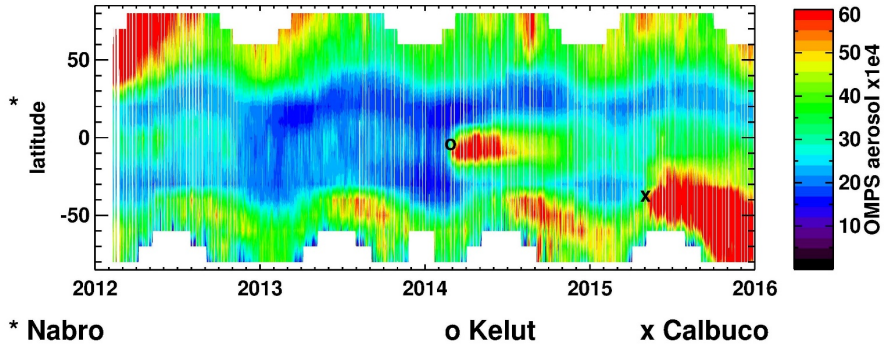
Wunch et al. (2016)

Tracking and Correcting Biases

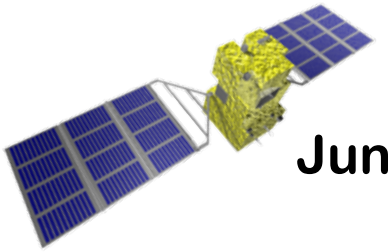
With Strat Aerosols



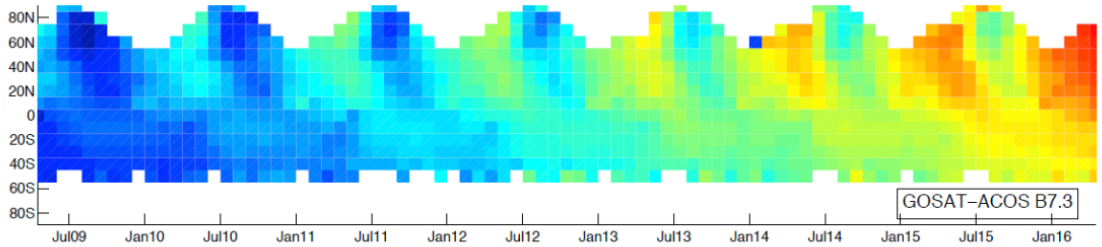
- High bias seen over southern hemisphere oceans (glint) March-September, relative to models.
- Traced to Optically-thin stratospheric aerosol layers
  - The largest effects are seen at high latitudes over the ocean during the southern winter months
  - Effect was enhanced by volcanic activity (Wolf and Calbuco) which enhanced stratospheric aerosols
- Corrected in the next data product (V8)

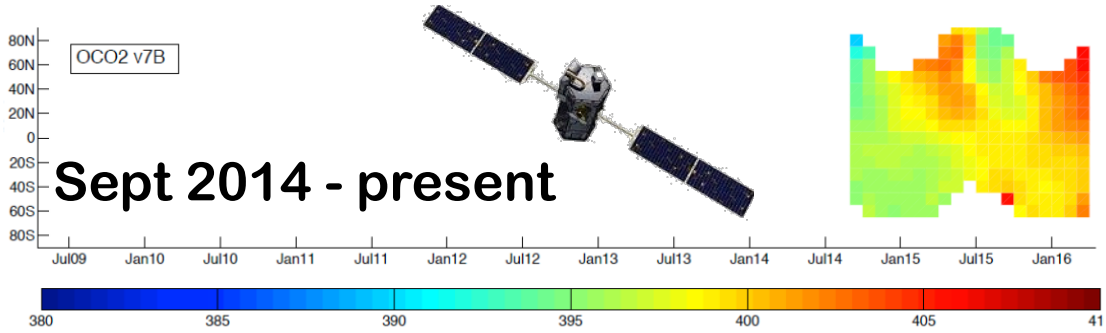


ACOS/GOSAT B7.3, and OCO-2 v7 XCO2



June 2009 - present

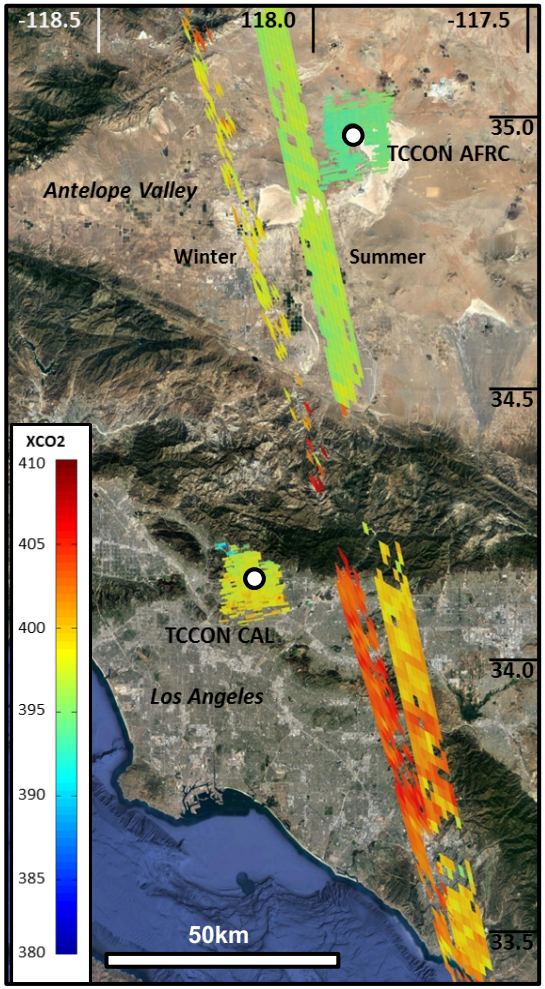


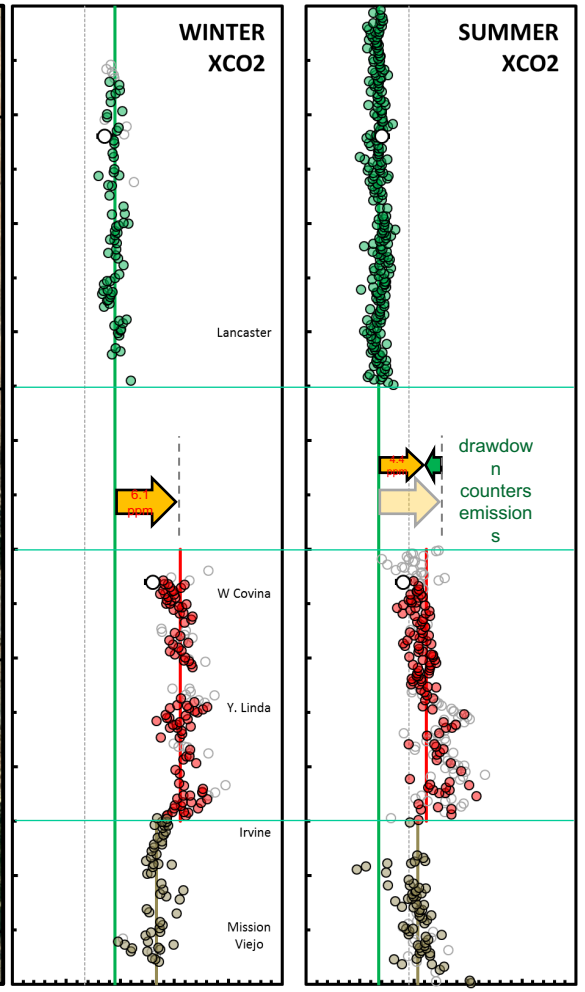


TCCON and other standards have been used to cross validate OCO-2 and GOSAT X_{CO2} to extend the climate data record

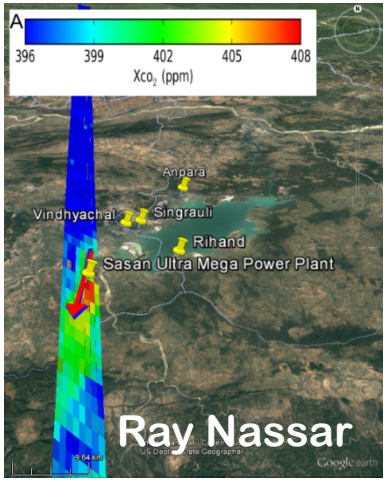
- The magnitude of differences between GOSAT-ACOS B7.3 and OCO2 v7r are within ±1 ppm for overlap regions

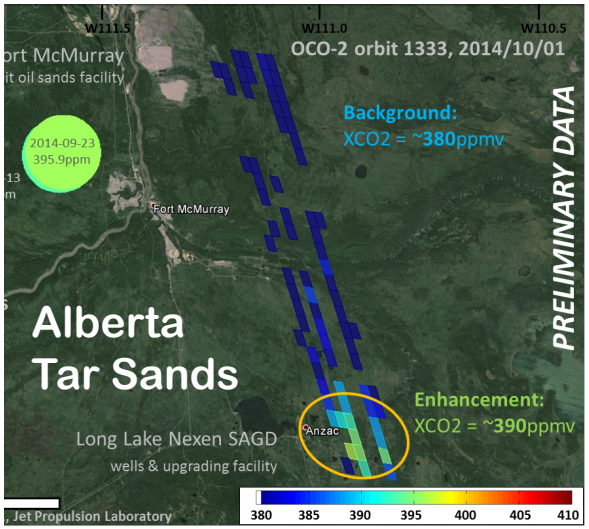
Localized Sources





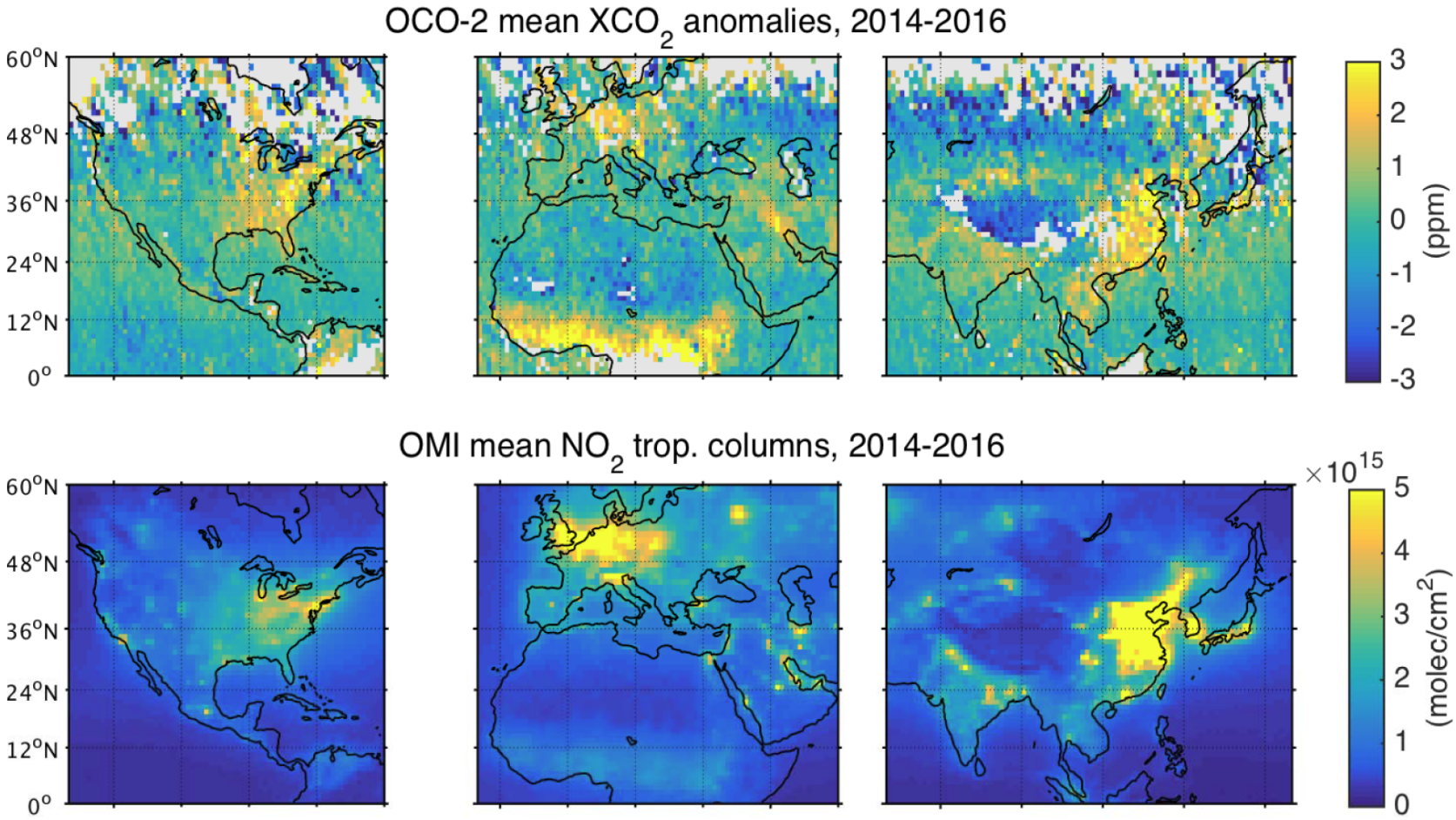
Los Angeles Basin





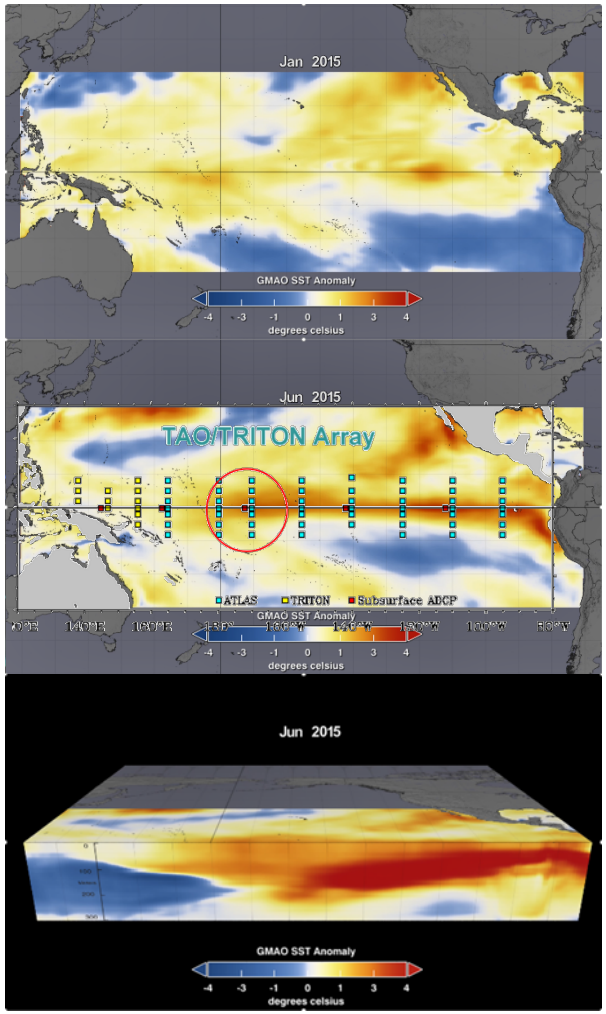
Florian Schwandner et al.(Accepted, Science 2017)

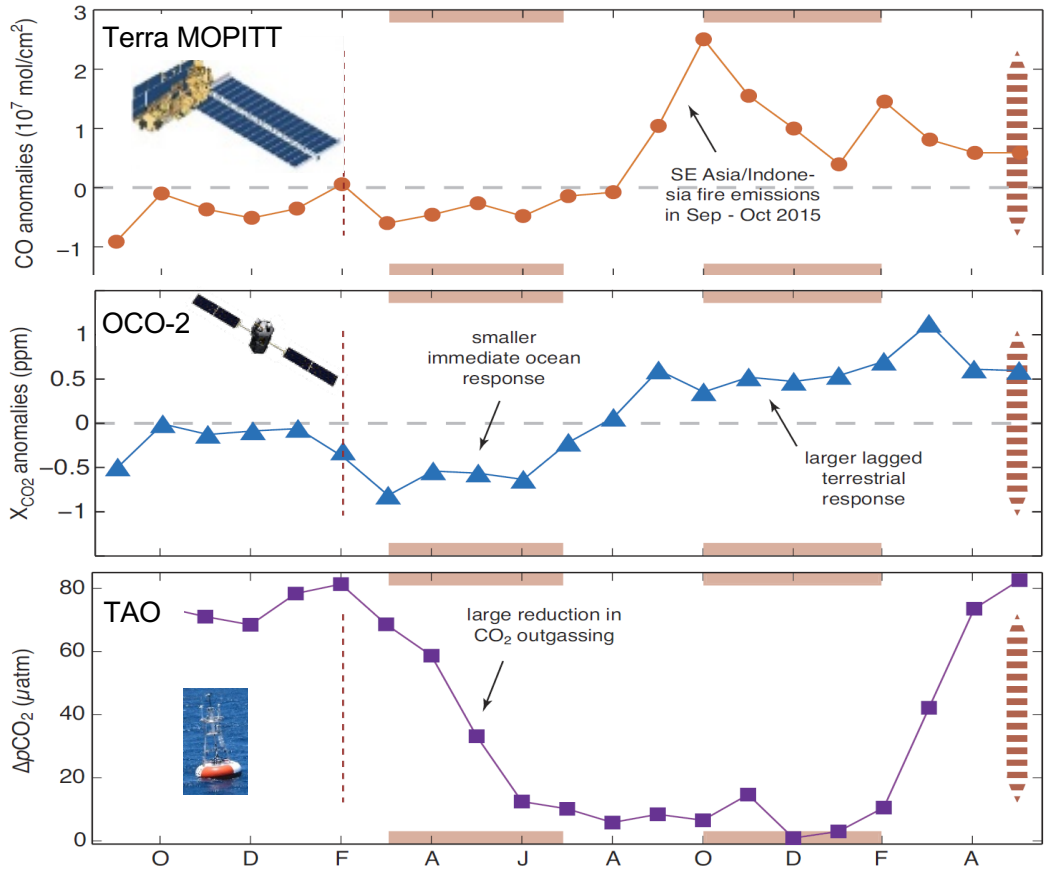
Anthropogenic Emissions



Janne Hakkarainen et al. GRL (2016)

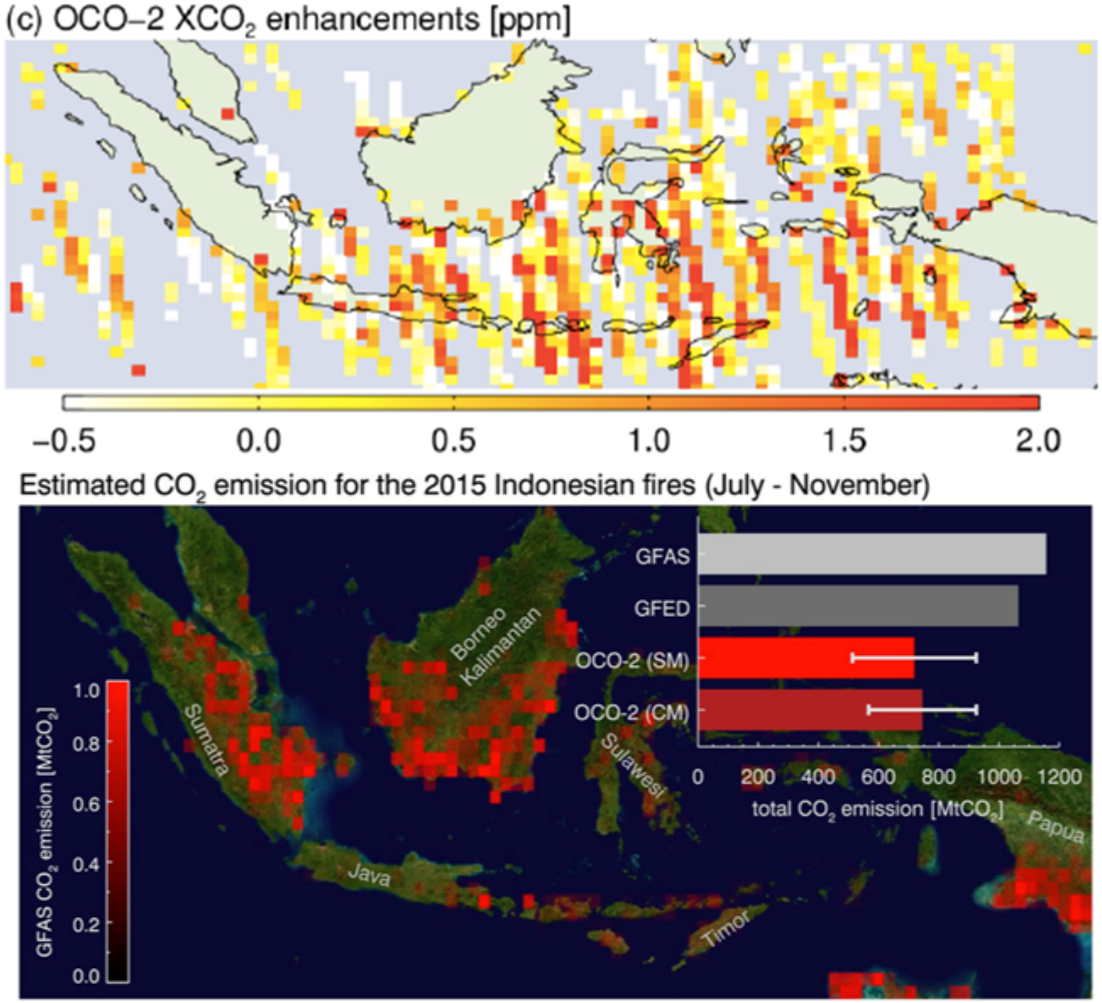
2015-2016 El Niño: Ocean Response





Abhishek Chatterjee et al. (submitted)

2015-2016 El Niño: Fires

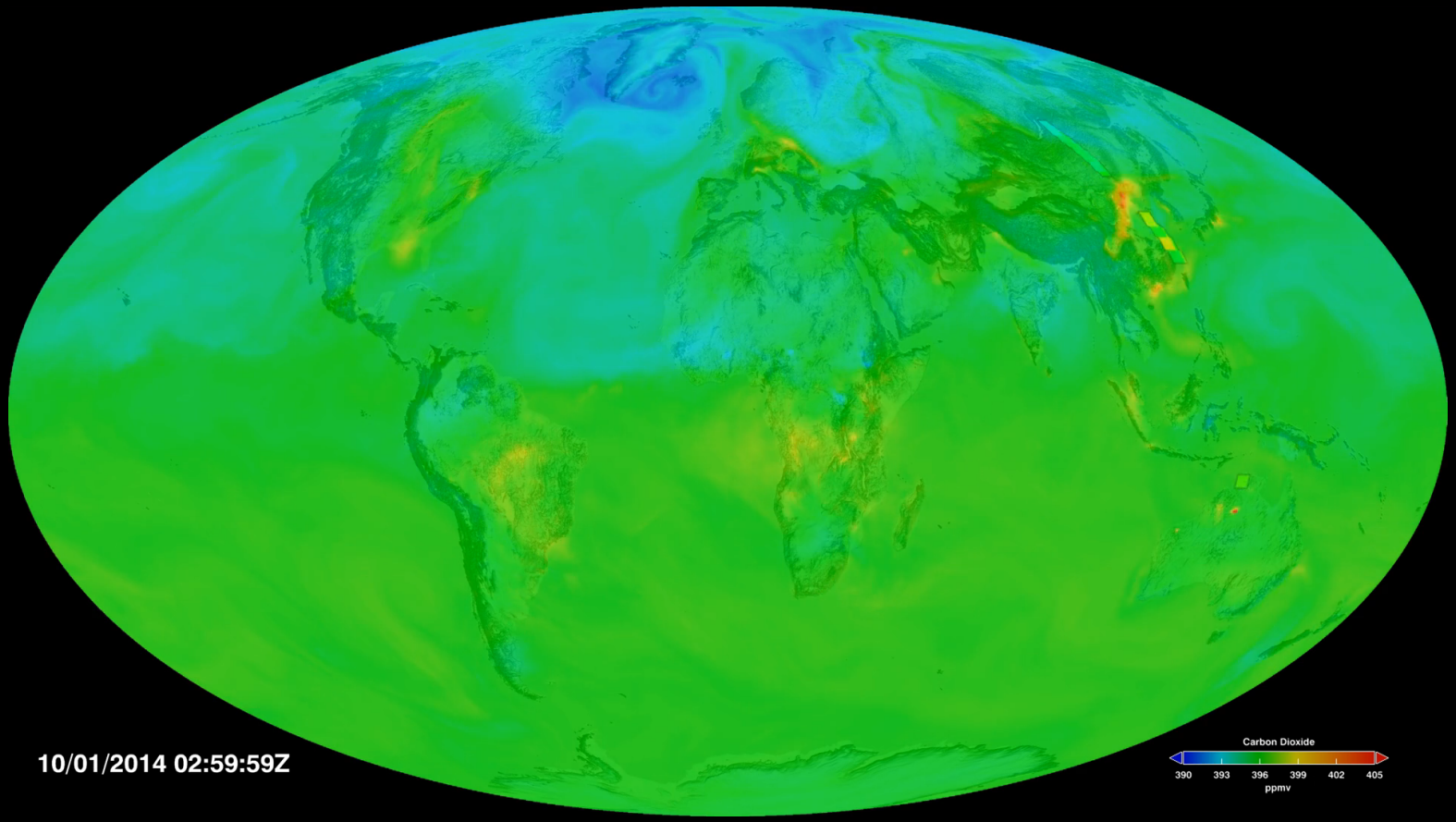


Jenns Heymann et al. (GRL, Accepted 2017)

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

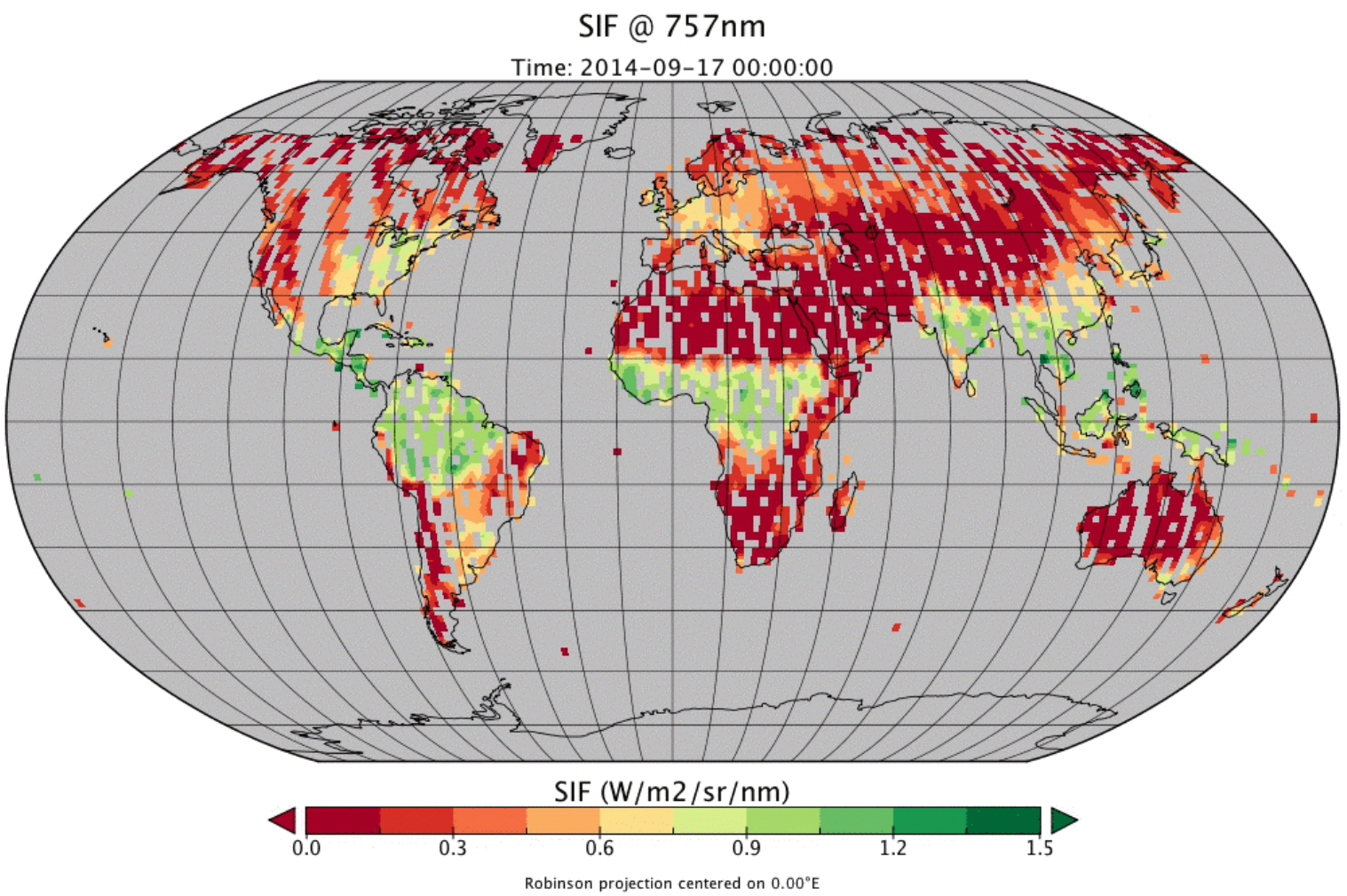
Fire emissions estimates from the GFAS and GFED inventories to emission estimates obtained from OCO-2 data, using two analysis approaches. The OCO-2 estimates are less than 70% as large as those in the inventories.

Assimilation of OCO-2 X_{CO2}

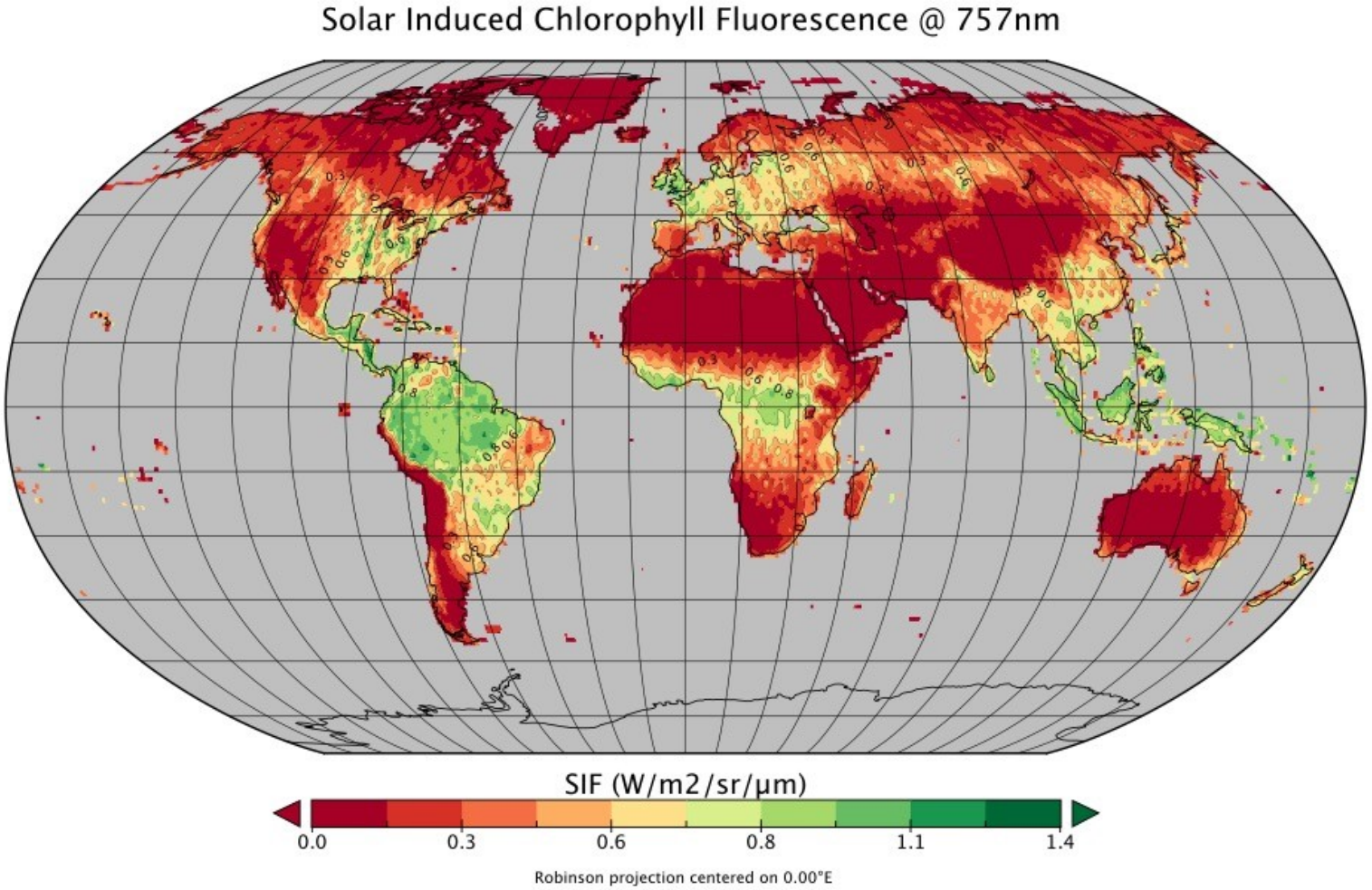


Brad Weir et al. GSFC GMAO

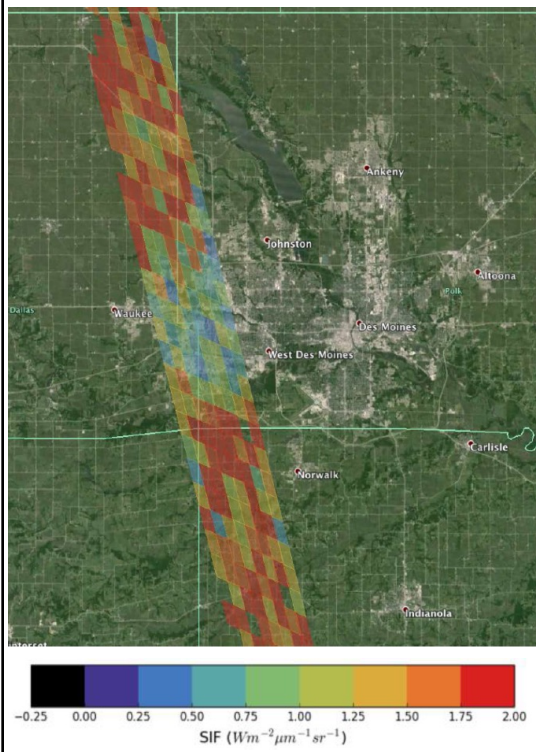
Solar-Induced Chlorophyll Fluorescence (SIF)



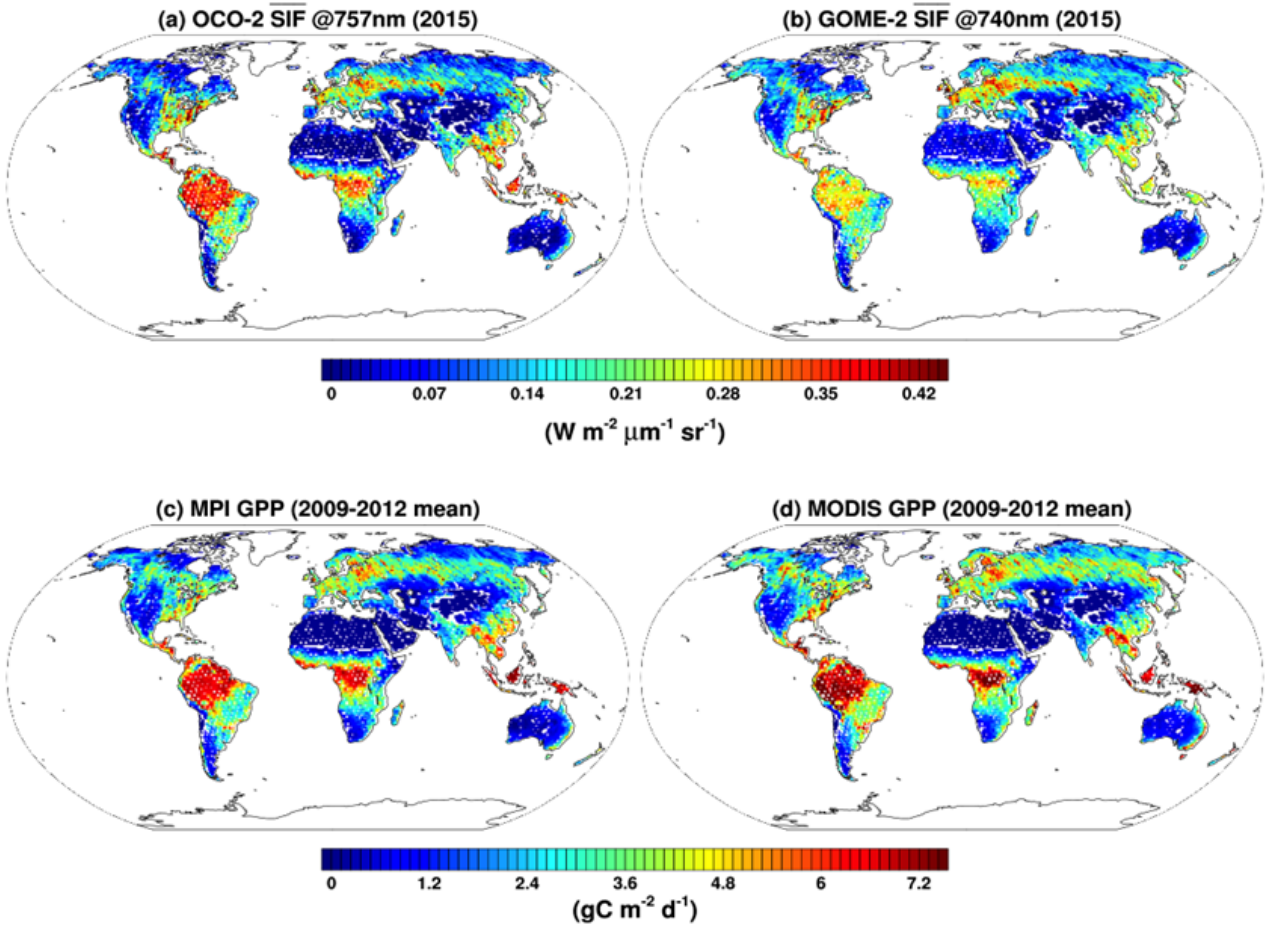
Annual Average OCO-2 Observations of SIF



Solar Induced Chlorophyll Fluorescence (SIF)



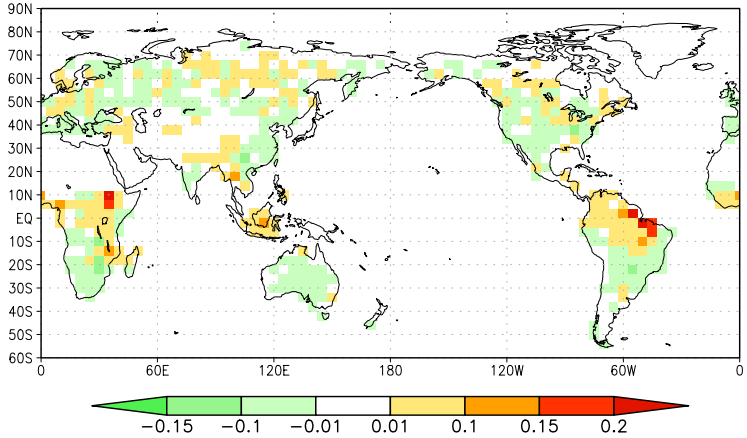
OCO-2 SIF over Des Moines, Idaho



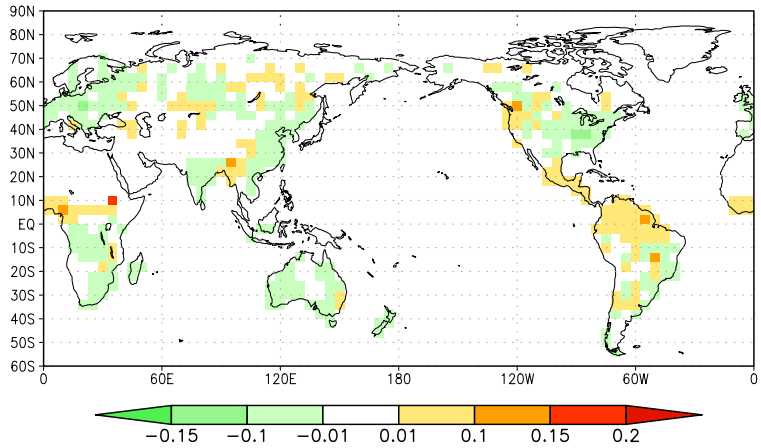
Ying Sun et al. (submitted 2017)

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

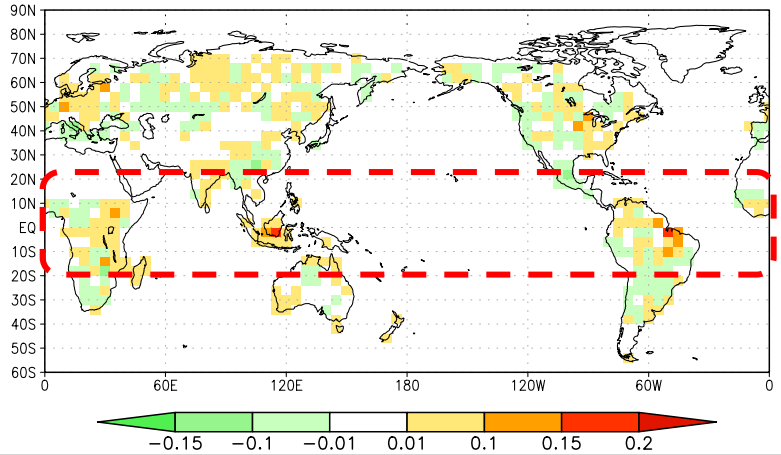
2015 (GtC/yr)



2011 (GtC/yr)



2015- 2011 (GtC/yr)



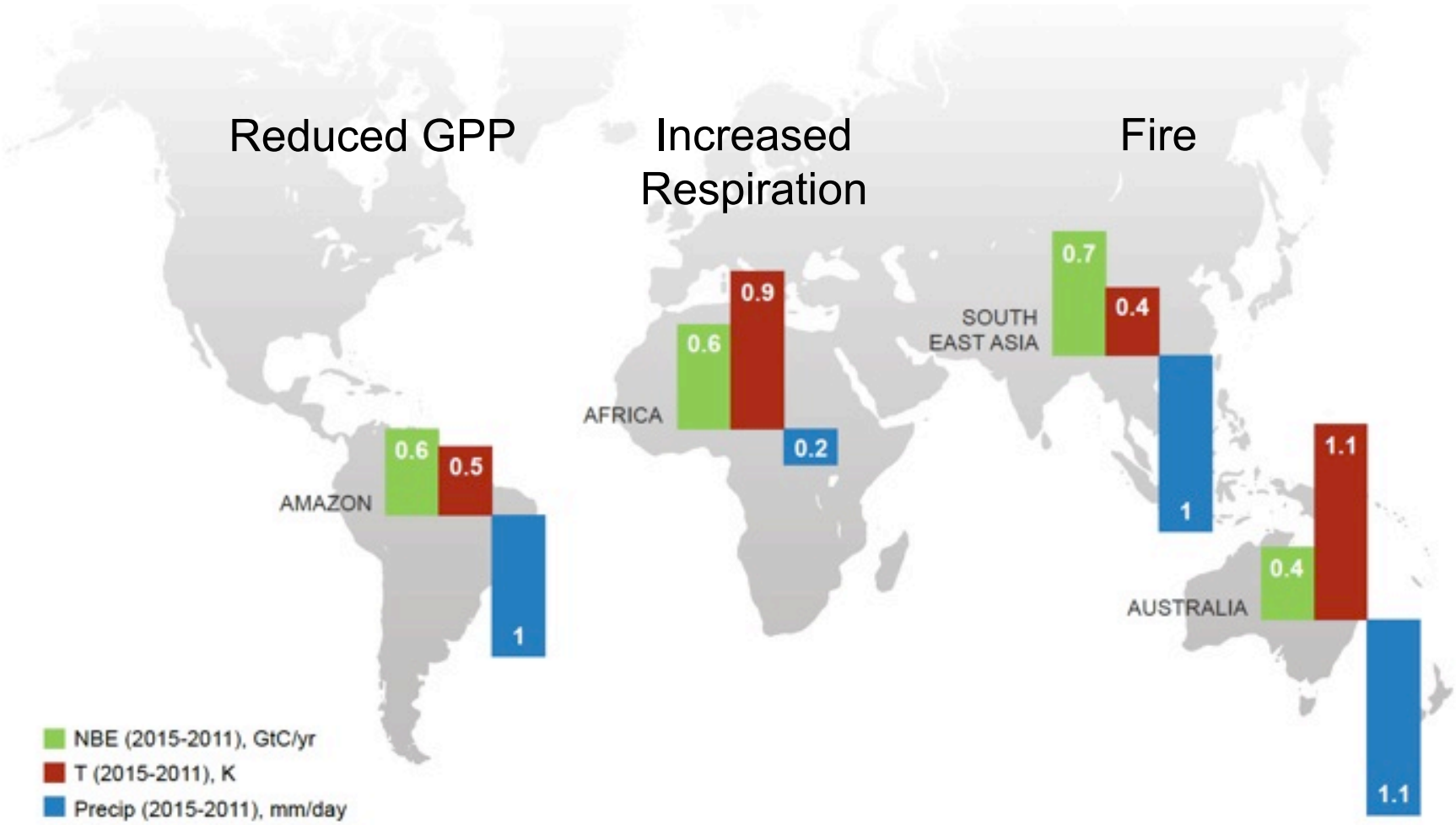
Red: release CO_2 into atmosphere

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**

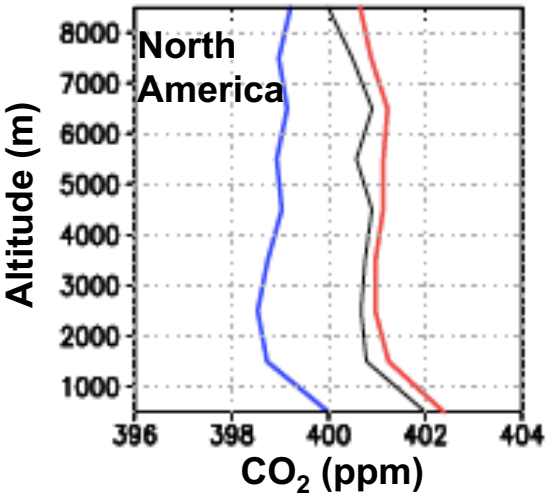
Junjie Liu et al. (Accepted 2017)

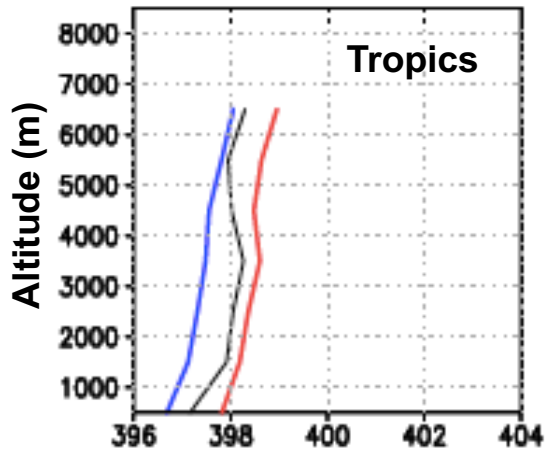
2015-2016 El Niño: 3 Continents, 3 Stories



Validating Regional Flux Changes

Aircraft vs OCO-2

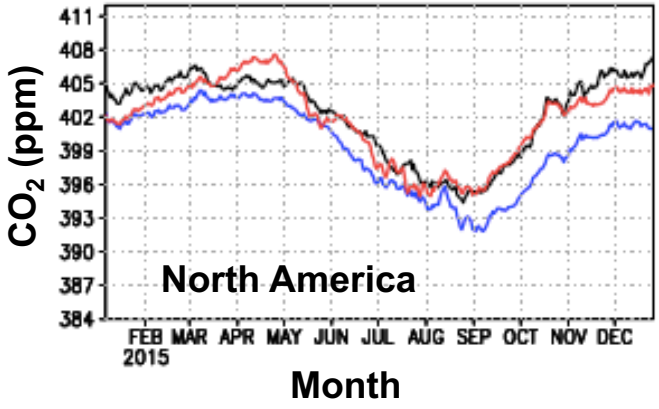


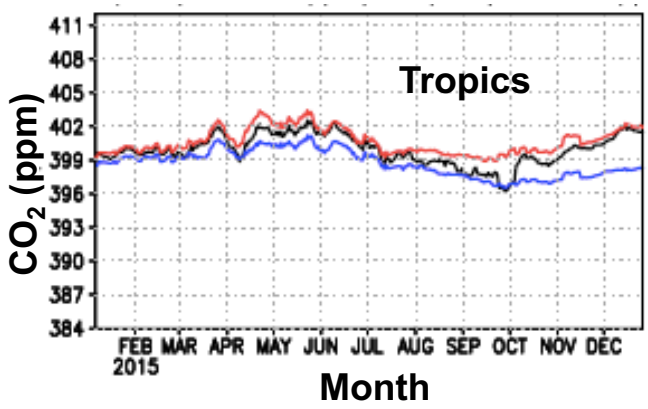


Junjie Liu et al. compare modeled profiles derived in their studies to aircraft and modeled in situ surface values to flask in situ measurements

- Blue: model prior
- Red: model posterior
- Black: in situ observation

Surface Flask vs OCO-2





Coming Attractions: OCO-2 Build 8

- Improved calibration, accounting for ice accumulation and associated zero level offset on 0.76 um O_2 A-band detector.
- Improved Spectroscopy
- Inclusion of Stratospheric Aerosols
- Change from ECMWF to GEOS-5 for prior Meteorology (T, q, surface pressure)
- Improved CO_2 prior
- Improved Land surface reflectance model
- Better pre-screening → more nadir ocean and high-latitude land data.

- Operational processing has begun. The entire OCO-2 data set should be reprocessed by the end of September.

Aircraft Campaigns of Interest to GOSAT and OCO-2

- ASCENDS Alaska Campaign: July 27 – August 8
  - The first and last days are transit days (typically with measurements).
  - The Alaska deployments will be between those two dates.

- ACT-America Campaign#3: October 3 – November 13.
  - LaRC: 2-16 October
  - Lincoln Nebraska: 17-30 October
  - Shreveport, Louisiana: 31 October – 13 November
  - The ACT-America calendar is here: https://actamerica.larc.nasa.gov/calendar.html

- ATom: 1-26 October
  - Preceded by shakedown and test flights from September 12-28.
  - The ATom calendar is here: https://espo.nasa.gov/home/atom/calendar/2017-09

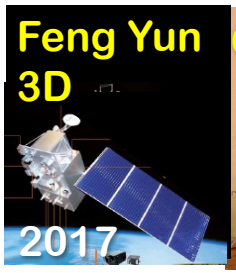
Space-based GHG Measurement Capabilities are Advancing Rapidly

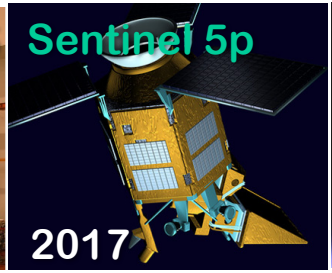
- TanSat Successfully Launched on 22 Dec 2016
- NASA Earth Ventures GeoCarb Selected
- CNES MicroCarb Approved for Implementation

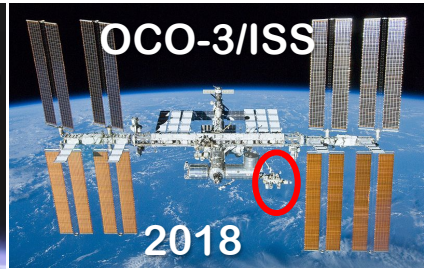
PAST

PRESENT

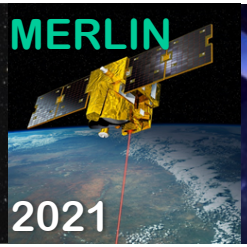
NEAR FUTURE*

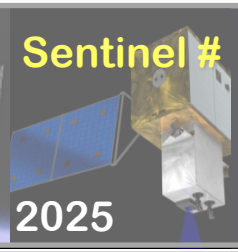


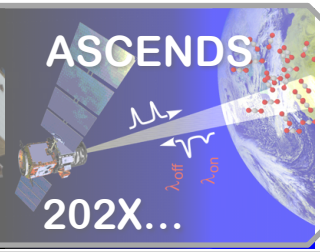




LATER*







Summary

- OCO-2 was successfully launched on 2 July 2014, and started its first extended mission on October 16, 2016
  - Now returning about 100,000 full-column measurements of X_{CO2} each day over the sunlit hemisphere
  - These products are being validated against TCCON and other standards to assess their accuracy

- Over 34 months of data have been delivered to the Goddard Earth Sciences Data and Information Services Center (GES-DISC) for distribution to the science community

  http://disc.sci.gsfc.nasa.gov/OCO-2

- These products are now being used by the CMS team and others in carbon cycle science community to identify and quantify the CO_2 sources and sinks on regional scales

Thank You for Your Attention

Questions?