IWGGMS-13, Helsinki

Existing space-based greenhouse gas measurement capabilities and near-term plans

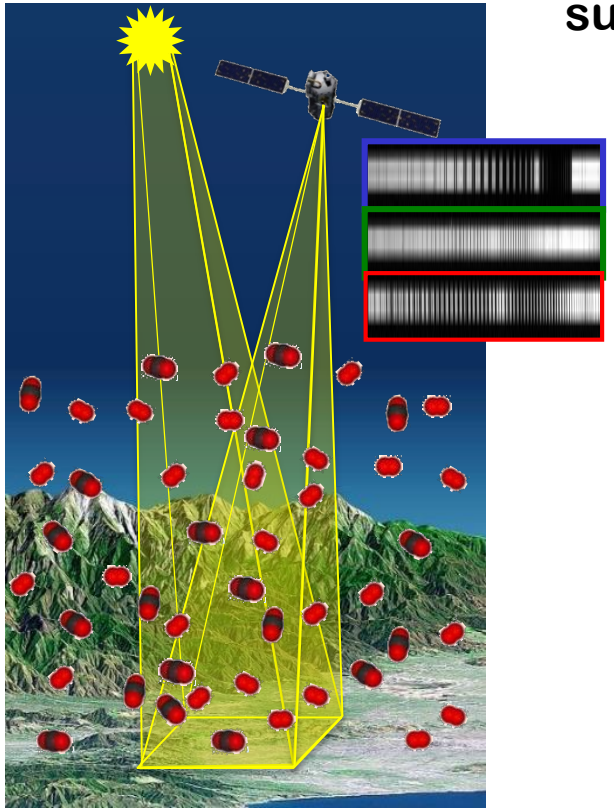
David Crisp, Jet Propulsion Laboratory, California Institute of Technology

6 June 2017

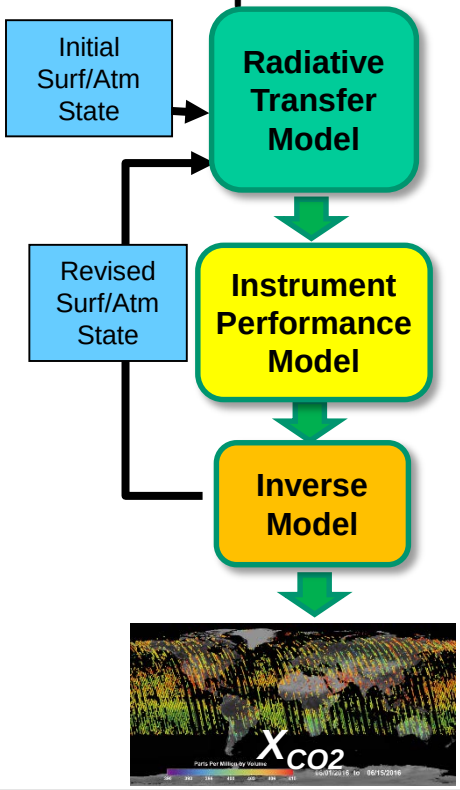
Copyright 2017 California Institute of Technology.
Government sponsorship acknowledged.

Measuring CO_2 from Space

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



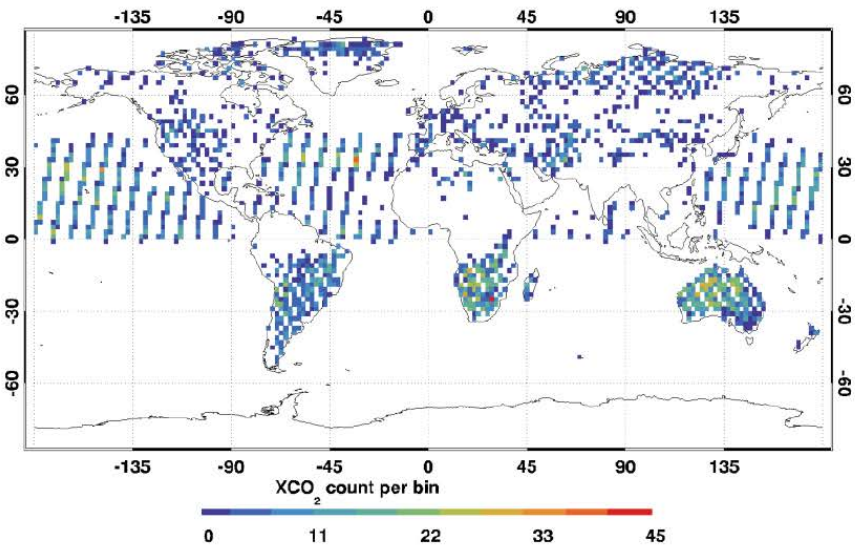
Retrieve variations in the **column averaged CO_2 dry air mole fraction, X_{CO2}** over the sunlit hemisphere



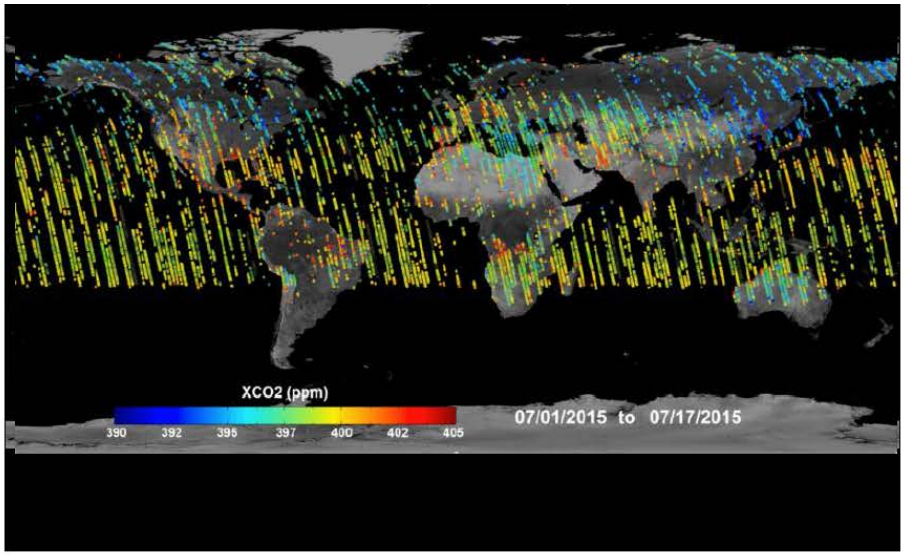
Validate measurements to ensure X_{CO2} accuracy of 1 ppm (0.25%)

Retrieving X_{CO2} from GOSAT and OCO-2 Data

GOSAT



OCO-2

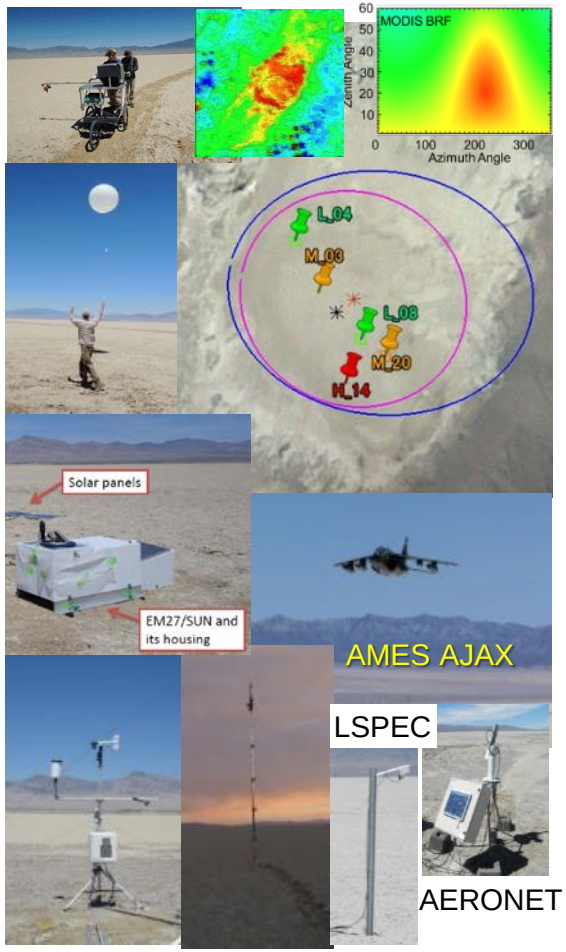


GOSAT TANSO-FTS has been returning data since April 2009. The ACOS/GOSAT team has been using these data to retrieve X_{CO2}.

OCO-2 has been returning data since September 2014. The ACOS/GOSAT algorithm has been modified to retrieve X_{CO2} from these data.

Creating a Combined Data Product: the OCO-2/GOSAT Collaboration

Vicarious Calibration

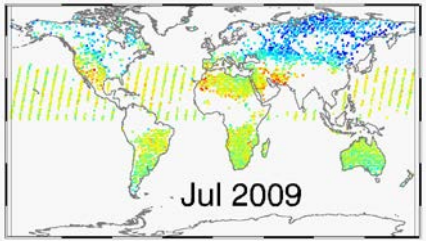


Retrieval Algorithm

Forward Radiative Transfer Model
Spectra + Jacobians

Instrument Model
Spectral+Polarization

Inverse Model
- Compare obs. & simulated spectra
- Update State Vector

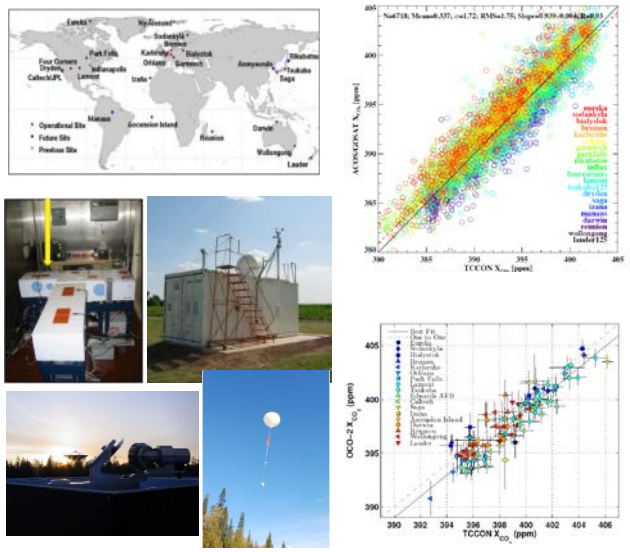


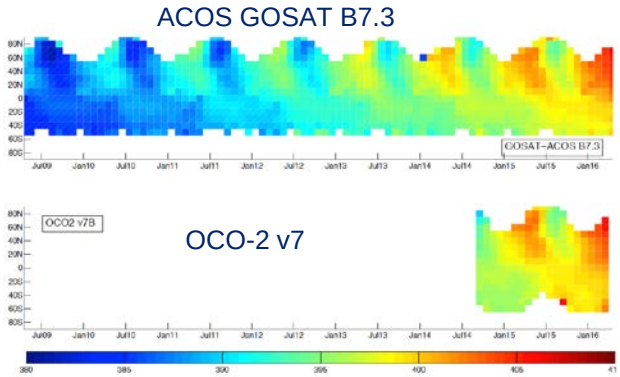
not converged

?

converged

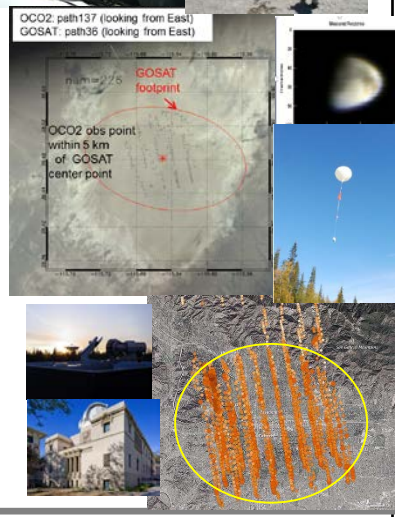
Cross Validation



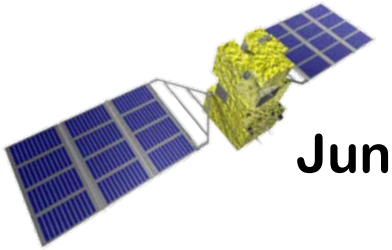


Lessons Learned from GOSAT and OCO-2: Cross-Calibration and Cross Validation

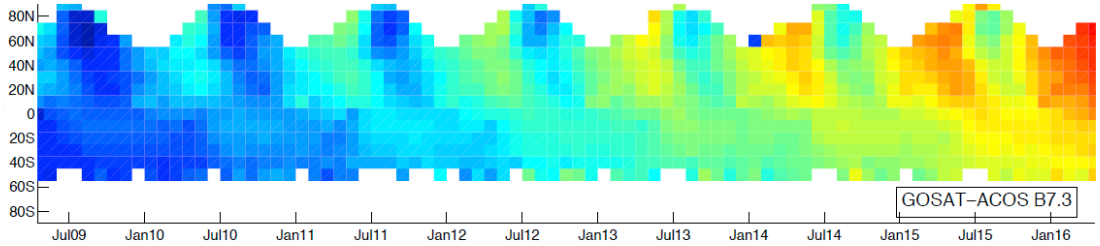
- Pre Launch:
  - Exchange information on best practice for pre-launch instrument characterization
  - Cross calibration of pre-launch radiometric standards
  - Exchange of gas absorption coefficient and solar data
  - Retrieval algorithm development/intercomparison
  - Validation system development (TCCON, aircraft)
  - Multi-Satellite OSSE's – what do you gain with truly coordinated observations
- Post Launch:
  - Cross calibration of solar/lunar/Earth(vicarious: RRV+?) observations
  - Including exchange of solar and lunar standards
  - Cross validation: TCCON, EM27/Sun, and aircraft validation campaigns
  - Continued retrieval algorithm development/intercomparisons

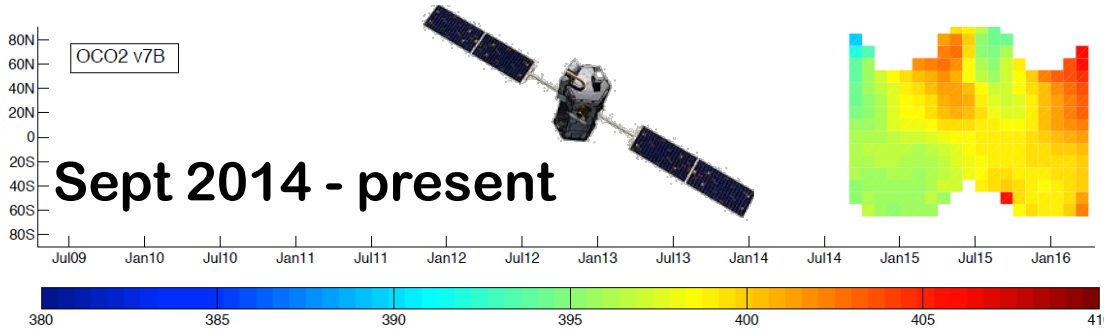


Lessons Learned from the GOSAT/OCO-2 Collaboration



June 2009 - present

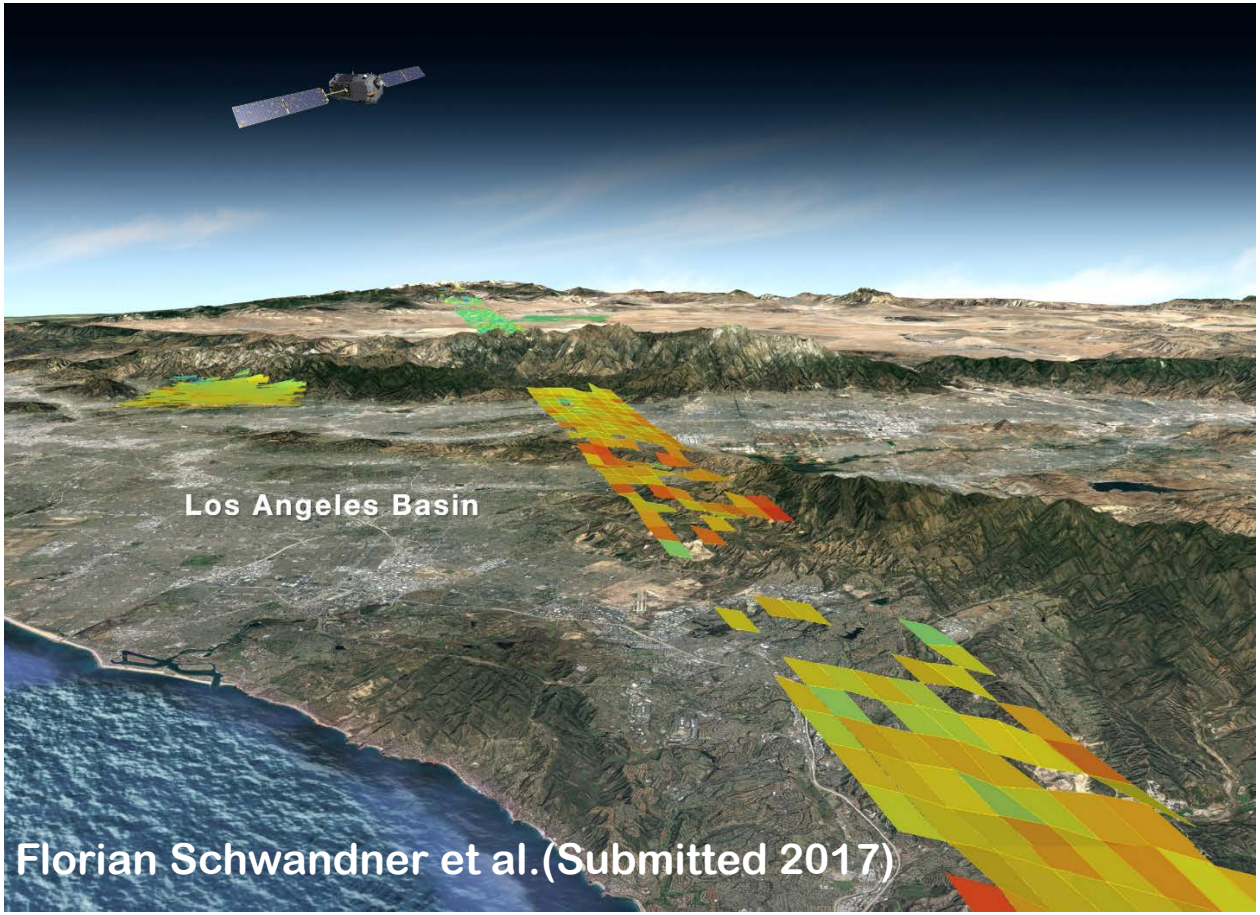




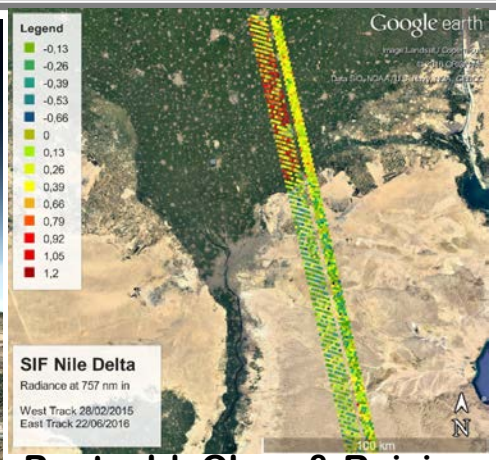
TCCON and other standards have been used to cross validate OCO-2 and GOSAT X_{CO2} to extend the climate data record

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

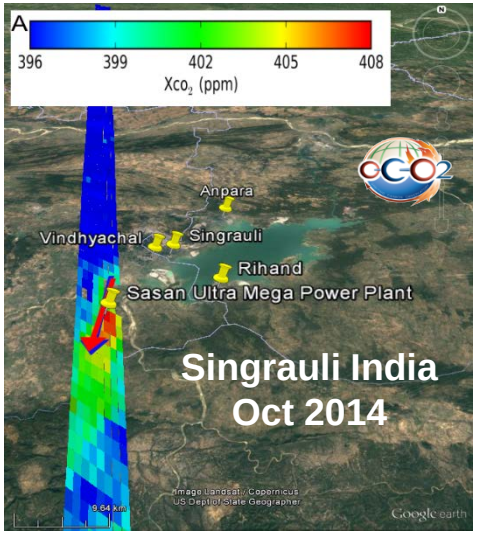
Quantifying Localized Sources



Florian Schwandner et al.(Submitted 2017)



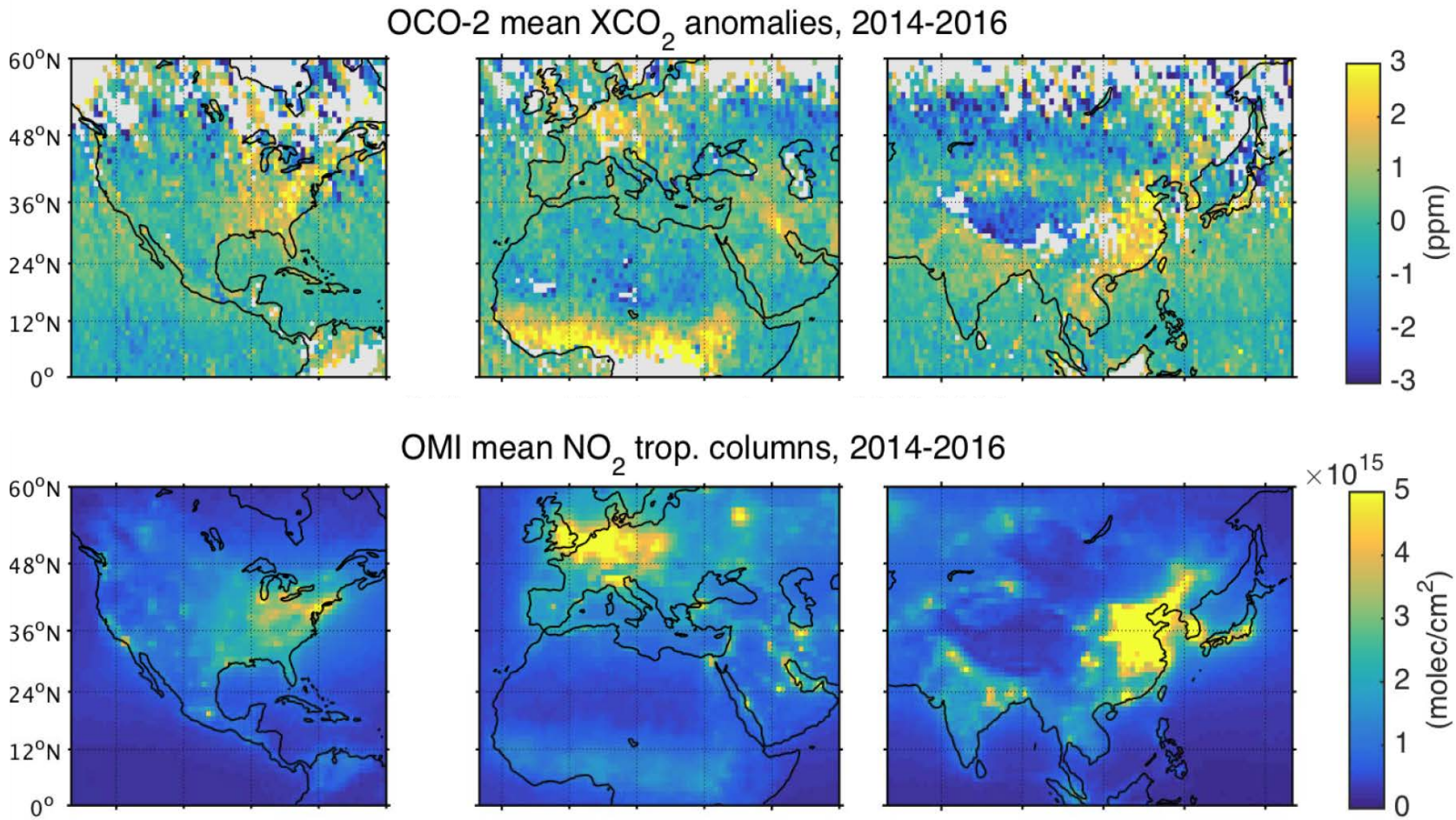
Paetzold, Chen & Ruisinger



Nassar et al.(Submitted 2017)

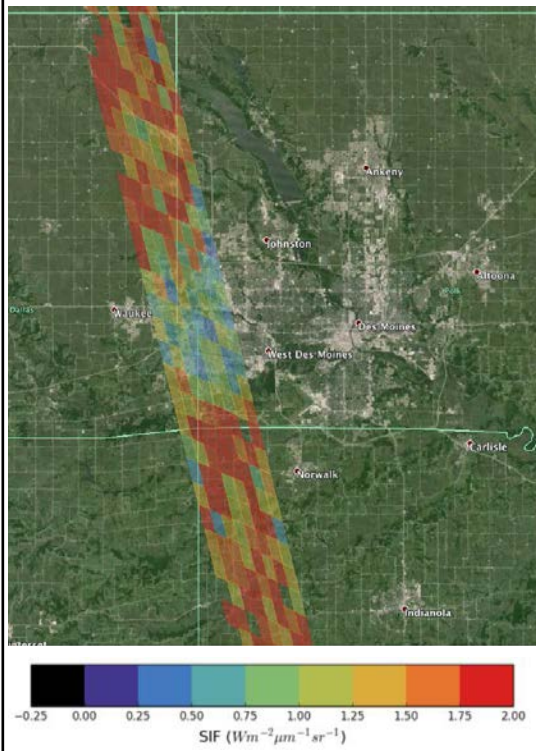
High spatial resolution and full coverage are critical for quantifying localized sources

Anthropogenic Emissions

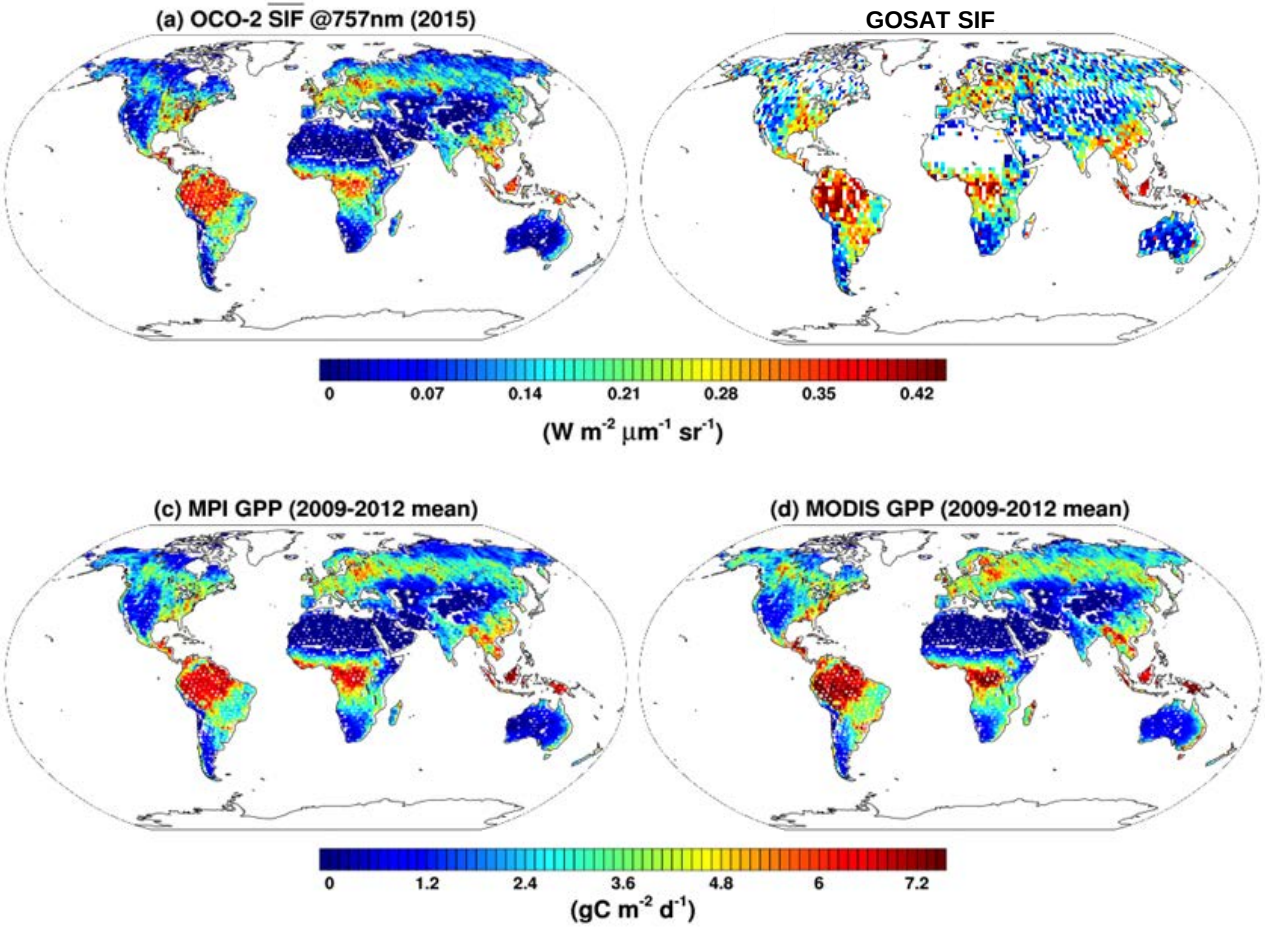


Janne Hakkarainen et al. GRL (2016)

Solar Induced Chlorophyll Fluorescence (SIF)



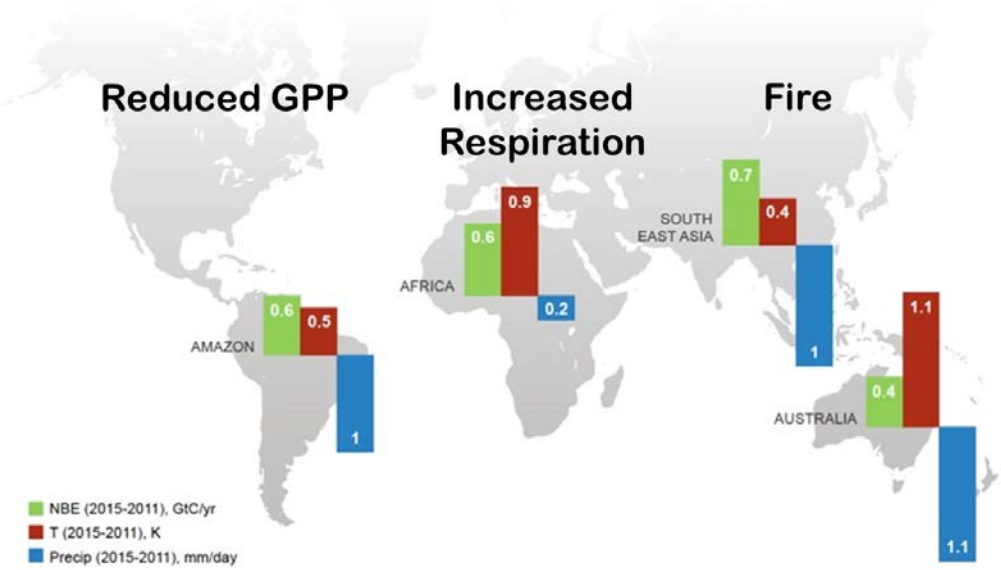
OCO-2 SIF over Des Moines, Idaho



Sun et al. (submitted to Science 2017)

Biospheric Fluxes: Relative Roles of heat, drought and fires in 2015 El Niño

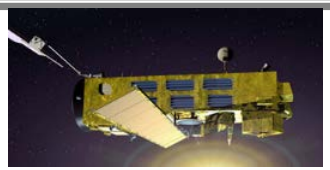
- **Question**: Are fires, high temperatures or drought responsible for increases in carbon release during El Niños?
- **Approach**: X_{CO2} and SIF estimates from OCO-2 and GOSAT were combined with satellite MOPITT CO measurements and other data
- **Results**: In South America, plants went dormant due to heat and drought; in Africa, high temperatures enhanced plant respiration; in Asia, drought and heat increased the intensity of fires



Significance: OCO-2 and GOSAT provide the first direct constraints of the relative roles of heat, drought, and fires on the regional CO_2 exchange during El Niño years.

Liu et al. (Submitted to Science 2017)

Remote Sensing of CO_2 and CH_4 using Reflected Sunlight: The Pioneers



- **SCIAMACHY (2002-2012)** – First sensor to measure O_2, CO_2, and CH_4 using reflected NIR/SWIR sunlight
  - Regional-scale maps of X_{CO2} and X_{CH4} over continents

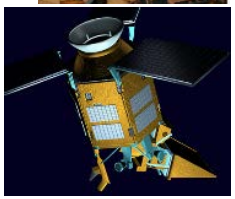
- **GOSAT (2009 - ?)** – First Japanese GHG satellite
  - FTS optimized for hgh spectral resolution over broad spectral range, yielding CO_2, CH_4, and chlorophyll fluorescence (SIF)

- **OCO-2 (2014 - ?)** – First NASA satellite to measure O_2 and CO_2 with high sensitivity, resolution, and coverage
  - High resolution imaging grating spectrometer small (< 3 km^2) footprint and rapid sampling (10^6 samples/day)

- **TanSat (2016-?) -** First Chinese GHG satellite
  - Imaging grating spectrometer for O_2 and CO_2 bands and cloud & aerosol Imager: 0.38, 0.67, 0.87, 1.38 and 1.61μm channels

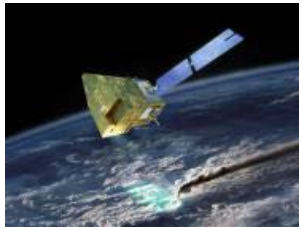
Remote Sensing of CO_2 and CH_4: The Next Generation

- **Feng Yun 3D (2017)** – Chinese GHG satellite on operational meteorological bus
  - GAS FTS for O_2, CO_2, CH_4, CO, N_2O, H_2O
- **Gaofen 5 (2017)** - 2nd Chinese GHG Satellite
  - **Spatial heterodyne spectrometer for O_2, CO_2, and CH_4**
- **Sentinel 5p (2017)** - Copernicus pre-operational Satellite
  - TROPOMI measures O_2, CH_4 (1%), CO (10%), NO_2, SIF
  - Imaging at 7 km x 7 km resolution, daily global coverage
- **OCO-3 (2018)** – NASA OCO-2 spare instrument, on ISS
  - First solar CO_2 sensor to fly in a low inclination, precessing orbit
- **GOSAT-2 (2018)** – Japanese 2nd generation satellite
  - CO as well as CO_2, CH_4, with improved precision (0.125%), and active pointing to increase number of cloud free observation



Future GHG Satellites

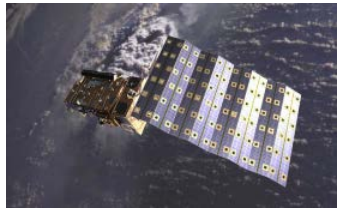
- **CNES MicroCarb (2020)** – compact, high sensitivity
  - Imaging grating spectrometer for O_2 A, O_2 $^1\Delta_g$, and CO_2
  - ~1/2 to 1/3 of the size, mass (< 200 kg) of OCO-2, with similar sensitivity in 4.5 km x 9 km footprints



- **CNES/DLR MERLIN (2021)** - First CH_4 LIDAR (IPDA)
  - Precise (1-2%) X_{CH4} retrievals for studies of wetland emissions, inter-hemispheric gradients and continental scale annual CH_4 budgets

- **NASA GeoCarb (2022)** – First GEO GHG satellite
  - Imaging spectrometer for XC_{O2}, X_{CH4}, X_{CO} and SIF
  - Stationed above 85° E for North/South America

- **Sentinel 5A,5B,5C (2022) - Copernicus operational services for air quality and GHG**
  - Daily global maps of X_{CO} and X_{CH4} at < 8 km x 8 km



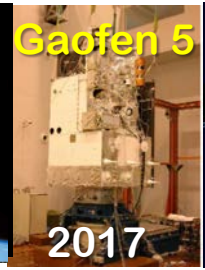
Evolving Carbon Measurement Capabilities

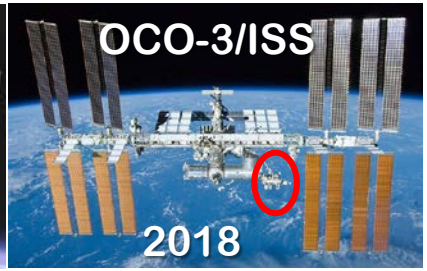
- TanSat Successfully Launched on 22 Dec 2016
- NASA Earth Ventures GeoCarb Selected
- CNES MicroCarb Approved for Implementation

PAST

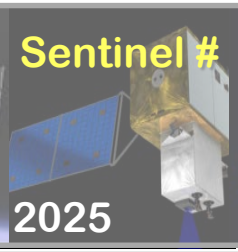
PRESENT

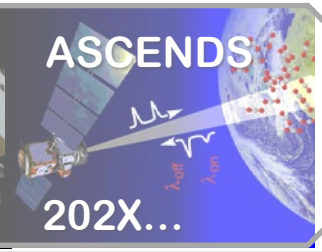
NEAR FUTURE





LATER





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, OCO-2 and TanSat missions are beginning to demonstrate these capabilities
  - GOSAT and OCO-2 teams have pioneered methods for cross-calibrating measurements and cross-validating products
  - Their products have been combined to produce an 8-year record that is now being used in studies of the global carbon cycle
- Over the next decade, a succession of missions with a range of CO_2 and CH_4 measurement capabilities will be deployed
  - Much greater benefits could be achieved if these sensors can be cross-calibrated and their products can be cross-validated so that they can be combined into a long, continuous GHG data record

Thank You for Your Attention

Questions?