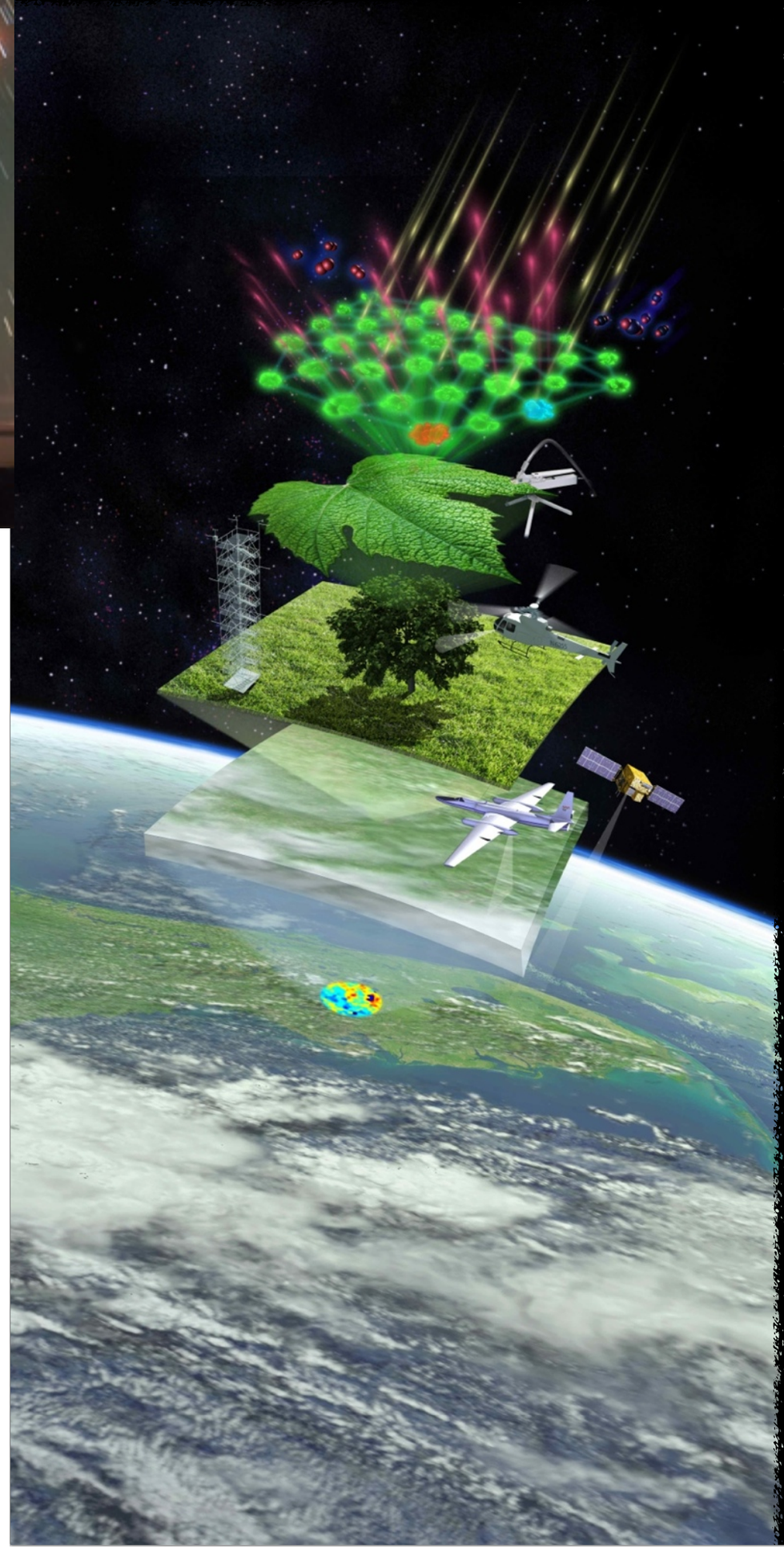
http://www.jeffsullivanphotography.com/

OCO-2/3

A global view on carbon dioxide and solar induced chlorophyll fluorescence

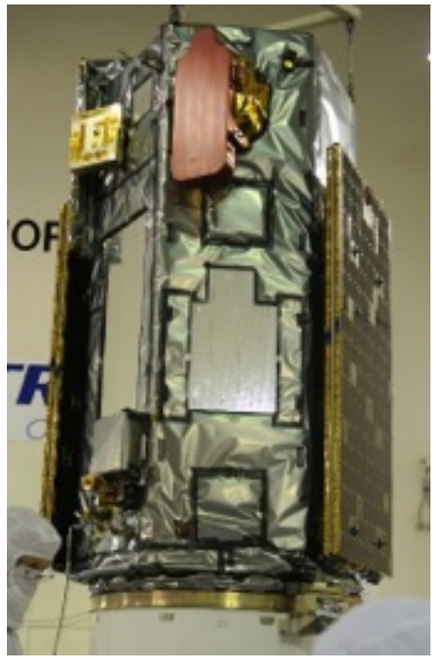
Christian Frankenberg, on behalf of the OCO-2/3 and TCCON teams



The OCO-2 Mission Architecture

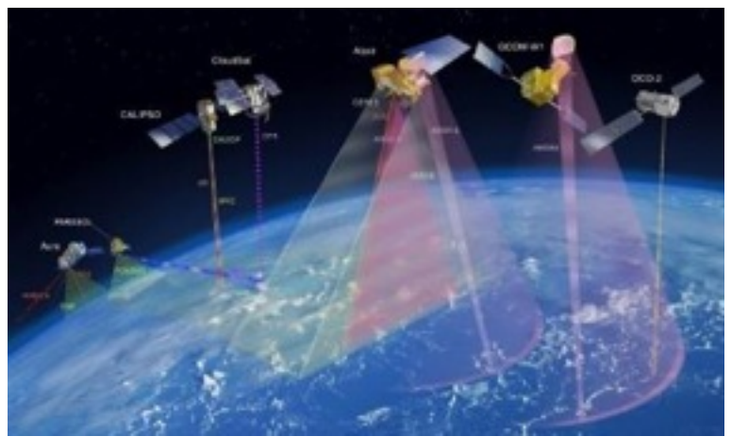
3-Channel Grating Spectrometer

Dedicated Spacecraft



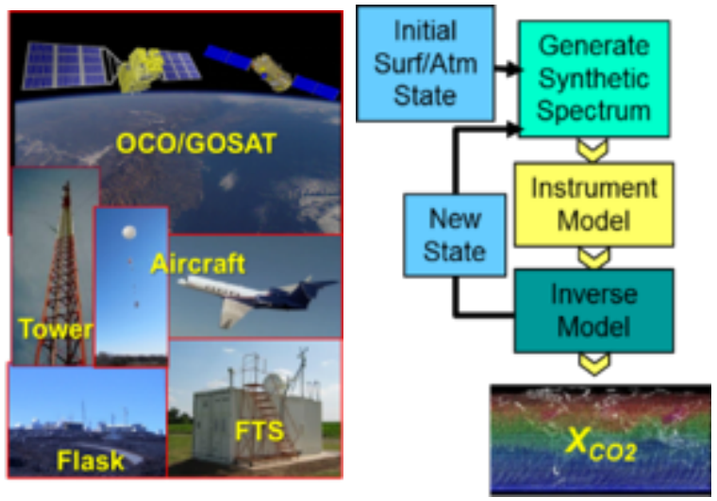
Delta-II Launch Vehicle

Formation Flying in the A-Train Constellation



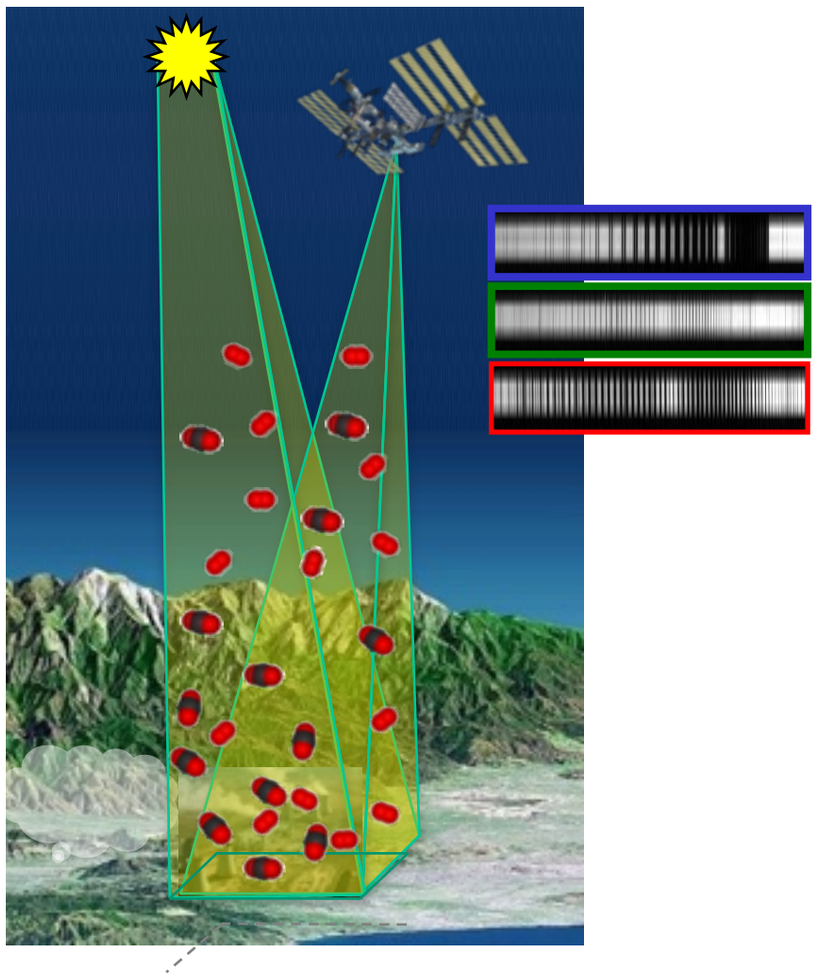
Data Transmitted to NASA NEN and SN

Data Product Generation

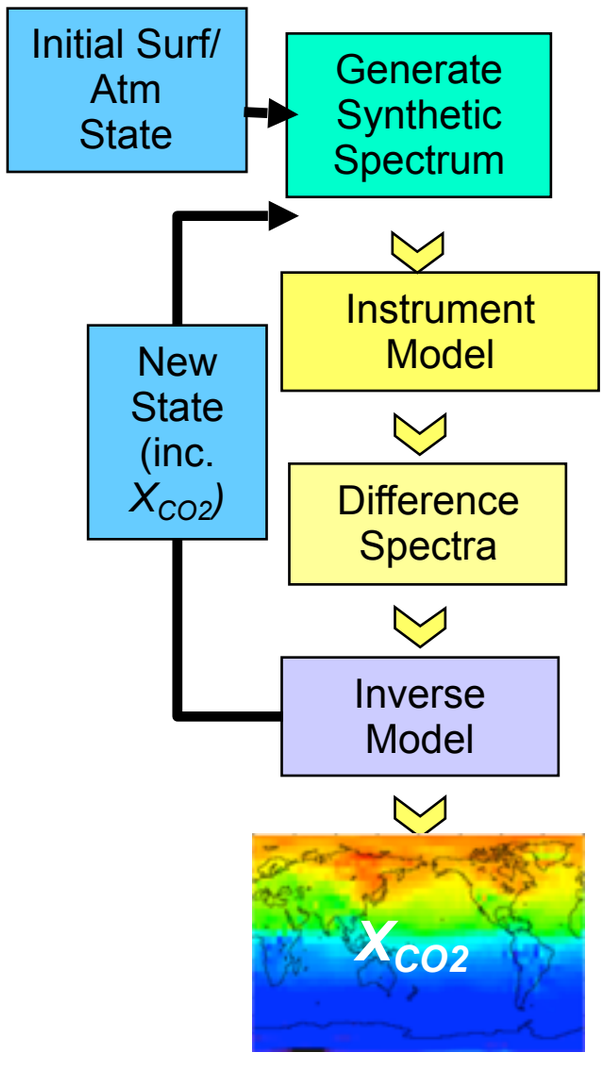


Measurement Approach – OCO-2/3

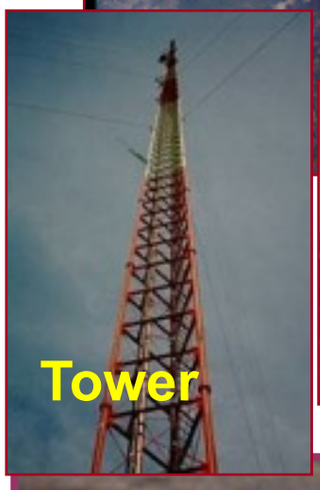
Collect spectra of CO_2 & O_2 absorption in reflected sunlight over the globe



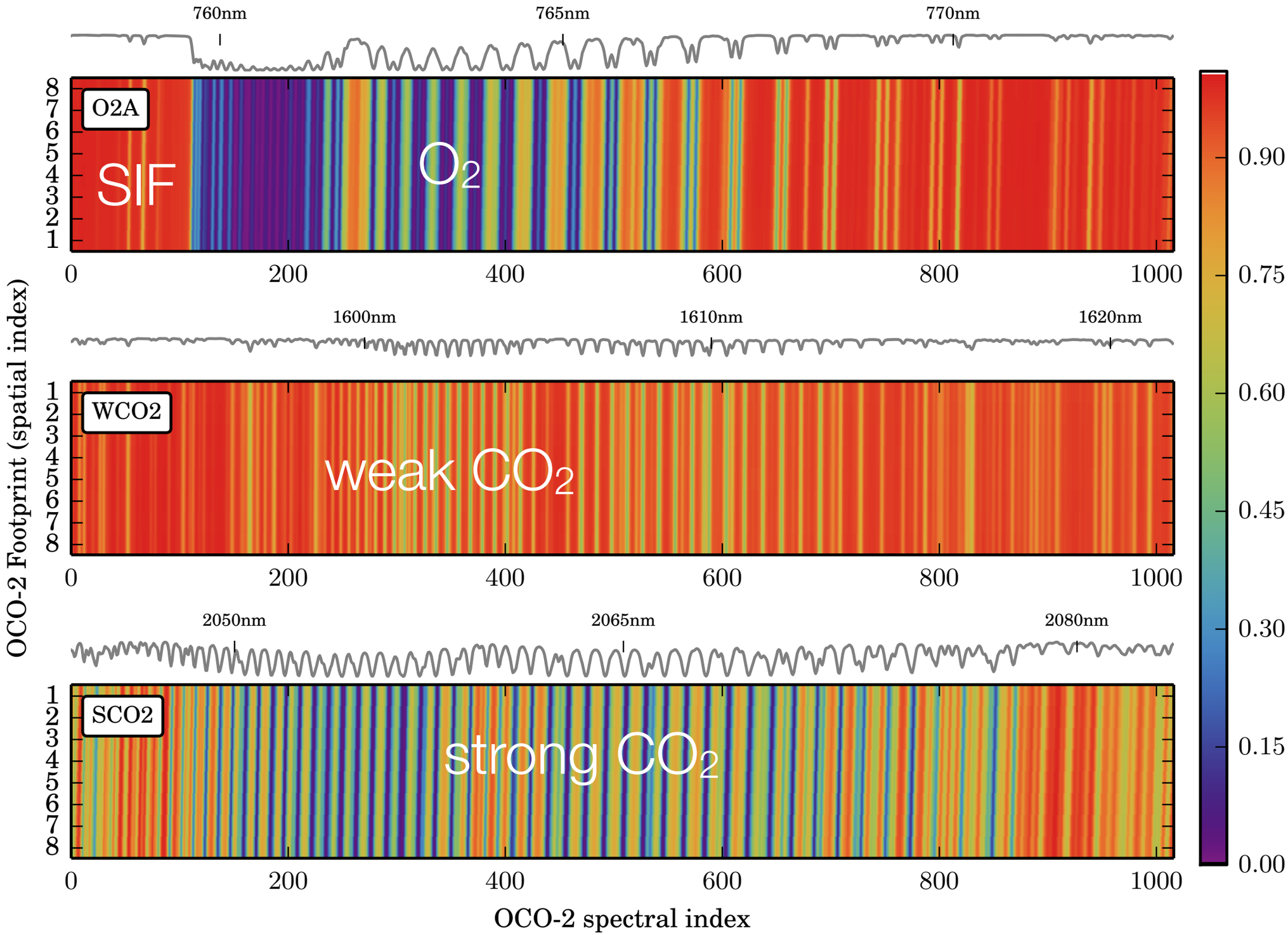
Retrieve variations in the *column averaged CO_2 dry air mole fraction, X_{CO2}* over sunlit hemisphere



Validate measurements to ensure X_{CO2} precision of 1 - 2 ppm (0.3 - 0.5%)

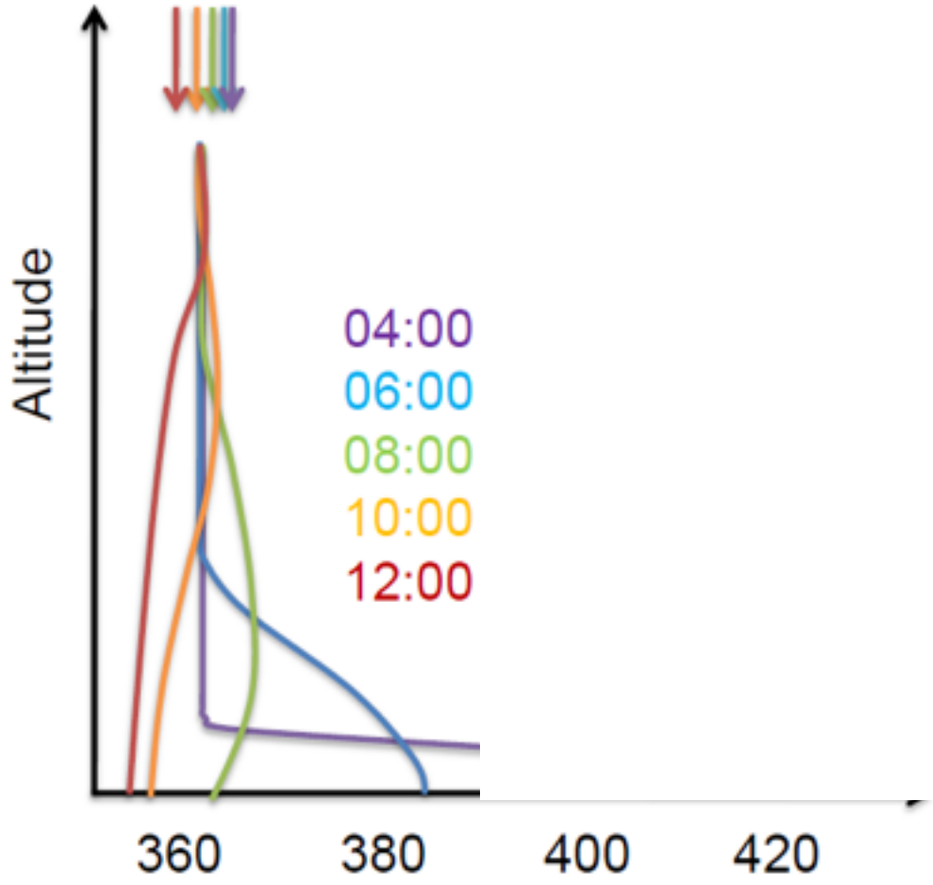


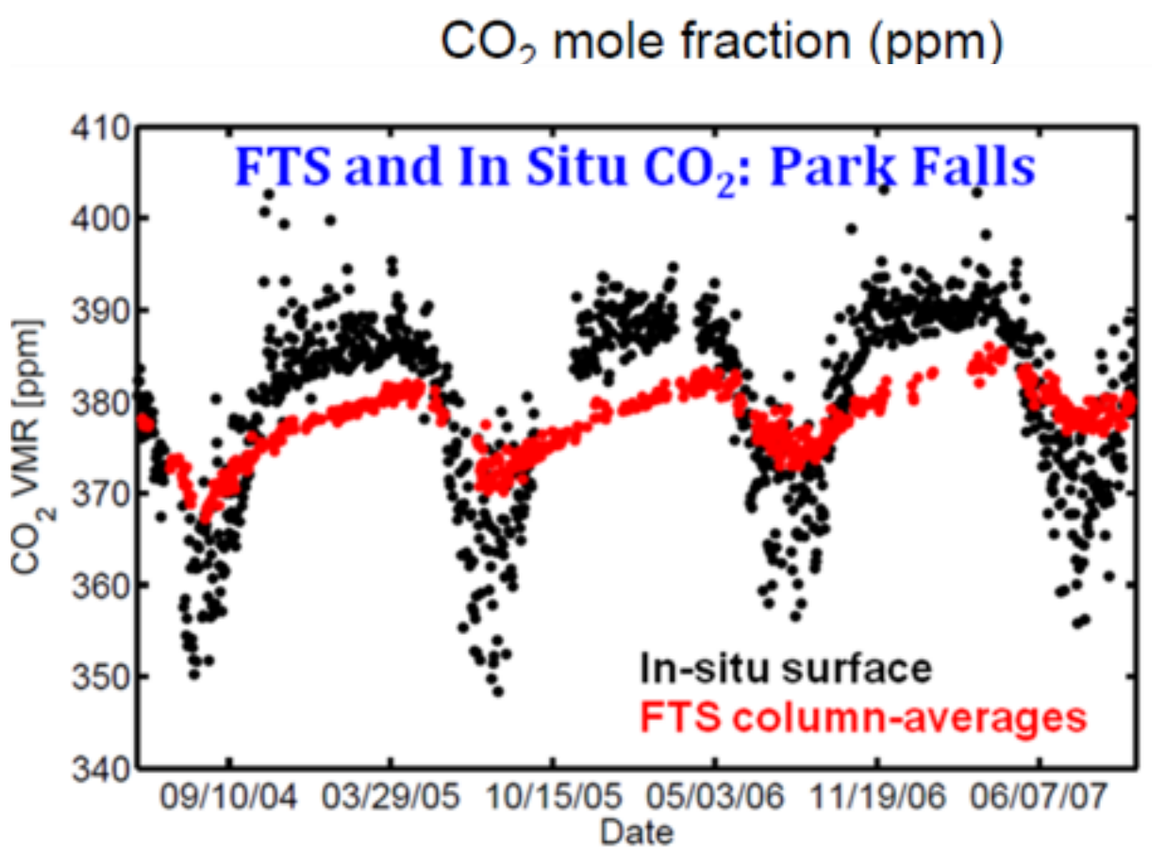
What does OCO-2/3 measure? Reflected sunlight in 3 spectral bands yield column averaged CO_2



Column Measurements of CO_2

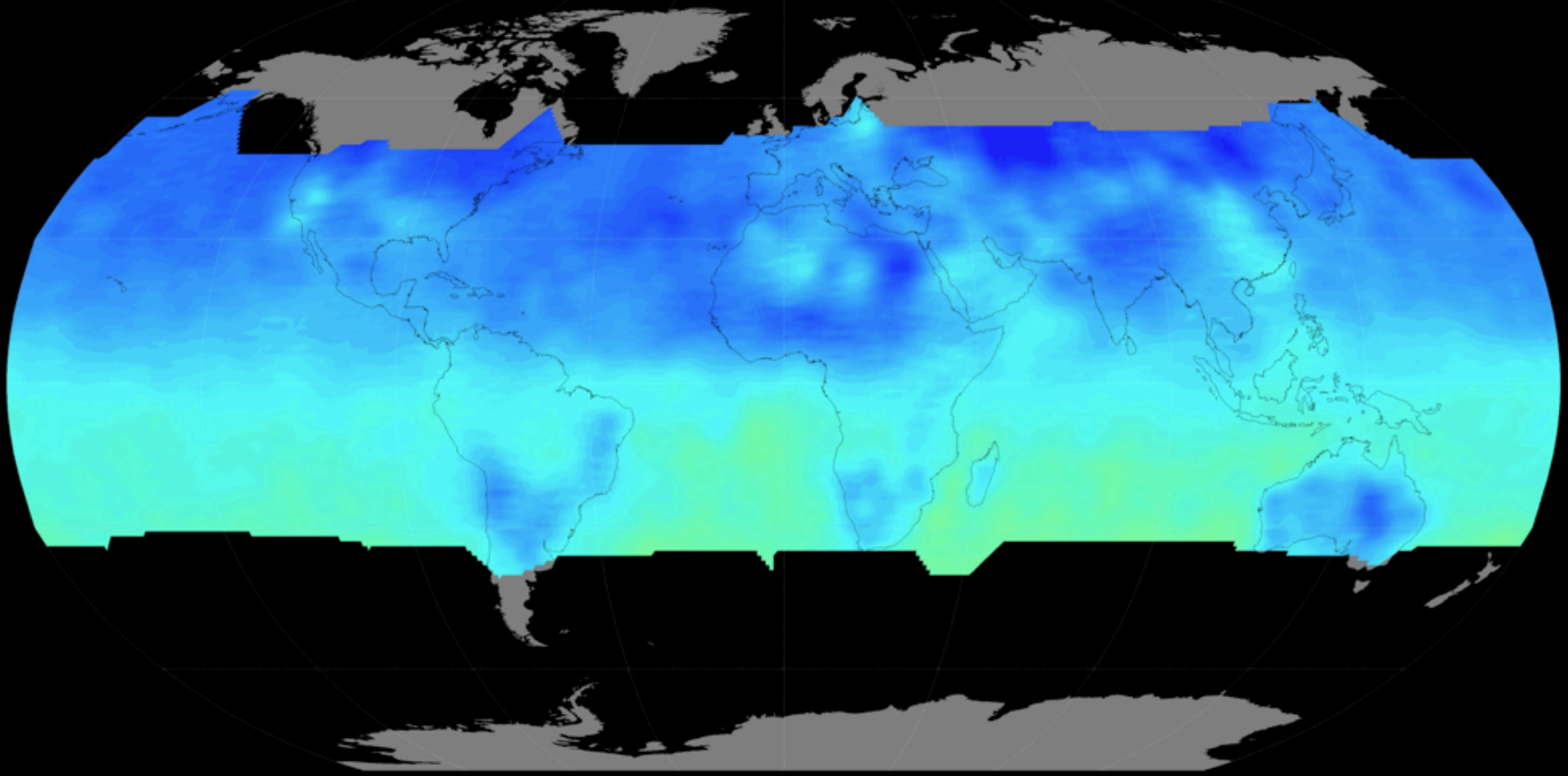
- The CO_2 profile is affected by:
  - Photo-synthesis (removes CO_2)
  - Respiration (produces CO_2)
  - Vertical transport (re-distributes CO_2)
  - Advection
- The interplay of these processes causes the CO_2 profiles to vary diurnally
- Vertical arrows at the represent column-averaged CO_2 mole fractions.
- Their diurnal variation is much smaller than that of the surface CO_2 and much less sensitive to vertical transport.
- Column-averaged CO_2 is more directly related to regional surface exchange





Orbiting Carbon Observatory - 2

Atmospheric Carbon Dioxide Concentration (Sept 2014 – Sept 2015)

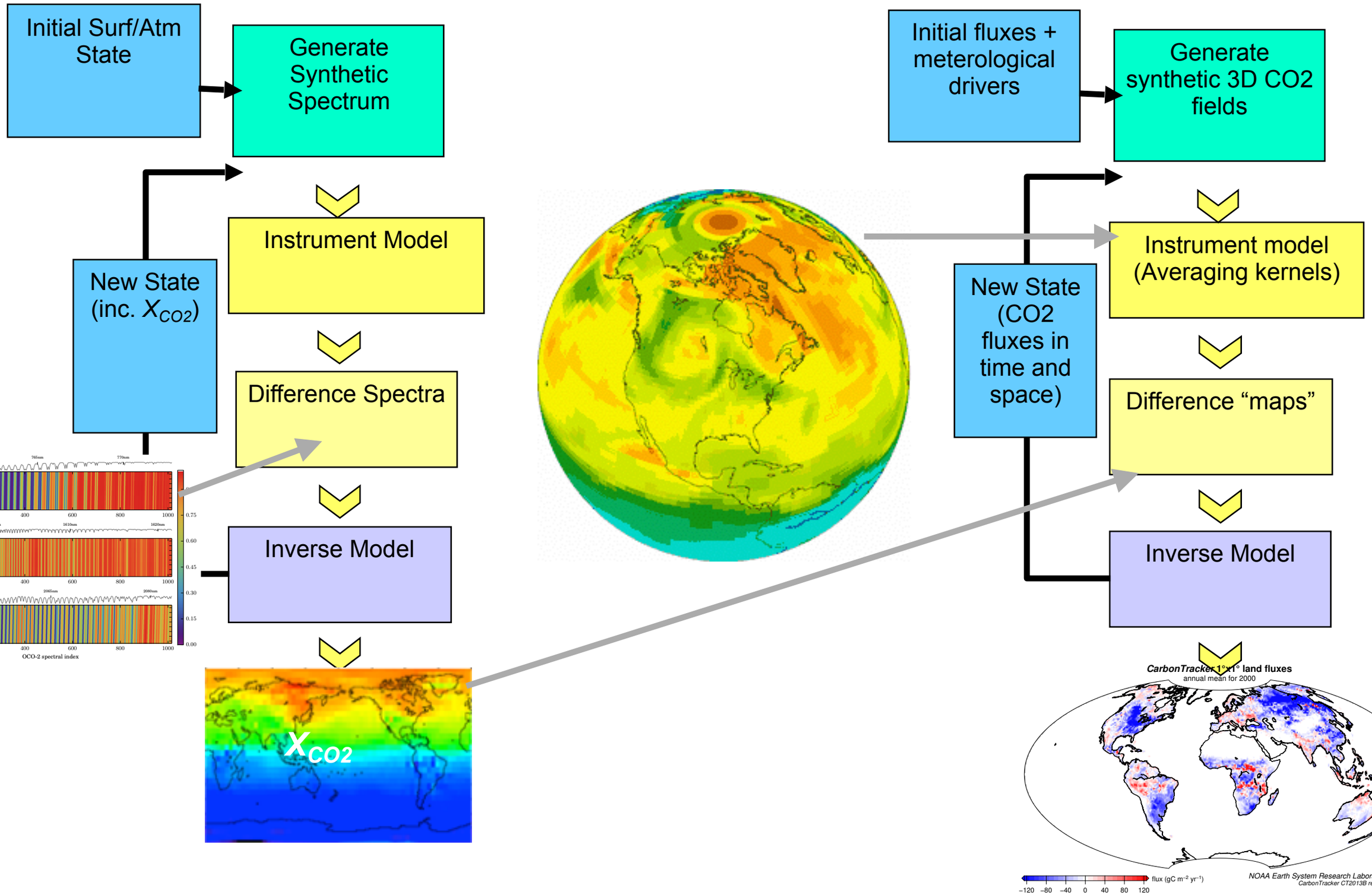


XCO2 Parts Per Million by Volume

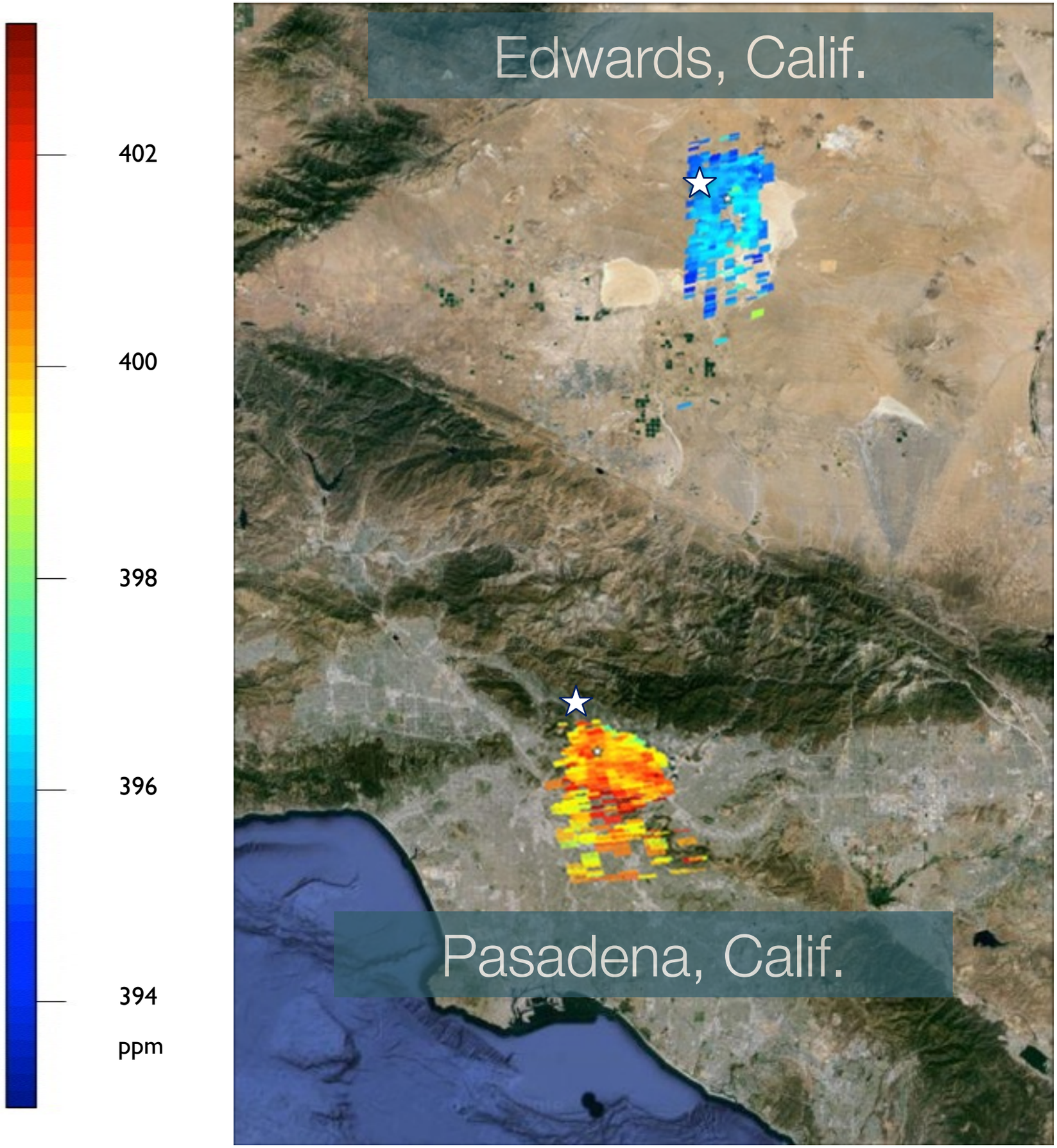
390 392 395 397 400 402 405

Global level 3 Data 09/06/2014 to 09/23/2014

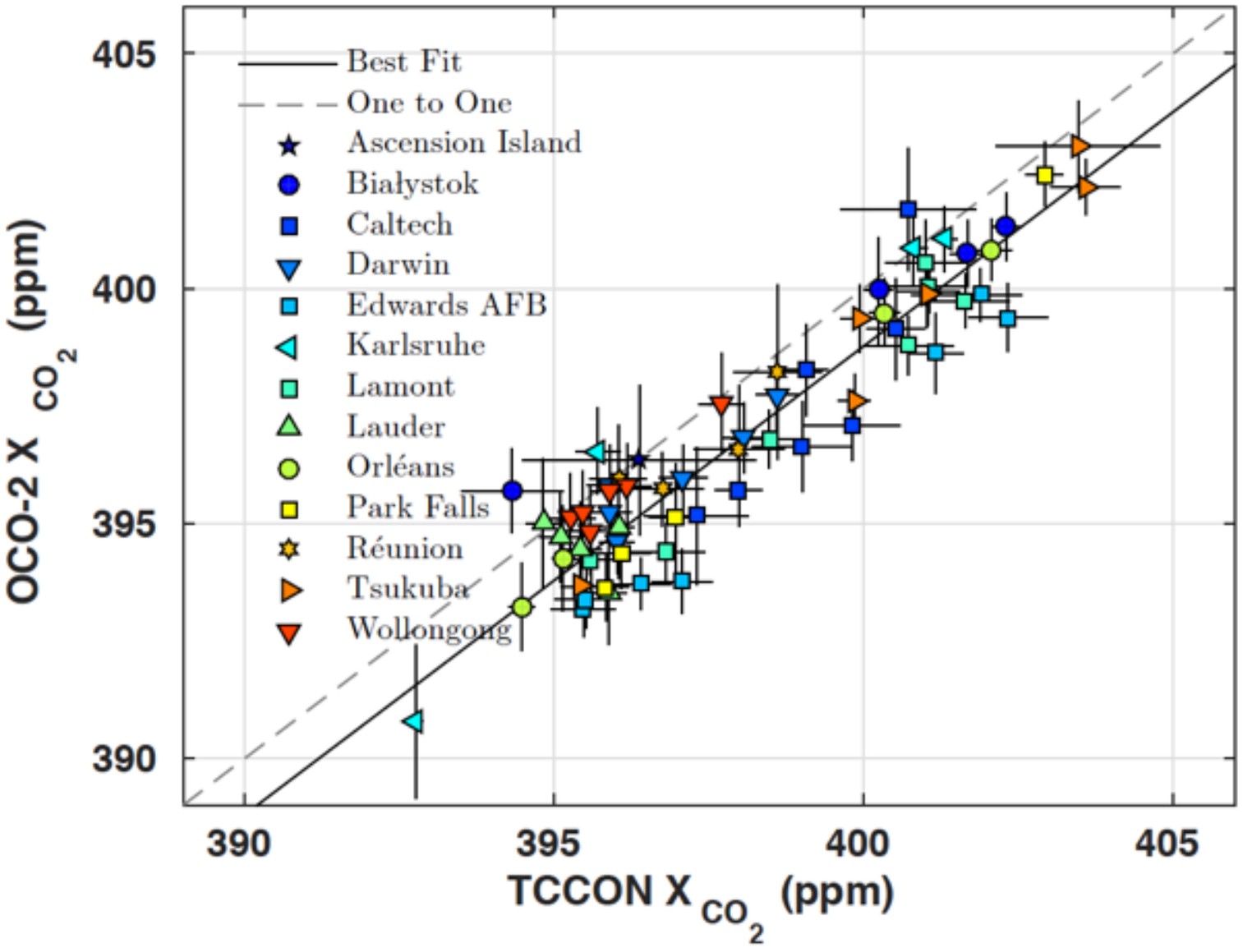
The next steps…



Validation



Comparison of TCCON and OCO-2 XCO2

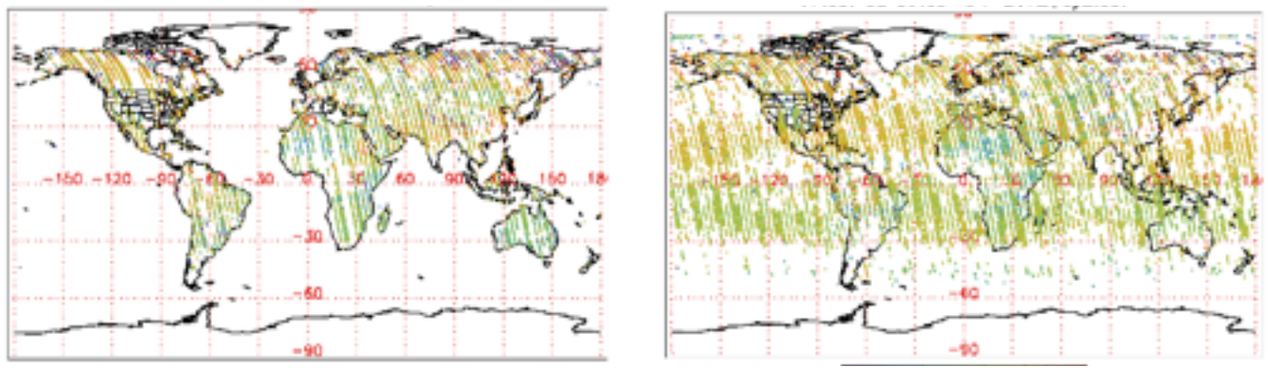


Comparisons with Total Carbon Column Observing Network (TCCON) stations are being used to identify and correct biases in target observations.

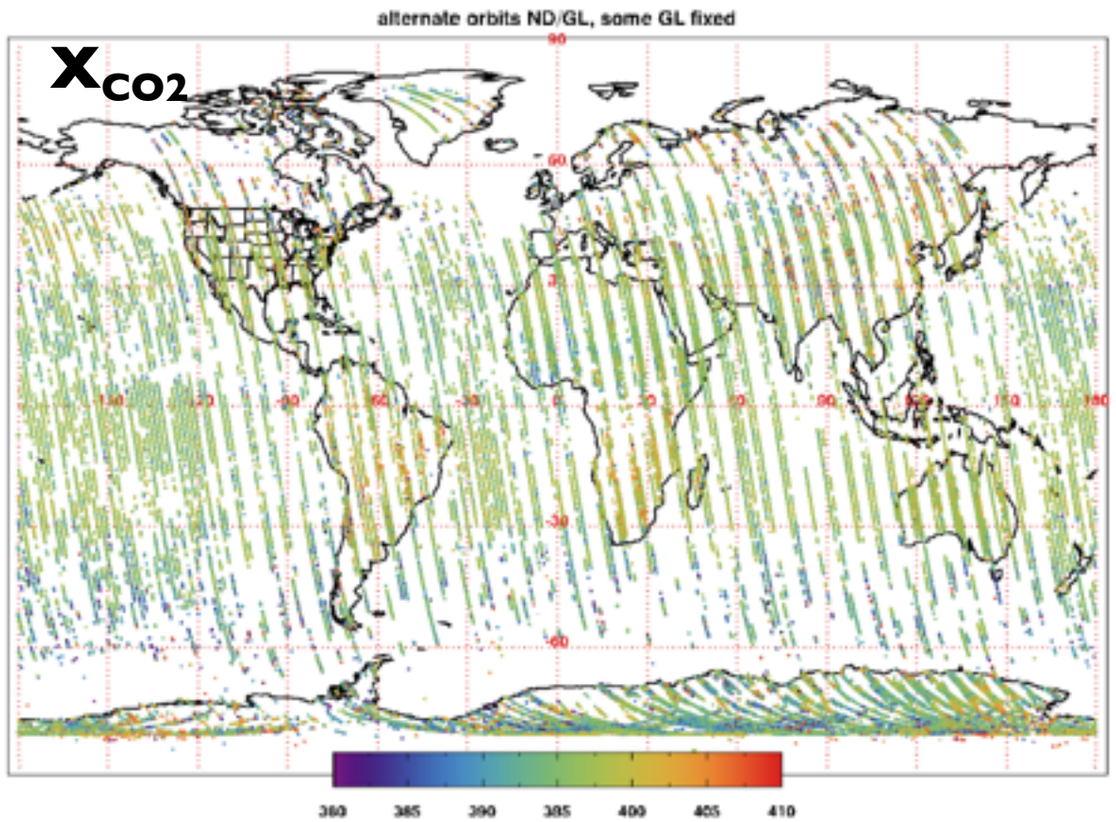
Differences between OCO-2 and TCCON X_{CO2} estimates were smaller than ~2 ppm (0.5%).

Changes in the Glint/Nadir Scheduling

Original Approach



Revised Approach



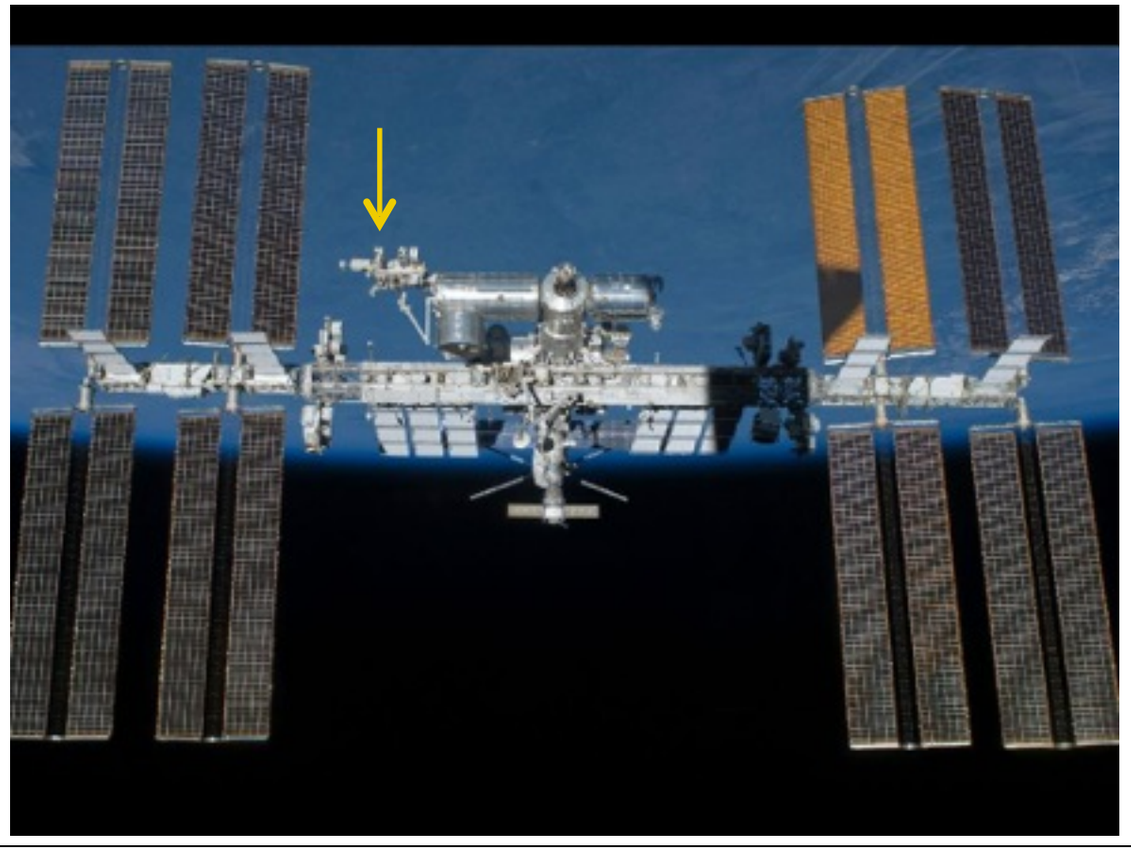
- Original sampling approach
  - –Alternates between glint and nadir on successive 16-day ground repeat cycles
  - –Precludes observations of oceans and high latitude continents for 16-day periods

- Revised glint/nadir strategy:
  - –Step 1: Alternate between glint and nadir on successive orbits that include both land & ocean
  - –Step 2: For orbits that are predominately over ocean, always stay in glint

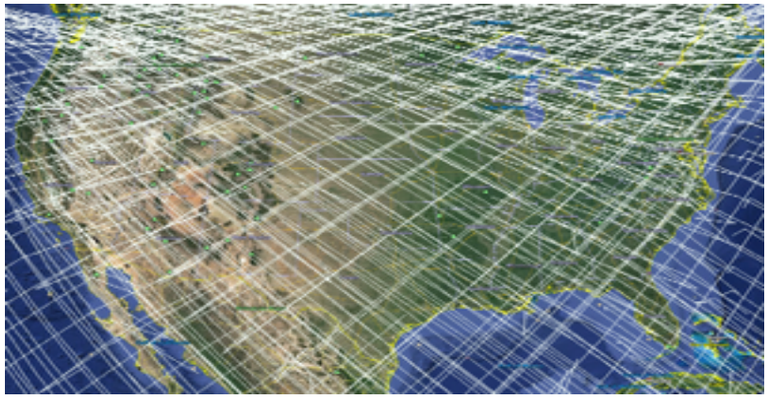
- Changes implemented in early summer 2015

What's next? … OCO-3 …

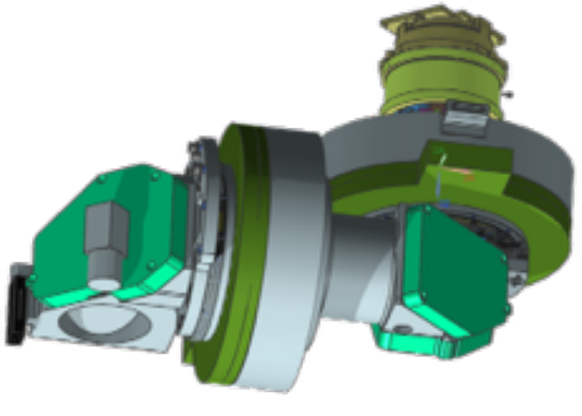
- The orbit of the International Space Station does not have a simple, repeating pattern
- Measurement time of days spans all sunlit hours
- OCO-3 on ISS would require a pointing mirror system to make validation measurements and to see the bright reflection off the ocean (glint). OCO-2 points the whole spacecraft to do this.



OCO-3 sampling varies in space and time



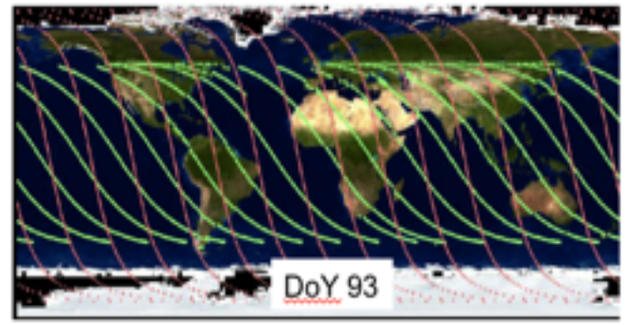
Pointing Mirror required for use in ISS

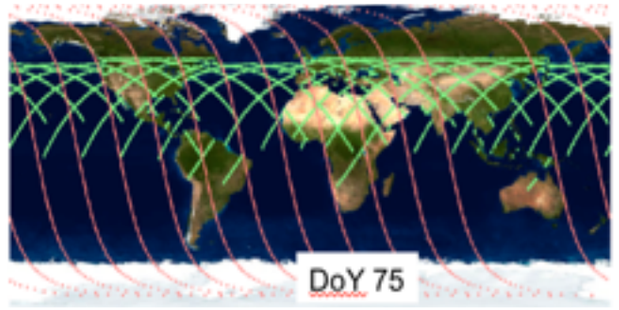


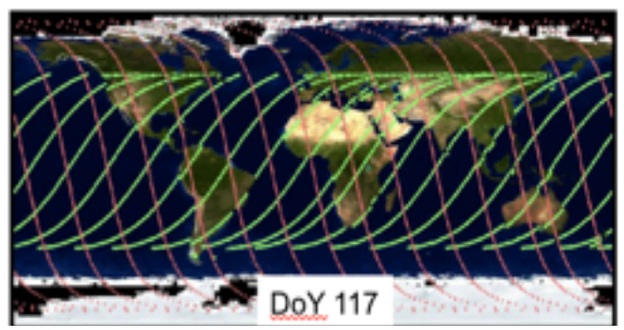
Comparison of OCO-2 and OCO-3

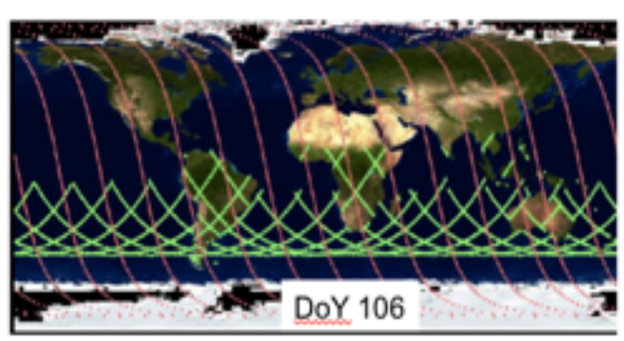
	OCO-2	OCO-3 on ISS
Latitudinal coverage	+/- 80 degrees	+/- 52 degrees (on ISS)
Local time of day sampling and repeat	~1:30pm with 16 day routine and repeated measurements	Ranges across all sunlit hours with variable revisit (0 to multiple per day)
Land Sampling	Every day (using glint and nadir measurements)	Every day (transition to nadir over land masses each orbit)
Glint/Ocean Sampling	16 days on/16 days off	Every day (transition to glint over oceans each orbit)
Target mode capability	Yes, with spacecraft pointing	Yes, expanded with pointing mirror assembly
Polarization approach	Keep instrument slit in principal plane (we thought.....)	Gather measurements over wide range of polarization angles

OCO-3 orbit tracks (in green)



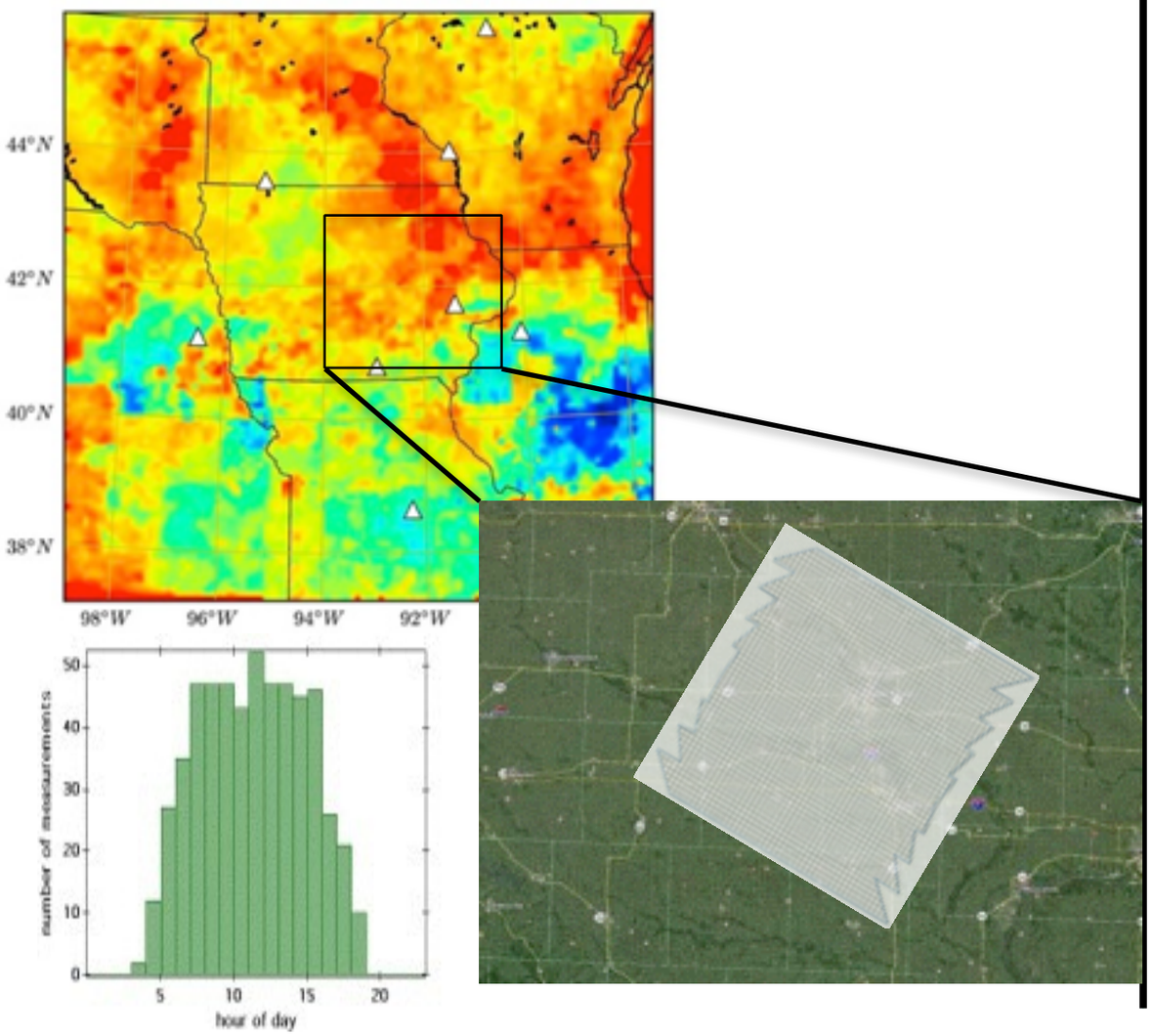






Terrestrial Carbon Cycle Processes can be Studied with Mapping Mode

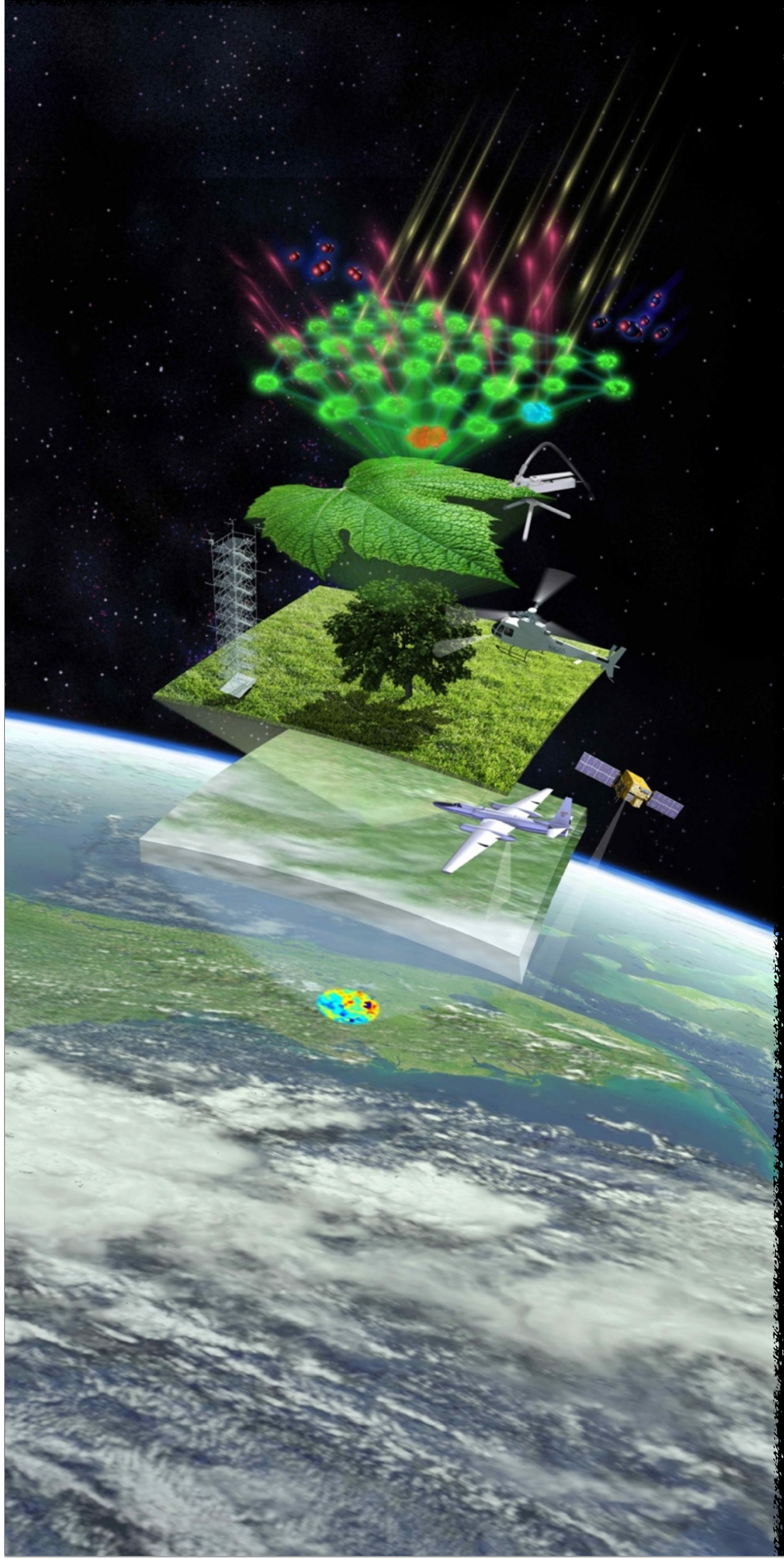
The Mid-Continent Intensive was a field campaign to study the uptake of CO_2 by crops. OCO-3 measurements would add a dense dataset at varying times of day to such process studies.



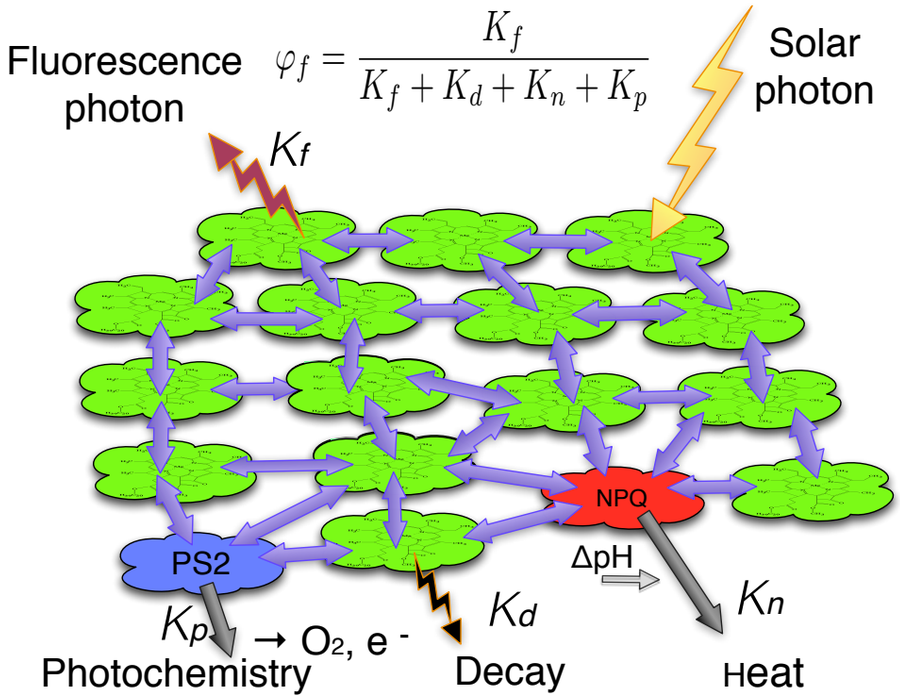
OCO-2 fluxes estimates are the size of states. Process studies are on scale of 1km. OCO-3 can aid in bridging between the process scale and the global scale

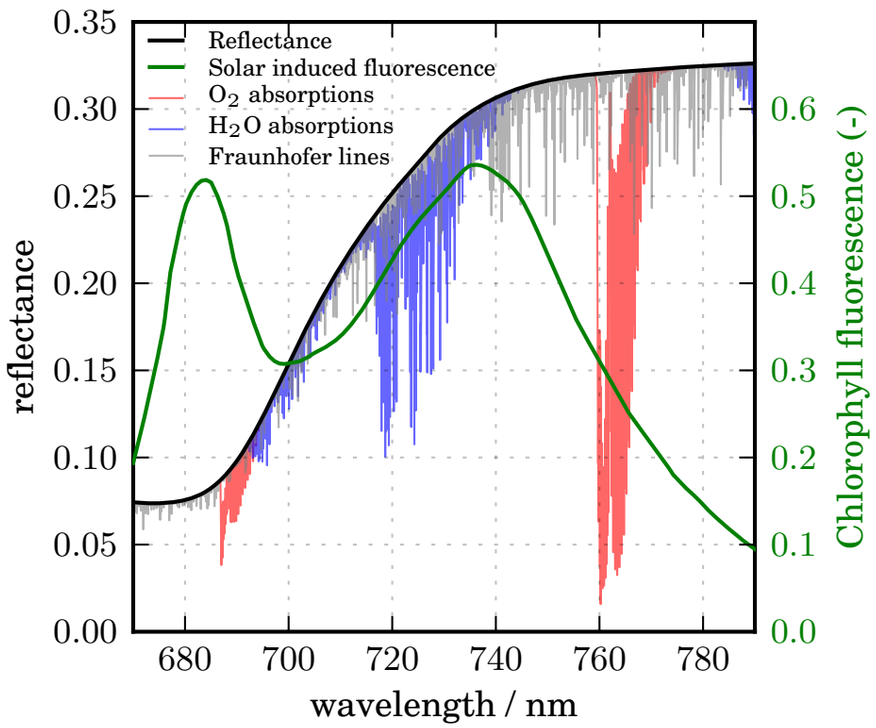
Targeted measurements of the Amazon would be possible every day, covering all sunlit hours over a month.
We could cover a wide area, or collect repeated measurements over a smaller region.

SIF - Solar Induced Chlorophyll Fluorescence



Solar-induced chlorophyll fluorescence (SIF) in a nutshell





- A fraction (1-2%) of absorbed photosynthetic active radiation (PAR) is always re-emitted as chlorophyll fluorescence

- The measured fluorescence at TOA is:

$$\mathrm{SIF} = \mathrm{PAR} \cdot \mathrm{fPAR} \cdot \epsilon_F$$

- This is similar to the expression of gross primary production:

$$\mathrm{GPP} = \mathrm{PAR} \cdot \mathrm{fPAR} \cdot \epsilon_P$$

- Hence:

$$\mathrm{GPP} = \mathrm{SIF} \cdot \frac{\epsilon_P}{\epsilon_F}$$

The carbon water cycle link -- water limitation

Flexas et al, 2002, PHYSIOLOGIA PLANTARUM
Daumard et al (IEEE)

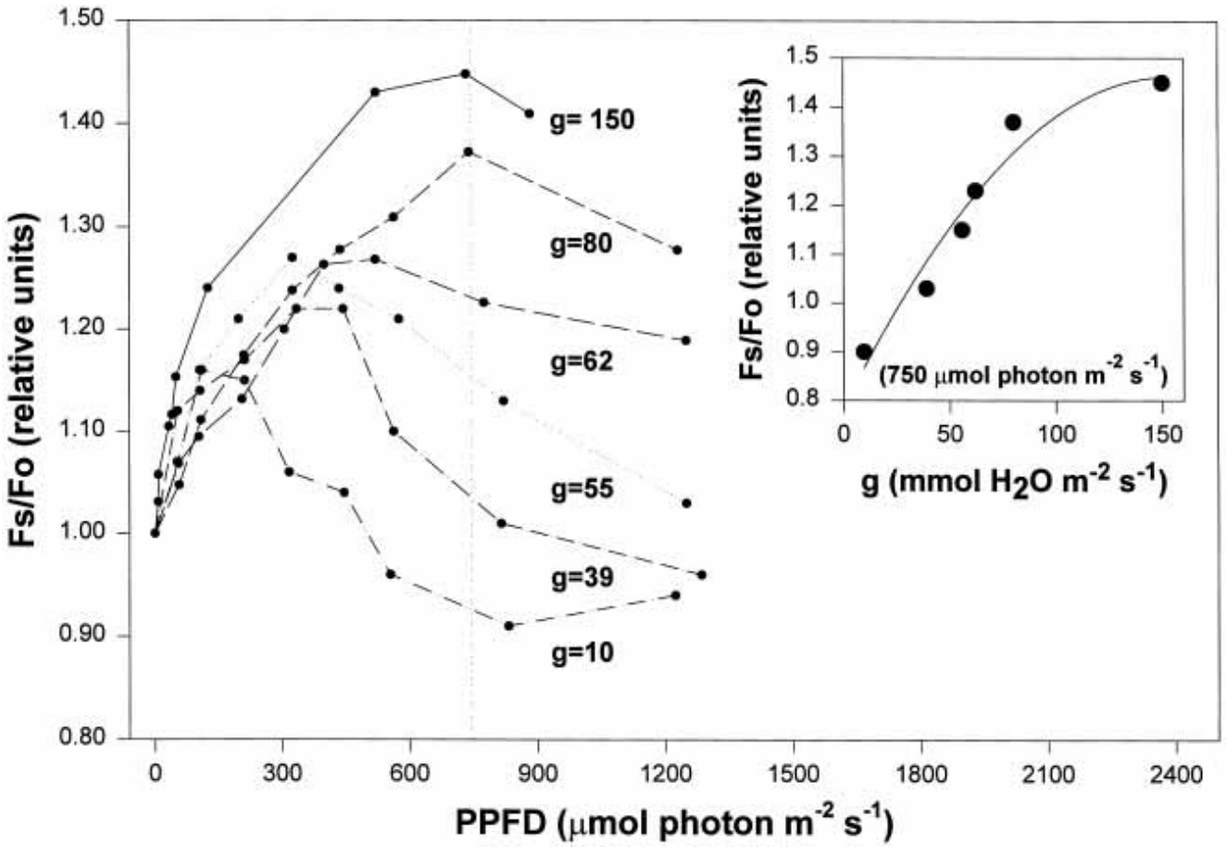
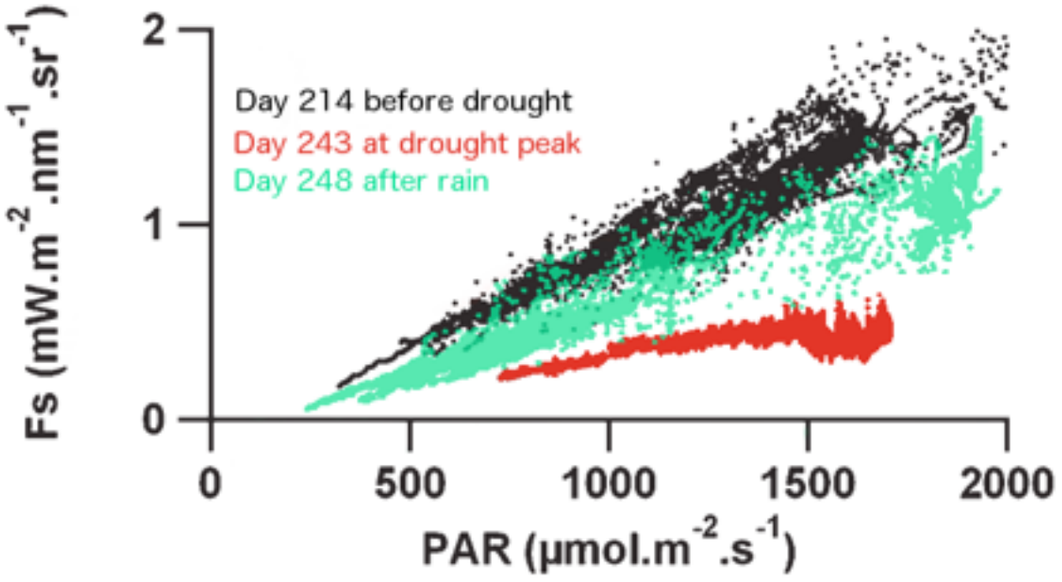


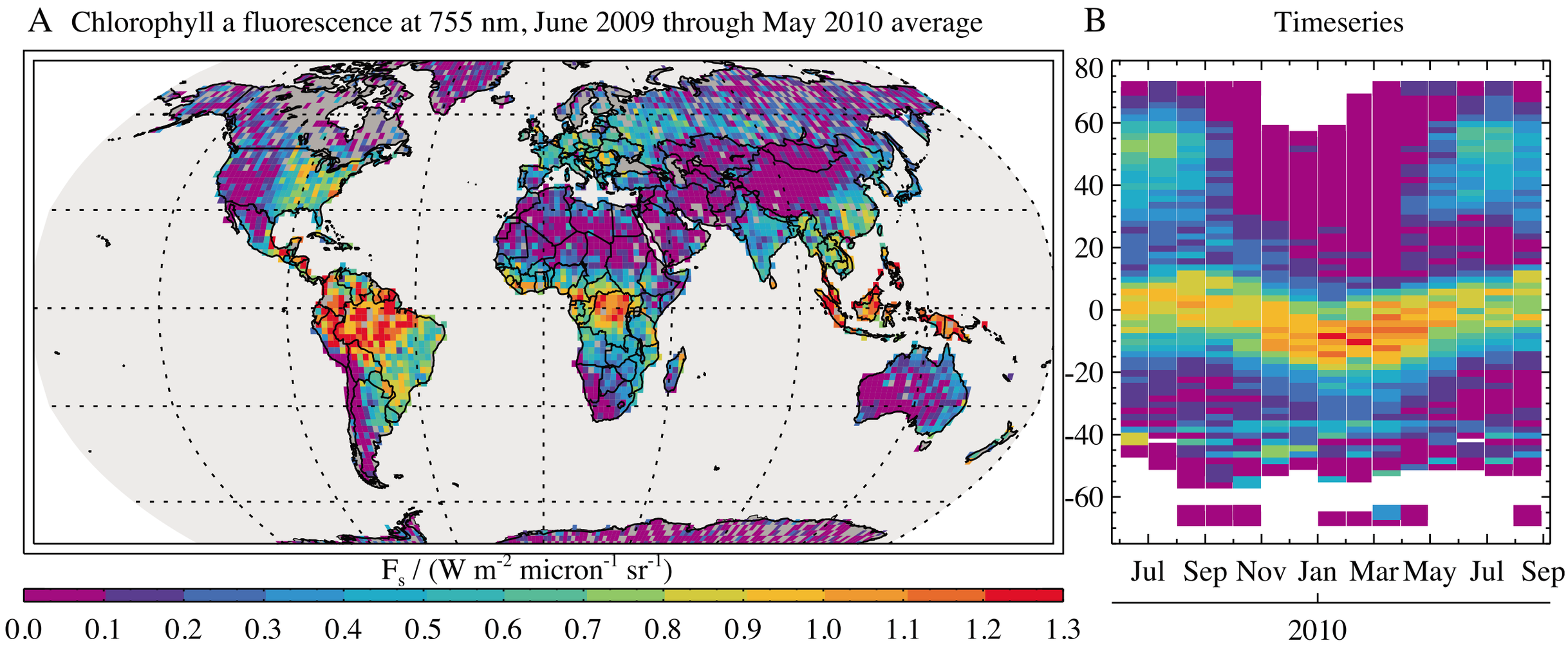
Fig. 2. Light response curves of Fs/Fo at six different gradients of water stress, determined by their g (in $\mathrm{mmol\,m^{-2}s^{-1}}$) at 750 $\mathrm{\mu mol\,m^{-2}s^{-1}}$ PPFD. Insert: Fs/Fo vs. g at 750 $\mathrm{\mu mol\,m^{-2}s^{-1}}$ PPFD (the vertical line in the main figure).

adapted from Daumard
measurements over 38 days have been carried out in summer 2008 over a sorghum field



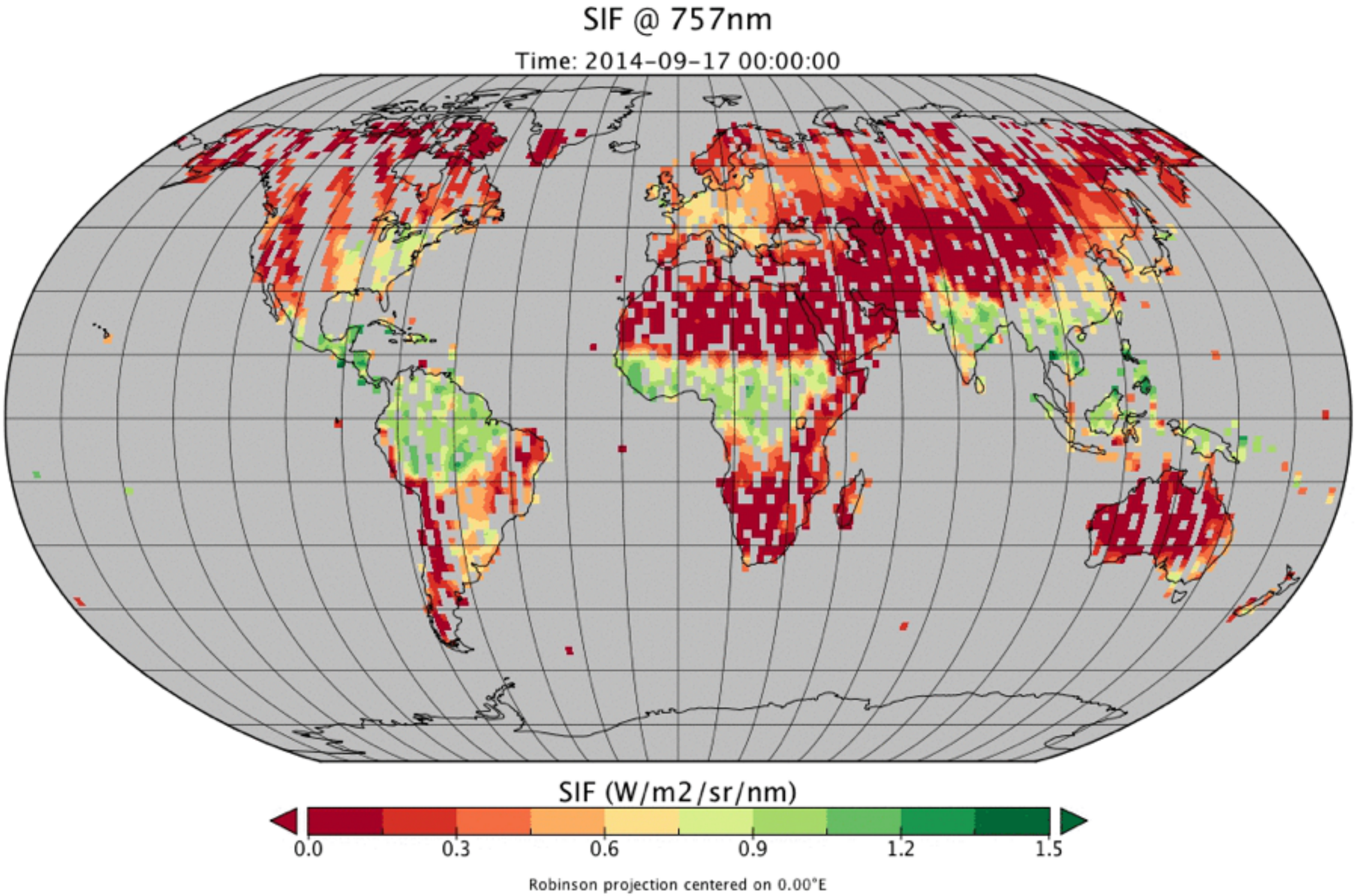
Science highlights from GOSAT

Frankenberg, C. Fisher, J., Worden, J., Badgley, G., Saatchi, S., Lee, J.-E., et al. (2011).
New global observations of the terrestrial carbon cycle from GOSAT: Patterns of plant fluorescence with gross primary productivity.
Geophysical Research Letters, 38(17), L17706.

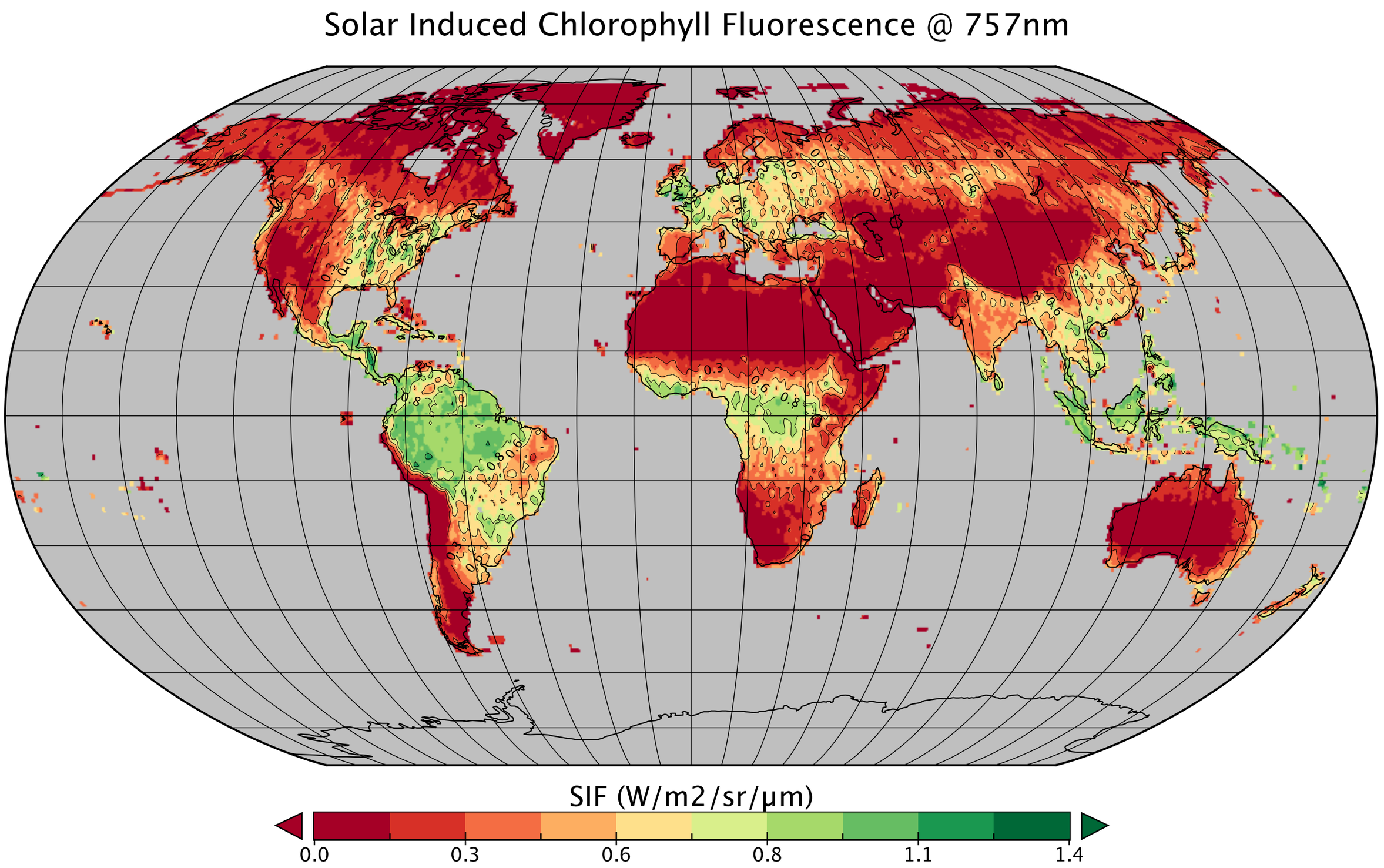


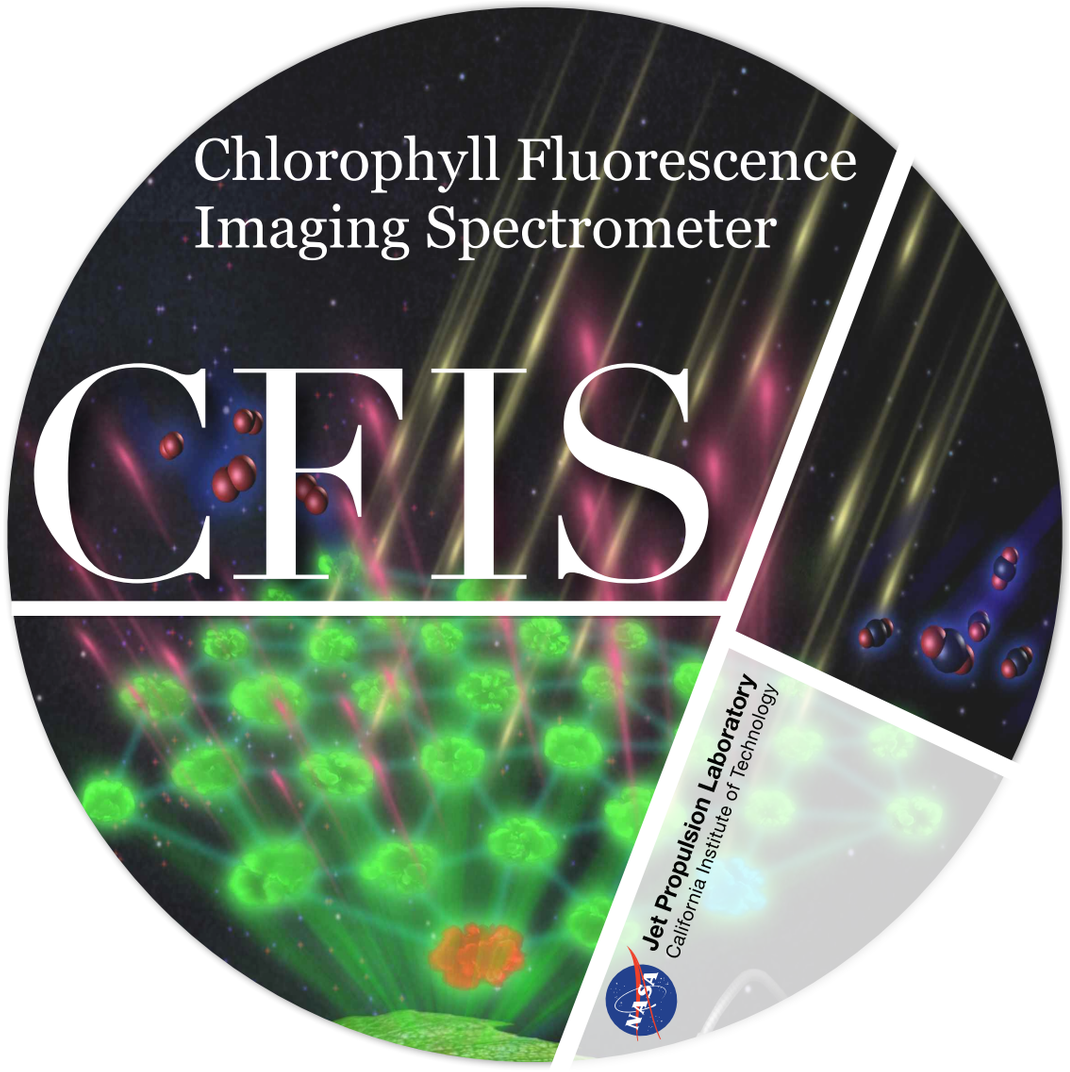
First quantification of global solar induced fluorescence (SIF) made possible by GOSAT (Joiner et al; Frankenberg et al)
--> tracks spatial and temporal variability of GPP very well

One year of OCO-2 data (biweekly averages)

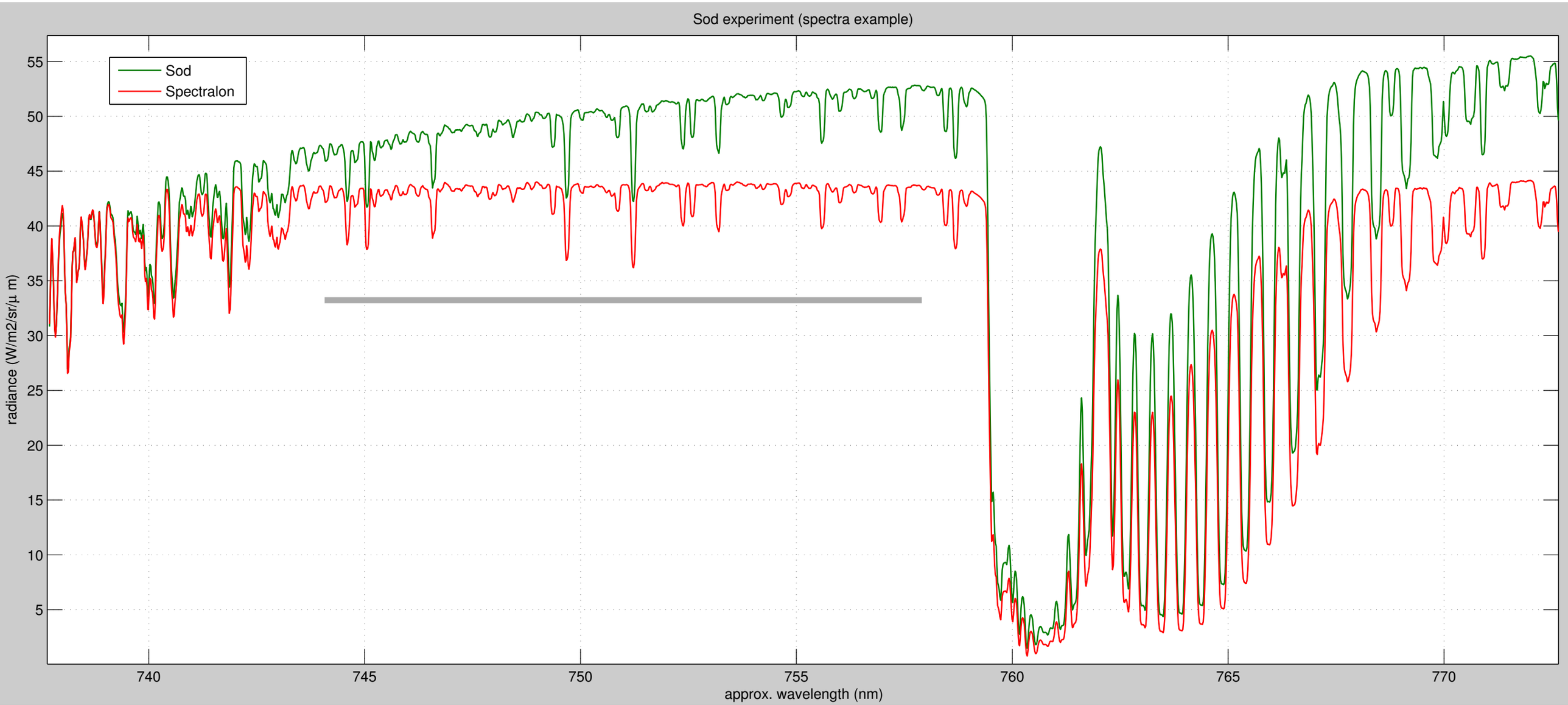


Long term average



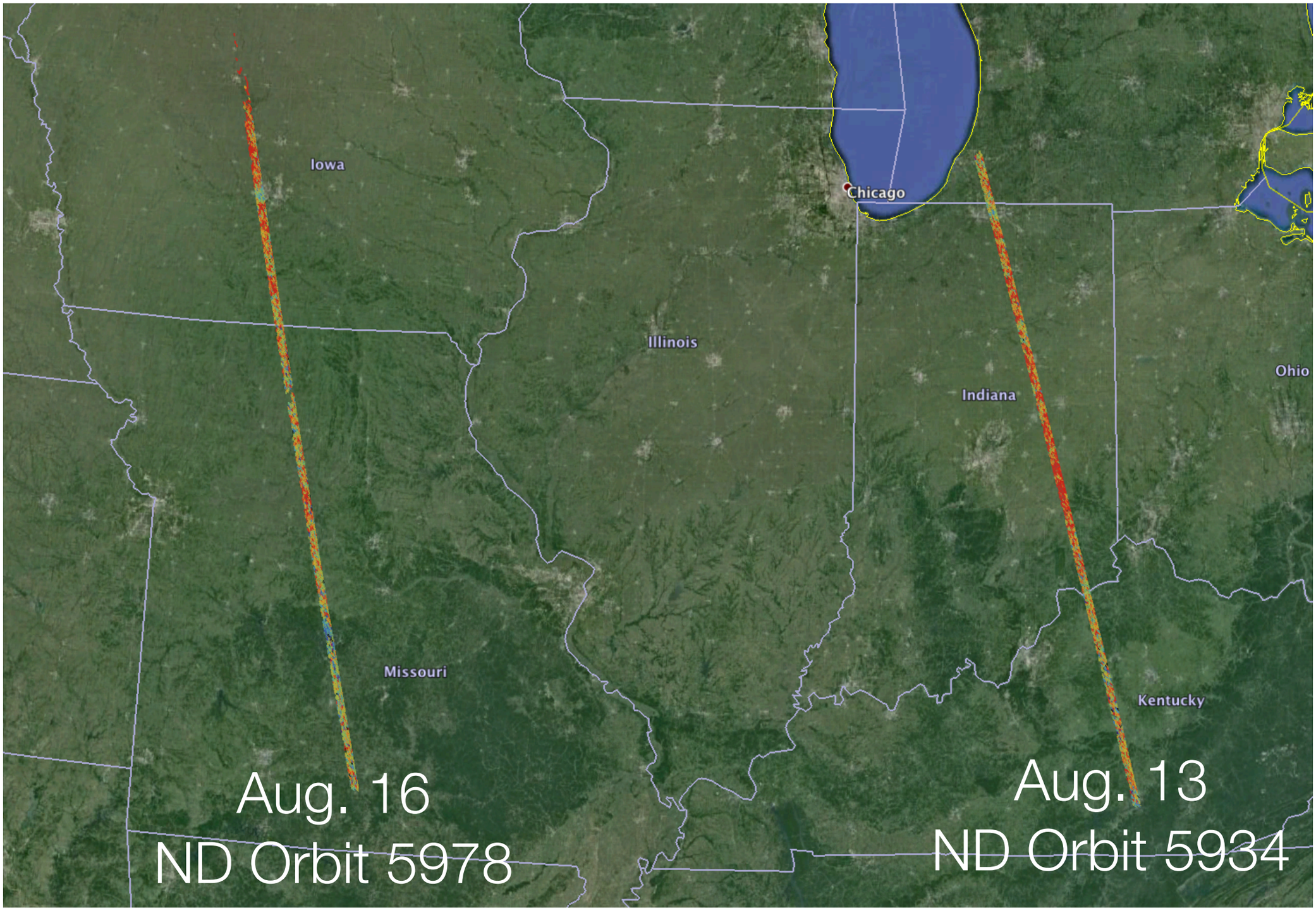

Chlorophyll Fluorescence
Imaging Spectrometer
CFIS
Jet Propulsion Laboratory
California Institute of Technology
NASA

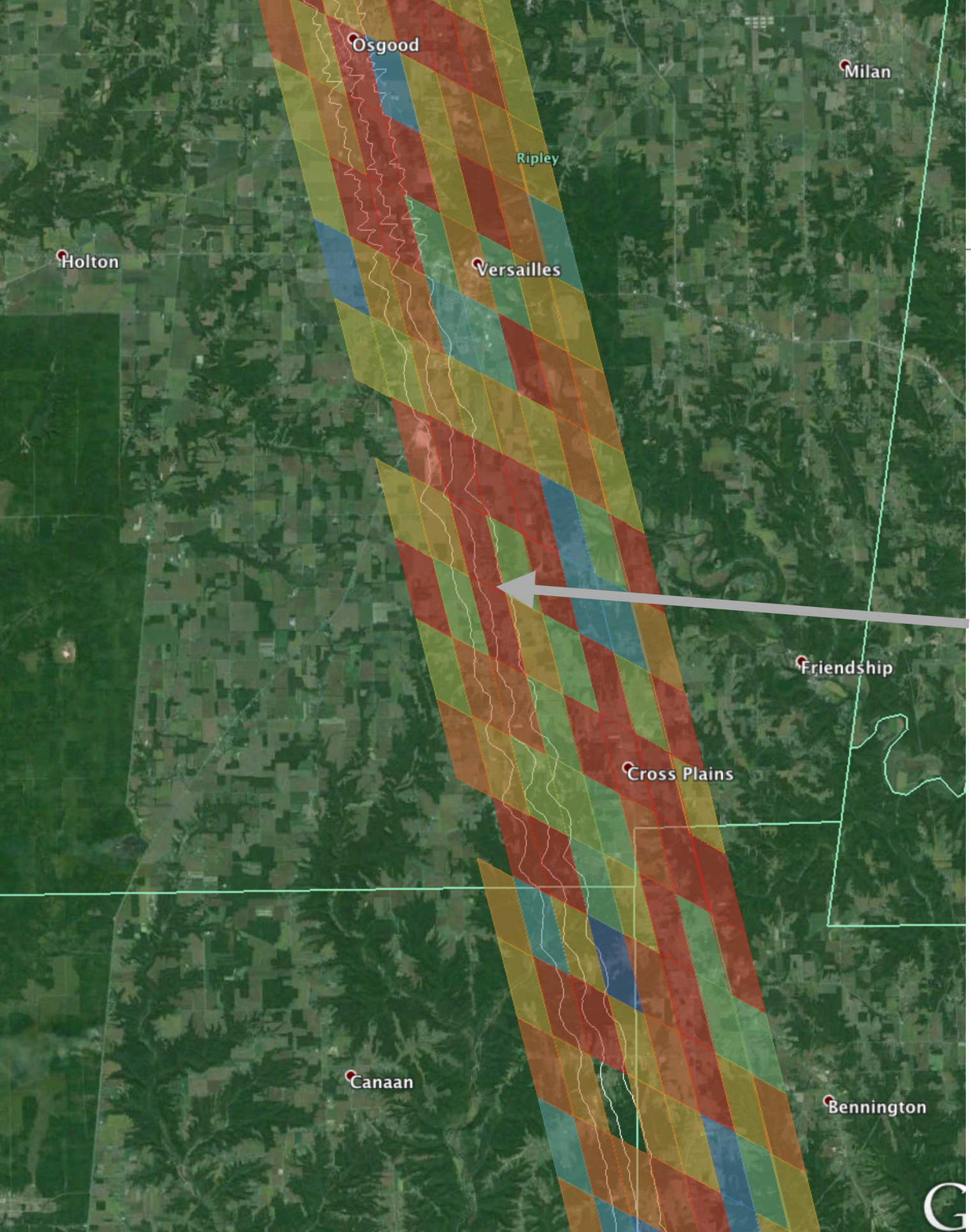

Chlorophyll Fluorescence
Imaging Spectrometer
CFIS



CFIS Example Spectra

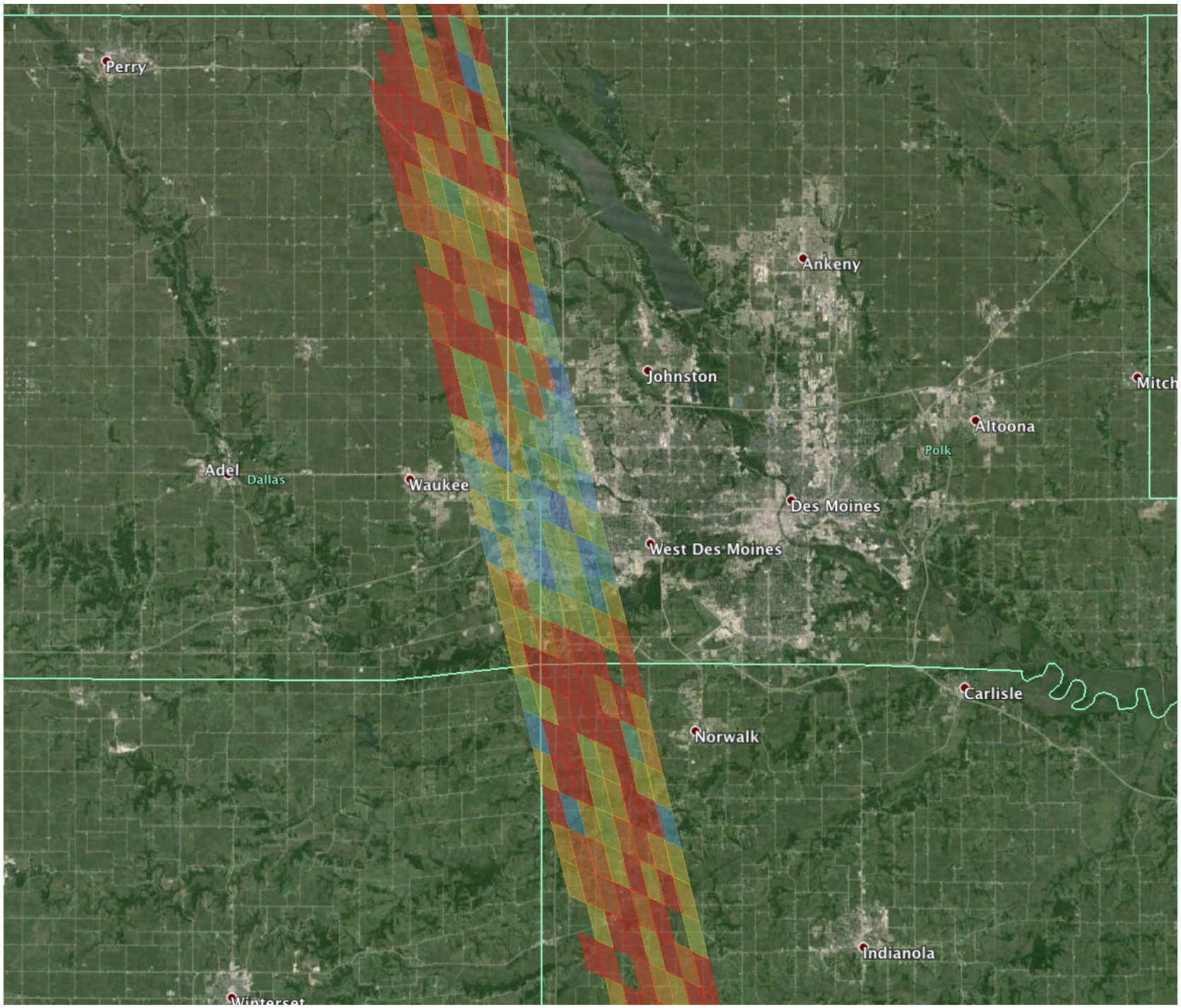
OCO-2 underpasses — OCO2 SIF





White lines indicate edges and center of CFIS swath

Crossed Des Moins



OCO-2 SIF shown