Jet Propulsion Laboratory
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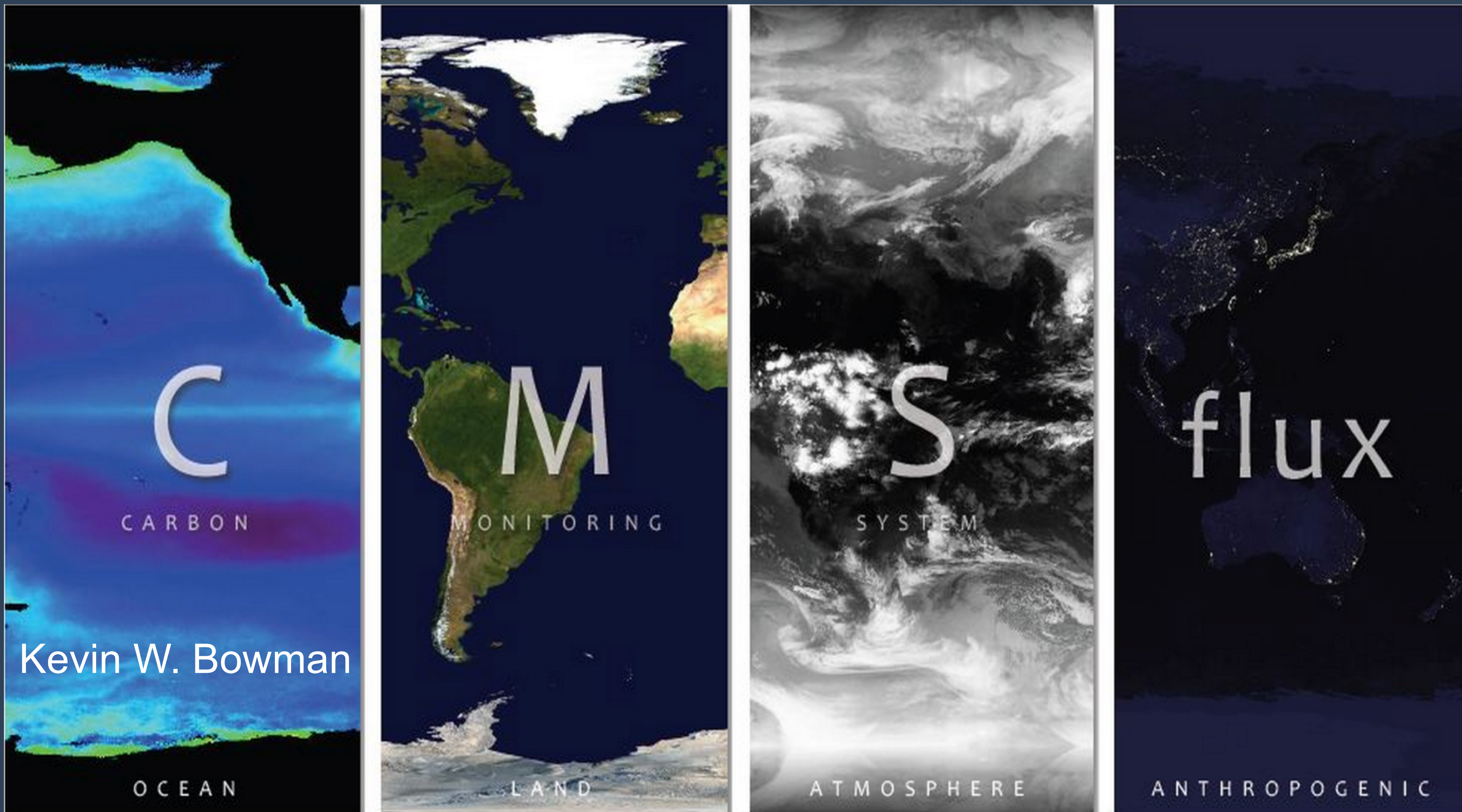
Harnessing the Carbon Constellation:

A Multi-constituent Perspective



Kevin W. Bowman

COP23 and beyond

Credit: @COP23 Twitter

- COP23 in Bonn, Germany held in Nov, 2017 built upon the momentum of COP21 and the Paris Accord.
- With the inclusion of Syria in COP23, all countries have pledged to the Paris Accord…with a notable exception.
- A key challenge is to develop a “rulebook” that accounts for transparency in reported emissions before COP24 in Katowice, Poland
- The challenges of mitigation include more than emissions….

The Challenge of Carbon Mitigation: Feedbacks

nature geoscience
FOCUS | PROGRESS ARTICLES
PUBLISHED ONLINE: 17 NOVEMBER 2009 | DOI: 10.1038/NGEO689

Trends in the sources and sinks of carbon dioxide

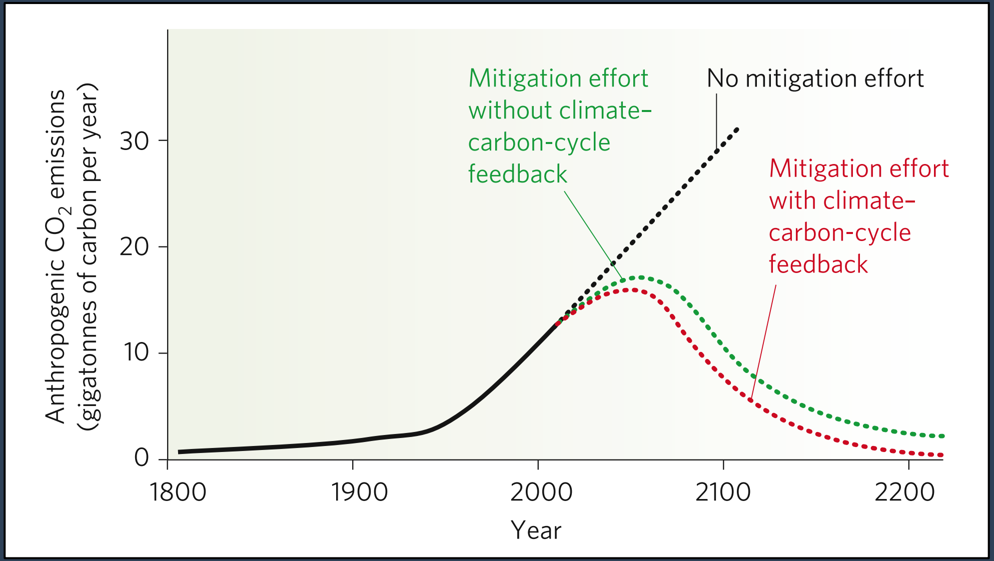
Corinne Le Quéré, Michael R. Raupach, Josep G. Canadell, Gregg Marland *et al.**

A steep road to climate stabilization

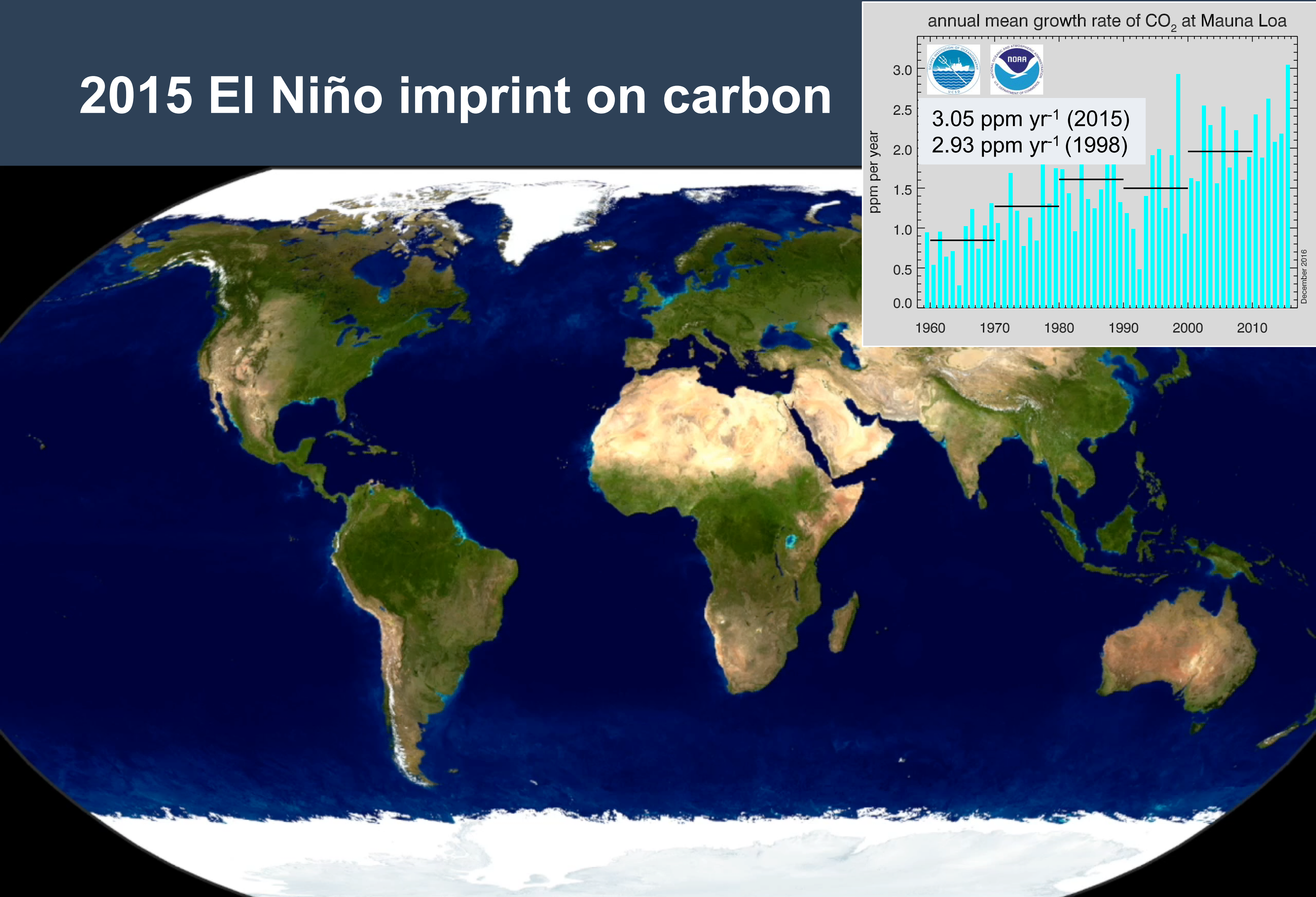
Pierre Friedlingstein

The only way to stabilize Earth's climate is to stabilize the concentration of greenhouse gases in the atmosphere, but future changes in the carbon cycle might make this more difficult than has been thought.

"major gaps remain….in our ability to link anthropogenic CO_2 emissions to atmospheric CO_2 concentration on a year-to-year basis…. and adds uncertainty to our capacity to quantify the effectiveness of climate mitigation policies."

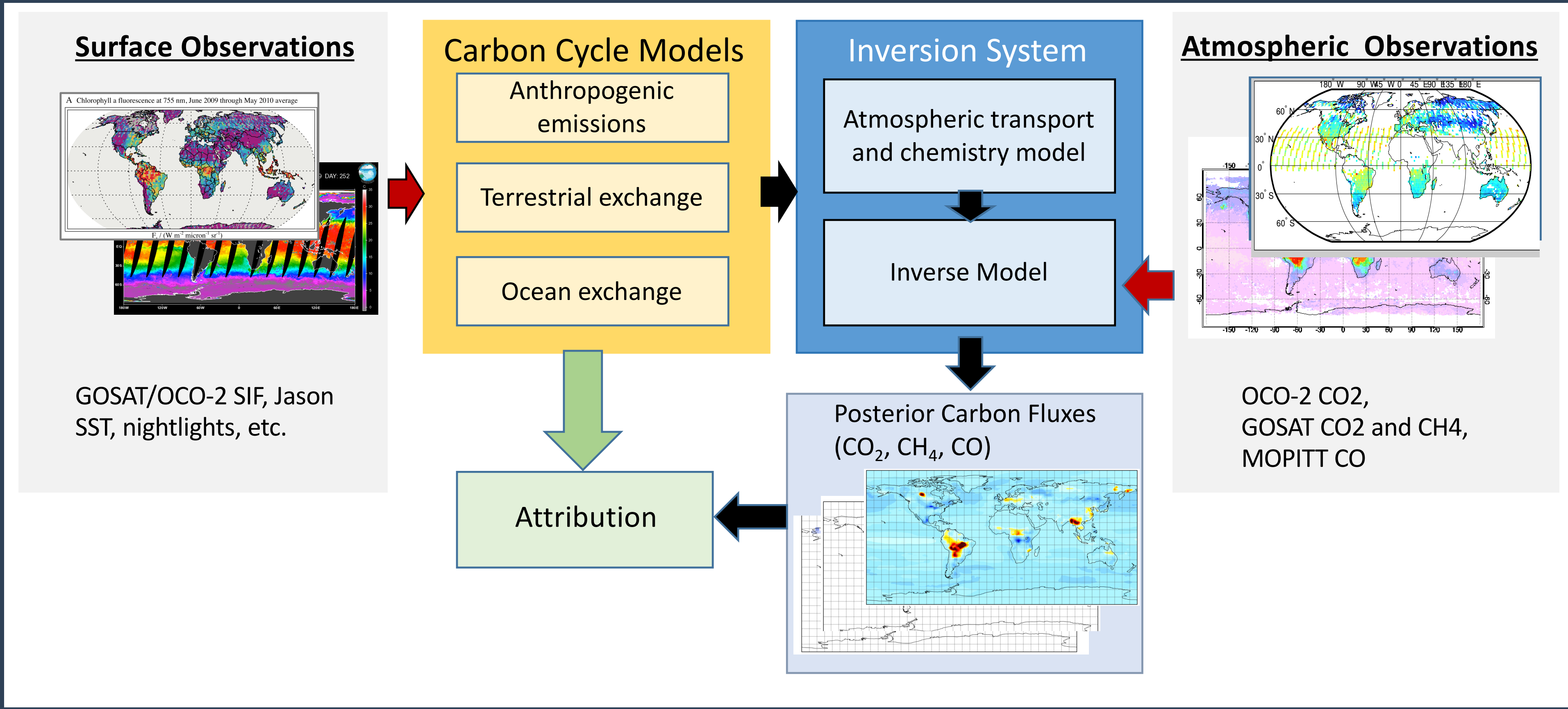


2015 El Niño imprint on carbon



What were the spatial drivers of this growth rate? How are they related to climate forcing?

NASA Carbon Cycle Data Assimilation



The NASA Carbon Monitoring System Flux (CMS-Flux) attributes atmospheric carbon variability to spatially resolved fluxes driven by data-constrained process models across the global carbon cycle.

Study in contrast

Estimate and contrast fluxes during an “extreme” year (2015) (OCO-2) against a nominal year (2011) (GOSAT).

The total flux inferred from CMS-Flux can be decomposed into a sum of terms representing key processes within the carbon cycle.

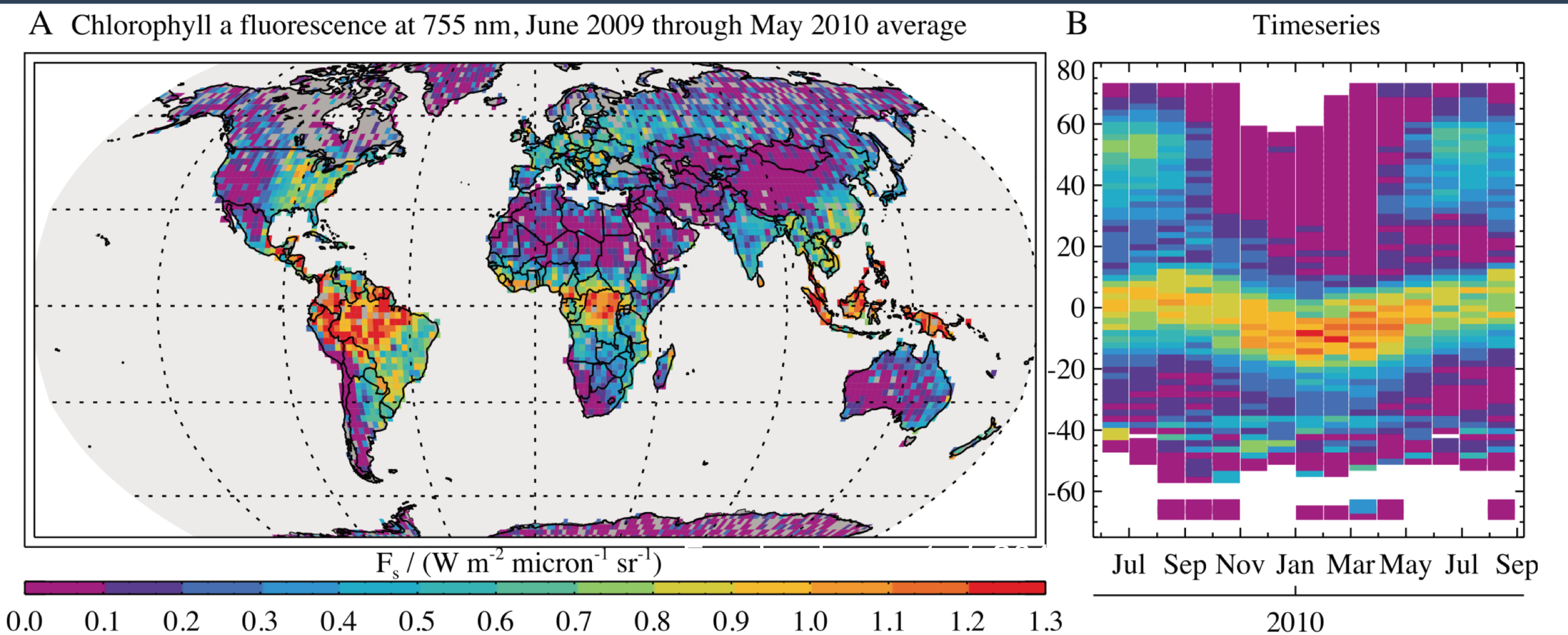
Net flux into the atmosphere is positive

Fossil Fuel Ocean Biomass burning NEP Chemical Source

$$F^{\uparrow}(x,y,t) = F_F + F_O + F_{BB} + \underbrace{(R - GPP_{SIF})}_{-F_{NEP}} + F_{chem}$$

Need to separate NEP into GPP and respiration.

GPP inferred from solar induced



Optimal estimation provides a framework to determine GPP that accounts for uncertainty in the fluorescence, prior uncertainty in GPP, satellite coverage and timing.

$$\hat{\mathbf{x}} = \min_{\mathbf{x}} C(\mathbf{x}) = \min(\|\mathbf{y} - \mathbf{F}(\mathbf{x})\|^2_{\mathbf{S}_n^{-1}} + \|\mathbf{x} - \mathbf{x}_a\|^2_{\mathbf{S}_a^{-1}})$$

$\mathbf{x}_a$=mean Trendy GPP

y: GOSAT SIF at time $\{t_i\}$

F(**x**): Observation operator: GPP to GOSAT overpass

$\mathbf{S}_n$: Error in GOSAT SIF, **$\mathbf{S}_a$**:Ensemble Trendy spread

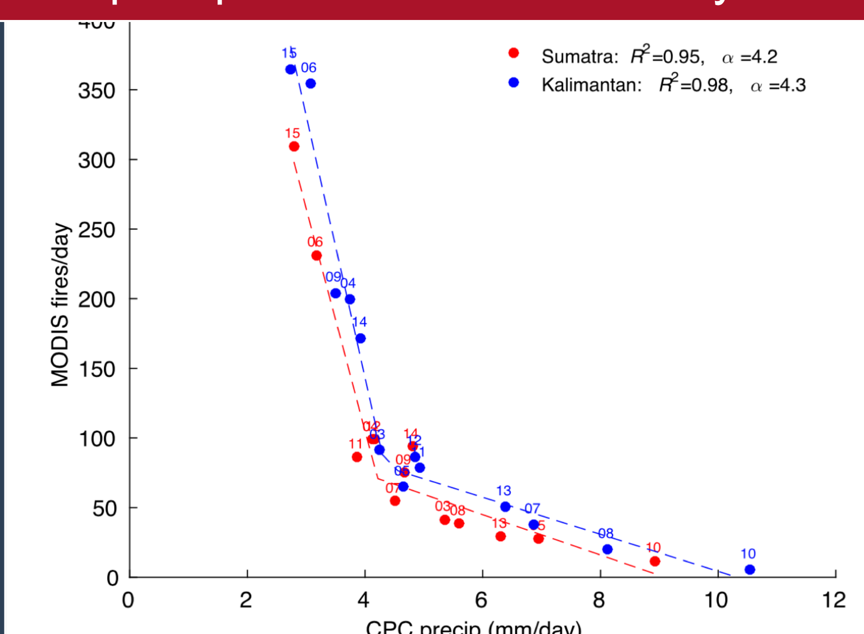
$$\hat{\mathbf{S}} = (\mathbf{K}^\top \mathbf{S}_n^{-1} \mathbf{K} + \mathbf{S}_a^{-1})^{-1}$$

Parazoo et al, 2013

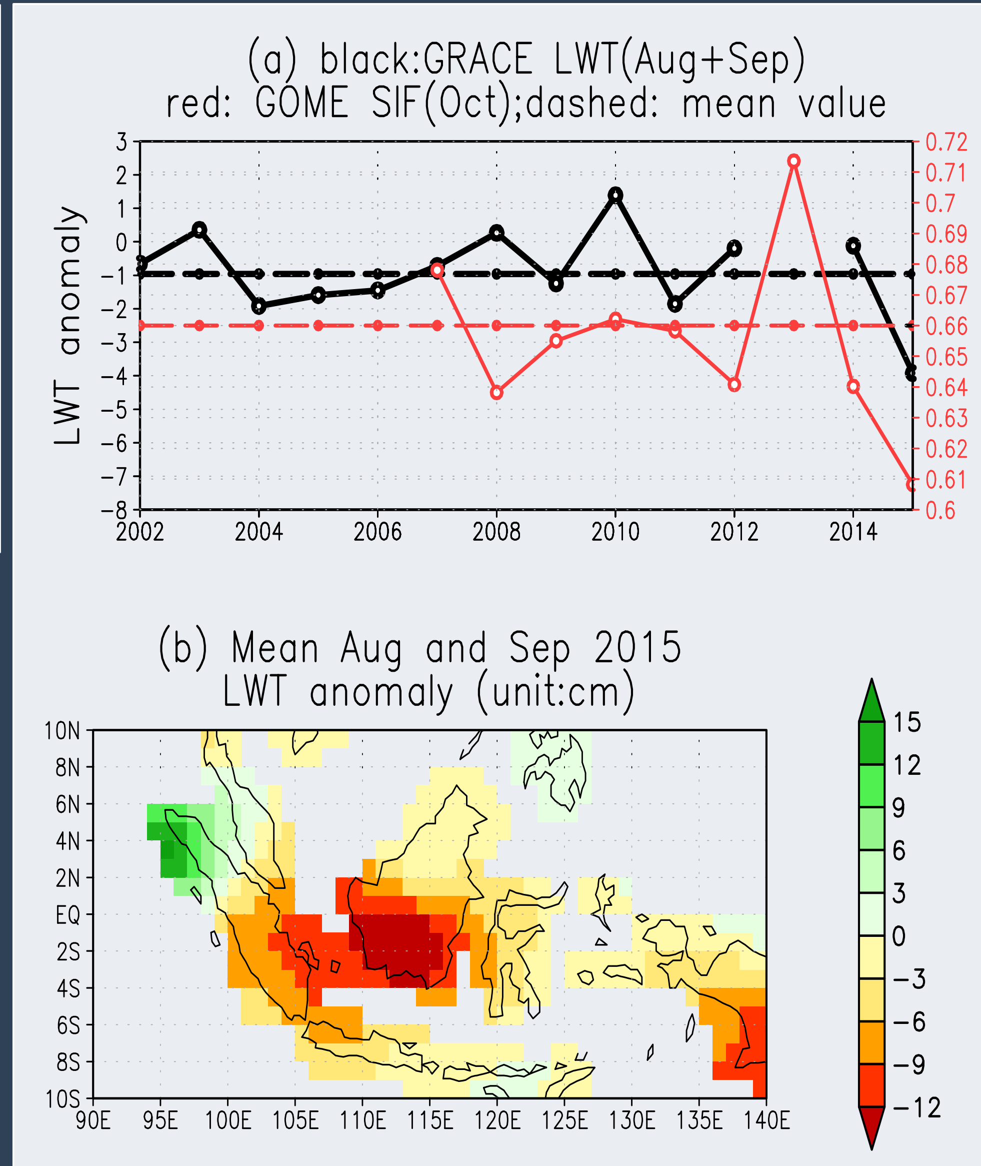
Tipping points: the hydrological context

Centered on Kalimantan, GRACE gravity data shows a liquid water equivalent thickness (LWT) anomaly of -4 cm, 4x larger than then decadal mean anomaly.

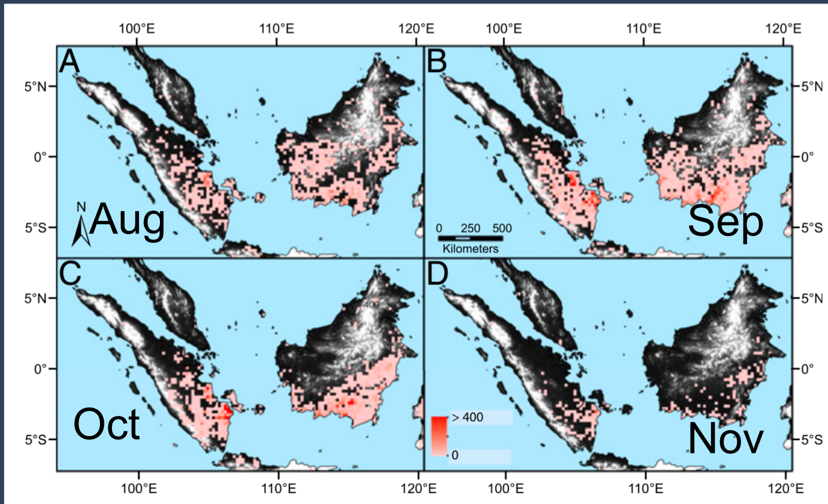
Field et al, 2016 PNAS reported a non-linear relationship between firecounts and precipitation below 4 mm/day



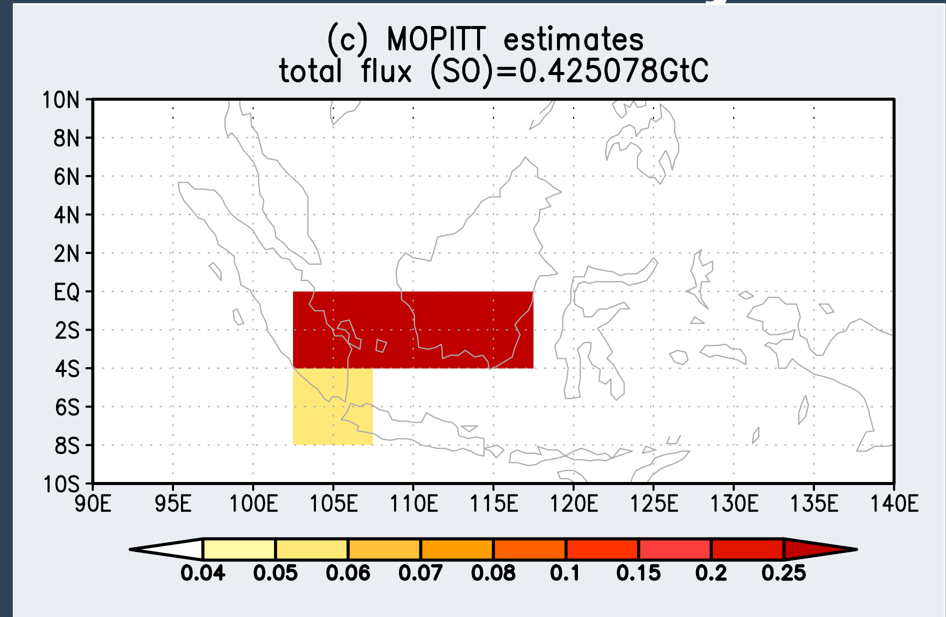
Fields et al, 2016 (PNAS)



The Balance of Combustion and Productivity



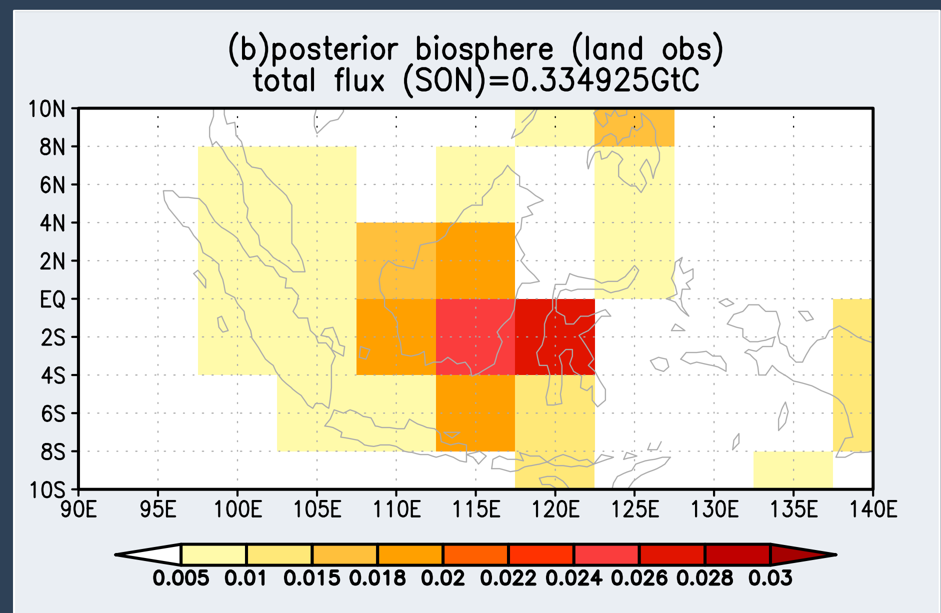
Field et al, 2016 (PNAS)



“Top-down” emissions constrained by MOPITT CO show elevated biomass burning in Sumatra and Kalimantan. CO:CO2 calculated from Stockwell et al, ACP (2016)

CO2 fluxes constrained from OCO-2 are centered in S. Kalimantan.

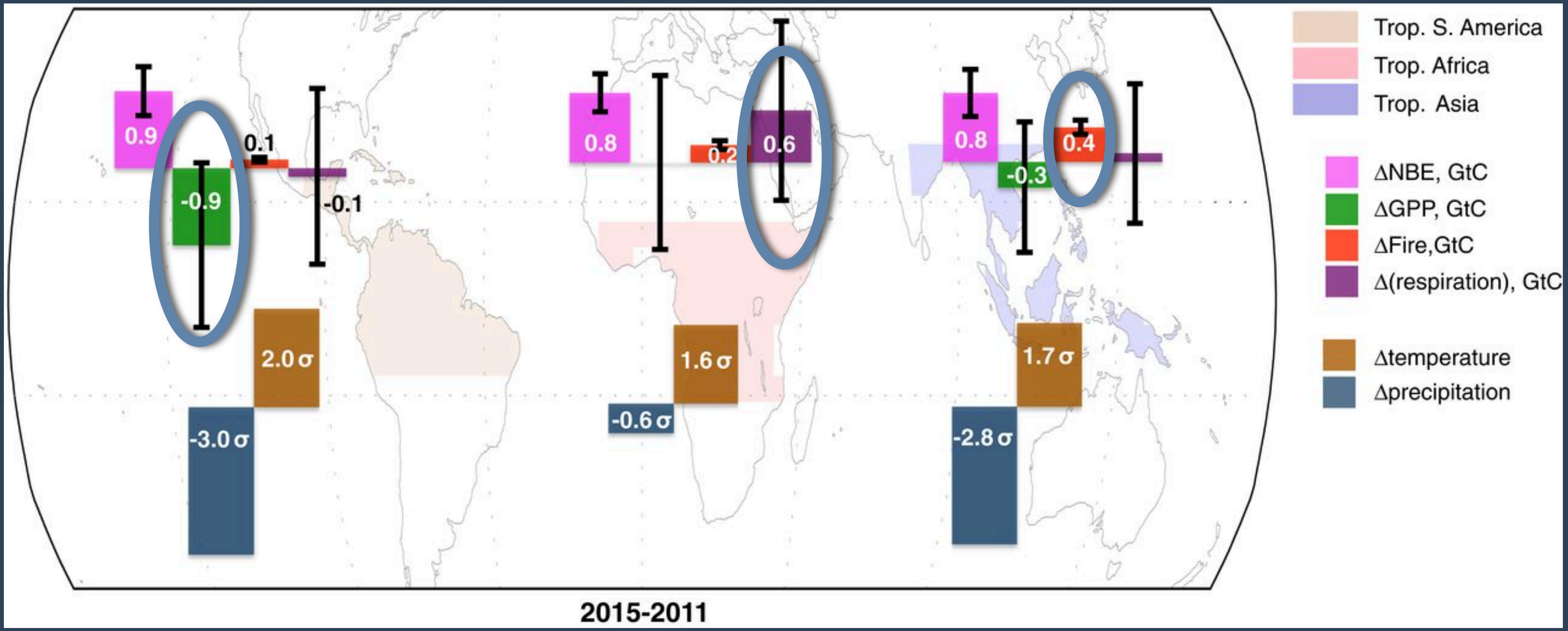
BB CO2 similar to 0.5 PgC in Yin et al, 2016 (GRL)



CMS-Flux SON 2015
BB CO2 = 0.4 ± 0.03 GtC
NBE CO2 = 0.3 ± 0.02 GtC
NEP = 0.1 ± 0.04 GtC

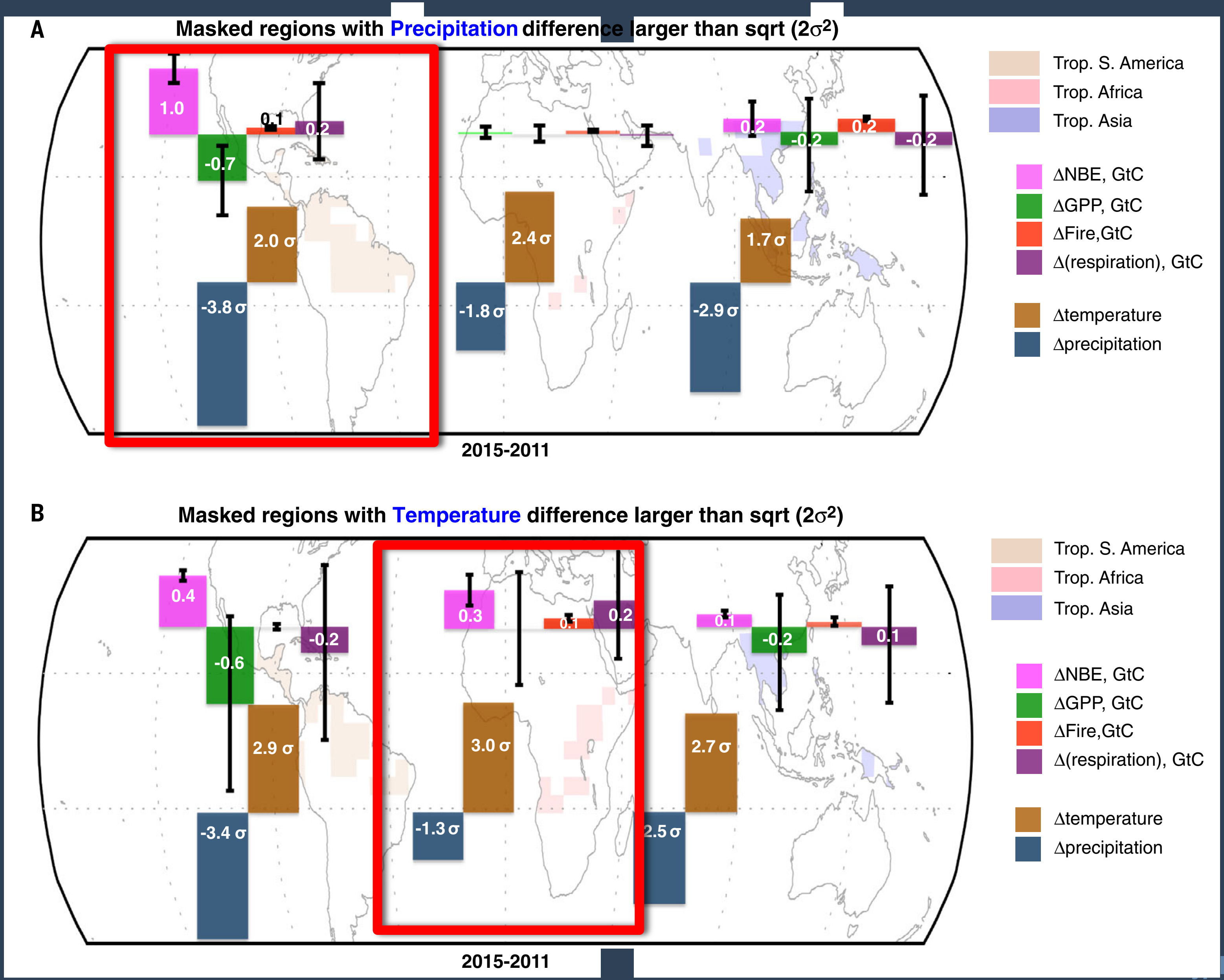
Diversity of Carbon Process Drivers

Liu et al, Science, 2017



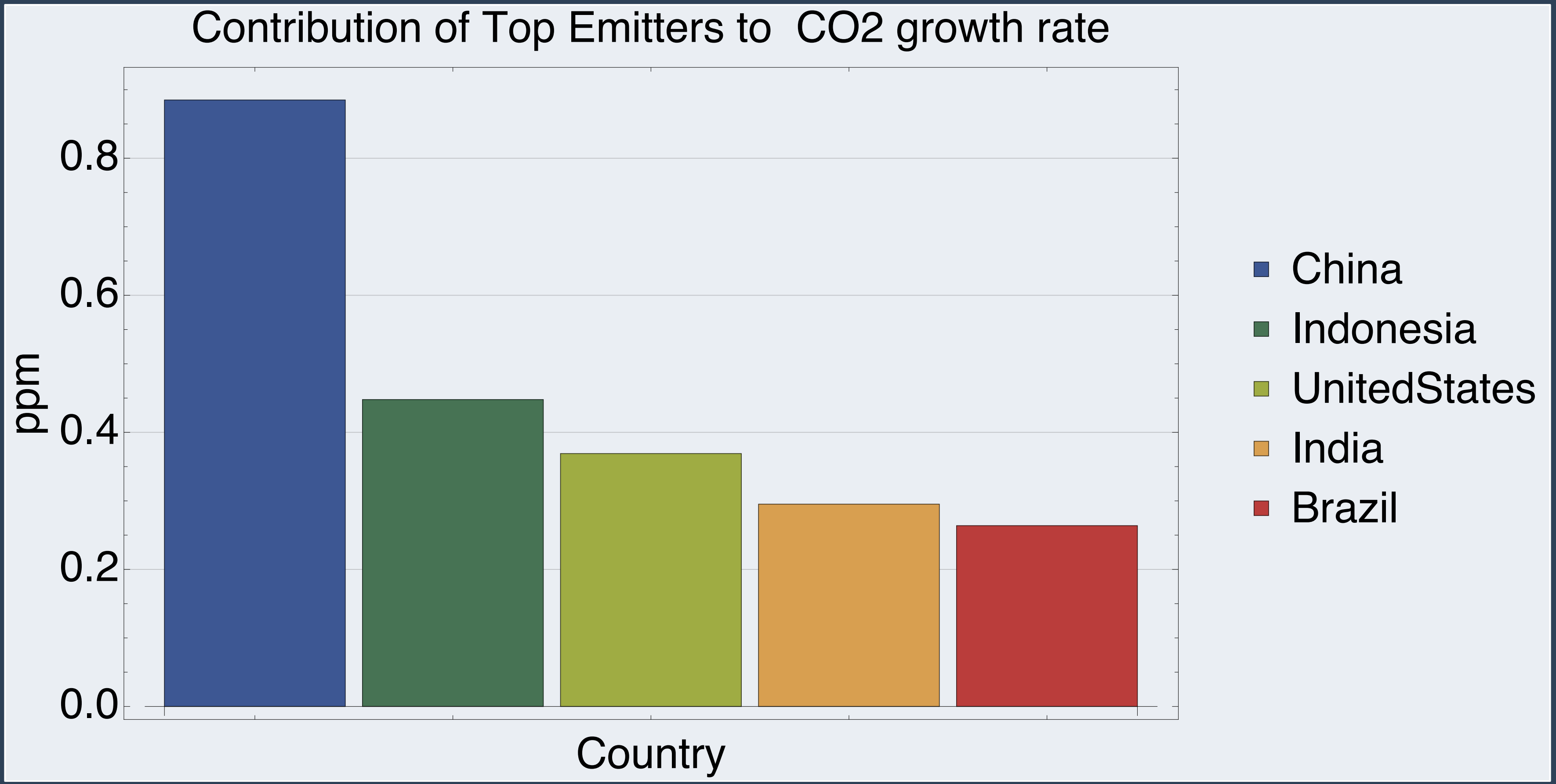
- Reduction of GPP dominated over tropical South America
- Increased respiration dominated over tropical Africa
- Increased carbon from fire dominated over tropical Asia

Carbon Response of Extreme Climate Anomalies



Liu et al, Science, 2017

Implications for CO2 growth rate

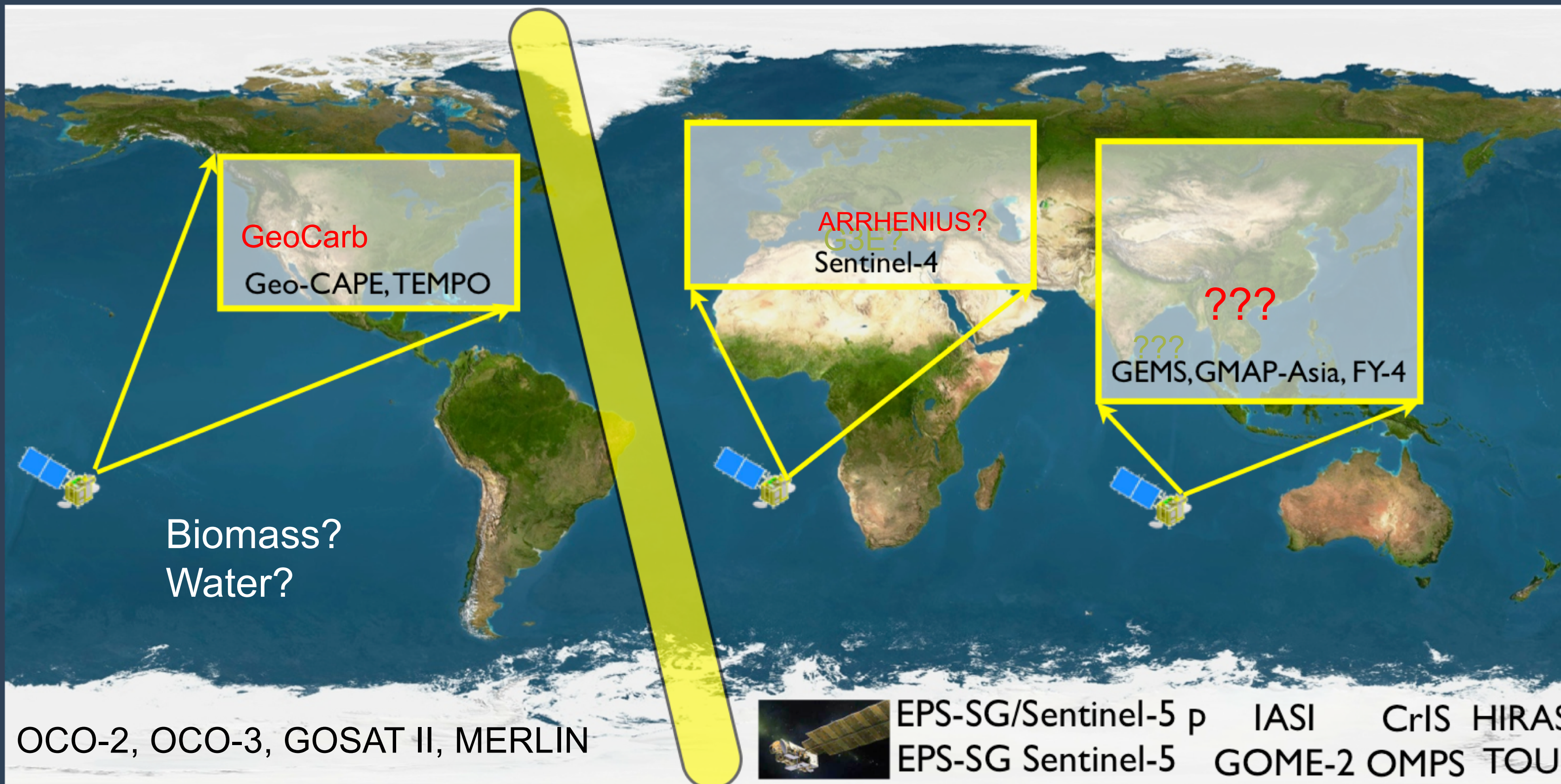


The Indonesian and the Brazilian region were the 2nd and 5th highest contributor (0.45 ppm, 0.27 ppm) in total flux to the record CO_2 growth rate in 2015.

These rivaled countries with far higher fossil fuel emissions.

Toward an Air Quality-Carbon-Climate Constellation

Bowman et al, Atm.Env. 2013



- LEO:
  - IASI+GOME-2, AIRS+OMI, CrIS+OMPS could provide UV+IR ozone products for more than a decade.
  - Combined UV+IR ozone products from GEO-UVN and GEO-TIR aboard Sentinel 4 (Ingmann *et al*, 2012 Atm. Env.)
  - Sentinel 5p (TROPOMI) will provide column CO and CH4.
  - OCO-2+AIRS, GOSAT II (IR+NIR) could provide vertical discrimination.
- GEO
  - TEMPO, Sentinel-4, and GEMS, would provide high spatio-temporal air quality information.
  - GeoCarb and G3E could provide geo-carbon information.

Conclusions

- A CEOS-VC can be harnessed to relate climate forcing to emissions.
- Natural variability, trends, and feedbacks will modulate that relationship on multiple spatial and temporal scales.
- Tropics must be sufficiently sampled.
- CO_2 alone is not enough to interpret variability
  - CO, SIF, and other measurements must be integrated.
- The spatial pattern of extremes needs to be considered
  - Potential of geostationary sounders needs to quantified.

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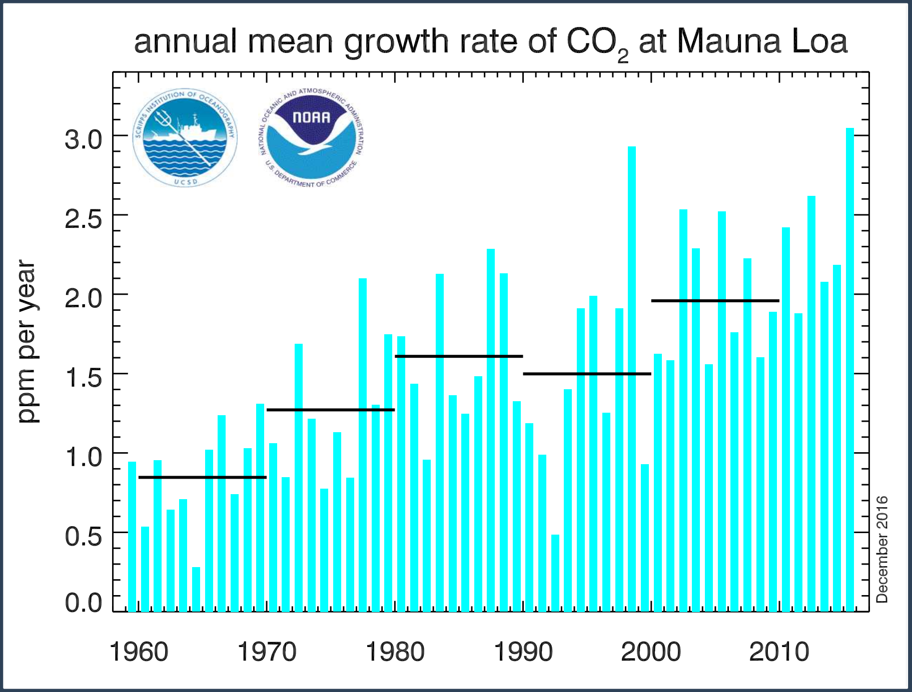
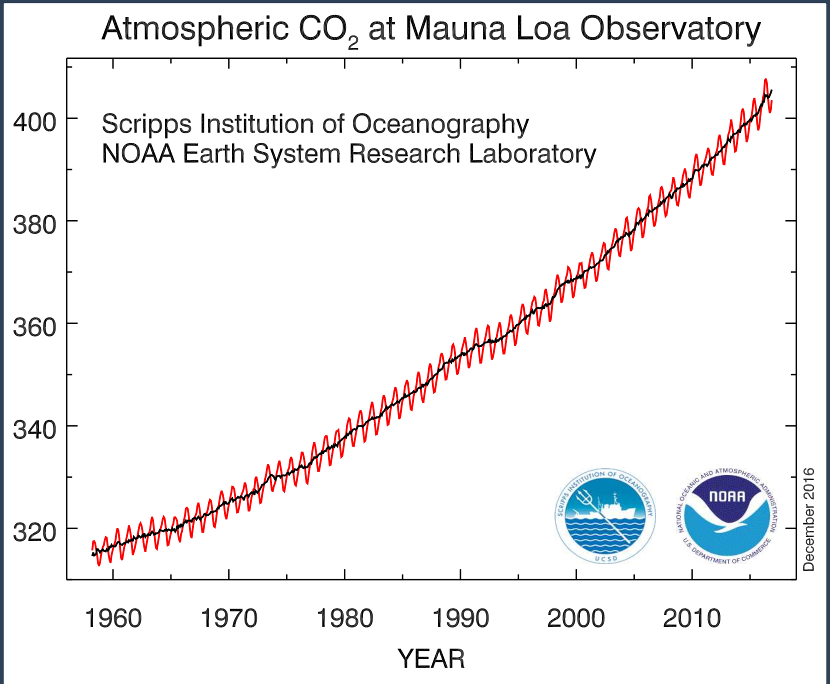
Largest CO2 Growth Rate in 50 years





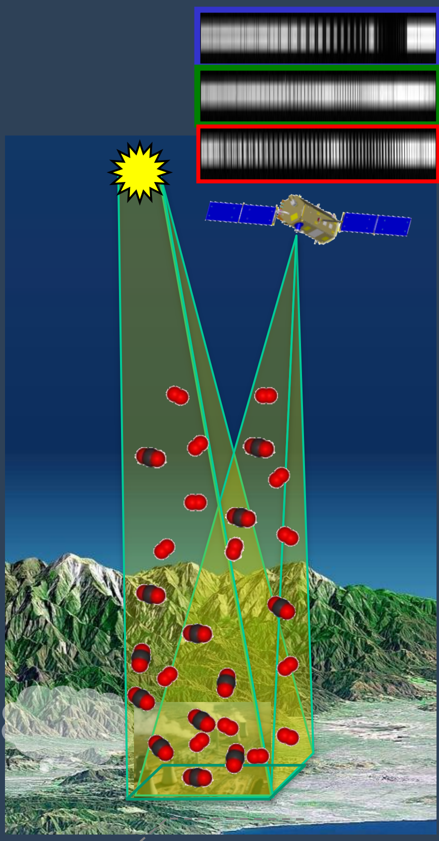
2015 had the highest atmospheric growth record in the Mauna Loa record, beating out the 1998 growth rate.

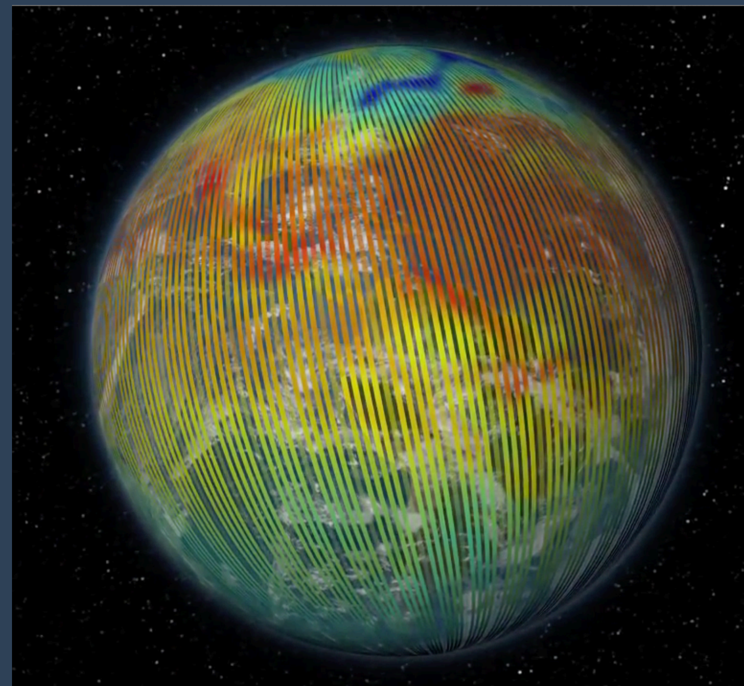
Growth rate was 50% higher than the previous year but anthropogenic emissions were roughly the same.

What were the spatial drivers of this growth rate? How are they related to climate forcing?

Orbital Carbon Observatory (OCO-2)

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





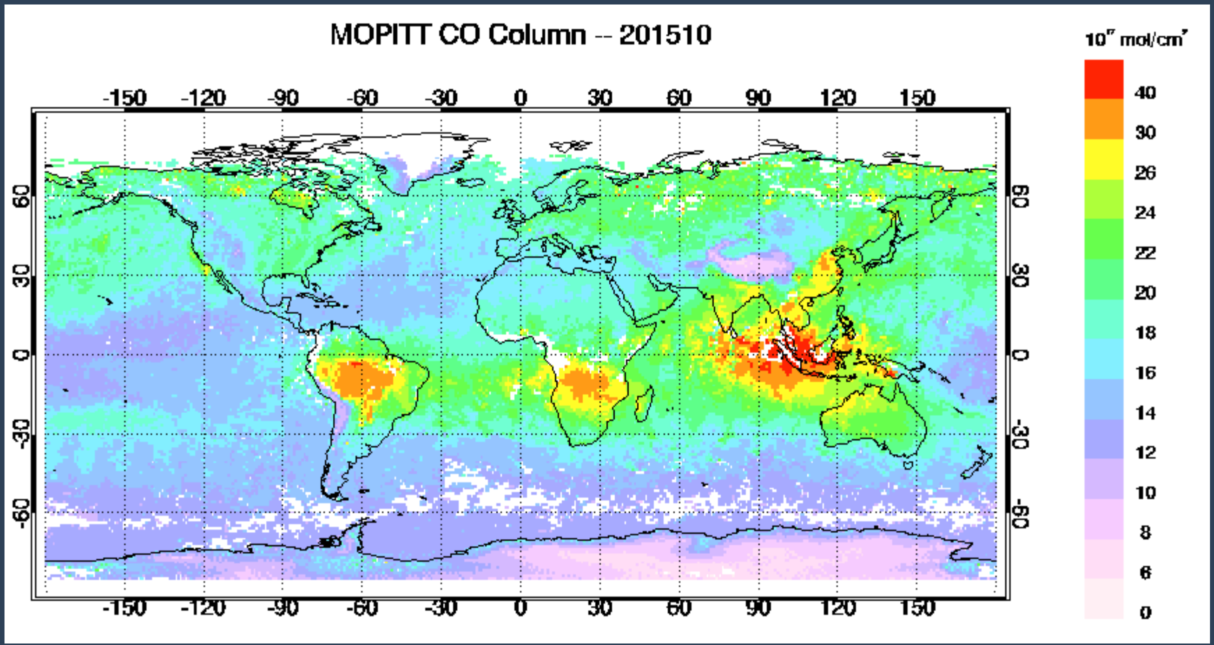
16 day repeat cycle

1.29x2.25-km footprint; eight cross-track footprints create a swath width of 10.3 km

Launched in June, 2014 into an afternoon, polar sun-synchronous orbit as part of the NASA “A-Train” constellation, OCO-2 provides dry-column mole fraction CO2 (XCO2).

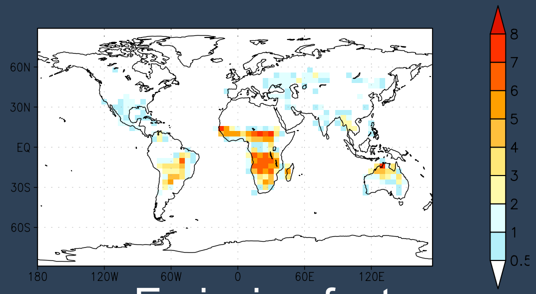
Compared to TCCON, median differences are less than 0.5 ppm and RMS differences typically below 1.5 ppm (Wunch et al, 2016 AMTD)

Respiration: combustion



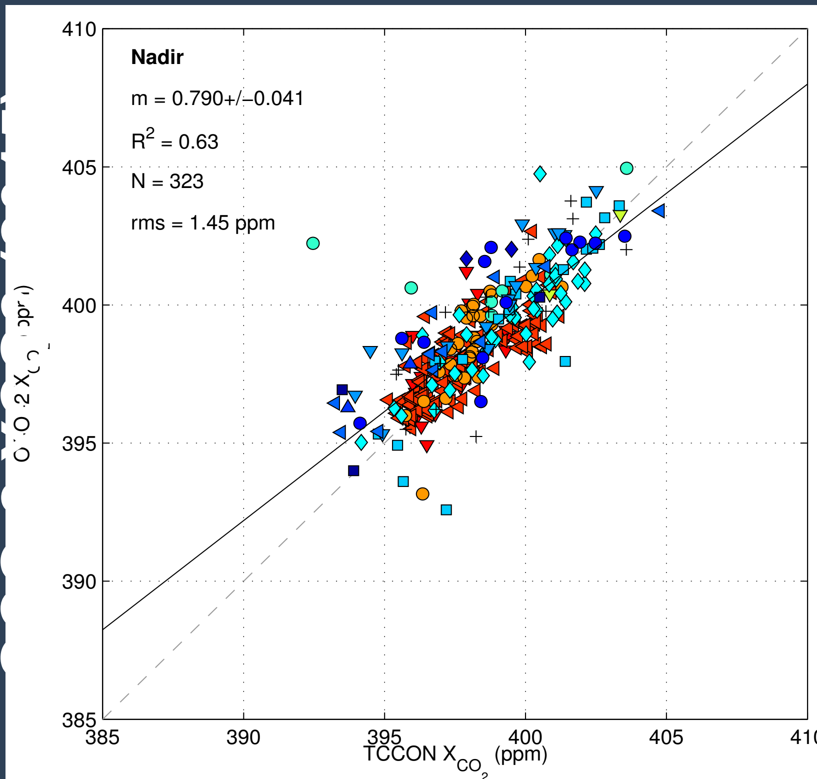
- Carbon monoxide is a by-product of incomplete combustion.
- MOPITT provides CO verticals with near surface sensitivity.
- CMS-Flux estimates CO from MOPITT and converts to CO_2

- CO_2 from biomass burning is calculated from CO/CO2 ratios (Andreae and Merlet, GBC, 2001)
- Emission factors are a function of dry mass (given) and burning efficiency, which is a function of plant function type.

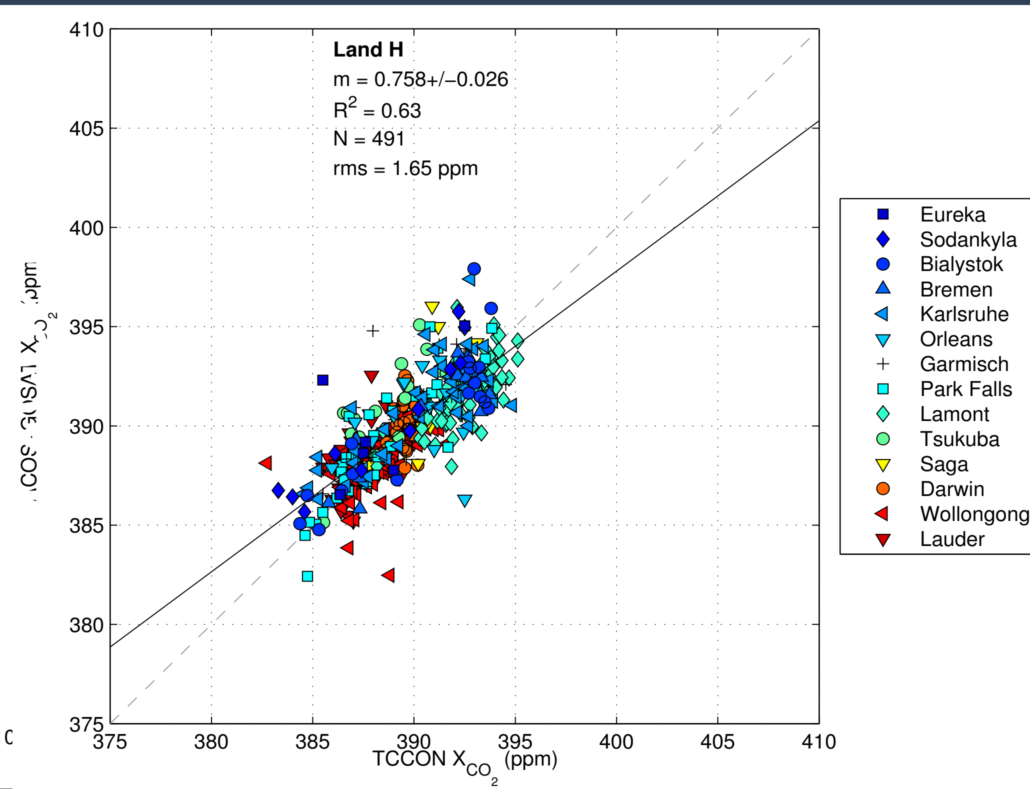


Emission factors

Do 2015 OCO-2 and 2011 GOSAT have relative bias?



TCCON XCO2



TCCON XCO2

- **The relative differences between OCO-2 X_{CO2} and GOSAT X_{CO2} were negligible when both were compared to X_{CO2} from Total Carbon Column Observing Network**

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Contributions from CMS-Flux

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