Role of Climate Variability and Land-Use on Fire Emissions in the 21rst Century: Implications for the Global Carbon Cycle

John Worden[1], Anthony Bloom[1], Yi Yin[2], Zhe Jiang[3], Helen Worden[4], Kevin Bowman[1], Junjie Liu[1], Sassan Saatchi[1], and David Schimel[1]

1) Jet Propulsion Laboratory / California Institute of Technology

2) California Institute of Technology

3) USTC

4) National Center for Atmospheric Research

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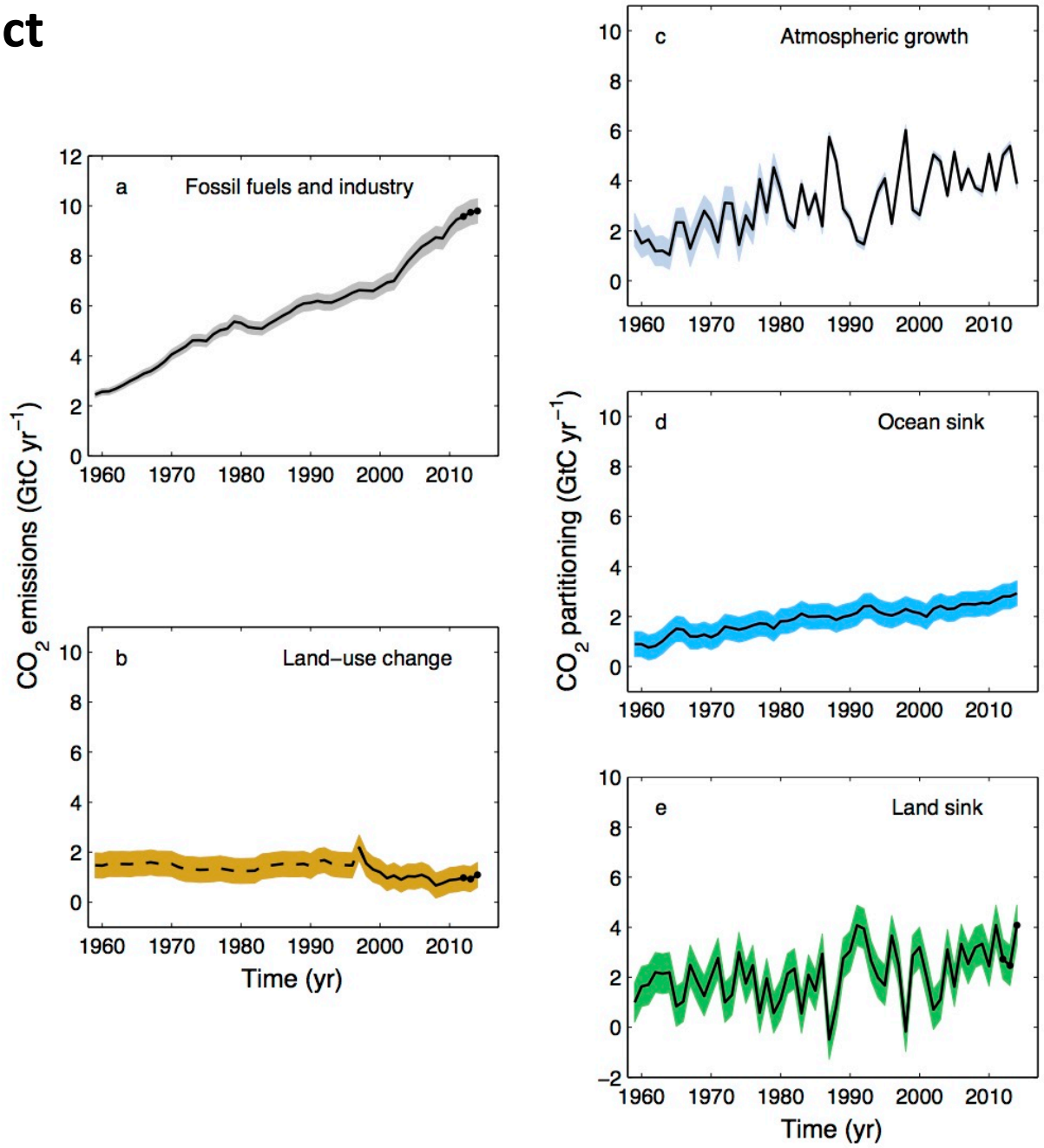
Changes in carbon fluxes as inferred by the Global Carbon Project

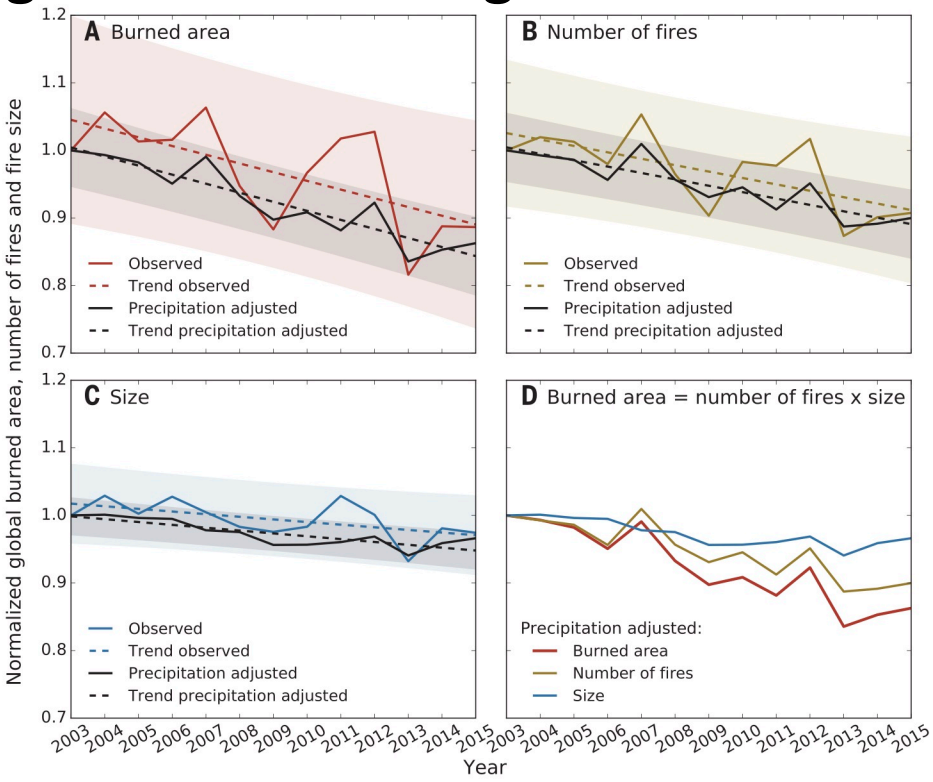
Le Quere GMD 2015

Land Use Emissions decreased by ~0.2 PgC/yr
Land sink increased by about 1 PgC/yr since 2000.

The ocean sink is thought to be increasing, reflecting a balance between decreasing CO_2 capacity and increasing biological activity



What is the role of reduced burning during the 21rst century on the global carbon budget?



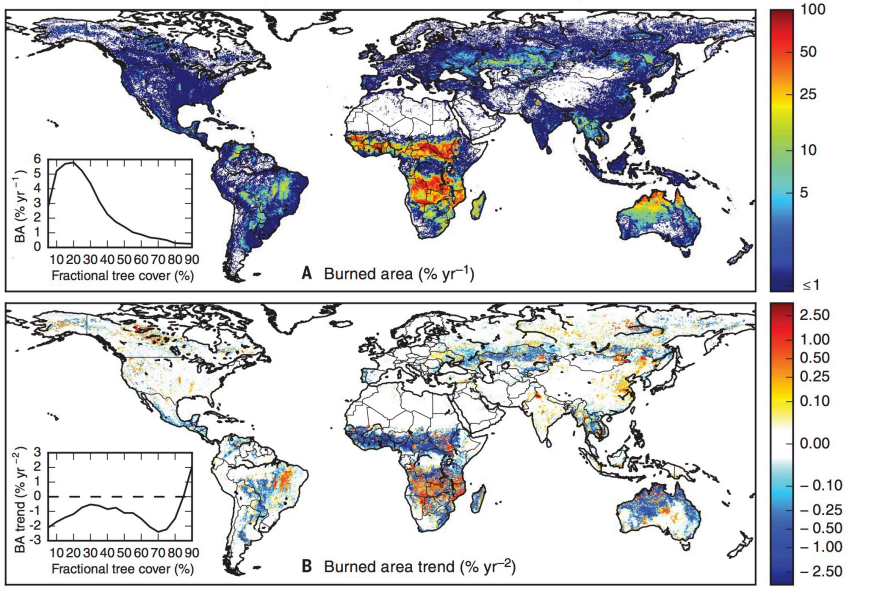
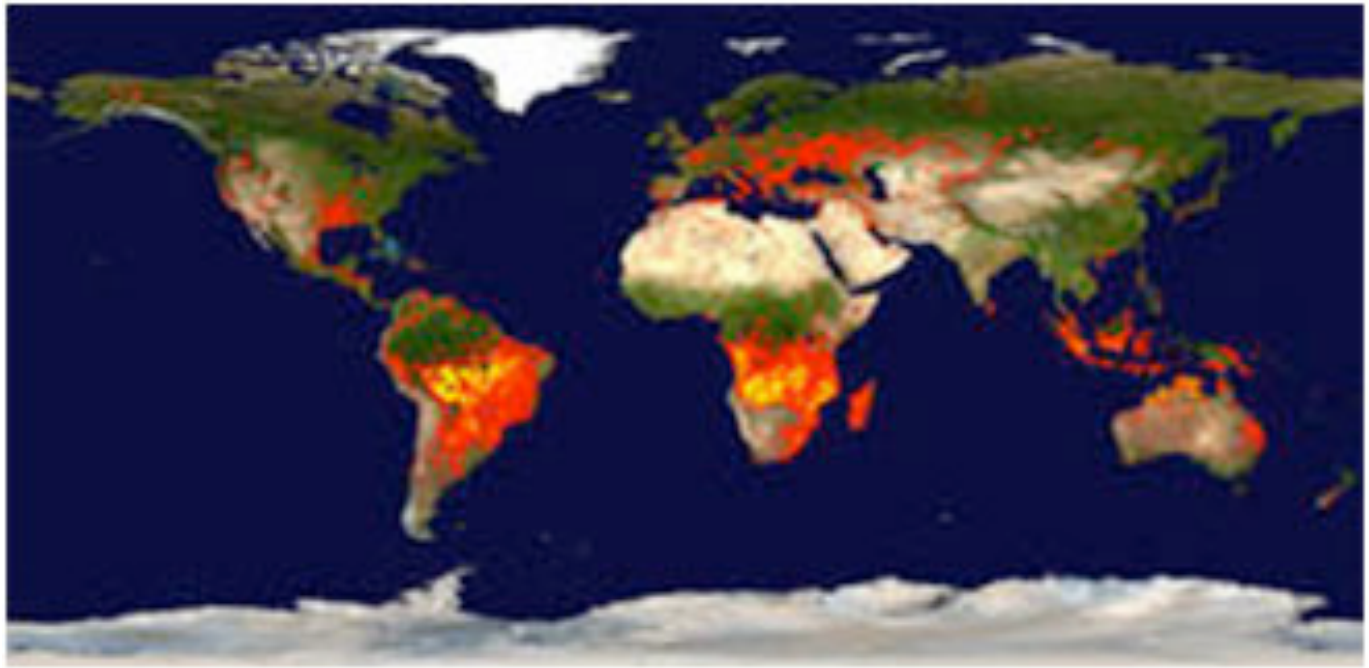


Fig. 1. Satellite observations show a declining trend in fire activity across the world's tropical and temperate grassland ecosystems and land-use frontiers in the Americas and Southeast Asia. (**A**) mean annual burned area and (**B**) trends in burned area (GFED4s, 1998 through 2015). Line plots (inset) indicate global burned area and trend distributions by fractional tree cover (*28*).

Reduced biomass burning is observed in the tropics as a result of shifting agricultural practices → increased fragmentation of landscapes in all tropical regions but also reduced logging in S. America due to policy. Short and long-term shifts in precipitation also play a role

Andela and van der Werf, Nat. Clim. Ch. 2014;Andela et al., Science 2017

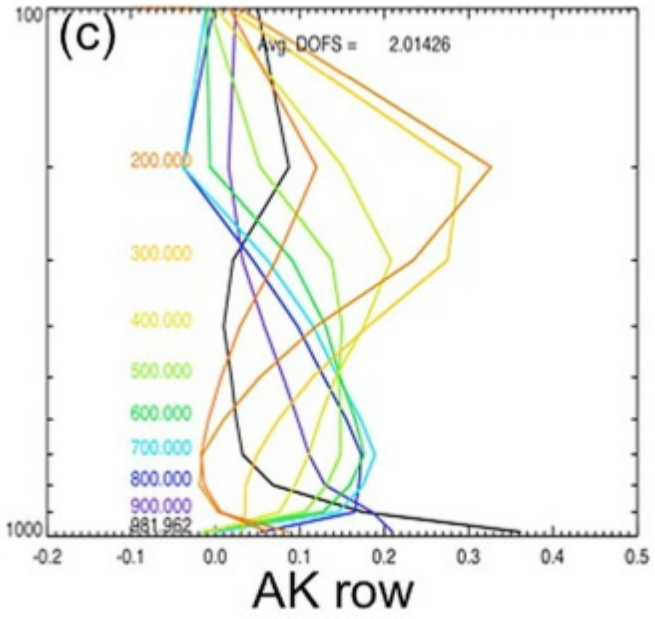
What is the role of reduced burning during the 21rst century on the global carbon budget?



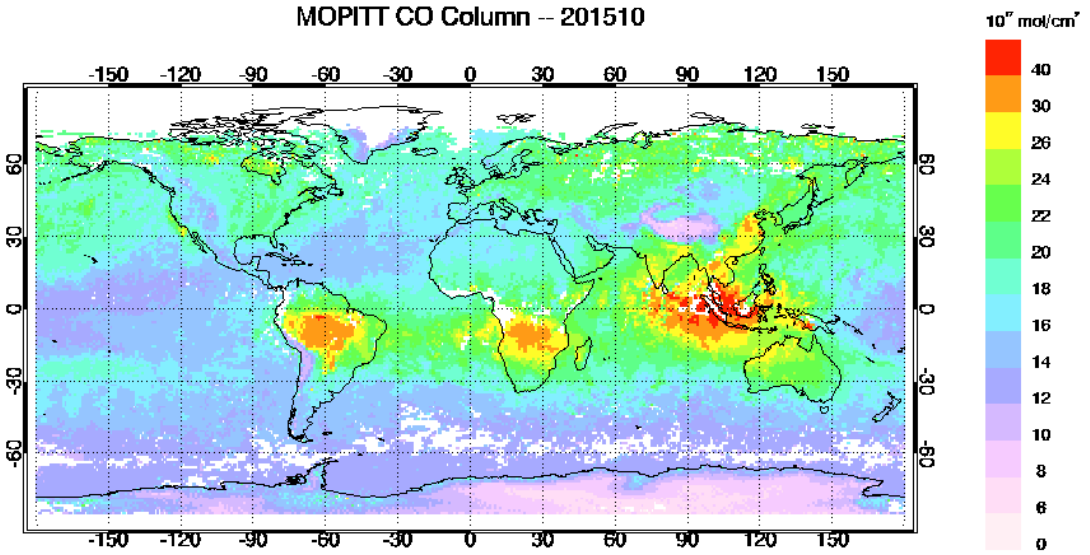
CO_2 ~ 7300 Tg / yr
CH_4 ~ 16 Tg/ yr
CO ~ 350 Tg / yr
Total Carbon ~ 2.1 PtG C/ yr
Emissions estimates depend on Burnt area, Fuel loads, and combustion completeness
(e.g. van der Werf et al. 2010, 2017, Giglio et al., 2006, 2009, 2010)

Quantify CO_2 emissions using CO based observations

MOPITT CO Near IR / IR Averaging Kernel



H. Worden et al., JGR, 2010



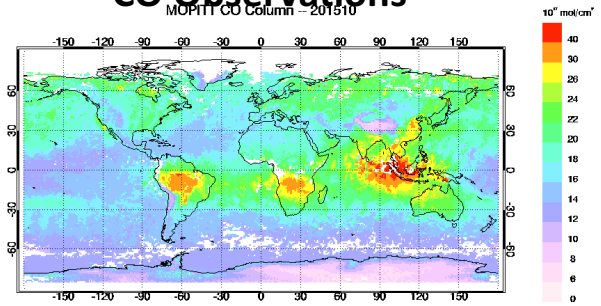
~20-30% uncertainty in the lower troposphere
~5% uncertainty in the total column

Use MOPITT CO data and the 4-D Variational GEOS-Chem model to quantify CO emissions

Jiang et al. JGR 2013; Bloom et al. GRL 2015; Jiang et al. 2017; Worden et al., 2017

Prior Emissions

CO Observations



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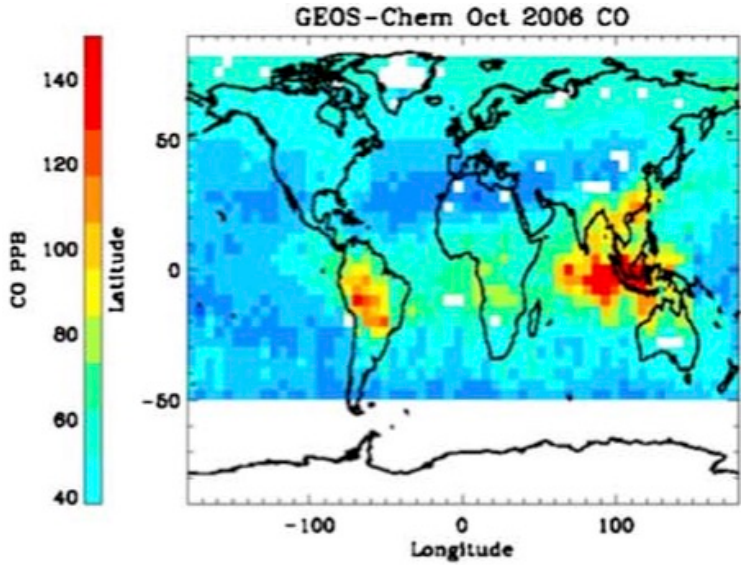

CO Emissions

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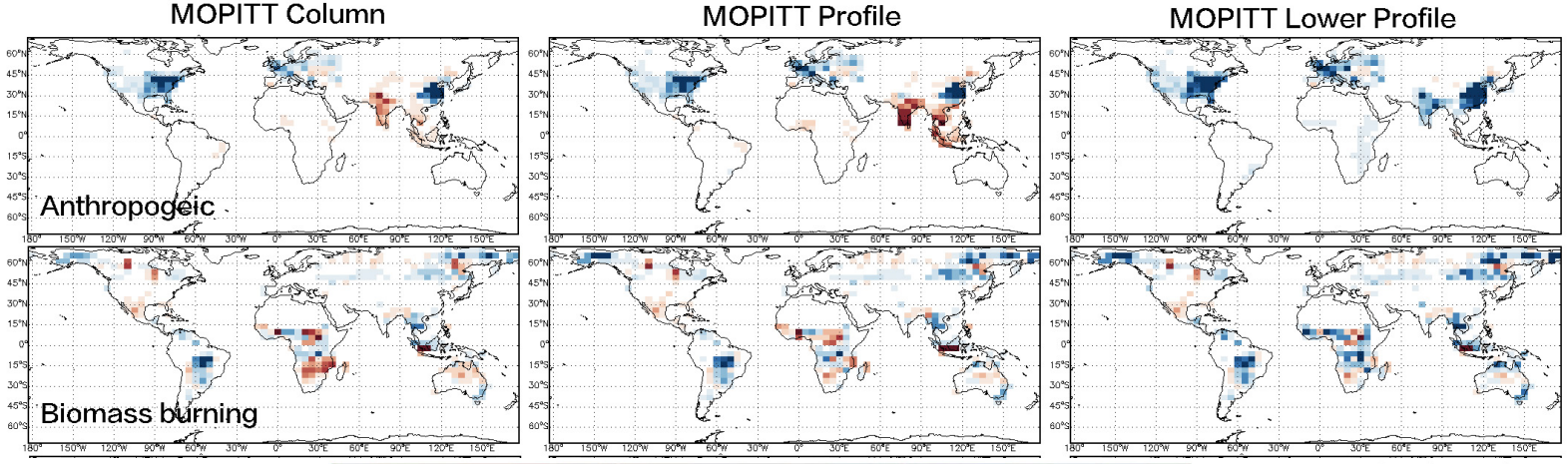
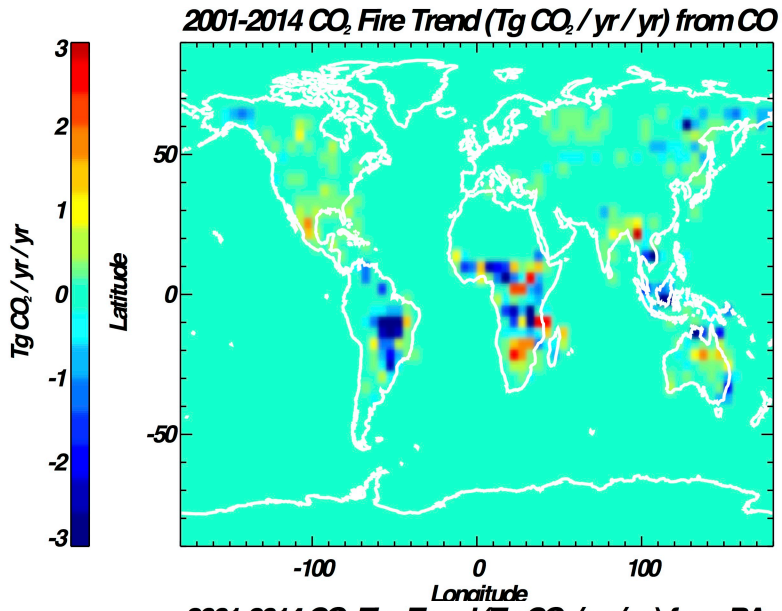
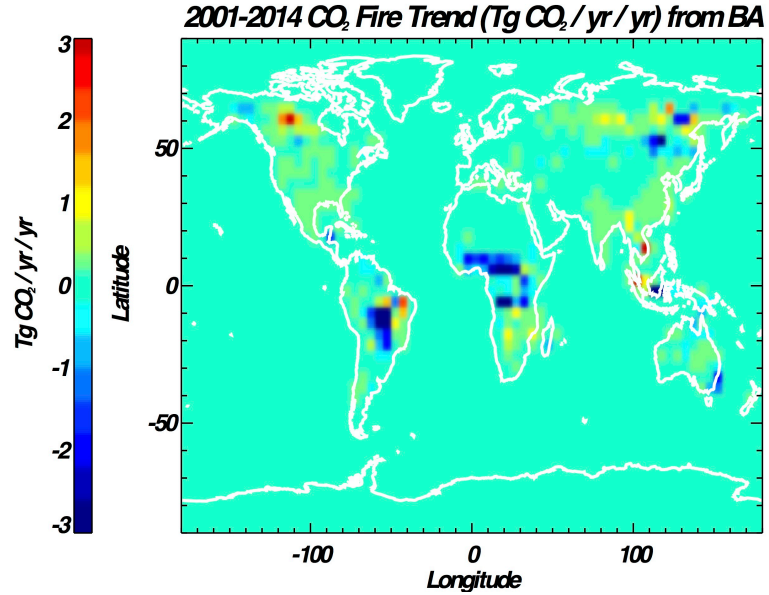


Trends in CO_2 from fires





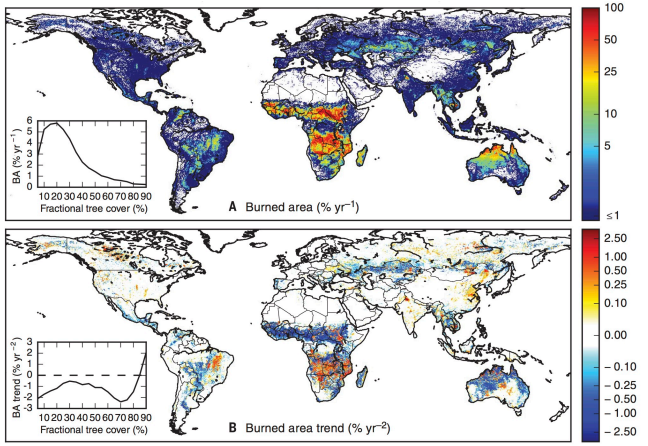


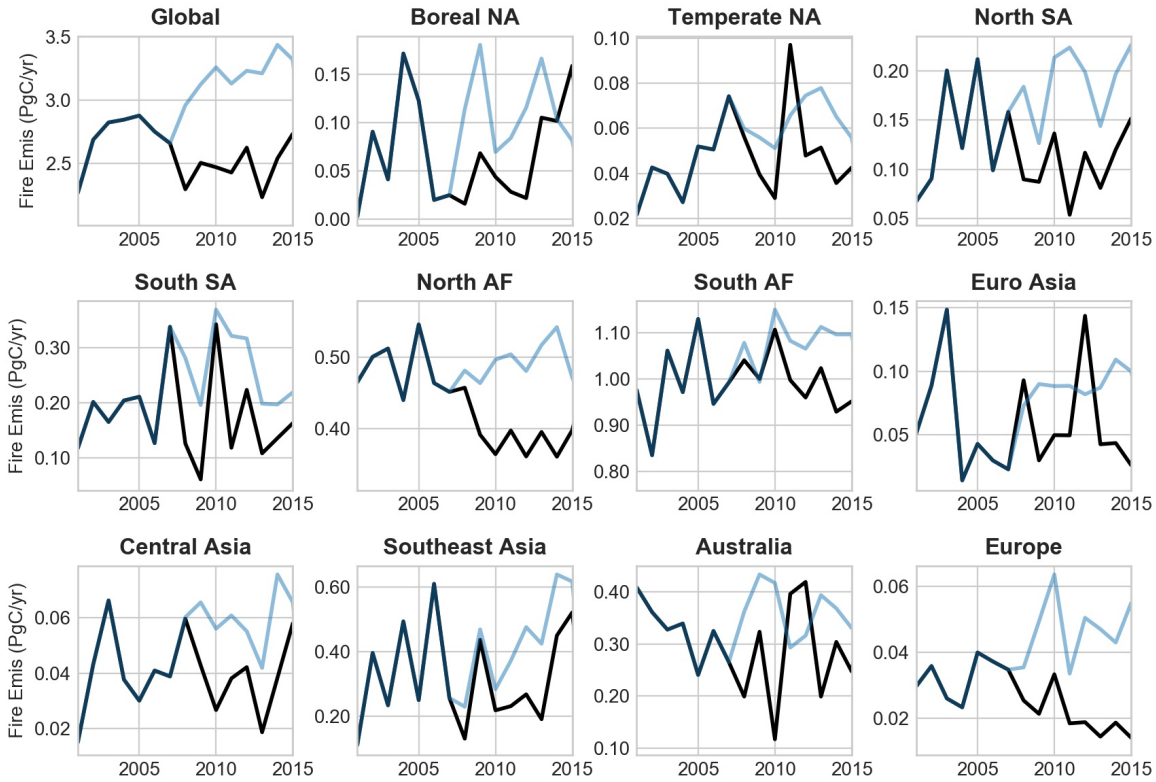
Fig. 1. Satellite observations show a declining trend in fire activity across the world's tropical and temperate grassland ecosystems and land-use frontiers in the Americas and Southeast Asia. (**A**) mean annual burned area and (**B**) trends in burned area (GFED4s, 1998 through 2015). Line plots (inset) indicate global burned area and trend distributions by fractional tree cover (*28*).

CO and CO_2 emissions decline until 2015 are in same region as burnt area but different magnitudes → larger decreases than expected in S. America, Indonesia, N. Africa and Siberia.

Different combusted biomass amount and combustion efficiencies likely

e.g. Bloom et al., GRL 2015

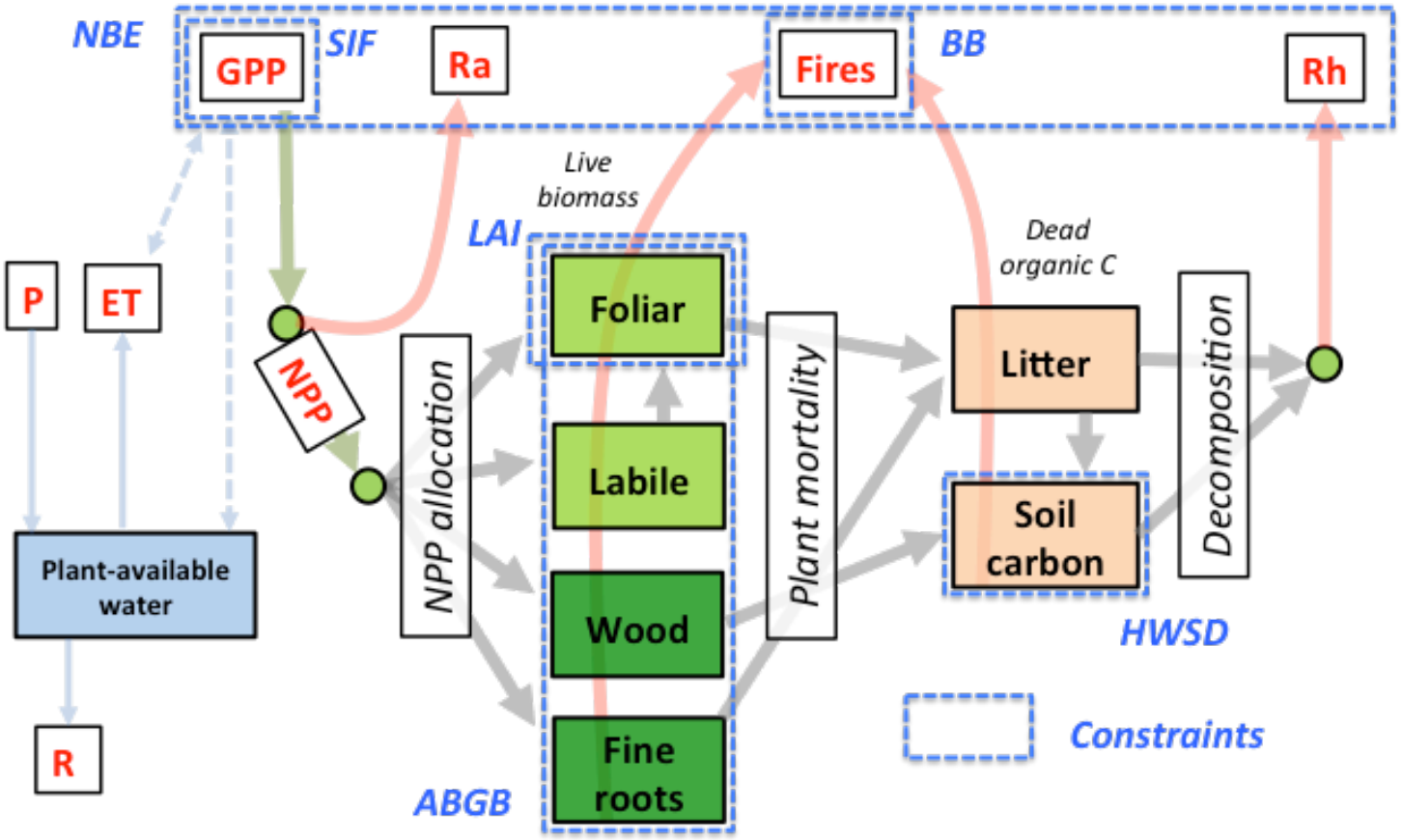
How does climate variability and human (land-use) affect fire emissions and trends?



A model driven by climate related parameters (temperature, precipitation, VPD) suggests that fire emissions should strongly increase by nearly ~ 0.6 PtG C / yr. We observe that fire emissions decrease by ~0.2 PtG C / yr indicating that human effects have decreased fire-based carbon emissions by ~0.8 PtG C / yr likely due to changes in agricultural practices and policy

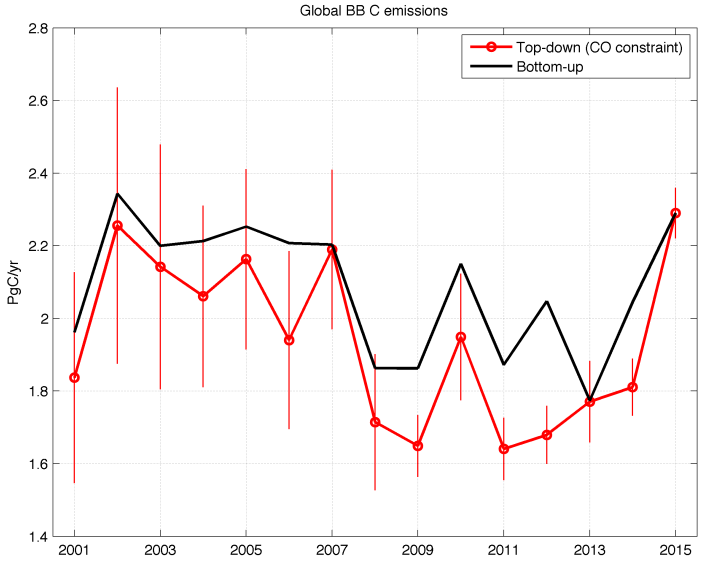
What is the total effect of decreased burned area on carbon emissions?
"If its not burning than its growing"

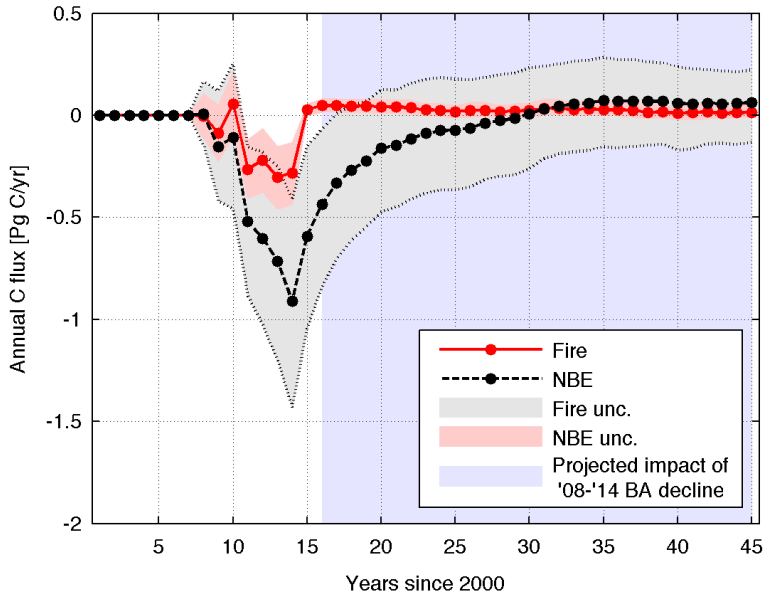
Use the CARDAMOM diagnostic ecosystem model which assimilates burnt area, CO emissions, LAI, and biomass to investigate direct and indirect effects of reduced burning
(Bloom et al. PNAS, 2016)



Total direct emissions of carbon reduced by about 0.2 PgC/yr

But combination of direct and indirect effects of reduced burning (modeled by CARDAMOM) is nearly 1 PgC / yr





The combination of direct reduction of emissions and indirect effects (less burning means more growing) is ~1. PgC/yr

~1. PgC/yr comparable to combined change in land-sink and land-use flux during this same time period

2015 El Nino (temporarily?) negates downward trend

Summary

Climate variability (changes in precipitation, temperature, and water vapor deficit) would likely have increased carbon emissions by about 0.6 PtG C / yr. Instead biomass burning emissions decreased ~0.2 PtG C / yr suggesting human related reductions in biomass burning had a direct impact of approximately 0.8 PtG C / yr

The "indirect" emissions were even larger (if its not burning its growing), suggesting that fires are a substantial component of the observed changes in tropical carbon fluxes over the last 15 years.

The total indirect + direct effect is ~1 PtG C / yr and is comparable to the inferred change in land-use + land sink of ~ 1.2 PtG C/yr

Follow on studies:
What is role of nutrient cycling on "indirect effect": Assimilate new biomass maps to test decadal growth rates estimates after fire disturbance

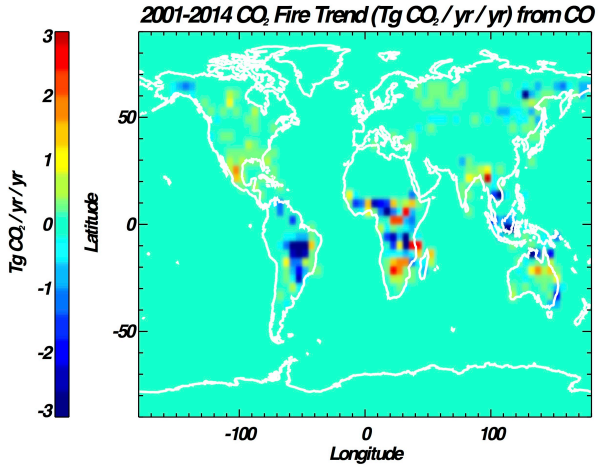
Bring in XCO_2 constraints on Net Biome Exchange (NBE) and SIF constraints on GPP in order to better partition the respiration components from the fires.

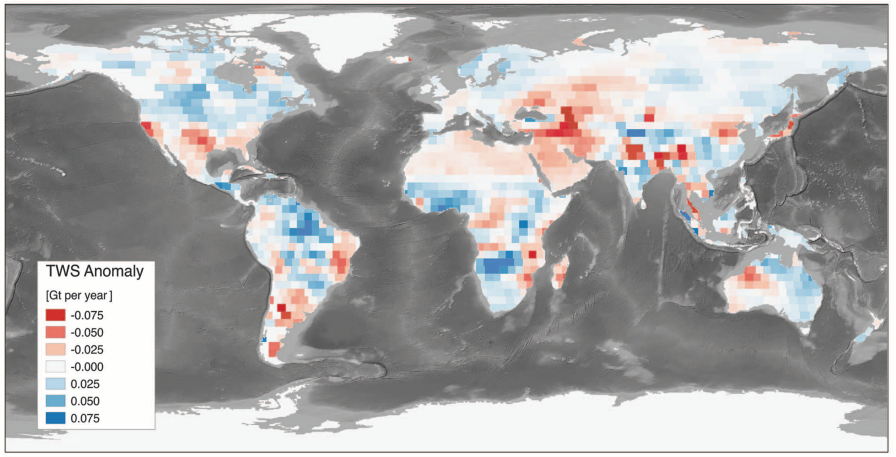
Summary

Changes in global fire characteristics resulted in ~0.2 PtG/yr reduction in direct emissions and between 0.2 to 1.0 PtG/yr in "indirect" emissions, suggesting that fires are a substantial component of the observed changes in tropical carbon fluxes over the last 15 years. These changes are primarily thought to be due to land-scape fragmentation and policy (Andela et al., 2017).

Follow on studies:
What is role of nutrient cycling on "indirect effect": Assimilate new biomass maps to test decadal growth rates estimates after fire disturbance

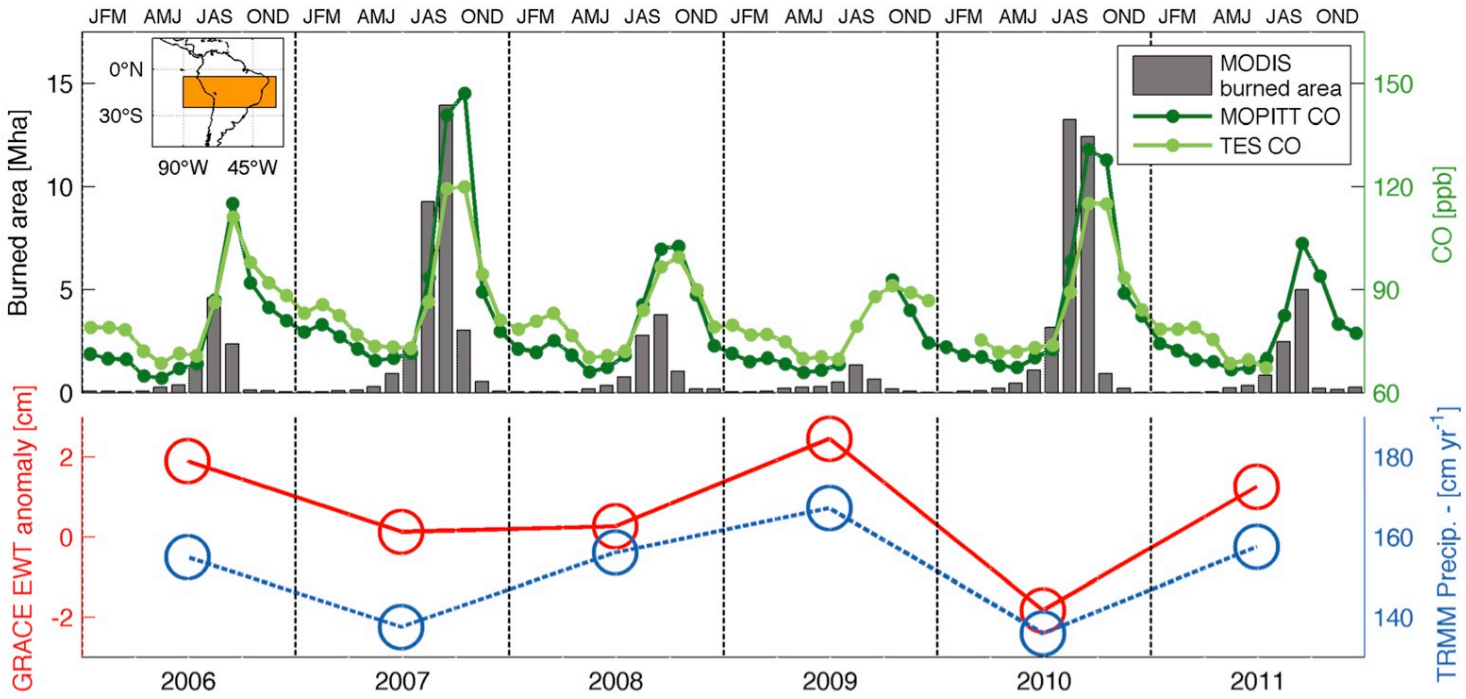
How much of this change is due to human effects and how much is due to short/long term climate variability? (Train fire variability against TRMM/GRACE data)





GRACE data show (2002-2014) increased water storage despite increasing droughts (Reager et al., Science 2015)

Case Study: Comparison of 2010 and 2007 Amazon fires
Bloom, Worden, Jiang et al. GRL 2015



Burnt area ~5% larger but CO emissions ~30% lower

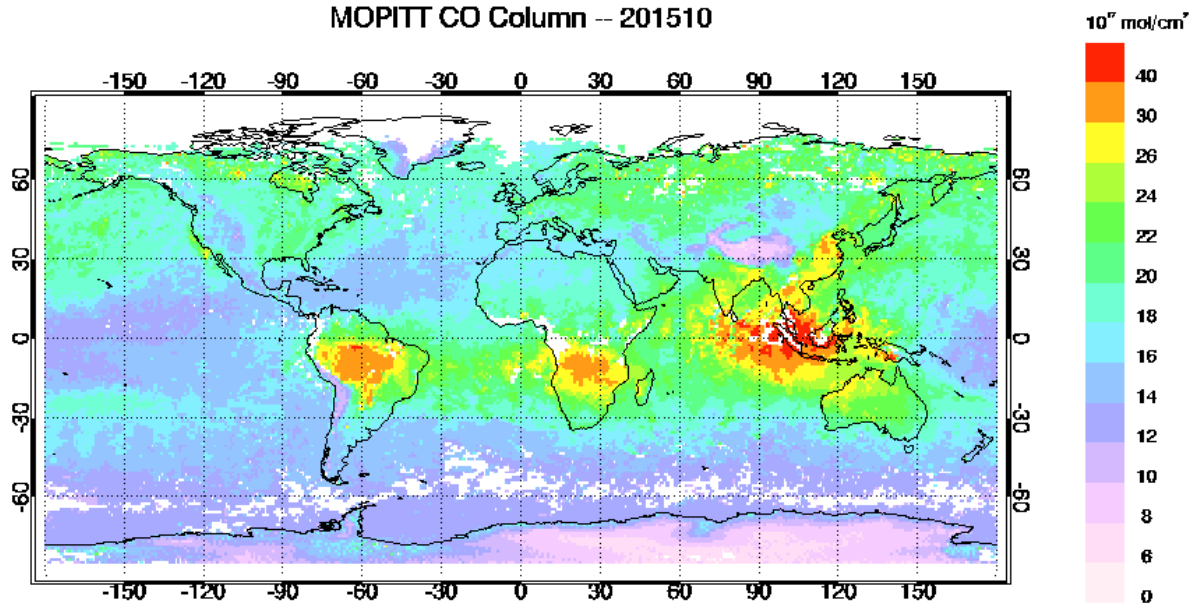
We combine land-surface and CO measurements constrain 2007 and 2010 fire emission factors and combusted biomass.

Likely reason for relative decline in emissions is reduced combustion biomass density (88%) possibly due to decreased GPP in 2010

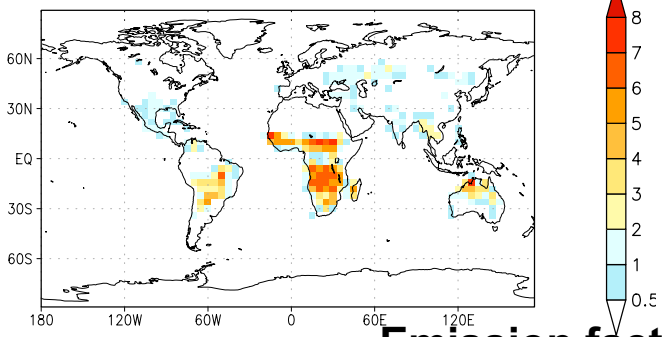
African and SE Asia due to shift in agricultural practices / land-use changes?

CO and Biomass Burning CO_2 fluxes

MOPITT Measurements of Pollution in the Atmosphere



- Carbon monoxide is a by-product of incomplete combustion.
- MOPITT provides CO vertical profiles with near surface sensitivity.
- Footprint is 22 km x 22 km

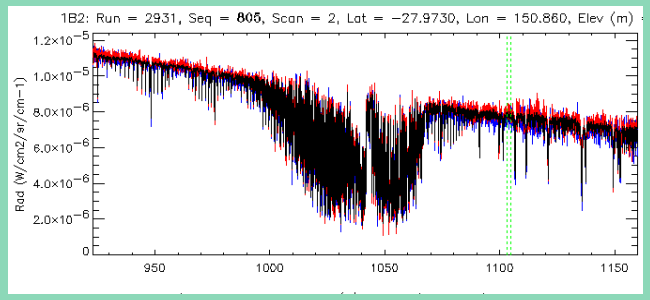


Emission factors

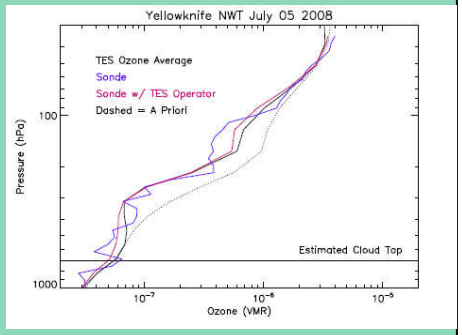
- CO_2 from biomass burning is calculated from CO/CO2 ratios (Andreae and Merlet, GBC, 2001)
- Emission factors are a function of dry mass and burning efficiency
- Uncertainties from burnt-area prior propagated to posterior (based on CO)

Jiang et al., 2017; Bowman et al., 2017; Liu et al., 2017

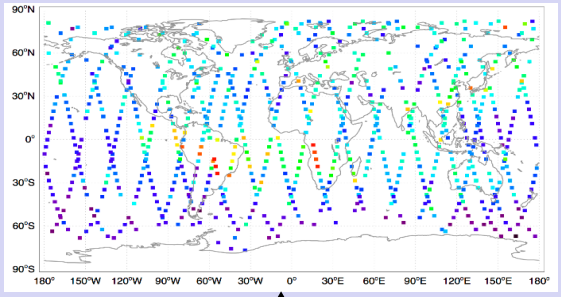
How do we turn measured top-of-atmosphere radiances to profiles of composition?



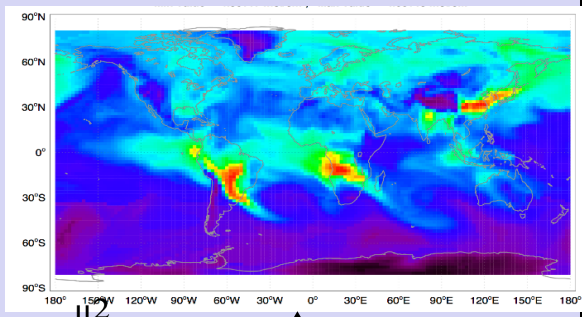
$$\left\|\mathbf{y}-\mathbf{F}(\mathbf{x}_a)\right\|^2_{\mathbf{S}_n^{-1}}+\left\|\mathbf{x}-\mathbf{x}_a\right\|^2_{\mathbf{S}_a^{-1}}$$



$$\hat{\mathbf{x}}=\mathbf{x}_a+\mathbf{A}(\mathbf{x}-\mathbf{x}_a)+\mathbf{Gn}$$



$$\mathbf{H}(\mathbf{x})=\mathbf{x_a}+\mathbf{A}(\mathbf{x}-\mathbf{x_a})$$



$$\sum_i\left\|\hat{\mathbf{x}}_i-\mathbf{H}_i(\mathbf{x})\right\|^2_{(\mathbf{G}_i\mathbf{S}_n^i\mathbf{G}_i^T)^{-1}}+\left\|\mathbf{x}_0-\mathbf{x}_B\right\|^2_{\mathbf{B}^{-1}}$$

Optimal estimation provides the error characterization and averaging kernels needed to test uncertainties and use data with models