Tropical drivers of the Atmospheric Growth Rate 2011-2010

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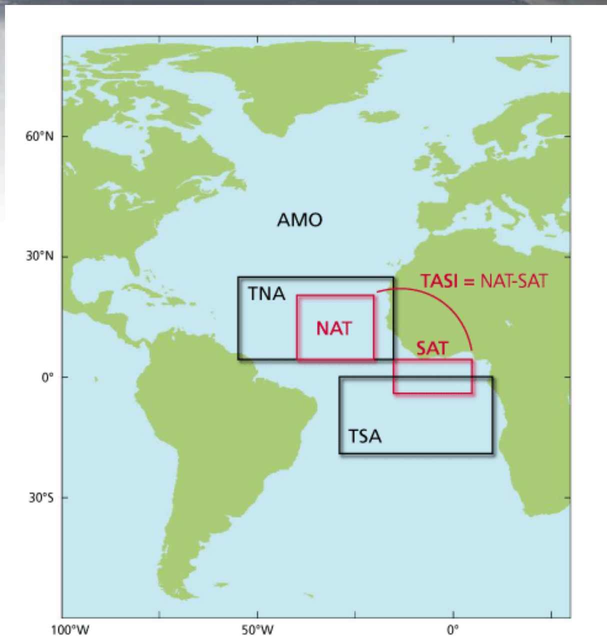
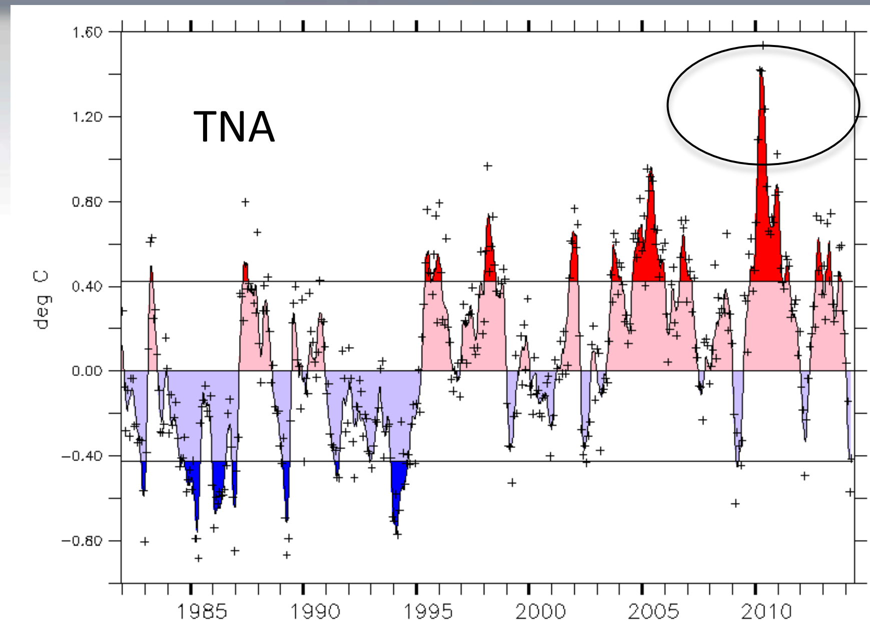
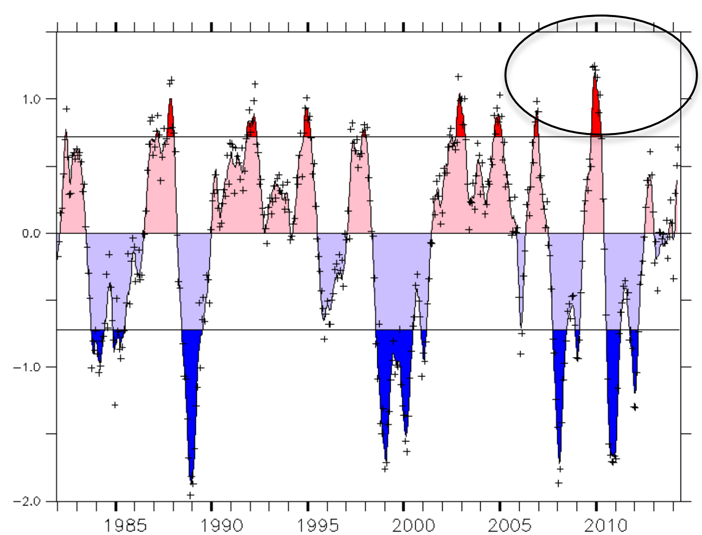
Drought and the Tropical North Atlantic





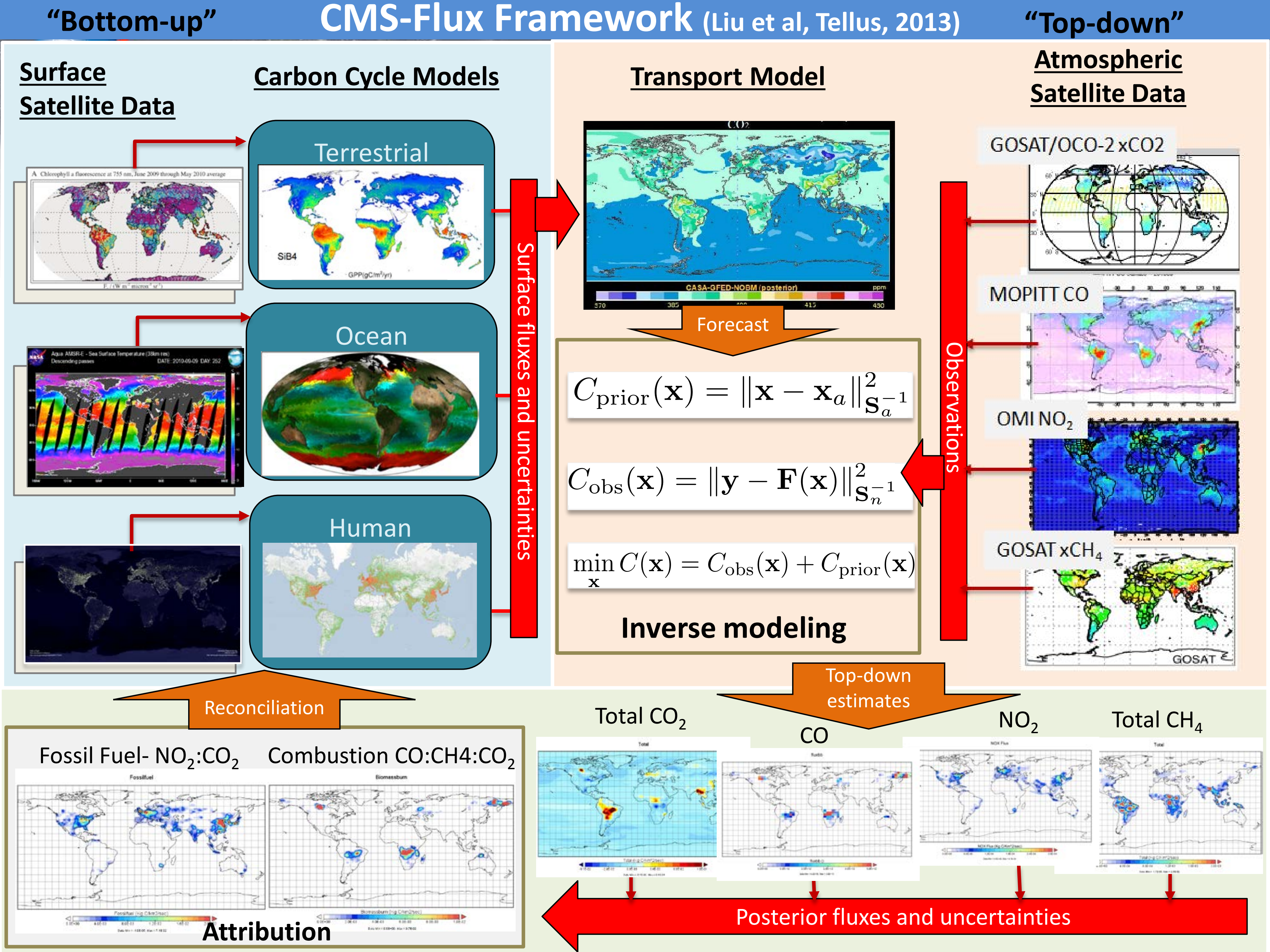
El Nino 4.0



The tropical North Atlantic experienced a record-breaking SST anomaly >1.5°C.

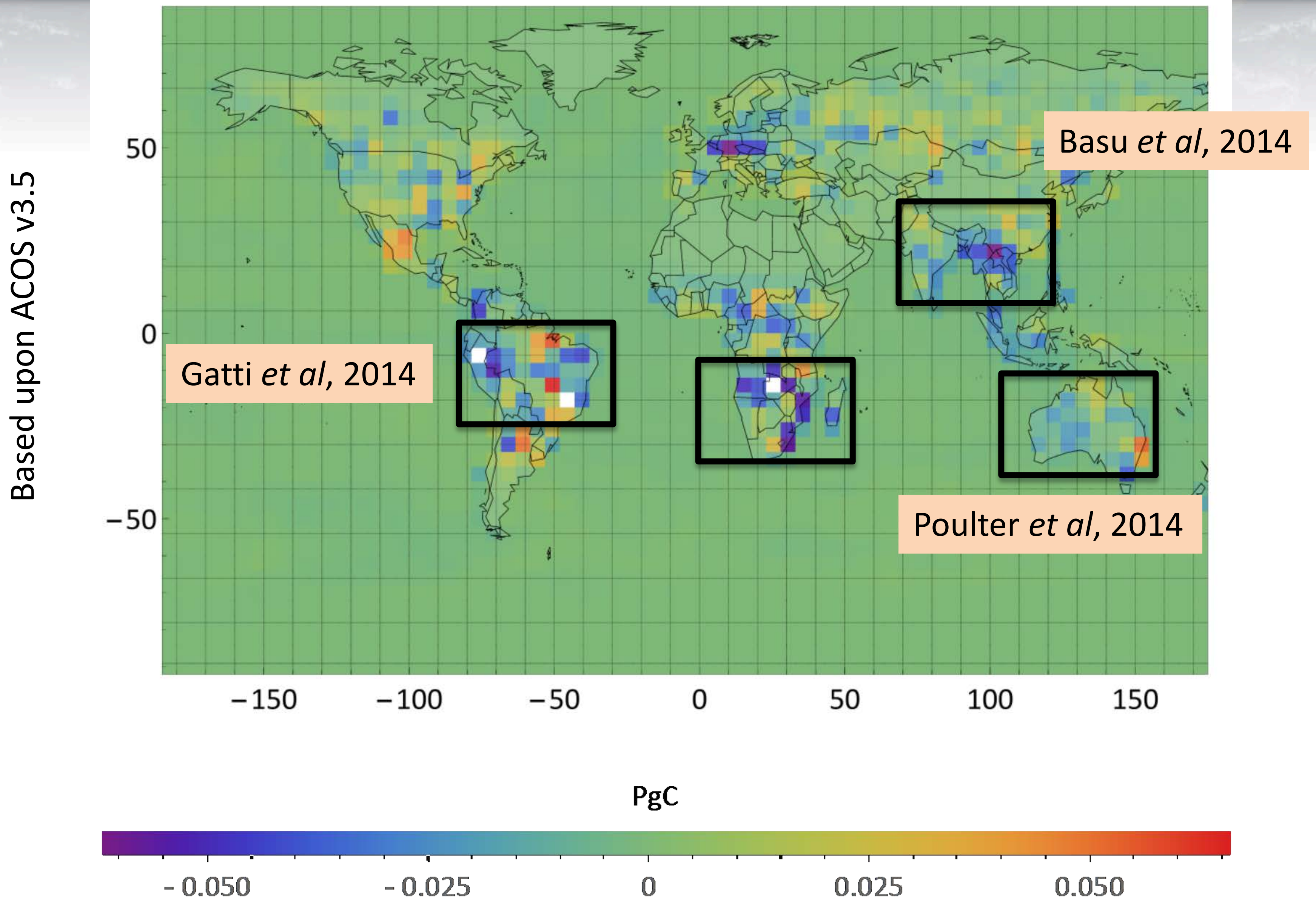
Consequence of a strong Central-Pacific "Modoki" El Nino amplified by a strong and persistent negative phase of the North Atlantic Oscillation (NAO) (Hu *et al*, J. Climate 2011)

Shifted ITCZ north leading to a dramatic Amazonian drought (Lewis *et al*, Science, 2010)



"Bottom-up"
CMS-Flux Framework (Liu et al, Tellus, 2013)
"Top-down"
Surface Satellite Data
Carbon Cycle Models
Transport Model
Atmospheric Satellite Data
Terrestrial
SiB4
Ocean
Human
Surface fluxes and uncertainties
CASA-GFED-NOBM (posterior)
Forecast
GOSAT/OCO-2 xCO2
MOPITT CO
OMI NO_2
GOSAT xCH_4
GOSAT
Observations
$C_{\text{prior}}(\mathbf{x}) = \|\mathbf{x} - \mathbf{x}_a\|^2_{\mathbf{S}_a^{-1}}$
$C_{\text{obs}}(\mathbf{x}) = \|\mathbf{y} - \mathbf{F}(\mathbf{x})\|^2_{\mathbf{S}_n^{-1}}$
$\min_{\mathbf{x}} C(\mathbf{x}) = C_{\text{obs}}(\mathbf{x}) + C_{\text{prior}}(\mathbf{x})$
Inverse modeling
Reconciliation
Top-down estimates
Fossil Fuel- NO_2:CO_2
Combustion CO:CH_4:CO_2
Attribution
Total CO_2
CO
NO_2
Total CH_4
Posterior fluxes and uncertainties

Changes in total flux 2011-2010

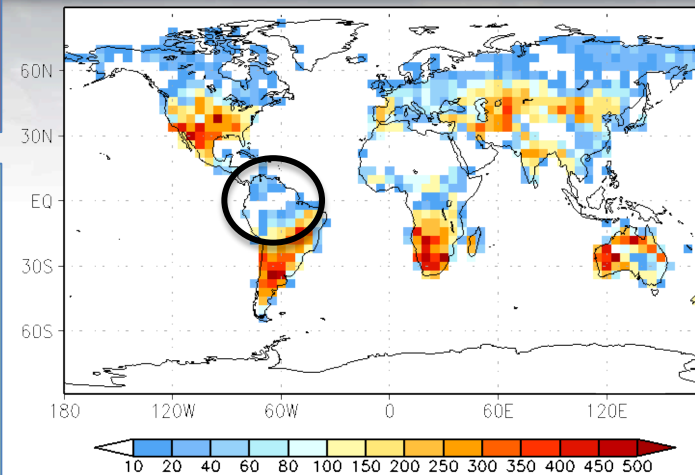


Cloud Canopy: Brazilian Challenge

Amazon is a critical but challenging region
for satellite observations because of persistent cloud cover

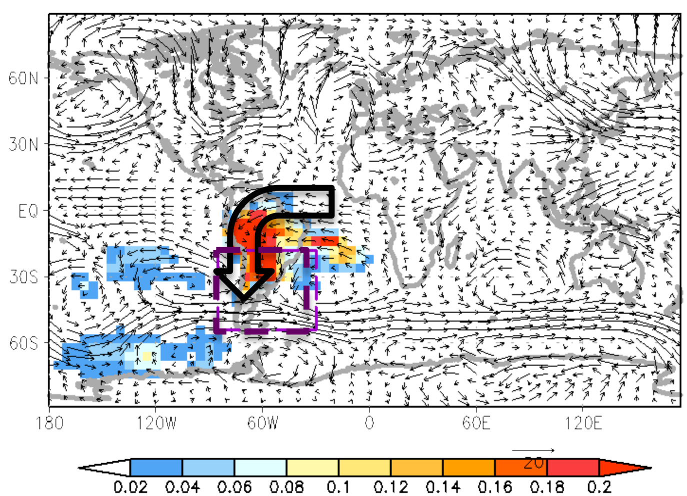
Adjoint analysis (Liu, Bowman, and Henze, JGR 2015) shows that mid-latitude S. America obs. can help infer Amazonian fluxes:

- The fluxes over Amazonia contribute more than 40% to the X_{CO2} variability over mid-lat. S. America (rectangle area) due to the persistent wind direction (Fig. 2).
- The impact of GOSAT over mid-lat. S. America on Amazonia flux estimation is between 30% and 59% of full observation impact (right figure).

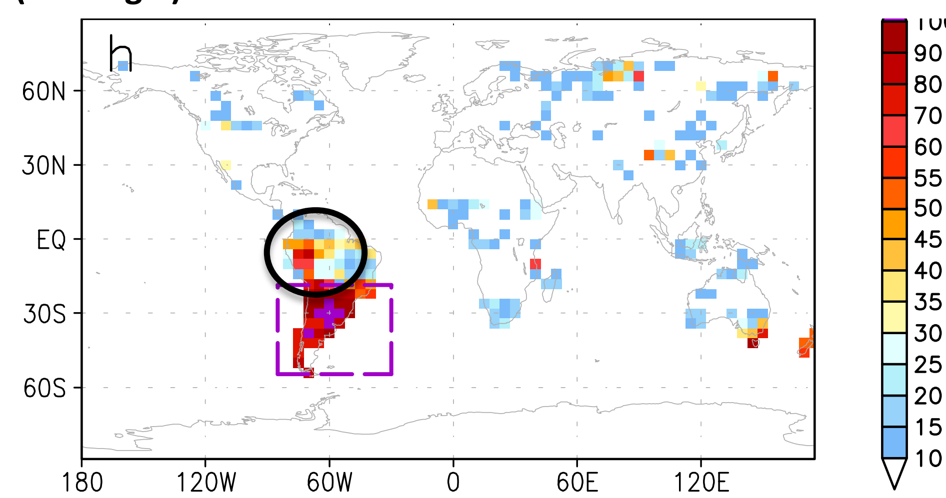


Annual total number of good quality nadir ACOS-GOSAT v3.5 obs at 4° x 5° resolution

700 hPa wind vector and sensitivity of X_{CO2} in S-S- America (rectangle) at Jan 31 to surface fluxes on Jan 23rd

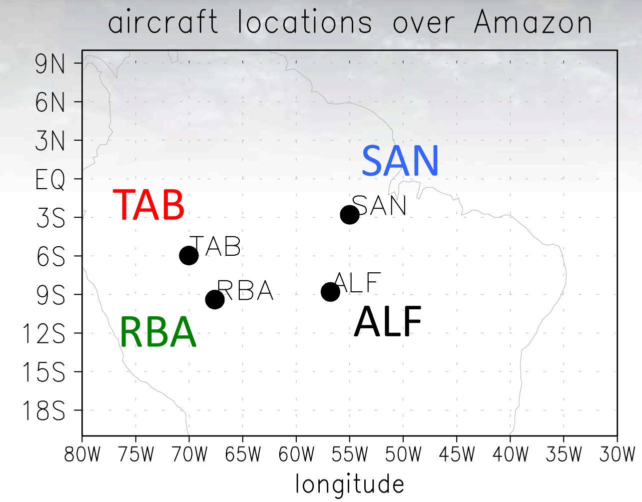


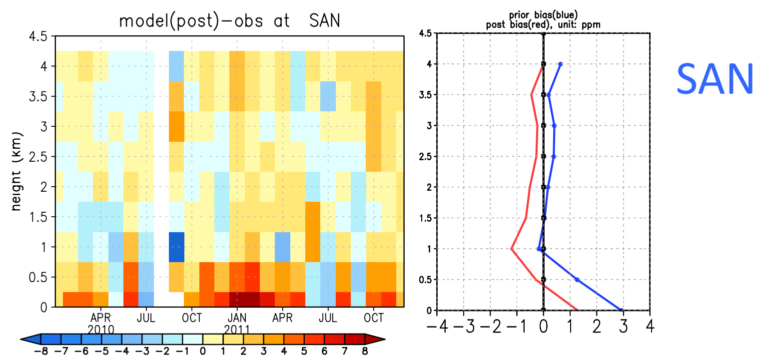
The lower bound impact of GOSAT X_{CO2} within S-S-America (rectangle) on local and nonlocal flux estimation

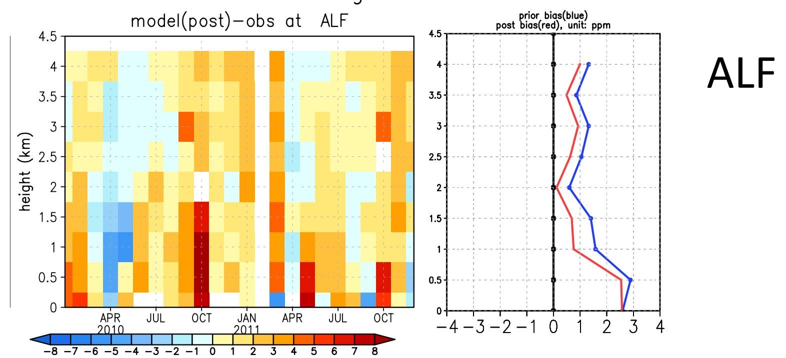


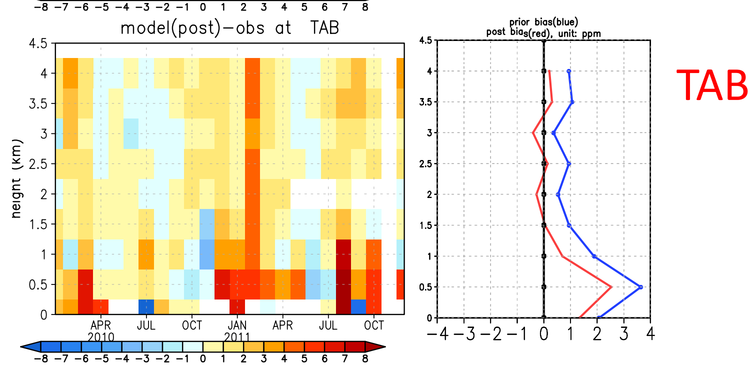
Comparison against aircraft obs.

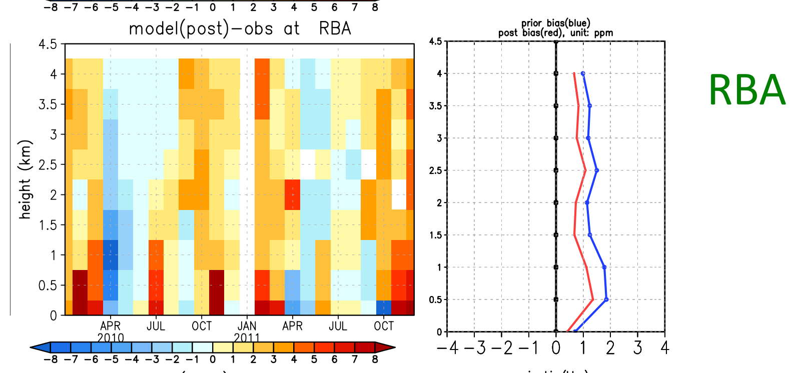
- Aircraft spirals (from Gatti *et al.*) taken twice per month from 2010-2011.
- The mean posterior CO_2 bias is less than 1 ppm above 1 km.
- The bias in posterior CO_2 is smaller than prior CO_2 for TAB, ALF, RBA, but not SAN
- TAB region has strongest impact on midlatitude S. American obs.











Flux Decomposition

Net flux into the atmosphere is positive

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

Fossil Fuel | Ocean | Biomass burning | NEP | Chemical Source

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

The interannual change in total flux can be similarly decomposed:

$$\delta F_{2011-2010}{}^{\uparrow}(x,y,t) = \delta F_F + \delta F_O + \delta F_{BB} - \delta F_{NEP} + \delta F_{chem}$$

Strategy: Use multiple satellite observations to constrain individual terms and infer the others as a residual.

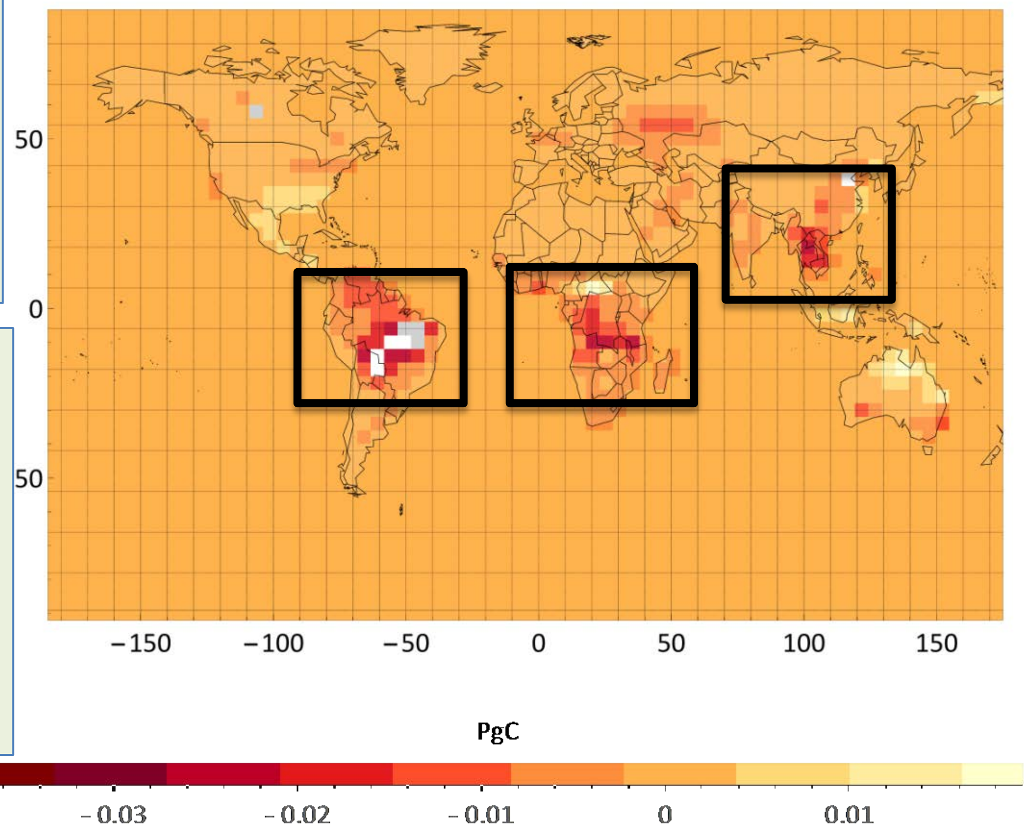
Respiration: combustion

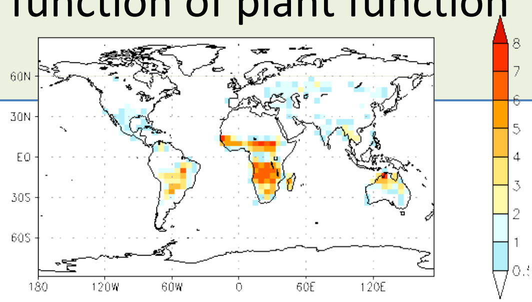
MOPITT Measurements of Pollution in the Atmosphere

- 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.

δBB (2011-2010)





Emission factors

Incorporation of Bloom et al uncertainties underway

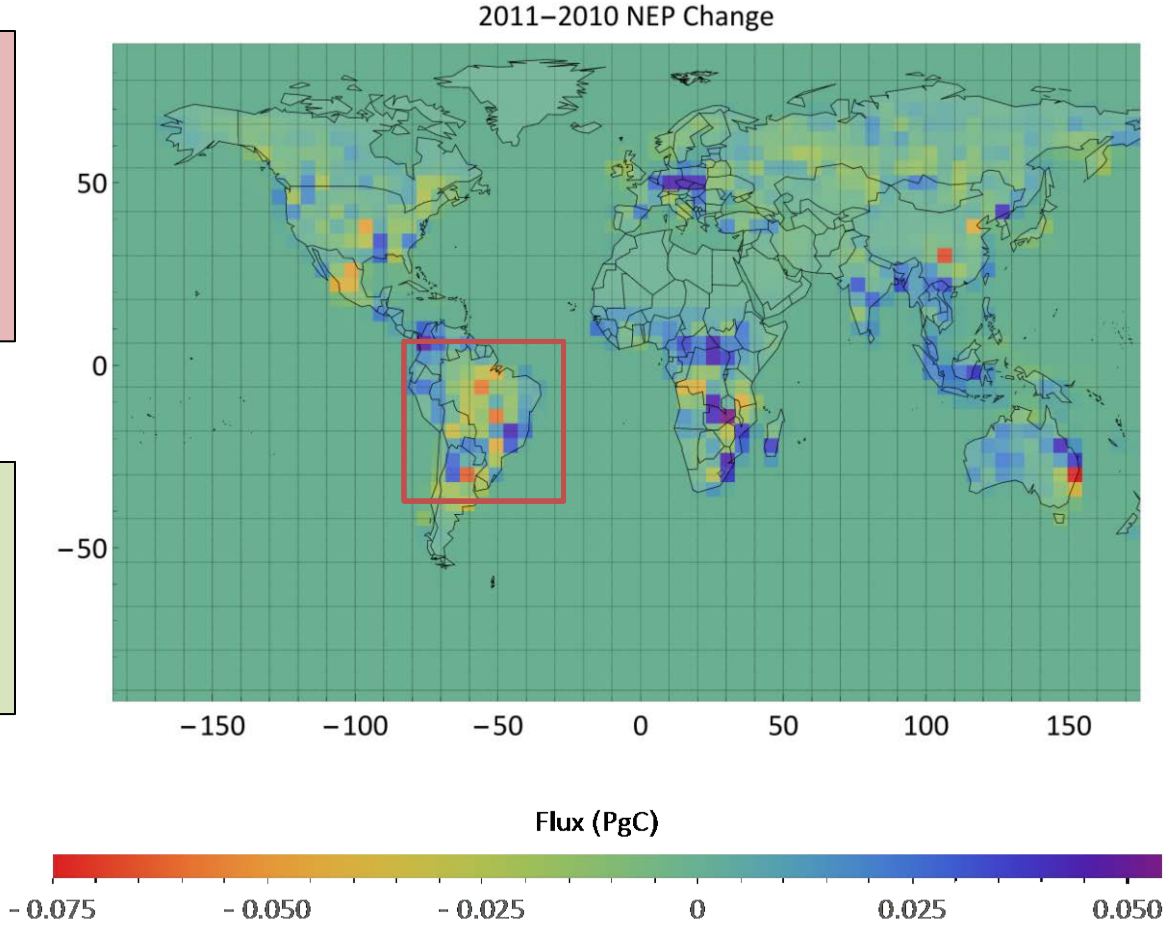
Flux decomposition: NEP

$$\delta F_{2011-2010}^{\uparrow}(x,y,t) = \delta F_F + \delta F_O + \delta F_{BB} - \delta F_{NEP} + \delta F_{chem}$$

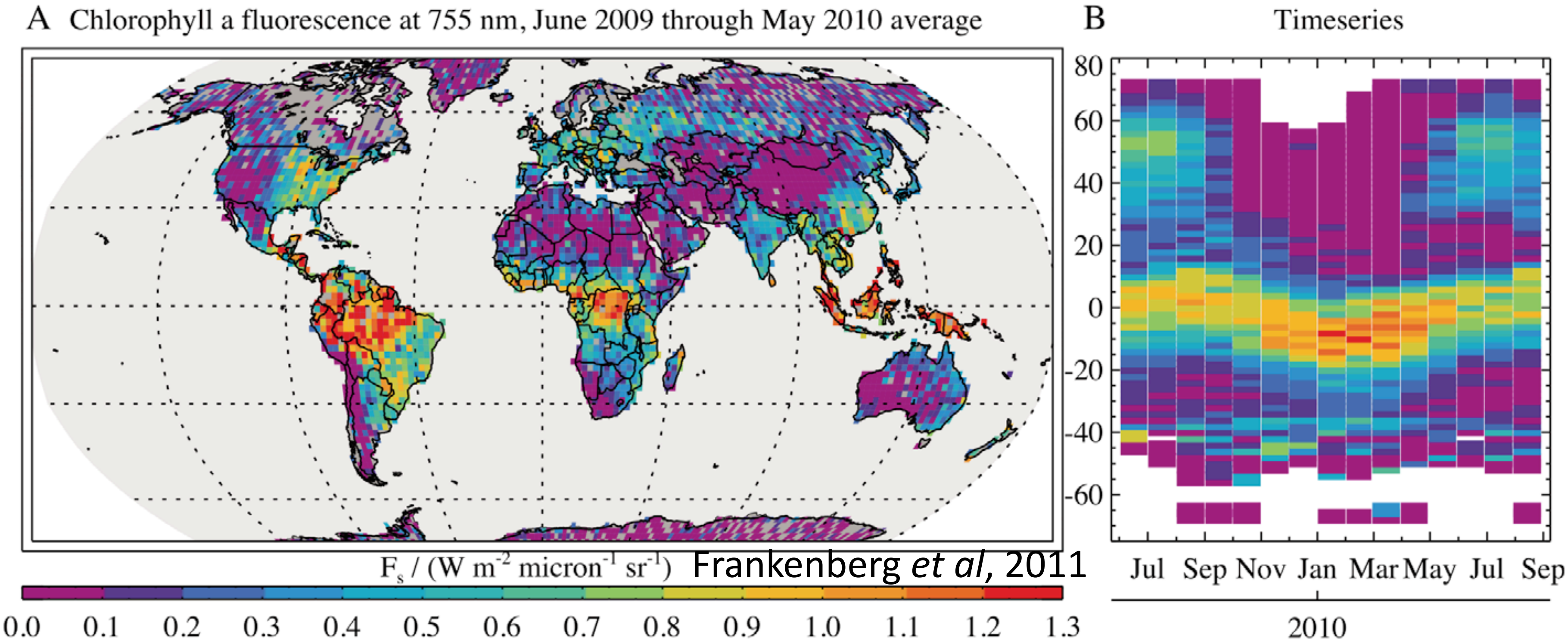
Net flux into the atmosphere is positive

Net ecosystem production (NEP) can be inferred as a residual from the posterior total flux, biomass burning, fossil fuel, and chemical production.

The inferred NEP was greater in 2011 in Africa, Southeast Asia, and Australia while lower in Brazil and Mexico.



GPP inferred from solar induced fluorescence



Frankenberg *et al*, 2011

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 $\{t_i\}$

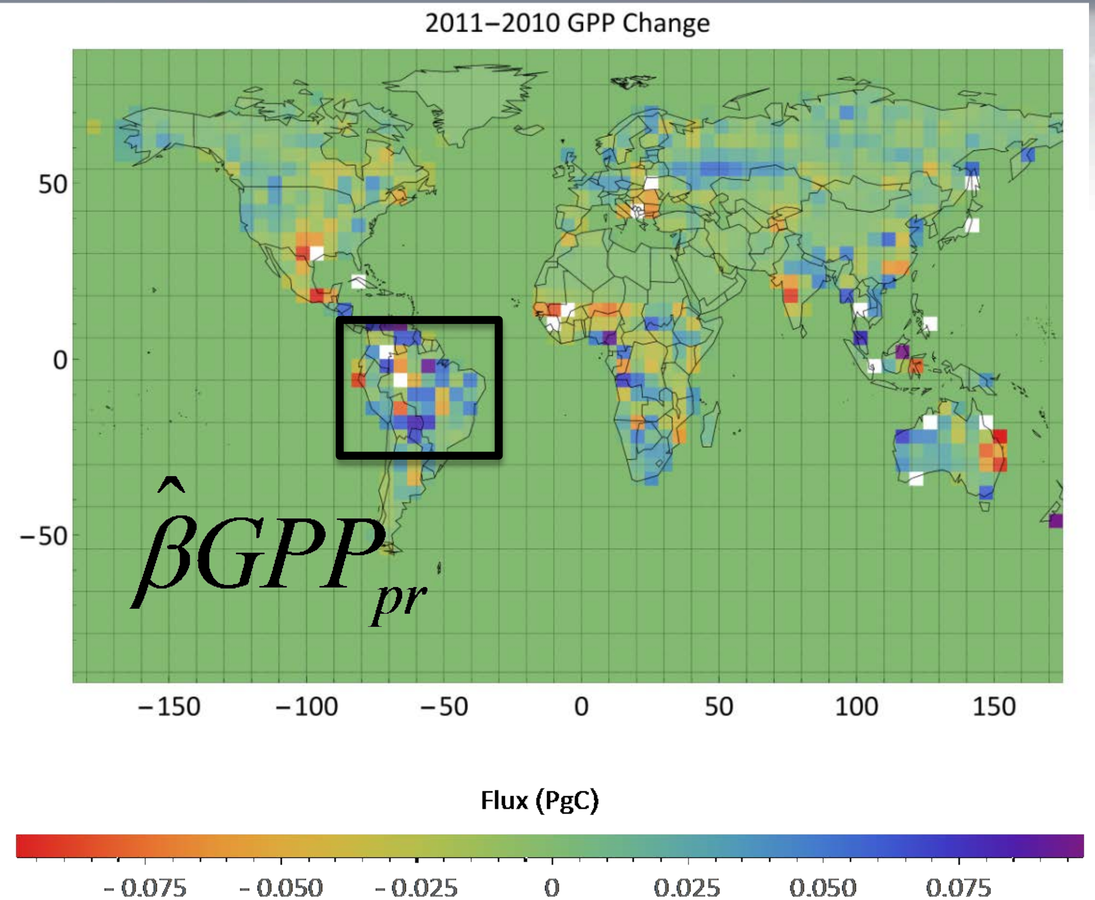
F(x): Observation operator: GPP to GOSAT overpass

$\mathbf{S}_n$: 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

GPP-Solar induced fluorescence



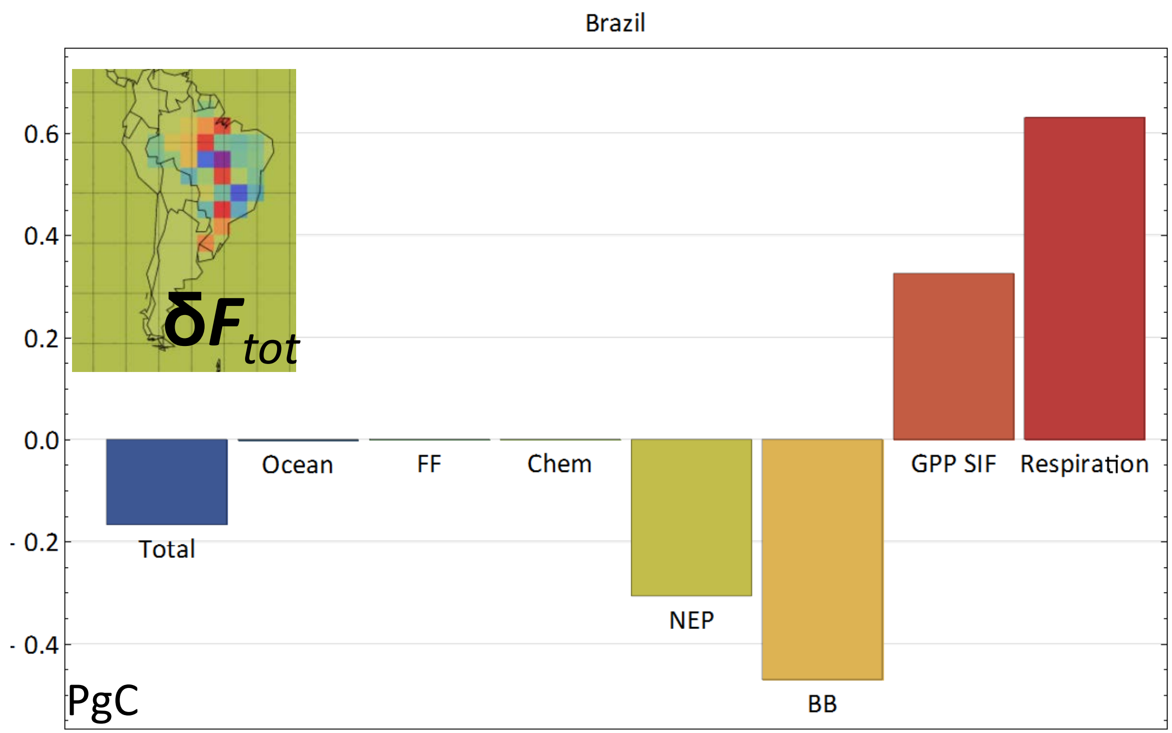
- Solar induced fluorescence (SIF) is a direct measure of photosynthetic activity (e.g., Porcar-Castell *et al,* 2014)
- Parazoo *et al*, GCB, 2014 introduced an optimal estimation method for GPP balancing satellite SIF and carbon cycle models (TRENDY and Casa-GFED)
- Brazil shows increased productivity in 2011

Brazil

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

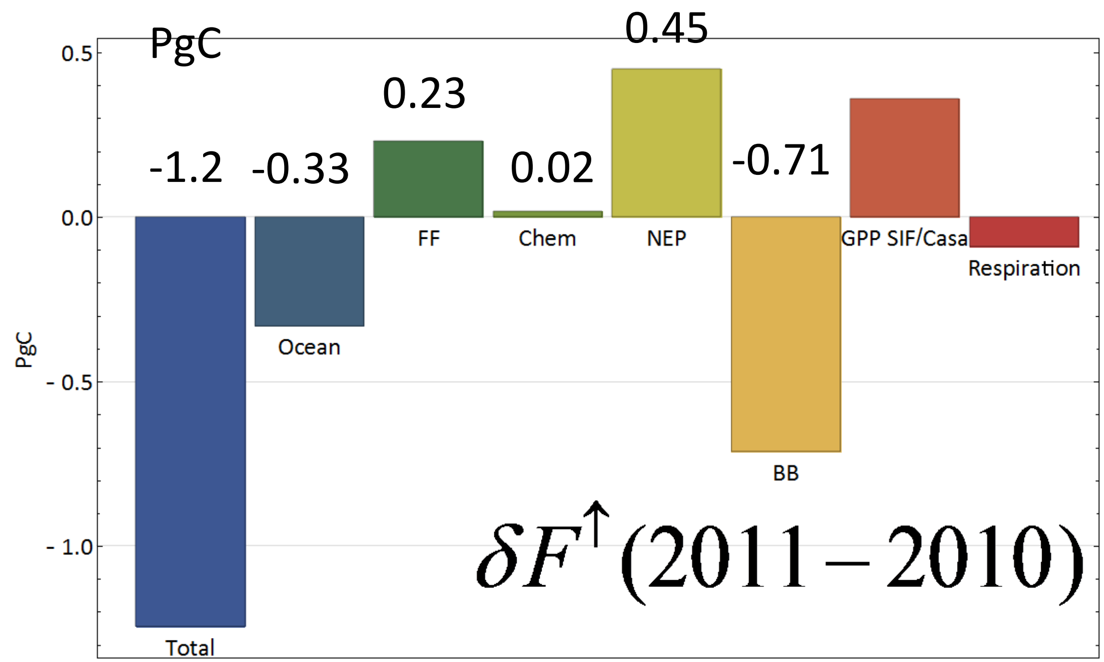
Net flux into the atmosphere is positive

- Weak total flux tendency and strong biomass burning tendency implies negative NEP.
- GPP is positive→R must be higher to compensate.
- GPP →fast carbon pool?
- R→slow carbon pool?
  - Mortality (Saatchi et al, PNAS, 2013)?
  - High precipitation in 2011 could stimulate response



Complex global carbon cycle response to historic Central Pacific El Nino

- Globally, change in CO2 growth rate (GR) driven by biomass burning (~50%)
  - Brazil was primary contributor
- Global NEP (30% CO2 GR) was driven by GPP
  - Implies fast carbon pools readjusted.
- Brazilian NEP was driven by respiration
  - Slow carbon pools possibly impacted
- Increased Ocean uptake accounts for 20% CO2 GR
  - Climatologies, e.g., Takahashi atlas, would miss process

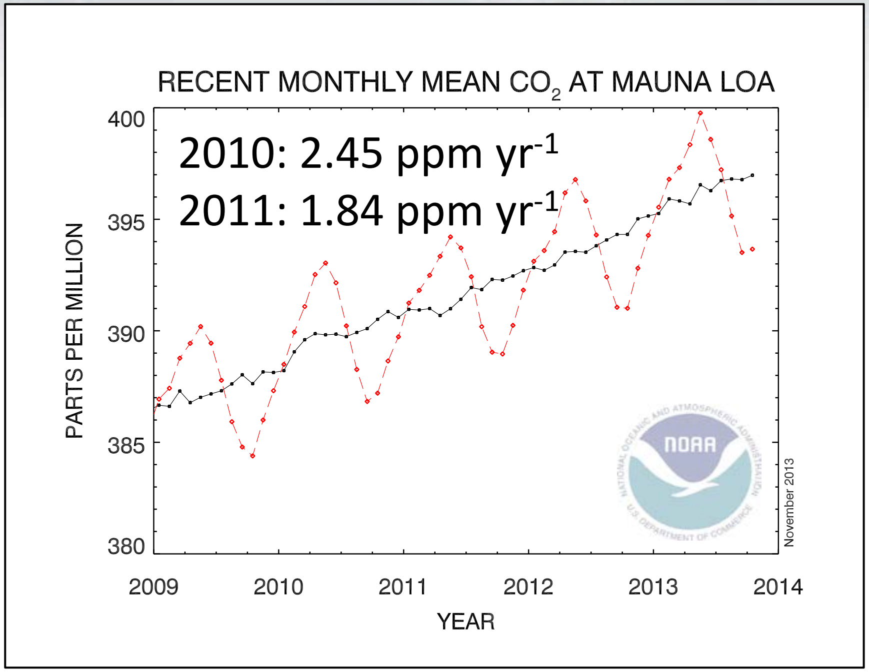


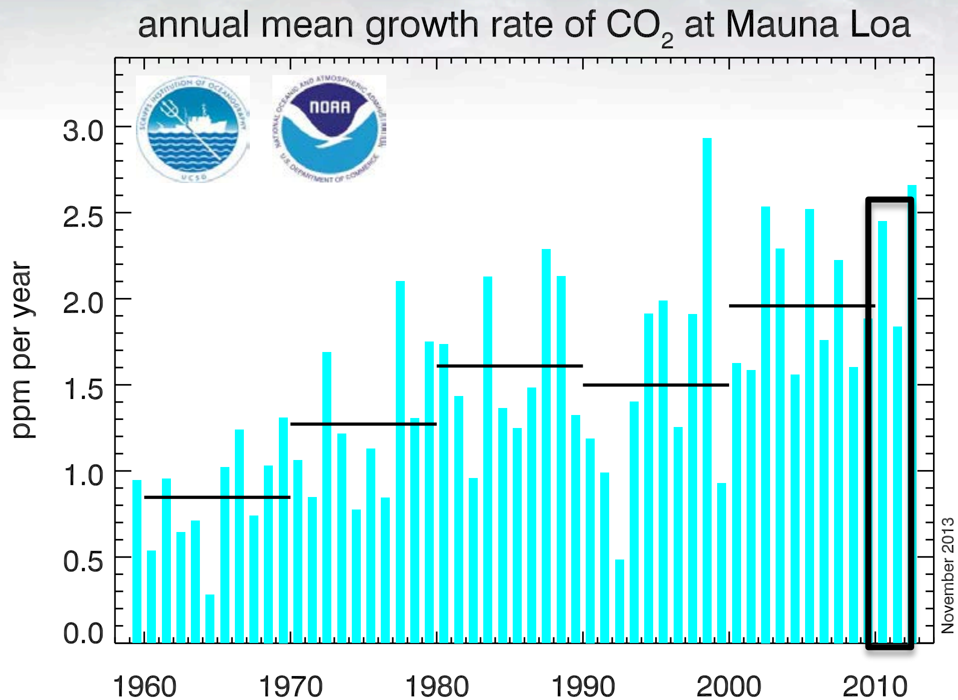
More frequent extreme events like the 2010 mega-drought on Brazil could favor respiration processes, which could accelerate the CO2 growth rate.

Long-term observations of CO2, CO, and SIF from OCO-2, CrIS, TROPOMI will help disentangle slow and fast carbon pools and their response to climate.
See Dejian Fu *et al* poster

Backup

Atmospheric CO2 Growth Rate

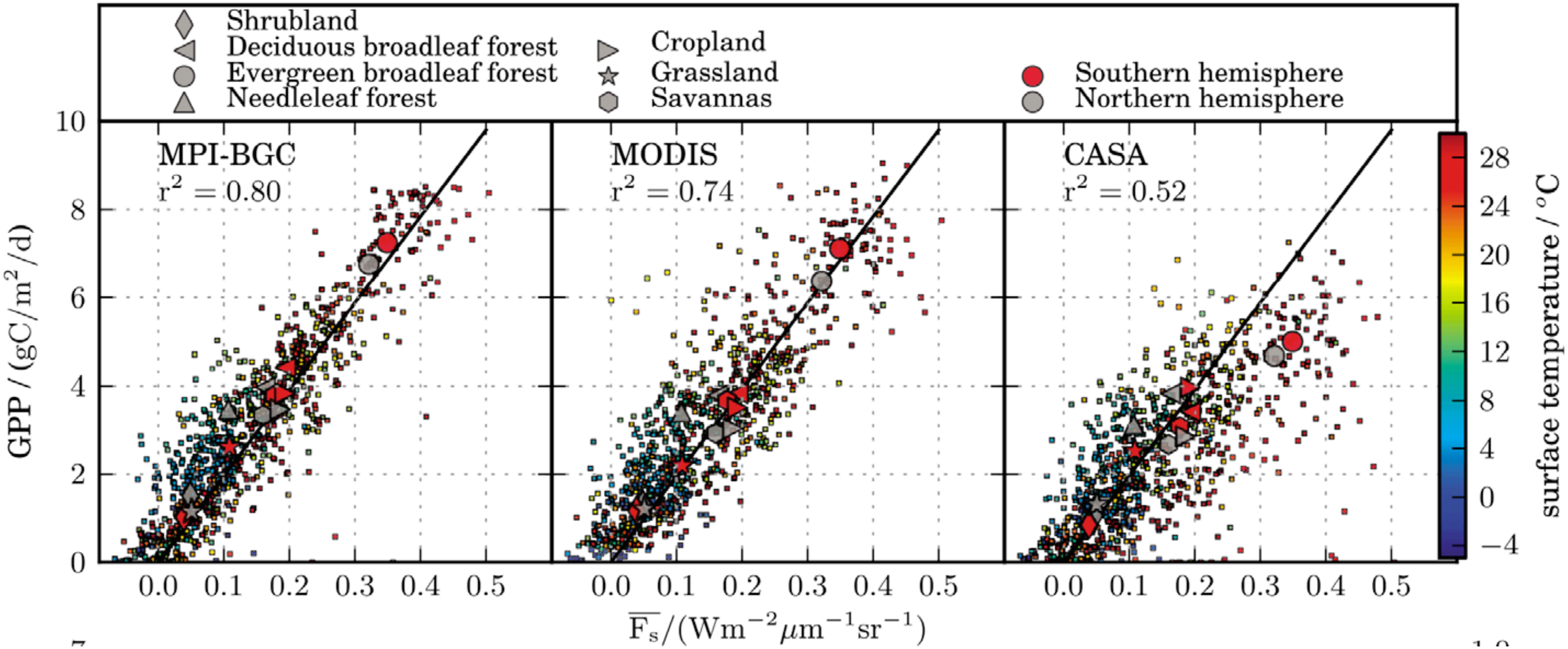




The atmospheric growth rate of CO2 in 2010 was about 33% higher than 2011.
Why?

What are the processes driving those differences?
What are the spatial drivers of the CO2 growth rate?

Covariation with GPP



Frankenberg *et al*, 2011

Comparisons with MPI-BGC point to the proportionality of GPP to fluorescence.

Flux decomposition

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

Net flux into the atmosphere is positive

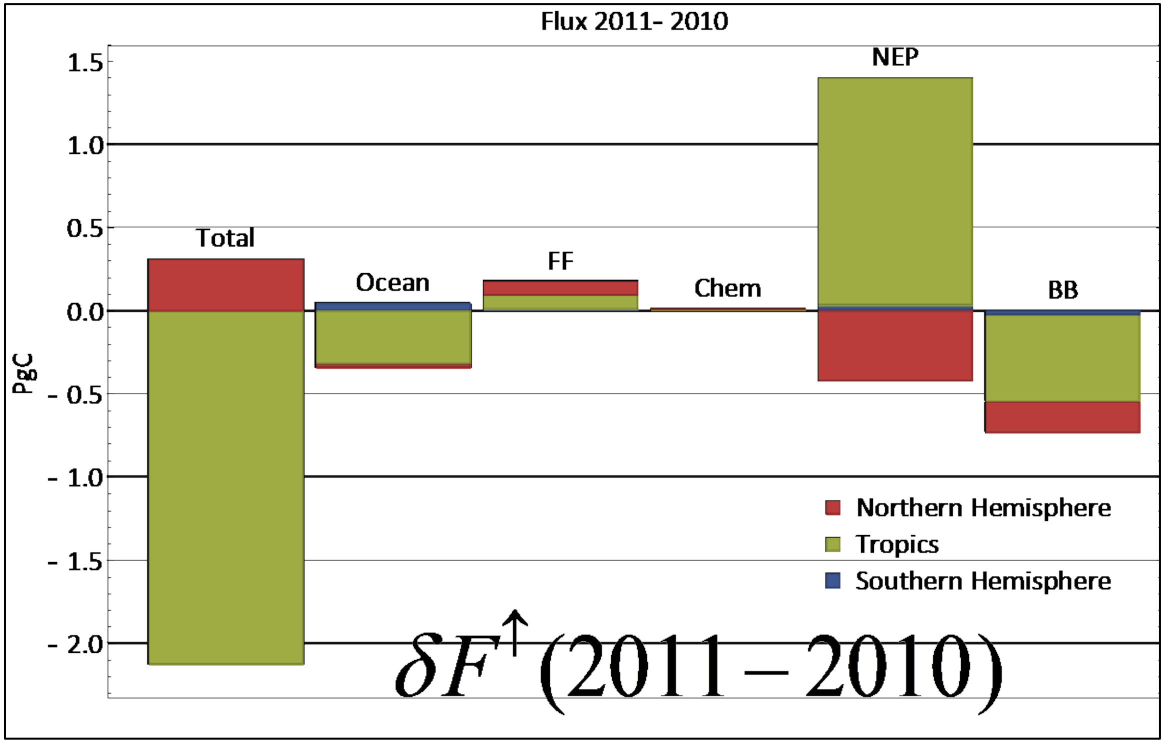
Atmospheric growth rate was driven by changes in tropical flux.

Tropical net ecosystem production (NEP) change was offset by reductions in the NH.

Biomass burning dropped in both hemispheres.

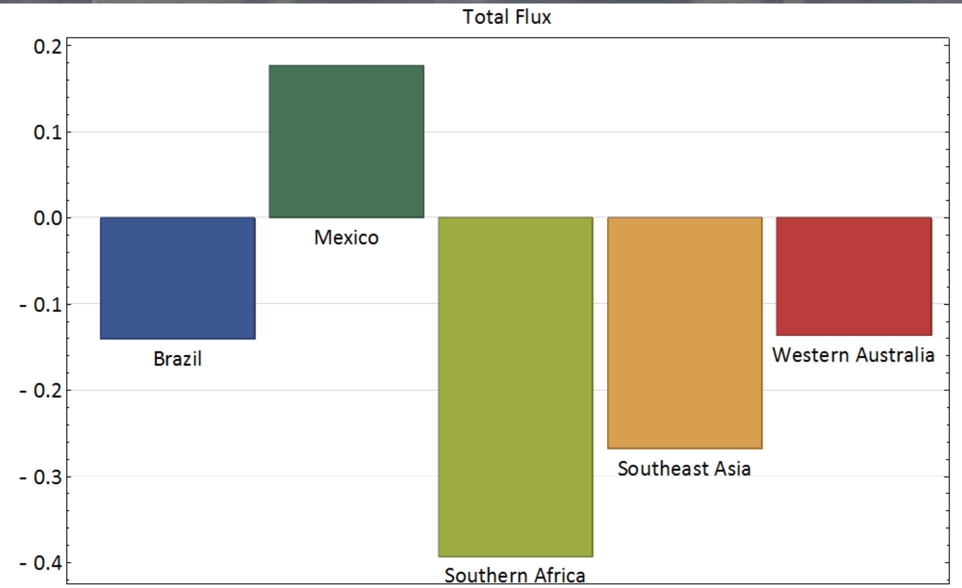
The combination of reduced biomass burning and increased NEP reduced the atmospheric growth rate in 2011 relative to 2010.

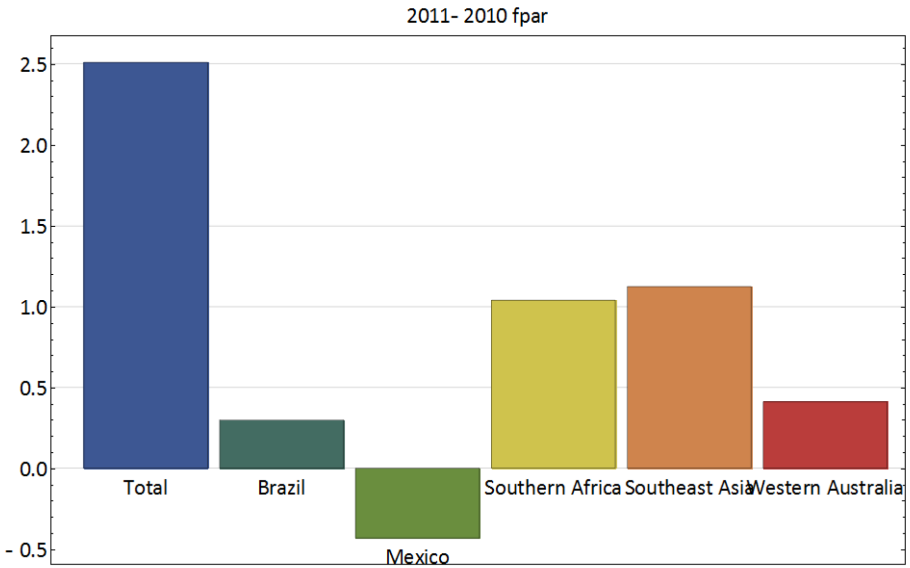
What drove NEP?

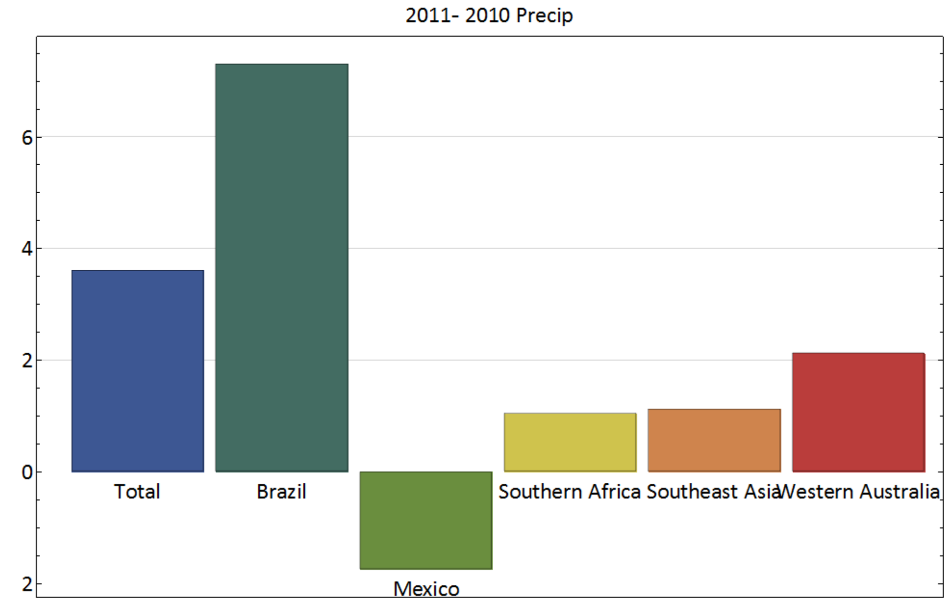


Regional drivers

- Southern Africa dominated growth reduction
- Southeast Asia response dominated by NPB (consistent with Basu *et al*, 2013)
- Sign of Fpar and precipitation consistent with total flux response

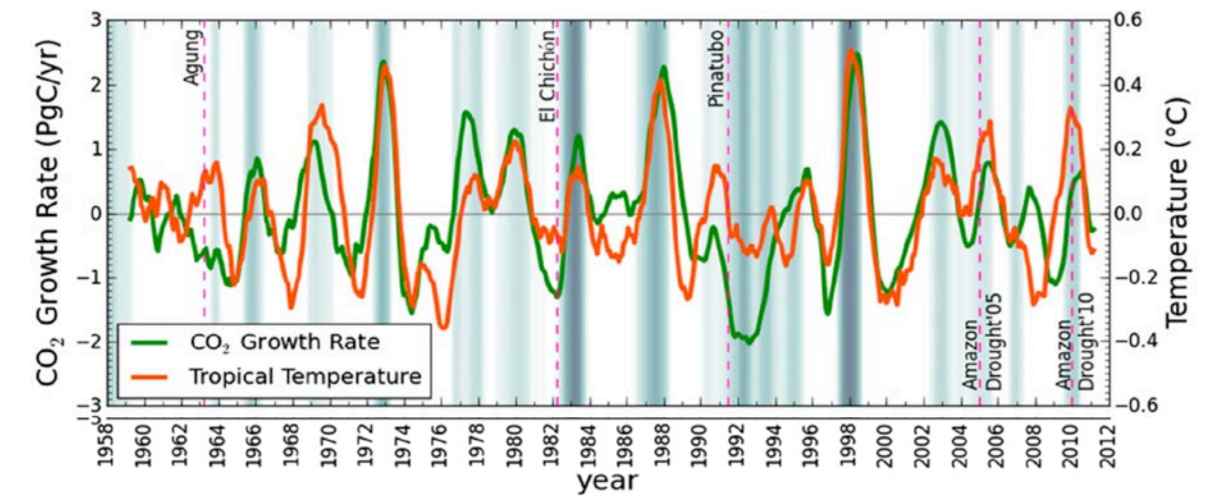




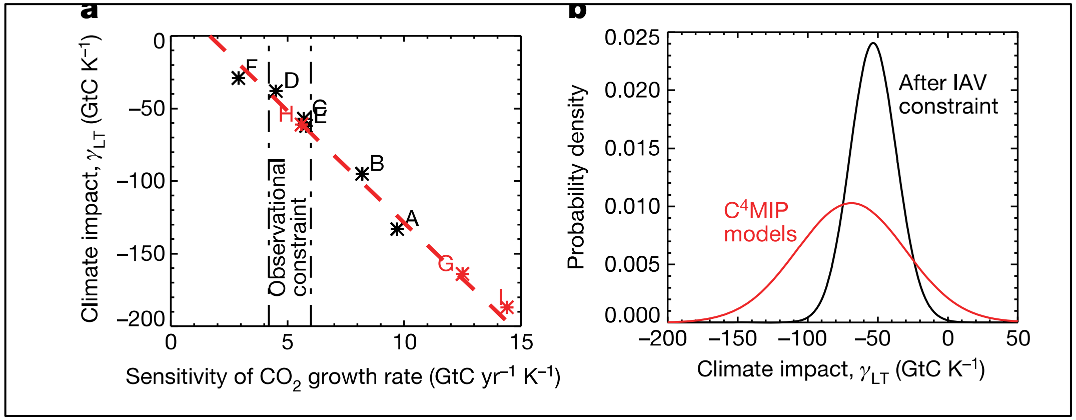


Link between tropical temperatures and CO_2 growth rate

Wang et al, 2013 (PNAS) showed that 1 °C tropical temperature anomaly leads to a 3.5 ± 0.6 PgC yr^{-1} CO2 growth rate anomaly (1959-2011) ($r^2 \approx 0.5$).



Cox et al, 2013 (Nature) used that same relationship to apply an observational constraint on carbon-cycle climate feedback parameter-> γ (GtC K^{-1}) in C^4MIP models



Spatially explicit drivers of atmospheric CO2 growth rate and ancillary species could provide better process scale constraints

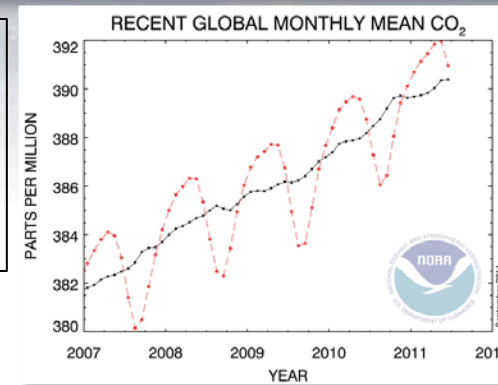
Attribution Strategy

A priori carbon cycle budgets are constructed to be consistent with atmospheric CO2 growth

9.25 PgC yr^{-1} (2010)
9.50 PgC yr^{-1} (2011)

CO2 accumulation
2010 2.44 ppm yr^{-1}
2011 1.84 ppm yr^{-1}

≈



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4.85 - 2.92 PgC y^{-1}(2010)
5.79 - 2.24 PgC y^{-1}(2011)

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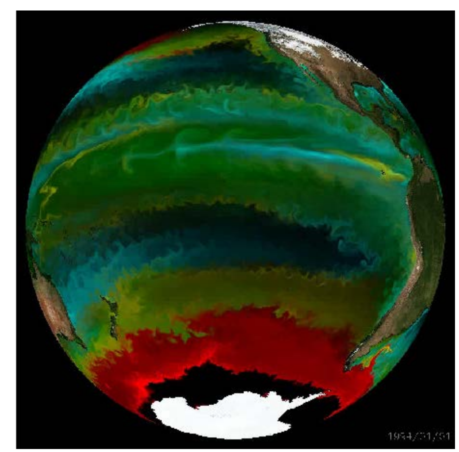
2.38 (2010) PgC y^{-1}
2.71 (2011) PgC y^{-1}
Derived from ECCO-2 ocean flux estimate



Fossil Fuel (FFDAS)
Incorporates separate chemical CO2 production, aviation, bunker, and shipping (Nassar et al, 2010)

Land-use change and river export are not included

GPP-Solar induced fluorescence

$$C_{\beta,j} = \frac{1}{2}[\boldsymbol{y}_j - \boldsymbol{f}_j(\beta_j)]^T \boldsymbol{R}_j^{-1}[\boldsymbol{y}_j - \boldsymbol{f}_j(\beta_j)] + \frac{1}{2}[\beta_j - \beta_b]^T P_j^{-1}[\beta_j - \beta_b]$$

- Solar induced fluorescence is a direct measure of photosynthetic activity (e.g., Porcar-Castell *et al,* 2014)
- Parazoo *et al*, GCB, 2014 developed an inverse method to estimate GPP from satellite SIF and TRENDY models

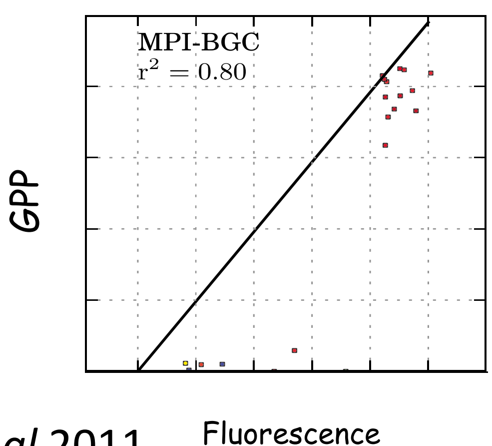
f(β)=GPP(x,y,t) = β_{GPP} (x,y,t) * GPP_{pr}(x,y,t)

y: Inferred GPP (Fluorescence scaled to MPI)

R: GPP Uncertainty (Measurement Error)

P: Prior Uncertainty (TRENDY)

β_b Prior Scale Factor (CASA or JULES)



Frankenberg *et al* 2011