The Global Stocktake: a top-down view

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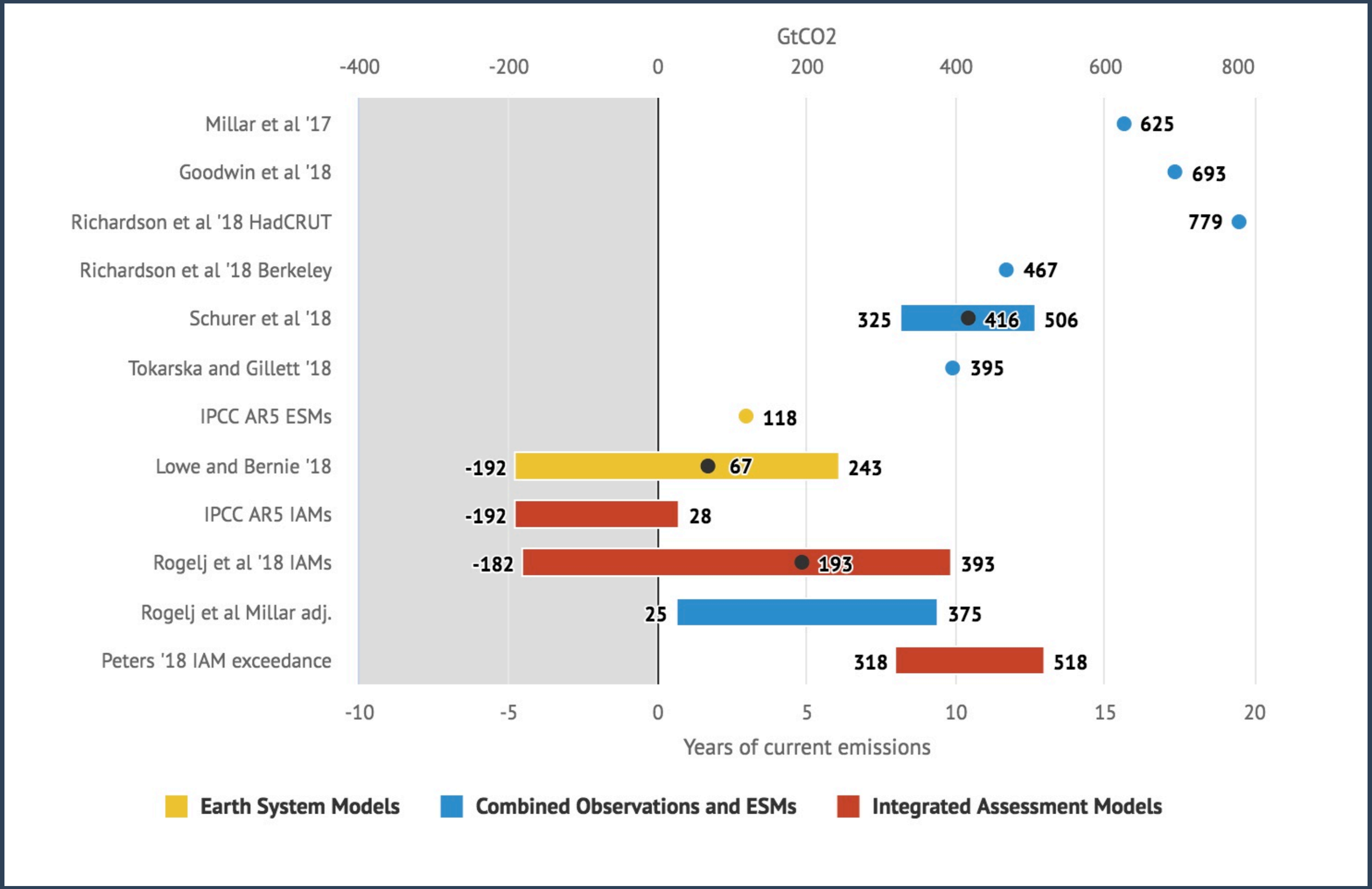
How much can we emit?

Remaining carbon budgets in gigatonnes CO_2 ($GtCO_2$) from various studies that limit warming to a 66% chance of staying below 1.5C



Z. Hausfather, Carbon Brief

The uncertainties in allowable emissions is driven by 1) the relationship between concentrations and temperature and 2) the relationship between emissions and concentrtations

https://www.carbonbrief.org/analysis-how-much-carbon-budget-is-left-to-limit-global-warming-to-1-5c

The Global Stocktake

The Global Stocktake every 5 years (starting in 2023) will assess progress and adjust commitments towards the Paris Accord.

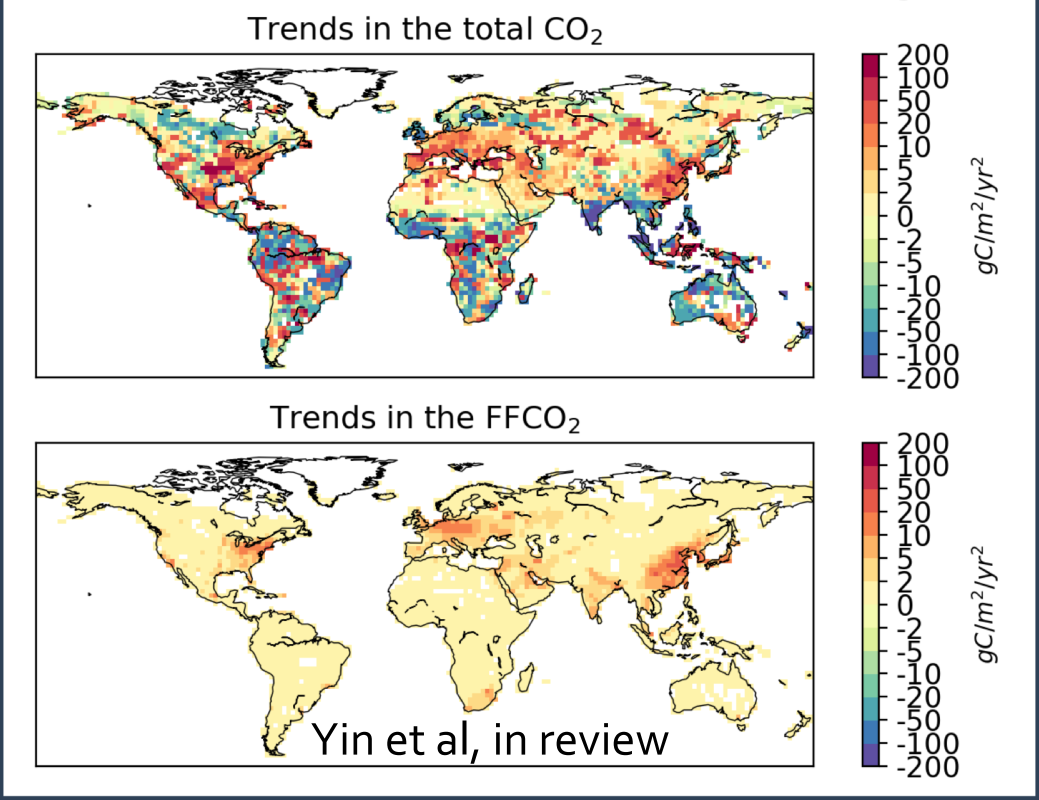
How will emission commitments be related to concentration requirements?

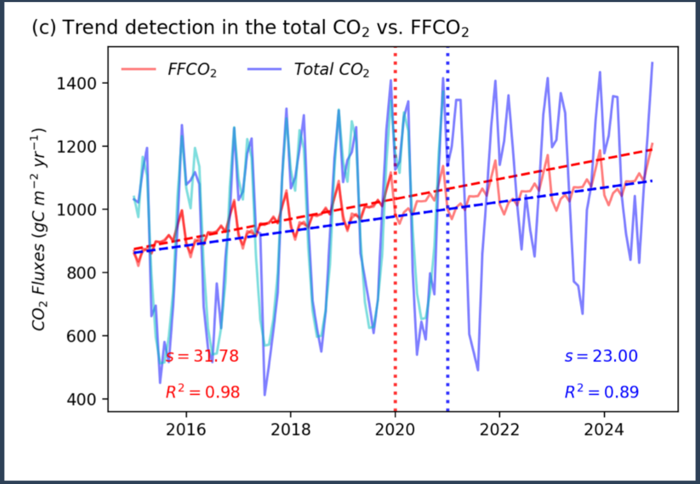
The gap between fluxes and concentrations

In an ideal system, the time-to-detection of total CO2 flux trends for many parts of the world is within 10-15 years (2-3 stocktakes). But, the relationship between those trends and FF trends is complex

In China, about 20% of total CO2 trends is within 25% of the underlying FFCO2 trends

Both anthropogenic and natural processes drive trends at stocktake scales





Confounding variables: Carbon-climate feedbacks

A steep road to climate stabilization

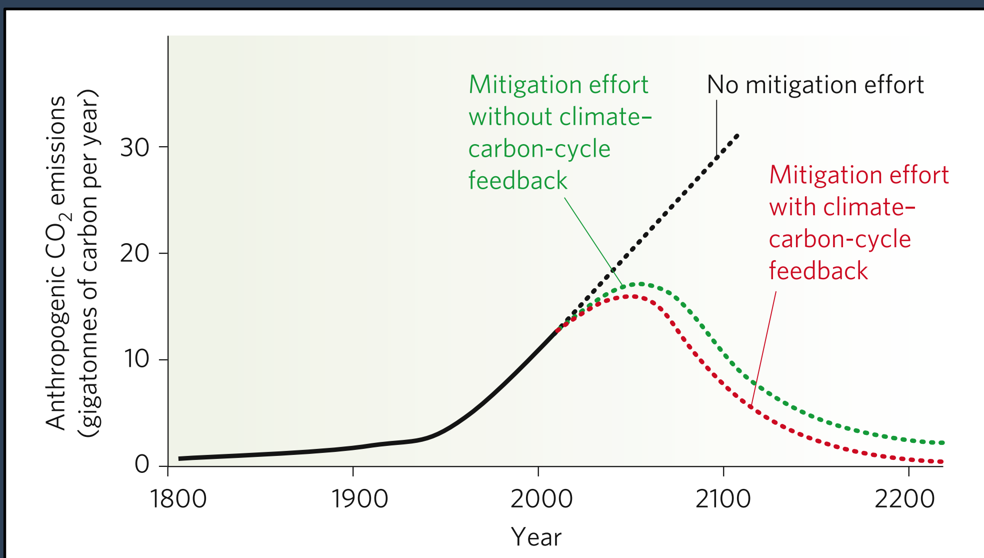
Pierre Friedlingstein

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.

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

Trends in the sources and sinks of carbon dioxide

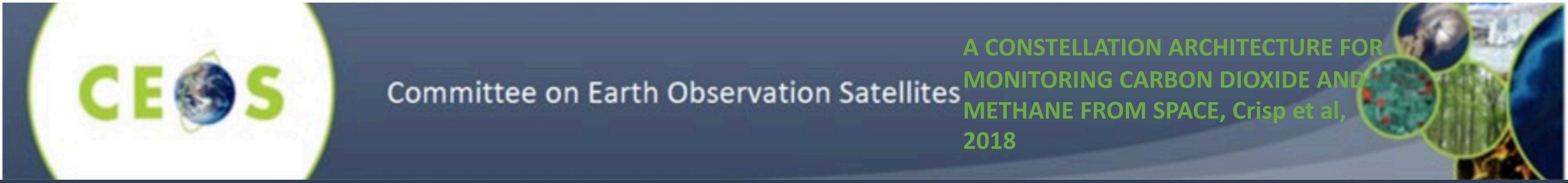
Corinne Le Quéré, Michael R. Raupach, Josep G. Canadell, Gregg Marland *et al.**



"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."

Both forced (carbon-climate feedbacks) and unforced (natural variability) can impact net carbon fluxes on decadal time-scales.

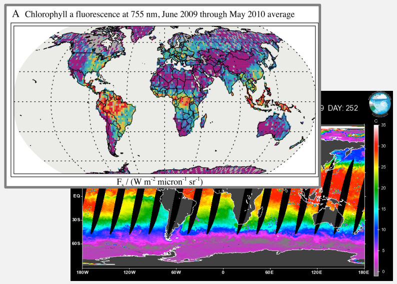
From emissions to concentrations—and back again



How can a CEOS constellation attribute concentrations to emissions ?

Prototype Carbon Cycle Assimilation System: CMS-Flux

Surface Observations



GOSAT/OCO-2 SIF, Jason SST, nightlights, etc.

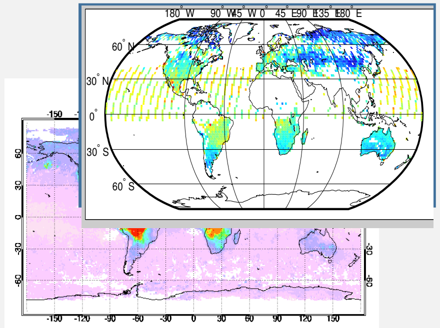
Carbon Cycle Models

- Anthropogenic emissions
- Terrestrial exchange
- Ocean exchange

Inversion System

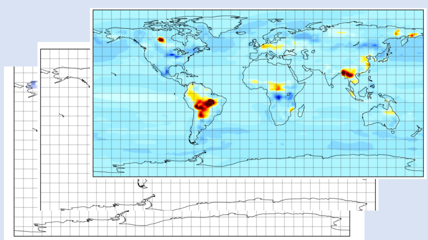
- Atmospheric transport and chemistry model
- Inverse Model

Atmospheric Observations



OCO-2 CO2,
GOSAT CO2 and CH4,
MOPITT CO

Posterior Carbon Fluxes (CO_2, CH_4, CO)



Attribution

Carbon cycle models

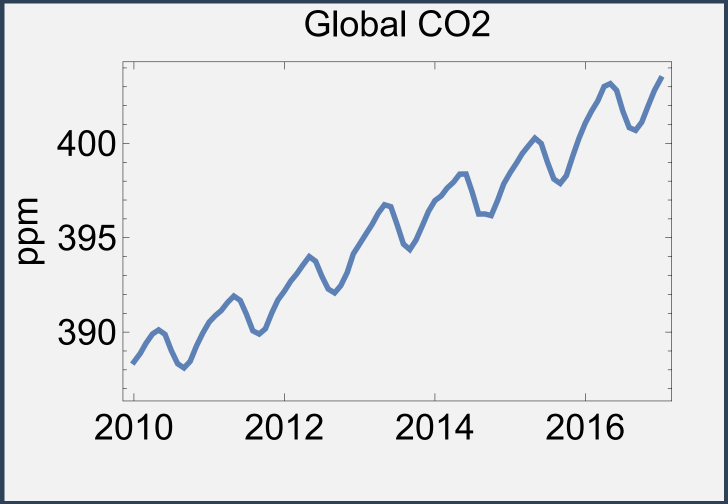
S. Asefi-Najafabady et al, 2014
Bloom et al, 2015, 2016, 2017
Brix et al, 2015
Carroll et al, *submitted*
Konings et al, ACP, 2019

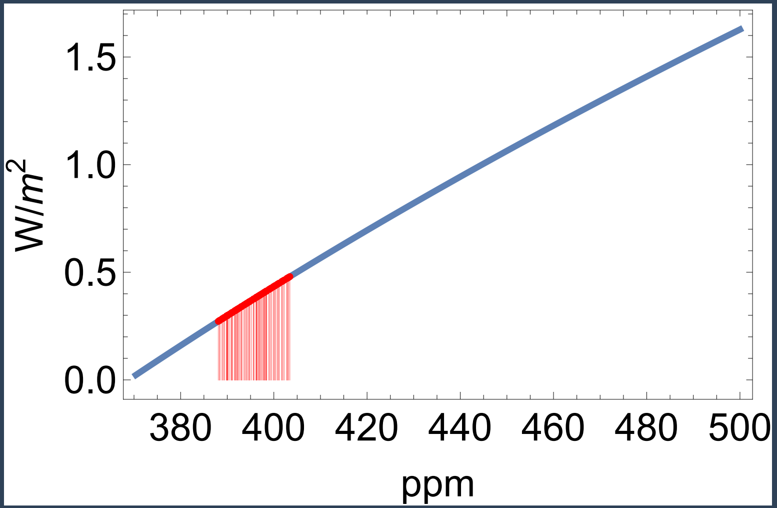
Atmospheric inverse model

Liu et al, *Tellus*, 2014
Liu, Bowman, and Lee, *JGR*, 2016
Liu et al, *Science*, 2017
Bowman et al, *E. Space. Sci.*, 2017
Liu et al, ERL, 2018

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.

Carbon concentration budget and radiative forcing





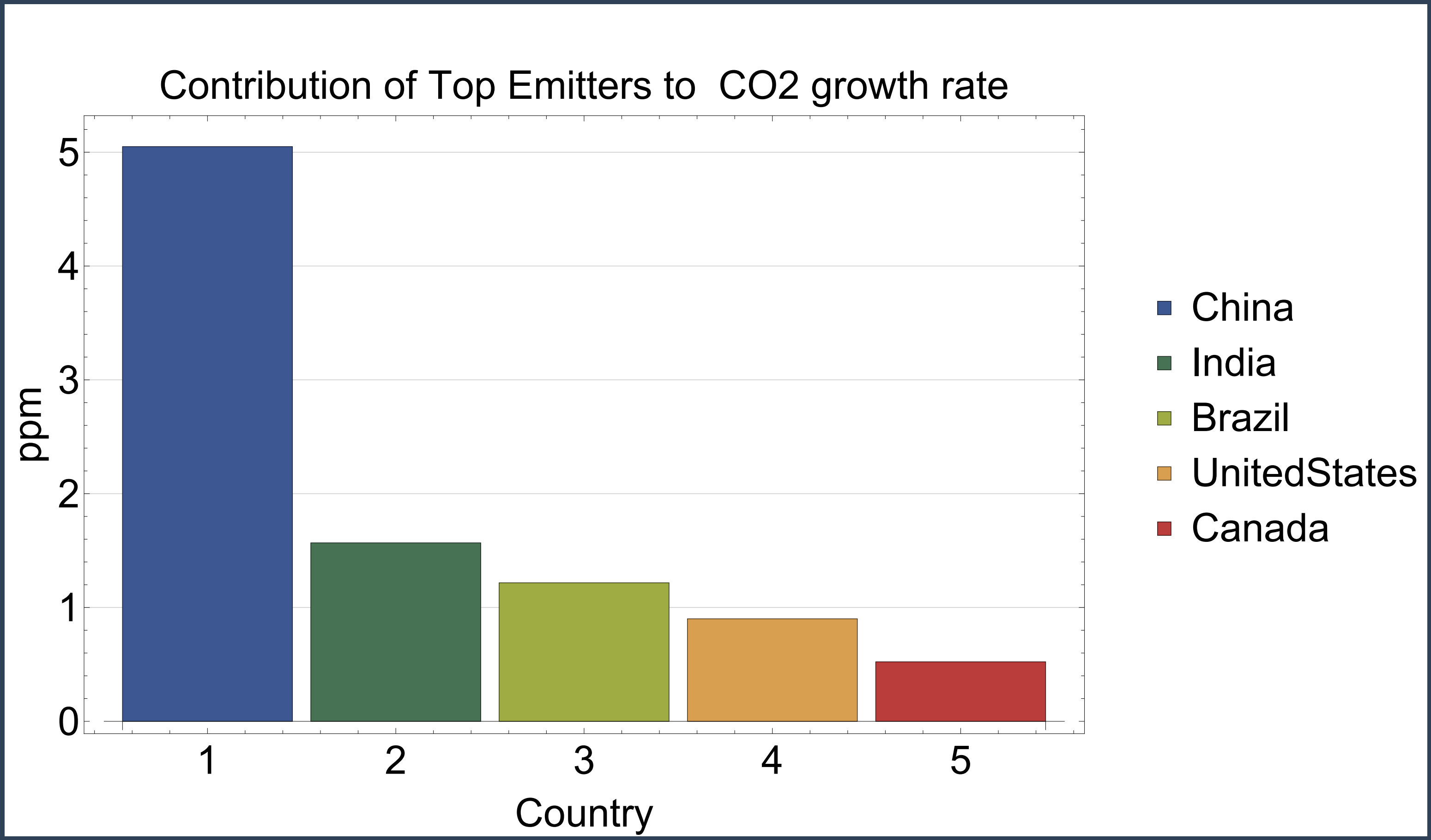
To meet 2C temperature target, CO_2 has to be stabilized to less than 500 ppm (debatable). Relative to 2010, ΔCO_2 = 112 ppm, which is equivalent to a radiative forcing of 1.36 Wm^{-2} .

From 2010-2016, CO2 increased by about 15ppm, leaving a 97ppm concentration "budget" or a CO2 RF of 0.21 Wm^{-2} over 7 years.

Climate physics *only* cares about this budget.

Where are the spatial drivers of the CO2 growth?

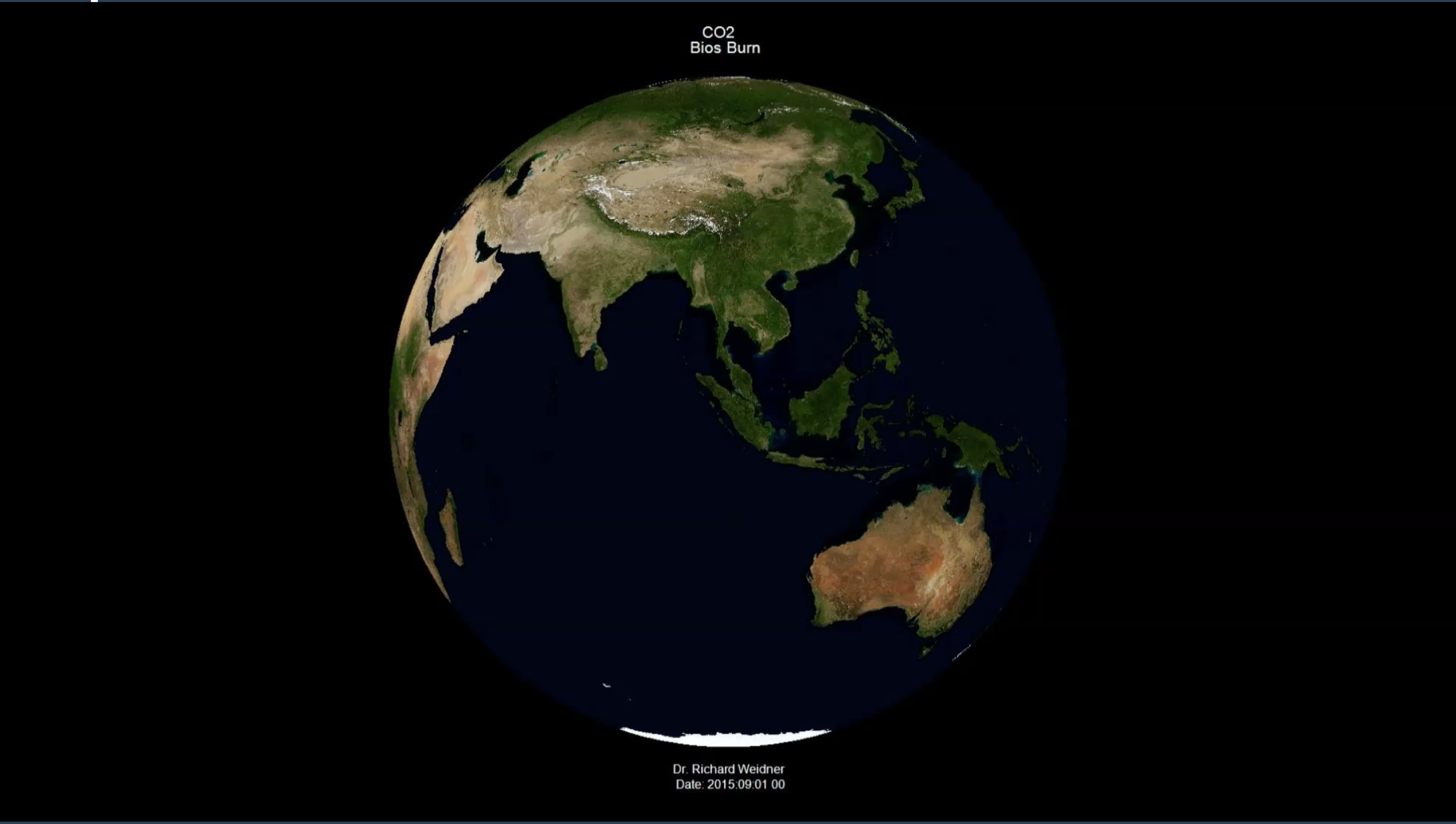
Spatial drivers of the CO_2 growth rate



These are the 5 largest contributors to the CO_2 growth rate based upon *total* regional fluxes. China is responsible for ~1/3 of the CO_2 increase over stocktake scales. However, India and Brazil collectively contribute almost 20%, while the US and Canada are collectively about 10%.

a.gov

Atmospheric signature of Indonesian carbon in 2015

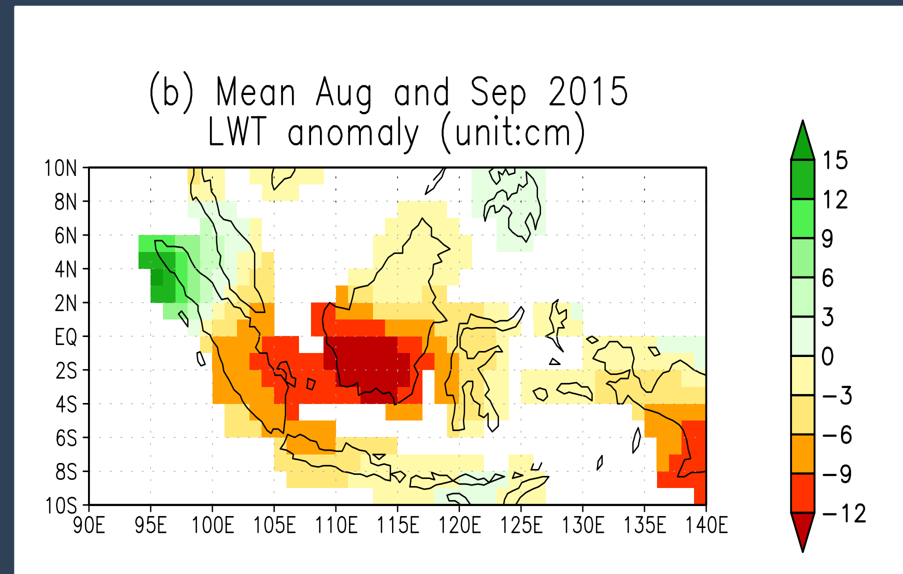


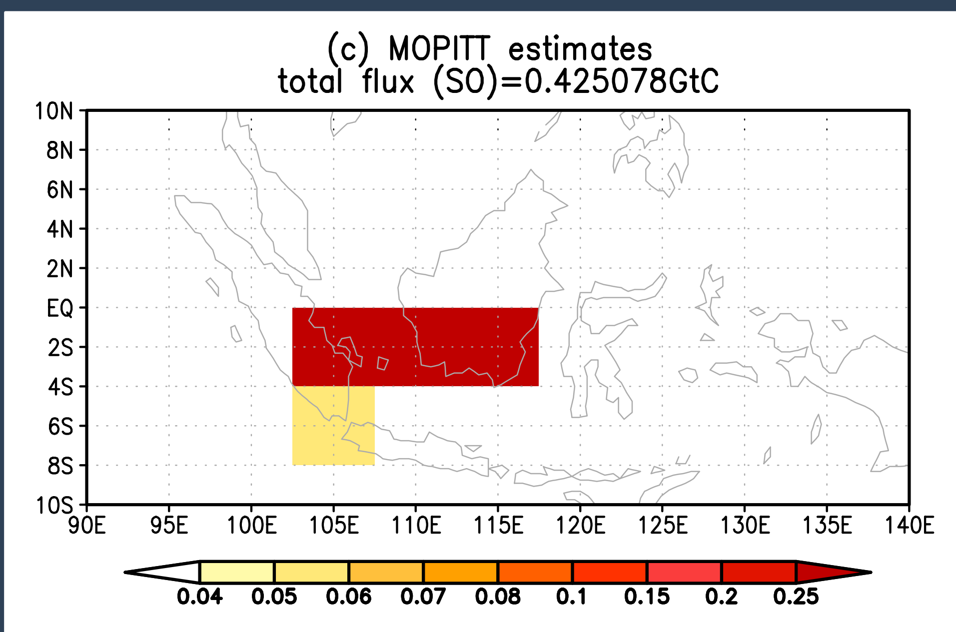
Tipping points: the hydrological context

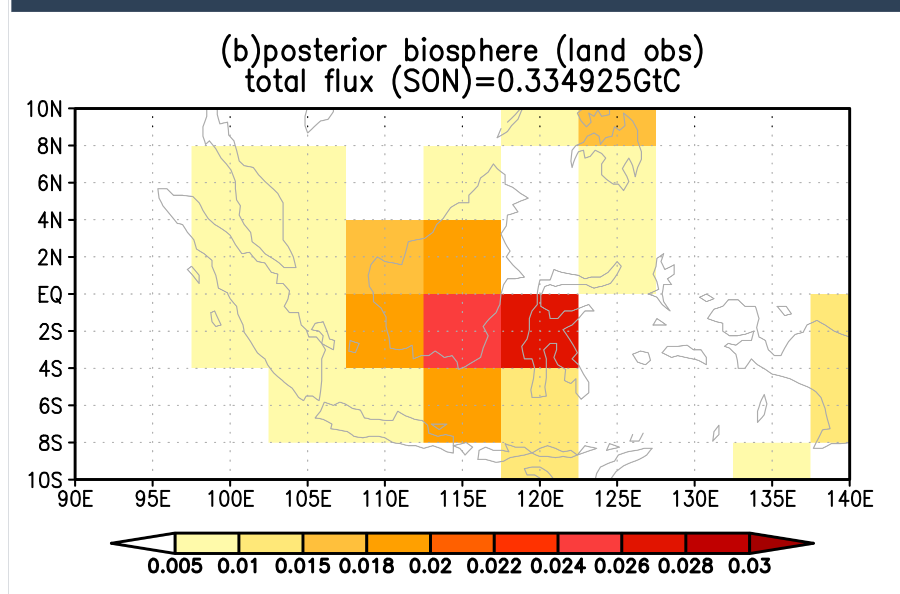
Centered on Kalimantan, GRACE gravity data shows a liquid water equivalent thickness (LWT) anomaly of -4 cm, 4x larger than then decadal mean anomaly.

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

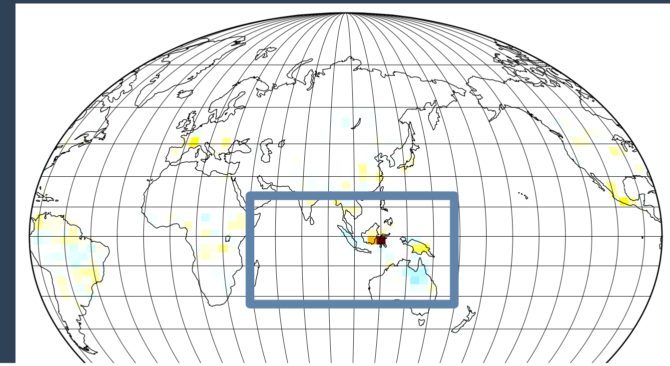
CMS-Flux CO and CO2 fluxes are correlated With GRACE LWT anomalies







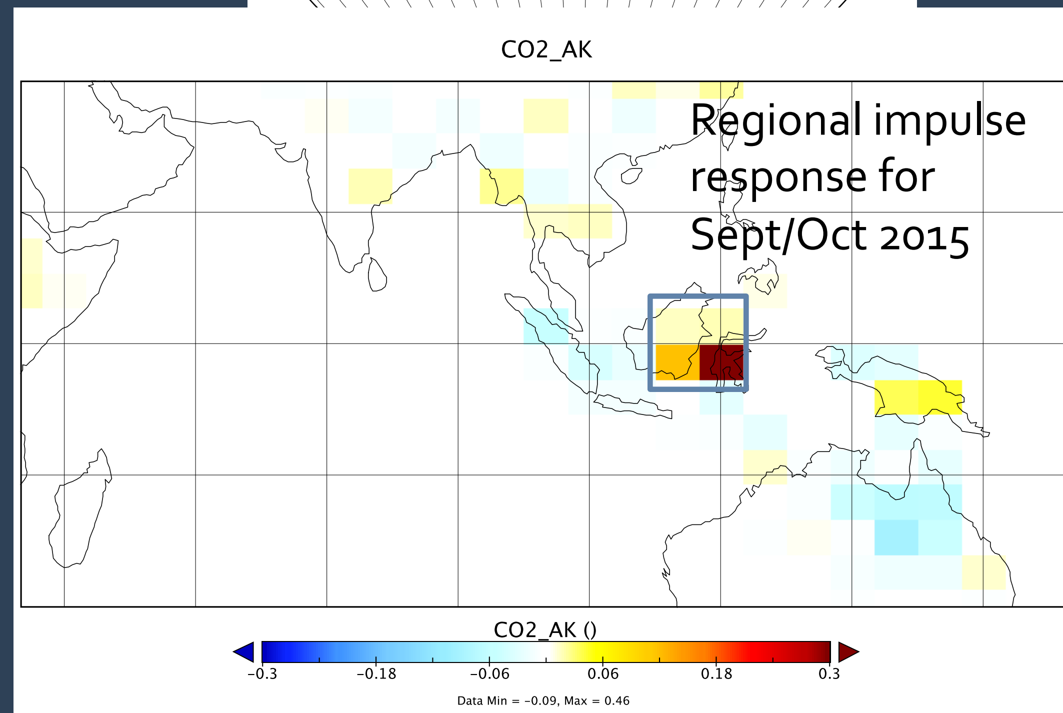
Resolving Indonesian Flux



The sensitivity of the CMS-Flux Indonesian flux estimate to the true flux is defined by the impulse response (IR):

$$\frac{\partial \hat{\mathbf{x}}}{\partial [\mathbf{x}]_{i\in L}}$$

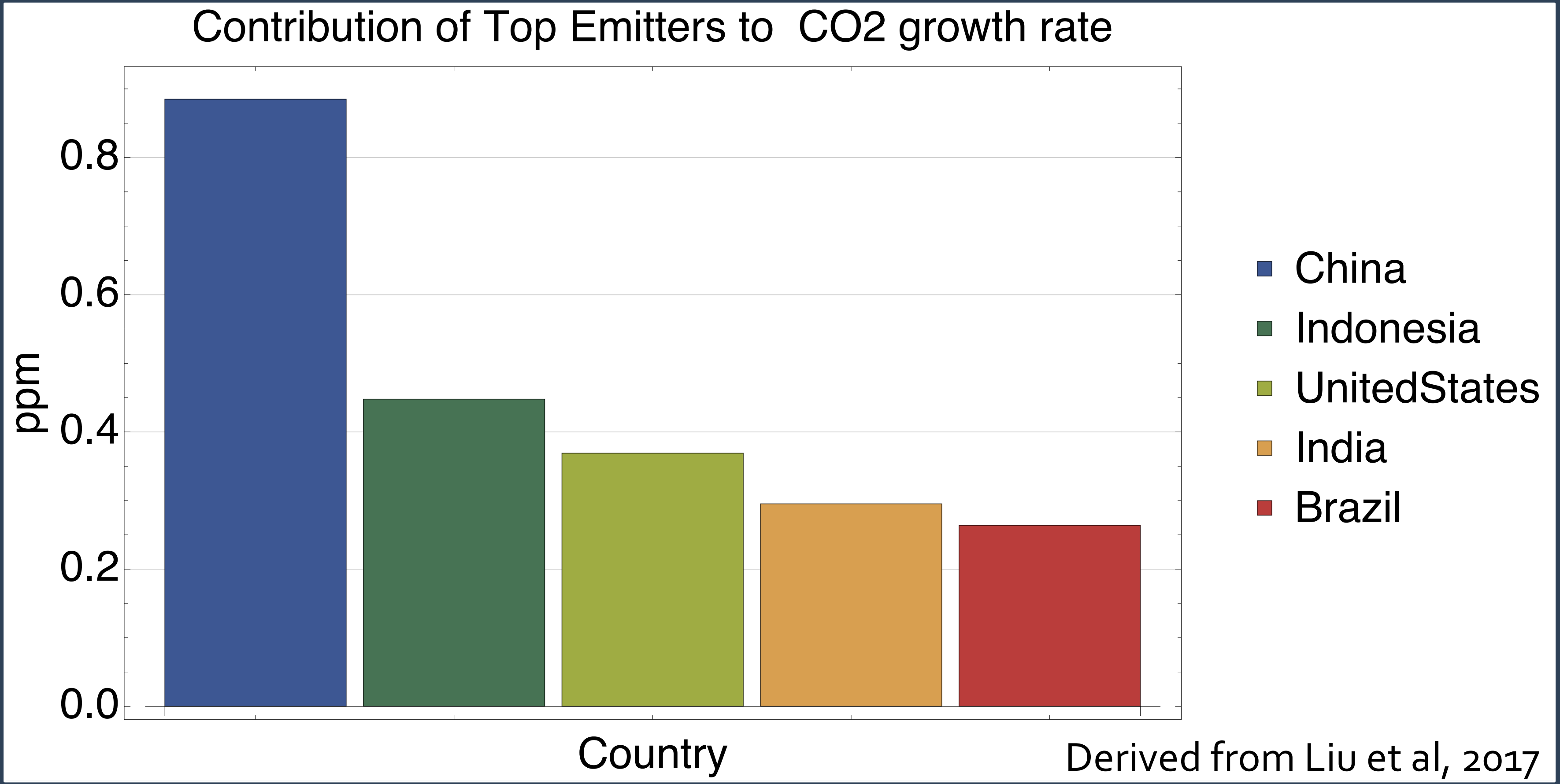
The IR response shows the fractional change in the OCO-2-constrained global flux if the *true* flux increased by 100%.



The IR can be approximated following techniques in Bousserez and Henze, 2018, which synthesize advances in probabilistic matrix decomposition and estimation techniques

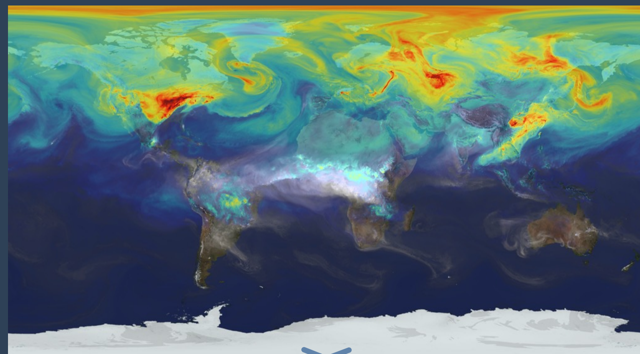
The high values over Indonesia and Borneo (and weaker responses elsewhere) show that the the peak biomass burning in Sept/Oct 2015 is well resolved by CMS-Flux.

Contributions to the CO_2 growth rate

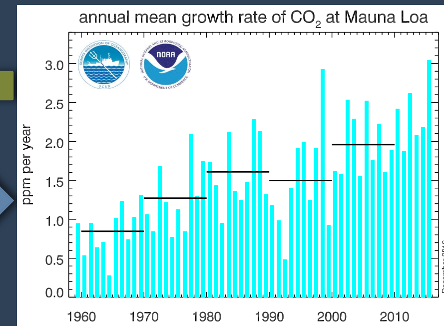


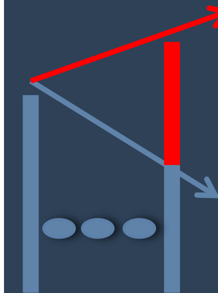
CMS-Flux was used to show that China was the highest and Indonesian region was the 2nd highest contributor (0.45 ppm) to total flux of the record CO_2 growth rate in 2015.

Top-Down Stocktake Framework

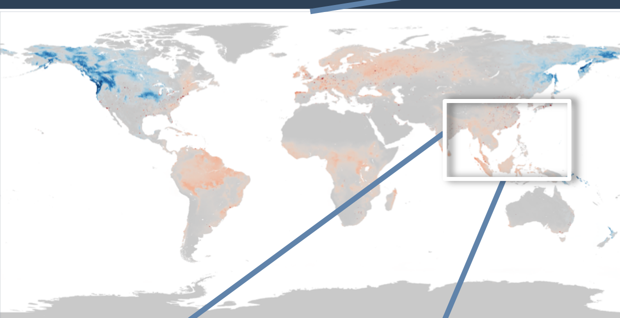


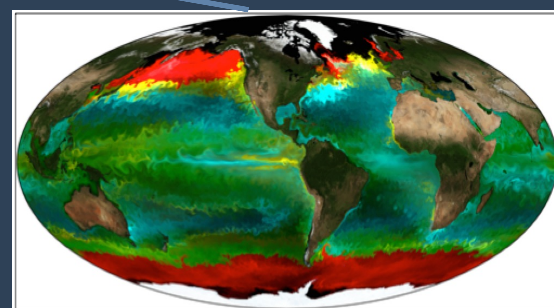
GEOS

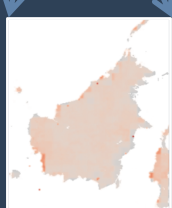




Anthropogenic and natural terrestrial







Carbon Cycle Framework

- Total Carbon
- Climate Variability
- Climate Feedback

Measurement, Reporting & Verification (MRV) frameworks

- Project-level forest carbon data
- GHG inventories & reporting

Conclusions

- The bidecadal stocktake requires a link between
  - net GHG flux ← → Concentrations (what the climate sees)
  - FFGHG ← → Emissions (what carbon mitigation sees)
- Top-down GHG monitoring systems, not the UNFCCC inventories, can make that link.
- The stability and cross-calibration of the CEOS GHG/AQ constellation will be critical considerations for trend estimates and attribution.
  - Important role for GHG OSSEs.
- GHG/AQ synergies will be key to understand anthropogenic process (see Miyazaki and Arellano tomorrow)
  - At decadal time scales, short-lived climate pollutants (SLCPs) must be integrated.

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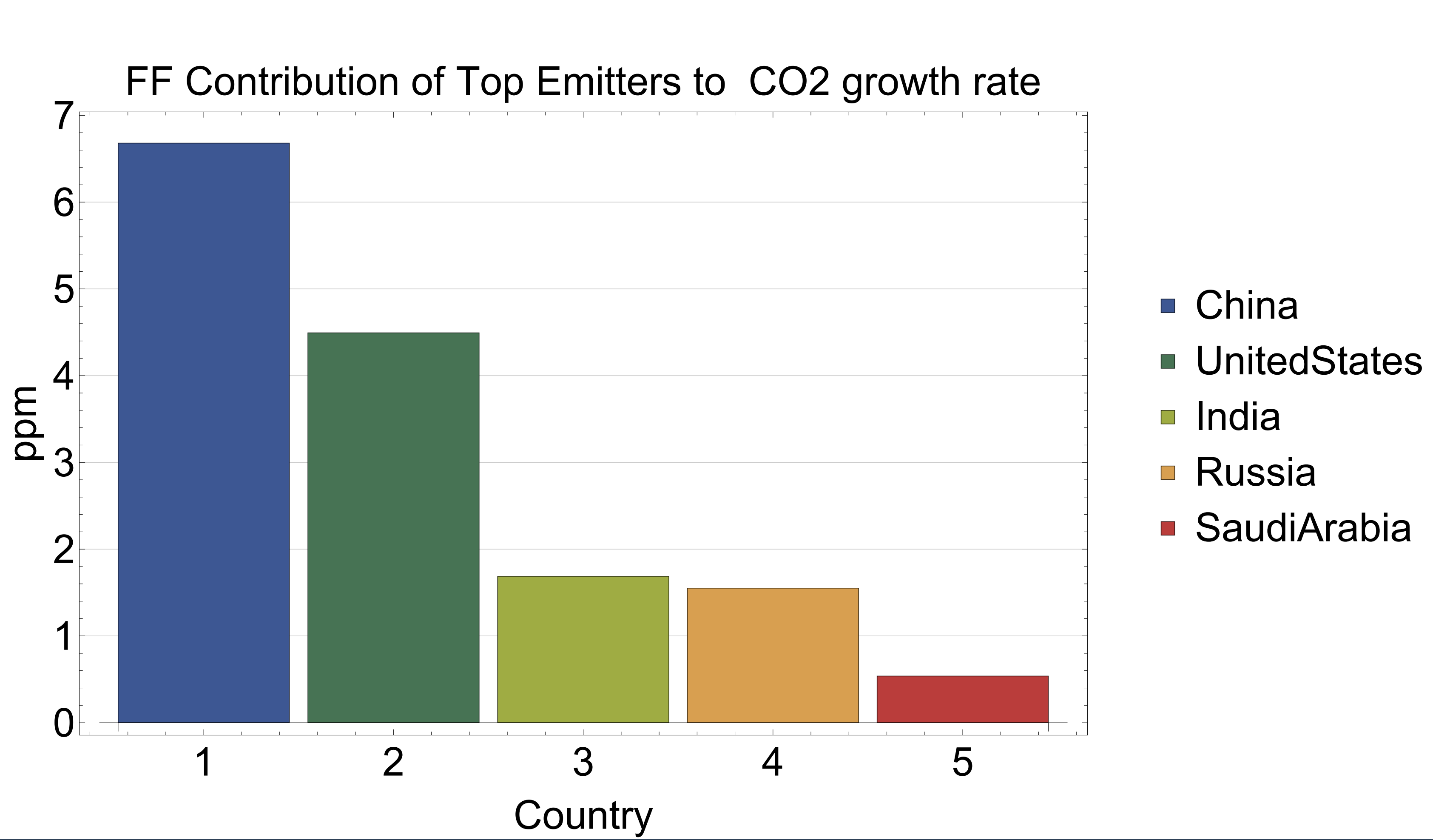
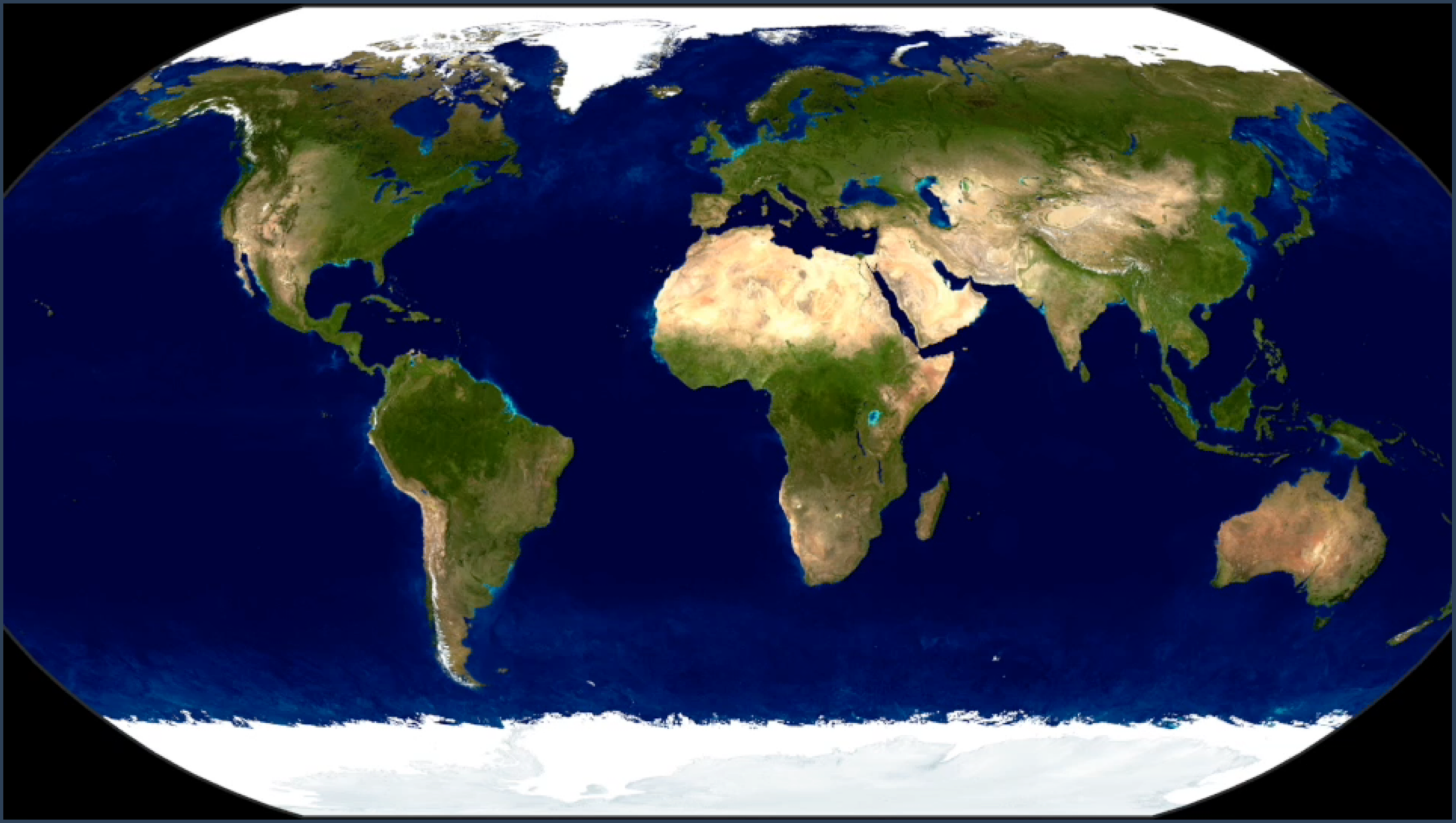
Top FF emitters



From emissions to concentrations

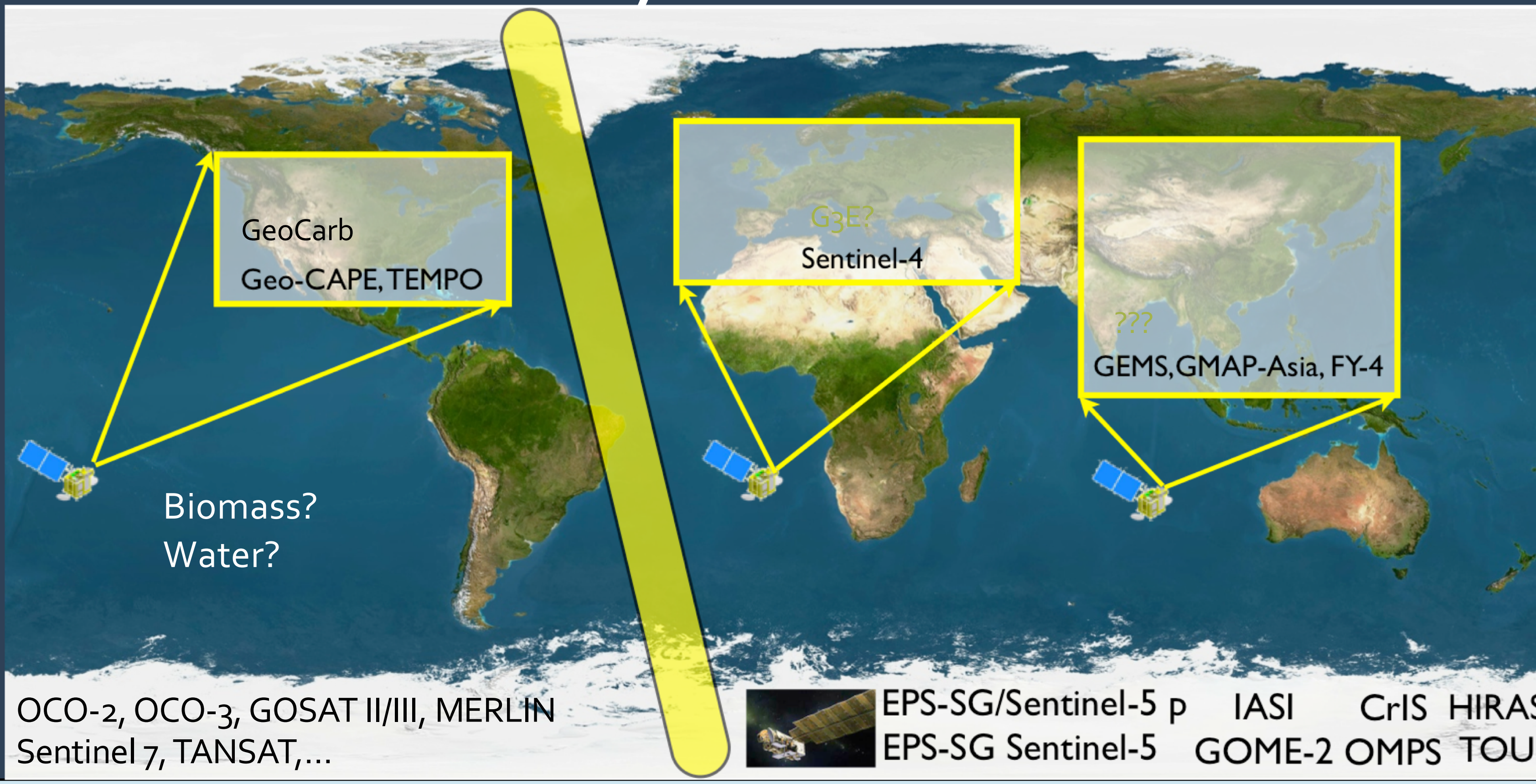
GEOS-Chem High Performance, C360



Courtesy, Sebastian Eastham, MIT

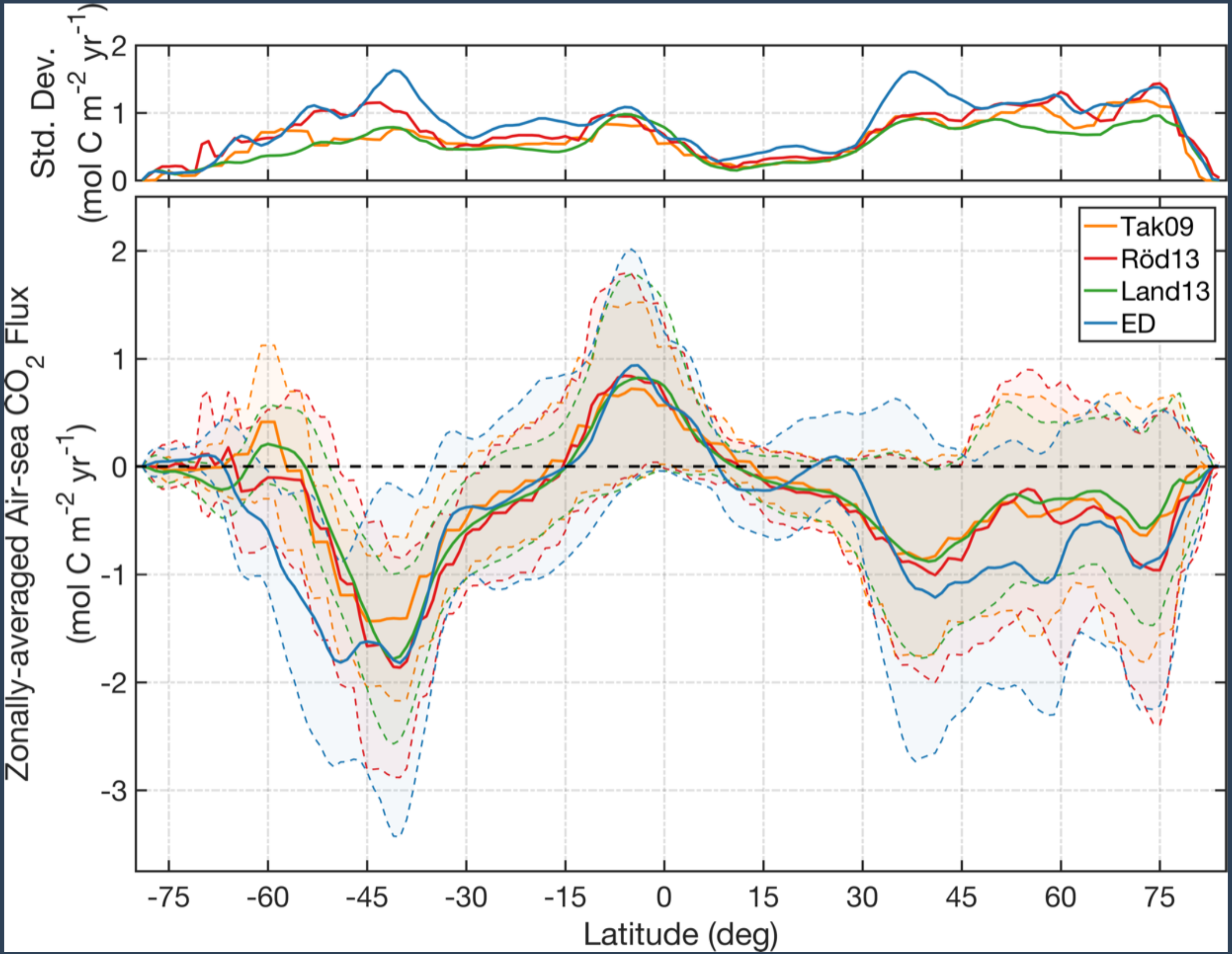
Toward an Air Quality-Carbon-Climate

Bowman et al, Atm.Env. 2013



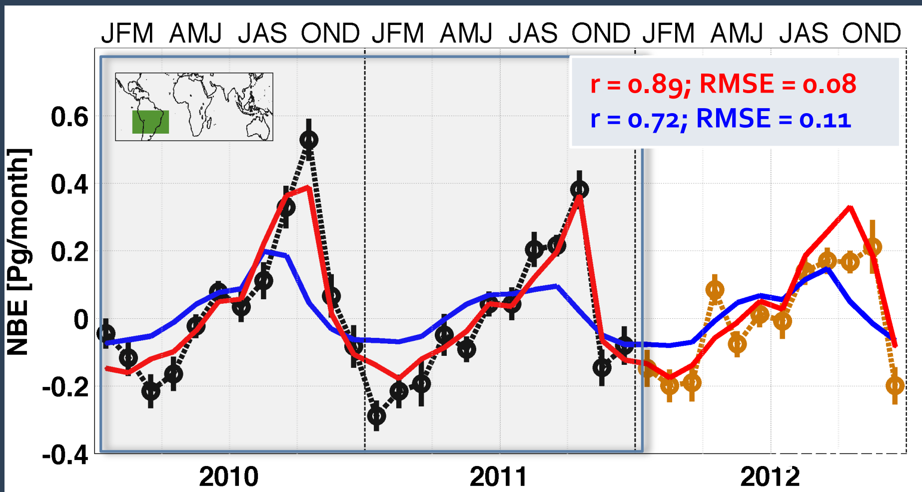
- LEO:
  - IASI+GOME-2, AIRS+OMI, CrIS+OMPS could provide UV+IR ozone products for more than a decade.
  - Combined UV+IR ozone products from GEO-UVN and GEO-TIR aboard Sentinel 4 (Ingmann *et al*, 2012 Atm. Env.)
  - Sentinel 5p (TROPOMI) will provide column CO and CH_4.
  - OCO-2+AIRS, GOSAT II (IR+NIR) 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.

ECCO-Darwin evaluation

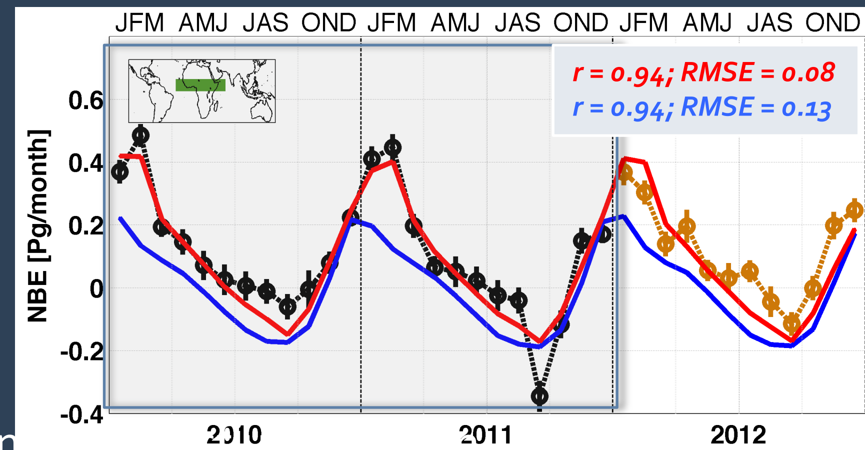


Results: 2012 NBE prediction

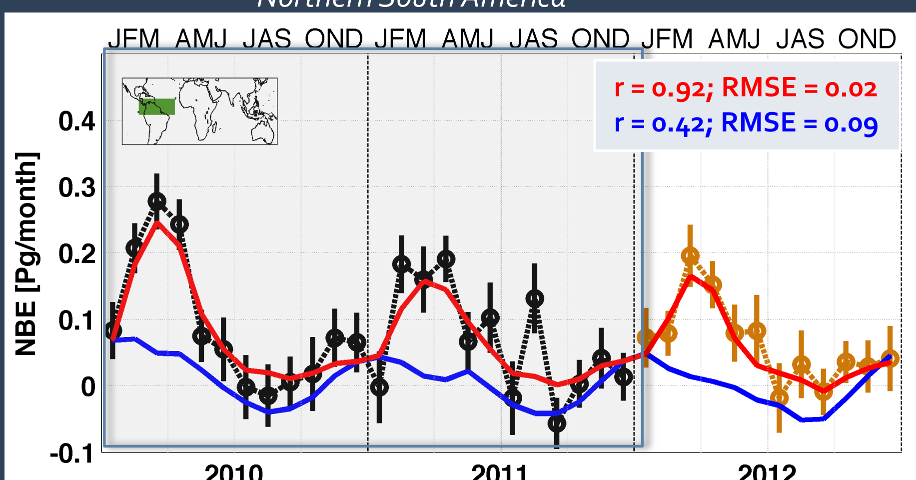
Southern South America



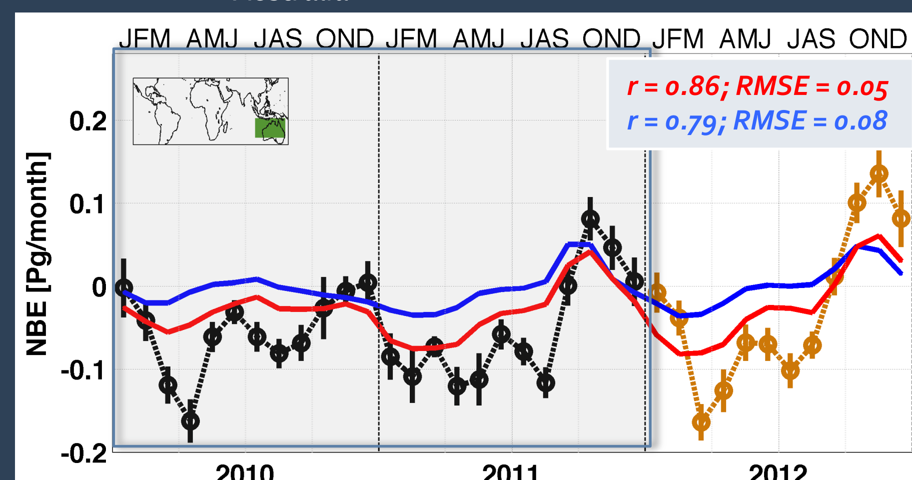
Northern Sub-Saharan Africa



Northern South America



Australia



BLACK = CMS-Flux NBE (assimilated);
ORANGE = CMS-Flux NBE (witheld)

CARDAMOM (NBE constrained)
CARDAMOM (Baseline)