Air Quality and Carbon constellation: possible synergies

Kevin W. Bowman

Jet Propulsion Laboratory

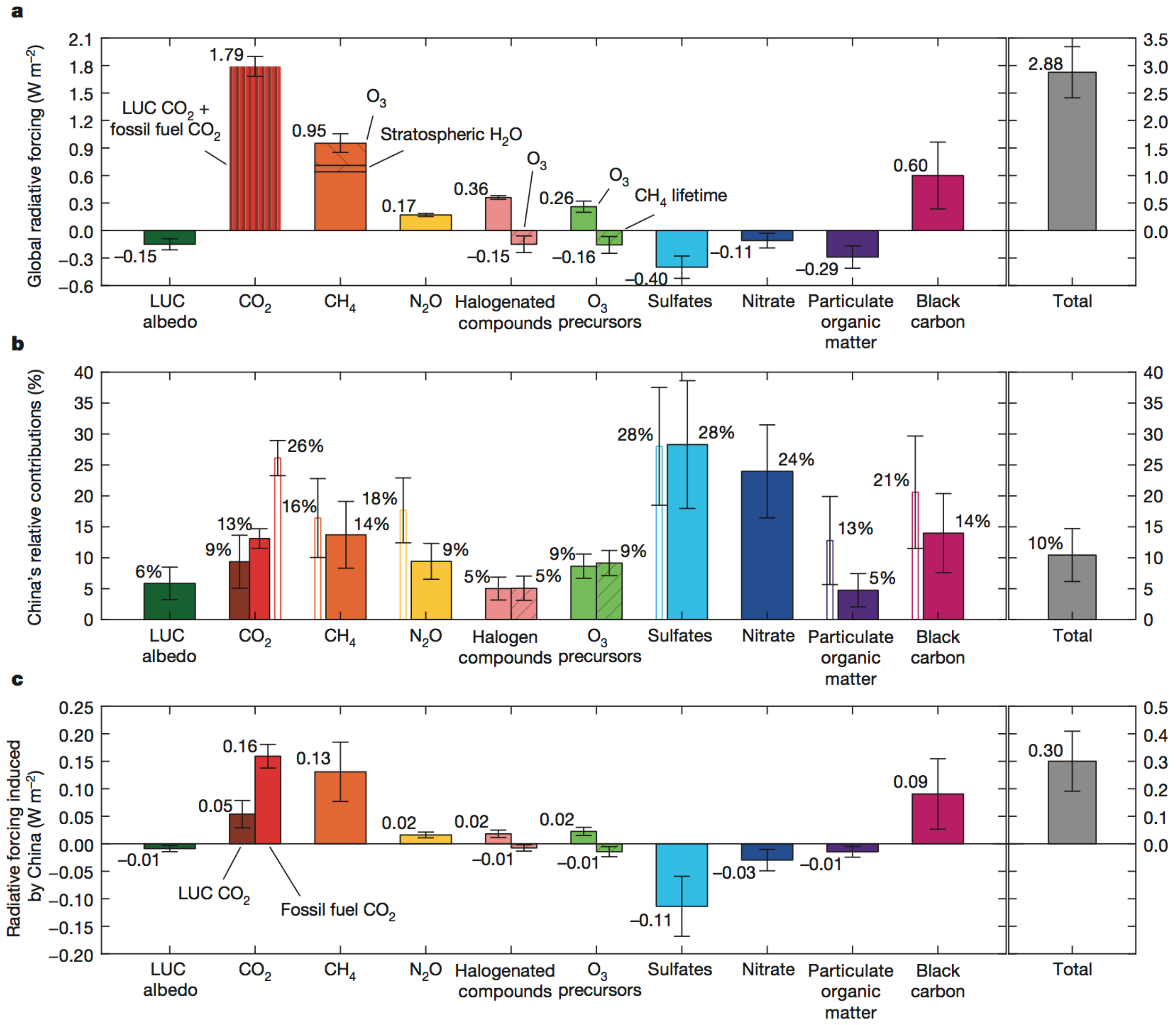
California Institute of Technology

Joint Institute for Regional Earth System Science and Engineering

University of California, Los Angeles

Total RF from China

- China contributes 10% ± 4% of the current global radiative forcing.
- CO2: 0.16 ± 0.02 W/m^2
- CH4: 0.13 ± 0.05 W/m^2 (includes effects on ozone and water vapour
- Sulfates: −0.11 ± 0.05 W/m^2 (from SO_2)



How will these change
In the future?

Li et al, 2016, Nature

The ties that bind: air quality and carbon

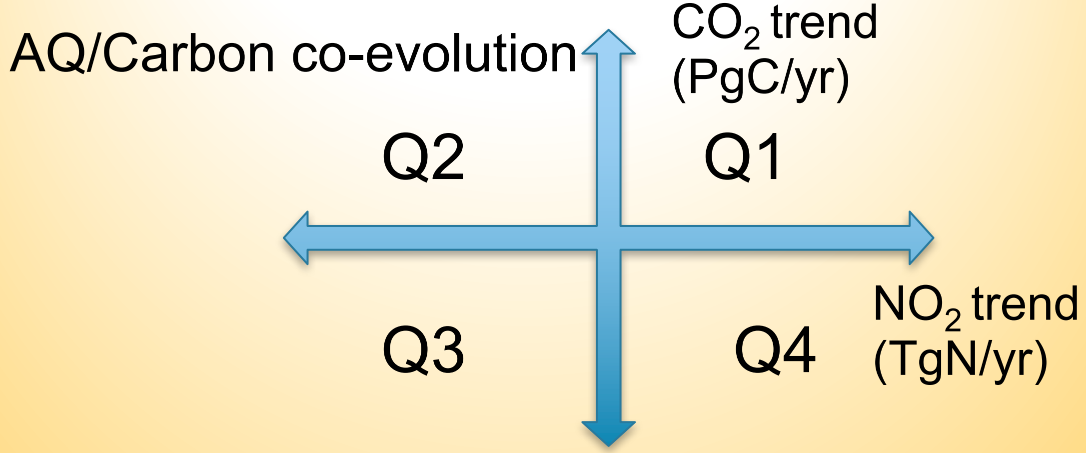
Deteriorating air quality in China such as the "Airpocalypse" in Harbin has led to ~500,000 premature deaths/yr (Chen et al, Lancet 2014) prompting a "war on air pollution" from government officials.

How will changes in air quality mitigation impact carbon emissions?

China's AQ mitigation (12th 5-year plan) effort has mainly centered on reducing, displacing, relocating, and scrubbing pollutant emissions from coal-based electrical power (Karplus et al, 2015; Nam et al, 2013).

AQ improvements could ***lock in*** commitments to coal-power generation and a high carbon pathway.

Director of the Development Research Center (DRC) of China's State Council energy objectives to show a strong shift towards natural gas and renewables within a decade. (Sheehan *et al*, 2014)



AQ/Carbon co-evolution

CO_2 trend (PgC/yr)

NO_2 trend (TgN/yr)

Q2

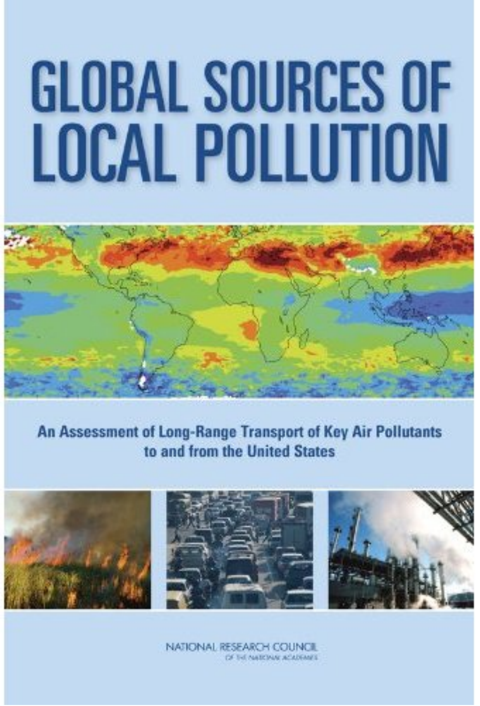
Q1

Q3

Q4

Q1: Business as usual (BAU)
Q2: AQ-only (CO_2 lock-in?)
Q3: AQ/Carbon (renewables)
Q4: Carbon-only

Supporting mitigation policies

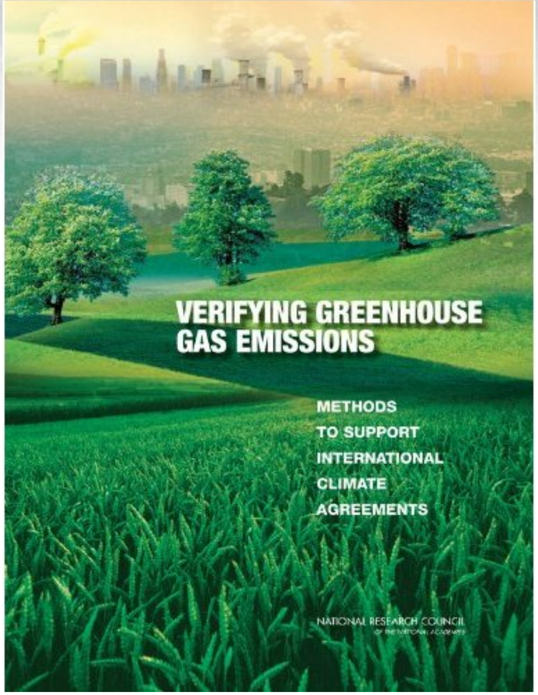


GLOBAL SOURCES OF LOCAL POLLUTION

An Assessment of Long-Range Transport of Key Air Pollutants to and from the United States

NATIONAL RESEARCH COUNCIL OF THE NATIONAL ACADEMIES

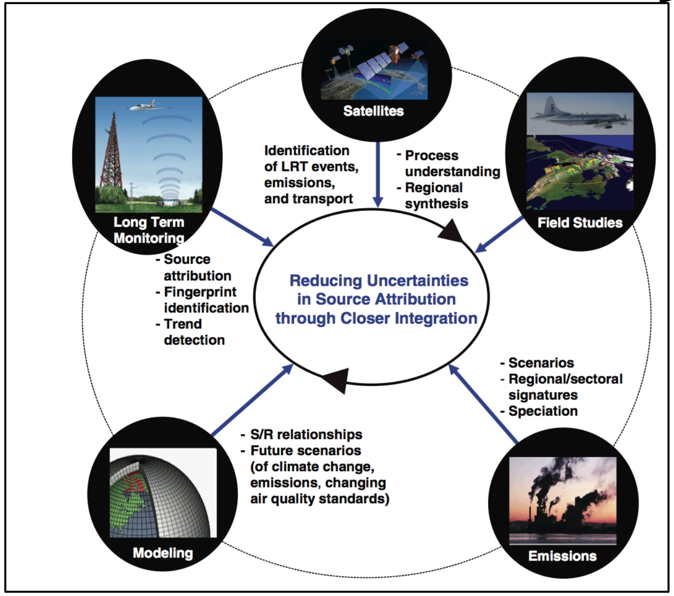
How can we develop science-based mitigation policies and monitor their effectiveness?



VERIFYING GREENHOUSE GAS EMISSIONS

METHODS TO SUPPORT INTERNATIONAL CLIMATE AGREEMENTS

NATIONAL RESEARCH COUNCIL OF THE NATIONAL ACADEMIES



Satellites

Field Studies

Long Term Monitoring

Modeling

Emissions

Reducing Uncertainties in Source Attribution through Closer Integration

Identification of LRT events, emissions, and transport

- Process understanding
- Regional synthesis

- Source attribution
- Fingerprint identification
- Trend detection

- Scenarios
- Regional/sectoral signatures
- Speciation

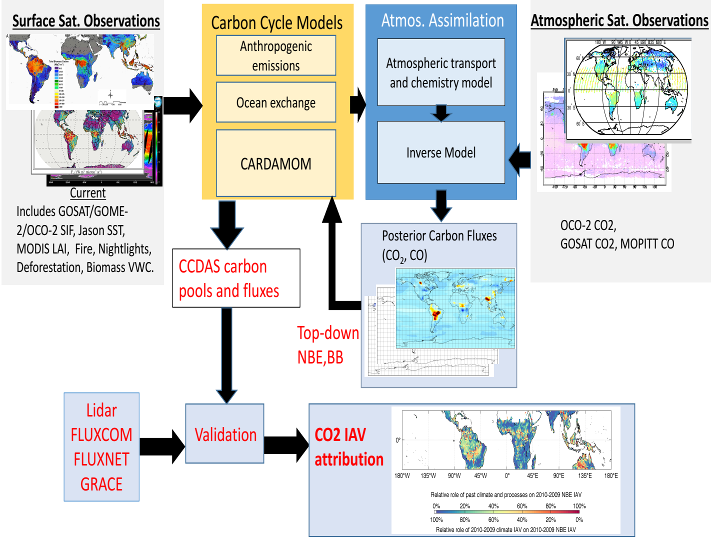
- S/R relationships
- Future scenarios (of climate change, emissions, changing air quality standards)

COP21 · CMP11

PARIS 2015

UN CLIMATE CHANGE CONFERENCE

Carbon Cycle Data Assimilation System (CMS-Flux)



Surface Sat. Observations

Current

Includes GOSAT/GOME-2/OCO-2 SIF, Jason SST, MODIS LAI, Fire, Nightlights, Deforestation, Biomass VWC.

Carbon Cycle Models

- Anthropogenic emissions
- Ocean exchange
- CARDAMOM

Atmos. Assimilation

- Atmospheric transport and chemistry model
- Inverse Model

Atmospheric Sat. Observations

OCO-2 CO2,
GOSAT CO2, MOPITT CO

Posterior Carbon Fluxes (CO_2, CO)

CCDAS carbon pools and fluxes

Top-down NBE,BB

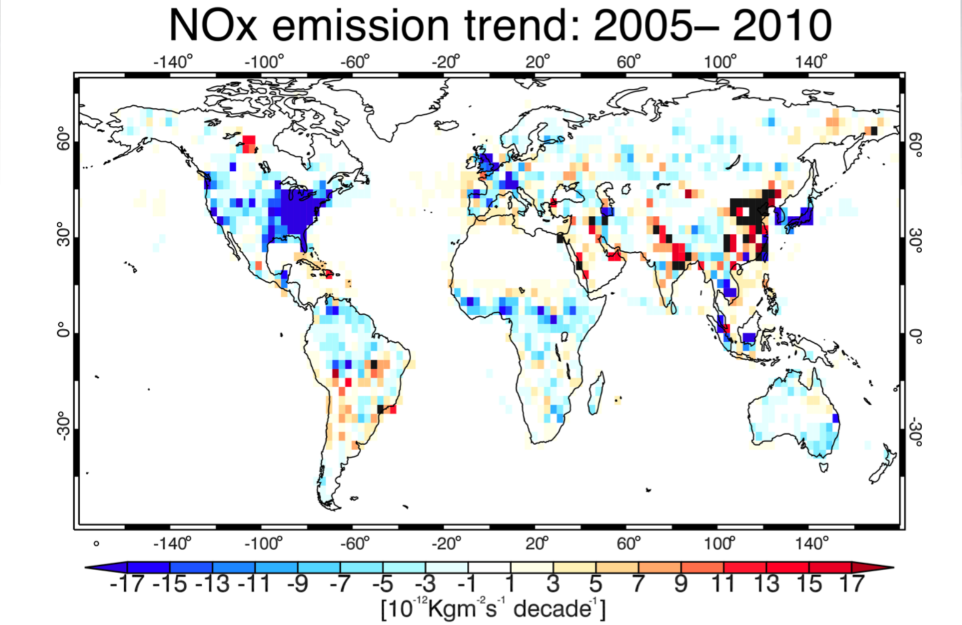
Lidar
FLUXCOM
FLUXNET
GRACE

Validation

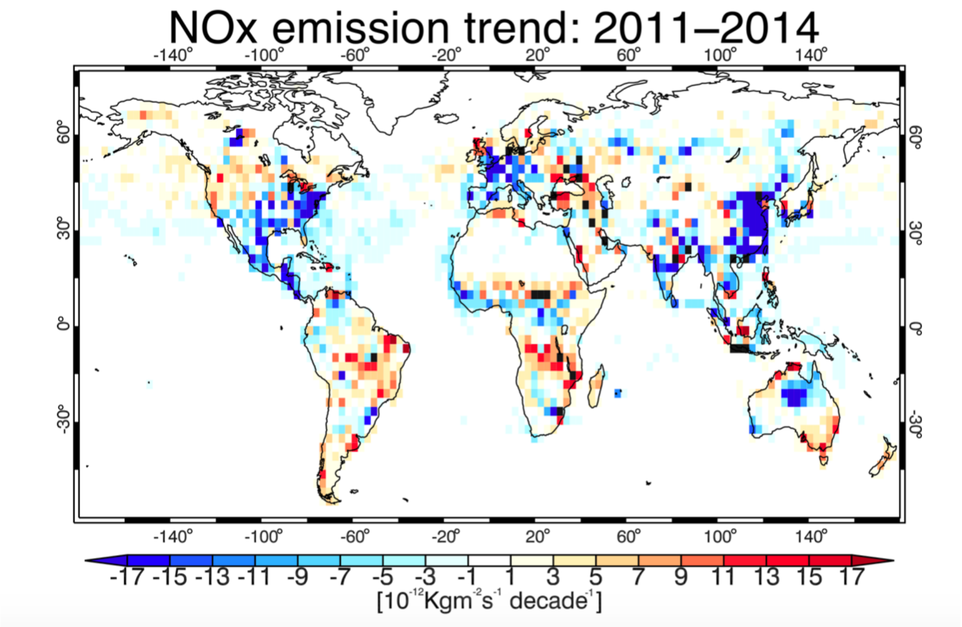
CO2 IAV attribution

The turning point NOx emissions

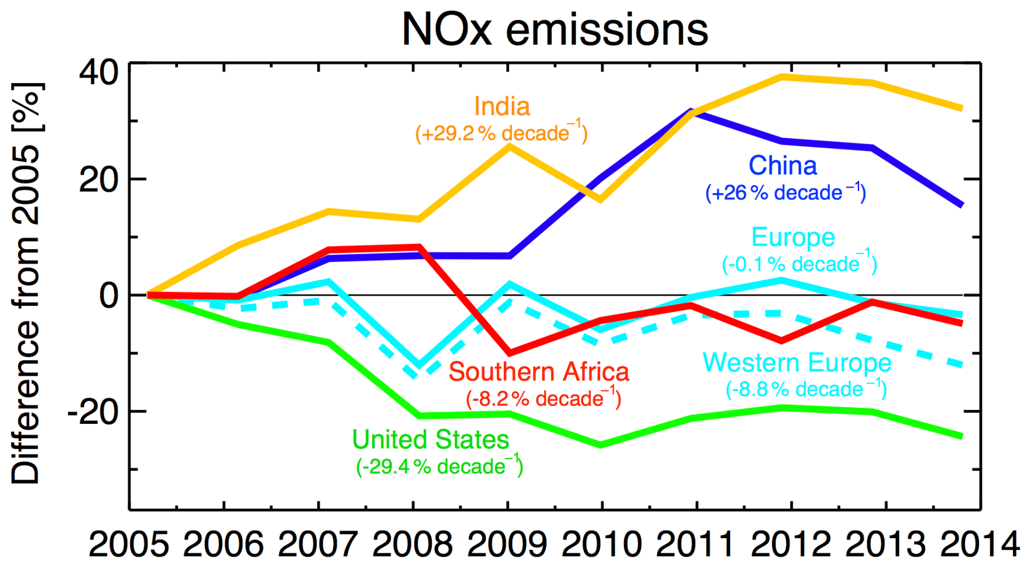
Based upon a multi-constituent satellite data assimilation/inversion system (TES, MOPITT, MLS, OMI), Miyazaki et al, 2017 showed that China dramatically increased NOx emissions until turning a corner in 2011.



NOx emission trend: 2005– 2010



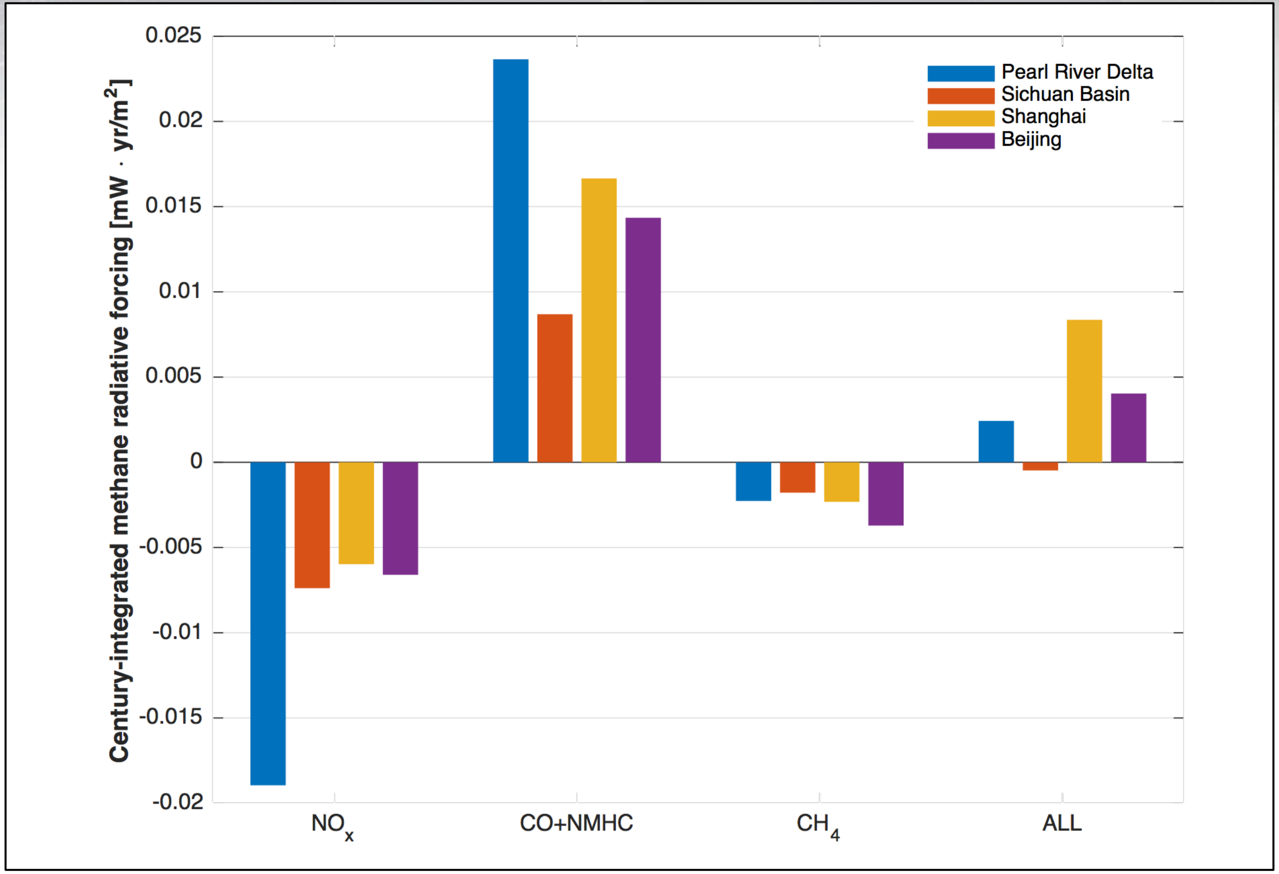
NOx emission trend: 2011–2014



NOx emissions

Miyazaki et al, 2017, ACP

Location matters: spatial gradients of CH4 forcing



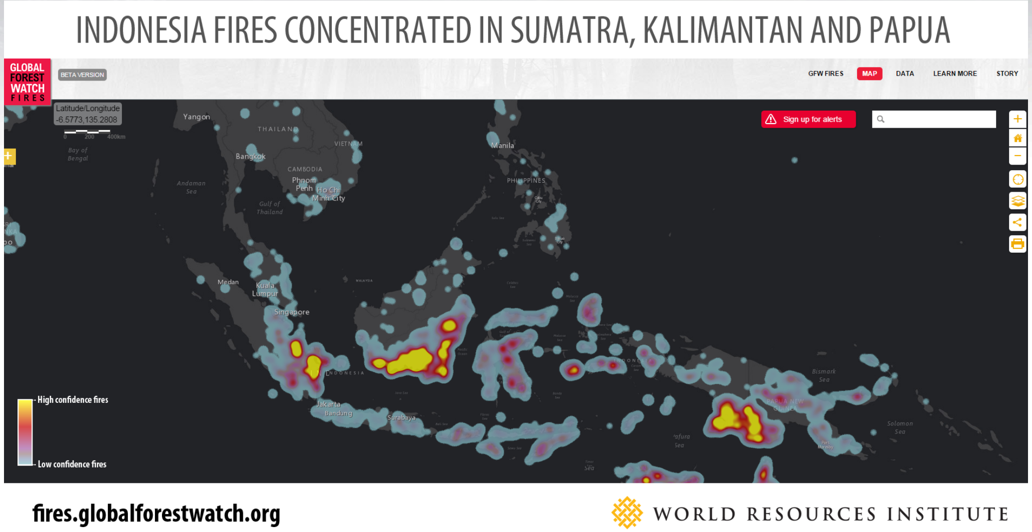
Walker and Bowman, *in Rev.*

In China, the sensitivity of global methane loss rates to precursor emissions varies by a factor of 2 between 20N and 45N for NOx and a by a factor of 7 between 120E and 90E for CO.

CH4 RF is driven by the balance between the magnitude of CO and NOx emissions trends and the spatially dependent sensitivity

For RCP6, total CH4 RF in Beijing and Shanghai is dominated by CO emissions whereas Pearl River Delta and Sichuan Basin are largely balanced.

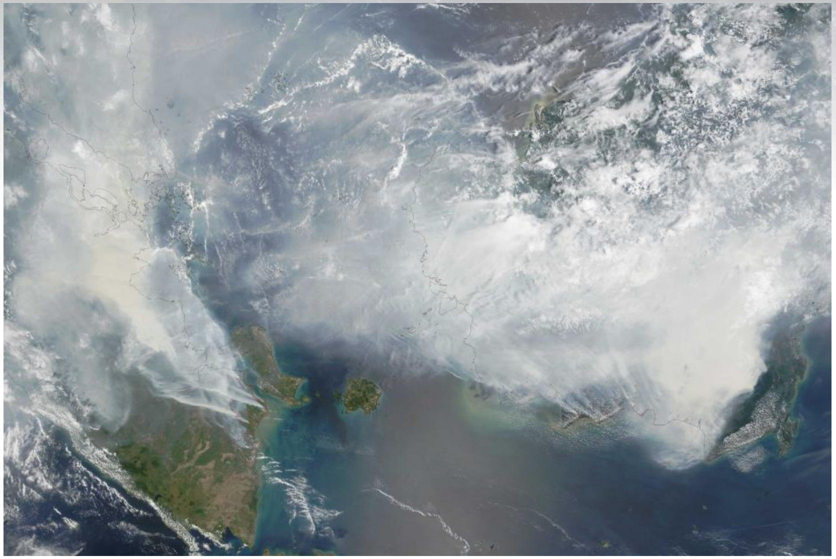
Indonesia Fires



INDONESIA FIRES CONCENTRATED IN SUMATRA, KALIMANTAN AND PAPUA

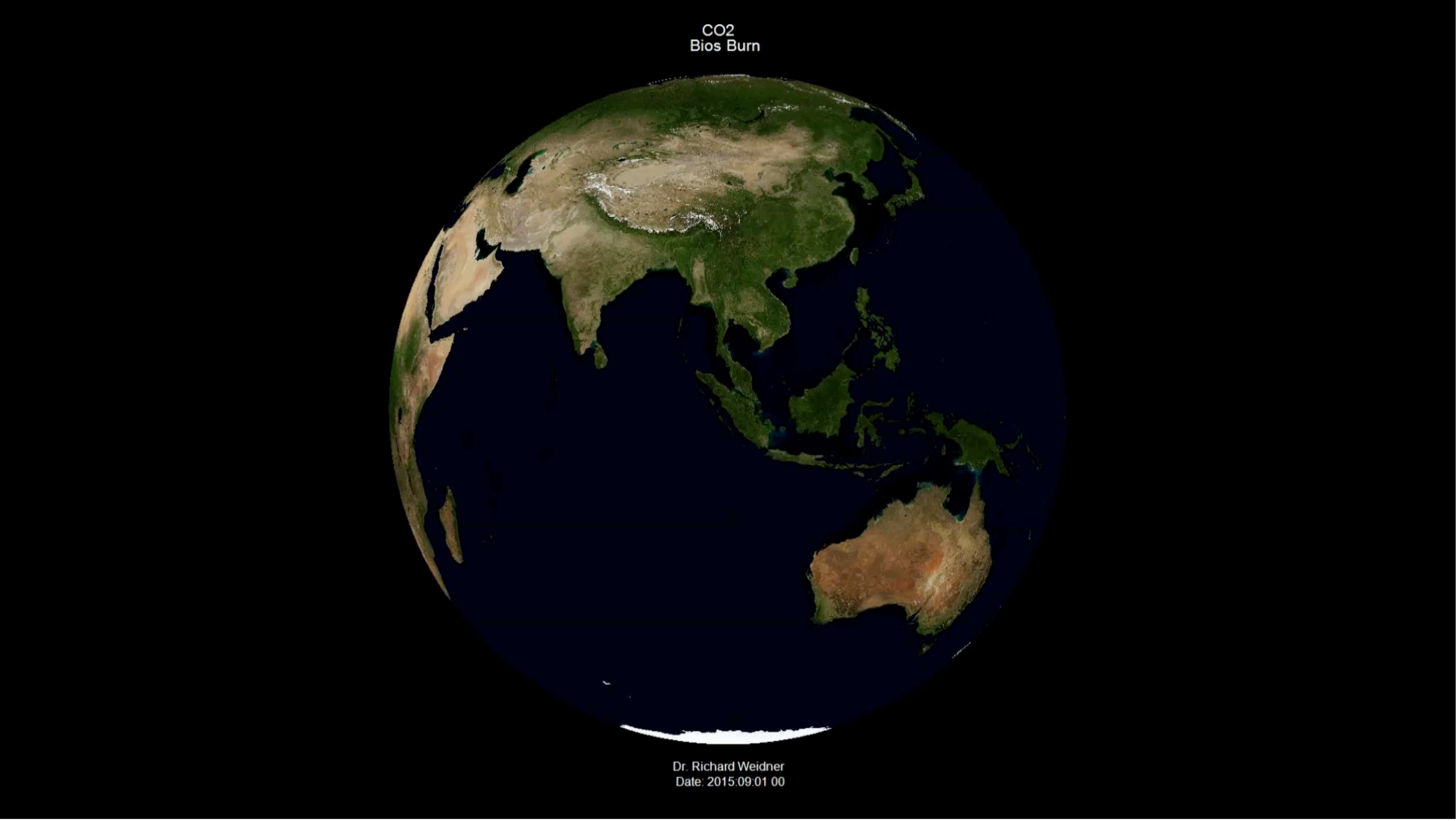
fires.globalforestwatch.org

WORLD RESOURCES INSTITUTE

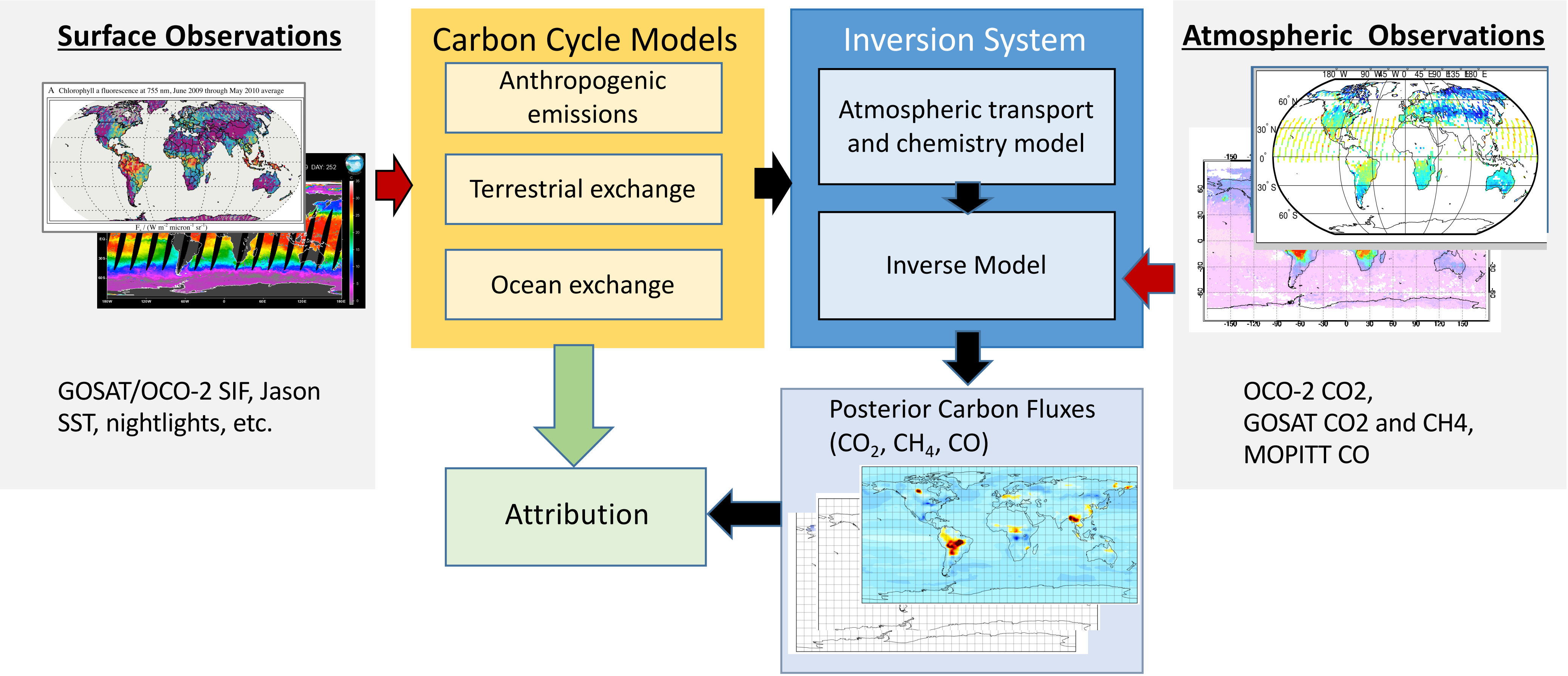


NASA Earth Observatory

Atmospheric signature of Indonesian composition



NASA Carbon Monitoring System Flux (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

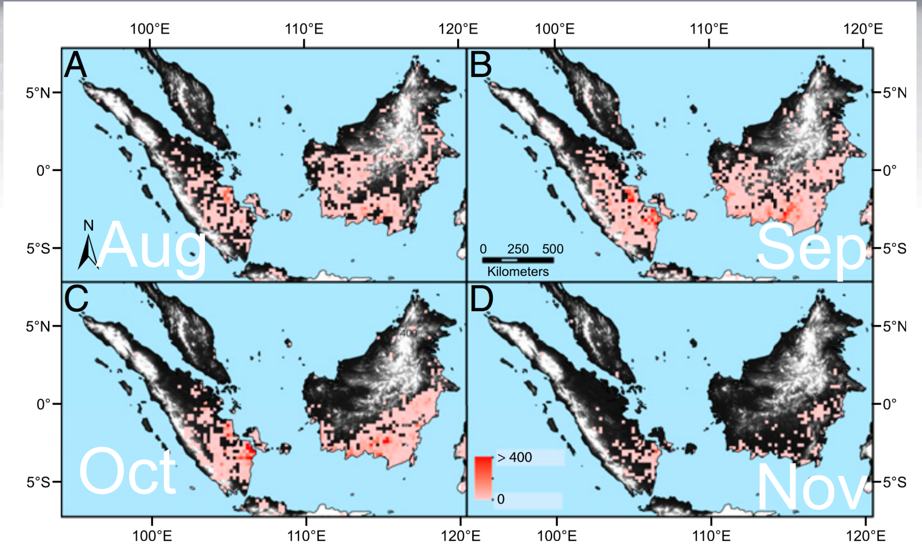
OCO-2 CO2,
GOSAT CO2 and CH4,
MOPITT CO

Posterior Carbon Fluxes (CO_2, CH_4, CO)

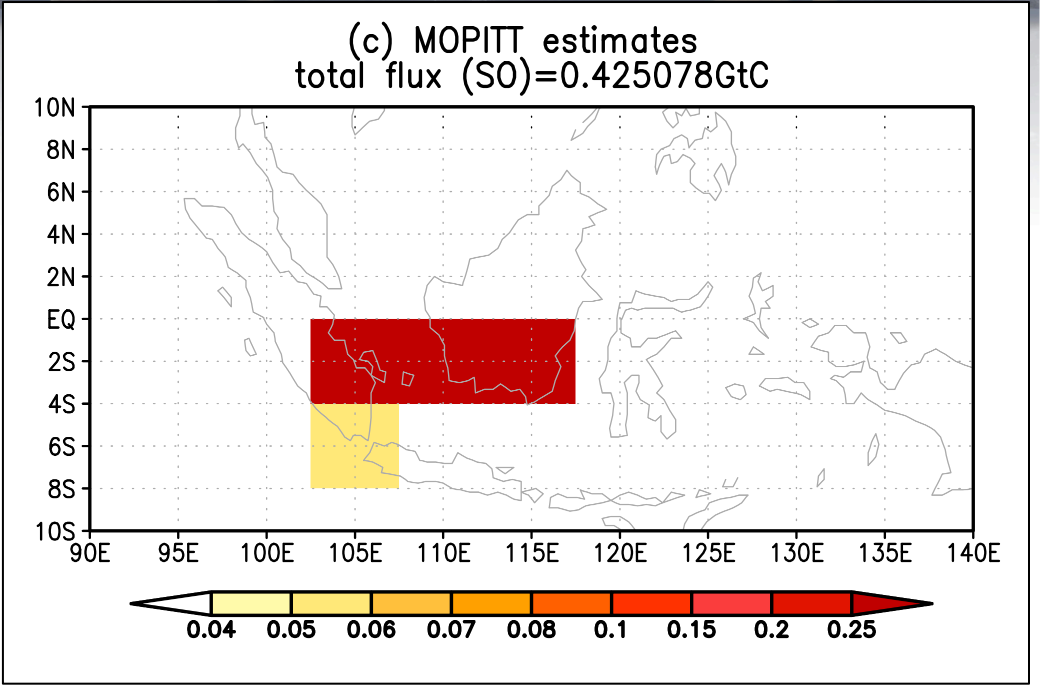
Attribution

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.

CMS-Flux Carbon Fluxes



Field et al, 2016 (PNAS)

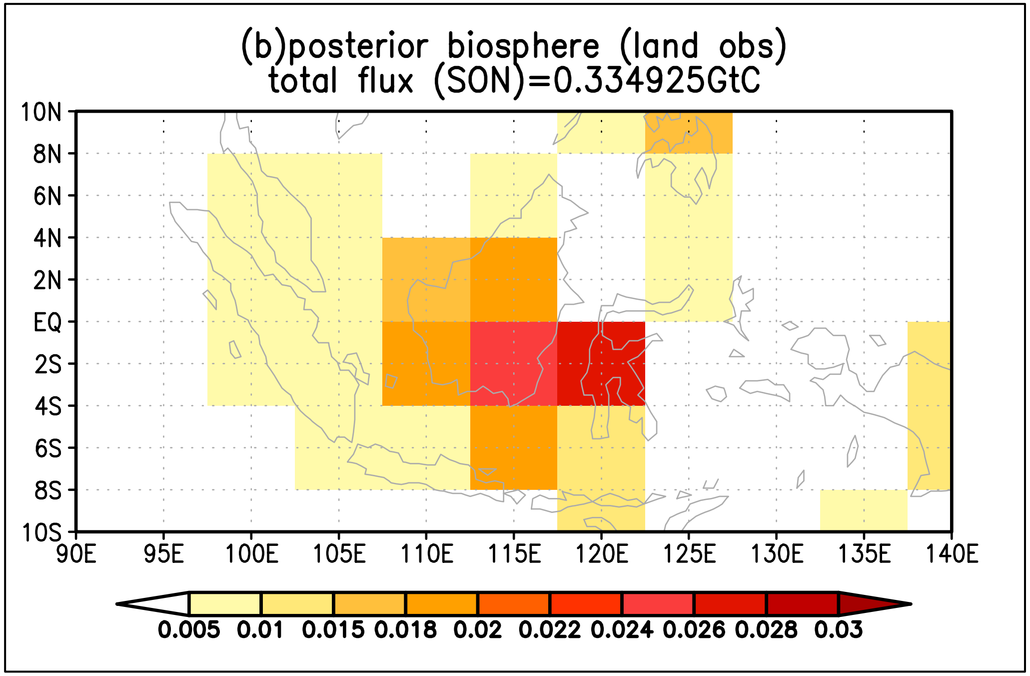


(c) MOPITT estimates
total flux (SO)=0.425078GtC

"Top-down" emissions constrained by MOPITT CO show elevated biomass burning in Sumatra and Kalimantan. CO:CO2 calculated from Stockwell et al, ACP (2016) (see E. Putra GC21C-1107).

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

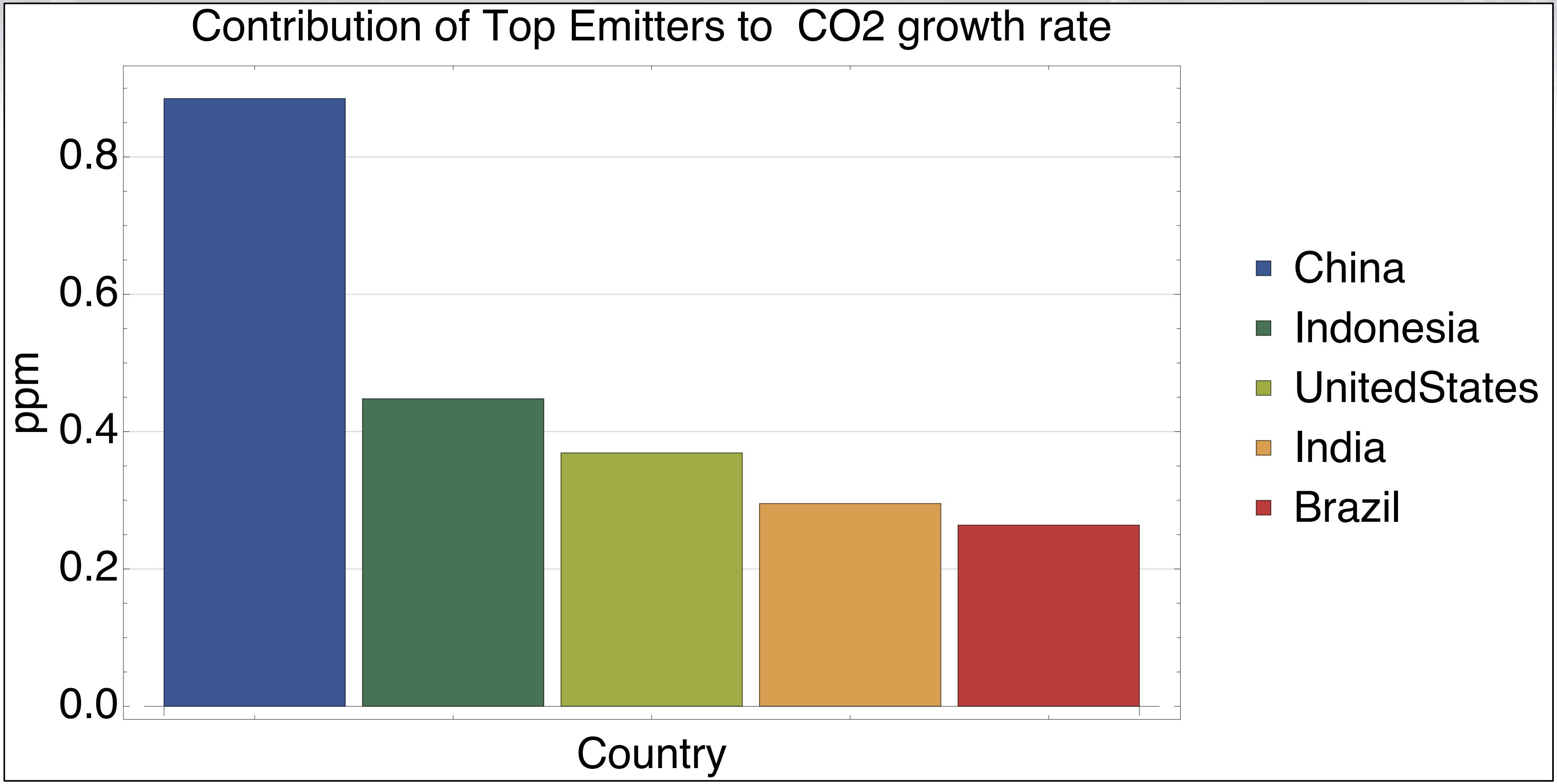
BB CO2 similar to 0.5 PgC in Yin et al, 2016 (GRL)



(b)posterior biosphere (land obs)
total flux (SON)=0.334925GtC

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

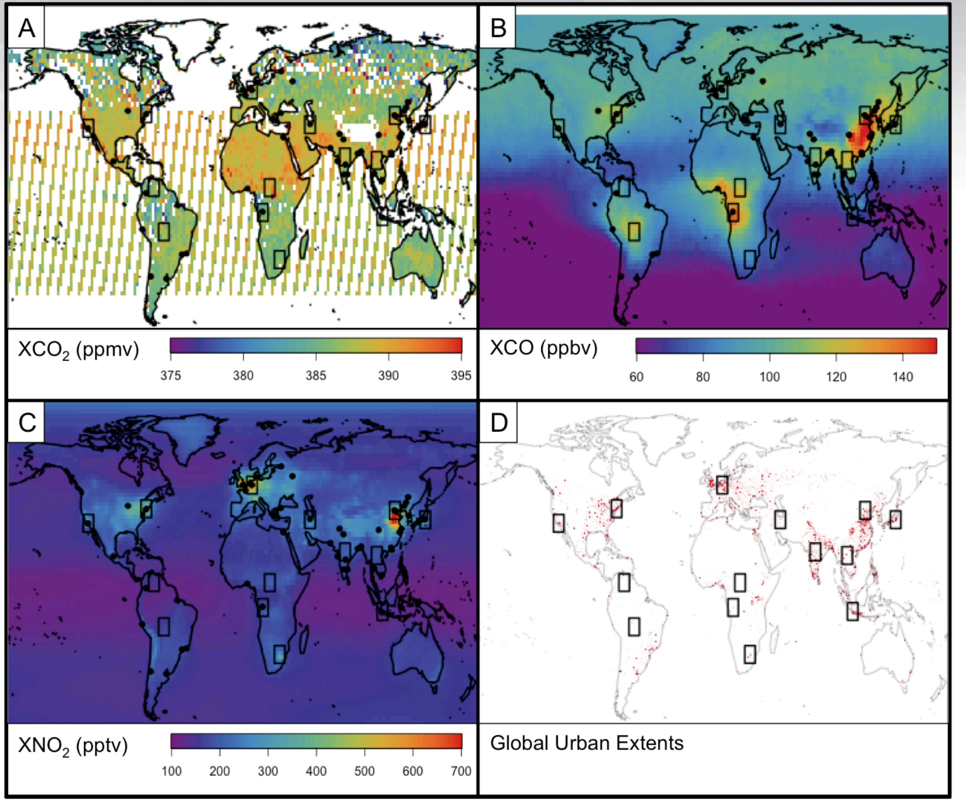
Implications for 2015 CO2 growth rate



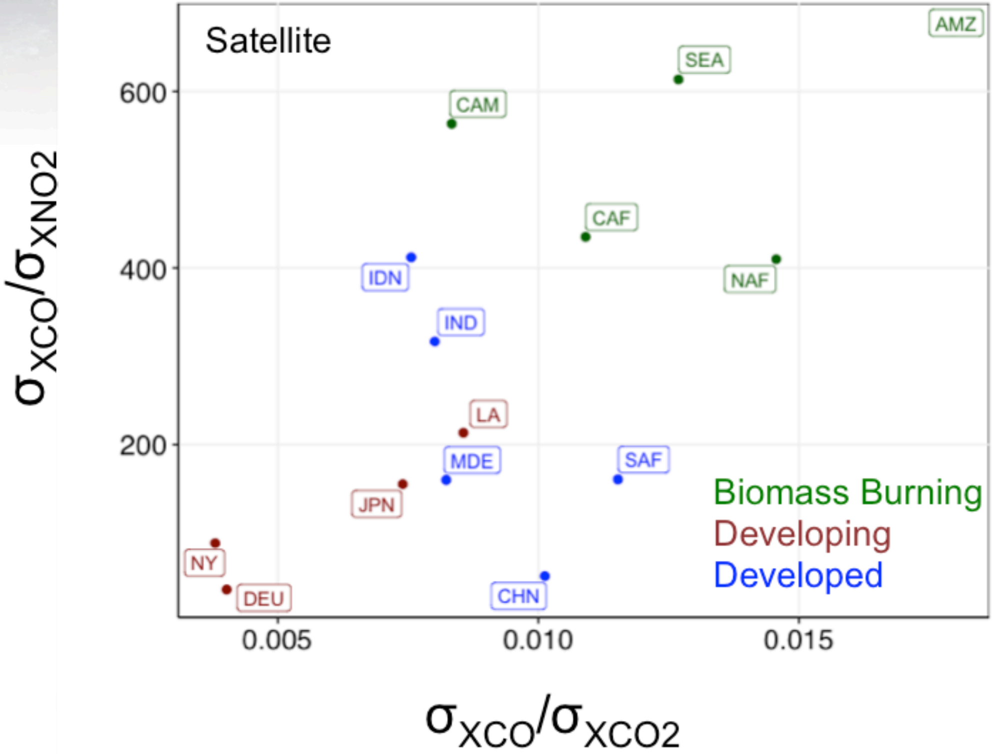
The Indonesian region was the 2nd highest contributor (0.45 ppm) in total flux to the record CO2 growth rate in 2015.

But, Brazil was almost as important.

Linking CO_2, CO, and NO_2



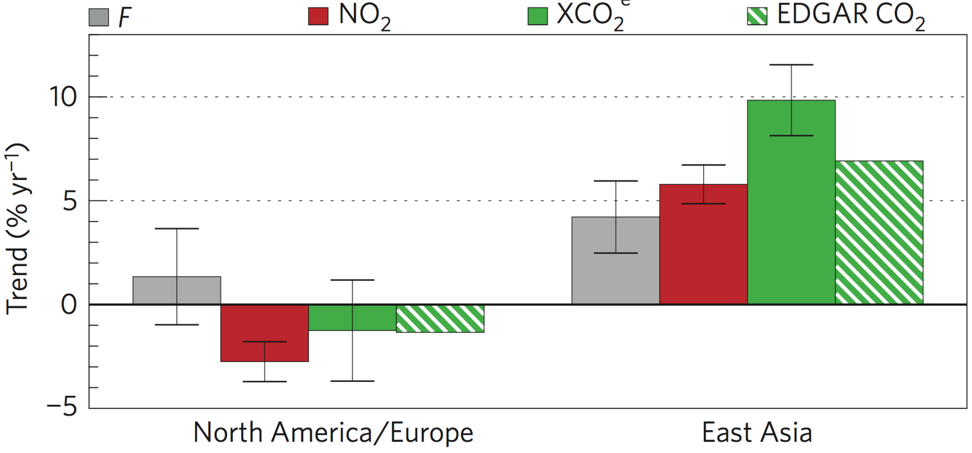
Silva and Arellano, submitted



Silva and Arellano, *submitted* show ratios of the variability in CO, NO_2, and CO_2 show distinct patterns relating to local combustion processes.

Reuters et al, 2014 showed that trends Between NO_x and CO_2 are diverging

Reuters et al, 2014 Nat. Geo



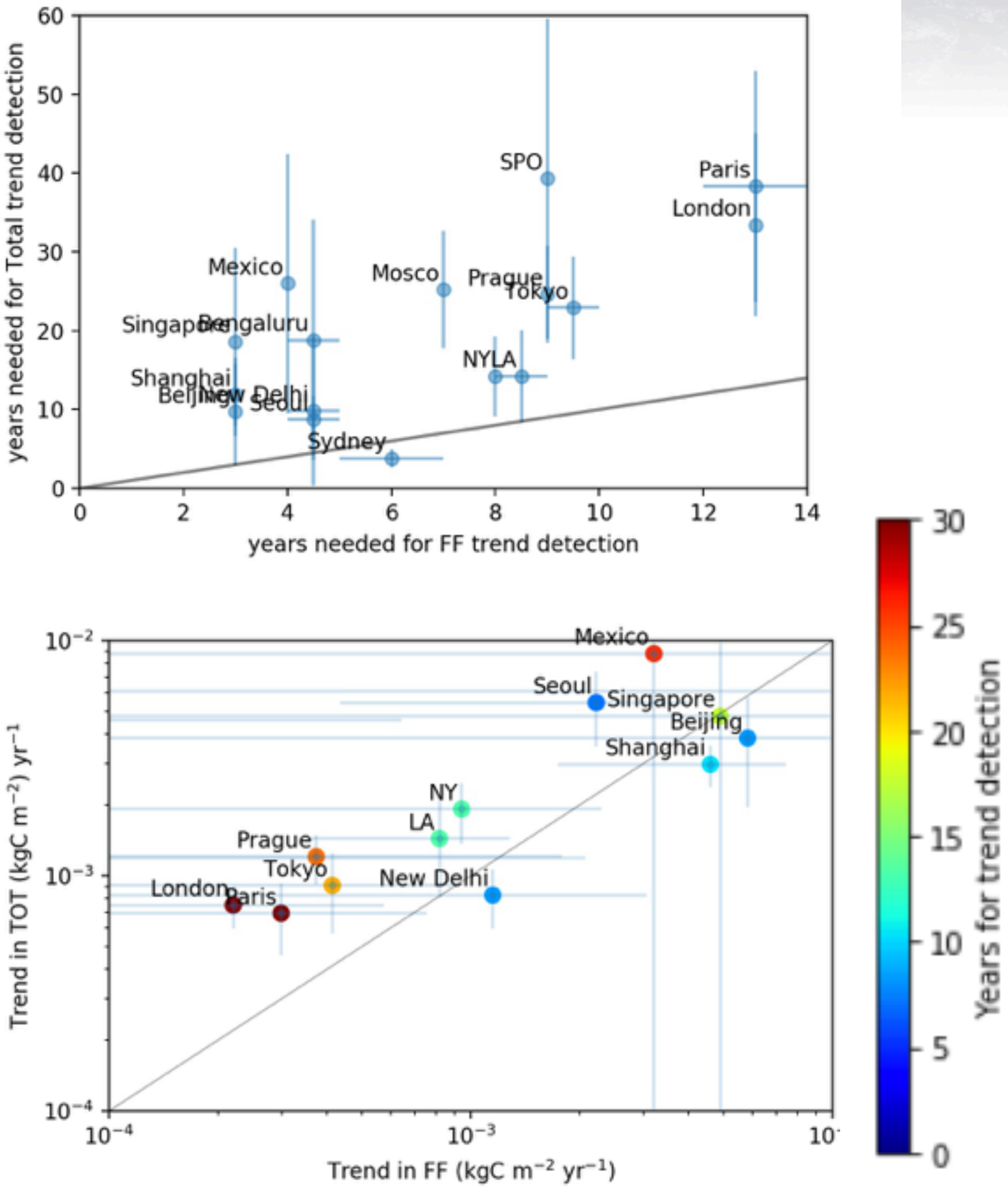
The times they are a-changing

A key need for COP21 is how fossil fuel emissions are changing.

FF trend amplitude and variability leads to time-to-detection between 3 to >10 years.

However, natural carbon variability increases time-to-detection (factor 1.2 to >3)

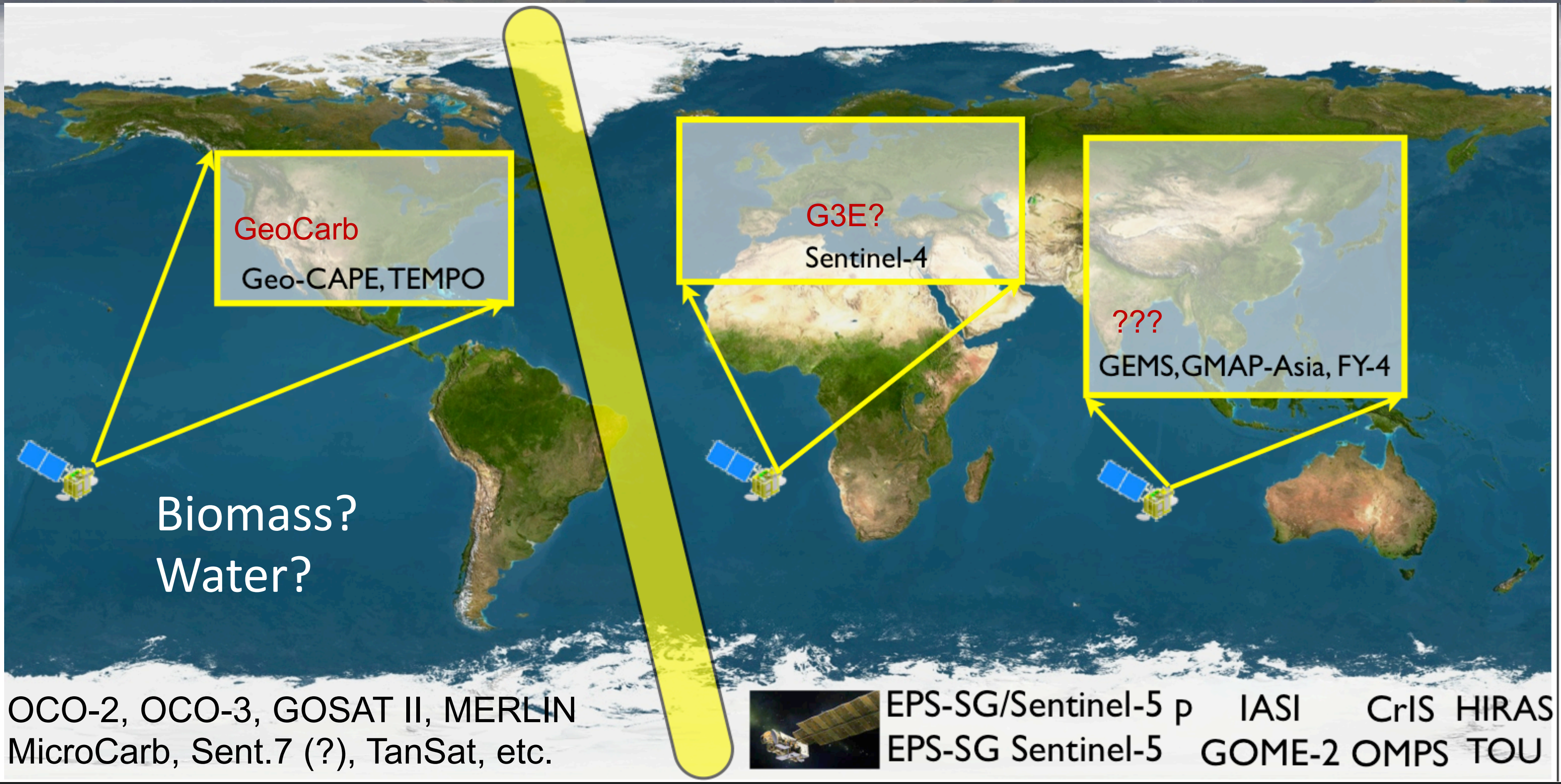
Carbon feedbacks (carbon-concentration and carbon climate) contribute their own trend.
Both are important.



Yin and Bowman

Toward an Air Quality-Carbon-Climate Constellation

Bowman et al, Atm.Env. 2013

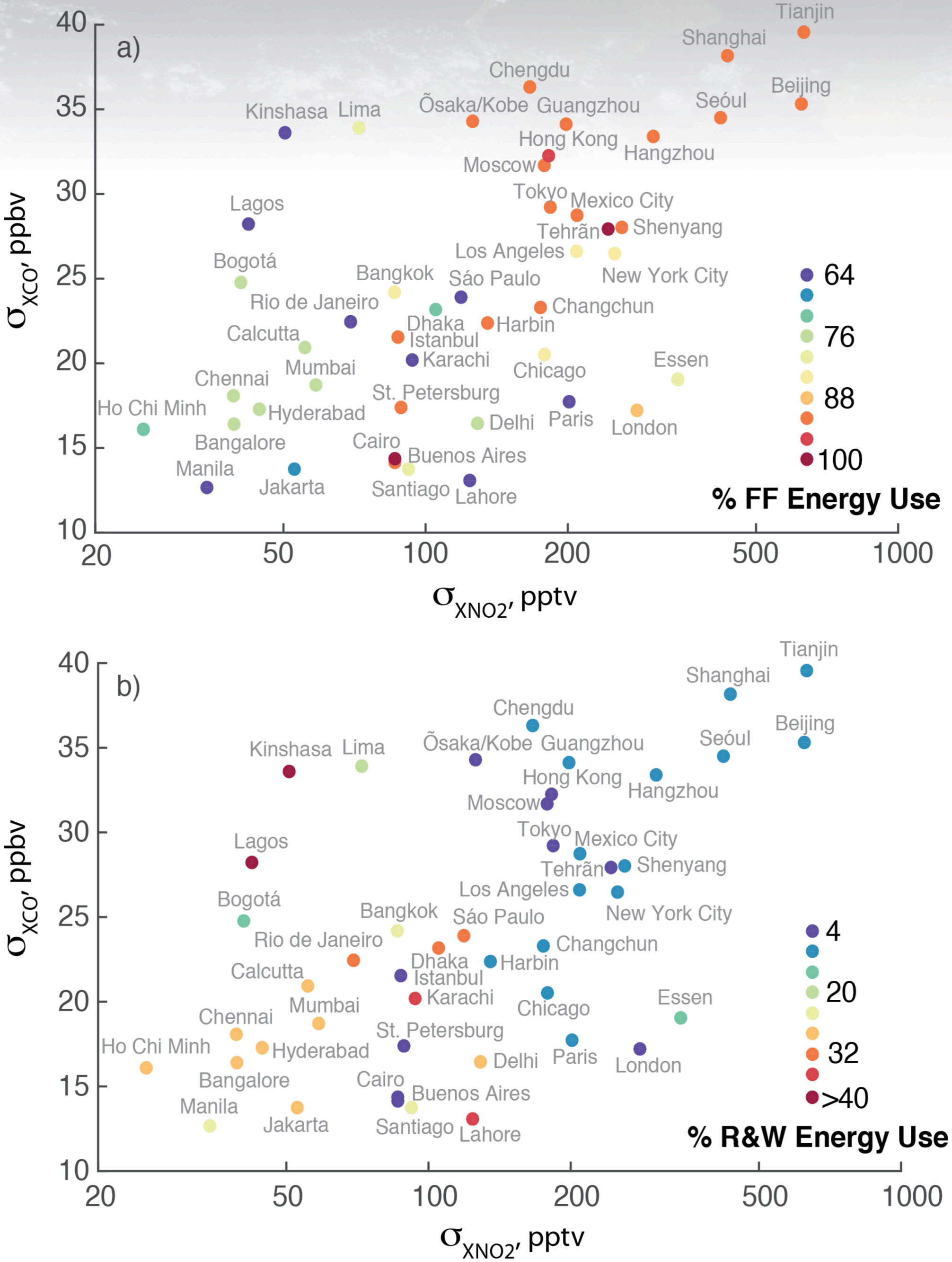


- LEO:
  - IASI+GOME-2, AIRS+OMI, CrIS+OMPS could provide UV+IR ozone products for more than a decade.
  - Combined UV+IR ozone products from GEO-UVN and GEO-TIR aboard Sentinel 4 (Ingmann *et al*, 2012 Atm. Env.)
  - Sentinel 5p (TROPOMI) will provide column CO and CH4.
  - OCO-2+AIRS, GOSAT II (IR+NIR) 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

- Climate mitigation requires an observation system of both long and short-lived climate pollutants.
- AQ mitigation in developing countries will impact the near-term trajectory of carbon emissions.
  - The co-evolution of CO2, NO2, CO, and particulates can provide insight
- Climate variability and feedbacks can coherently amplify AQ and carbon distributions
  - ”Extreme” events may hinder policy objectives
  - Trend detection of AQ and carbon must account for natural variability
- Integrating AQ and carbon constellations will provide an unprecedented capability
  - Need quantitative analysis of constellation(s), e.g., OSSEs.

Backup



Observations of composition typically used for the study of air quality contain information regarding local energy use.

These have the potential to complement analyses of CO_2, improving our process-based understanding of emissions.

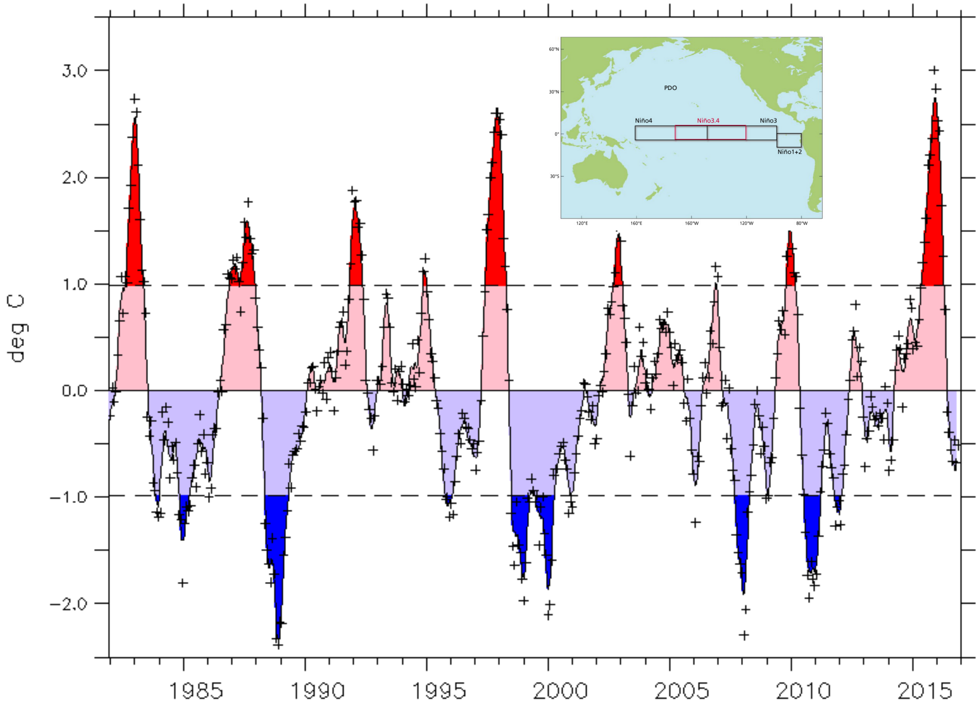
Conclusions

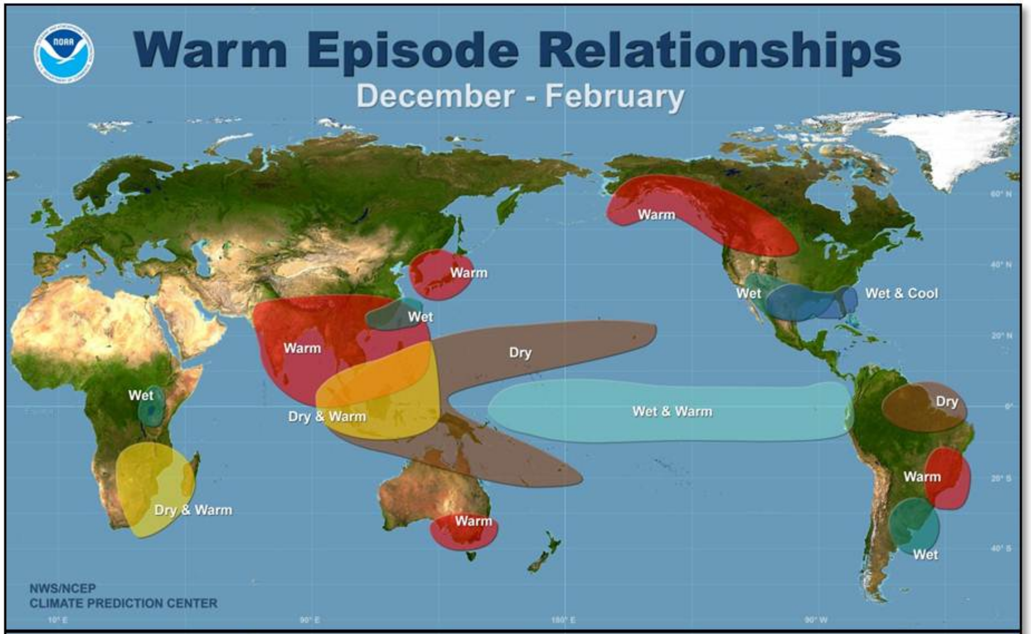
- Climate change mitigation requires attribution of climate forcing to spatial scales at which mitigation occurs.
  - Top 10% of emissions account for the majority of net CH4 RF.
  - Expansion of emissions in Southeast Asia will have a proportionally larger impact because of efficient ozone and CH4 RF export.
- CO2 growth rate mitigation requires attribution of forcing and feedbacks at the spatial scales on which they occur.
  - The tropics released 2.4 ± 0.34 Gt more carbon into the atmosphere in 2015 than in 2011 accounting for 78.7% of the global total 3.0 GtC NBE difference, and 88% of the atmospheric CO2 growth rate differences.
  - While tropical continental contributions were roughly the same, the dominant carbon processes were different: S. America (GPP), Africa (Resp), and Asia (Fire)
  - Fluxes associated with climate “extremes” were the dominant drivers of the tropical fluxes.
- A framework common to both ”emergent” constraints and verifiable predictions of climate forcing provides a basis for linking observations and models within an assimilation paradigm.

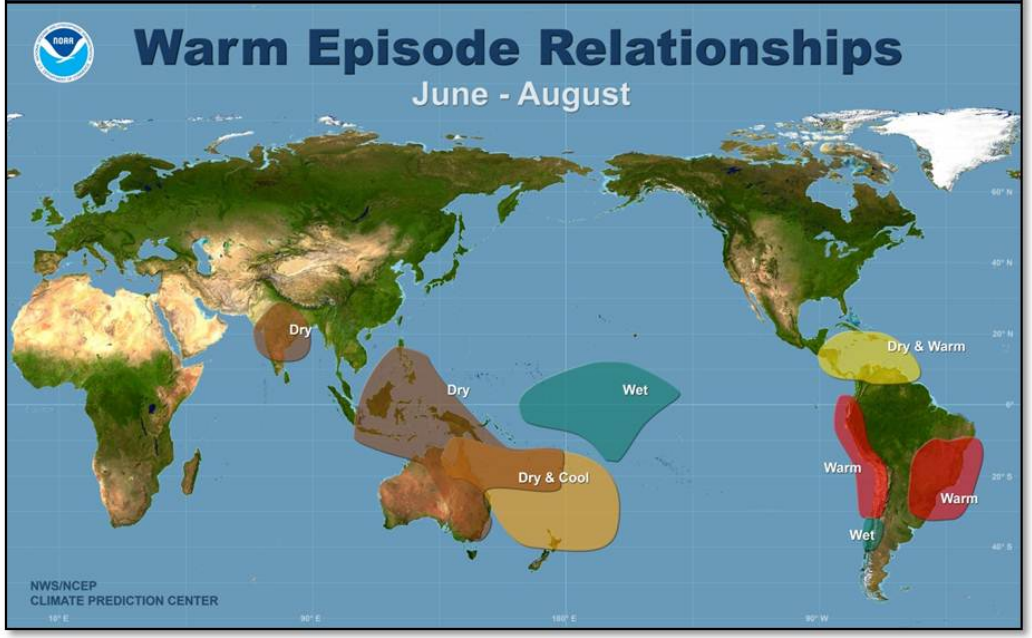
The epicenter of the 2015 El Niño

The 2015 rivals the 1997-1998 ENSO (ENSO 3.4 index).

ENSO lead to dry and warm forcing patterns centered over Indonesia.







High Resolution Images can be found at:
http://www.cpc.ncep.noaa.gov/products/precip/CWlink/ENSO/ENSO-Global-Impacts/

Radiative Forcing in 2050 (RCP6)

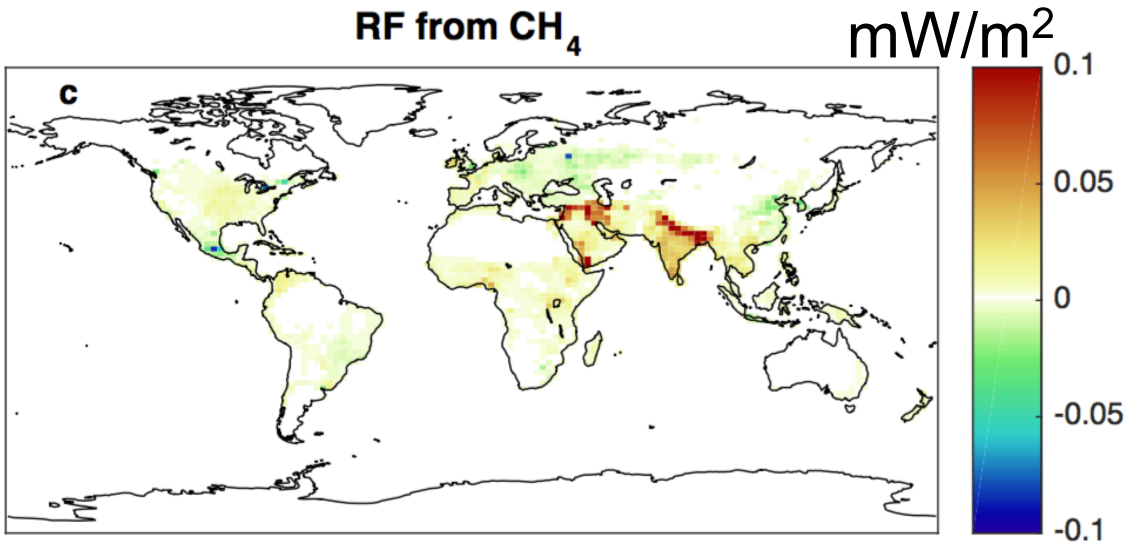
CH4 emissions RF is driven primarily in the Middle East And in Northern India (Gangetic plain)

Total CH4 RF is balanced between chemical reductions in central/south China and increases in US/Europe.

Chemical-driven increases are a consequence of improved air quality standards

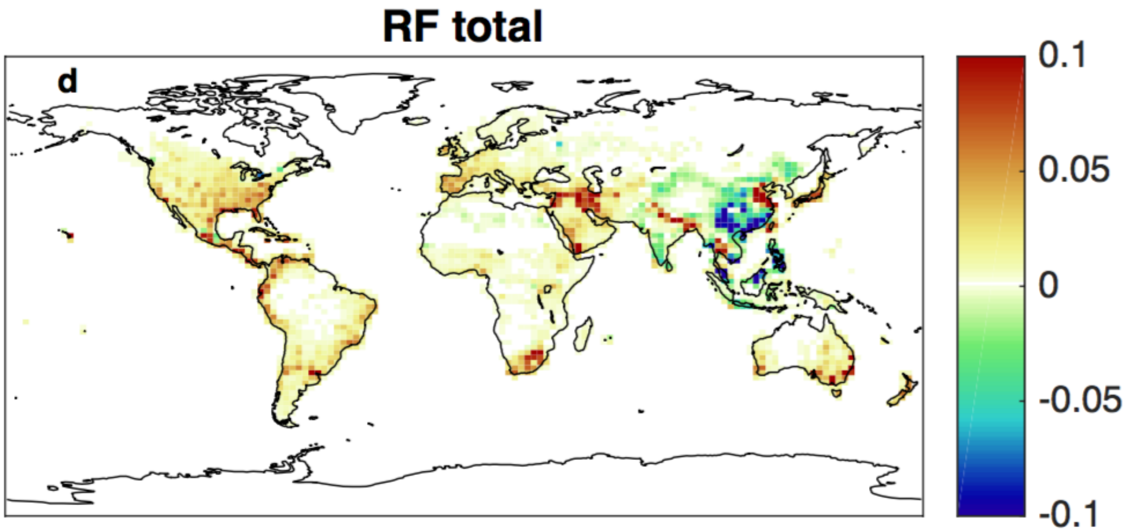
Chemical-driven decreases are a consequence of deteriorating air quality.

Air quality-climate *dis*benefits



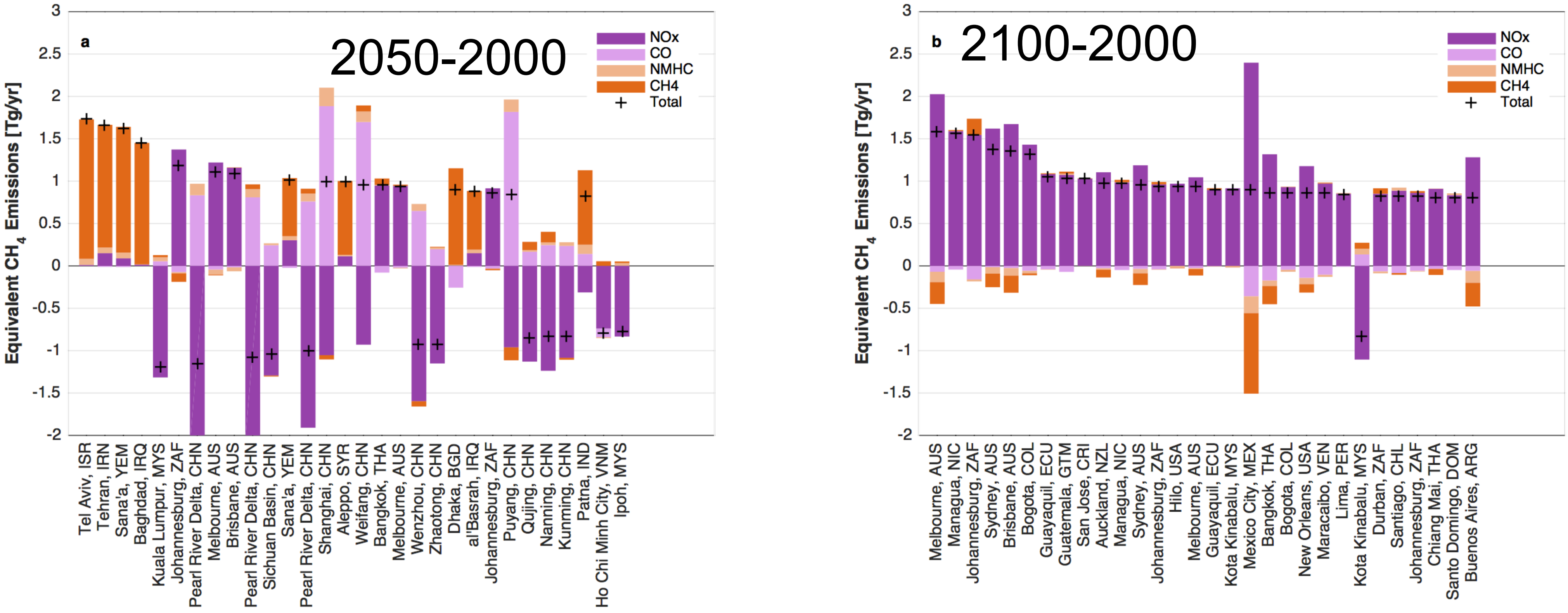
RF CH4 emissions

Walker and Bowman, *in Rev.*



RF CH4 emissions+chemistry

Ranking total CH4-equivalent emissions



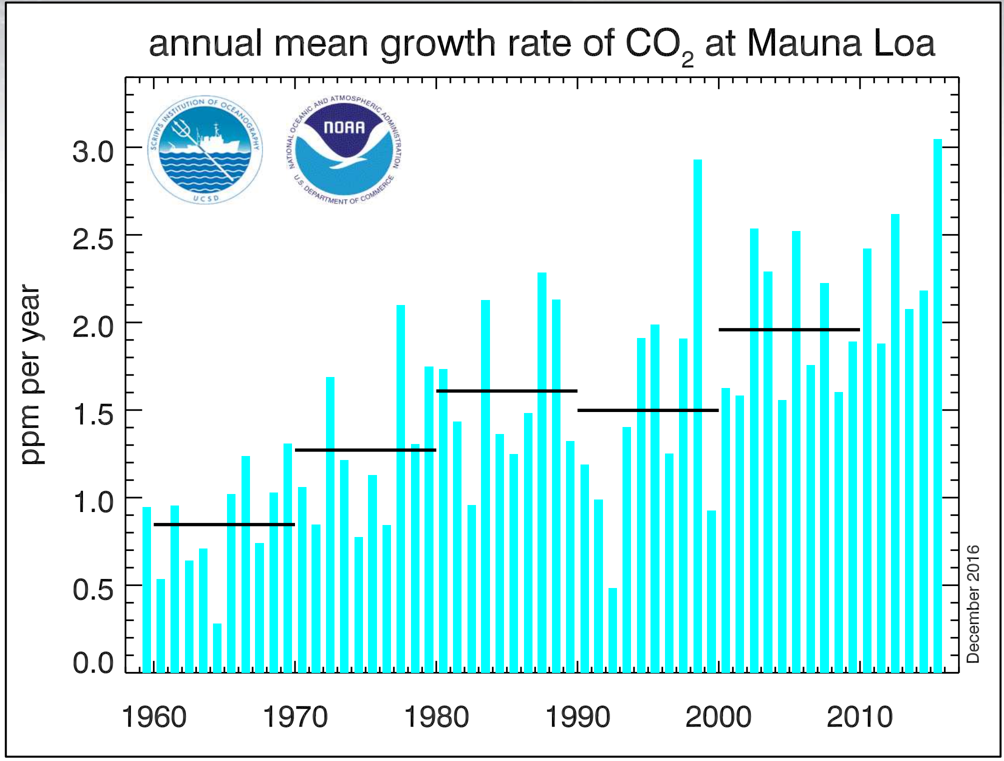
Walker and Bowman, *in Rev.*

RF CH4 from NOx, CO, and VOC can be converted to an equivalent emission of RF CH4.

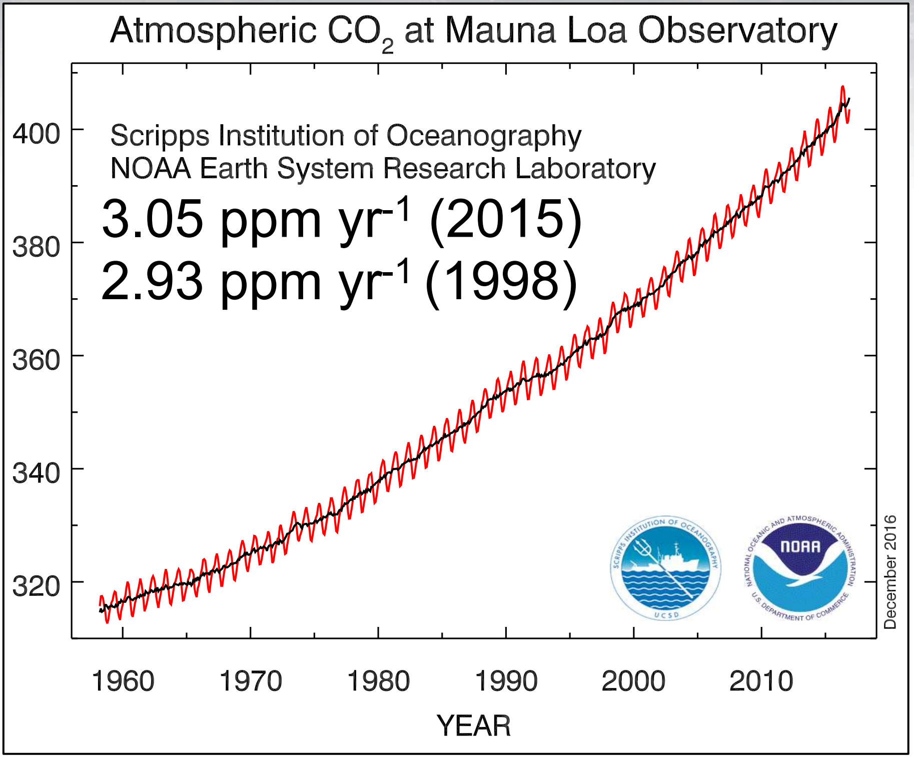
CH4 direct emissions drive mid-century RF but NOx emissions drive end-of-century RF

The top 10% of positive equivalent emissions (eqem) account for 50% of the total positive eqem. The top 10% of negative eqem account for 60% of the total negative eqem

Largest CO2 Growth Rate in 50 years



annual mean growth rate of CO_2 at Mauna Loa



Atmospheric CO_2 at Mauna Loa Observatory

Scripps Institution of Oceanography
NOAA Earth System Research Laboratory

3.05 ppm yr^{-1} (2015)
2.93 ppm yr^{-1} (1998)

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?

Paris Accord

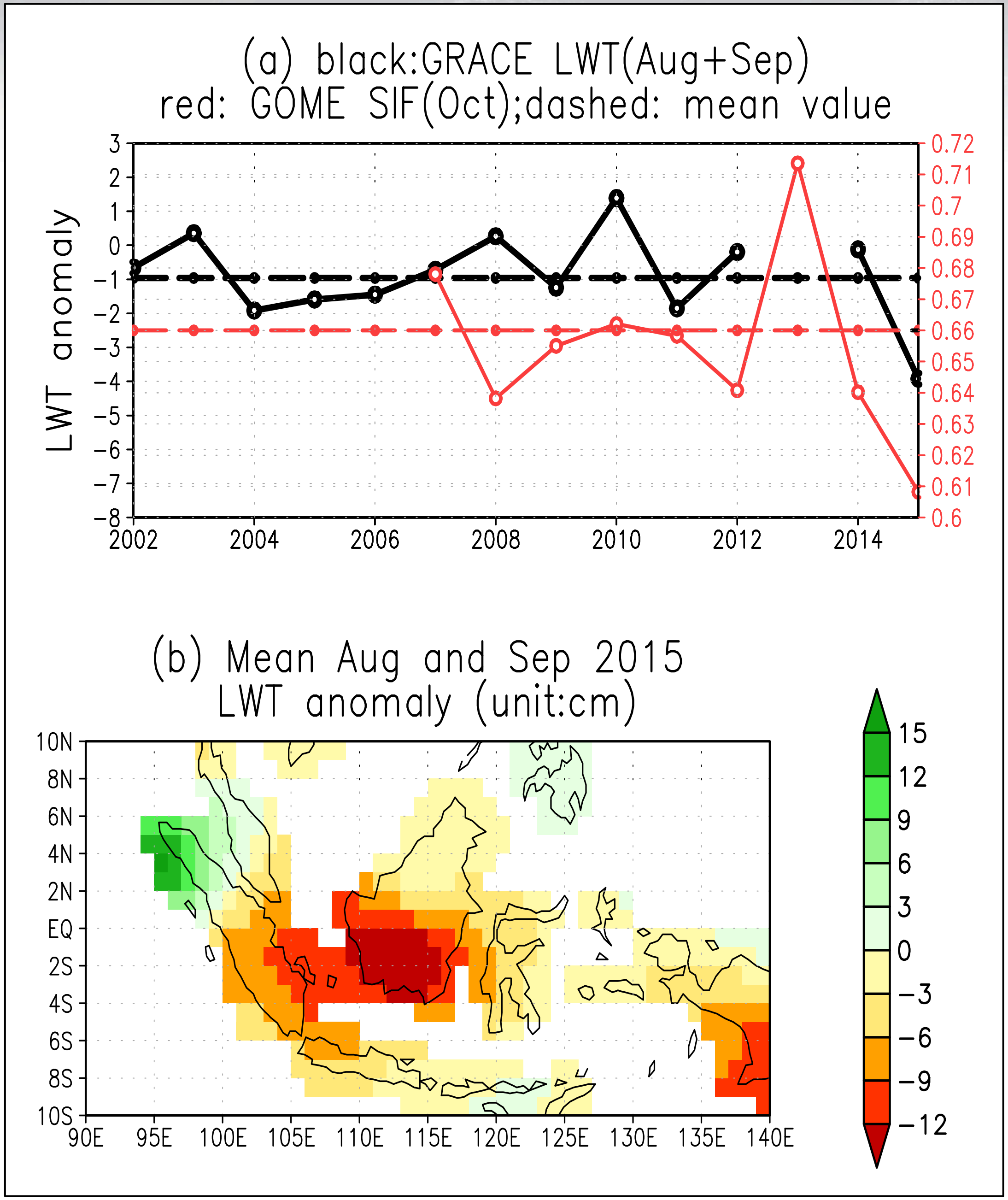
- On Oct. 24, 2016 Indonesian President Joko "Jokowi" Widodo signed the Paris Agreement into law.
- On Nov. 4, 2016 the landmark Paris Agreement for carbon mitigation was put into effect.

According to Indonesia's official BAU, the country's emissions level is expected to increase from 1,805 $MtCO_2e$/year in 2020 to 2,885 $MtCO_2e$/year in 2030. Indonesia's pledge corresponds to absolute emission levels of 1,335 $MtCO_2e$/year unconditionally by 2020, 2,050 $MtCO_2e$/year unconditionally by 2030, and 1,700 $MtCO_2e$/year conditionally by 2030. http://climateactiontracker.org/countries/indonesia/2016.html

Tipping points: the hydrological context

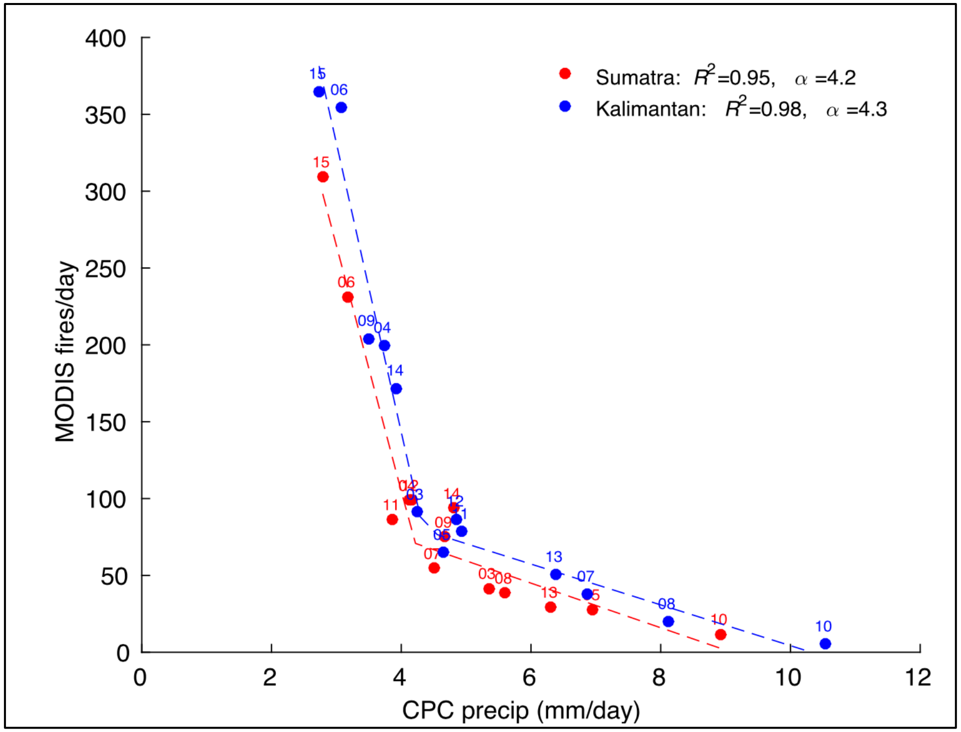
Centered on Kalimantan, GRACE gravity data shows a liquid water equivalent thickness (LWT) anomaly of -4 cm, 4x larger than then decadal mean anomaly.

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



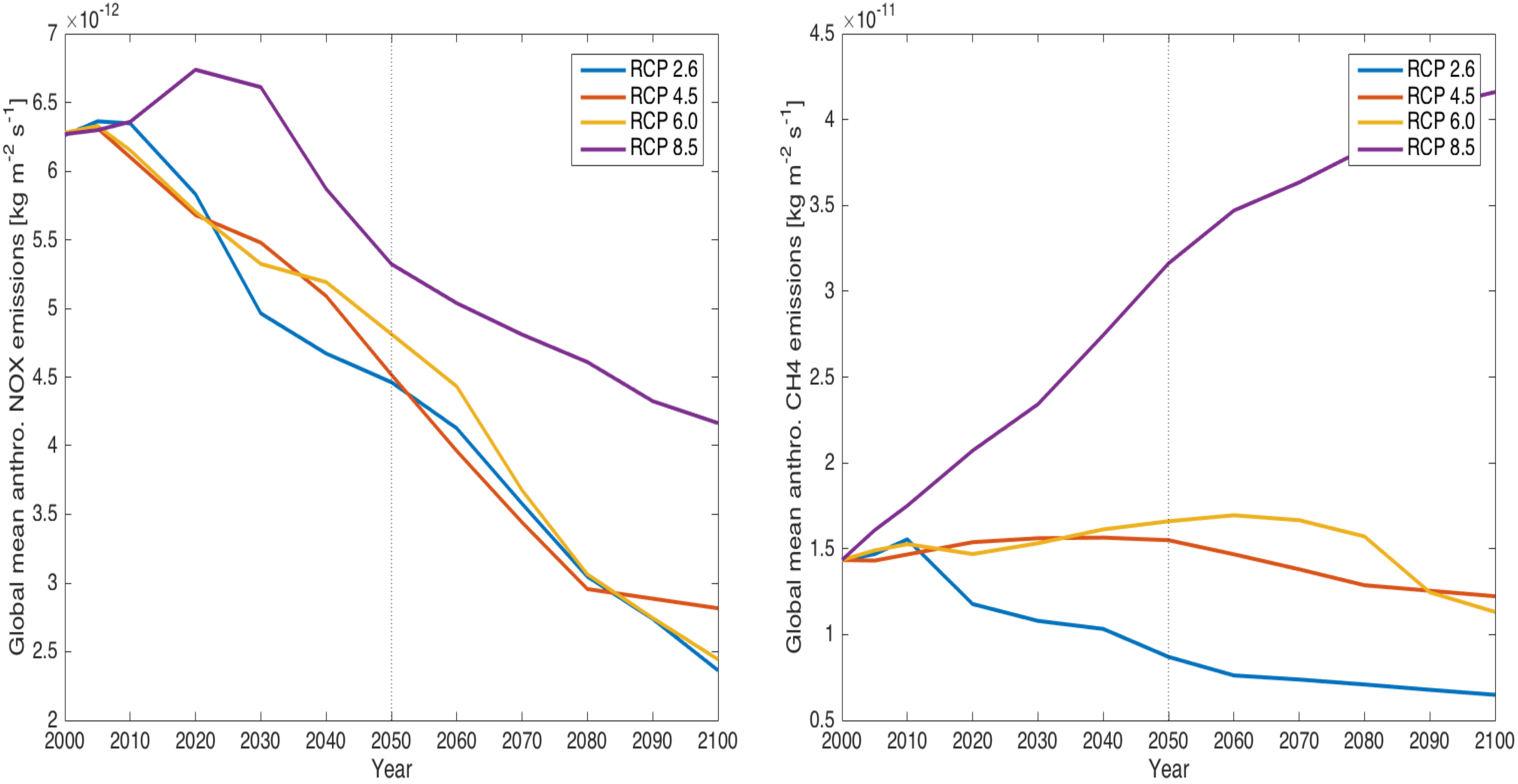
(a) black:GRACE LWT(Aug+Sep)
red: GOME SIF(Oct);dashed: mean value

(b) Mean Aug and Sep 2015
LWT anomaly (unit:cm)



Fields et al, 2016 (PNAS)

Representative Concentration Pathways



RCP 6.0 includes monotonic NOx reductions but non-monotonic CH4 increase