Observational Constraints of Anthropogenic Combustion from Space: Opportunities for Monitoring Efficiency

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Top-down Constraints On Combustion Characteristics Over Megacities and Fire Regions

Combustion of hydrocarbon fuels produce not only CO_2, but several pollutants like CO and NO_2

fuel + air and heat

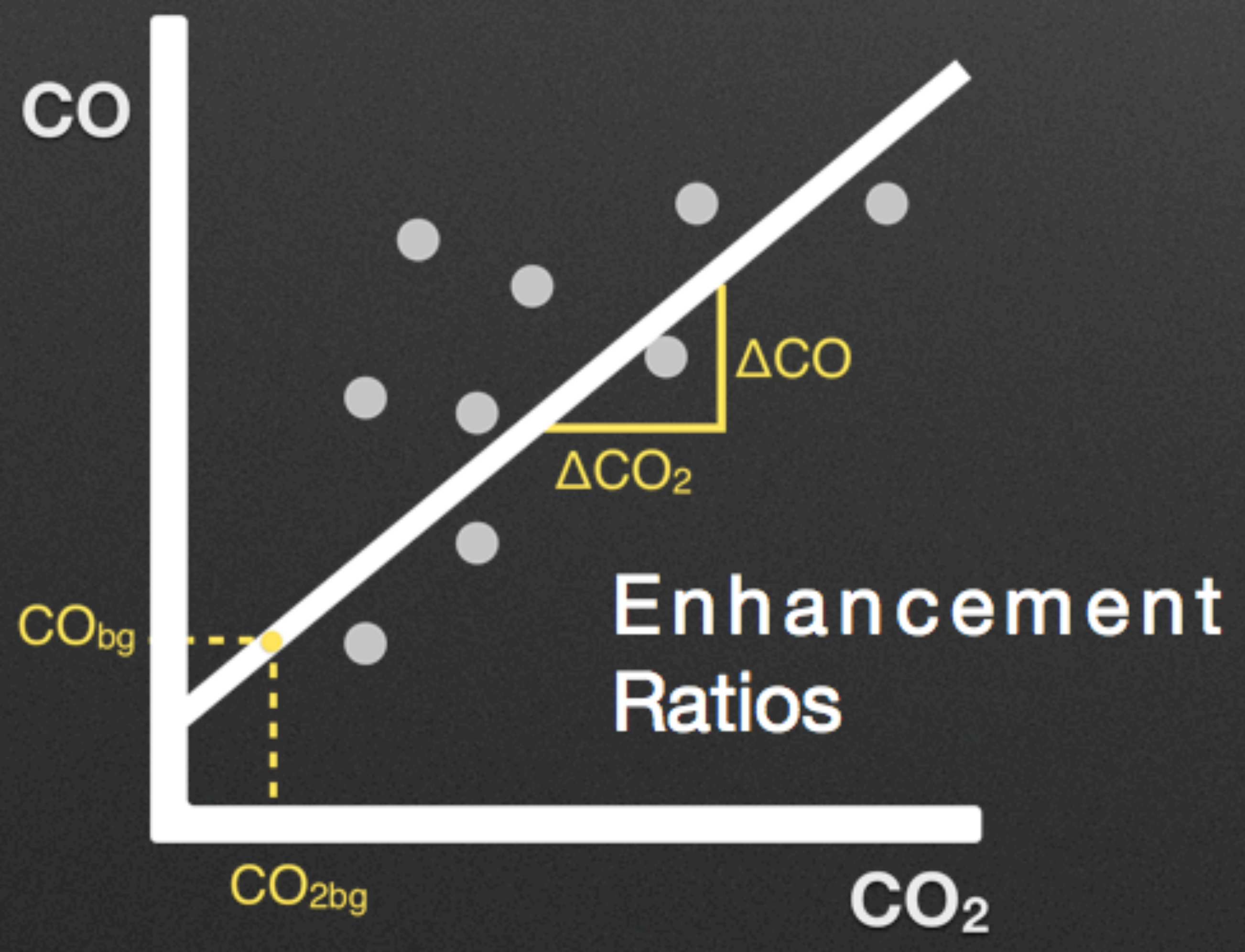
$$C_{x_1}H_{x_2}O_{x_3}N_{x_4}S_{x_5} + n_1(1+e)(O_2 + 3.76N_2)$$

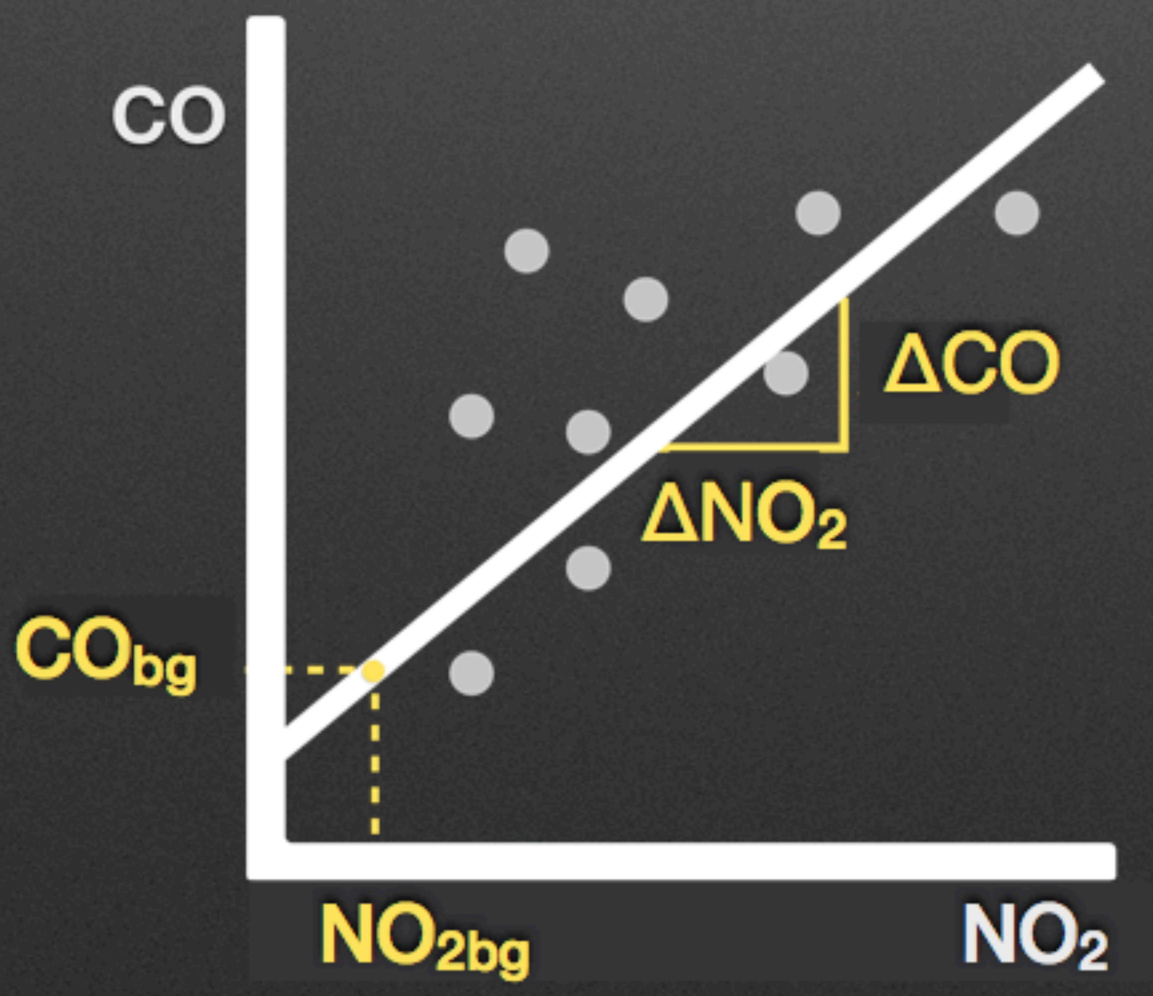
= combustion products

$$\rightarrow n_2CO_2 + n_3H_2O + n_4O_2 + n_5N_2$$

$$+ n_6CO + n_7NO + n_8NO_2 + n_9SO_2 + n_{10}C + \cdots$$

High Efficiency Combustion: High CO_2, Low CO, High NO_2
Low Temperature Combustion: High CO, Low NO_2, High OC
High Temperature Combustion: Low CO, High NO_2, High BC





Emission Ratios

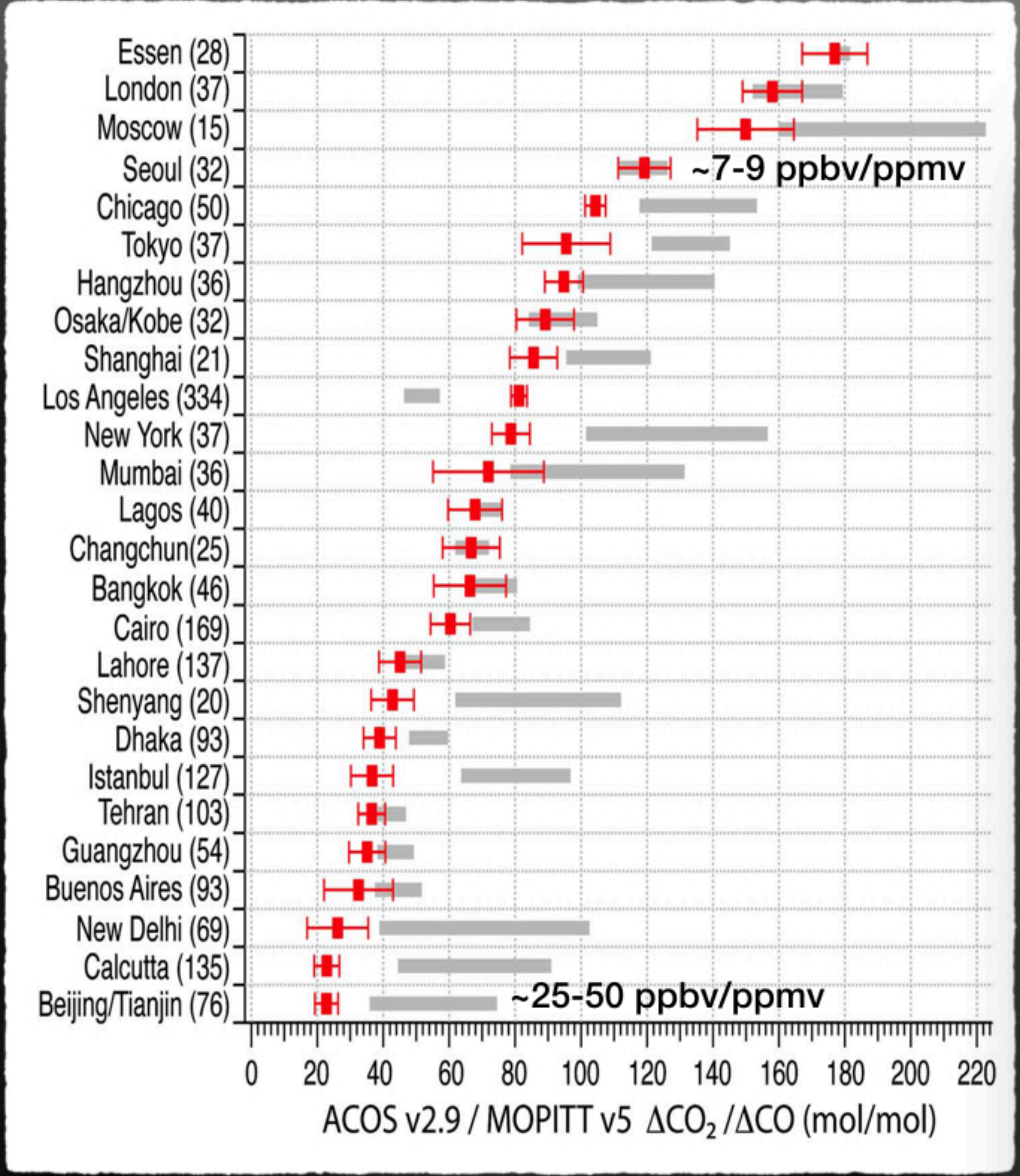
$$E^{CO}_{city} = \sum A_{sector} \times EF^{CO}_{sector} \times (1 - CE^{CO}_{sector})$$

$$E^{CO_2}_{city} = \sum A_{sector} \times EF^{CO_2}_{sector} \times (1 - CE^{CO_2}_{sector})$$

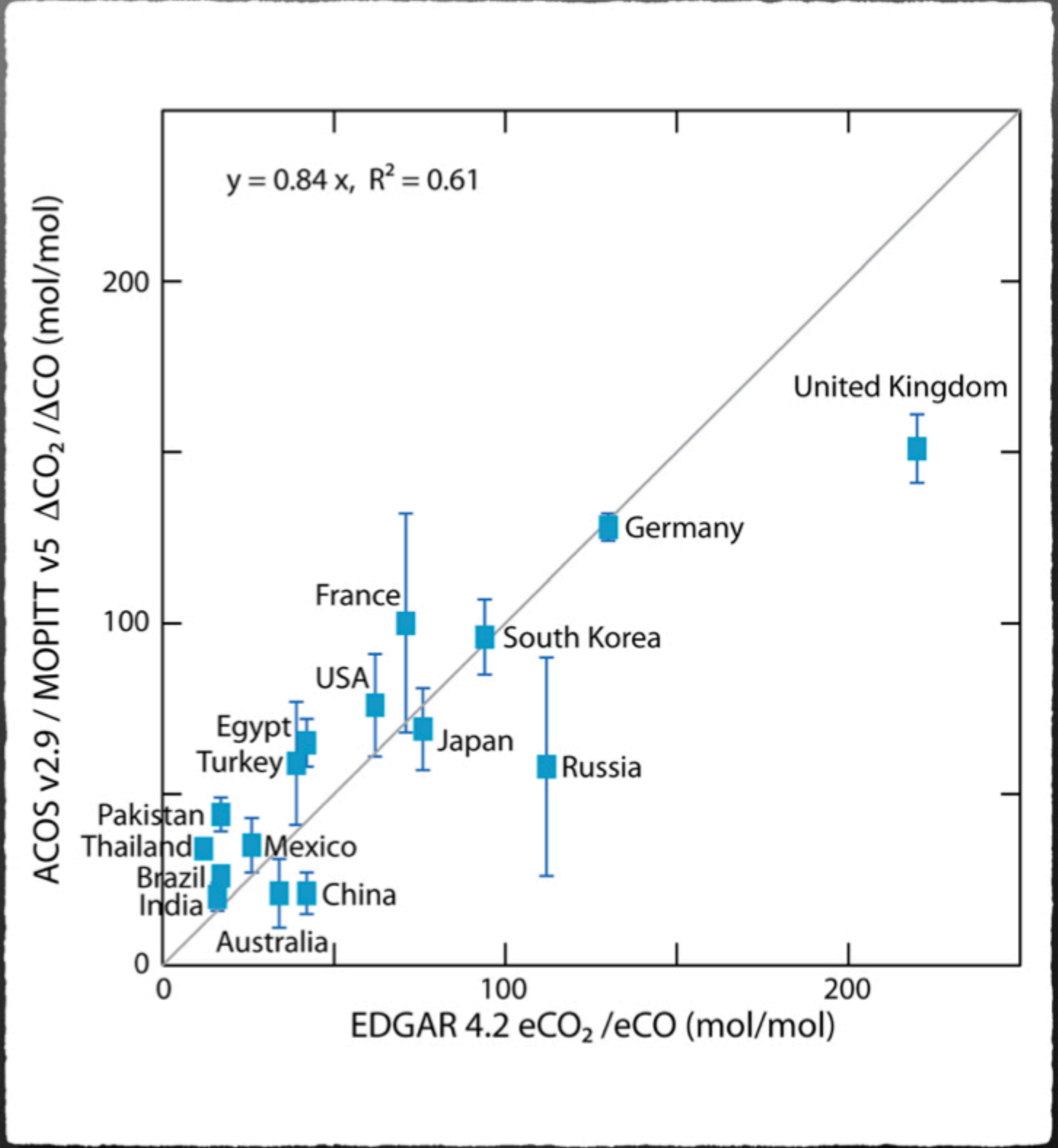
$$\left(\frac{\Delta CO}{\Delta CO_2}\right)_{city} \sim \left(\frac{E^{CO}}{E^{CO_2}}\right)_{city} = \sum \left(\frac{E^{CO_2}_{sector}}{E^{CO_2}_{total}}\right) \times \frac{EEF^{CO}_{sector}}{EEF^{CO_2}_{sector}}$$

Previous Work (Silva et al. 2013 on MOPITT XCO and GOSAT XCO_2)

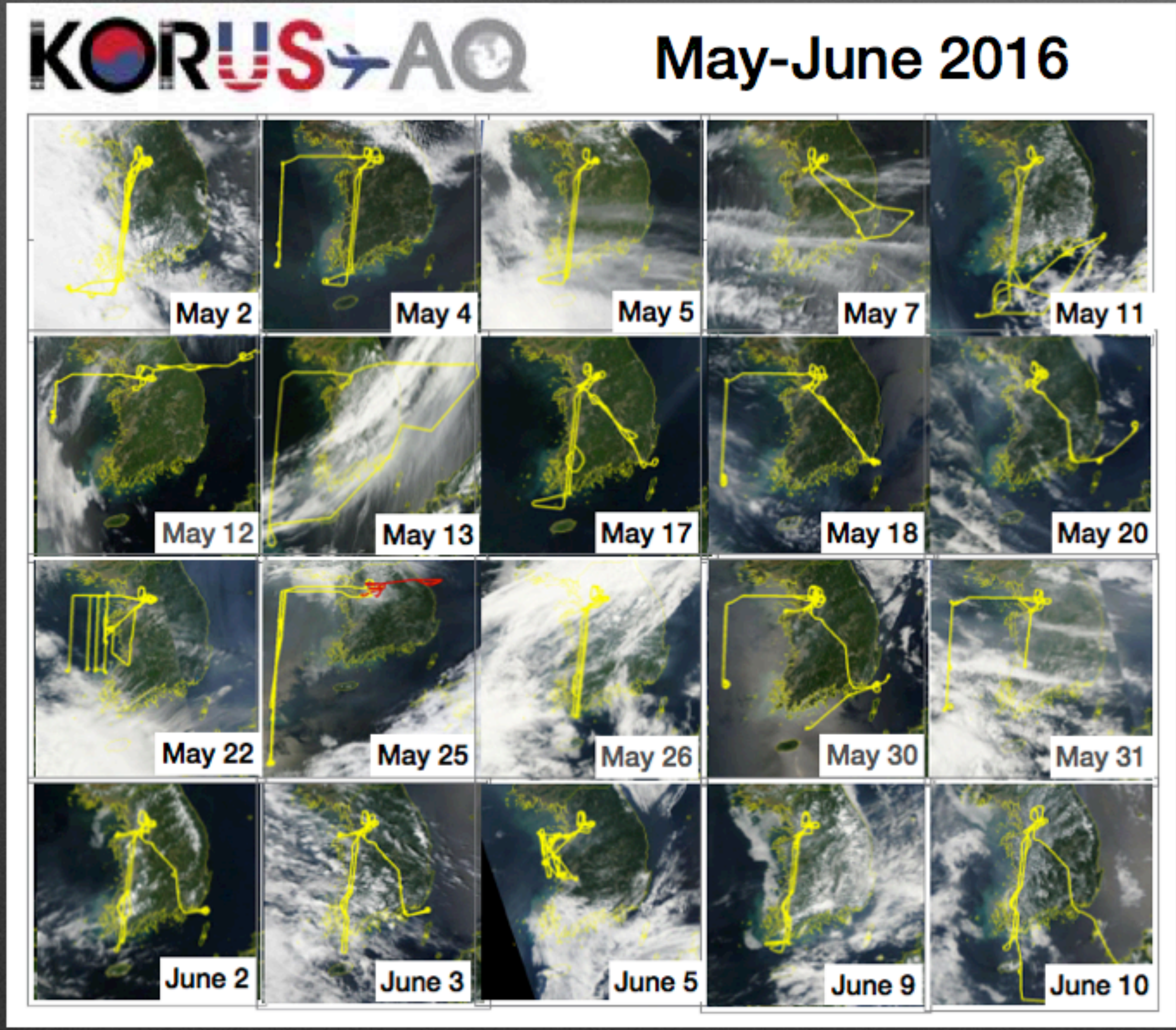
$\Delta CO_2/\Delta CO$ over Megacities



$\Delta CO_2/\Delta CO$ over Countries

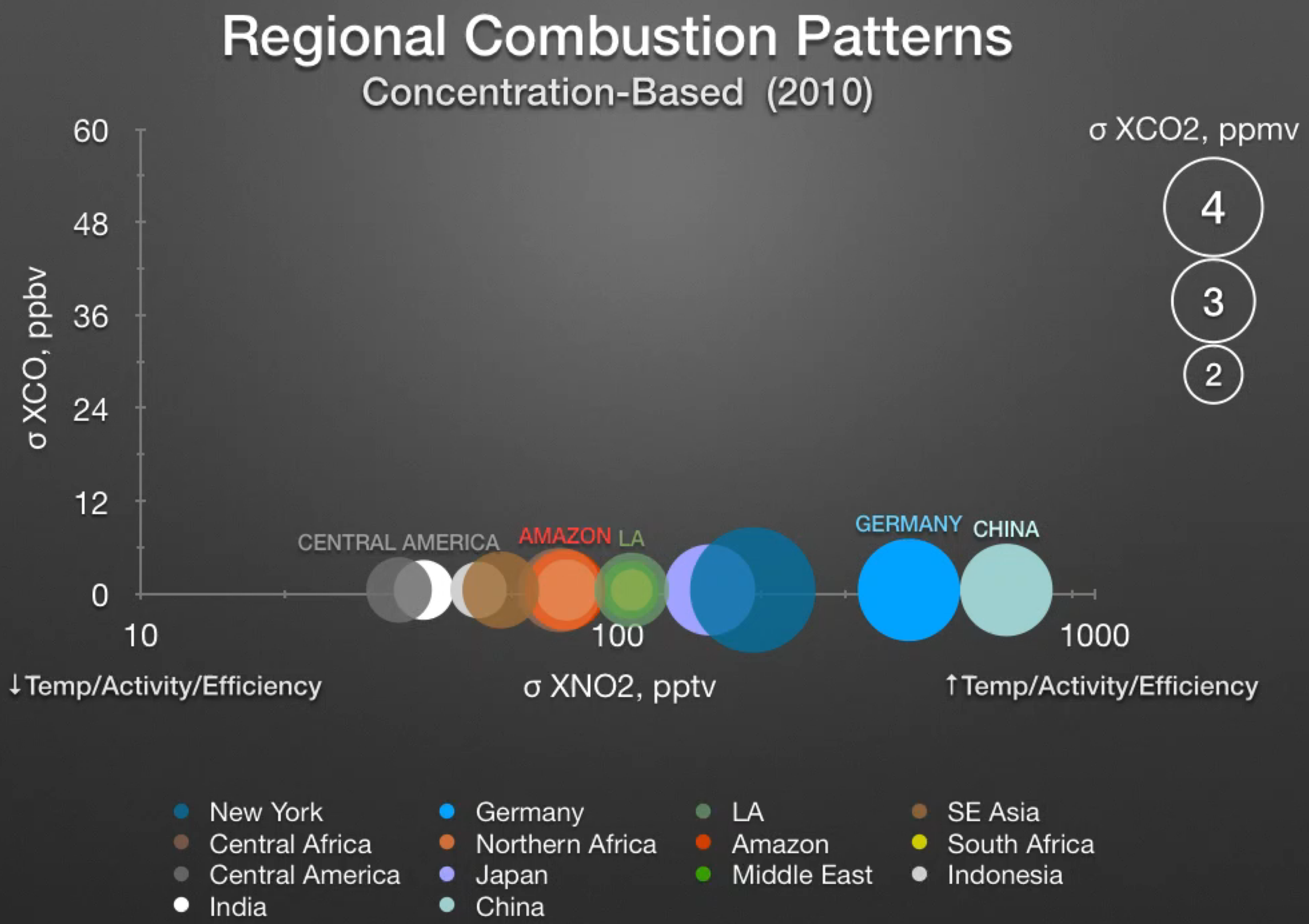


Tang et al., Evaluating High-Resolution Forecasts of Atmospheric CO and CO_2 from a Global Prediction System during KORUS-AQ Field Campaign, ACPD, 2017

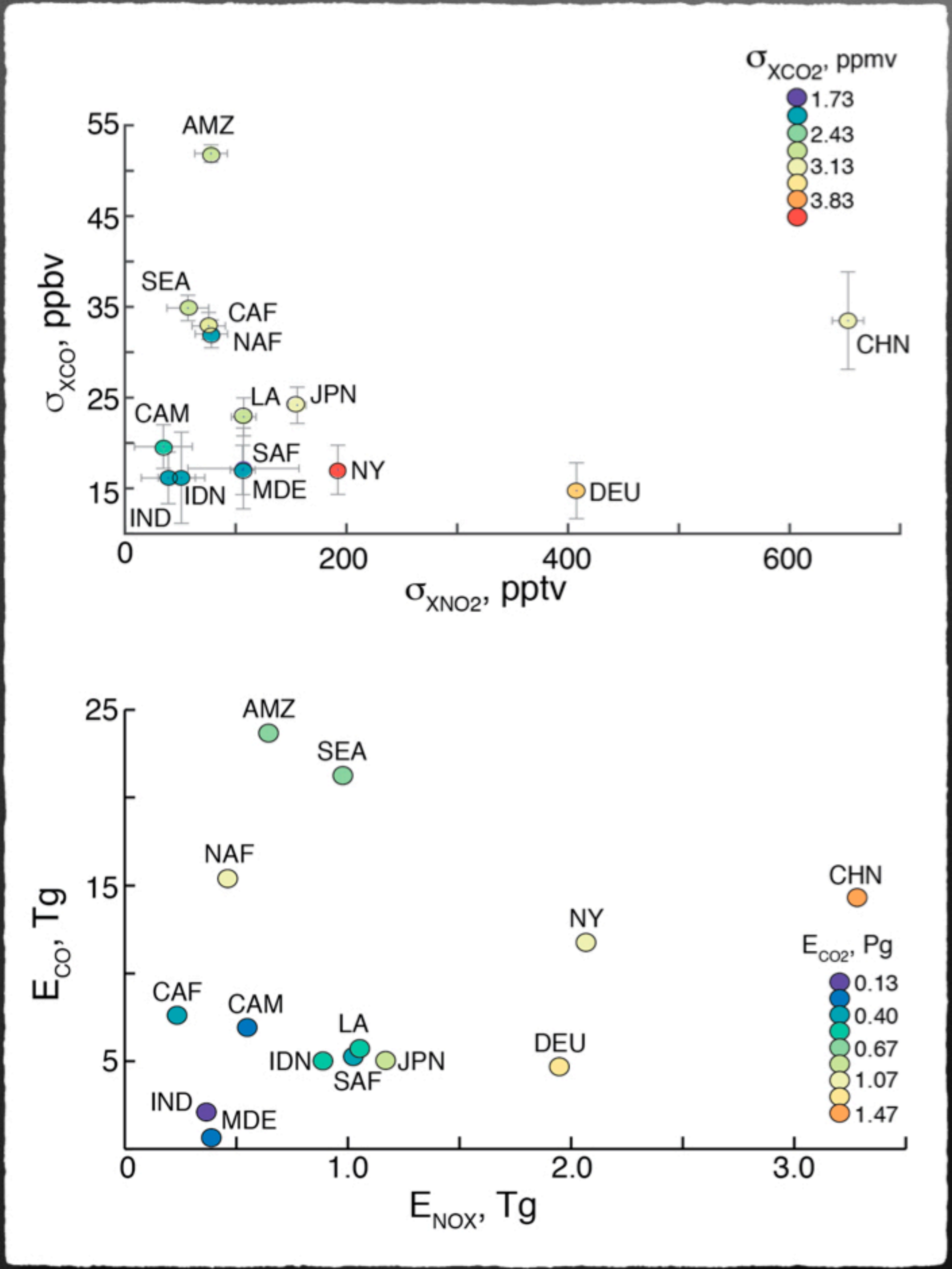


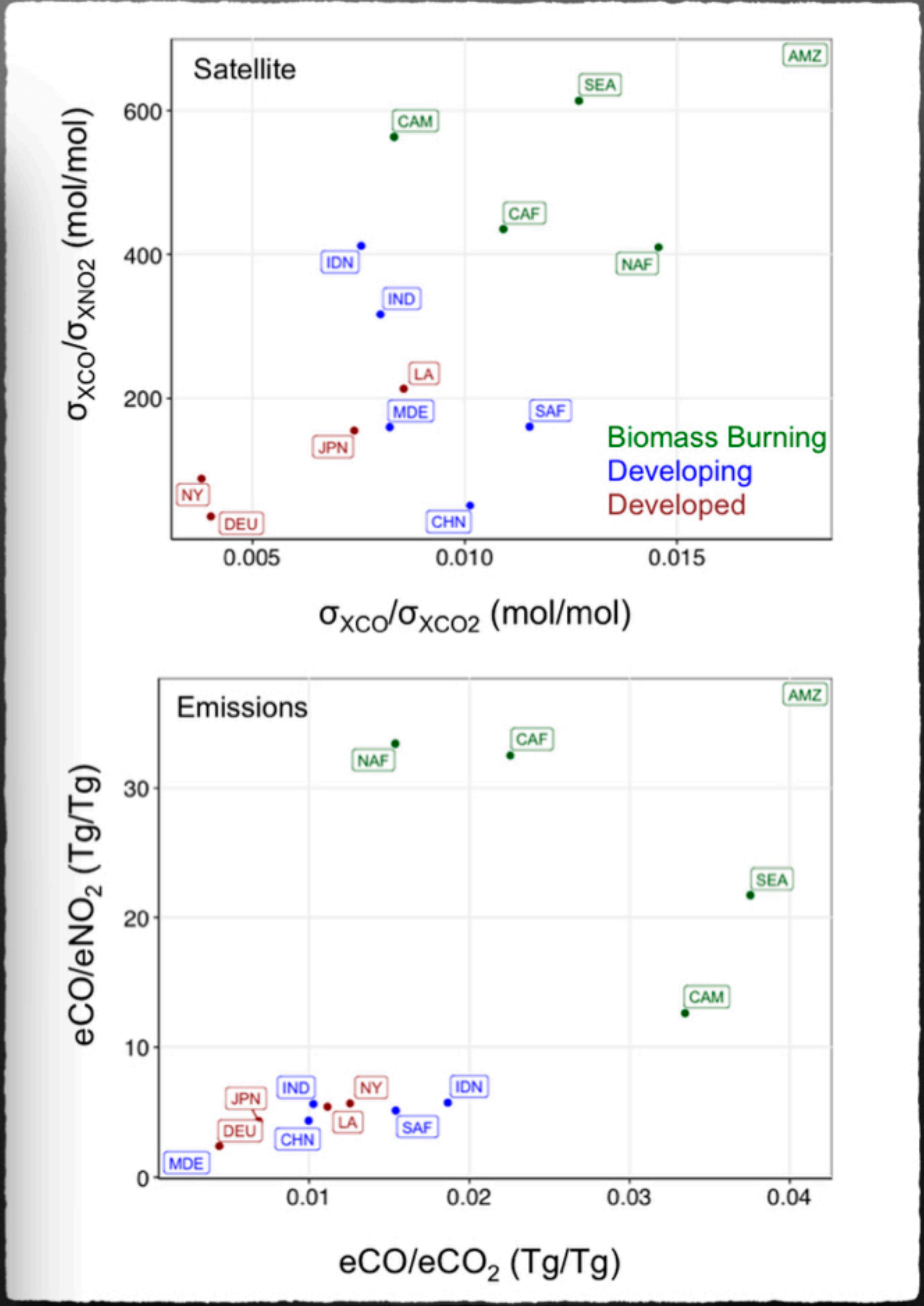
	Region	DC-8	16-km Fx	Analysis	9-km Fx+An
$\Delta CO/\Delta CO_2$	Seoul	9.1±0.5	9.9±0.3	8.2±0.5	11.6±0.6
	West Sea	28.2±0.8	30.9±1.6	30.6±1.7	32.4±1.8
$R(CO,CO_2)$	Seoul	0.78	0.94	0.77	0.78
	West Sea	0.89	0.42	0.25	0.36
$R(bCO,bCO_2)$	Seoul		0.90	0.66	0.64
	West Sea		0.80	0.82	0.82

ARIAs	20-100 ppbv/ppmv (2016)
Seoul	9 ppbv/ppmv (2010)
Pasadena	11 ppbv/ppmv (2008)
SoCAB	14 ppbv/ppmv (2010)
TRACE-P (2001)	50-100 ppbv/ppmv (China) 12-17 ppbv/ppmv (Japan)
near Beijing	22 ppbv/ppmv (2008) 34-42 ppbv/ppmv (2005)
Tae-Ahn Peninsula	13 ppbv/ppmv (2009/2010)


Regional Combustion Patterns
Concentration-Based (2010)
σ XCO2, ppmv
4
3
2
σ XCO, ppbv
60
48
36
24
12
0
10
100
1000
CENTRAL AMERICA
AMAZON
LA
GERMANY
CHINA
↓Temp/Activity/Efficiency
σ XNO2, pptv
↑Temp/Activity/Efficiency
New York
Central Africa
Central America
India
Germany
Northern Africa
Japan
China
LA
Amazon
Middle East
SE Asia
South Africa
Indonesia

Silva and Arellano, Characterizing Regional-Combustion Using Satellite Retrievals of CO, NO_2 and CO_2, Remote Sensing, 2017





Can satellite data of combustion products (CO, NOx, aerosols) provide constraints on trends in megacity combustion characteristics (complementary to ground-based & airborne measurements)?

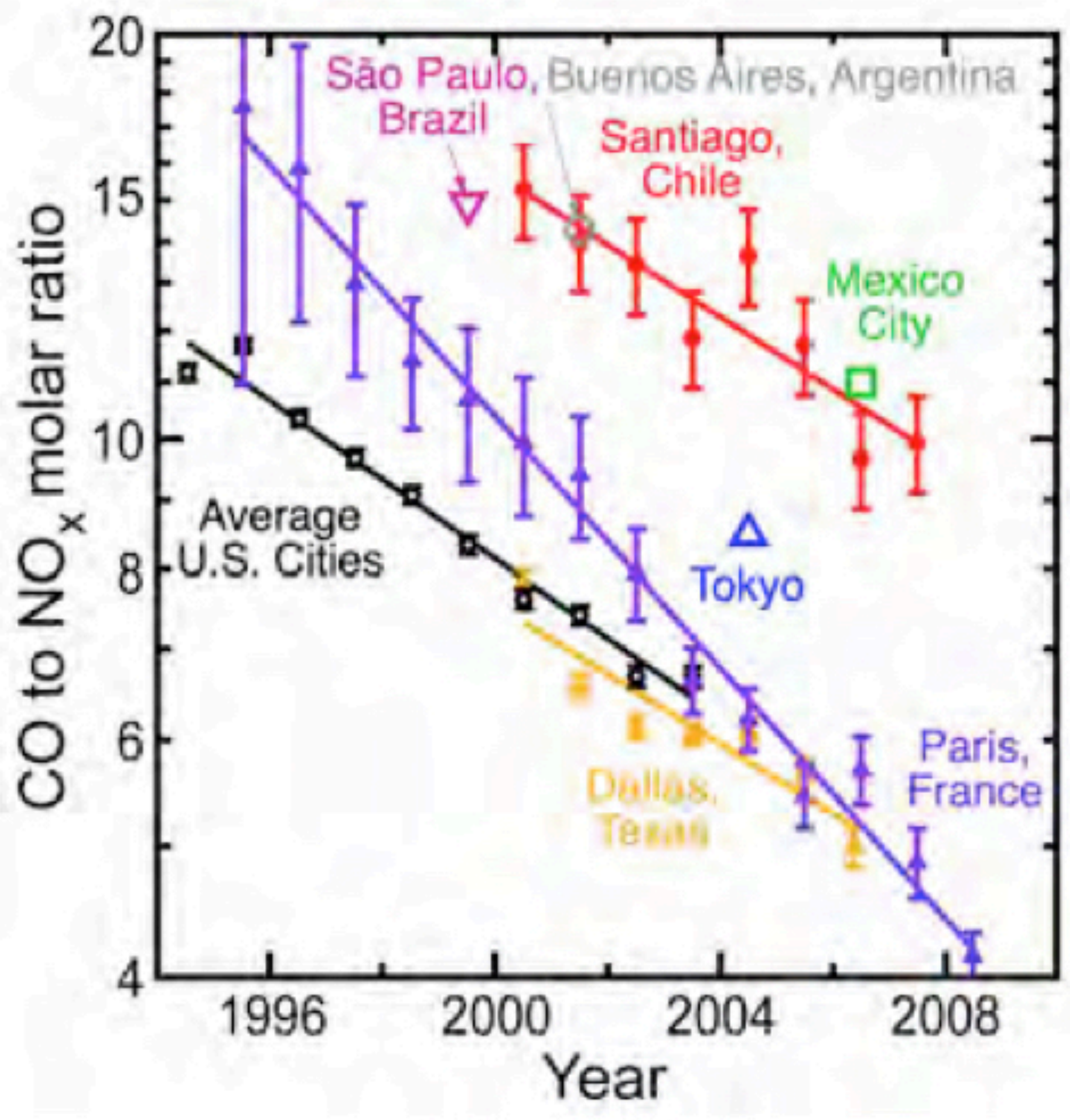
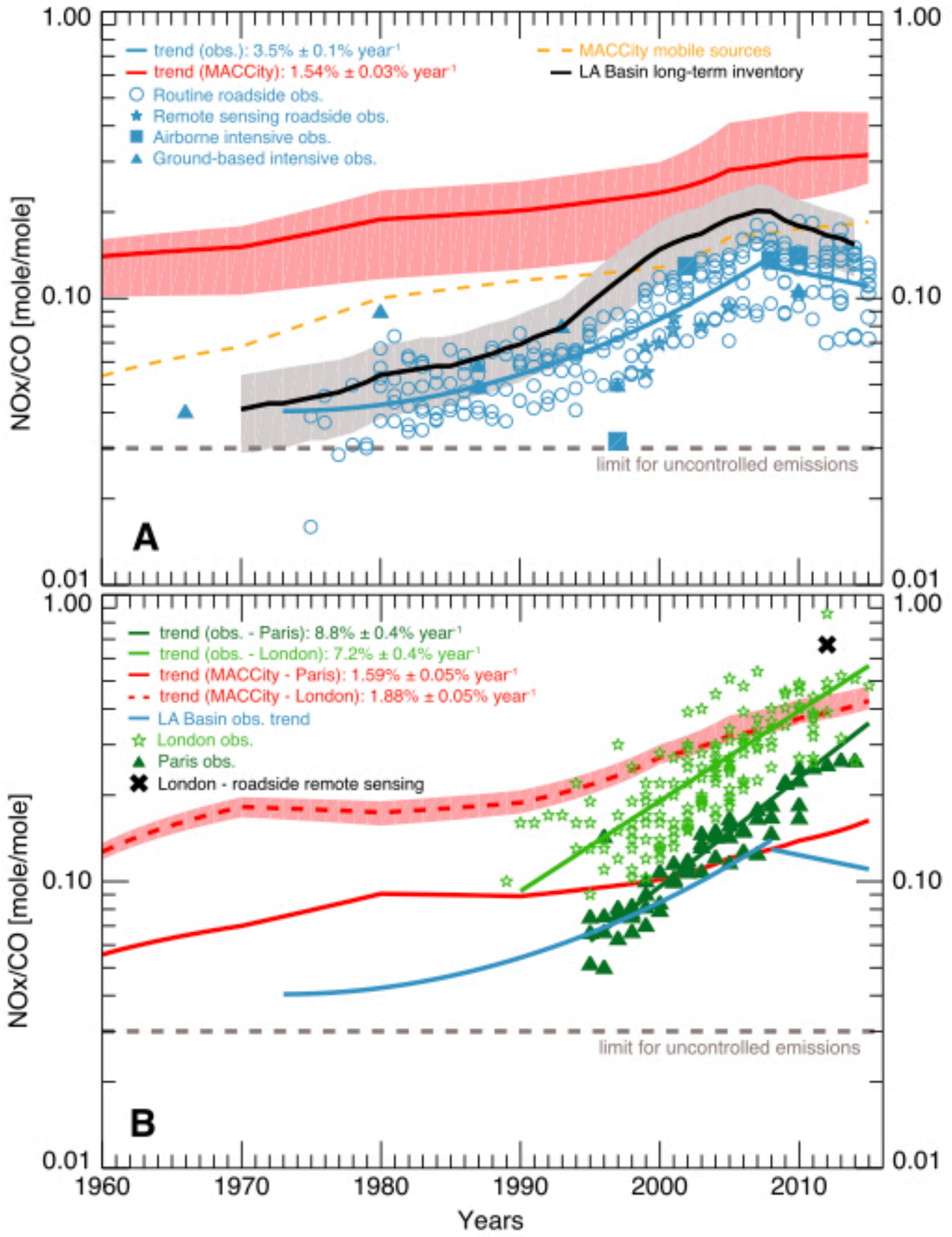


Fig. 9, Ch. 8, D. Parrish (lead)
WMO/IGAC Impacts of Megacities on Air Pollution and Climate, (2012)

Geophysical Research Letters

Analysis of long-term observations of NO_x and CO in megacities and application to constraining emissions inventories

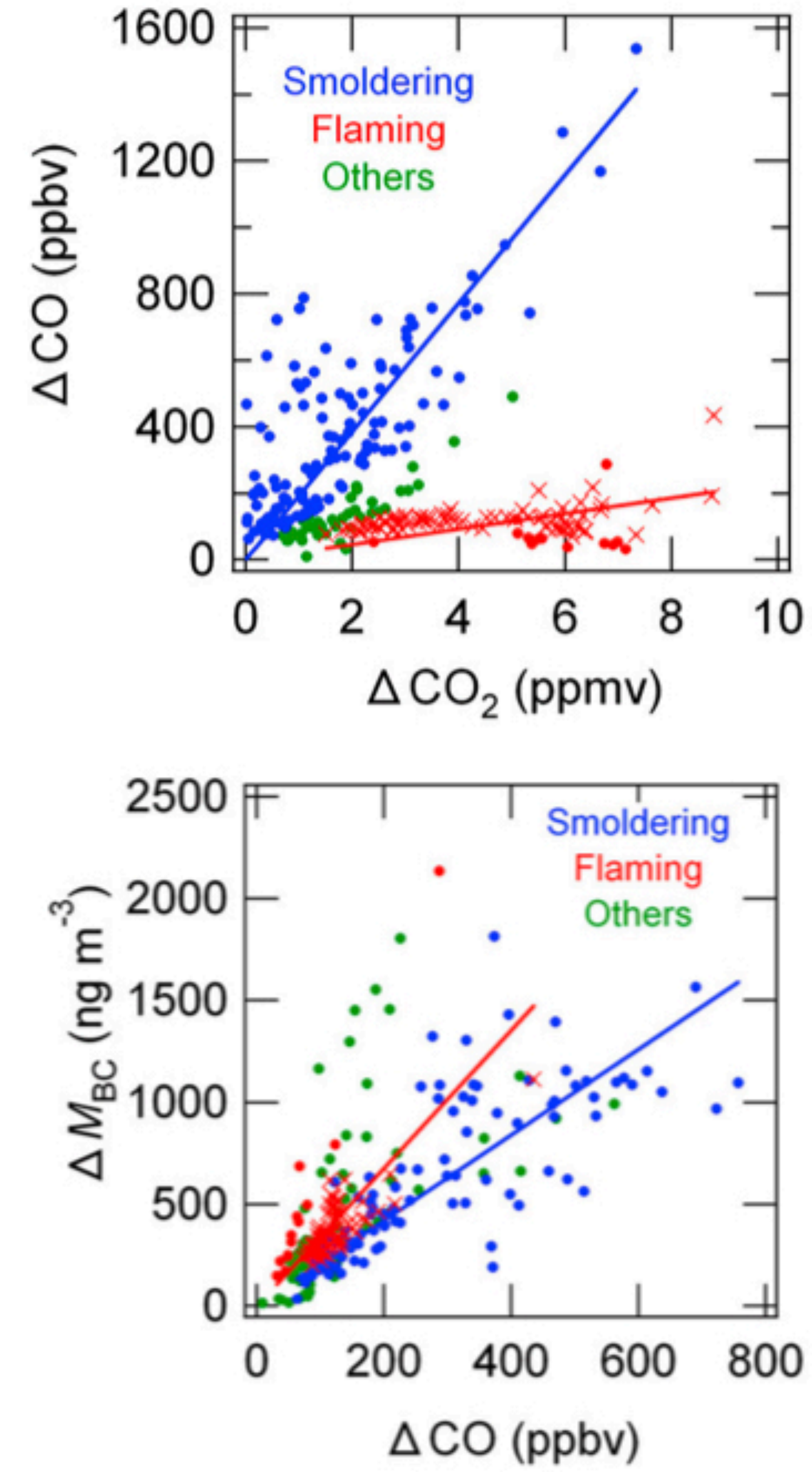
Birgit Hassler[1,2], Brian C. McDonald[1,2], Gregory J. Frost[2], Agnes Borbon[3], David C. Carslaw[4], Kevin Civerolo[5], Claire Granier[1,2,6], Paul S. Monks[7], Sarah Monks[1,2], David D. Parrish[1,2], Ilana B. Pollack[1,2,8], Karen H. Rosenlof[2], Thomas B. Ryerson[2], Erika von Schneidemesser[9], and Michael Trainer[2]



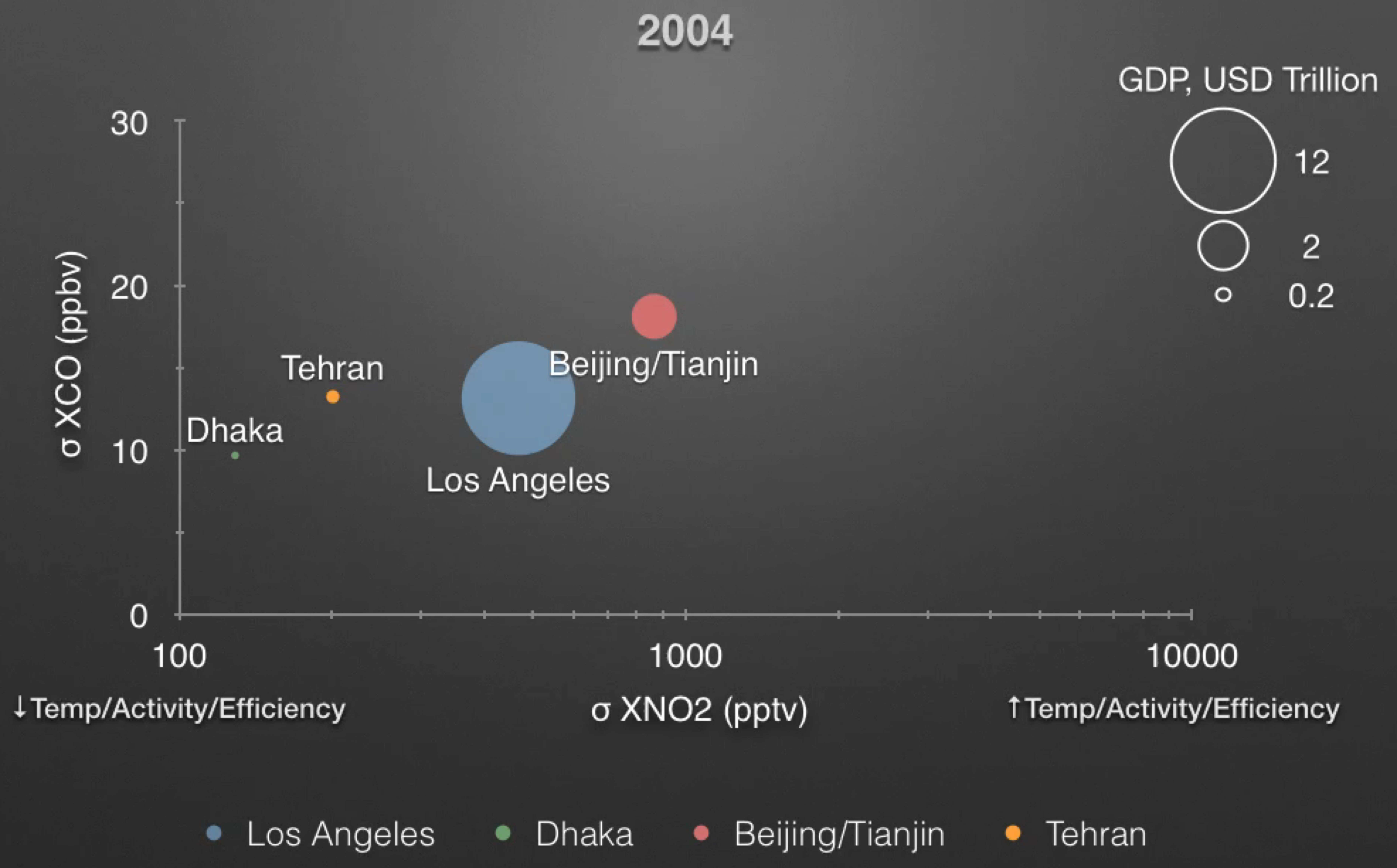
JOURNAL OF GEOPHYSICAL RESEARCH
doi:10.1029/2010JD015152

Emissions of black carbon, organic, and inorganic aerosols from biomass burning in North America and Asia in 2008

Y. Kondo,[1] H. Matsui,[1] N. Moteki,[1] L. Sahu,[1,2] N. Takegawa,[1] M. Kajino,[1,3] Y. Zhao,[4] M. J. Cubison,[5] J. L. Jimenez,[5] S. Vay,[6] G. S. Diskin,[6] B. Anderson,[6] A. Wisthaler,[7] T. Mikoviny,[7] H. E. Fuelberg,[8] D. R. Blake,[9] G. Huey,[10] A. J. Weinheimer,[11] D. J. Knapp,[11] and W. H. Brune[12]



Megacity Combustion Trends



Opportunity to Monitor From Space Anthropogenic Combustion Pathways

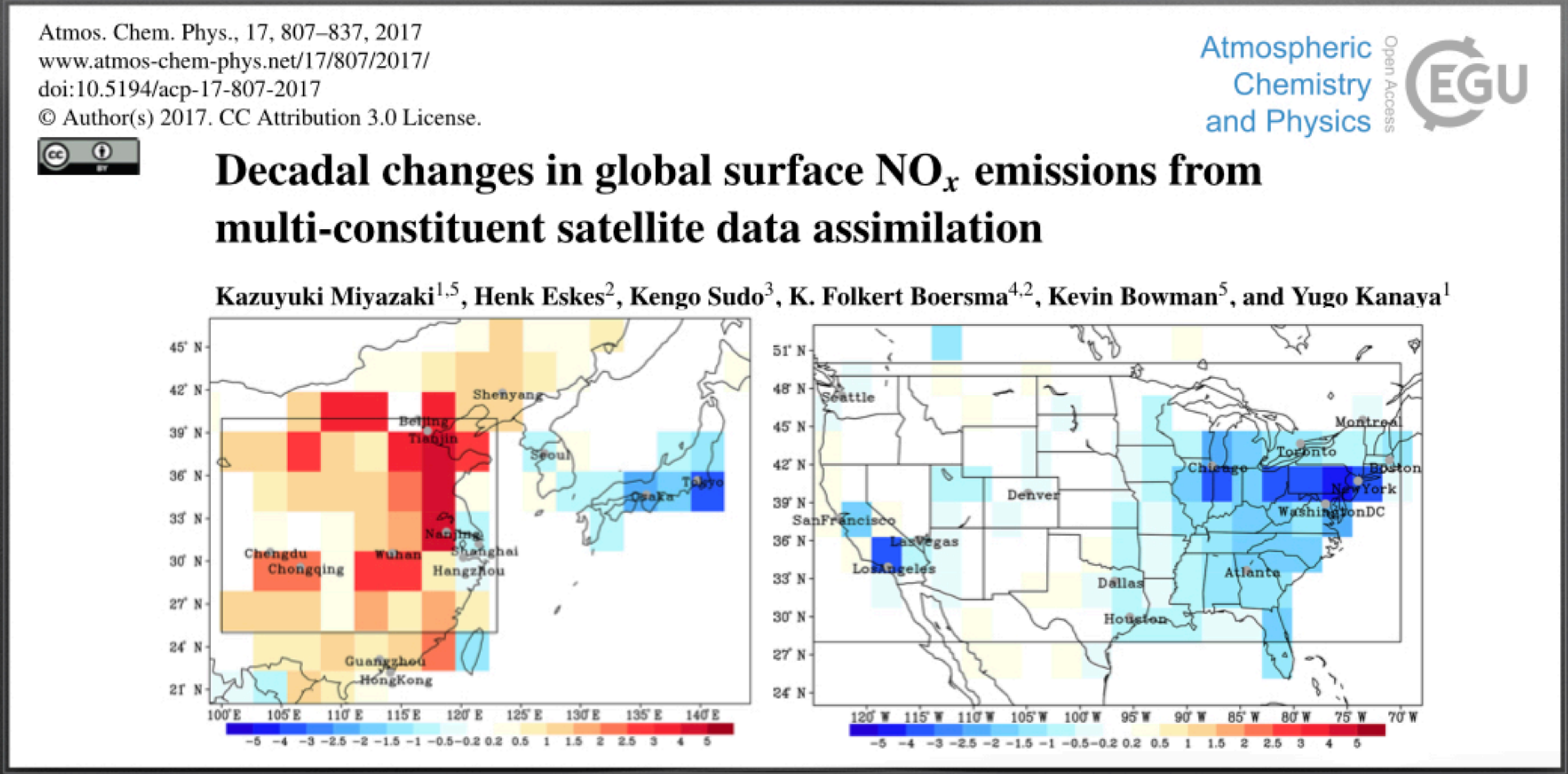
SATELLITE DATA (2005-2016)
MOPITT v6 TIR/NIR total CO column
OMI Domino v2 trop NO_2 column
OMI NASA PCA v3 PBL SO_2 column

REGRESSION & TIME SERIES ANALYSIS
Reduced Major Axis Regression
Seasonal Trend decomposition with LOESS
Robust Regression Using Iteratively Reweighted Least-Squares

Regressions were conducted with respect to NO_2 across 2x2 degree spatial extent centered within each megacity. Only positive correlations are included in the analysis.

Tang et al. (2018), in revision

Opportunities to confront models and analysis



Atmos. Chem. Phys., 17, 807–837, 2017
www.atmos-chem-phys.net/17/807/2017/
doi:10.5194/acp-17-807-2017

Atmospheric Chemistry and Physics
Open Access
EGU

Decadal changes in global surface NO_x emissions from multi-constituent satellite data assimilation

Kazuyuki Miyazaki[1,5], Henk Eskes[2], Kengo Sudo[3], K. Folkert Boersma[4,2], Kevin Bowman[5], and Yugo Kanaya[1]

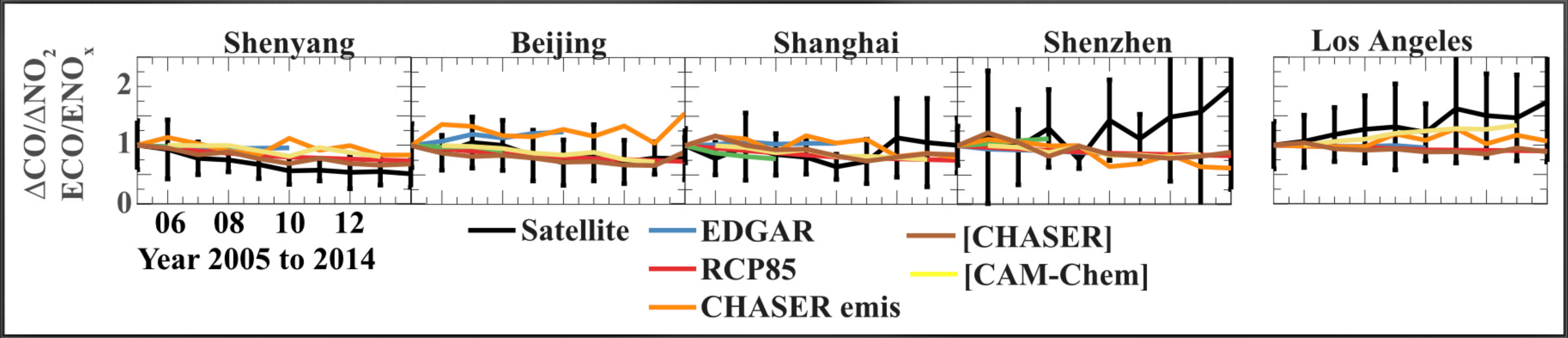
Assess consistency:

$$x^a = x^f + P^f H^T \left(H P^f H^T + R\right)^{-1} \left(y - Hx^f\right)$$

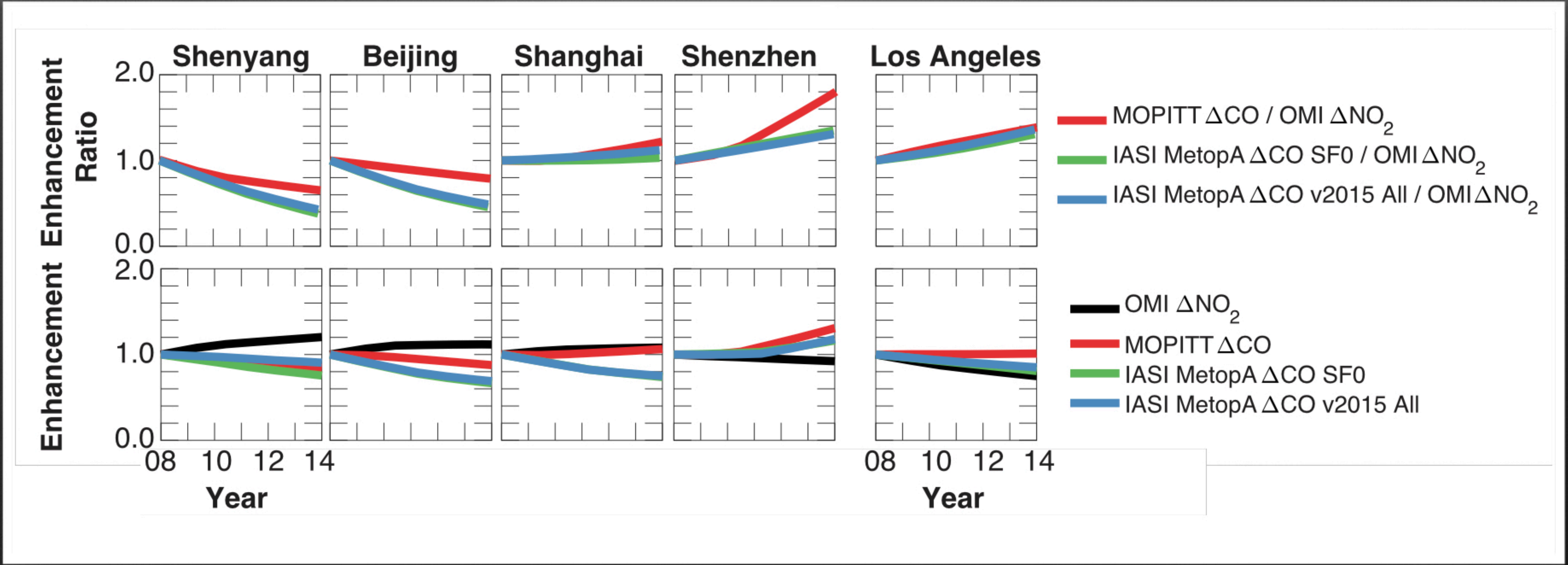
$$x^a - x^f = P^f H^T \left(H P^f H^T + R\right)^{-1} (\Delta y)$$

$$\Delta x = \left({}^{\Delta x}/_{\Delta y}\right) \left(H P^f H^T\right) \left(H P^f H^T + R\right)^{-1} (\Delta y)$$

Some inconsistencies exist between model or analysis-derived versus observed trends

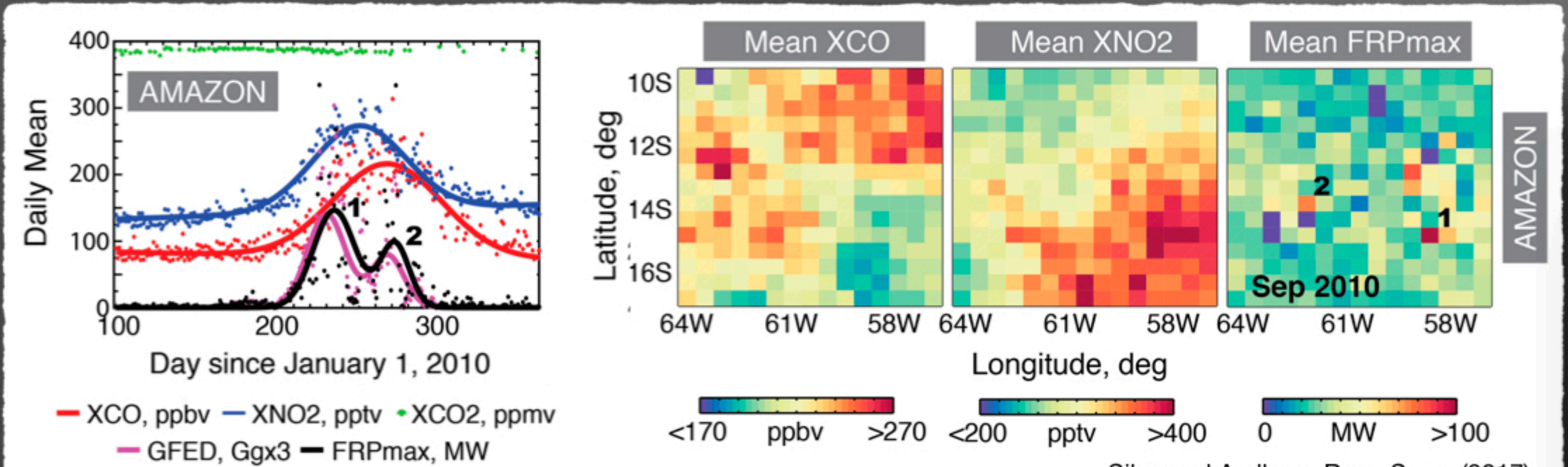


These findings are consistent in terms of pattern across cities with IASI products

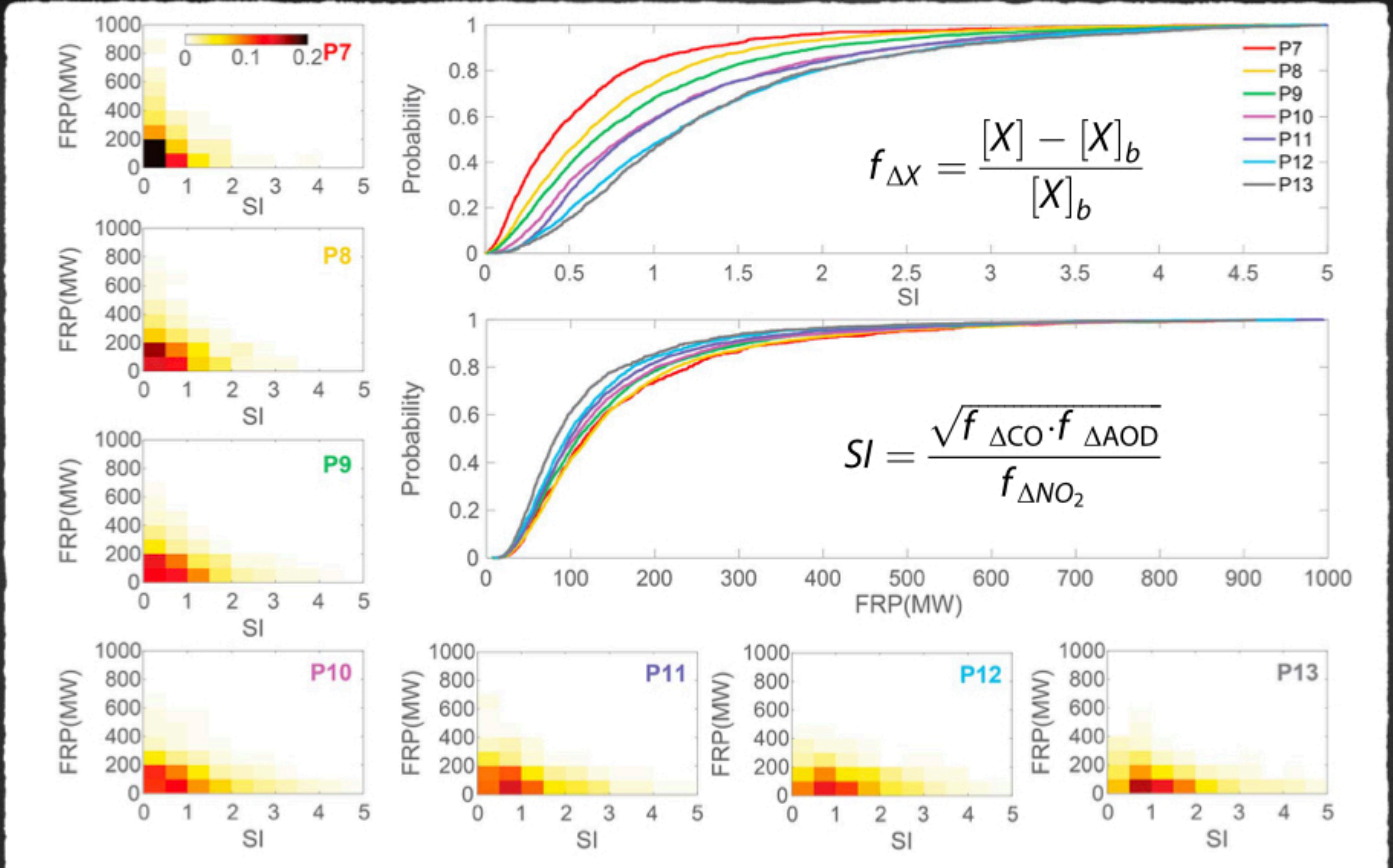


… with patterns driven by differences in the rate of change of NO_2 and CO across the decade

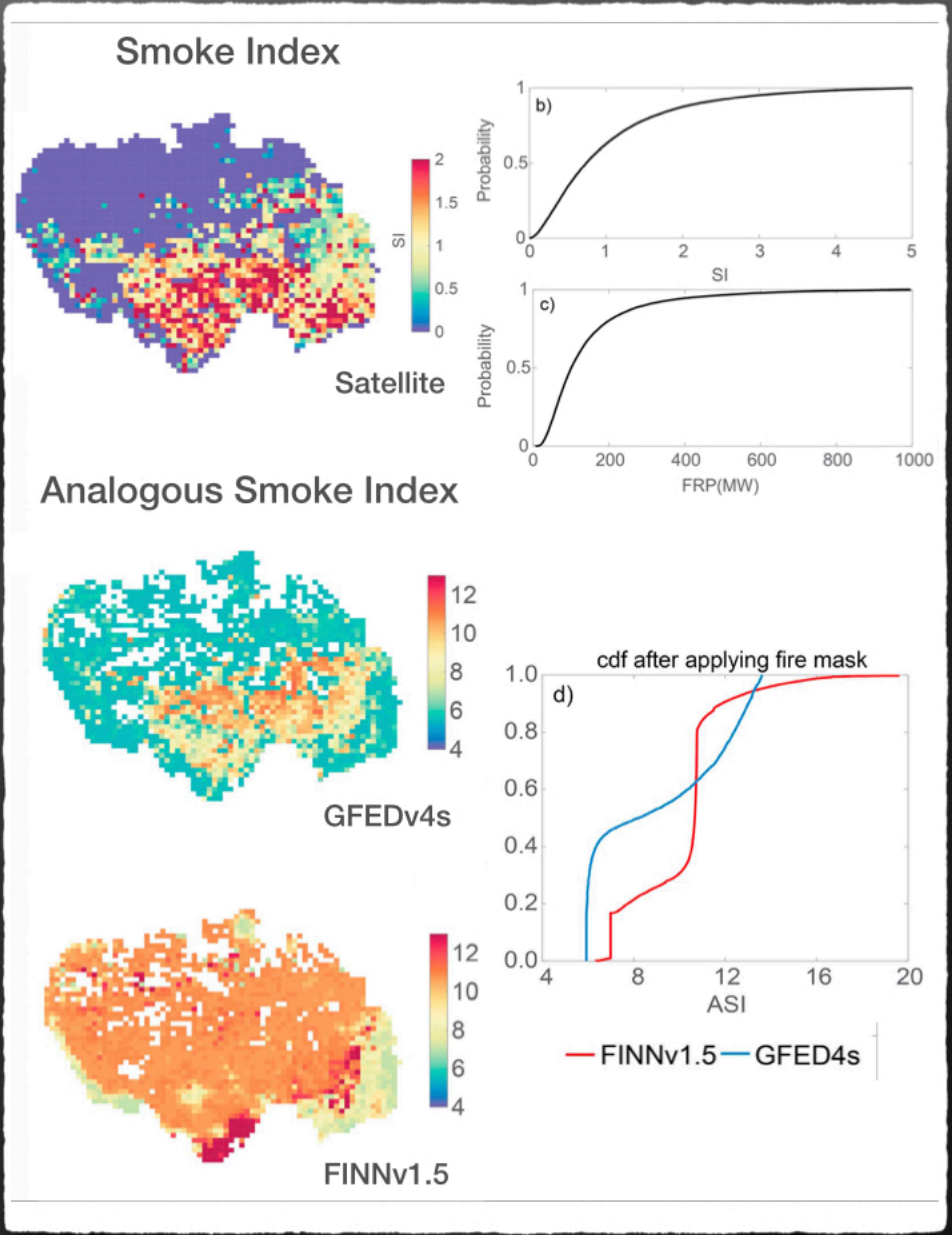
Opportunity to Distinguish Flaming and Smoldering Fire Phases



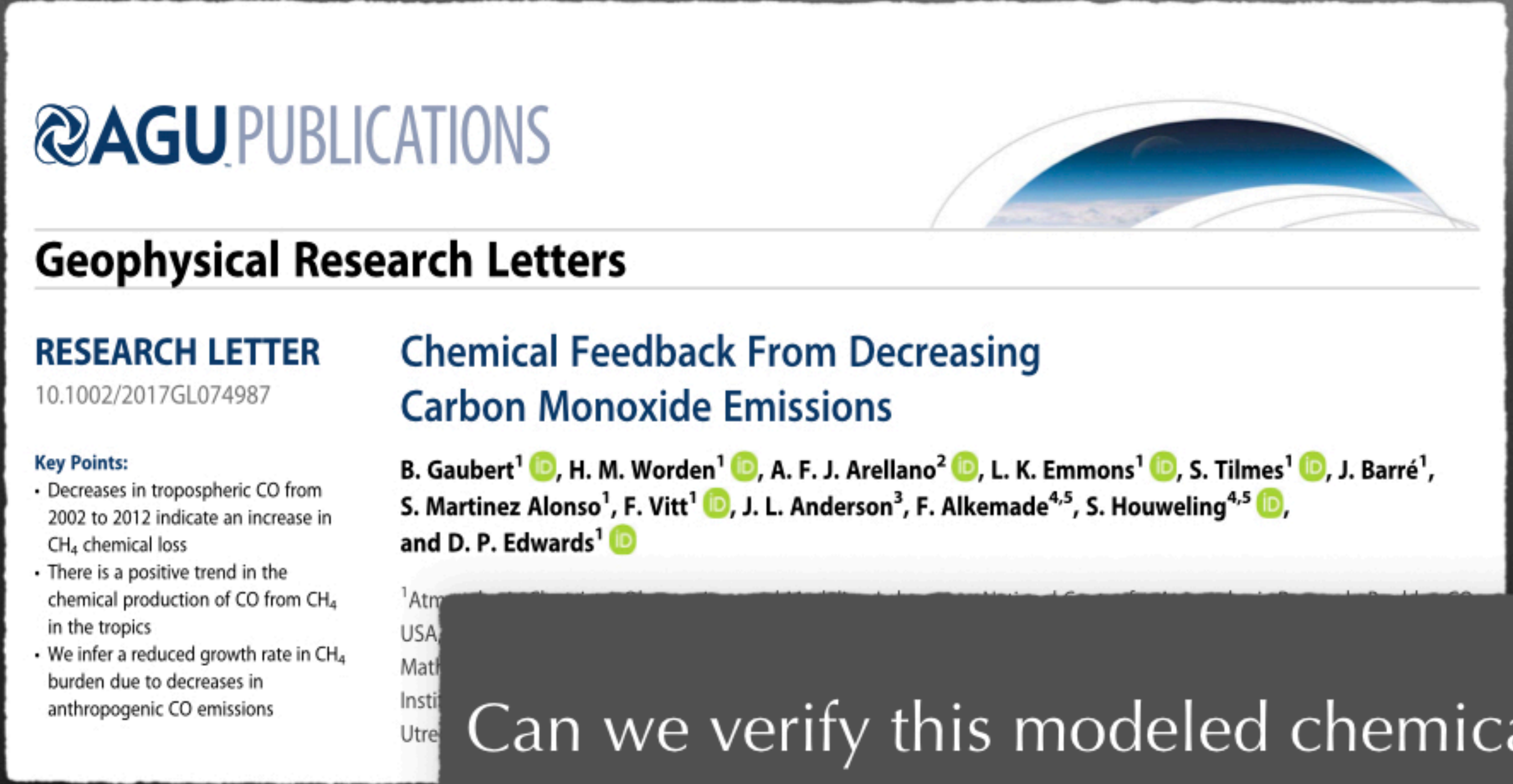
Silva and Arellano, Rem. Sens, (2017)



Tang and Arellano, JGR,



Top-down Constraints On Other Species Chemically Coupled with CO



AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER

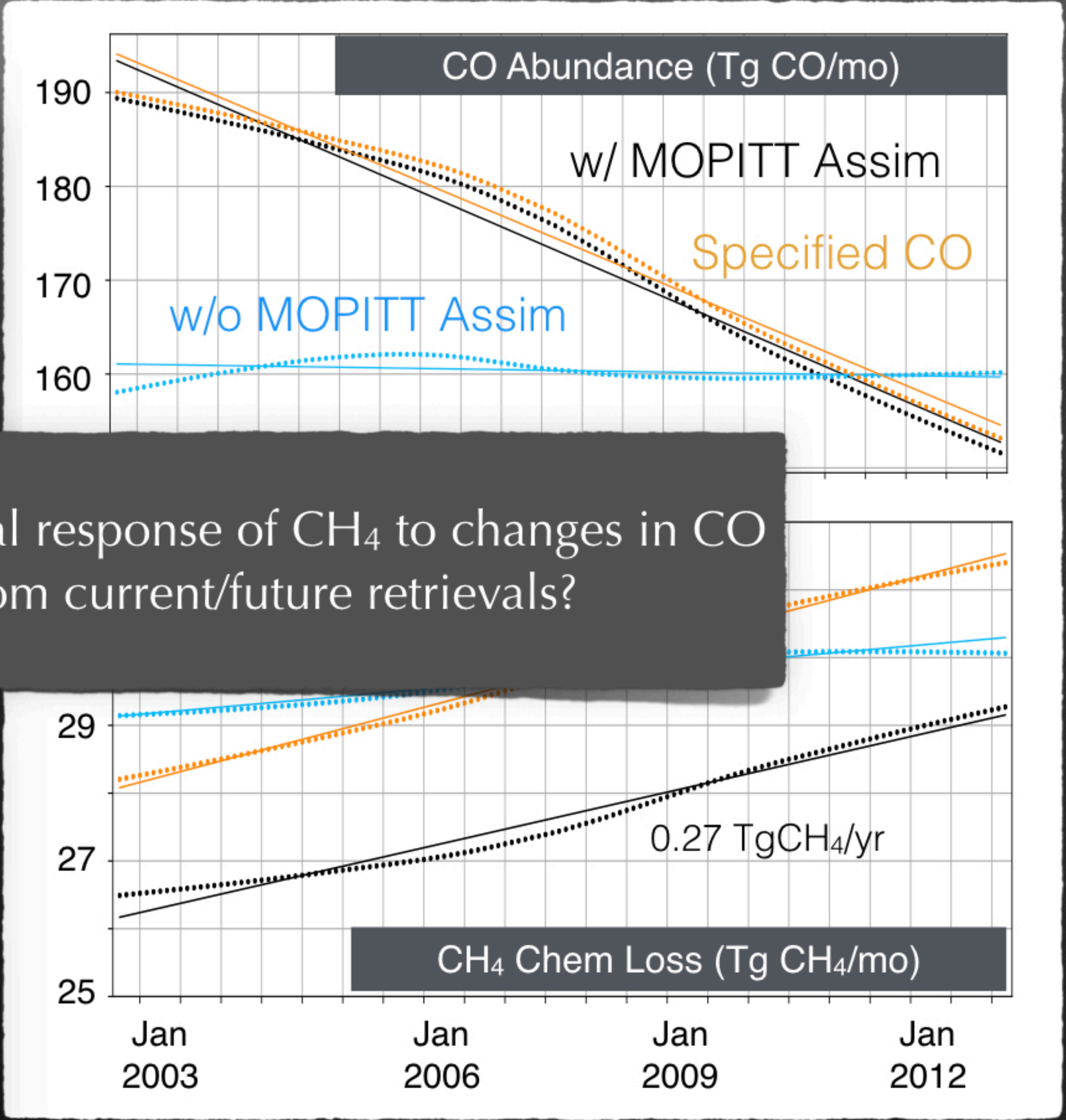
10.1002/2017GL074987

Chemical Feedback From Decreasing Carbon Monoxide Emissions

B. Gaubert[1], H. M. Worden[1], A. F. J. Arellano[2], L. K. Emmons[1], S. Tilmes[1], J. Barré[1], S. Martinez Alonso[1], F. Vitt[1], J. L. Anderson[3], F. Alkemade[4,5], S. Houweling[4,5], and D. P. Edwards[1]

Key Points:

- Decreases in tropospheric CO from 2002 to 2012 indicate an increase in CH_4 chemical loss
- There is a positive trend in the chemical production of CO from CH_4 in the tropics
- We infer a reduced growth rate in CH_4 burden due to decreases in anthropogenic CO emissions



Can we verify this modeled chemical response of CH_4 to changes in CO by observed $\Delta CH_4/\Delta CO$ from current/future retrievals?

$$\frac{d[CH_4]}{dt} = S_{CH_4} - R1; R1 = k_1[CH_4][OH]$$

$$\frac{d[CO]}{dt} = S_{CO} + R1 - R2; R2 = k_2[CO][OH]$$

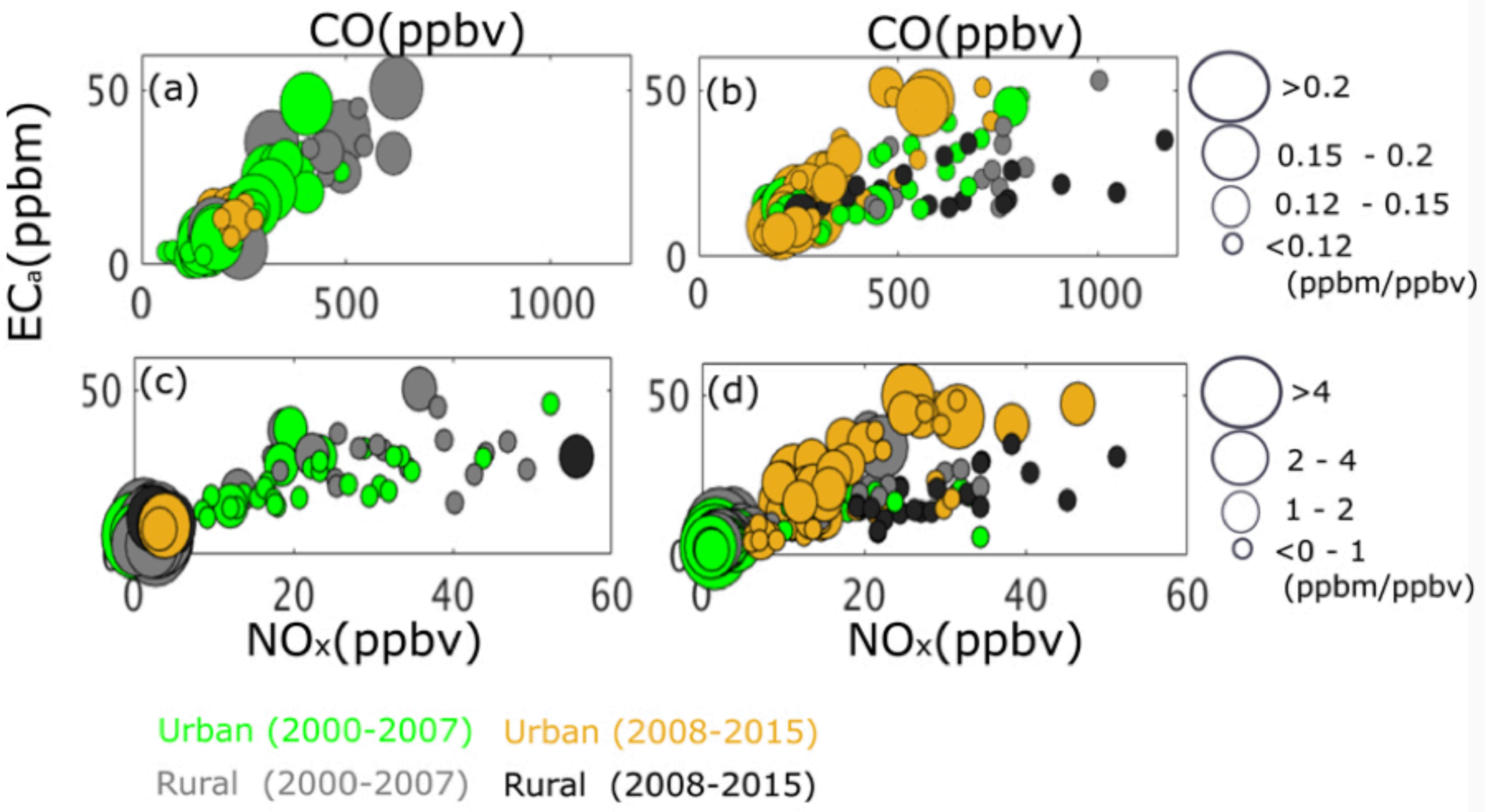
$$\frac{d[OH]}{dt} = S_{OH} - R1 - R2 - R3; R3 = k_3[X][OH]$$

Top-down constraints on other species that can be associated with CO

Environmental Science & Technology
Article
pubs.acs.org/est

Spatial and Temporal Variations in Characteristic Ratios of Elemental Carbon to Carbon Monoxide and Nitrogen Oxides across the United States

Aishwarya Raman* and Avelino F. Arellano, Jr.



Emerging Patterns of O_3 Sensitivity to CO over Megacities Derived from IASI Retrievals (in preparation)

9-year Linear Trend (% per year)

	Beijing	Shanghai	Shenzhen	Los Angeles
ΔO_3	-2.63±1.18	-0.72±0.17	1.14±1.89	-0.47±0.17
ΔCO	-4.85±4.45	-0.60±0.90	-0.98±0.58	-2.68±6.27
$\Delta O_3/\Delta CO$	0.58±2.15	-0.62±0.67	0.38±0.42	2.69±4.46

Some Thoughts

1) There is utility in multi-species analysis of satellite retrievals on atmospheric composition, especially from combustion-related constituents over megacities and fire regions (information on sectoral spatiotemporal distribution of emissions and consistency)

2) As these are obviously proof-of-concepts, the value has yet to be quantified through multi-species assimilation/inversions.

3) An OSSE activity towards bringing these pieces together would be an important first step to further demonstrate its value. Issues with regards to collocation, representativeness, retrieval sensitivities & errors can be addressed along with newer satellite retrievals.

4) In conjunction, validation with airborne and ground-based measurements is absolutely needed.

5) Confronting model simulations, forecast, and analysis with multi-species constraints may be the way to go in ensuring consistency in our estimates.

6) Such proposed OSSE activity has synergies with WMO/Integrated Global Greenhouse Gas Information System (IG3IS) and IGAC/Analysis of eMIssions usinG Observations (AMIGO)