Improving the Understanding of Emissions

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Outline

- Motivation for understanding emissions
- Challenges with current emissions knowledge
- Global Emissions InitiAtive (GEIA)
- Top-down emissions approaches & case studies
- Summary and future directions

Acknowledgements

Thanks to Claire Granier, Paulette Middleton, Leonor Tarrasón, Jean-François Lamarque, Steven Smith, Terry Keating, David Fahey, Megan Melamed, David Parrish, Owen Cooper, Jennifer Logan, David Stevenson, Paul Young, Cathy Liousse, Qiang Zhang, Jeff Peischl, Si-Wan Kim, Jerome Brioude, Ilana Pollack, Carsten Warneke, Gabrielle Pétron, Anna Karion, and many other colleagues who carried out the research and contributed to this presentation.

Motivations for Understanding Emissions

Actions and decisions about the atmosphere focus on emissions.

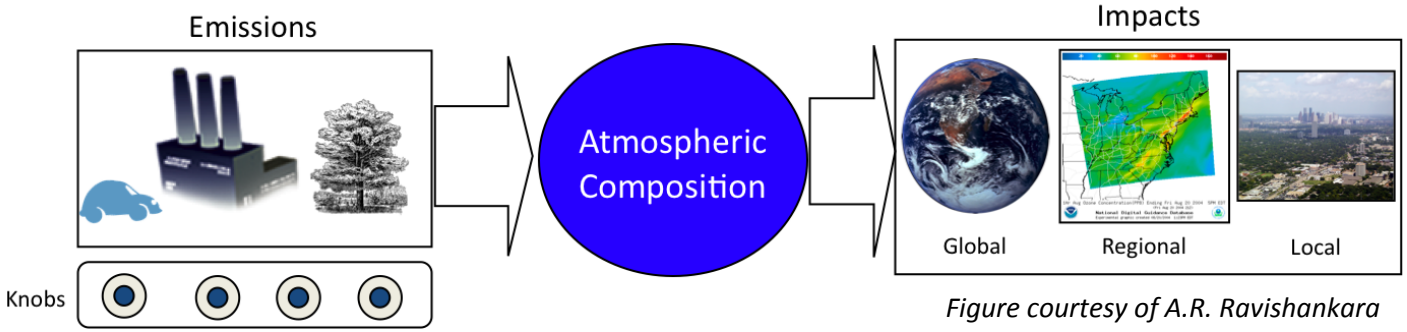


Figure courtesy of A.R. Ravishankara

Accurate emissions information is needed for many purposes.

- *Quantify and predict*
- *Understand changes*
- *Make choices*
- *Evaluate mitigation*
- *Demonstrate compliance*

This is the Century of Accountability.
David Fahey

Societal development and scientific innovation result in new challenges in emissions understanding.

- *Dynamic economies*
- *Changing demographics*
- *Evolving land use*
- *Emerging energy sources*
- *New measurements*
- *Better process descriptions*
- *Improved models*

Stakeholders and decision-makers have common requirements for emissions information, but challenges with emissions information persist.

- *Transparency*
- *Consistency*
- *Accuracy*
- *Timeliness*
- *Uncertainty*
- *Complexity*
- *Development*
- *Analysis*
- *Communication*

G. J. Frost et al., Atmos. Environ., 2012 & 2013

Many Needs for Emissions Information

- **Emissions information addresses multiple mandates & serves many uses**
- **Scientific research one of many consumers of emissions information**

Research
Forecasting & analysis
Air quality
Long-range transport
Climate change

Economics
Emissions trading
Control implementation

Regulation
Atmospheric modeling
Human exposure
Permitting & compliance
Standards attainment
Public reporting

Diplomacy
Pollution conventions
Data sharing
Multinational agreements
Assessments

Bottom-Up Inventory Methods

Total mass of compound X emitted

$$E_X = \sum_S [EF_{X,S} \bullet A_S \bullet (1 - CE_{X,S})]$$

Sum up all sources S

Emissions factor = mass of compound X emitted by source S per unit activity

Activity of source S, e.g., amount of fuel burned

Effectiveness of control measures for compound X at source S

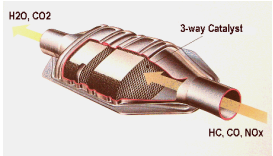
Calculated for…
Specific region
Specific time
Also need…
Spatial allocation
Temporal variation
Speciation

Example: On-road motor vehicles

Vehicle fleet

Fuel type

Control technology



Emissions source

Fuel economy

Vehicle condition

Road type

Distance driven

Vehicle load

Inventories are necessary, …

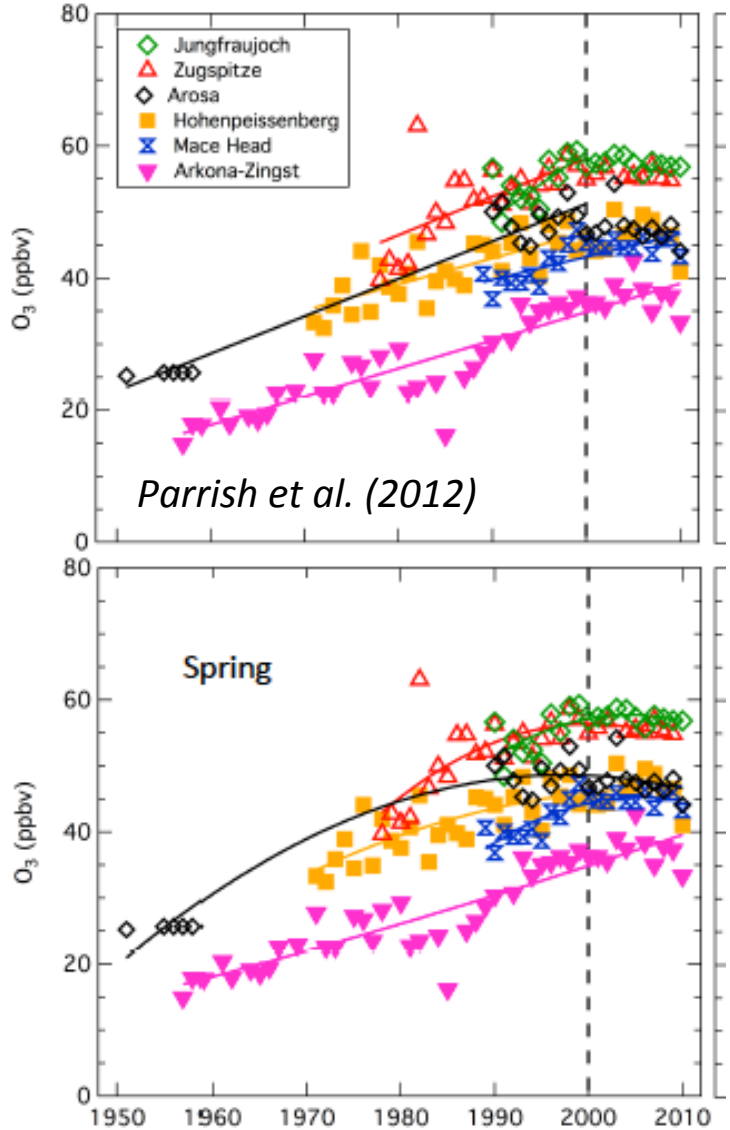
- Connect disciplines
- High granularity
- Comprehensive view
- Quantify changes
- Key model inputs
- Prediction
- Decision-making

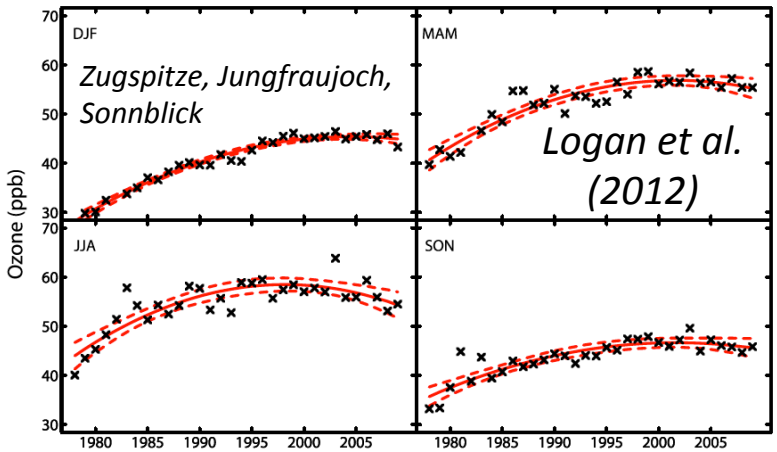
but they have many challenges

- Complexity
- Insufficient data
- Long, costly development cycle
- Diverse data providers
- Proprietary data
- Inconsistencies
- Uncertainties
- Analysis and evaluation
- Transparency
- Access
- Communication
- Education

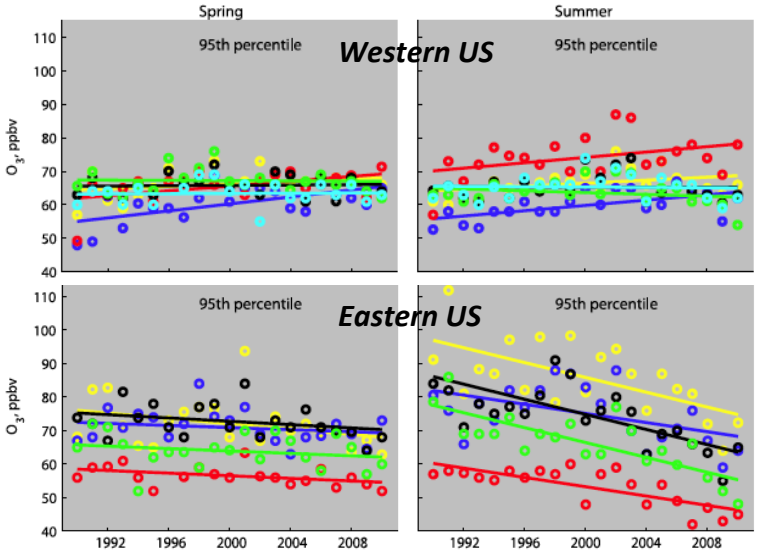
Challenge: Explaining Observed Composition

Do observed changes in atmospheric composition result from emissions changes?



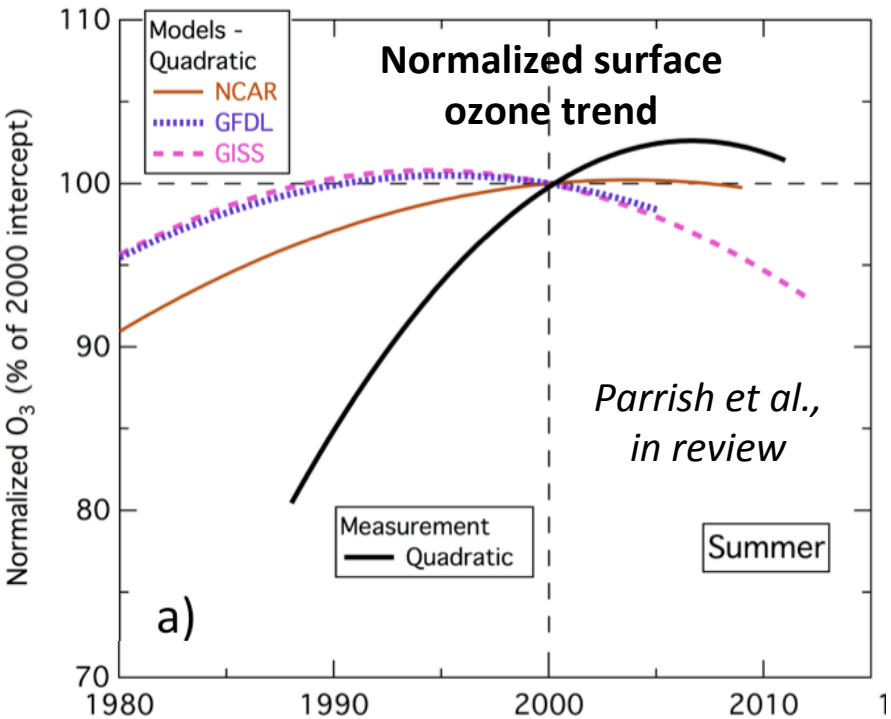


Cooper et al. (2012)



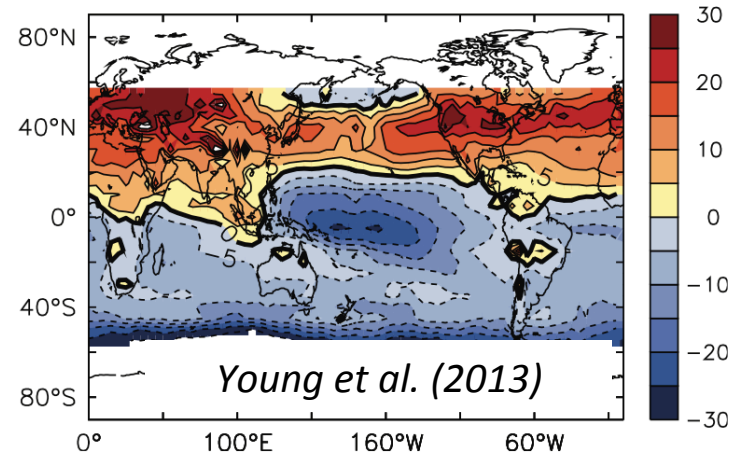
Challenge: Modeling Composition & Climate

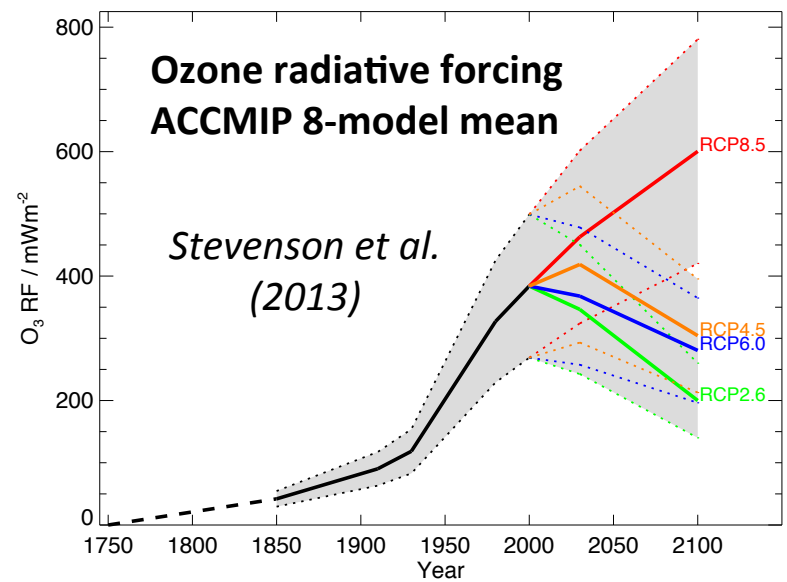
- Models are not able to simulate observed composition trends and distributions
- Emissions represent significant portion of uncertainty in modeled composition and climate forcing



Troposphere ozone column difference

(c) ACCMIP – OMI/MLS (%)





Global Emissions InitiAtive

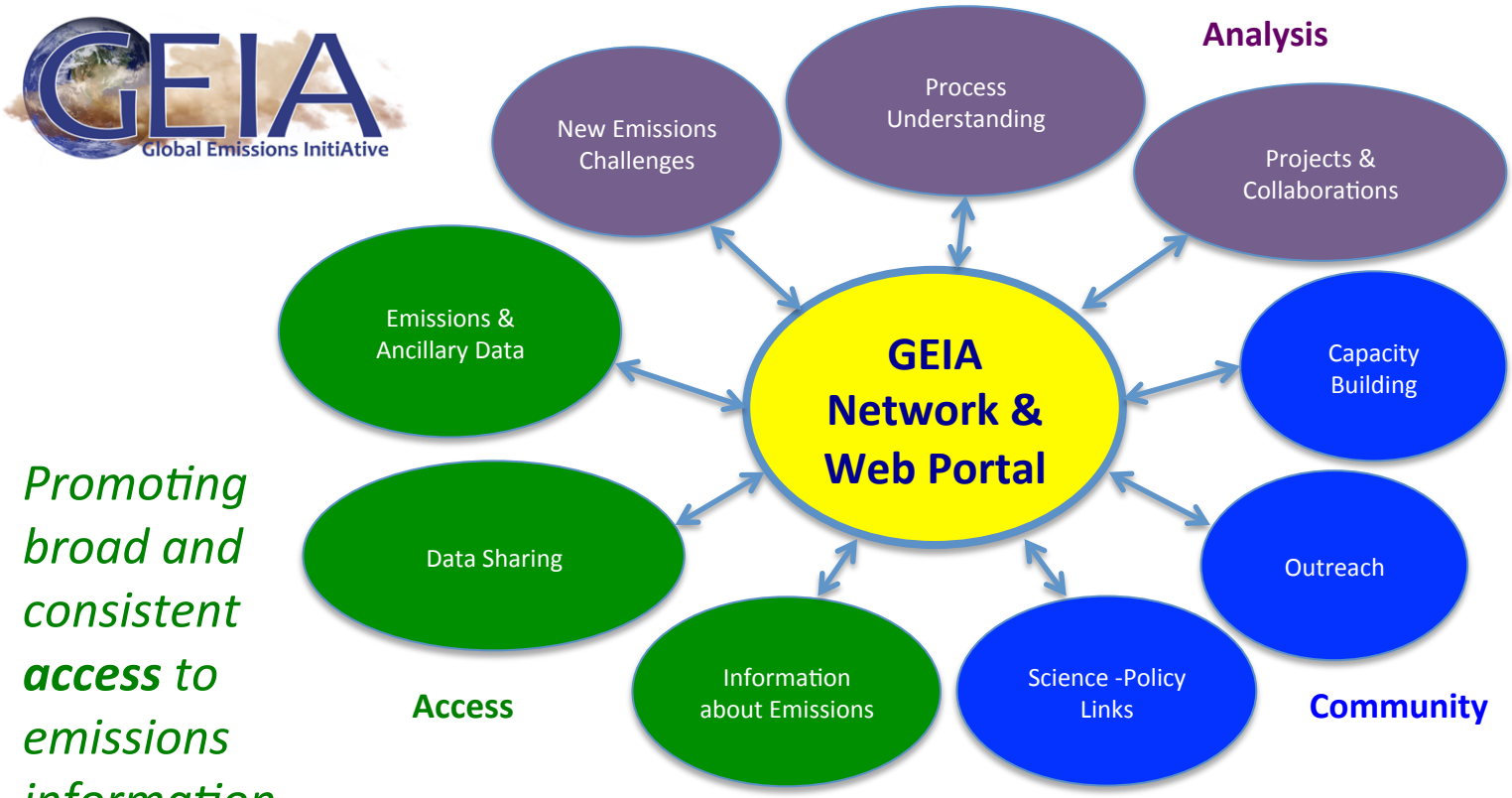
http://www.geiacenter.org/

GEIA Mission

GEIA is a global community initiative that builds bridges between environmental science and policy, by bringing together people, data, and tools to *create* and *communicate* the highest quality information about ***emissions*** to stakeholders and decision-makers.

GEIA Vision

By 2020, **GEIA** will be a key forum for emissions knowledge that serves stakeholders and decision-makers in a rapidly evolving global society.



*Building the scientific basis for emissions data by enhancing **analysis** of emissions processes*

*Promoting broad and consistent **access** to emissions information*

*Strengthening the **community** of emissions stakeholder groups*

http://www.geiacenter.org/

GEIA Community

GEIA Leadership Team

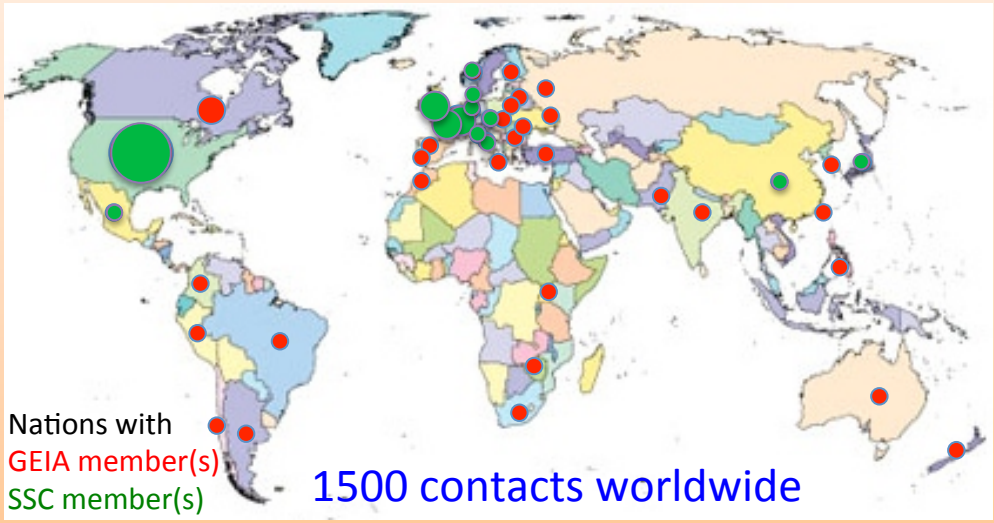
Co-Chairs: Gregory Frost, Leonor Tarrasón
Database Manager: Claire Granier
Network Manager: Paulette Middleton

GEIA Scientific Steering Committee

Gregory Frost
Leonor Tarrasón
Alexander Baklanov
Beatriz Cardenas
Hugo Denier van der Gon
Claire Granier
Alex Guenther
Greet Janssens-Maenhout
Johannes Kaiser
Terry Keating
Zbigniew Klimont
Jean-François Lamarque
Catherine Liousse
Paulette Middleton
Toshimasa Ohara
Martin Schultz
Ute Skiba
John van Aardenne
Yuxuan Wang

International Scientific Connections

GEIA Network



http://www.geiacenter.org/

GEIA History

Guiding programs

- Formed in 1990 under IGBP/IGAC
- Connections developed with other IGBP activities (iLEAPS, AIMES)

Original goal

- Develop one "best" inventory for anthropogenic & biogenic sources: "GEIA inventory"

Evolving goals

- Enhance access to available emissions data
- Standardize formats and documentation
- Facilitate analyses of emissions data
- Build emissions community

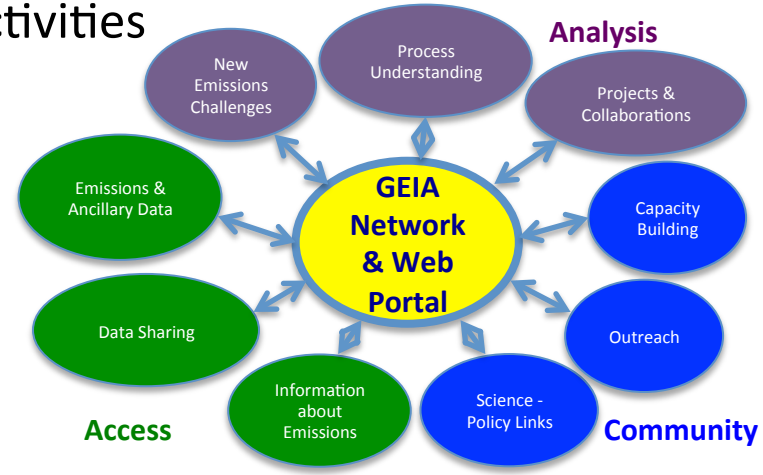
Chairs

- T. Graedel: 1990-1996
- G. Marland: 1996-1998
- J. Olivier & D. Cunnold: 1998-2004
- A. Guenther & C. Granier: 2005-2011
- G. Frost & L. Tarrasón: 2012-present

http://www.geiacenter.org/

Some Recent GEIA Activities

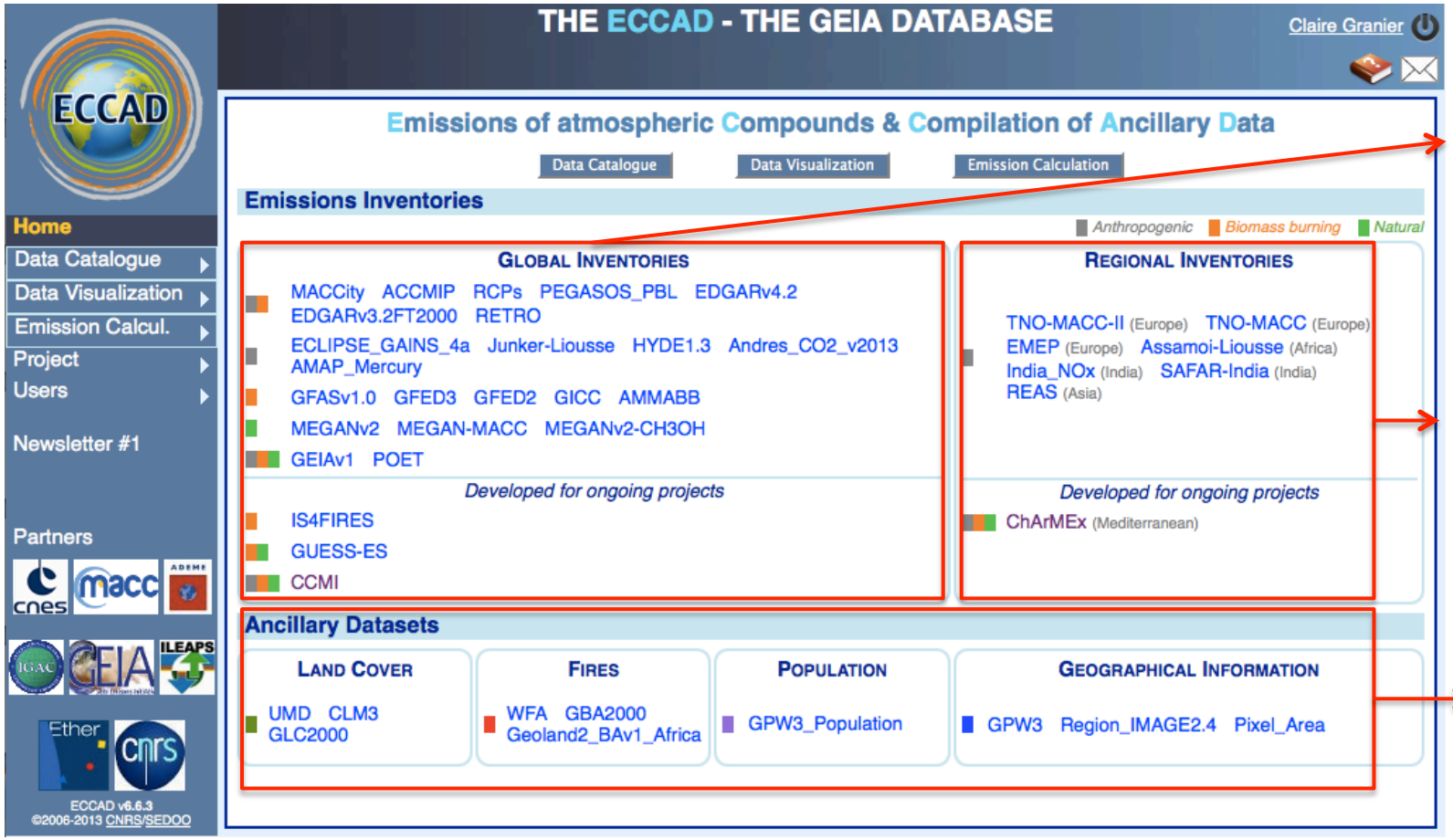
- New vision: Frost et al. (2013)
- New web site: http://www.geiacenter.org/
- Improved data access/visualization platform
- Emissions data for research & assessment activities
- Sessions at conferences (AGU, etc)
- China Emissions Working Group
- Interdisciplinary Biomass Burning Initiative
- VOC Speciation Working Group
- 2014 GEIA Conference in Boulder
- Community historical global emissions effort



ECCAD = Emissions of atmospheric Compounds & Compilation of Ancillary Data

http://pole-ether.fr/eccad

GEIA's emissions database and visualization/analysis platform



Global Inventories

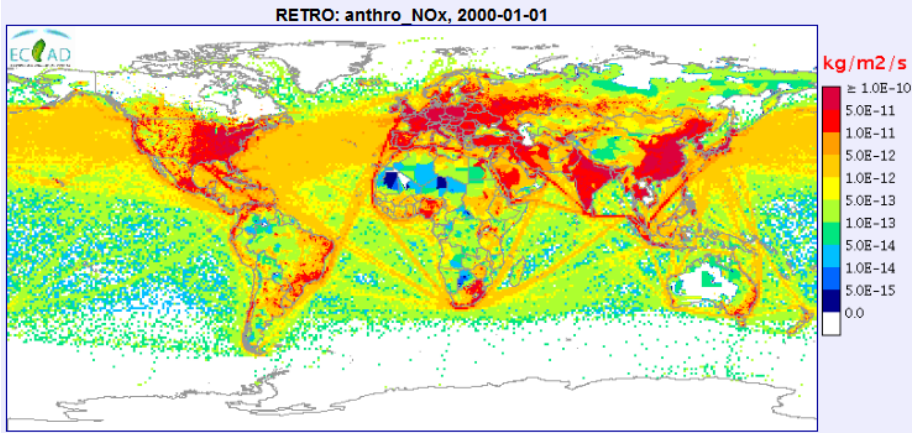
Regional Inventories

Ancillary Datasets

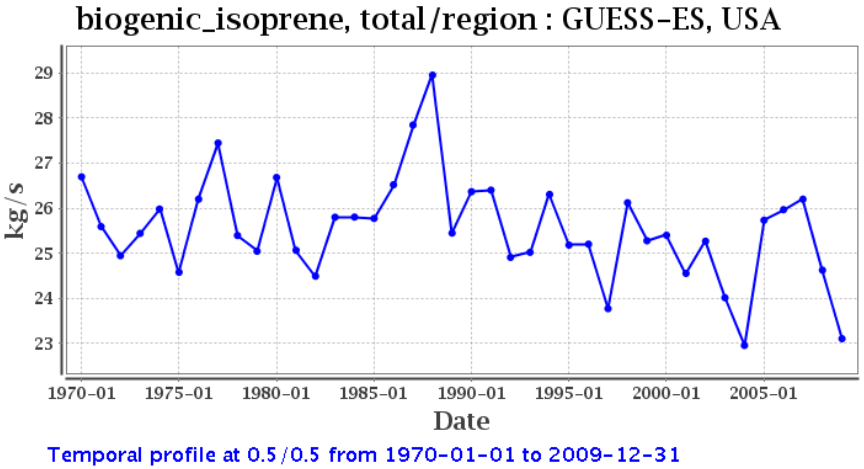
Examples of ECCAD tools

http://pole-ether.fr/eccad

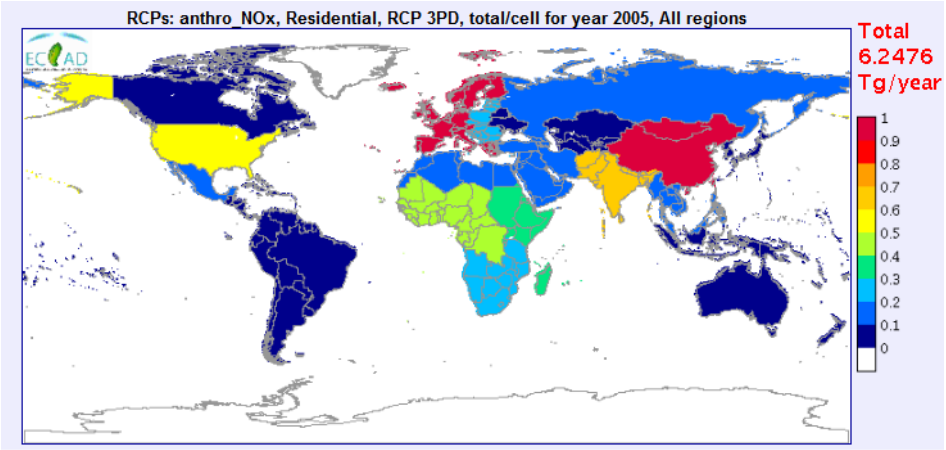
Visualization of emissions maps



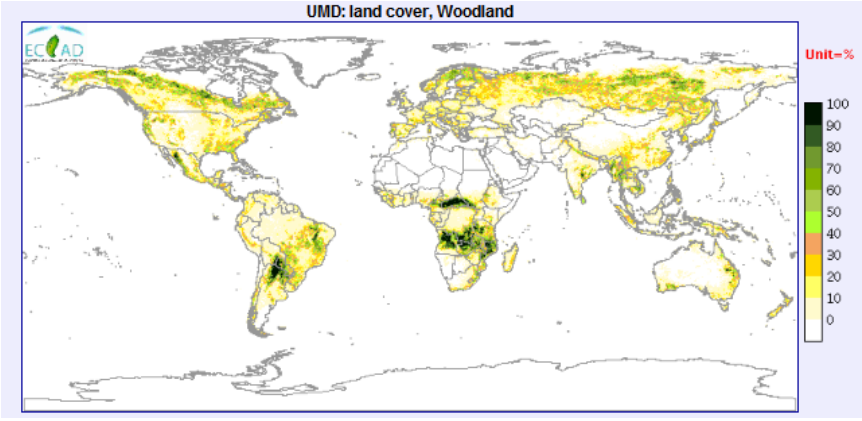
Temporal variation of national emissions



Total emitted for different regions



Ancillary data

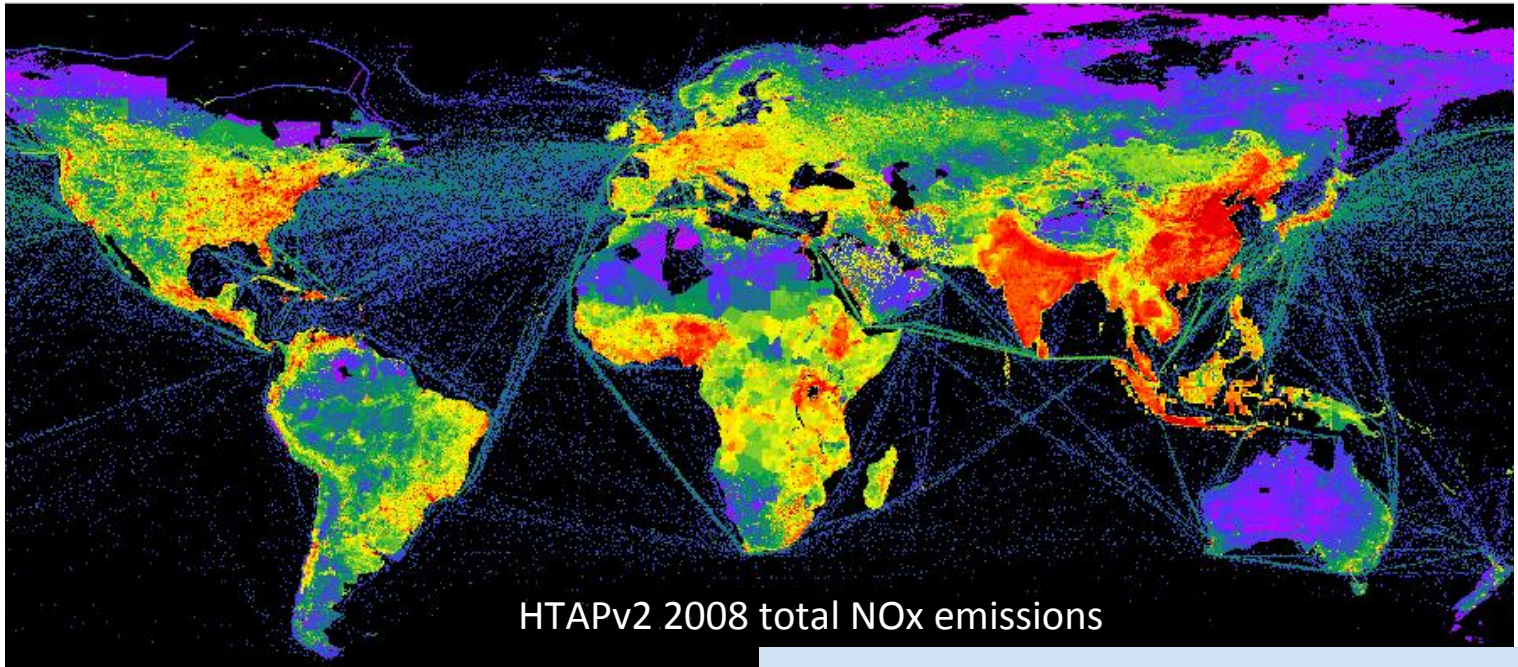


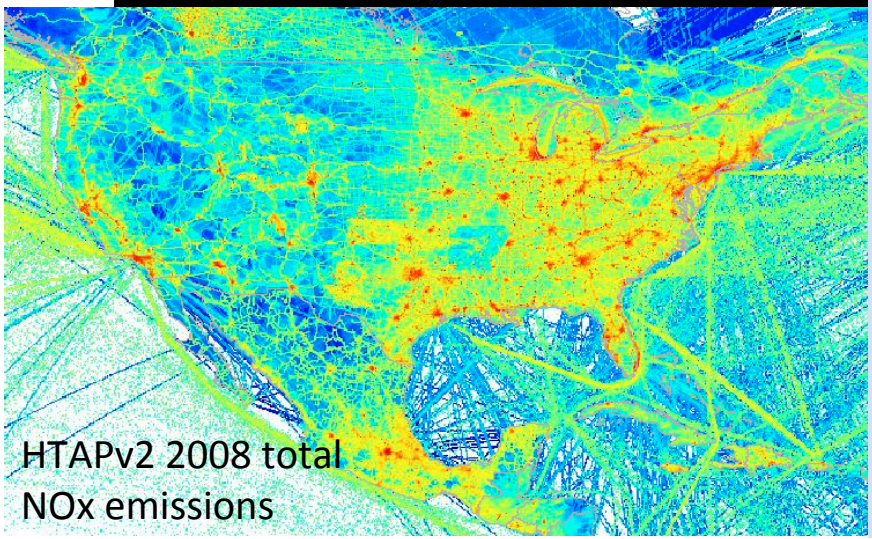
Currently under development: maps of comparison calculations, scatter plots

Limitations of ECCAD-1: resolution, download system, data selection

ECCAD-2 Platform Under Development

http://eccad2.sedoo.fr/interface/ *Thanks to US EPA!*



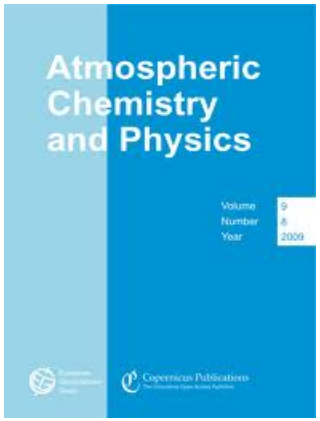


- Any lat/lon resolution
- Country-level data (summer 2014)
- Adapted to interoperability
- Detailed metadata, documentation
- Regrid to any lat/lon grid
- HTAPv2 currently available; other datasets to be added soon

China Emissions Working Group

Name	Affiliation
Chai, Fahe	Chinese Research Academy of Environmental Science, Ministration of Environmental Protection
Chen, Liangfu	Institute of Remote Sensing Applications, CAS
Cheng, Shuiyuan	Beijing University of Technology
Ding, Aijun	Nanjing University
Ding, Yan	Vehicle Emission Control Center
Fu, Qingyan	Shanghai Environment Monitoring Center
Han, Yongming	Institute of Earth Environment
He, Kebin	**Tsinghua University**
Jiang, Kejun	Energy Research Institute, CDRC
Louie, Peter	Hong Kong Environmental Protection Department
Shao, Min	Peking University
Song, Yu	Peking University
Tian, Hezhong	Peking Normal University
Wang, Jingnan	Chinese Academy of Environmental Planning
Wang, Shuxiao	Tsinghua University
Wang, Tao	Hong Kong Polytechnic University
Wang, Yuxuan	**Tsinghua University**
Wang, Xuemei	Sun Yat-Sen University
Wang, Xinming	Guangzhou Institute of Geochemistry, CAS
Wang, Zifa	Institute of Atmospheric Physics, CAS
Zhang, Chaolin	Natural Science Foundation of China
Zhang, Qiang	**Tsinghua University**
Zhang, Xiaoye	Chinese Academy of Meteorological Sciences
Zhao, Lijian	The Energy Foundation
Zheng, Junyu	South China University of Technology

GEIA
Global Emissions InitiAtive



East Asian Emissions Assessment

16th GEIA Conference

Bridging Emissions Science and Policy

GEIA Global Emissions InitiAtive

10-11 June 2014

National Center for Atmospheric Research
Boulder, Colorado, USA

Program, registration, etc. available at
www.geiacenter.org

NCAR

NSF

NASA

IGAC

NOAA

ACCENT Plus
ATMOSPHERIC COMPOSITION CHANGE
THE EUROPEAN NETWORK

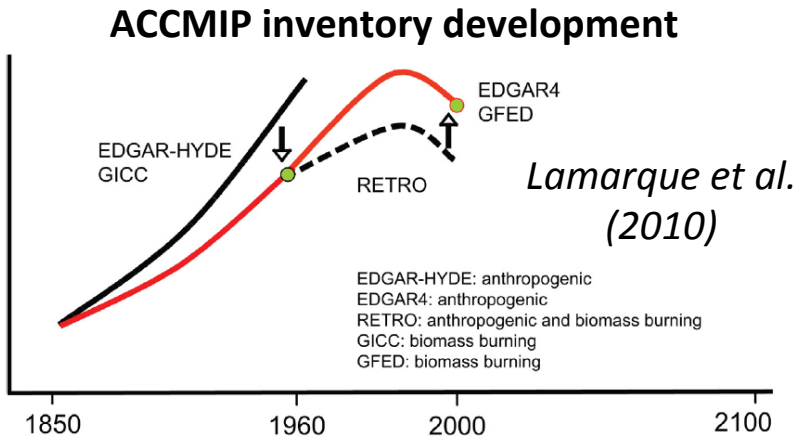
Conference Objective

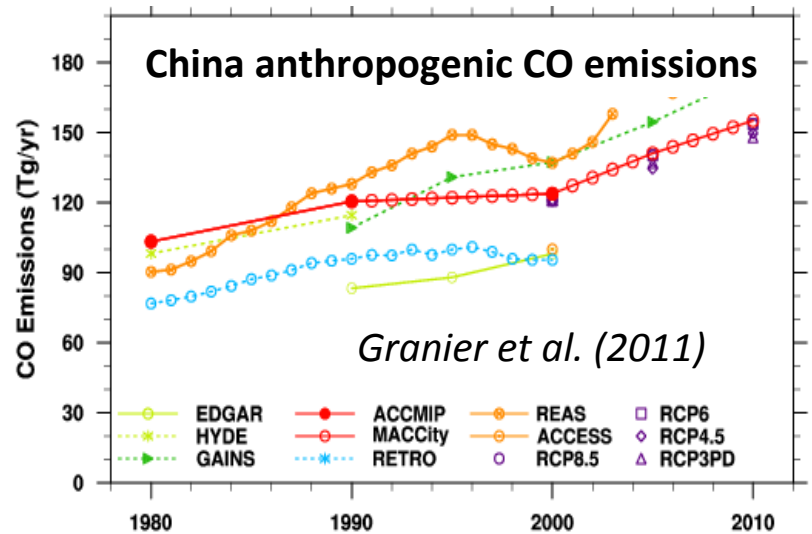
Explore role of emissions as crucial link between scientific innovation and societal development

Intended Audience

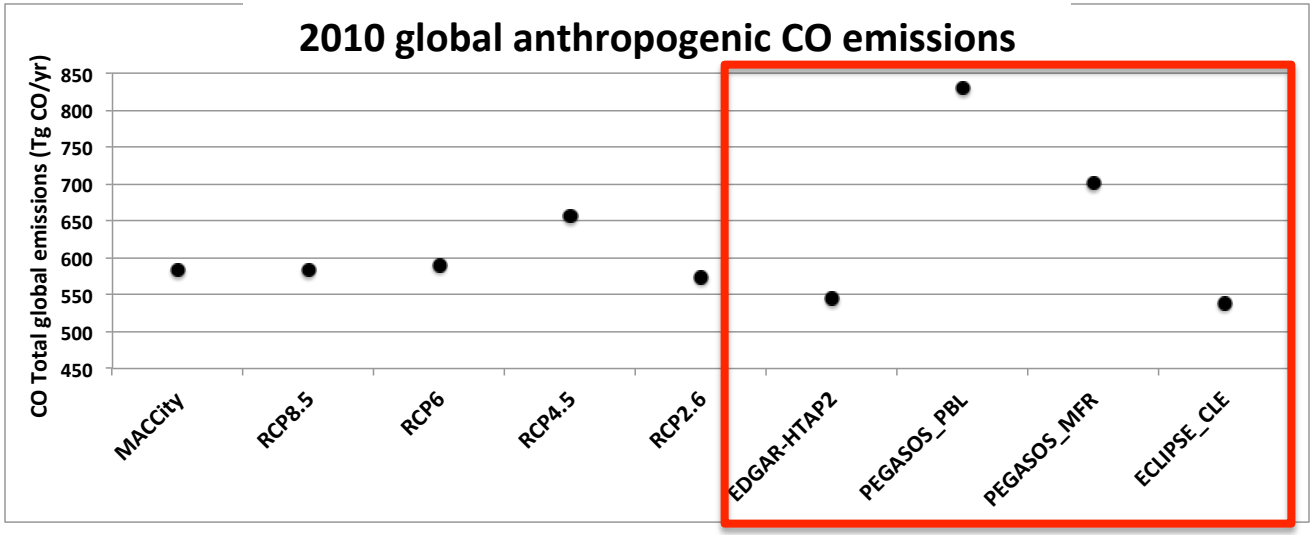
- Emissions information developers and users
- Research, regulatory, policy, and assessment communities

Community Historical Global Emissions





Update of Granier et al. including recent inventories (in preparation)



New community effort underway: See Smith presentation next!

Top-Down Emissions Evaluations

Atmospheric observations measure abundance of constituent and quantify spatial and temporal variability

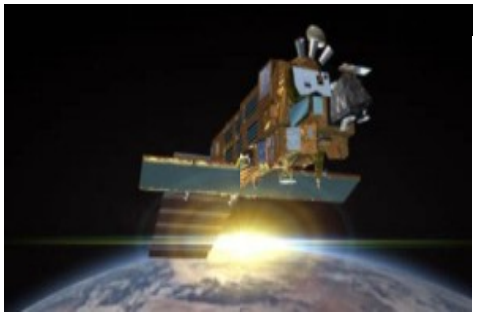
Models translate between atmospheric abundance and emission flux

Quantify:

- Interannual trends
- Day-of-week variability
- Sector partitioning
- Total emissions

Compare to bottom-up inventories

Uncertainties usually quantifiable



Examples of Top-Down Emissions Evaluations

Pollutants relevant to air quality & climate

- NOx, SO_2, CO, VOCs, CO_2, CH_4

Multiple species → source "fingerprint"

Examine US emissions sectors:

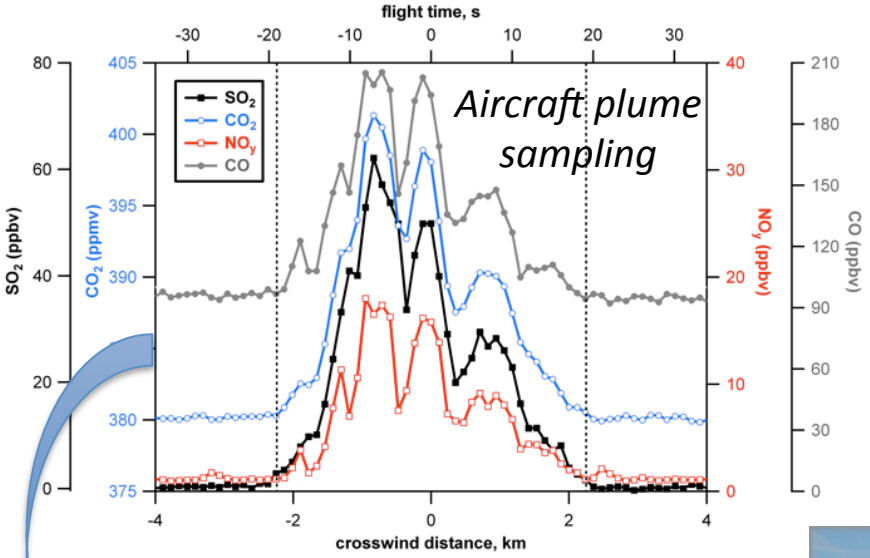
- Power plants
- Urban areas/motor vehicles
- Oil/natural gas production & distribution

Examples from NOAA/CU research

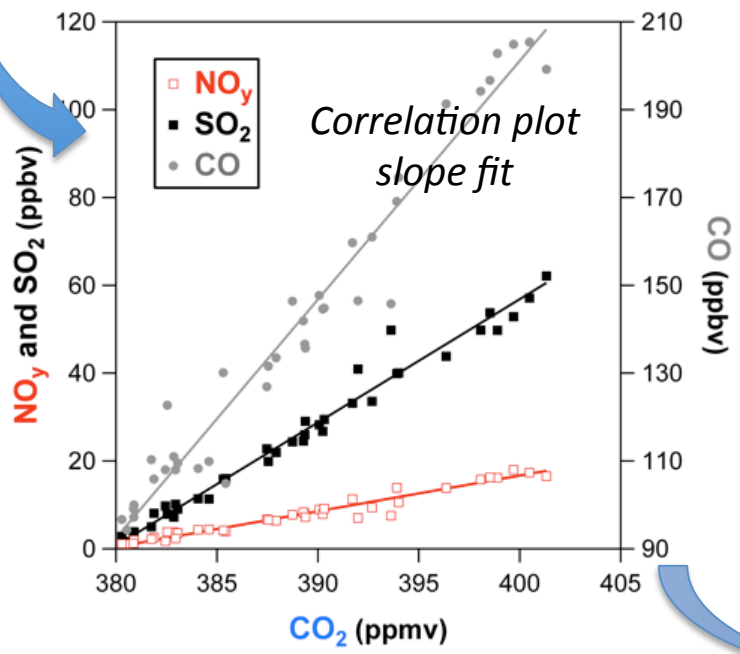
Power Plant Emissions Trends - Aircraft Sampling

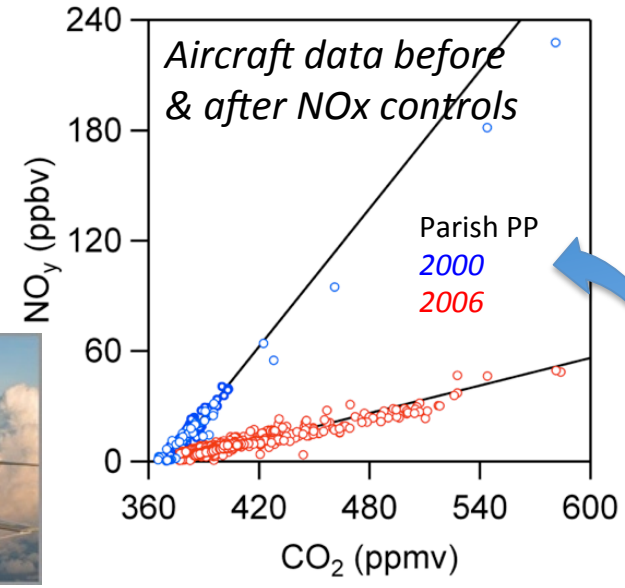
Aircraft sampling quantifies atmospheric NO_x declines downwind of power plants

Confirmation of in-stack monitoring (CEMS)

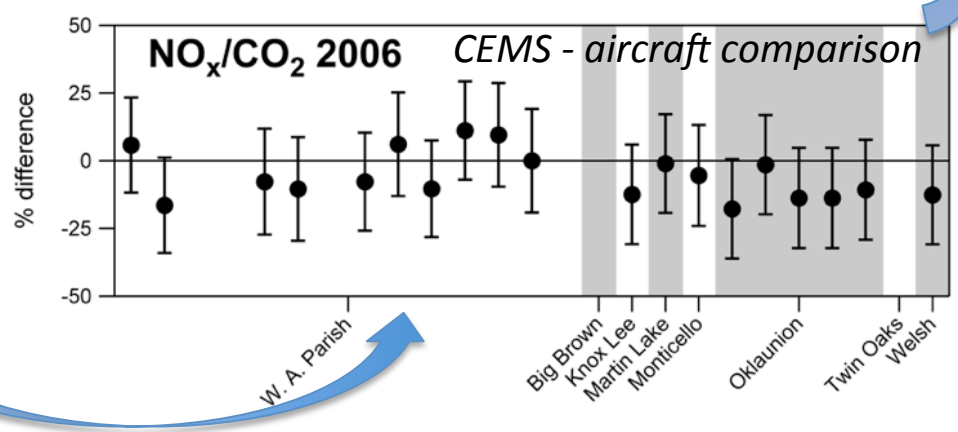


Monticello power plant (TX), 9/16/06

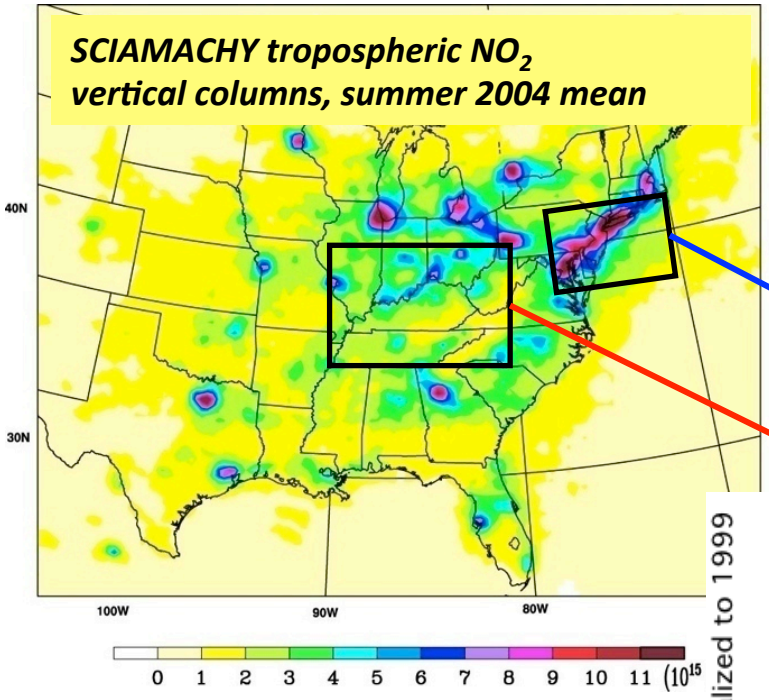




Peischl et al. (2010)



Power Plant Emissions Trends – Satellites

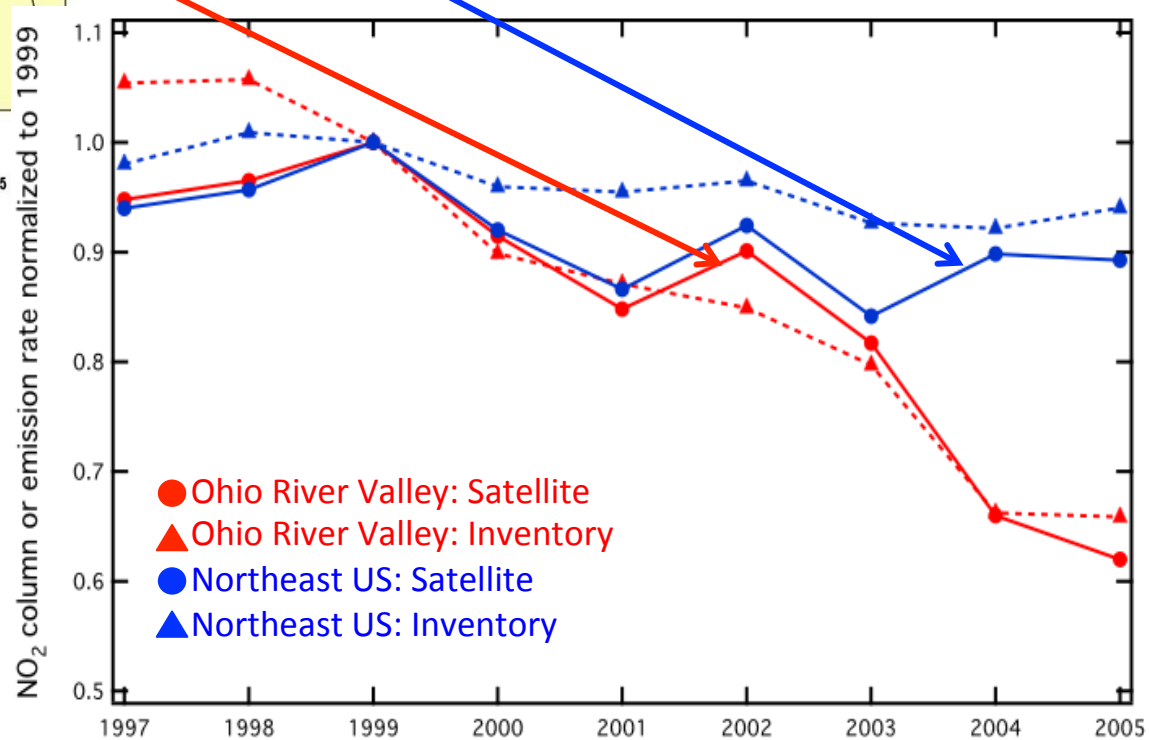


Kim et al. (2006)

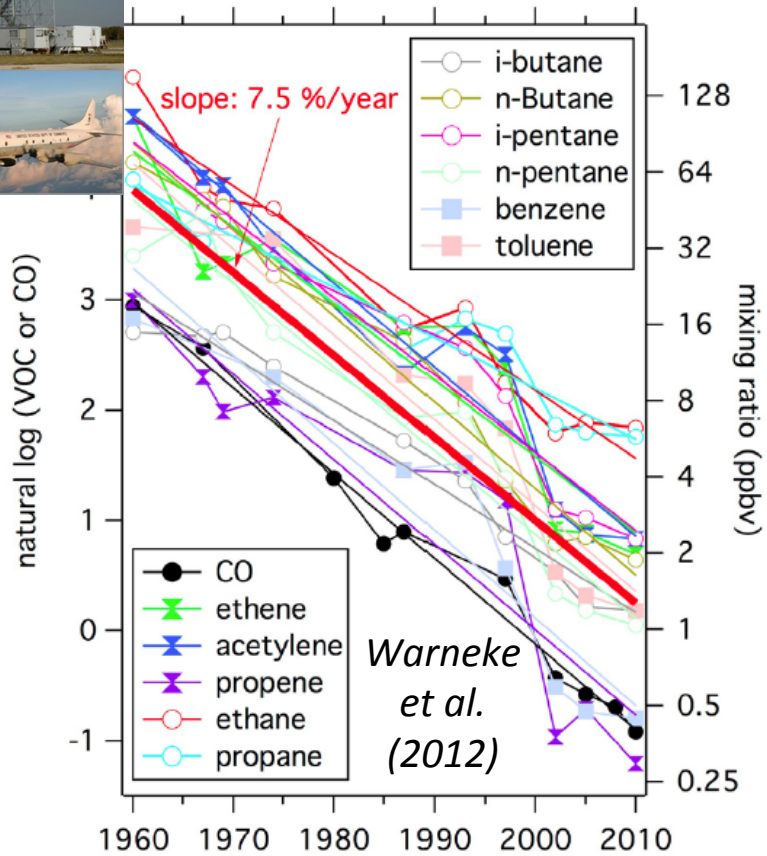
Satellite column NO_2 retrievals map point and urban sources

Satellite NO_2 column trends show impacts of NO_x controls on US power plants

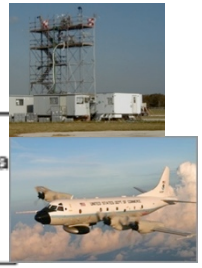
Confirmation of in-stack monitoring (CEMS)

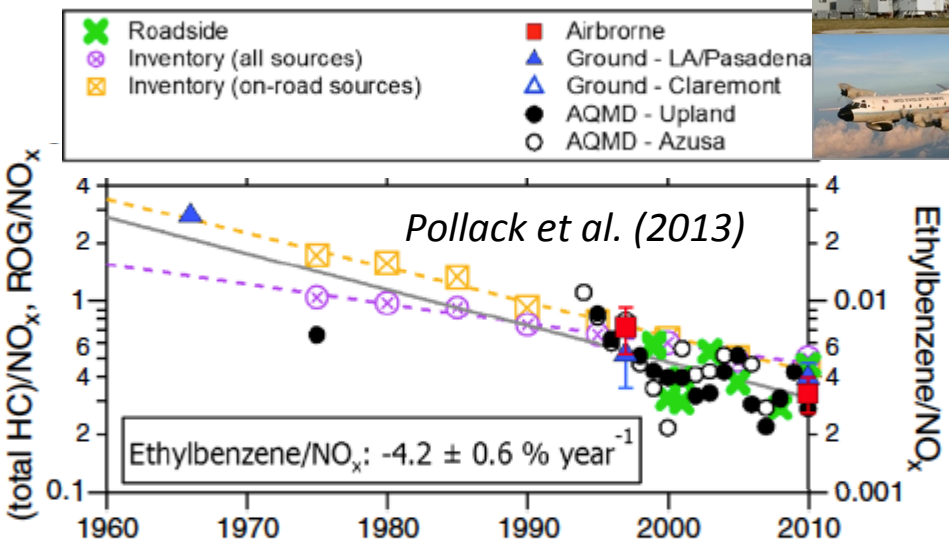


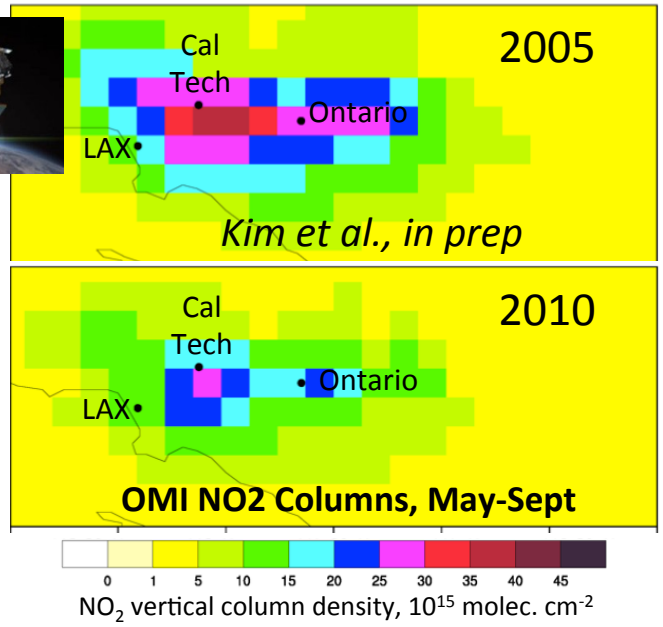
Urban Interannual Emissions Trends



South Coast Air Basin (Los Angeles)



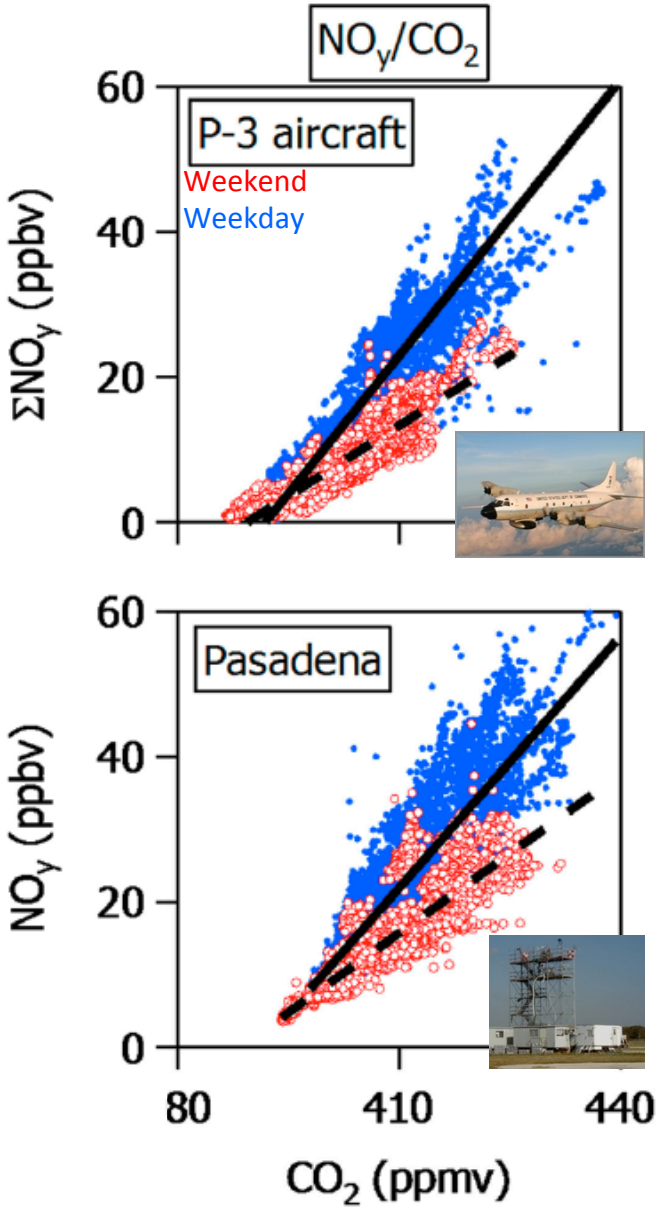




Surface, airborne, & satellite observations show consistency in interannual trends

- Ambient NOx & VOCs decreasing for 50 yrs
- Demonstrates declining motor vehicle emissions

Urban Day-of-Week Emissions Variations

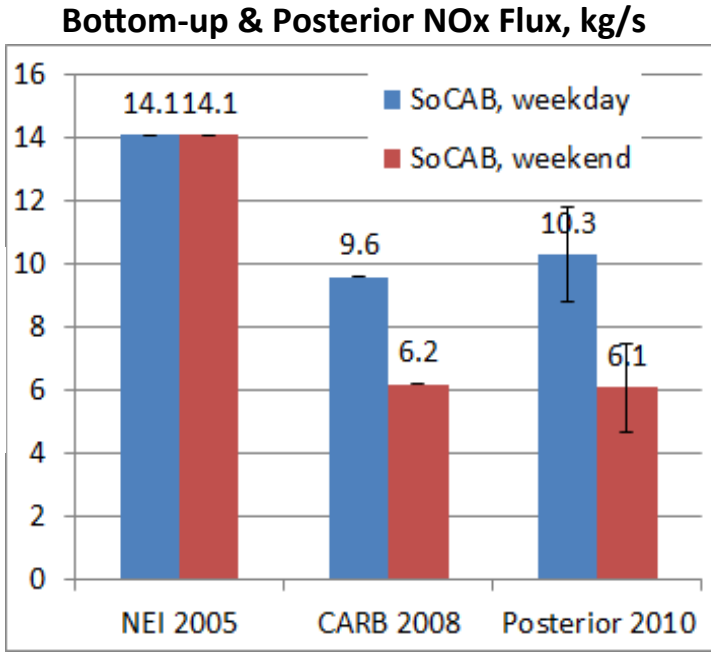


Pollack et al. (2012)

Surface, airborne, & satellite observations show consistency in weekend effect:

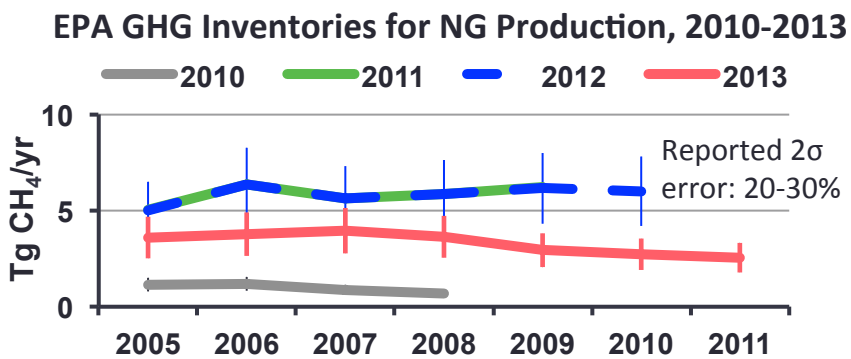
- Lower ambient NOx on weekends
- Atmospheric changes result from lower weekend NOx emissions
- Inverse modeling demonstrates which inventories capture weekend effect

CalNex 2010 South Coast Air Basin

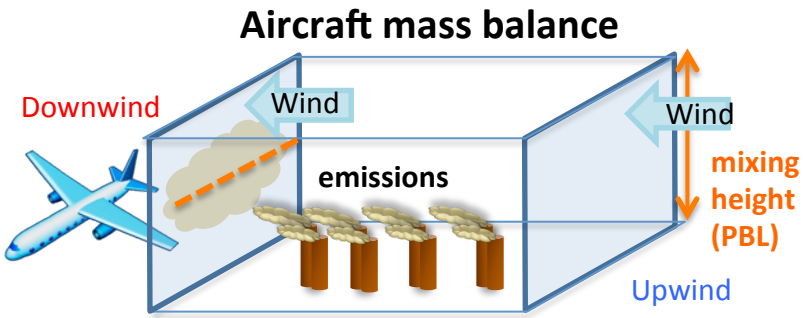


Brioude et al. (2013)

Oil and Natural Gas Production Emissions

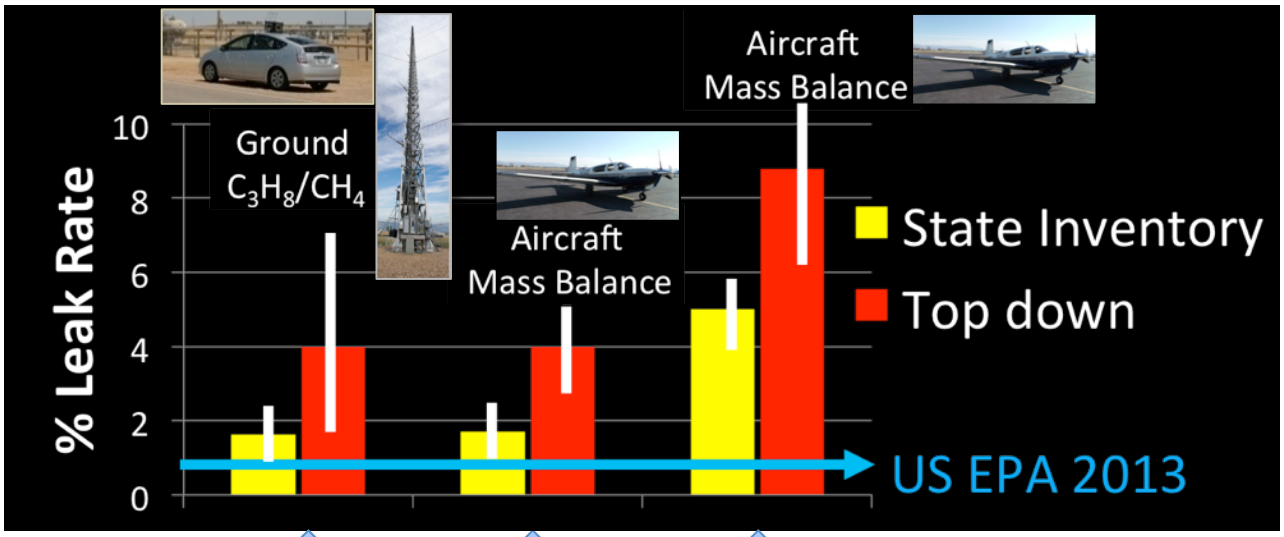


US GHG emission inventories for natural gas production revised frequently



Hydrocarbon leak rates inferred from observations in oil & gas production basins

Inventories underestimate methane leakage from natural gas production



2008
Denver-Julesburg Basin, CO
Pétron et al. (2012)

2012
Denver-Julesburg Basin, CO
Pétron et al., in review

2012
Uintah Basin, UT
Karion et al. (2013)

Urban CH_4 Emissions

CalNex 2010
Los Angeles Basin

Measured CH_4/CO + inventory CO
→ Total E(CH_4) in LA Basin

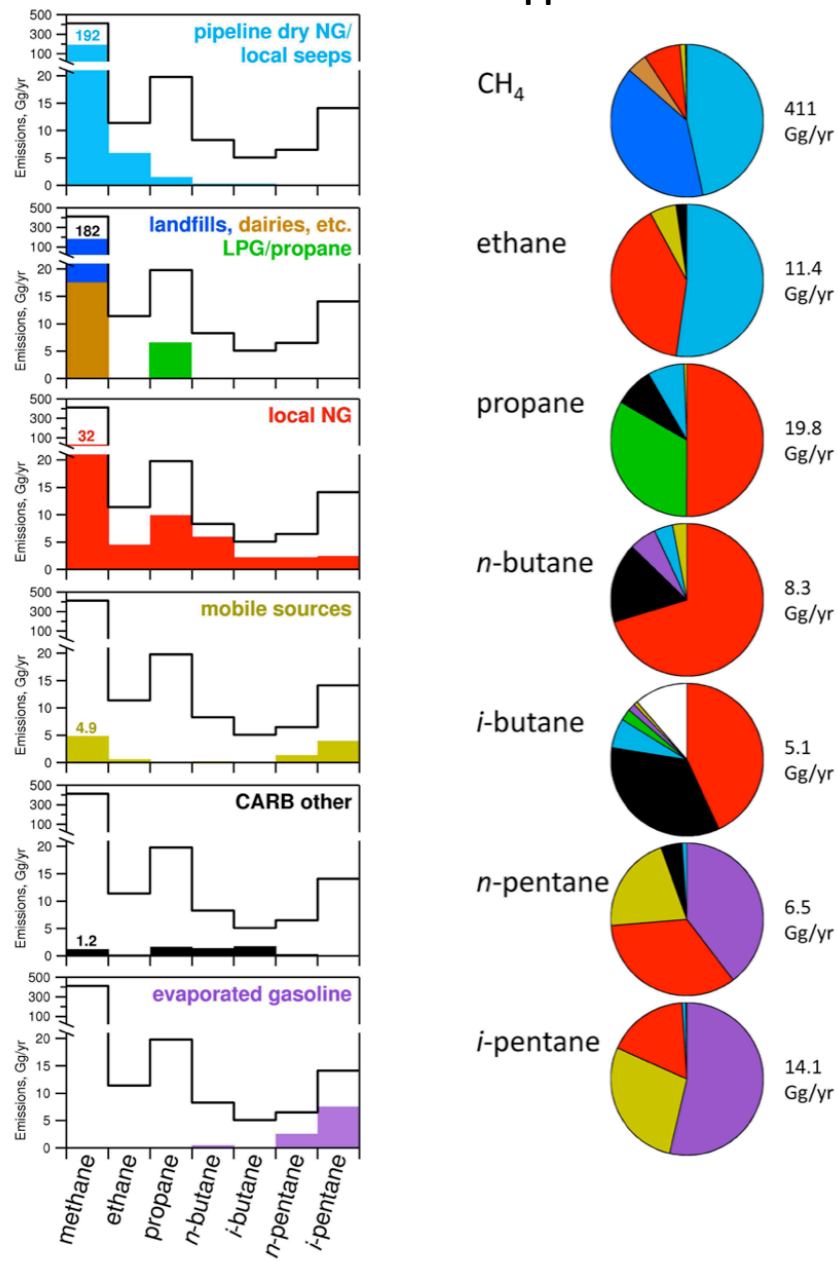
Mass balance of E(CH_4)
→ Validate landfill, dairy inventories

Alkane ratios
→ Partition source contributions

- ✓ Resolve top-down/bottom-up CH_4 discrepancy in LA Basin
- ✓ Raw gas leaks significant CH_4 sources (12-17%)

Peischl et al. (2013)

Multivariate source apportionment



Summary

- High quality emissions information is critical to understand the atmosphere and make good decisions about how to manage it.
- Bottom-up inventories are integral to these efforts, but there are challenges associated with these complex datasets.
- GEIA is helping a broad community of scientists, regulators, and policymakers to work together at improving and communicating emissions information.
- Atmospheric observations and modeling provide objective approaches for improving emissions understanding.
- Top-down methods have been successful at quantifying emissions across regions, between sectors, and over time.

Some Future Directions

- Long-term trends
- Fine temporal scales
- Spatial allocation
- Speciation
- Inverse approaches
- Satellite data
- Energy production
- Biogenic emissions
- Wildfires, trash burning
- Historic inventory system
- Regional working groups

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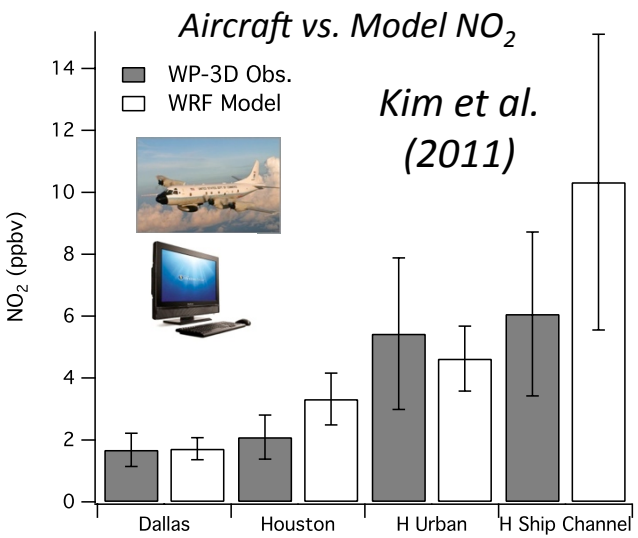
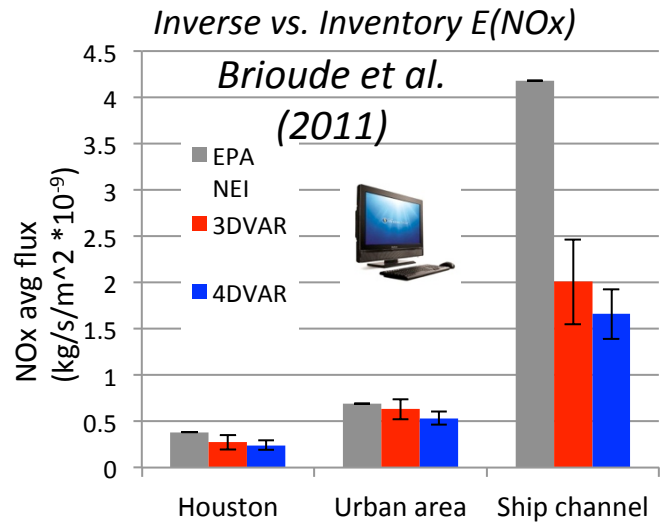
Separating Mixed Source Sectors

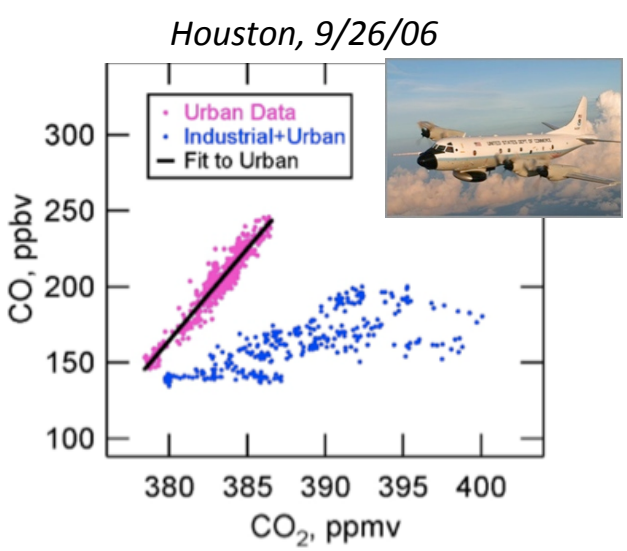
Houston and Dallas, TexAQS 2006

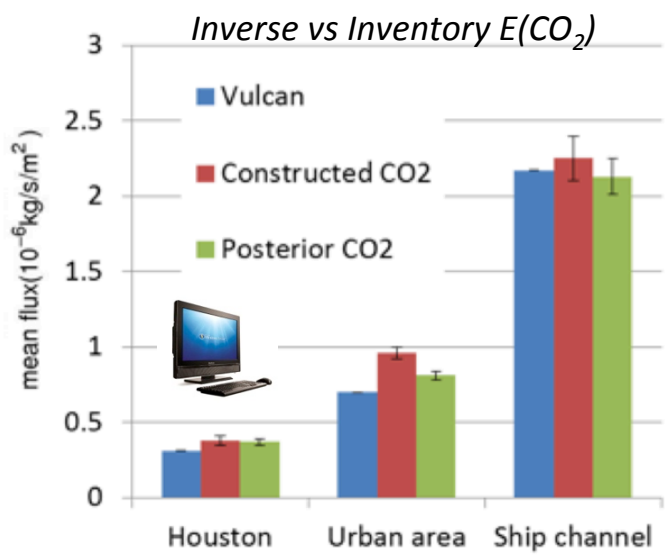




Aircraft measurements enable spatial separation of sources

- Evaluate sectoral partitioning
- Observations & models consistent





Use relationships between tracers in inversion

- Estimate fossil fuel CO_2 emissions

Brioude et al. (2012)