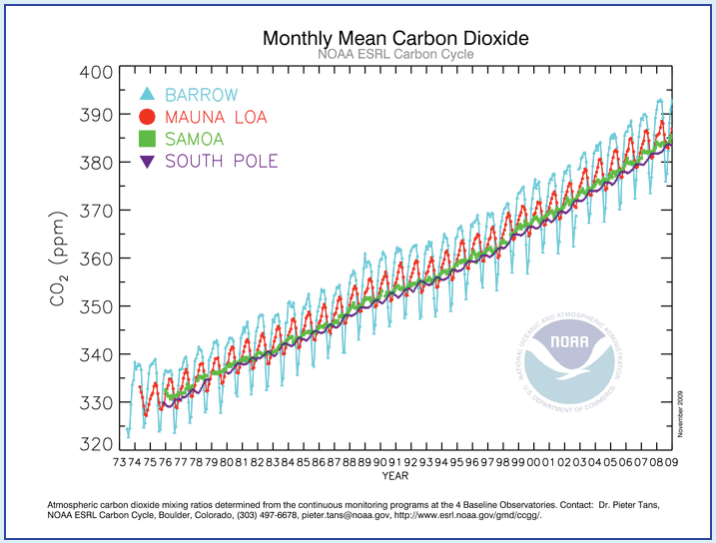
Inverse modeling and Multi-species analysis to quantify emissions

NOAA ESRL Global Monitoring Division

High-precision long-term measurements of long-lived greenhouse gases and ozone depleting substances

What drives the changes we observe? Emissions, Transport, Chemistry

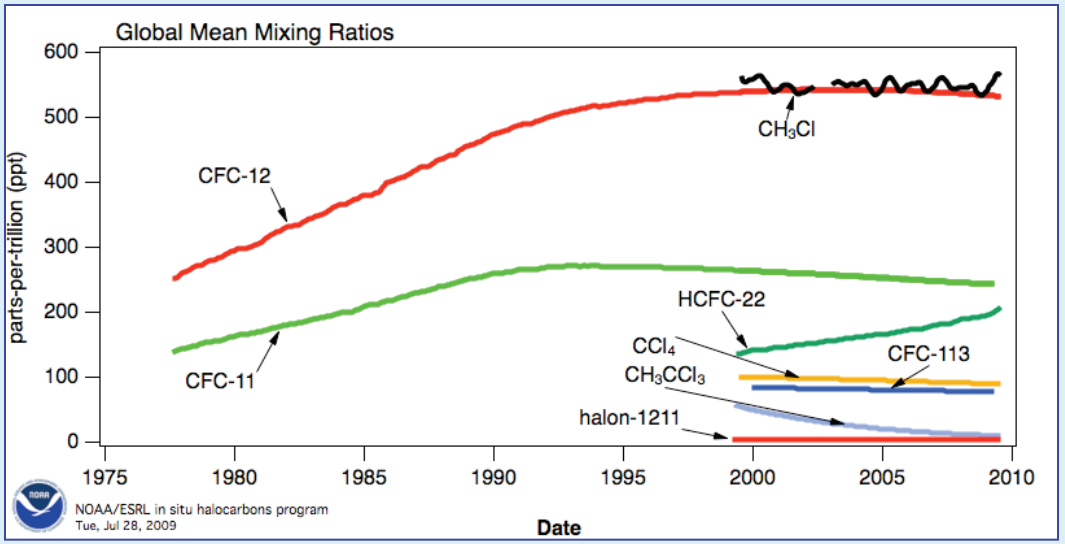
Carbon Cycle Group- Pieter Tans



CO_2, CO, CH_4, N_2O, SF_6, H_2

$^{14}CO_2$, $^{13}CO_2$,…

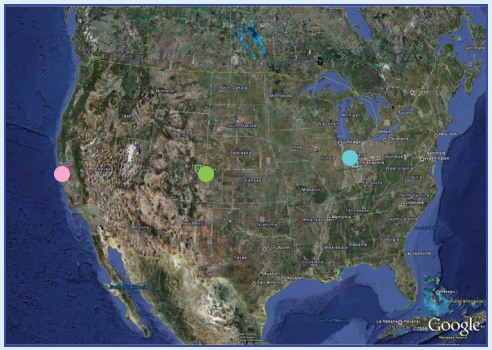
Halocarbons Group- Jim Elkins



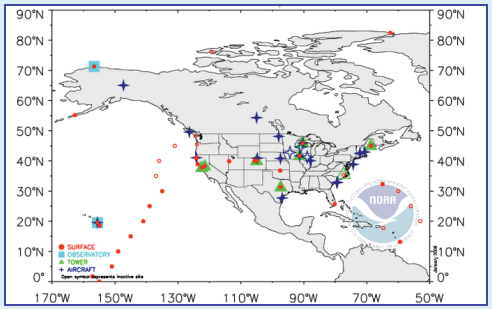
CFCs, HFCs, HCFCs, several hydrocarbons (Steve Montzka's group)

Top-down Emissions Quantification
From Local to Global Scales

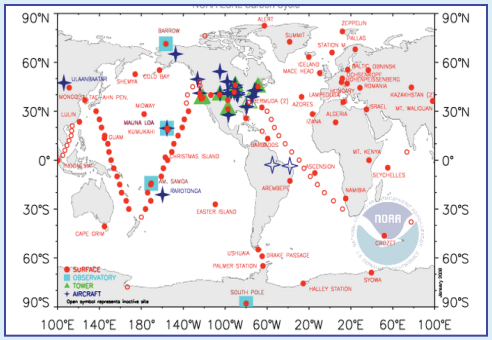
Local Cooperative Intensive Studies



North America Cooperative Network



Global Cooperative Network & NOAA Observatories



Intensive campaigns

Tall tower and aircraft networks

Surface network

Local

Indianapolis

Sacramento

Colorado Front Range

Continental

North America CO_2 Inversions

Multi species Analysis

Asian Emissions

Global

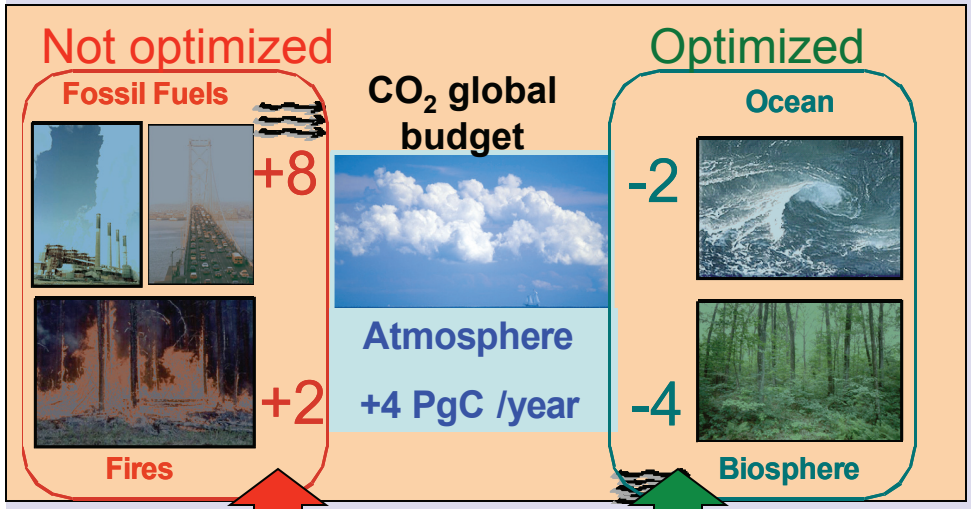
CarbonTracker CO_2

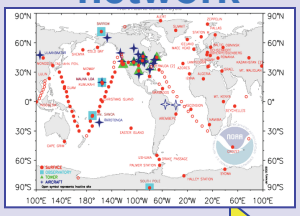
CarbonTracker CH_4

Global SF_6

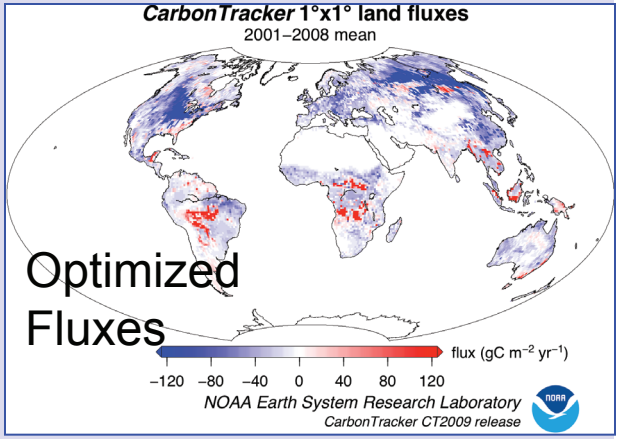
Global Atmospheric CO_2 and CH_4 Inversions: CarbonTracker

Can we use atmospheric measurements to quantify surface fluxes from human activities, the biosphere and the oceans?





Inversion



Prior Fluxes

Emission Inventories - global 1x1 deg from 2000 to present:

- **Fossil Fuel (CDIAC, BP, EDGAR)**
- **Biomass Burning (GFED)**

Emission Models - global 1x1 deg from 2000 to present:

- **Biospheric Fluxes (CASA)**
- **Ocean Fluxes (Jacobson et al.)**
- **Wetlands (Kaplan et al., Bergamaschi et al.)**

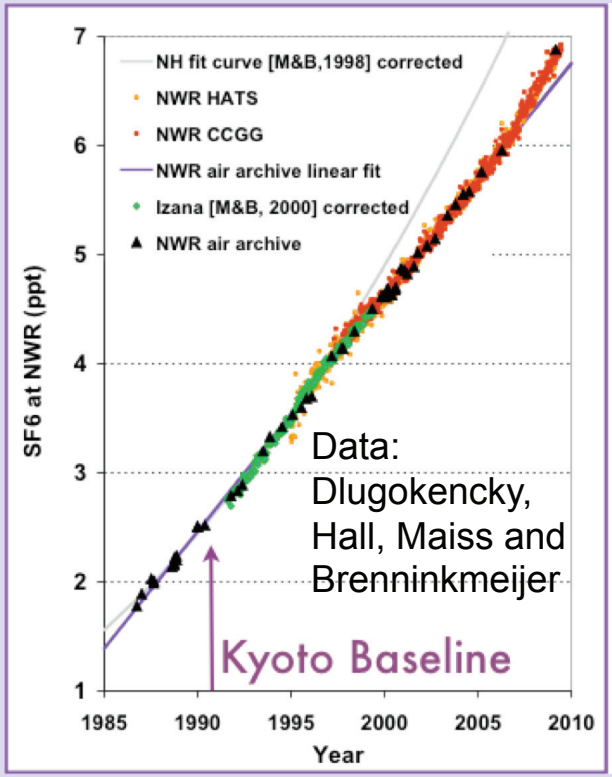
Modeling teams:

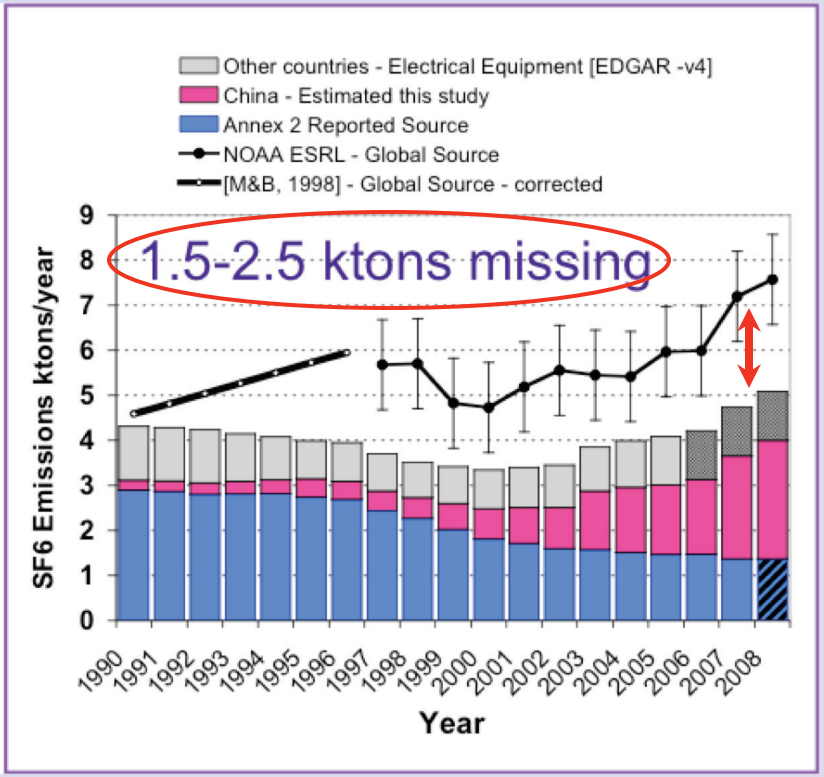
Andy Jacobson
Wouter Peters
Ken Masarie
John Miller
} CT-CO_2

Lori Bruhwiler CT-CH_4

Observing Networks: T. Conway, A. Andrews, C.Sweeney

Global SF_6 Budget





Top Down emissions

Other countries

China

UNFCCC Annex2

SF6 (one of the Kyoto gases) mostly used in the electrical grid.

Emissions Inventories Used –gridded 1x1 deg from 1970 to 2005:

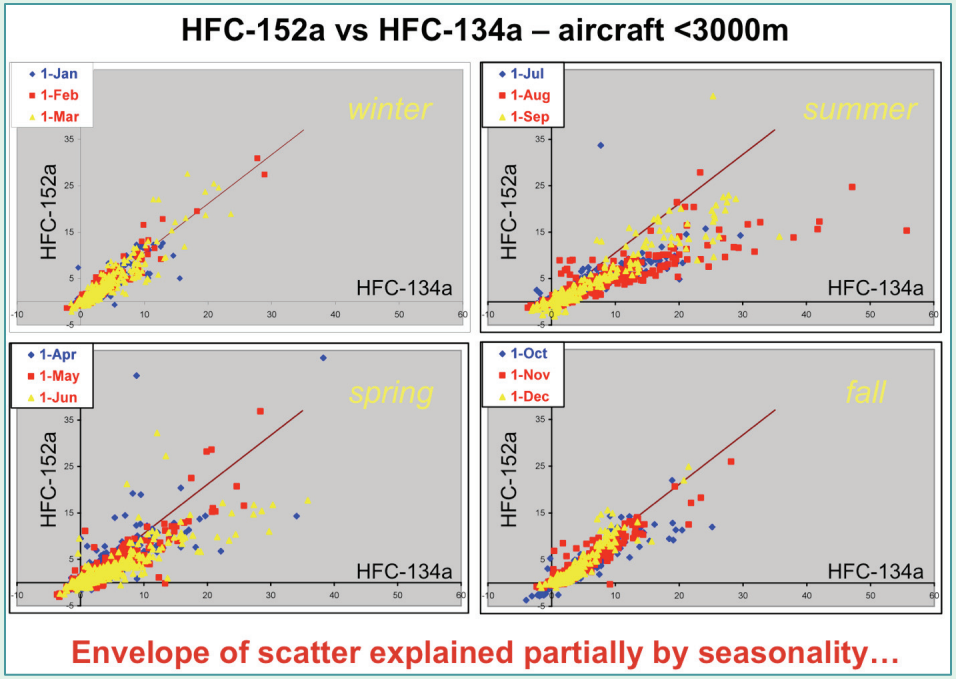
-EDGAR-4

-Extrapolation for recent years based on electricity production, Mg production,…

-Some countries/sectors are quite uncertain.

Multi-species Approach
Looking at HFCs enhancements in US lower troposphere

Steve Montzka's group



Envelope of scatter explained partially by seasonality…

List of species measured

Strong Ozone-depleting and/or Greenhouse Gases:

CFCs (6), HCFCs (4), HFCs (7), PFC (1)

Other ODSs: Chlorinated solvents, Halons, CH_3Cl, CH_3Br, $CHBr_3$, CH_2Br_2.

Indicators of specific processes:

Photosynthesis: *Carbonyl Sulfide*

Combustion: *Acetylene, Benzene, CH_3Cl, CH_3Br, (CO)*

Oceanic influence: *$CHBr_3$, CH_3I, CH_3Cl*

Anthropogenic input: *C3-C5 Hydrocarbons, PCE, CH_2Cl_2, Halocarbons*

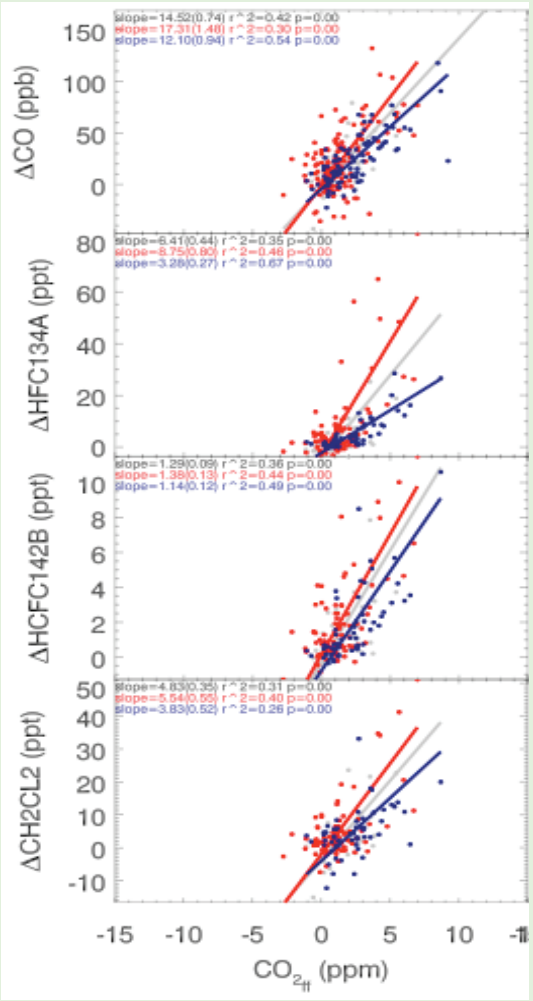
Land influence: *COS ↓, CH_3Cl ↓, $CHCl_3$↑ ,H_2↓*

- HFC-152a (used as propellant in aerosol cans) vs HFC-134a (used as refrigerant in automobiles) enhancements above background are correlated esp. in winter time.
- HFC-134a emissions are higher in the summer time

Multiple species observations are used to understand process-specific emissions (seasonality, geographic gradients, source chemical signature…) and to evaluate emissions inventories.

Multi-species Approach
Anthropogenic Emissions in Eastern US

John Miller et al.



m=19 ppb/ppm
m=12 ppb/ppm

m=7.2 ppt/ppm
m=3.0 ppt/ppm

m=1.2 ppt/ppm
m=1.2 ppt/ppm

m=4.0 ppb/ppm
m=2.3 ppb/ppm

Red=Summer; Blue=Winter

$^{14}CO_2$ is a tracer for fossil fuel CO_2 (C_{ff}) and correlates with anthropogenic species

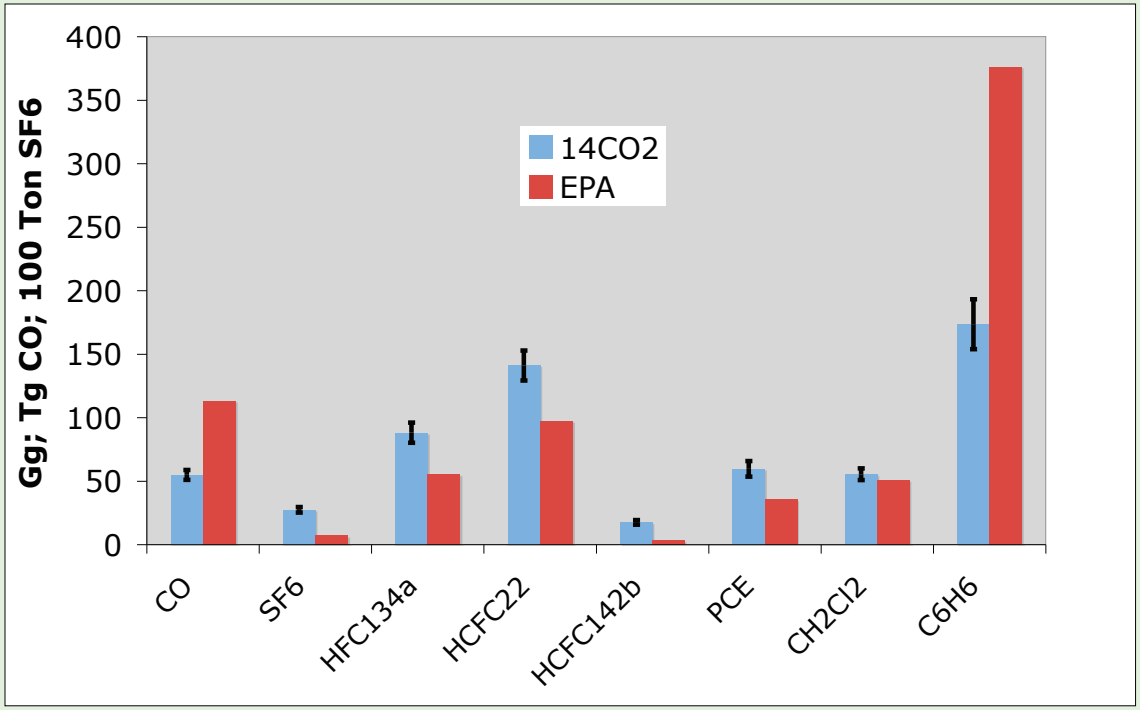
Fossil fuel CO_2 emissions inventories are known better than any other.

$$m_{gas} \times E_{ff} = E_{gas}$$

Data from 2 aircraft profile sites (CMA 200 km east of Washington DC and NHA 100 km east of Boston) collected between 2005 and 2009.

Multi-species Approach
Anthropogenic Emissions in Eastern US

John Miller et al.

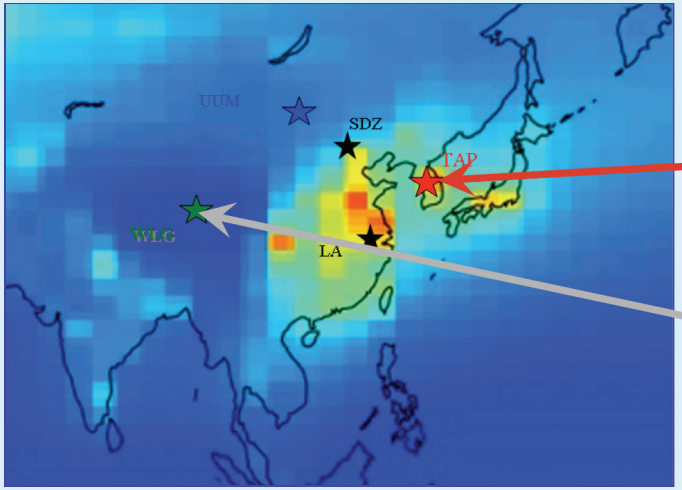


$^{14}CO_2$ based emissions differ substantially from bottom-up ones (and have quantifiable uncertainty)

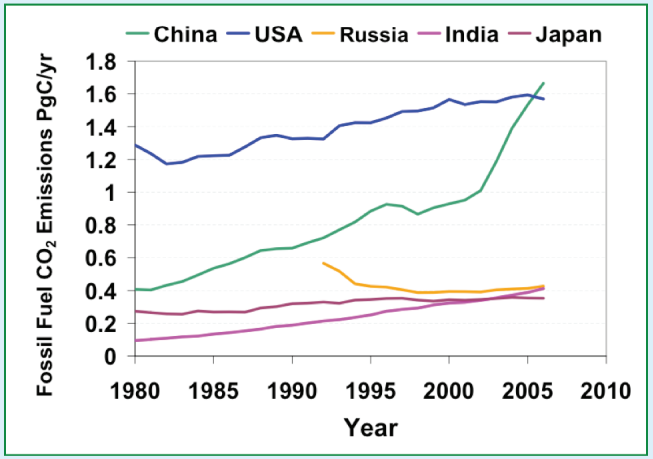
*This assumes NE emissions ratios are valid nationally

Multi-species Approach
Asian CO_2 and CO Emissions using $^{14}CO_2$ data

Jocelyn Turnbull et al.



Looking at CO/CO2ff enhancements ratio at Tae ahn (Korea) and comparing with emission inventories (Mt Waliguan data used as background).



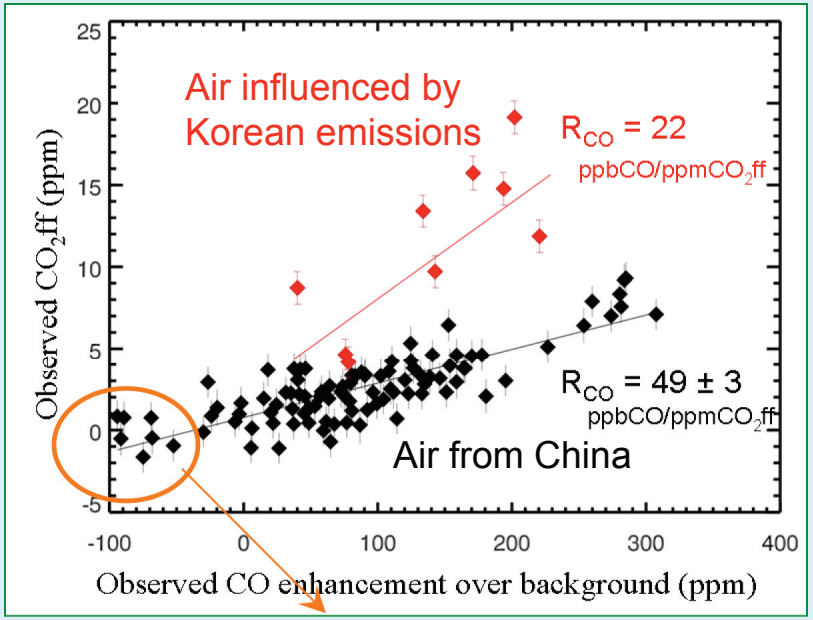
-Fossil fuel CO emissions (REAS:Ohara et al., 2007)

-Fossil fuel CO2 emissions (Marland et al., 2008)

Predicted RCO values for 2006:

42 ppb/ppm for China and 14 ppb/ppm for Korea.

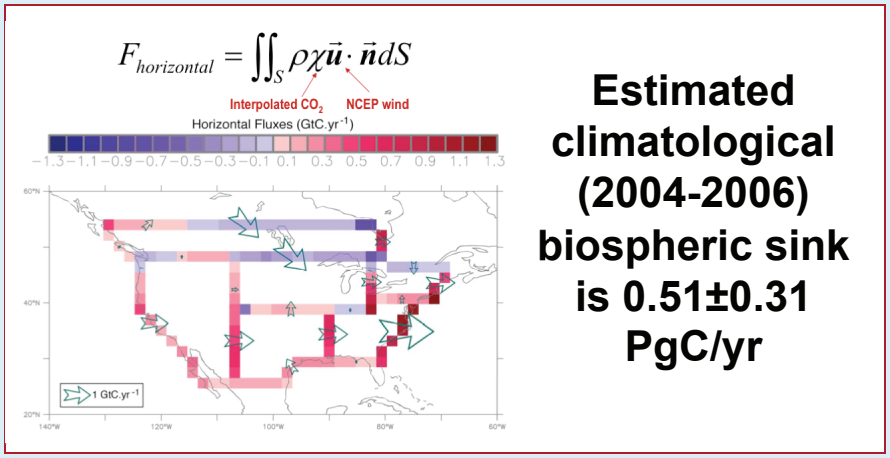
Consistent with observations!



Background CO influenced by fires

Temperate North America CO_2 Inversion using Aircraft Data

Colm Sweeney, Cyril Crevoisier

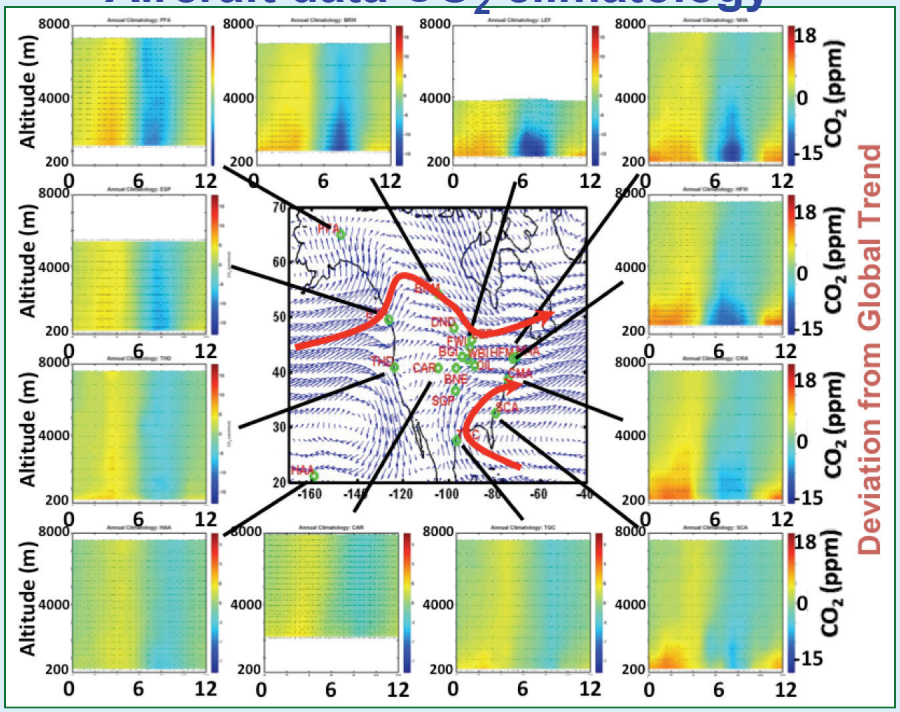


Estimated climatological (2004-2006) biospheric sink is 0.51±0.31 PgC/yr

Compares well with CT results which only use surface observations

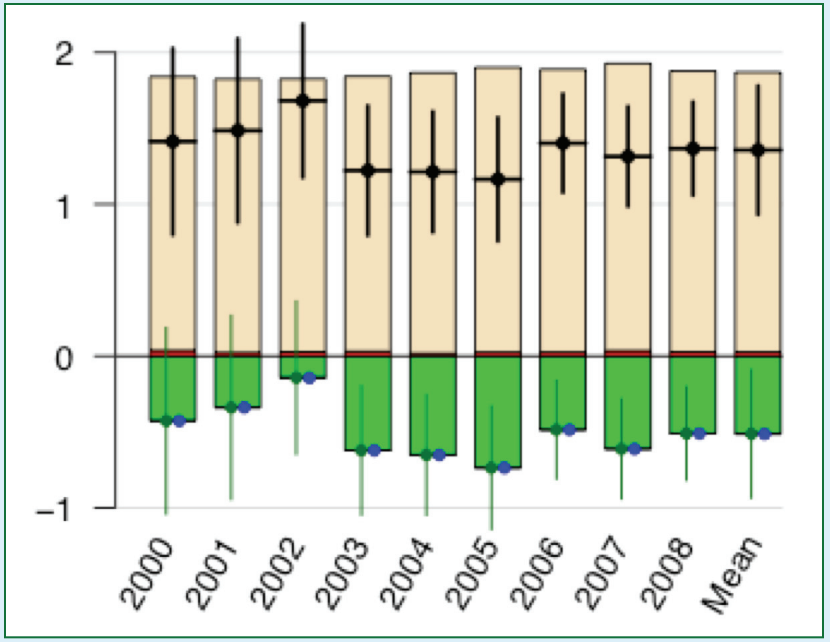
CT 2004-2006 average: -0.63PgC/yr

Aircraft data CO_2 climatology



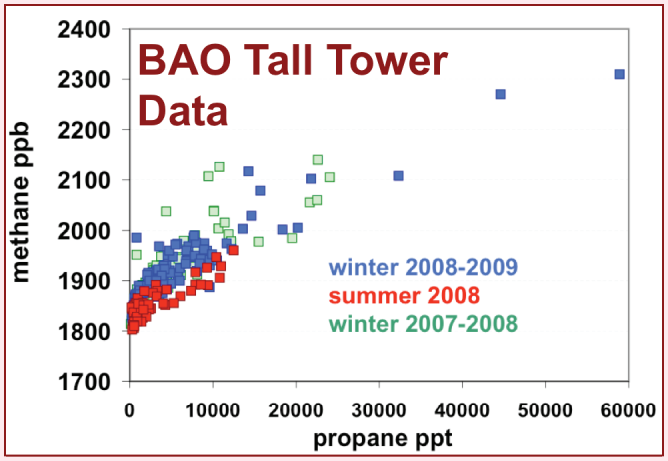
Optimized Land Fluxes- Global

Fossil Fuel, Fires, Biosphere



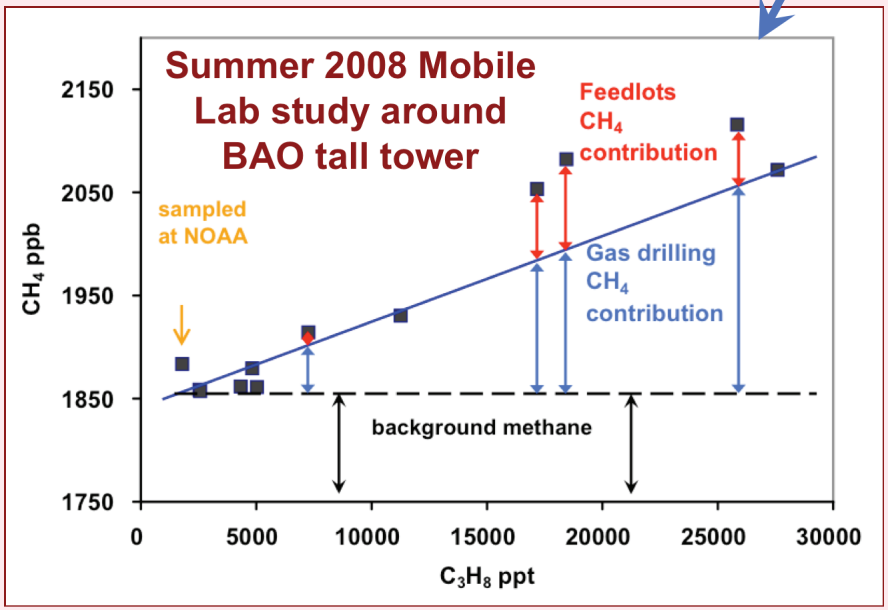
Local Scale: Colorado Front Range

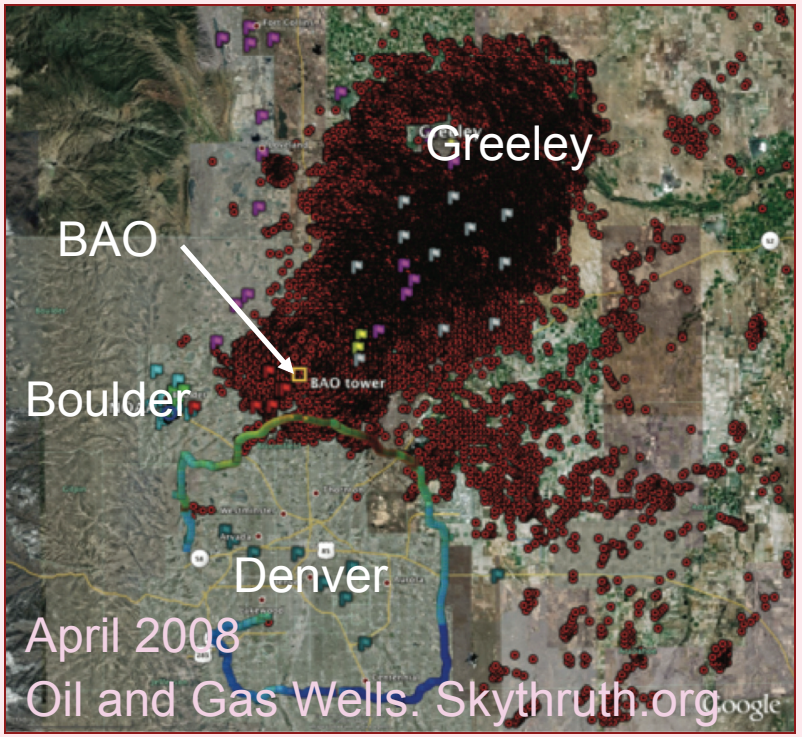
Pétron, Hirsch, Karion, Montzka, Miller, Sweeney, Andrews et al.



Influence of oil and gas drilling operations on alkanes variability observed at the BAO Tall Tower, CO (PI: A. Andrews) and in the Front Range.

Using propane measurements, we can separate the methane enhancements due to drilling operations from the ones due to feedlots.





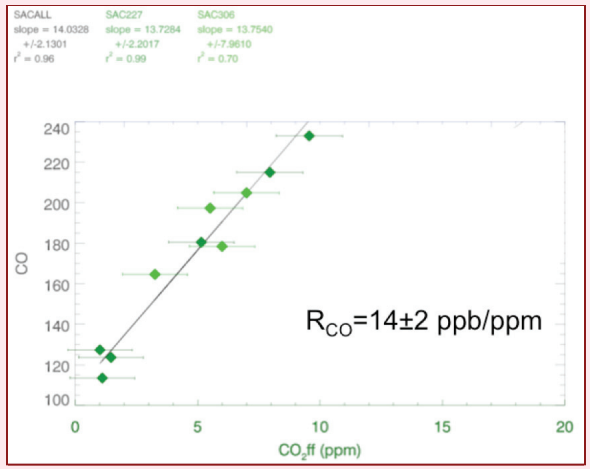
Local Scale: Sacramento Urban Plume

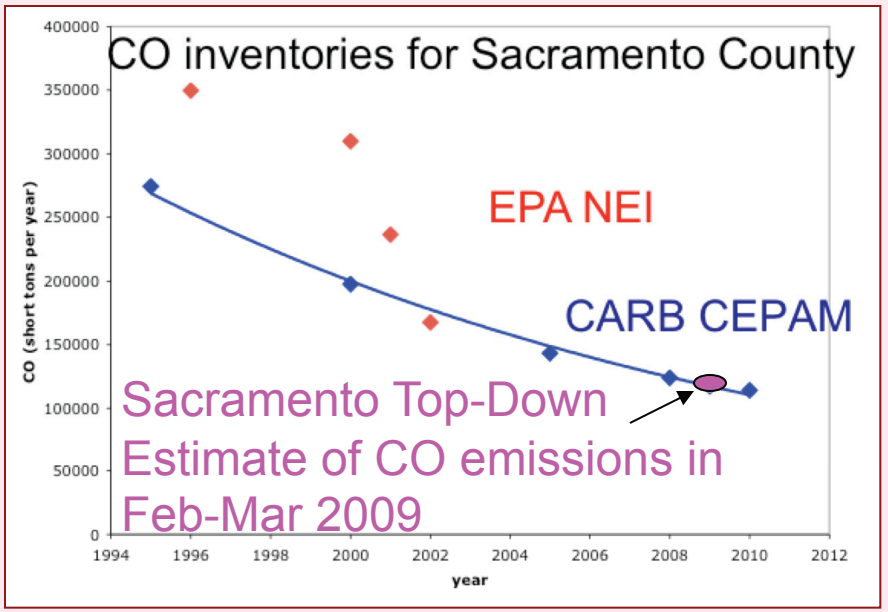
J. Turnbull, A. Karion et al., collaboration with DOE labs

Intensive aircraft campaign around California Tall Tower site (Walnut Grove)

Continuous CO_2 and CH_4 data + Targeted Air Samples analyzed for ~ 60 species including $^{14}CO_2$ as a marker of fossil fuel CO_2.

Fossil Fuel CO_2 (via $^{14}CO_2$) is used as a quantitative measure of fossil fuel combustion, and concentrations ratios for long lived species measured close to the sources, give a fairly close estimate of expected emissions ratios.

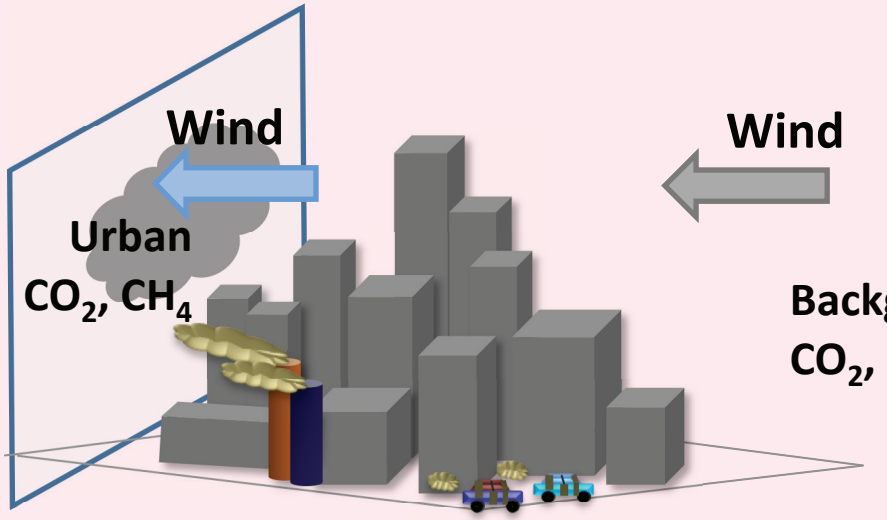




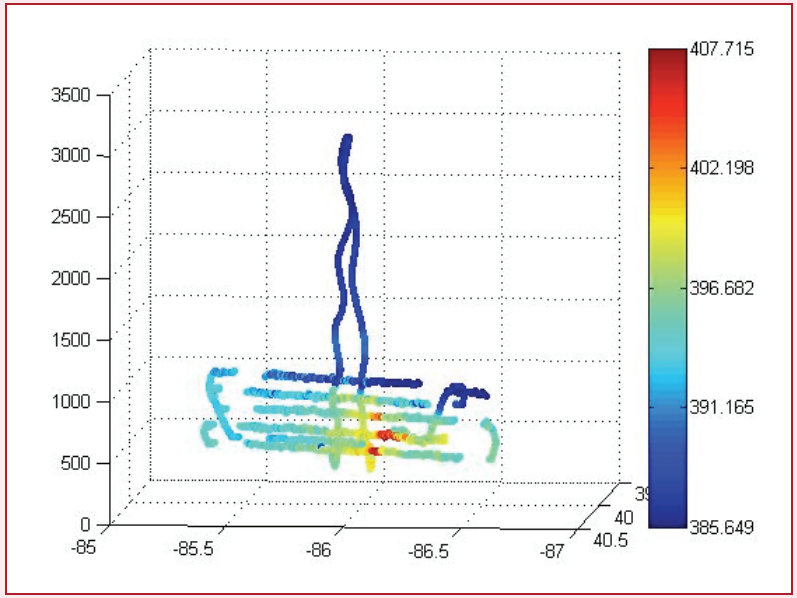
Using Fossil Fuel CO_2 emissions from Vulcan (2002) with 1.1%/yr increase from 2002 to 2009

Local Scale: Indianapolis Plume

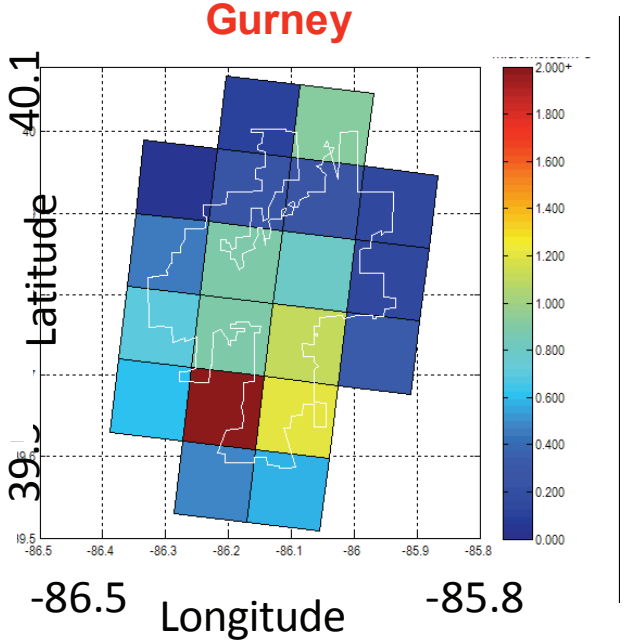
How can we evaluate high resolution inventories?



Kelly Ross(Purdue University)
Paul Shepson (Purdue University)
Colm Sweeney (NOAA/ESRL)
Anna Karion (NOAA/ESRL)



Vulcan 2002 Fossil Fuel Flux
Gurney

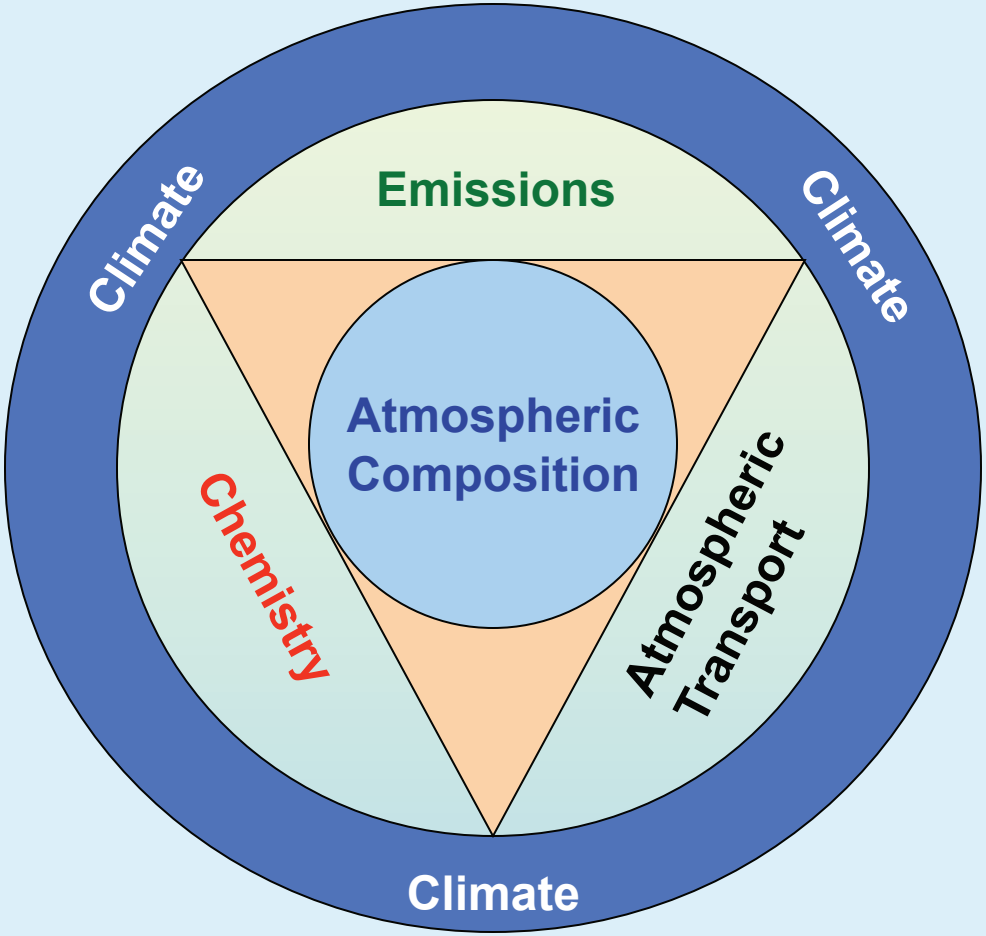


Conclusions

Emissions Inventories needed for GHG, HFCs, anthropogenic hydrocarbons…

- Updated
- Uncertainties
- Sector based emissions
- Multi-scales/resolutions: Local <=> Global
- Multiple species: fossil fuel CO_2 being a top priority
- Multi year (10-20 yrs) Emissions Inventories with consistent methodology

Perspectives…



Emissions inventories are key to improve our quantitative understanding of the atmosphere composition and how it changes over time and space.

For atmospheric constituents regulated by national laws or international protocols, only long-term high quality independent **atmospheric measurements** provide an objective assessment of changes in emissions.

Inventories like observations have uncertainties and potentially biases.

The analysis and combination of bottom-up and top-down approaches can reduce these uncertainties and biases