Fire emission inversions: CO

Yi Yin, Frederic Chevallier, Philippe Ciais

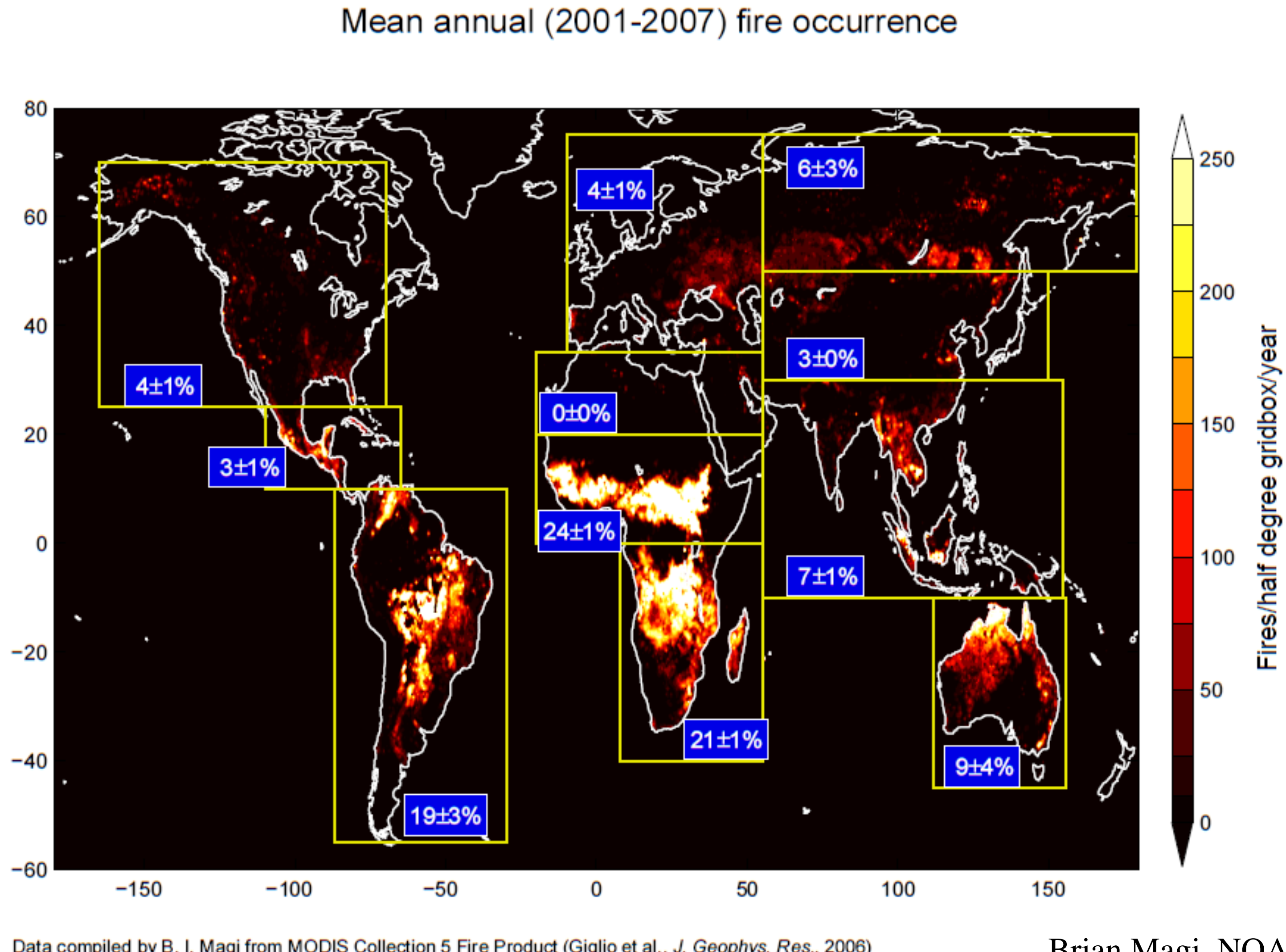
Biomass burning is a large source of atmospheric CO2, CO, aerosols and chemically important gases and is a major component of the carbon cycle and Earth climate system. It directly drives most of the interannual variability in carbon greenhouse gases and has also a direct influence on human societies. However, estimates of CO fire emissions still suffer from large uncertainties and the relationship between biomass, emission, climate, and anthopogenic activities is still uncertain. This ongoing project aims at firstly using top-down method to estimates CO emissions and then simulating emission factors for bottom-up fire modellings. Currently, using PYVAR-LMDz-SACs model, based on remote sensing retrievals of CO from MOPITT data and HCHO data from OMI as secondary control, with measurements of CH4 and MCF from surface station and airplane samplings, we estimated the overall monthly CO emissions from 2005 to 2010. The overall CO emissions shows strong correlation with satellite observed burned area, with some discrepancies might caused by other emission sources e.g. anthropogenic emissions, and uncertainties in emission factors. Further work in updating CO inversion from multiple remote sensing data till 2012, attributing CO emission sources and simulating emission factors in fire modeling will be the main focus.

Fire emission inversions: CO

Yi Yin, Frederic Chevallier,
Audrey Fortems-Cheiney, Philippe Ciais

LSCE

Background: Biomass burning



Brian Magi, NOAA GFDL

Background: Emissions from fire

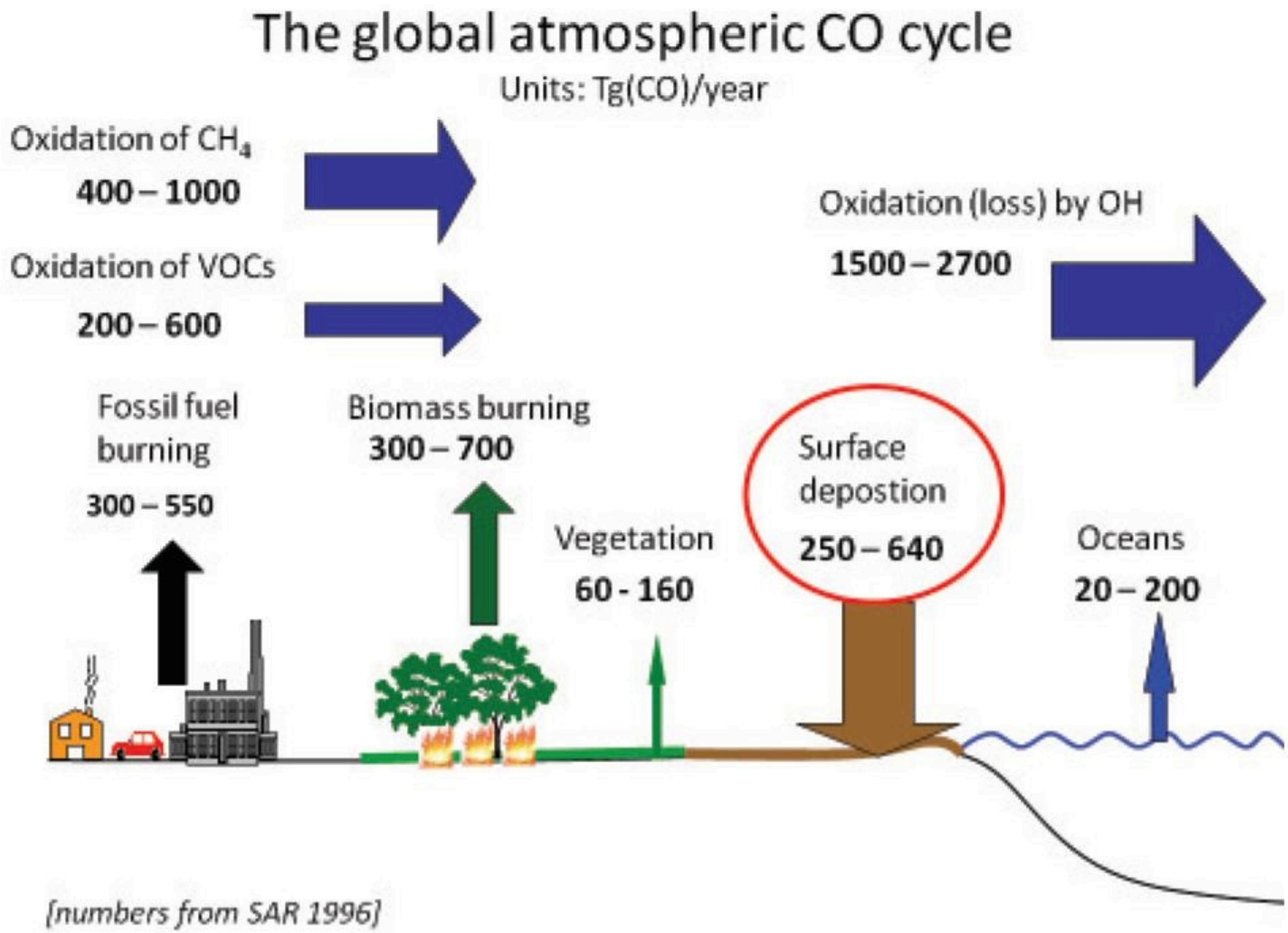
Carbon dioxide (CO_2)
Carbon monoxide (CO)
Methane (CH_4)
Ethane (C_2H_6)
Ethene (C_2H_4)
Ethyne (C_2H_2)
Propane (C_3H_8)
Propene (C_3H_6)
Propyne (C_3H_4)
n-butane (n-C_4H_{10})
i-butane (i-C_4H_{10})
1+i-butene (C_4H_8)
1-butene (C_4H_8)
i-butene (C_4H_8)
t-2-butene (C_4H_8)
c-2-butene (C_4H_8)
1,3 butadiene (C_4H_6)
n-pentane (n-C_5H_{12})
i-pentane (i-C_5H_{12})
1-pentene (C_5H_{10})
cis-2-pentene (C_5H_{10})
trans-2-pentene (C_5H_{10})
2-methyl-1-butene (C_5H_{10})
2-methyl-2-butene (C_5H_{10})
3-methyl-1-butene (C_5H_{10})
Cyclopentene (C_5H_8)
Isoprene (C_5H_8)

1,3-pentadiene (C_5H_8)
1,3-cyclopentadiene (C_5H_6)
Hexane (C_6H_{14})
Methylcyclopentane (C_6H_{12})
1-hexene (C_6H_{12})
trans-2-hexene (C_6H_{12})
cis-2-hexene (C_6H_{12})
2-methylpentene (C_6H_{12})
Heptane (C_7H_{16})
Octane (C_8H_{18})
1-octene (C_8H_{16})
1-nonene (C_9H_{18})
Decane ($C_{10}H_{22}$)
Benzene (C_6H_6)
Toluene (C_7H_8)
m+p-xylene (C_8H_{10})
o-xylene (C_8H_{10})
Xylenes (C_8H_{10})
Ethylbenzene (C_8H_{10})
Methanol (CH_4O)
Phenol
Formic acid (CH_2O_2)
Acetic acid (CH_4O_2)
Formaldehyde (CH_2O)
Acetaldehyde (C_2H_4O)
Propanal (C_3H_6O)
Propenal (C_3H_4O)
2-methylpropanal (C_4H_8O)
2-methylbutanal ($C_5H_{10}O$)

Acetone (C_3H_6O)
2-butanone (C_4H_8O)
2,3-butanedione ($C_4H_6O_2$)
2-pentanone ($C_5H_{10}O$)
Cyclopentanone (C_5H_8O)
Furan (C_4H_4O)
2-methyl-furan (C_5H_6O)
3-methyl-furan (C_5H_6O)
2-ethylfuran (C_6H_8O)
2,5-dimethyl-furan (C_6H_8O)
2-vinyl-furan (C_6H_6O)
Benzofuran (C_8H_6O)
Nitrogen oxides (as NO)
Nitric oxide (NO)
Nitrous oxide (N_2O)
Ammonia (NH_3)
Hydrogen cyanide (HCN)
Aectonitrile (CH_3CN)
Sulfur dioxide (SO_2)
Carbonyl sulfide (OCS)
$PM_{2.5}$

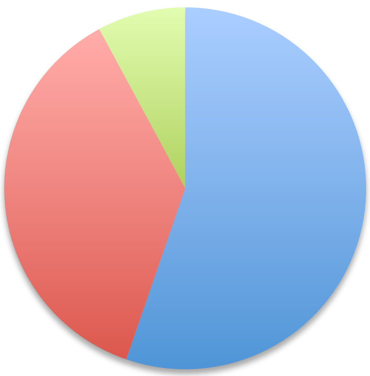
Urbanski et al., Wildland Fires and Air Pollution, (2009)

Background: Global atmospheric CO budget

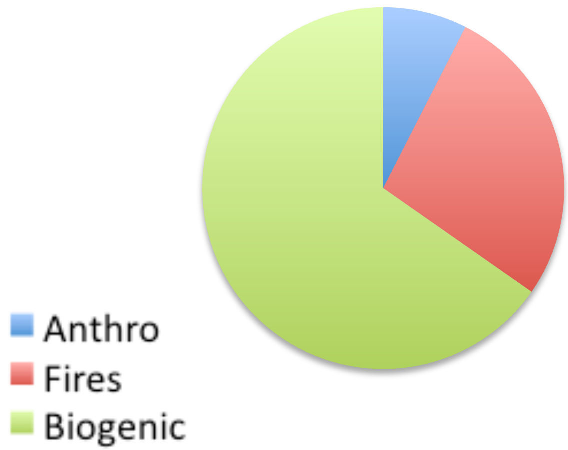


Background: Global Emissions estimates

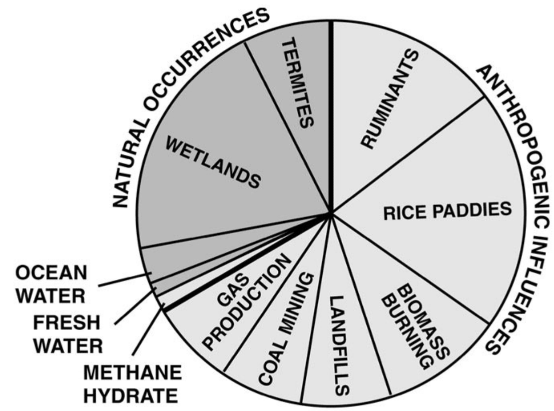
CO



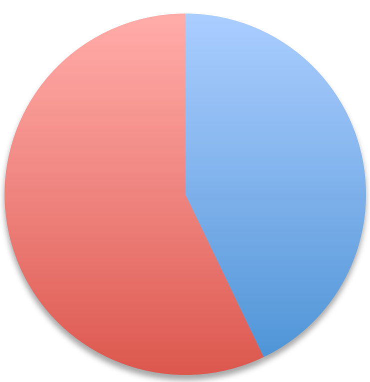
VOC



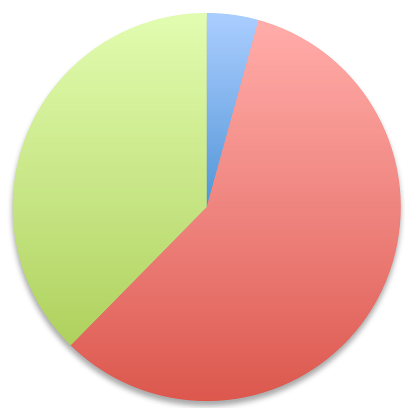
CH4



Black Carbon



Primary Oganic Matter



EDGAR4.2 （2000）
Yokelson et al., ACP, 2008
Andreae and Rosenfeld, *Earth Science Reviews*, 2008
Andreae and Merlet, GBC, 2001
Yan et al, GBC, 2005
Guenther et al., 1995; 2006; GFEDv3.1

A. Bottom-up methods

$$Emissions_i = f(A(x,t), B(x,t), E_{f_i})$$

- A(x,t): Area burned
- B(x,t): Biomass burned (biomass burned/area)
  - type of vegetation (ecology)
  - fuel characteristics:
    - amounts of woody biomass, leaf biomass, litter, …
  - fuel condition
    - moisture content
- E_{fi}: Emission factor (mass emission /biomass burned)
  - fuel characteristics
  - fuel condition

A. Bottom-up methods

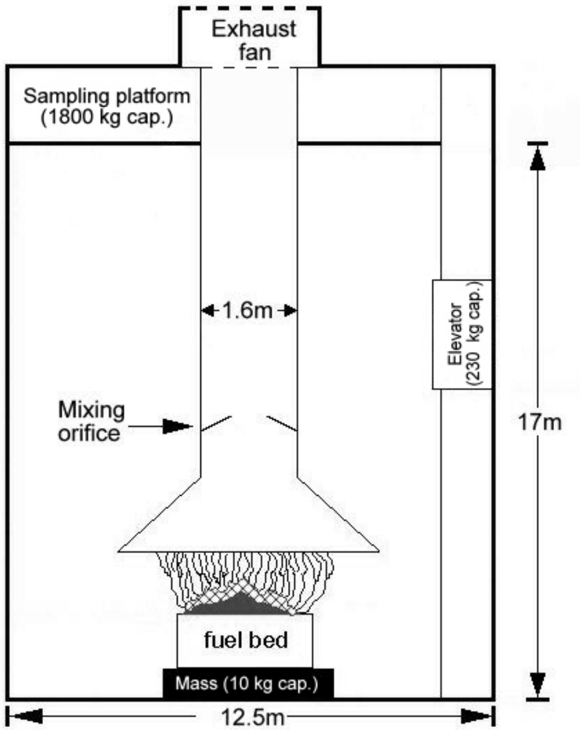
(1) Emission factors determined from field measurements

- Resolution and coverage inadequacy in temporal & spatial
- Dilution prior to measurements

http://www.umt.edu/chemistry/faculty/yokelson.htm

A. Bottom-up methods

(2) Emission factors determined from laboratory experiments



A schematic of the USFS Fire Sciences Laboratory (FSL)
combustion facility in Missoula, MT.

- Resolution and coverage inadequacy in temporal & spatial
- Dilution/accumulation prior to measurements

http://www.umt.edu/chemistry/faculty/yokelson.htm

B. Top-down method

- Surface flux inversion based on atmosphere concentration observations
- Question?
  - Biomass burning emission attribution
  - Emission factor validation in fire modelling
    - constant emission factors in different biomes
  - What influences the burning emission of CO?
    - dynamic emission factors simulation
      - Biome, biomass burned, fuel condition, season, weather, humidity…

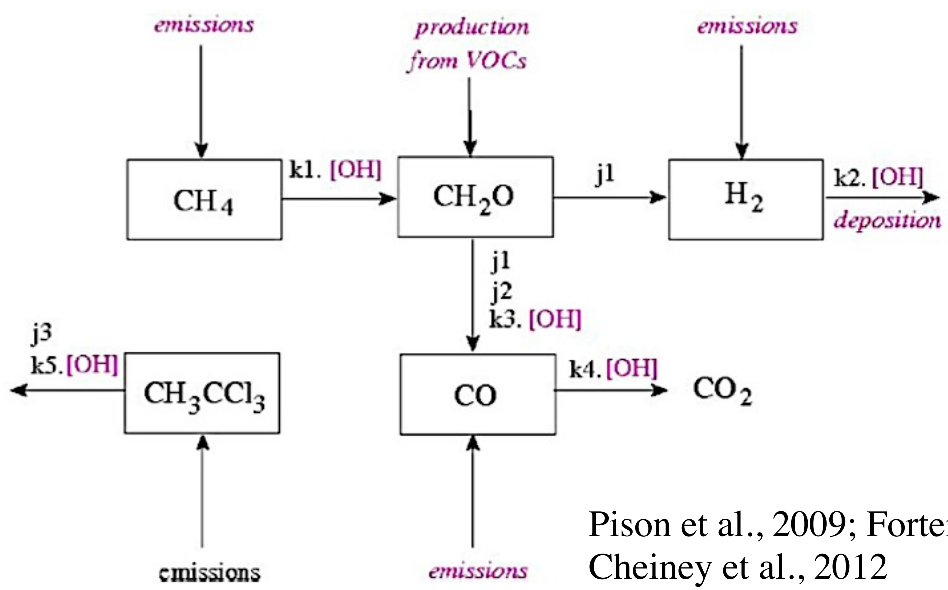
Data & Method

- **Data**
  - CO (remote sensing)
    - MOPITT
    - AIRS
    - IASI
  - HCHO (remote sensing)
    - OMI
  - CH4, MCF (measurements)
    - Surface sites
    - Airplanes
  - OH
    - INCA simulated

- **Inversion System**
  - Pyvar (Chevallier et al., 2009)

$$\nabla J(\mathbf{x}) = 2\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_b) + 2\mathbf{H}^T\mathbf{R}^{-1}(\mathbf{y}-H[\mathbf{x}])$$

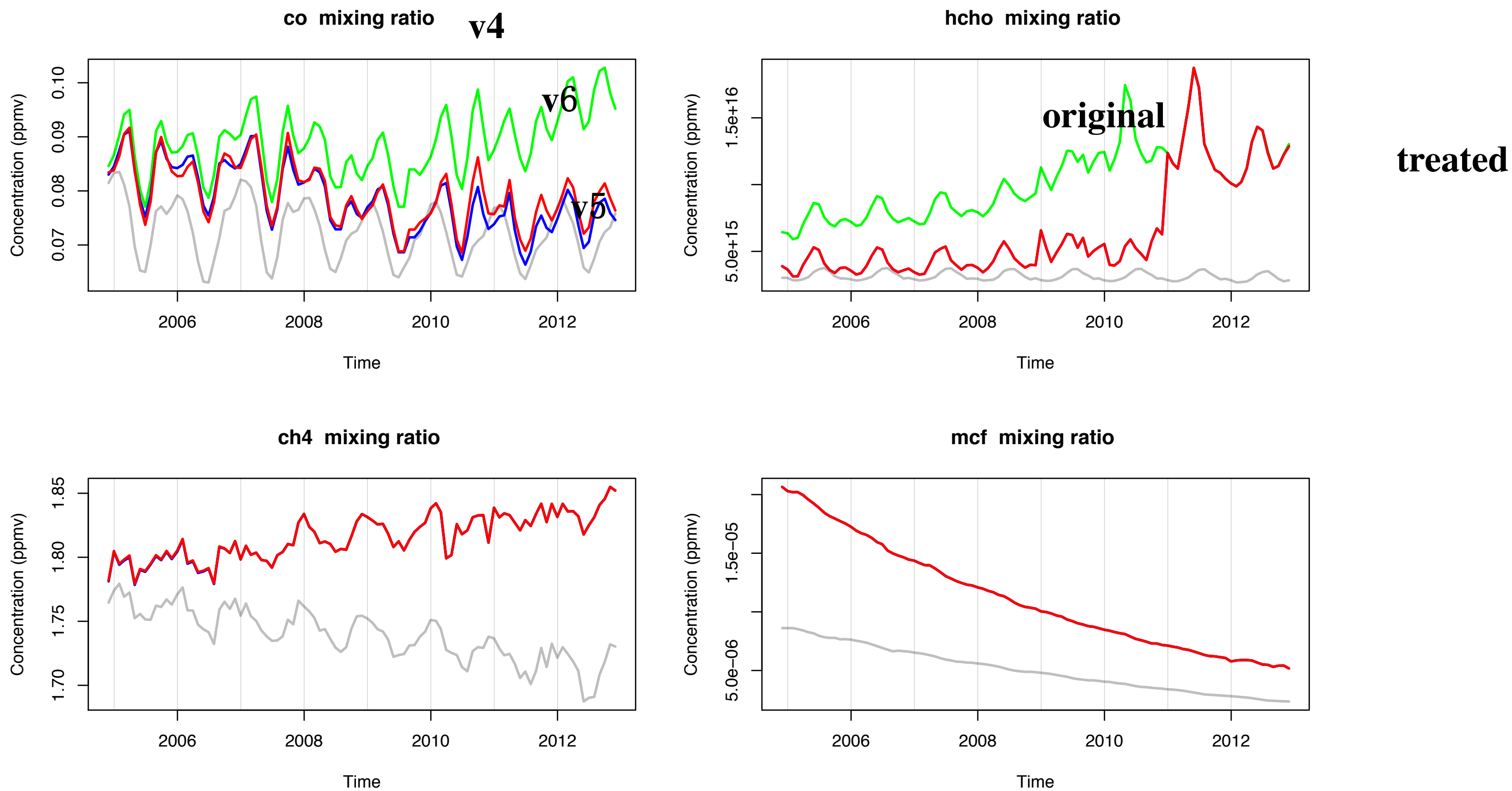
  - Transportation model
    - LMDz
  - Chemical model
    - INCA - SACS



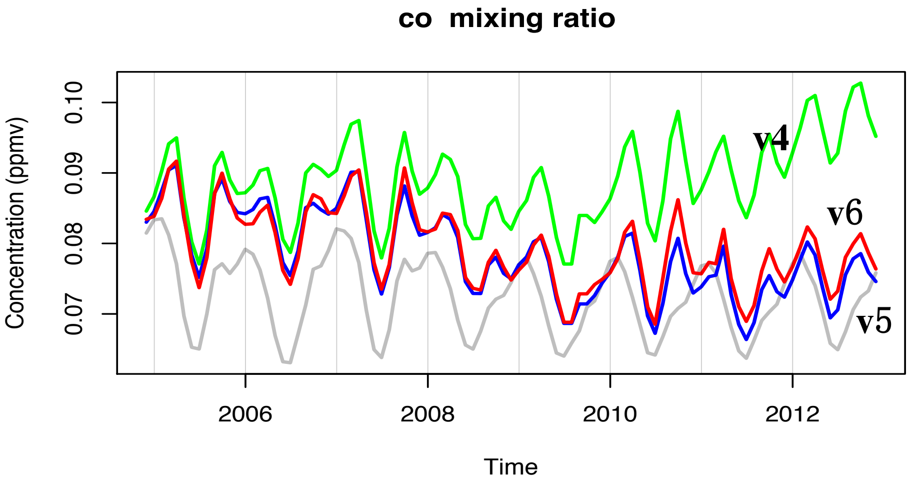
Pison et al., 2009; Fortems-Cheiney et al., 2012

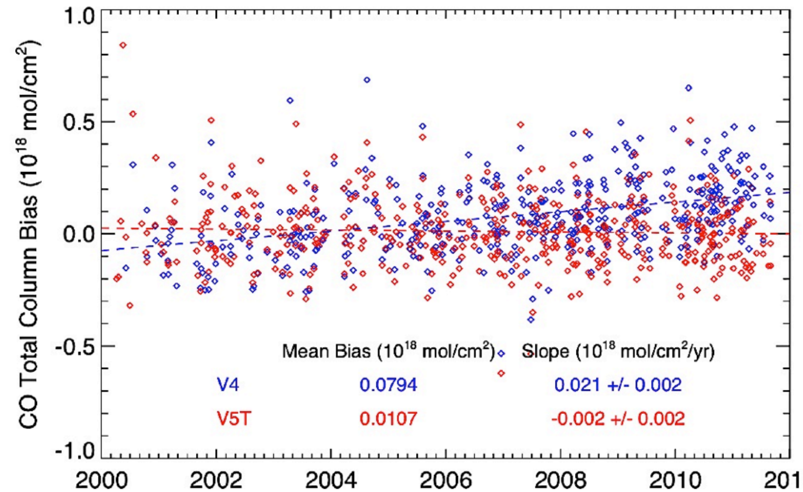
Data selection

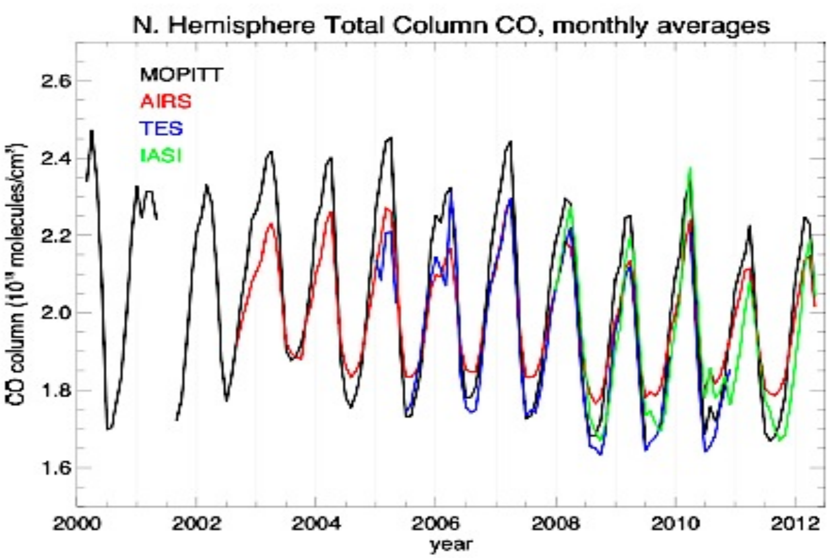
Grey line – prior emission computed mixing ratio by forward LMDz; Color lines- observation

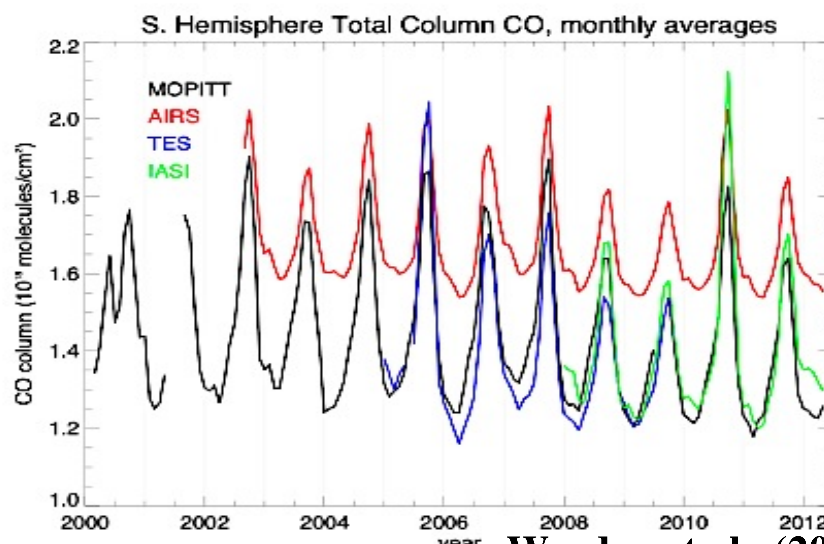


Data selection



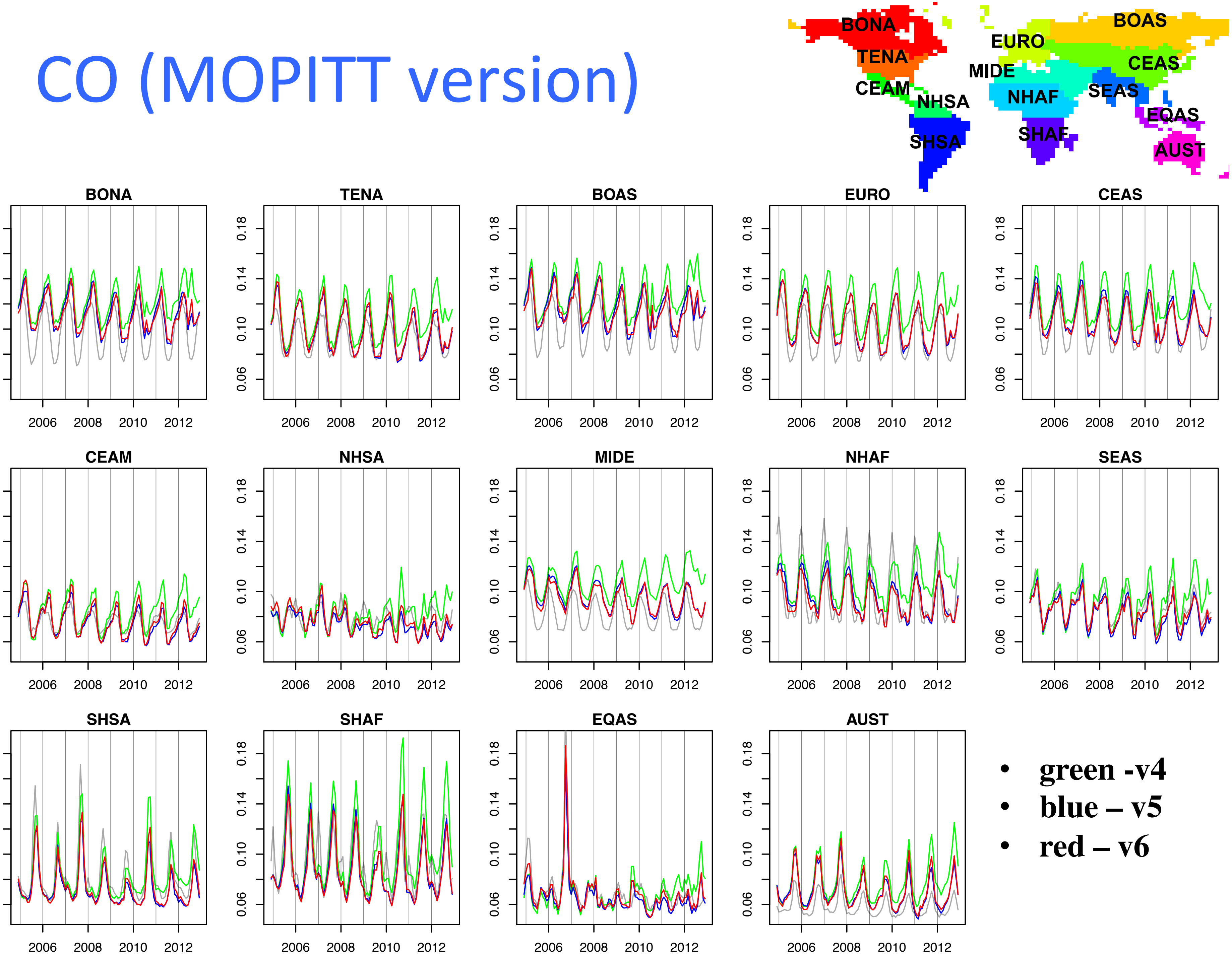






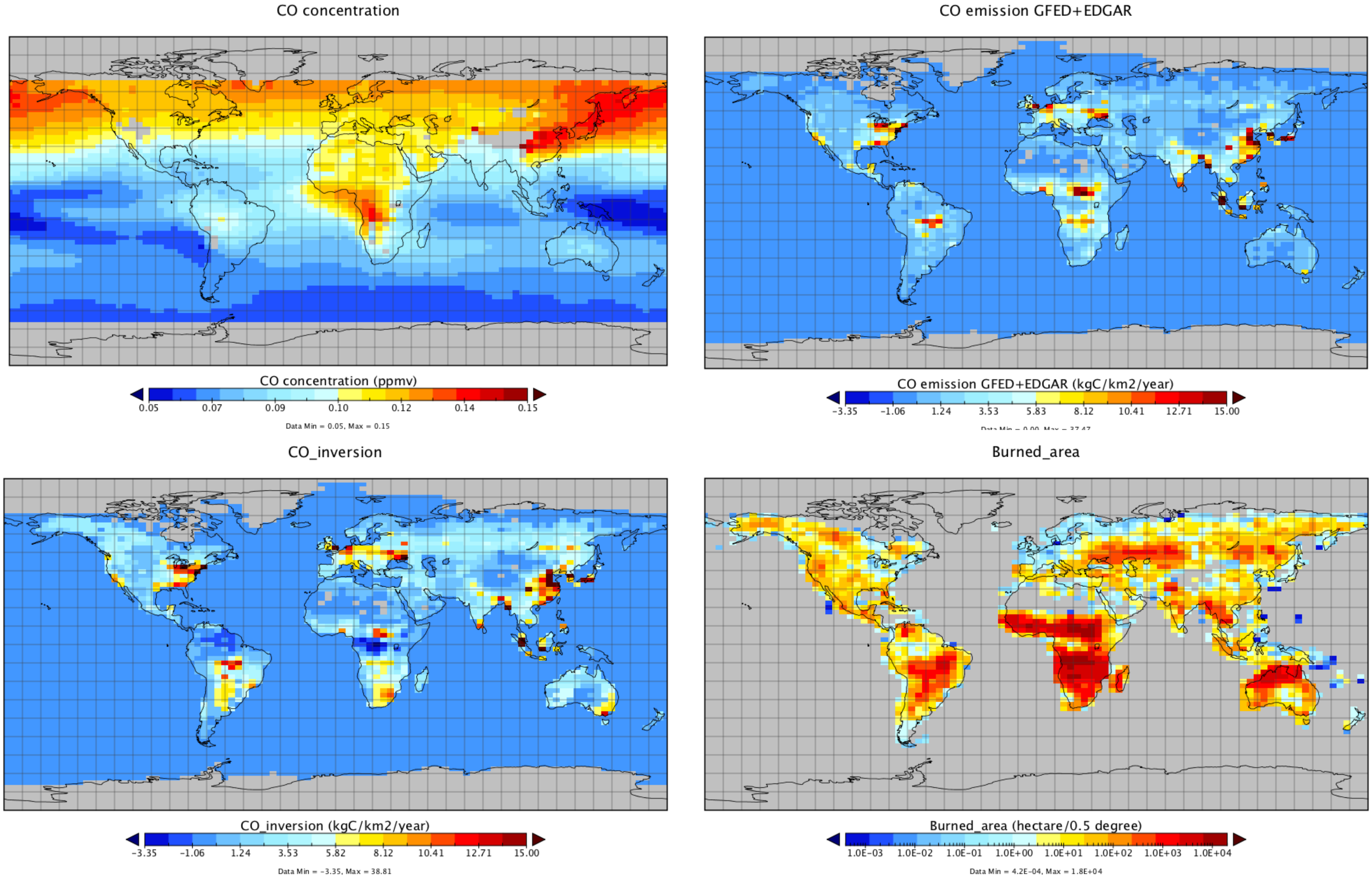
Worden et al., (2013)

CO (MOPITT version)

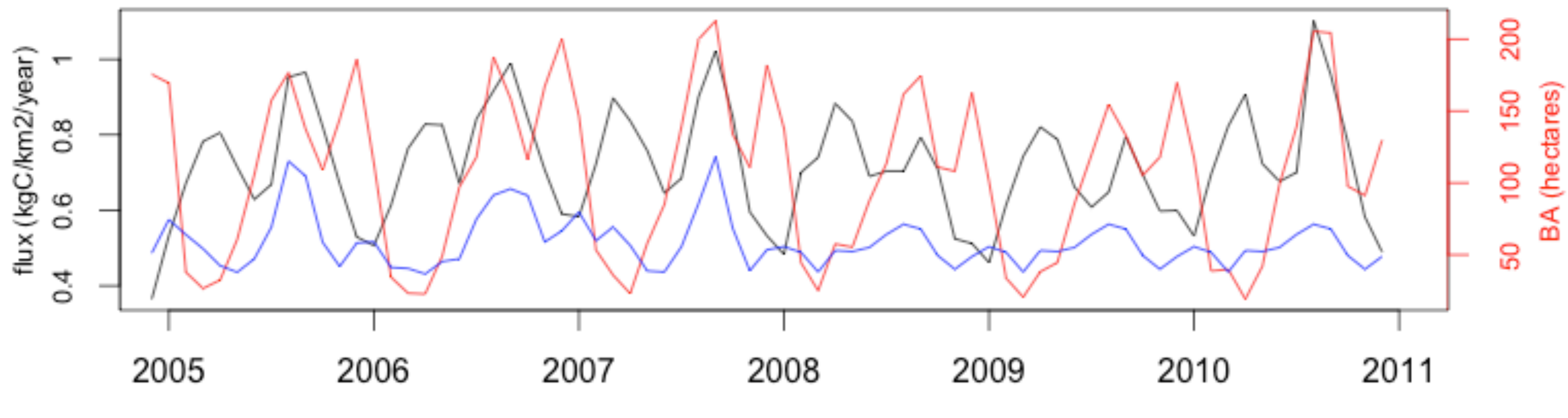


- green -v4
- blue – v5
- red – v6

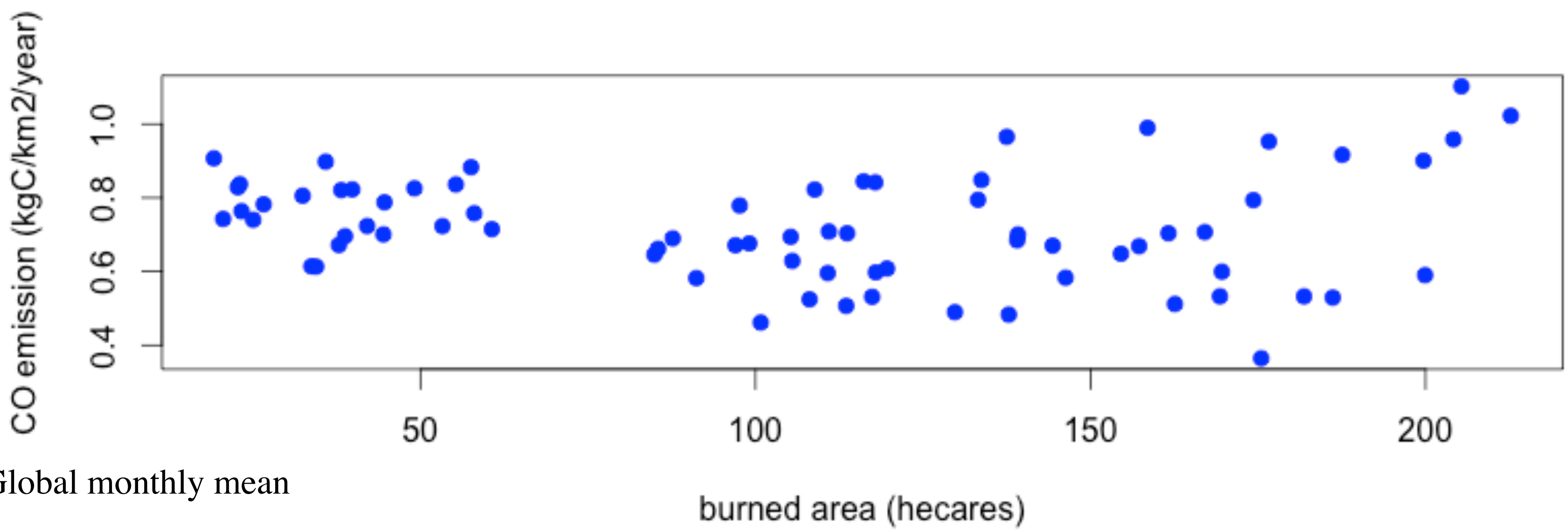
Global pattern of CO obs, prior, inversion and burned area



Temporal change of CO flux (prior vs. inversion) and burned area

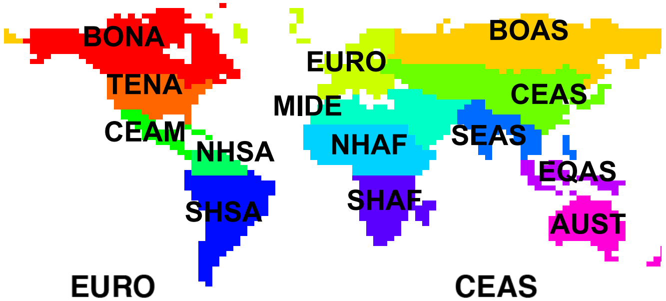


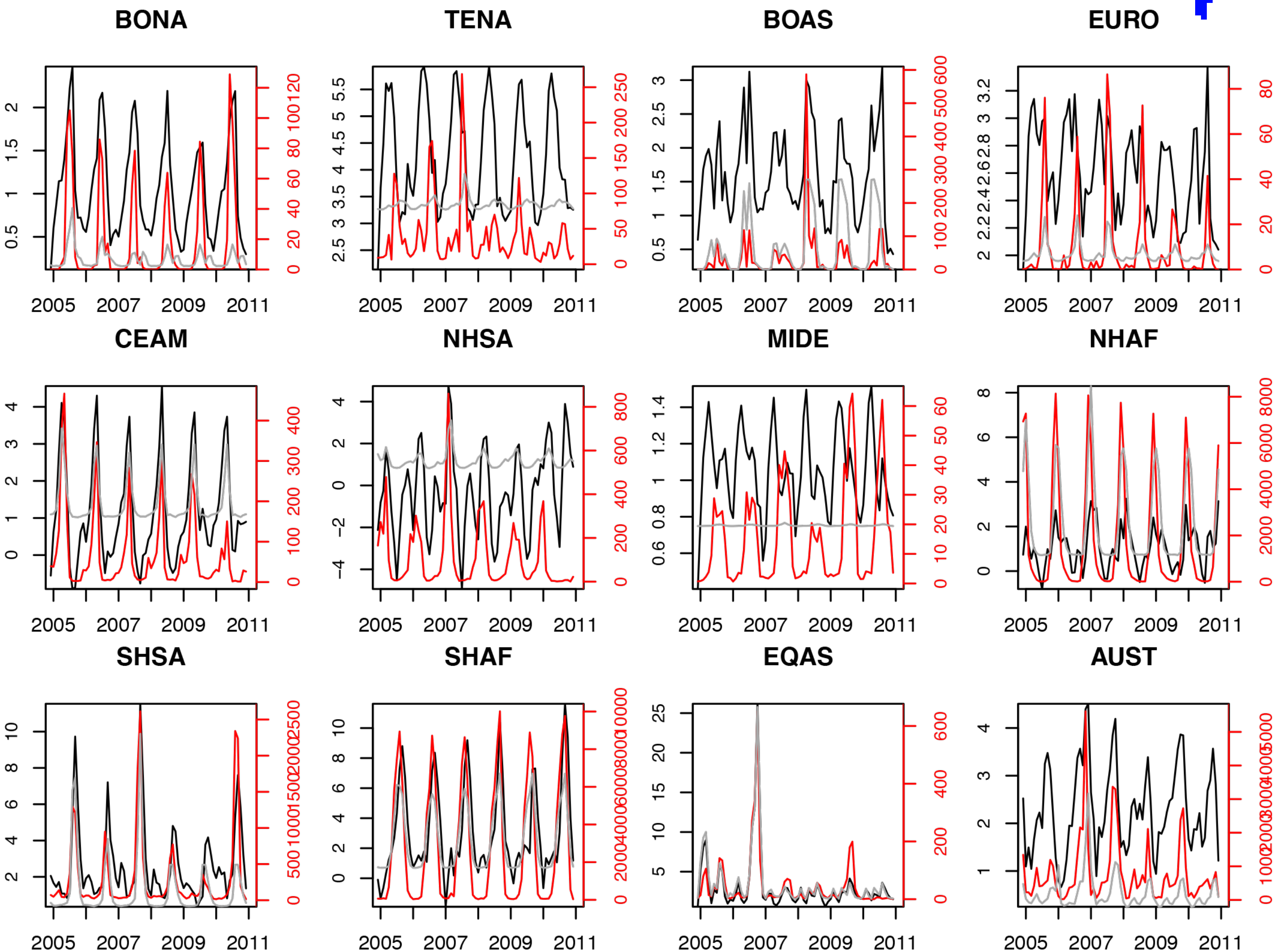
Total CO emission inversion (black)
vs. prior emission (blue-EDGAR+GFED)
vs. burned area (red)



Global monthly mean

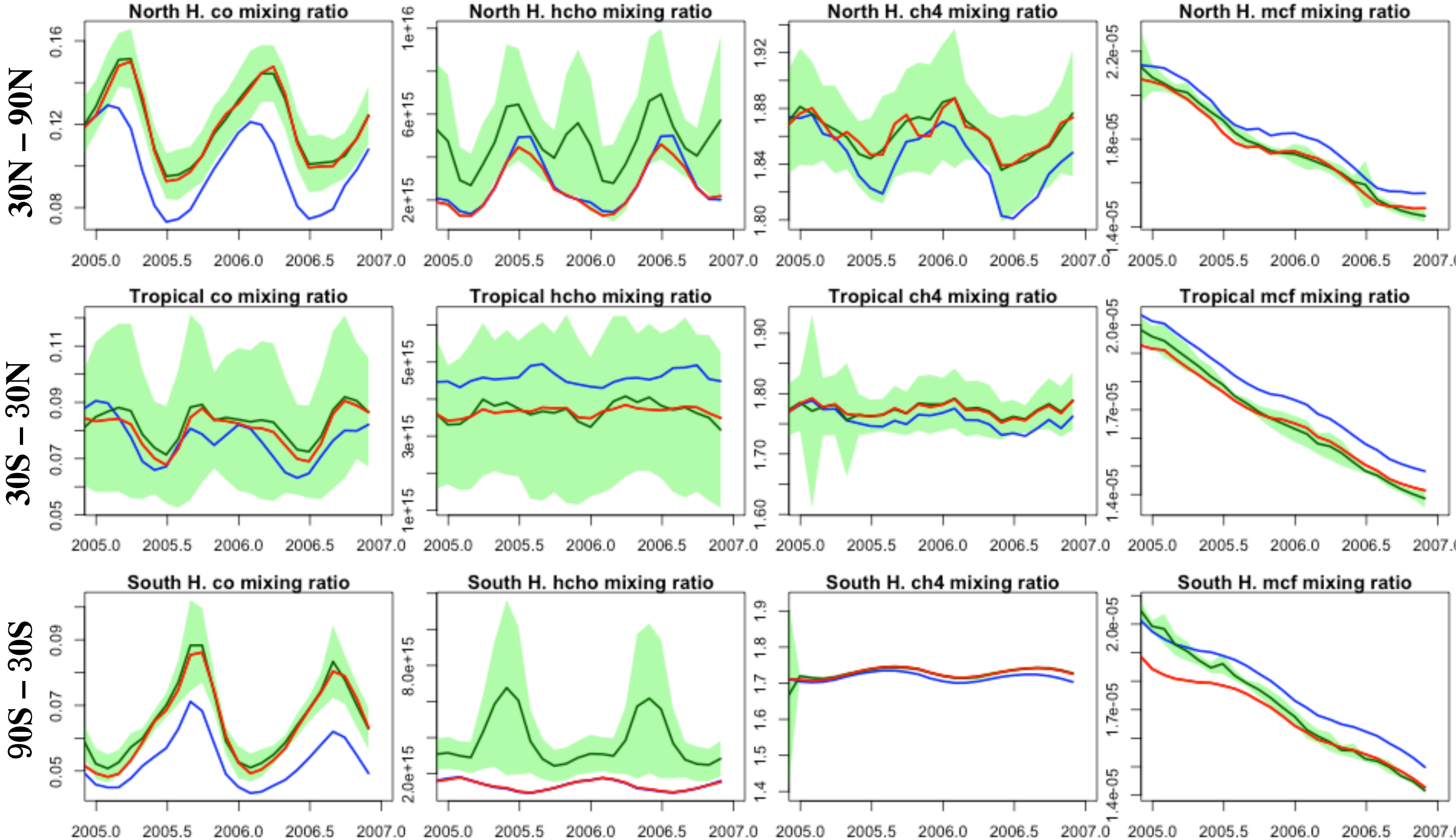
CO inversion vs. prior



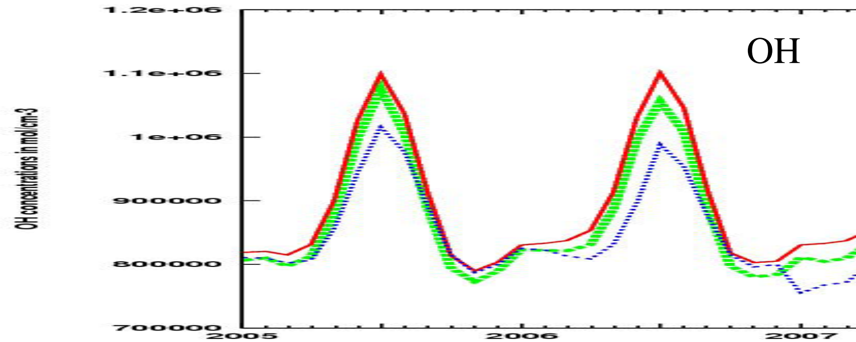


Black – inv
Grey – prior
Red – burned_area

Obs (green) – Prior (blue) – Inv (red)



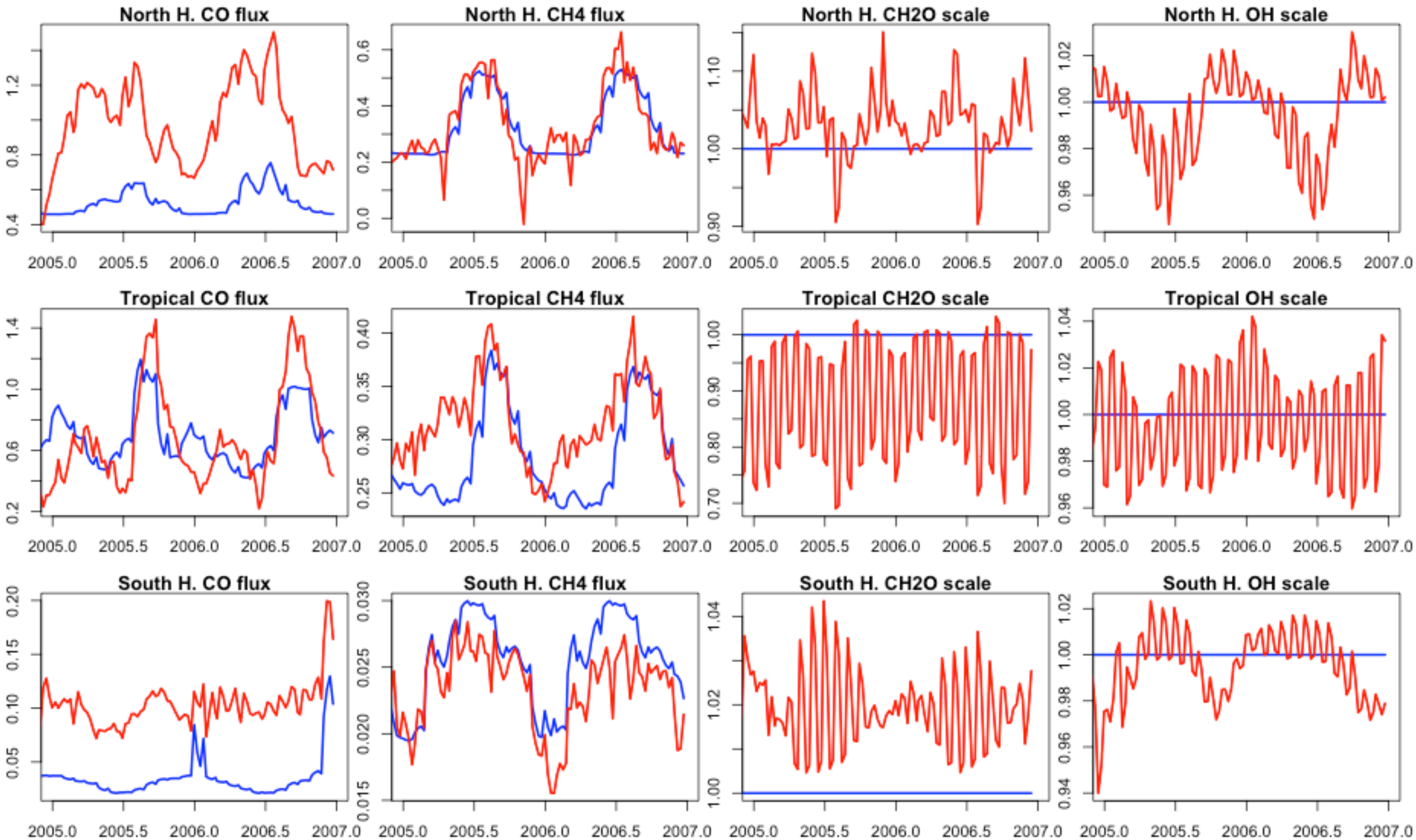
Prior flux vs. inversion



30N – 90N

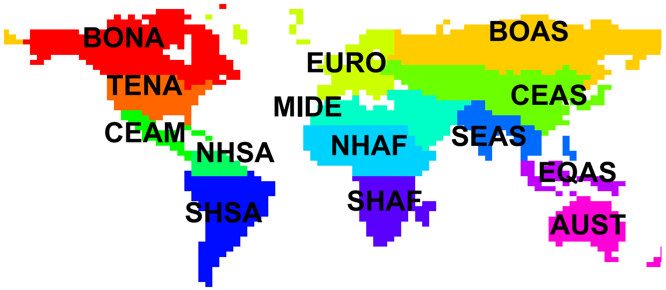
30S – 30N

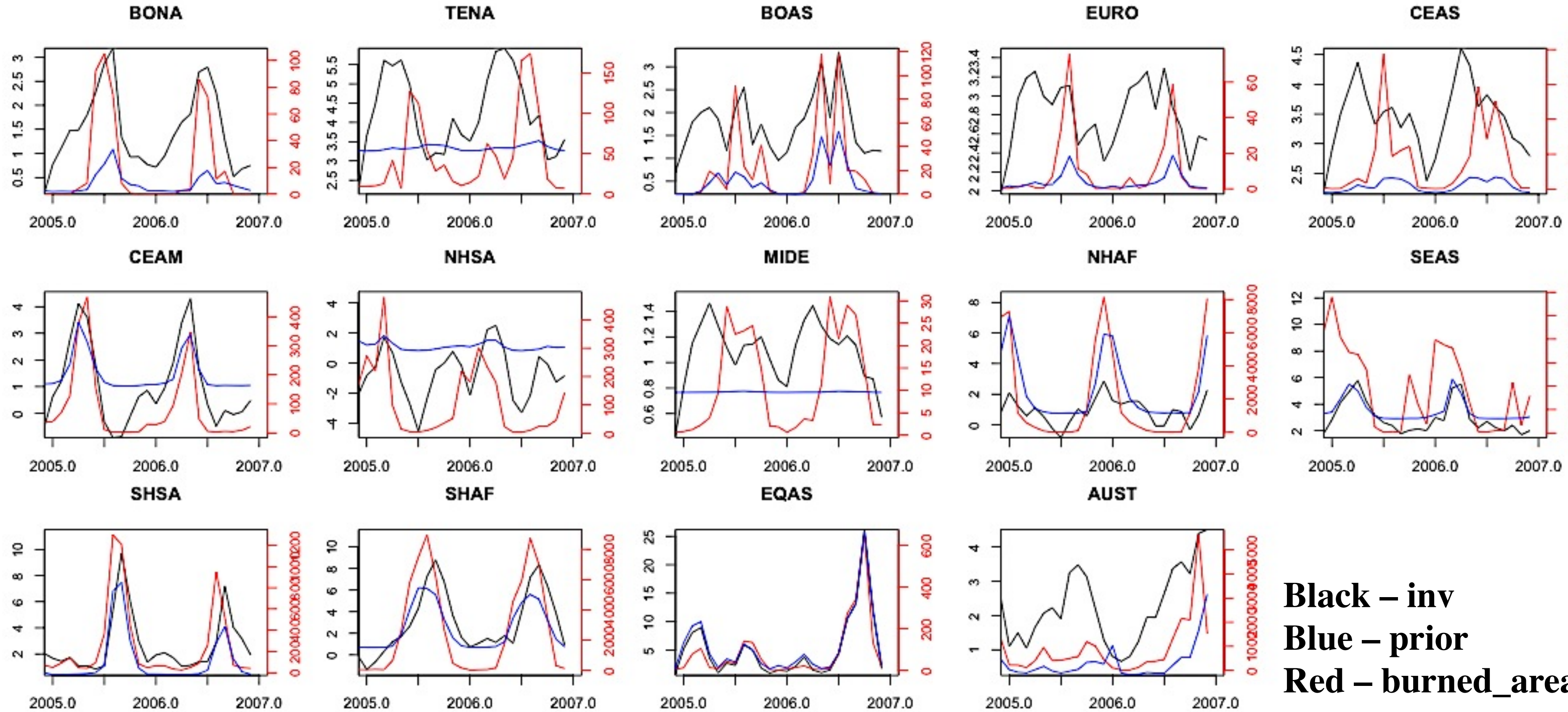
90S – 30S



SINO-FRENC

Inversion – prior – burned area





Black – inv
Blue – prior
Red – burned_area

Total budget

	2006	
	prior	post
North Am Boreal	9±13	**54±8**
USA	117±19	**150±18**
South Am Trop	34±12	**24±6**
South Am Temp	66±23	**158±13**
Northern Africa	141±23	**94±14**
Southern Africa	92±21	**137±13**
Western Europe	70±13	**92±7**
Eastern Europe	41±15	**71±10**
Eurasian Boreal	30±22	**110±16**
Middle East	24±10	**34±7**
South Asia	80±16	**66±11**
South East Asia	168±20	**208±15**
Indonesia	129±5	**122±4**
Australia	29±14	**96±10**
Globe	1047±68	**1434±66**

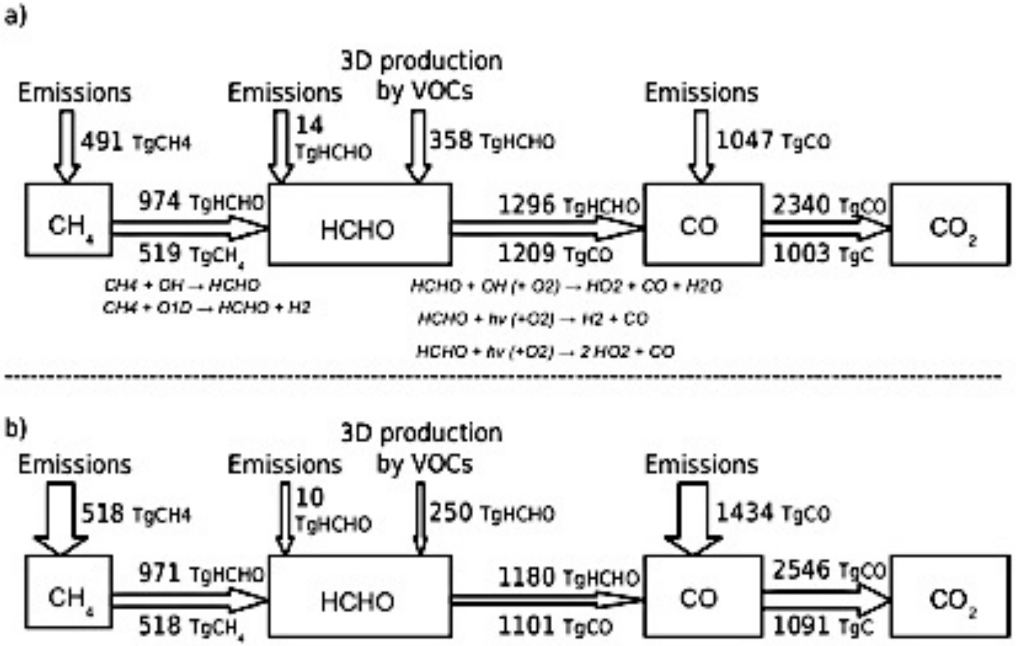
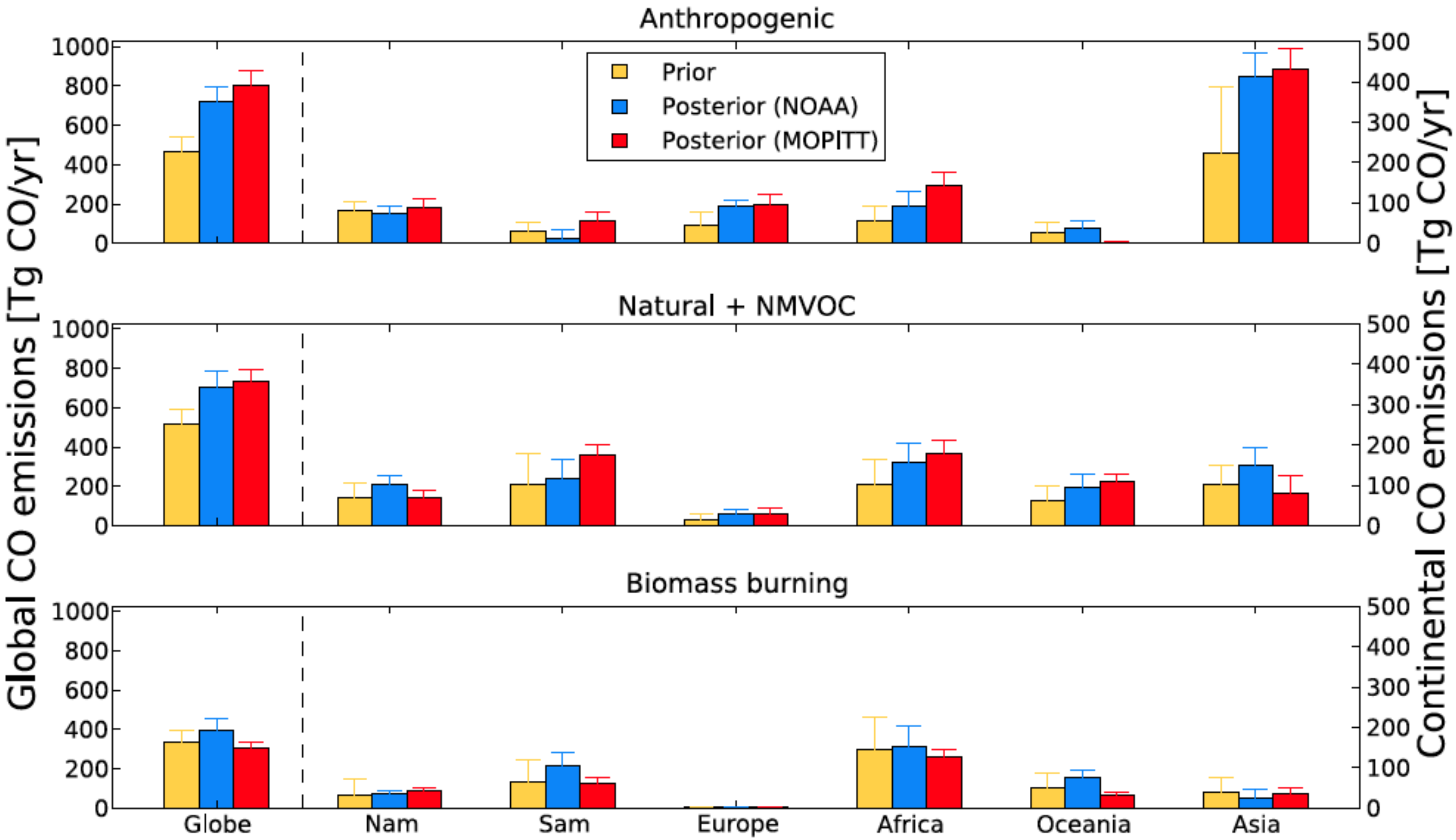


Fig. 1. Prior **(a)** and posterior **(b)** HCHO sources and sinks in the SACS mechanism. Sinks of H_2 and the HCHO deposition are included in SACS but not displayed. Changes of arrow thickness between prior and posterior indicate a reduction or an increase of the sources and sinks. Values are for year 2006.

Fortems et al., (2012)

Other inversion results



Hooghiemstra et al. (2012)

Possible explanations

- Missing emission in prior in North Hemisphere in spring?
  - Anthropogenic emissions: heating, vehicle
  - Moldering: burned area not detected…
- Inversion error?
  - High spring concentration
    - Low temperature, less radiation, less OH
    - Result in miss-calculated high emission?

Next steps

- Update CO emission inversions till 2012 with updated versions
- Multiple Remote sensing data sources to narrow the uncertainty
  - AIRS, IASI
  - OMI…
- Attribute biomass burning emissions
  - Seasonal change in anthropogenic emission
  - Multi-species attributions (CO to CH4, CO2 ratios)
- Emission factors estimation