Modeling Fire Emissions

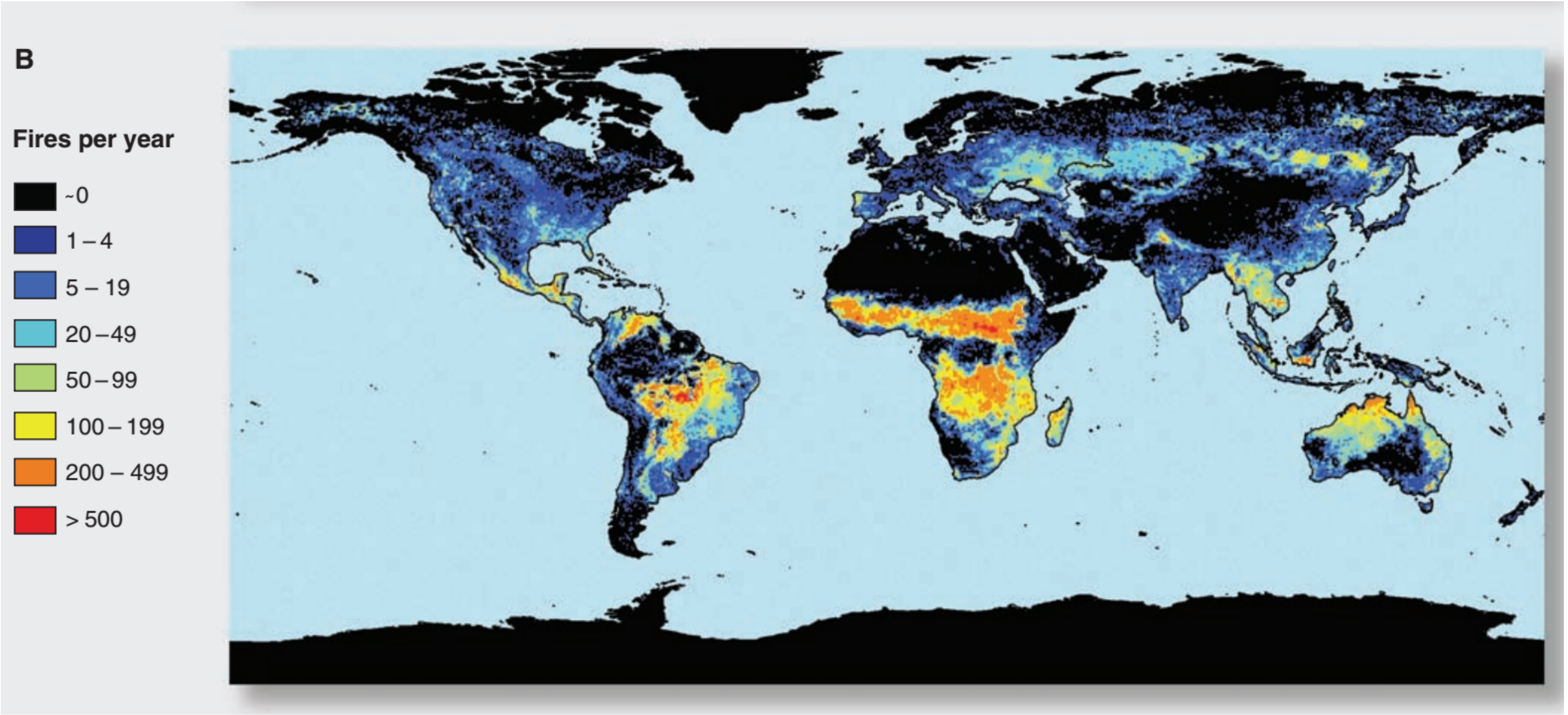
Christine Wiedinmyer

What do you need to know?

- Where and When?
  - Where is the fire happening? When?

Global Fire Activity

- Wildfires
- Prescribed Burning
- Agricultural Burning
- Land clearing



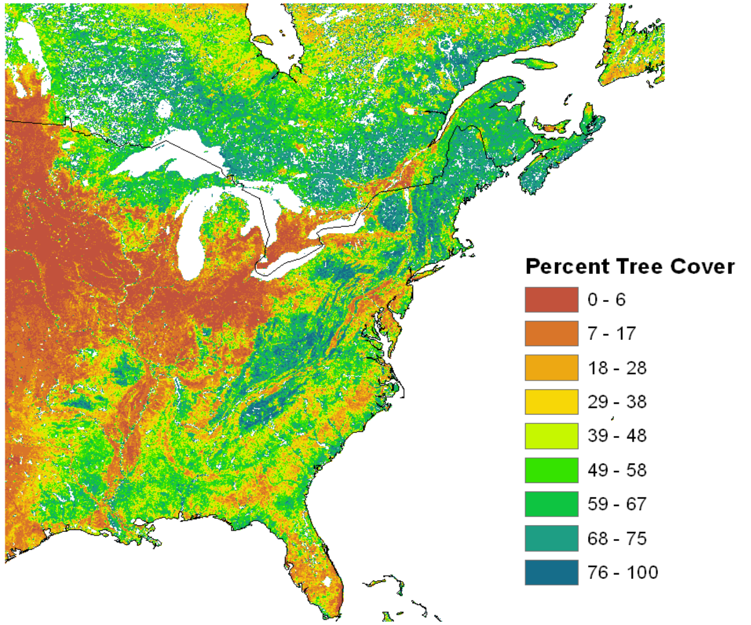
Bowman et al., *Science*, 2009

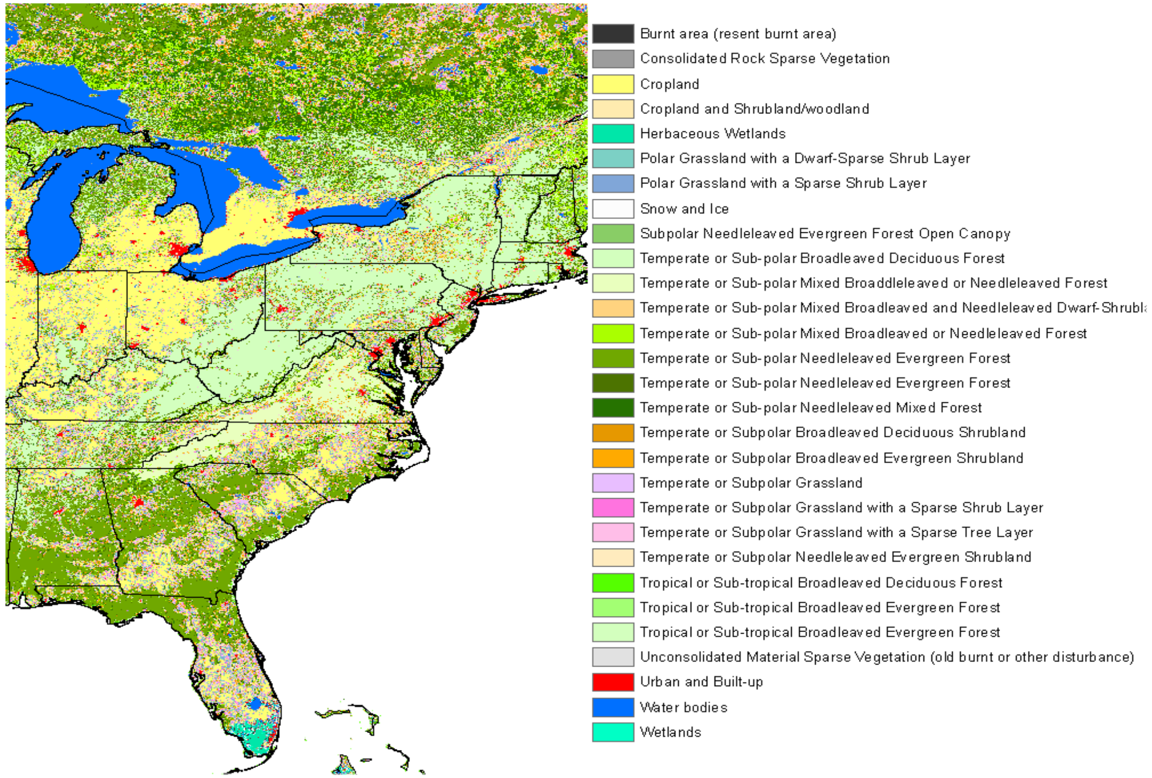
What do you need to know?

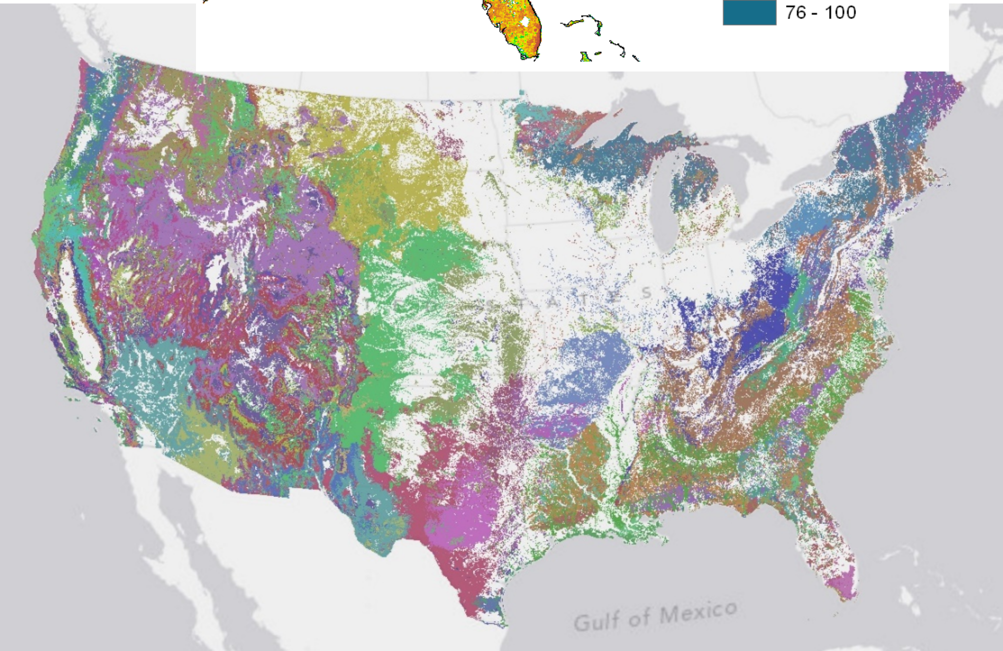
- Where and When?
  - Where is the fire happening? When?

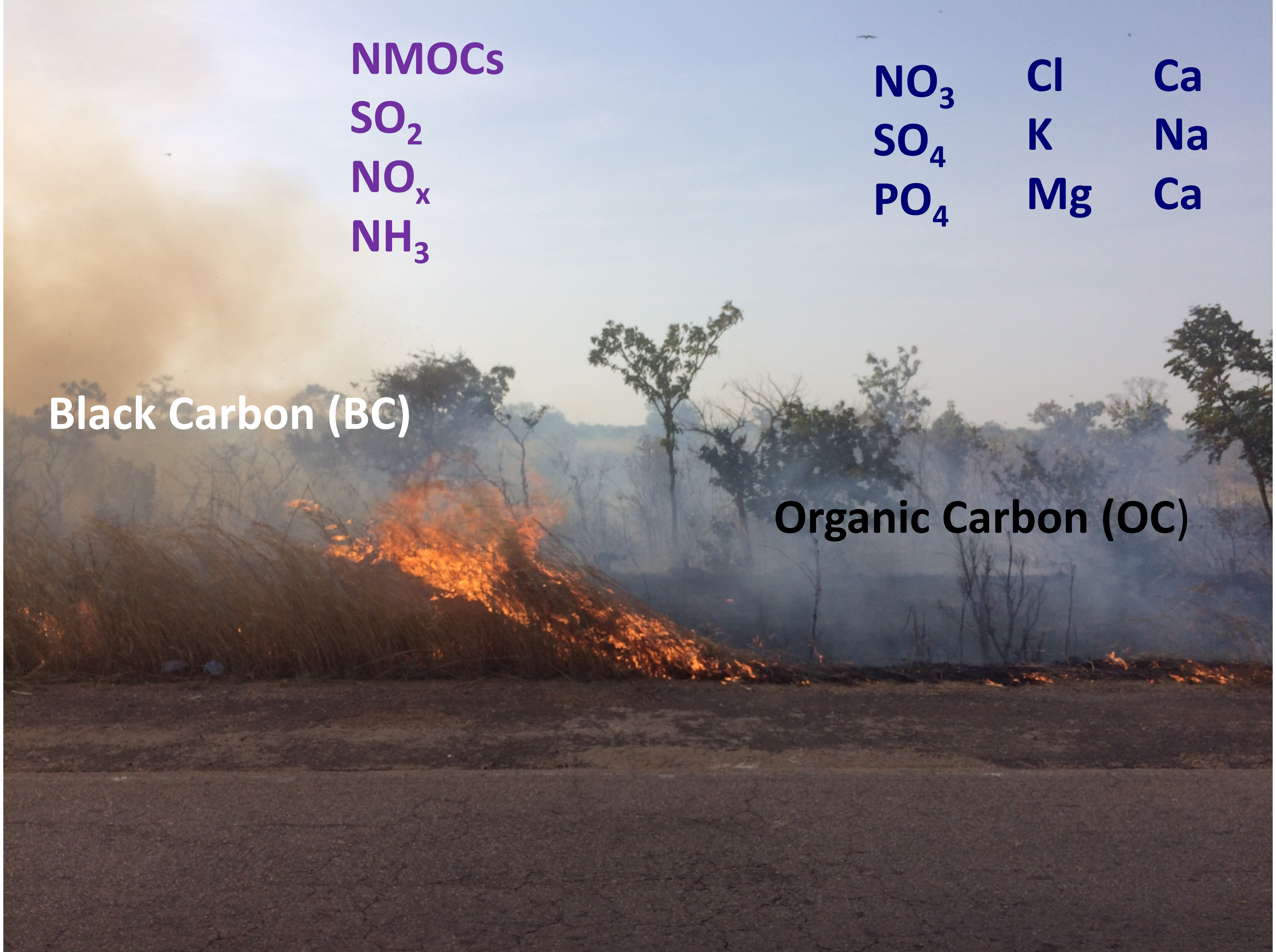
- What?
  - What is burning?

What is burning?








NMOCs
SO_2
NO_x
NH_3
NO_3
SO_4
PO_4
Cl
K
Mg
Ca
Na
Ca
Black Carbon (BC)
Organic Carbon (OC)

Estimating emissions from open burning

$$\textbf{Emission}_i = f(ef_i, \textbf{Biomass Burned})$$

Fire Radiative Power
- Intensity of the fire
- Temperature

Emission Factor

- Vegetation
  - Type
  - Condition
- Fire
  - Intensity

Biomass Burned

- Vegetation
  - Type
  - Condition
  - Density
  - Loading
- Fire
  - Intensity
  - Duration

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

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 $emission_i$ /biomass burned)

- fuel characteristics
- fuel condition

Applications for Open Burning Emissions

- Climate modeling
- Carbon/ecosystem dynamics
- Air quality/weather
- Emission inventories

Application determines area of study, temporal and spatial resolution needed, and emissions needed

Estimating Emissions

Emission Factor
(g/kg)

- Based on laboratory and field measurements
- Dependent on measurement techniques
- Function of type of burning

Montana Fire Sciences Laboratory (B. Yokelson)

(1) Emissions determined from field measurements

Thomas Karl, NCAR
TROFFEE Study, Brazil

Deforestation Fire in the Yucatan, Mexico (March 2006)
Bob Yokelson, UMT

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

Emission Ratios

Example: CH_3Cl

$$ER_{CH_3Cl/CO} = \frac{\Delta CH_3Cl}{\Delta CO} = \frac{(CH_3Cl)_{smoke} - (CH_3Cl)_{ambient}}{(CO)_{smoke} - (CO)_{ambient}}$$

Andreae and Merlet, *Global Biogeochemical Cycles*, 2001

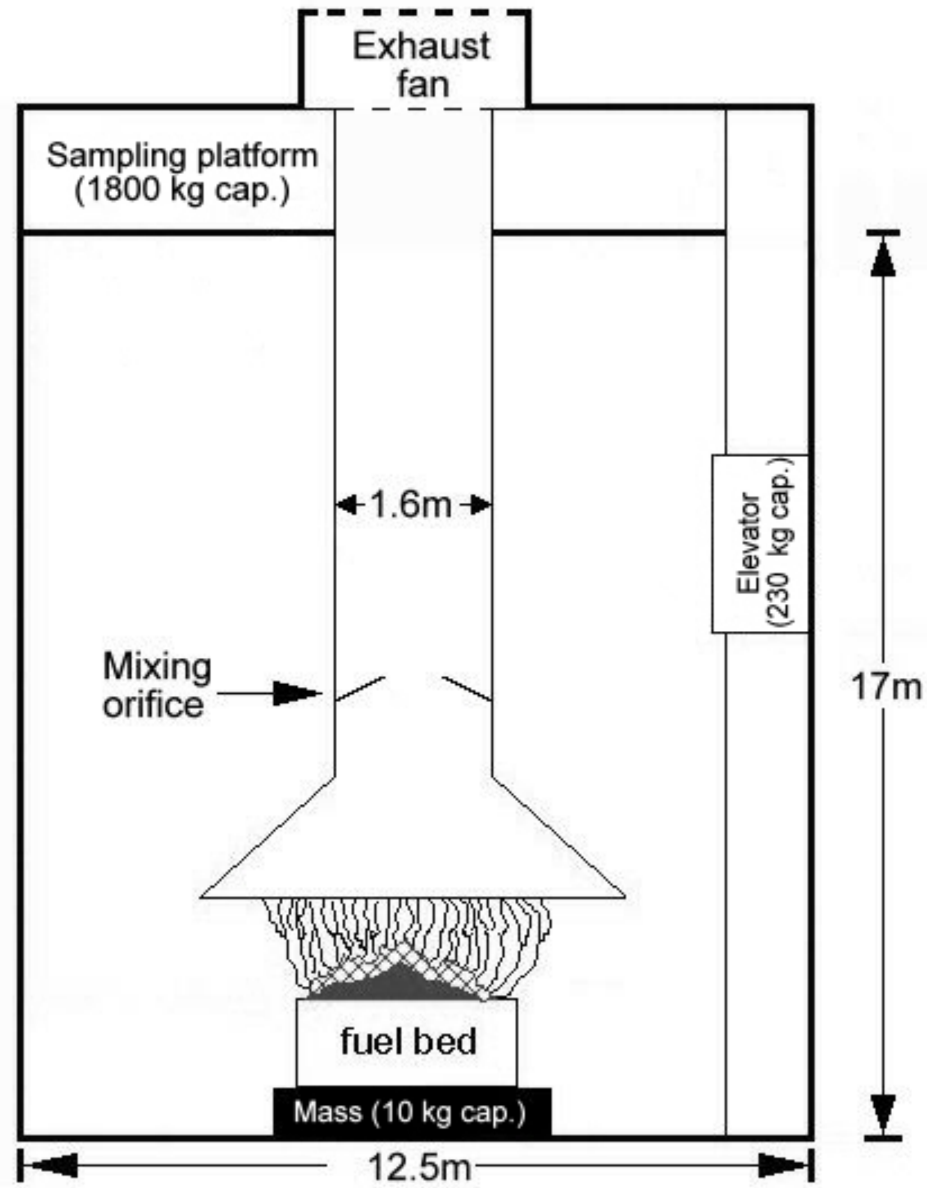
Measurements → Models

$$EF_x = ER_{(X/Y)} \frac{MW_X}{MW_Y} EF_Y,$$

EF_x	Emission factor for species X
$ER_{(X/Y)}$	Emission ratio of species X relative to the reference species Y
MW_x	Molecular weight of species X
MW_Y	Molecular weight of species Y
EF_Y	Emission factor of species Y

Andreae and Merlet, *Global Biogeochemical Cycles*, 2001

(2) Fire emissions determined from laboratory experiments



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

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

Getting at Emission Factors...

$$EF_x = \frac{M_x}{M_{\text{biomass}}} = \frac{M_x}{M_C}[C]_{\text{biomass}}$$

$$EF_x \cong \frac{[x]}{\sum([C_{CO_2}] + [C_{CO}] + [C_{CH_4}] + [C_{VOC}] + [C_{aeros}] + \ldots)}[C]_{\text{biomass}},$$

M_x	Amount of compound released
$M_{biomass}$	Amount of biomass burned
M_c	Mass of carbon emitted
$[C]_{biomass}$	Carbon concentration in biomass burned (45%)
[x]	Concentration of species x in the smoke
$[C_i]$	Concentration of species i in the smoke

Andreae and Merlet, *Global Biogeochemical Cycles*, 2001

Emission factors for open and domestic biomass burning for use in atmospheric models

S. K. Akagi[1], R. J. Yokelson[1], C. Wiedinmyer[2], M. J. Alvarado[3], J. S. Reid[4], T. Karl[2], J. D. Crounse[5], and P. O. Wennberg[6]

Atmos. Chem. Phys., 11, 4039–4072, 2011
www.atmos-chem-phys.net/11/4039/2011/
doi:10.5194/acp-11-4039-2011

Published 2011
2015 Update at:
http://bai.acd.ucar.edu/Data/fire/

Fire Emissions

Not just one thing emitted

Many different compounds

Some hazardous air pollutants

Numerous impacts on air quality and climate

Carbon Dioxide (CO_2)	2-Methyl-1-Pentene (C_6H_{12})	Nitric Oxide (NO)
Methane (CH_4)	*n*-Hexane (C_6H_{14})	Nitrogen Dioxide (NO_2)
Hydrogen (H_2)	Heptane (C_7H_{16})	Nitrous Acid (HONO)
Carbon Monoxide (CO)	Benzene (C_6H_6)	Methyl Nitrate ($MeONO_2$)
Acetylene (C_2H_2)	Toluene ($C_6H_5CH_3$)	Ammonia (NH_3)
Ethylene (C_2H_4)	Xylenes	Hydrogen Cyanide (HCN)
Ethane (C_2H_6)	Ethylbenzene (C_8H_{10})	Acetonitrile (CH_3CN)
Propadiene (C_3H_4)	Methanol (CH_3OH)	Propenenitrile (C_3H_3N)
Propylene (C_3H_6)	Phenol (C_6H_5OH)	Propanenitrile (C_3H_5N)
Propane (C_3H_8)	Formaldehyde (HCHO)	Pyrrole (C_4H_5N)
1-Butene (C_4H_8)	Glycolaldehyde ($C_2H_4O_2$)	Carbonyl Sulfide (OCS)
1,3 Butadiene (C_4H_6)	Acetaldehyde (CH_3CHO)	Dimethyl Sulfide (C_2H_6S)
trans-2-Butene (C_4H_8)	Propanal (C_3H_6O)	Sulfur Dioxide (SO_2)
n-Butane (C_4H_{10})	Hexanal ($C_6H_{12}O$)	Methyl Bromide (CH_3Br)
i-Butane (C_4H_{10})	Acetone (C_3H_6O)	Methyl Iodide (CH_3I)
trans-2-Pentene (C_5H_{10})	Methacrolein (C_4H_6O)	Trichloromethane ($CHCl_3$)
cis-2-Pentene (C_5H_{10})	Crotonaldehyde (C_4H_6O)	OC
n-Pentane (C_5H_{12})	Methyl Vinyl Ketone (C_4H_6O)	BC
i-Pentane (C_5H_{12})	3-Pentanone ($C_5H_{10}O$)	Total PM
3-Methyl-1-Butene (C_5H_{10})	Furan (C_4H_4O)	Total Particulate Carbon
Isoprene (C_5H_8)	Formic Acid (HCOOH)	$PM_{2.5}$
Cyclopentane (C_5H_{10})	Acetic Acid (CH_3COOH)	PM_{10}

Akagi et al., *Atmos. Chem. & Phys.*, 2011

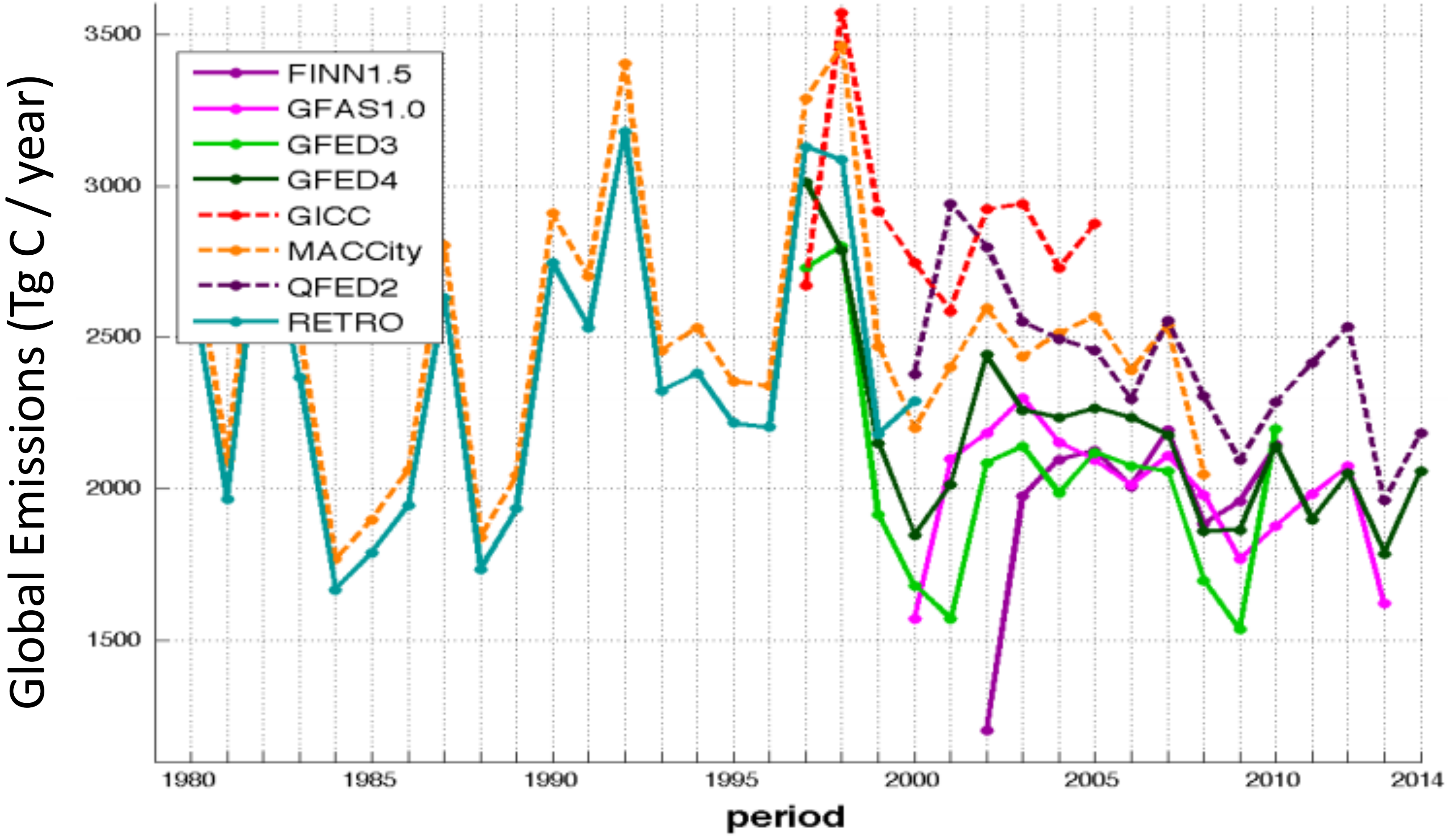
Estimating emissions from open burning

- Fire-Specific Estimates
  - Biscuit Fire (Campbell et al., 2007)
  - Black Saturday Fires Australia (Murphy et al., 2012)

- Regional Models
  - FLAMBE (Reid et al., 2008)
  - North America (Wiedinmyer et al., *AE,* 2006)
  - Himalaya (Vadrevu et al., *AE*, 2011)
  - Western U.S. (Urbanski, *ACP,* 2012)
  - Asia (Song et al., *ERL,* 2010)
  - Western Africa (Liousse et al., 2010)

- Global Models
  - GFED (van der Werf et al., *AC&P,* 2010 and others)
  - FINN (Wiedinmyer et al., *GMD*, 2011)
  - GFAS, (Kaiser et al. *Biogeosciences,* 2012)
  - QFED (Darmenov, A. S., and da Silva, A. 2015. *The Quick Fire Emissions Dataset (QFED): Documentation of versions 2.1, 2.2 and 2.4*. (R. D. Koster, Ed.) (Vol. 38). USA.)

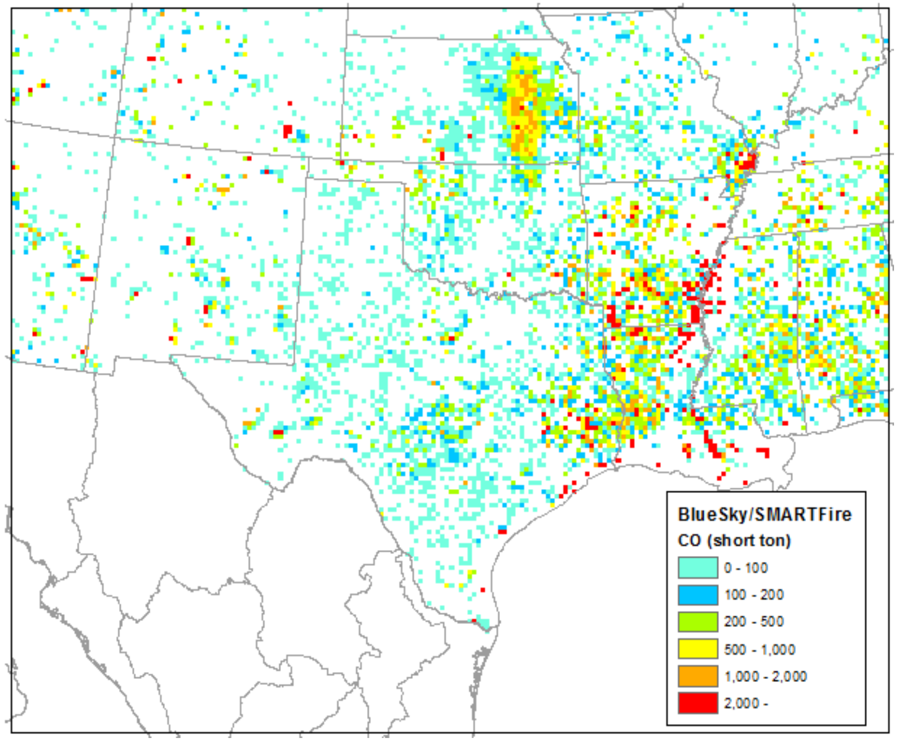
Uncertainties in the emission models

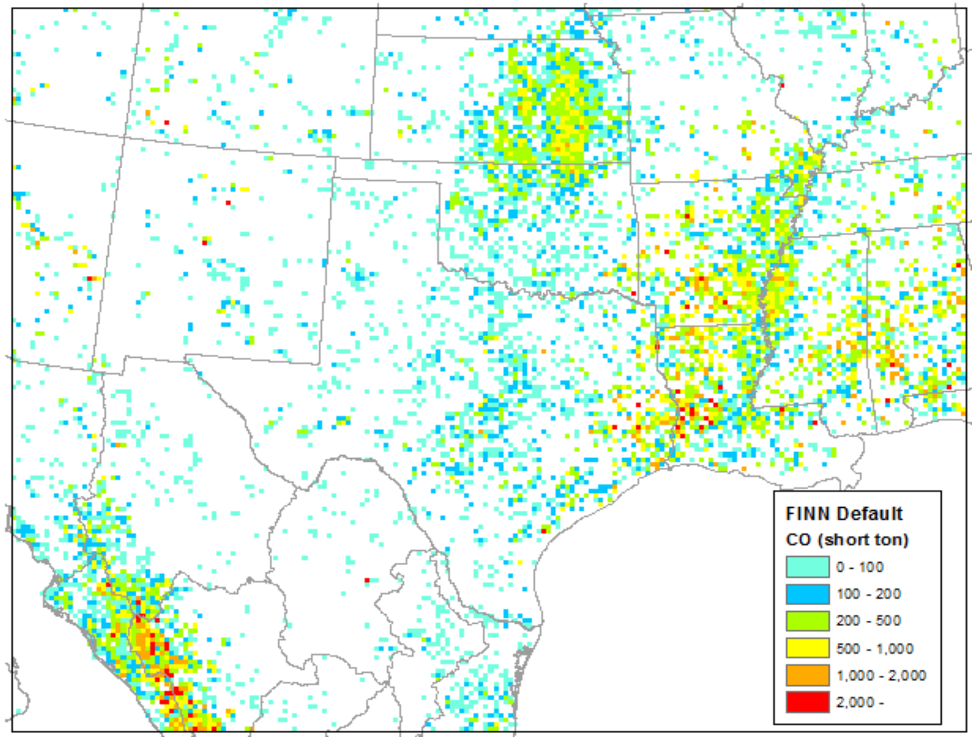


K. Sindelarova, *in prep*

Uncertainties in the emissions

- Emission Factors
- Fire location/timing
- Fuel loadings
- Fuel Consumption





E. McDonald-Buller, C. Emery, C. Wiedinmyer 2013

Use of available datasets to predict emissions

- Fire area, location and timing
- Vegetation datasets
- Emissions (quantity, ratios, chemistry)
- Processing
- Evaluation