

Emission Inventory Issues: Anthropogenic, Biogenic and Biomass Burning

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*Inventories of Greenhouse Gases and Aerosol
Emissions in the Mekong River Basin*

May 2, 2007

Emission Inventory (EI)

... a current, comprehensive listing, by *source*, of air pollutant emissions associated with a *specific geographic area* for a *specific time interval* ...



... USEPA

Why do we need EI data?

- To evaluate the existing air quality as related to air pollution problems
- To assess the effectiveness of air pollution policy
- To identify sources and general emission levels, patterns, and trends to develop control strategies
- To predict ambient pollutant concentrations through the use of atmospheric models
- To provide input for human health risk assessment studies
- To site ambient air monitors

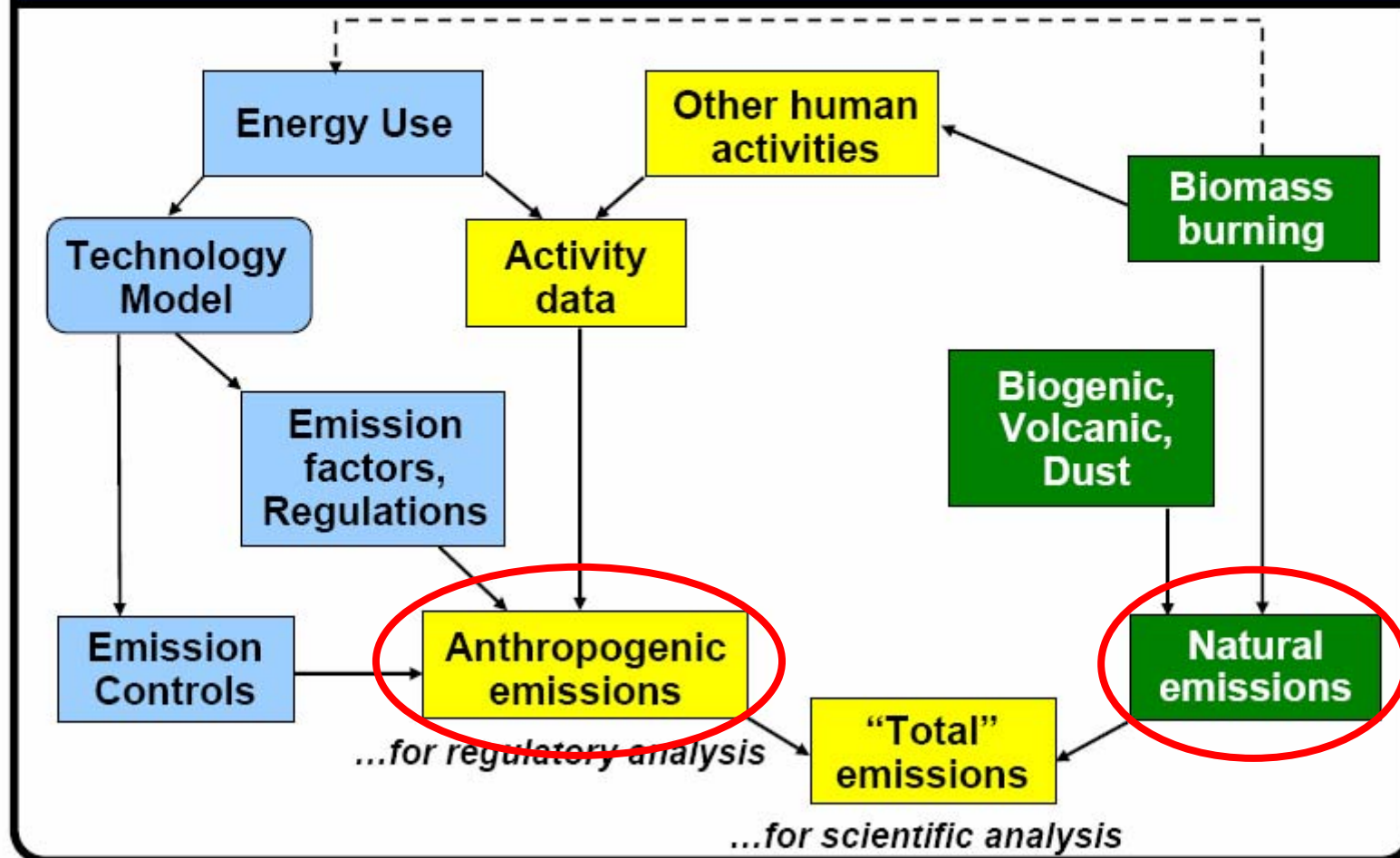
Air Pollutants of Interest

- **Greenhouse gases:** CO₂, CH₄, CFC, N₂O ...
- **SO₂:** health effects, acid rain, acid deposition, visibility ...
- **NO_x:** health effects, photochemical smog, O₃ formation, acid deposition, visibility ...
- **CO:** health effects, O₃ formation ...
- **VOC:** O₃ formation, secondary organic aerosol, visibility ...
- **Particulate matter (PM):** health effects, visibility, cloud formation, climate change ...
- **Air toxins:** mercury, lead, dioxin, toxic organics ...
- **NH₃:** formation of secondary PM.

What needs to be done?

- **Planning activities:** plan out the procedures and identify sources
- *Inventory development:* data collection, emission estimation, measurements ...
- **QA/QC:** ensure EI data quality
- **Documentation:** provide well-organized explanation of the data
- **Maintenance and update:** EI requires continuous updates

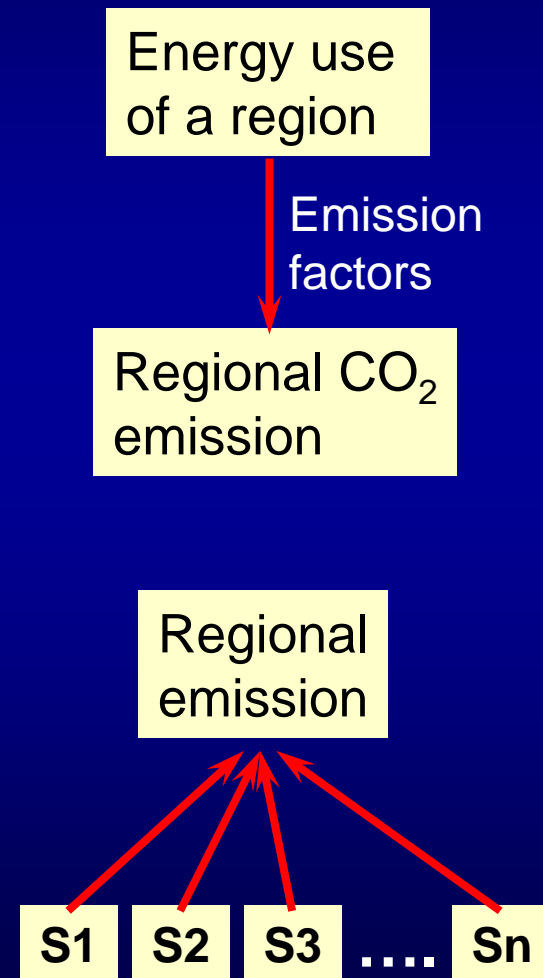
General methodology used for developing emission estimates at regional scale



Slide Courtesy: David Streets

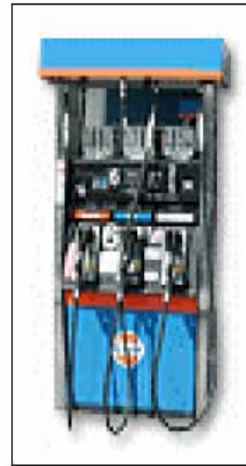
Top-down vs. Bottom-up

- **Top-down estimate:** EIs are developed based on data covering a large geographical area (i.e., regional or national levels)
- **Bottom-up estimate:** EIs are developed from the emission sum of individual sources to obtain the regional or national estimate



Anthropogenic Emission

Source Categories



Point Sources

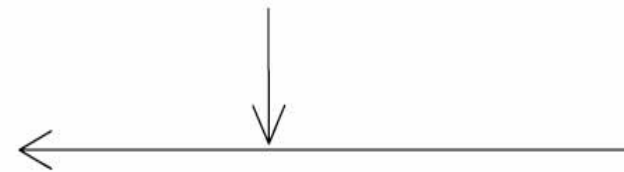
Area Sources

NonRoad Mobile Sources

OnRoad Mobile Sources



Inventory



Point Sources

- Source treated as an individual stationary source of emissions that release pollutants to the atmosphere.
- Emit large quantity of pollutants at higher elevation through stacks.



Examples of Point Source Emissions

- Fuel Combustion
 - Waste disposal
- Food and agriculture industry
 - Metallurgical industry
- Petroleum-related industries
 - Mineral products industry
- Chemical process industry
 - Wood products industry
 - Storage tanks

Estimating Point Source Emissions

- Continuous emissions monitor (CEMs)
- Source testing (short-term measurement)
- Emission factors
- Material balance
- Fuel analysis
- Emission estimation models
- Engineering judgment (not recommended)

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Emission Factors

$$E = R \times EF \times \frac{(100 - C)}{100}$$

**Emission
Quantity**

**Activity
Level**

**Emission
Factor**

**Emission
Control
Factor**

USEPA AP-42 provide the emission factor estimates!
Available at <http://www.epa.gov/ttn/chief/ap42/>

Mass Balance

$$E_x = (Q_{in} - Q_{out}) \times C_x$$

Emission
Quantity

Material
Quantity
Entering
System

Material
Quantity
Leaving
System
as Waste

Concentration
of Pollutant X

Fuel Analysis

$$E_x = Q_f \times \frac{W_p}{W_f}$$

**Emission
Quantity**

**Fuel Use
Mass**

**Weight Ratio
of Pollutant to
Fuel**

Emission Models (EPA)

- Landfill air emissions estimation model
- **TANKS**: for fixed and floating-roof storage tank (for fuel, petroleum, chemicals)
- **WATER**: for wastewater collection and treatment systems
- **MOBILE**: for *on-road vehicles*
- **NONROAD**: for *non-road vehicles*

Available at <http://www.epa.gov/ttn/chief>

Area Sources

- Individual emissions do not qualify as Point Sources
- Represents numerous facilities or activities with small amounts of a given pollutant
- Do not generate emission at large quantity individually but the combined emission may be significant in the inventory area



Examples of Area Source Emissions

- Biomass burning
- Small fuel combustion units
 - Cooking
 - Agriculture emission
 - Machinery emission
 - Solvent evaporation
- Gasoline/diesel evaporation
 - Construction emission
 - Storage tanks
 - *And Many Others!!!*

Estimating Area Source Emissions

- Emission factors (AP-42)
- Surveys
- Applying point source methods to area sources (bottom-up)
- Conducting local activity level surveys (bottom-up)
- Applying a top-down approach (e.g., allocating regional level emission estimates to the local level using spatial surrogates)

Mobile Sources

- Source is mobile and portable
- Source is generally Internal combustion powered
- Licensed for roadway use (**on-road**): automobiles, trucks, buses, motorcycles
- Not licensed for roadway use (**non-road**): planes, trains, boats, farm equipment, lawn & garden equipment, construction equipment



Estimating Mobile Source Emissions

Emission Model: Mobile 6

<http://www.epa.gov/otaq/m6.htm>

Calculations in Mobile 6

For on-road vehicles:

$$E = VMT \times EF \times K$$

Emission
Quantity

Vehicle
Miles
Traveled

Emission Factor
Depending on
*Speed, Roadway
Type, Vehicle Type
and Time Periods*

Conversion
Factor

Calculations in Mobile 6

For non-road vehicles:

$$E = EF \times A \times L \times P \times N$$

Emission
Quantity

Emission
Factor

Load Factor
Proportional to
Rated Power

Equipment
Population

Equipment
Activities

Average Rated
Power for Modeled
Engines

Important Model Inputs

- Vehicle Speed
- Ambient Temperature
- Gasoline Volatility
- Control Programs
 - Inspection/Maintenance
 - Reformulated gasoline
 - Oxygenated Fuels
 - New Vehicle Standards
- Registration Distributions

Comments on Uncertainty

- Emission factors being out-of-date.
- Difficult to identify all emission sources
- Hard to capture emission in the event of system (or facility) upset
- Double counting of emission sources in different source categories
- Spatial surrogates based on GIS not representing the true allocations
- Fugitive emission (e.g., system leaks) may significantly contribute to emission quantity

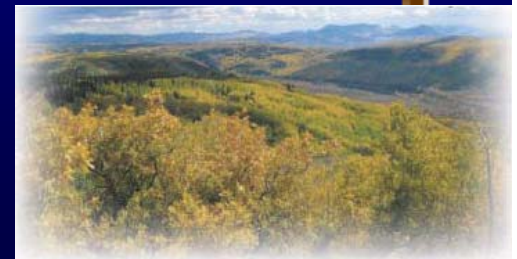
Recommendations

- USEPA's AP-42 and the emission models are not perfect, but they are a good starting point
- Whenever possible, use measurement data to estimate emission factors
- The staff performing the emission inventory estimate needs to understand the emission process (to prevent overlook)

Biogenic Emission

Biogenic (Natural) Emissions

- Natural emissions that are mediated through biological processes of soil and vegetation
- Represent a significant portion of the natural emissions of ozone precursors
- Estimated using Biogenic Emission Models (e.g., Biogenic Emissions Inventory System, BEIS; Global Biosphere Emission and Interactions System, BloBEIS)

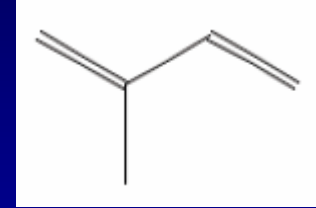


<http://www.epa.gov/asmdnerl/biogen.html>

What are emitted?

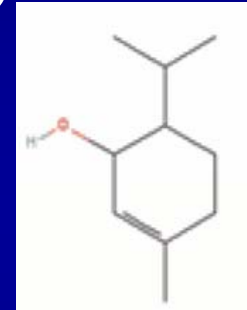
- **Isoprene (2-methyl-1,3-butadiene)**

- Emitted from vegetation foliage, oak (mostly) but also citrus and eucalyptus. (Chinkin et al., 1996a, 1996b)



- **Monoterpene (Piperitol)**

- Primarily emitted by pine, citrus, and eucalyptus.



- **Biogenic VOC**

- Emission of non-methane hydrocarbons (NMHC) through evapotranspiration process of vegetation

- **NO_x and N₂O**

- Emitted through microbial activities in soils, primarily from agricultural lands and grasslands

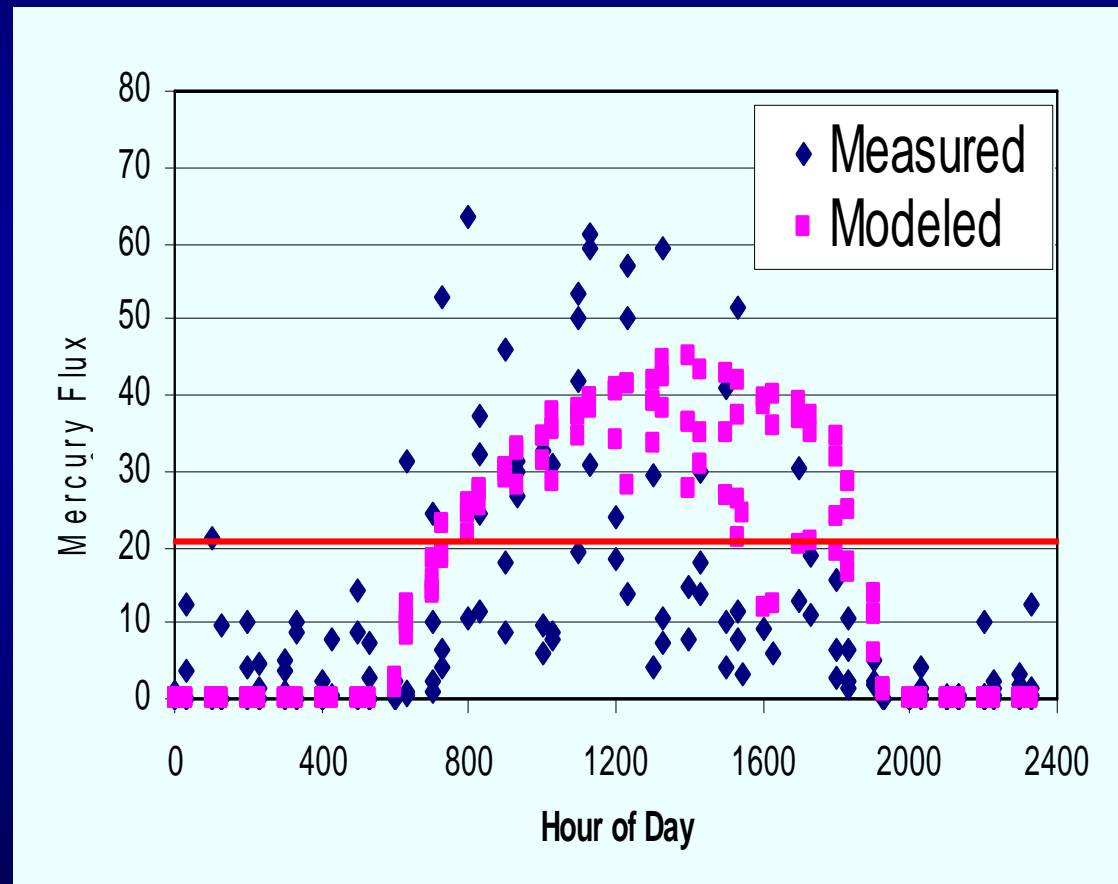
- **CH₄**

- Emitted through anaerobic process in soils

Emission Characteristics

	Anthropogenic	Natural
Diurnal/Seasonal Variation	Depending on emission units, usually no significant variation	Strong variation due to temperature and irradiation changes
Spatial Distribution	Intense stationary source emission	Weaker, diffused emission
Vertical Distribution	Subject to plume rise	Emit to surface layer only
Emission Quantity	Relatively “well” characterized	Highly uncertain, subject to landuse changes
Emission Speciation	Complex, requires emission monitoring	Usually better understood

Temp./Irradiation Corrections



$$I = I_s C_L C_T$$

$$C_L = \frac{\alpha C_{L1} L}{\sqrt{1 + \alpha^2 L^2}}$$

$$C_T = \frac{\exp\left[\frac{C_{T1}(T - T_s)}{RT_s T}\right]}{1 + \exp\left[\frac{C_{T2}(T - T_m)}{RT_s T}\right]}$$

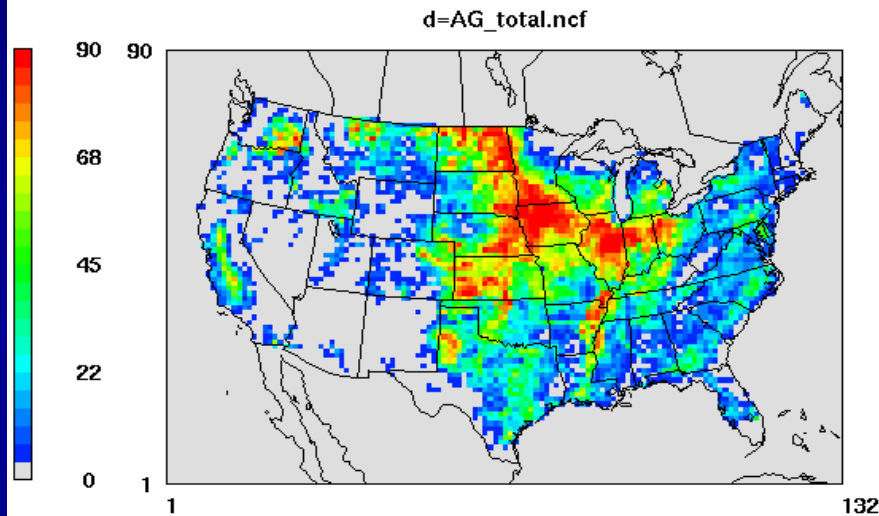
Guenther et al. (2005)

What are needed for biogenic emission estimate?

- Landuse/landcover data
- Vegetation distribution on land
- Photo-synthetically active solar radiation and temperature (usually from meteorological files)
- Measured emission factors and radiation/temperature correction factors

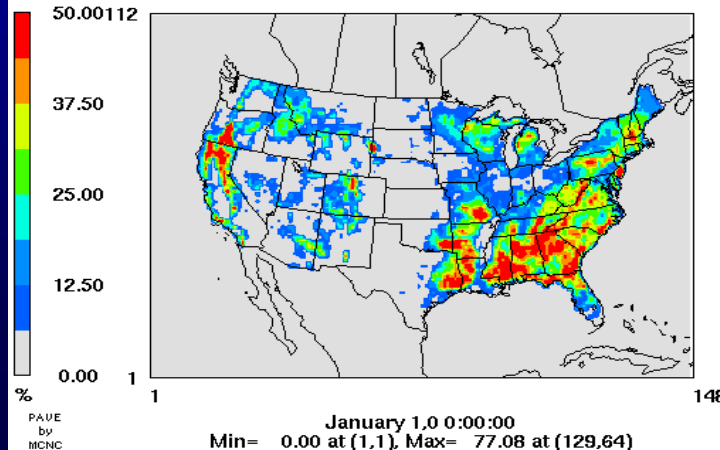
Example Landuse Categories

Layer 1 VARd

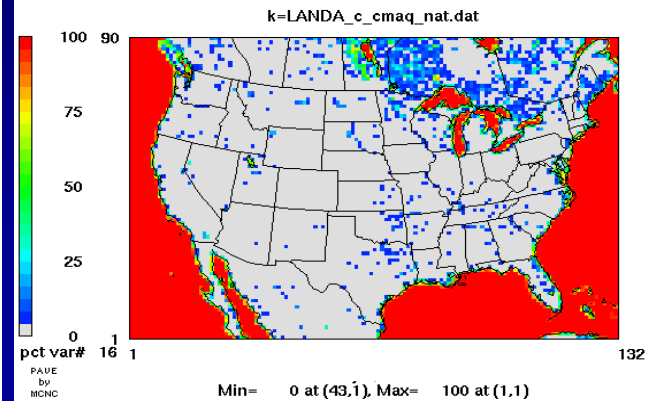


PAVE
by
MCNC

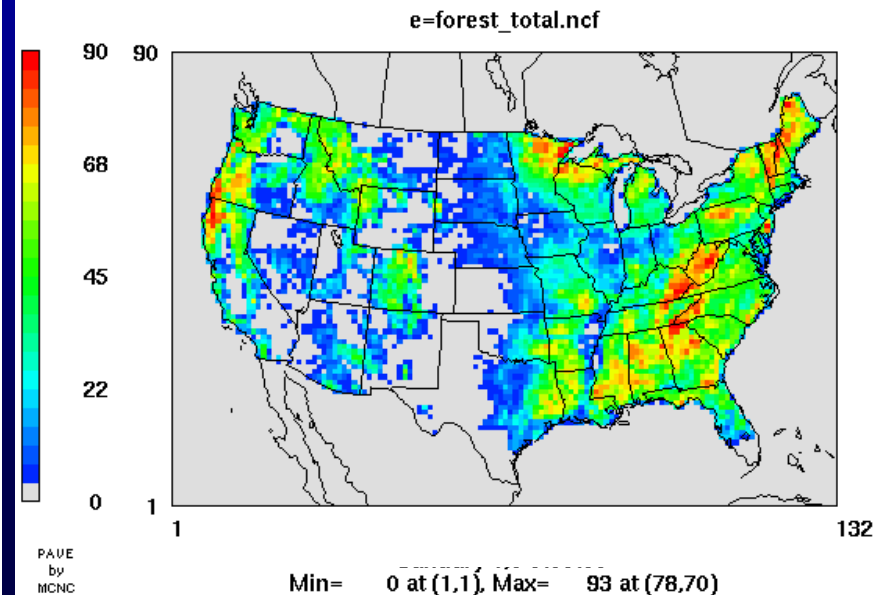
Min= 0 at (1,1), Max= 99 at (74,57)
oak + maple + pine



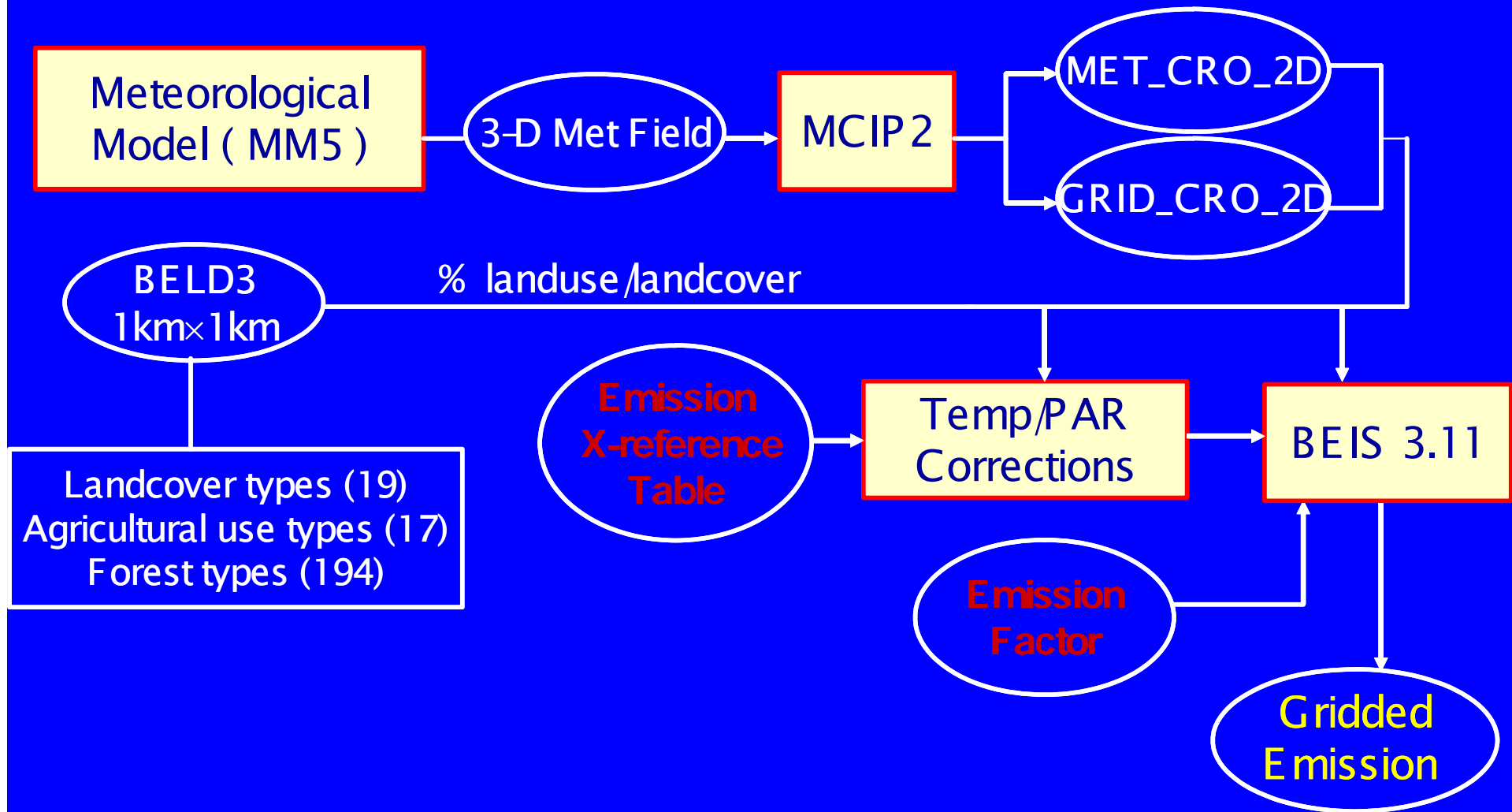
Layer 1 USGS_waterk



Layer 1 VARE



BEIS3 Data Flow

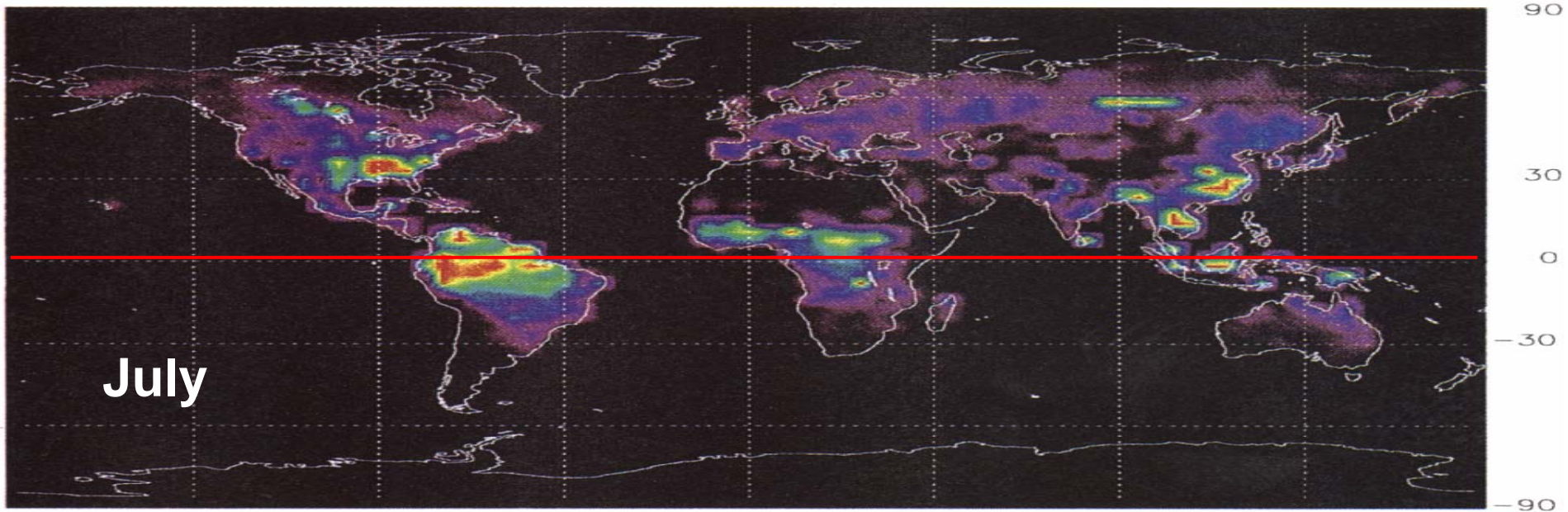


Global Isoprene emission, $\text{g C m}^{-2} \text{mo}^{-2}$

Guenther et al. (2005)

January

-180 -90 0 90 180



July

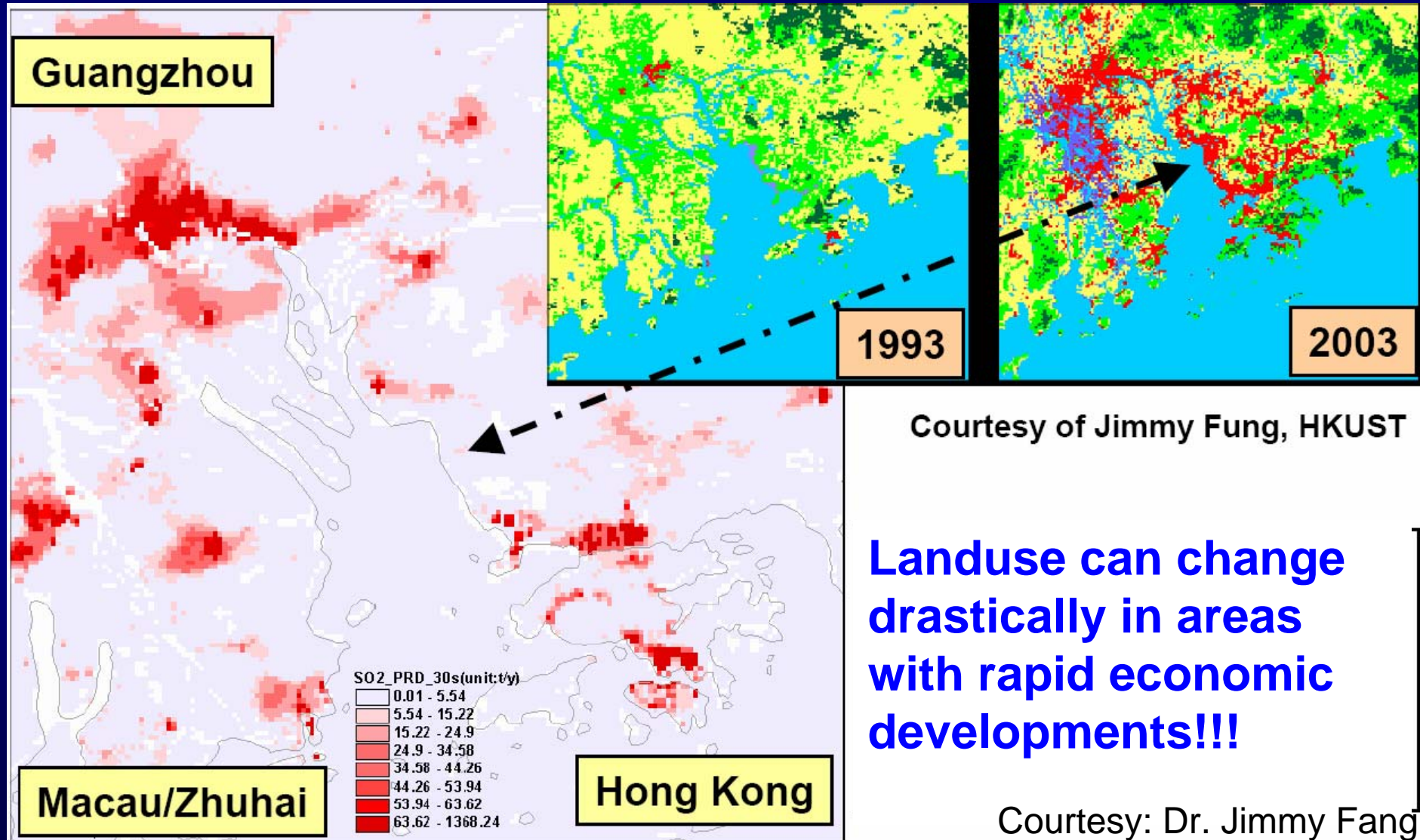
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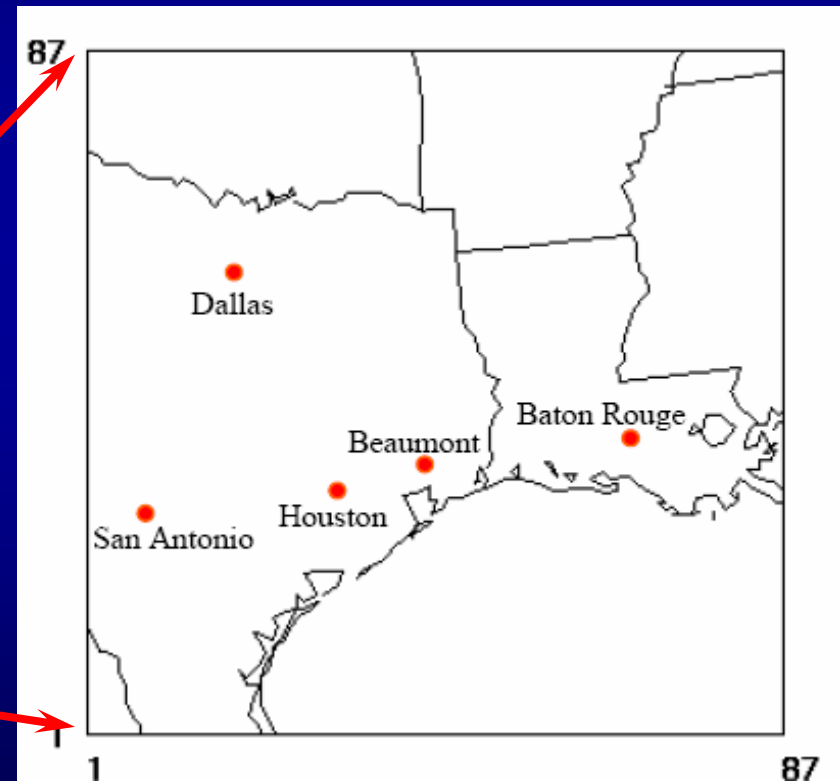
Comments on Uncertainty

- Biogenic emission factors (I_s) for the same vegetation type are not universal
- Biogenic emission factors (I_s) reported only for a limited numbers of vegetation types
- Uncertainty in meteorological data (temperature and ground-level radiation) can significantly affect the estimate
- Certain required data for biogenic emission models are hard to find (LAI, vegetation types, distribution, and seasonal variation, etc.)
- Landuse change, especially in rapid growing region

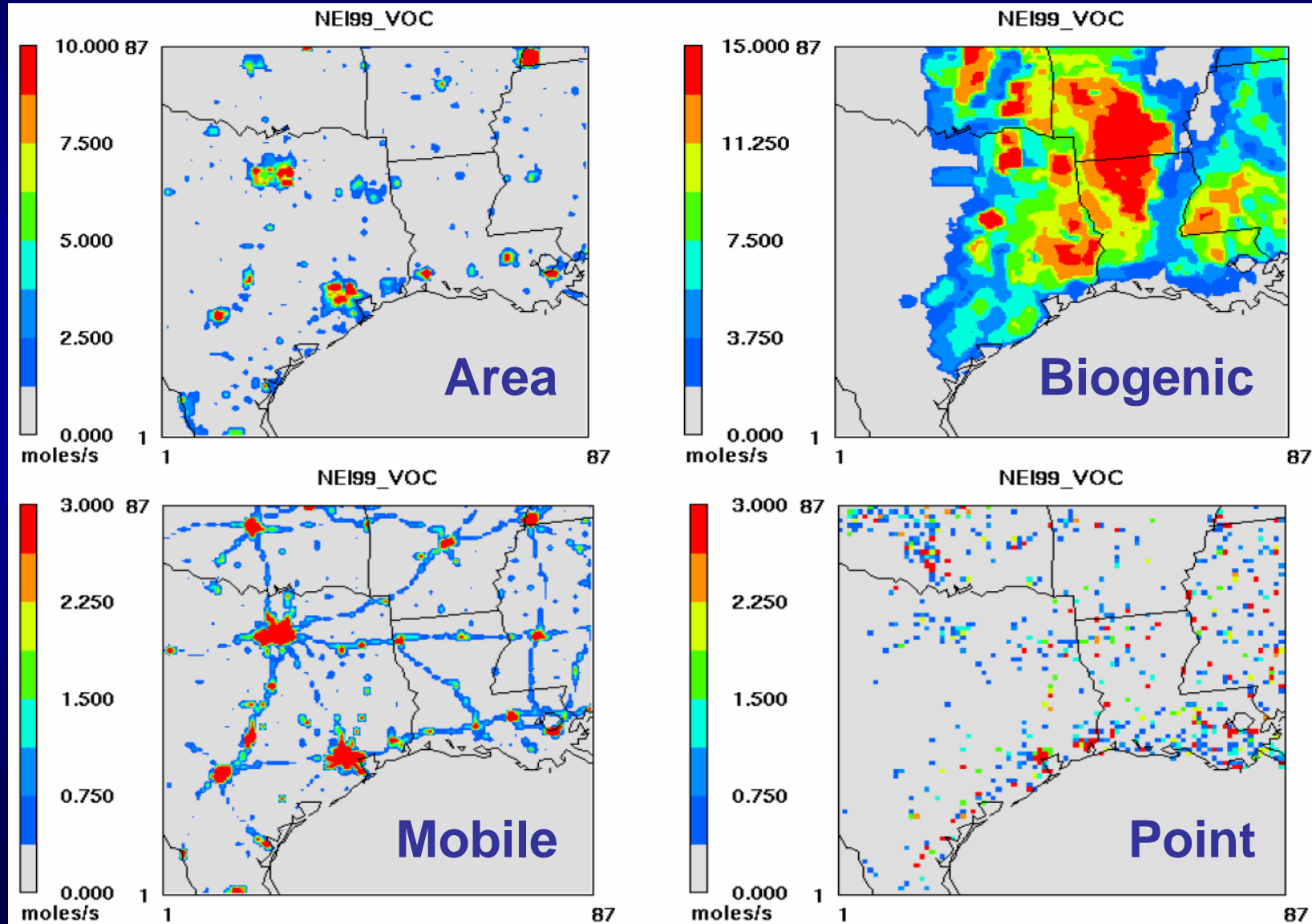
Landuse Change (China Pearl River Delta Region)...



Spatial Distribution - Domain



Spatial Distribution of Emissions



Source Contribution in Domain

Emission Sources	Daytime Emission (%)						Nighttime Emission (%)					
	CO	NH ₃	NO _x	SO ₂	PM _{2.5}	VOC	CO	NH ₃	NO _x	SO ₂	PM _{2.5}	VOC
Mobile	43.8	2.1	10.3	0.7	0.2	2.0	61.3	4.9	32.7	2.9	0.4	5.0
Area	42.8	91.5	24.4	9.4	84.5	9.0	32.8	89.6	25.1	13.5	85.3	3.4
Point	13.4	6.4	49.6	89.9	15.3	3.5	5.9	5.5	35.9	83.6	14.3	9.8
Biogenic	0	0	15.7	0	0	85.5	0	0	6.3	0	0	81.8

Emission from Biomass Burning

Biomass Burning

- Burning of the world's living and dead vegetation for land clearing, land use change, and natural burning resulting from lightning-induced fires.
- Can be natural (e.g., forest fire) or man-made
- Majority (>90%) of biomass burning is human initiated
- Has increased significantly over the last 100 years.

Prescribed burning



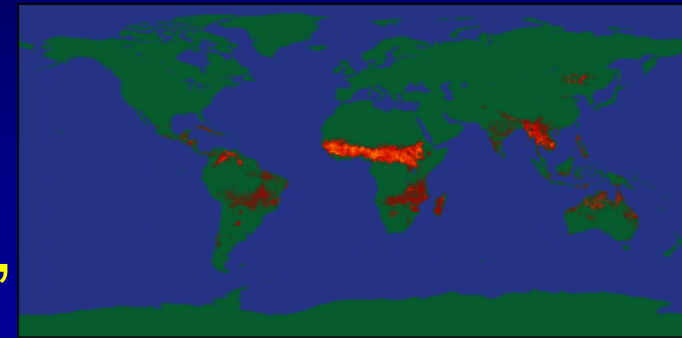
Photo by NASA



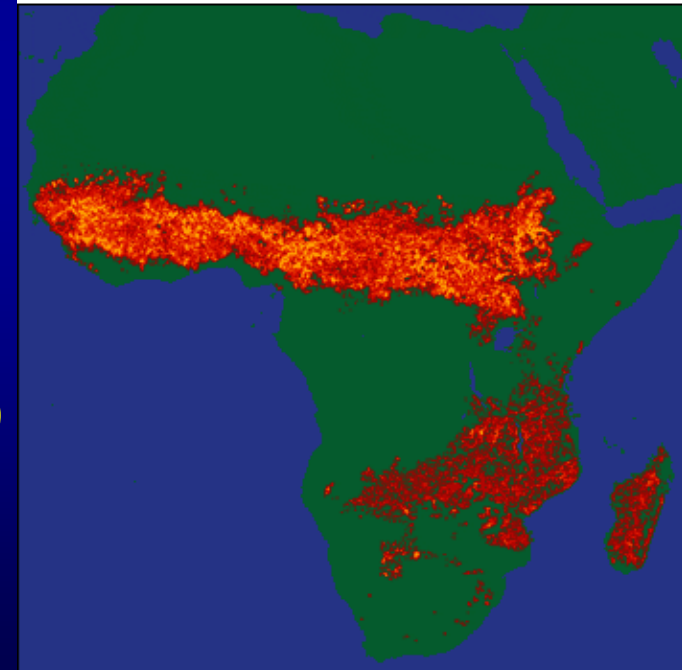
Locations of Biomass Burning

- Tropical forests (Brazil, Indonesia, Colombia, Ivory Coast, Philippines, Thailand, Laos, Nigeria, Burma, Peru)
- Temperate forests (U.S., Europe)
- Boreal forests (Alaska, Canada, Siberia, China)
- Savanna grasslands (Africa)
- Agricultural wastes after the harvest (Asia, U.S., Europe)

A Global Issue!!



Global Fire Distribution



African Fire Distribution

Photo Courtesy: NASA

Emissions of Biomass Burning

- Greenhouse gases (CO₂, and CH₄)
- Chemically active gases (CO, NO_x, SO₂, C₂H₆, C₂H₄, C₃H₈, C₃H₆, etc.)
- Methyl bromide (CH₃Br)
- Atmospheric aerosol (black carbon, organic matter, K⁺, Na⁺, Ca²⁺, Mg²⁺, NH₄⁺, H⁺, Cl⁻, H₂SO₄, HSO₄⁻, SO₄²⁻, NO₃⁻, etc.)

(Levine et al., 1995)

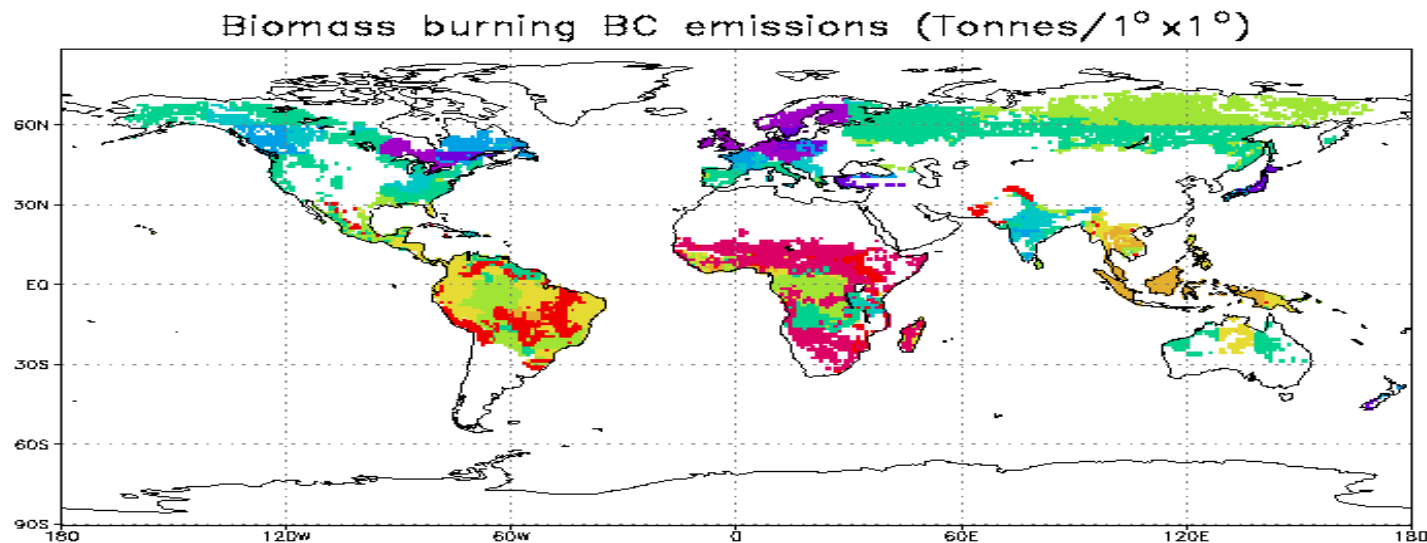
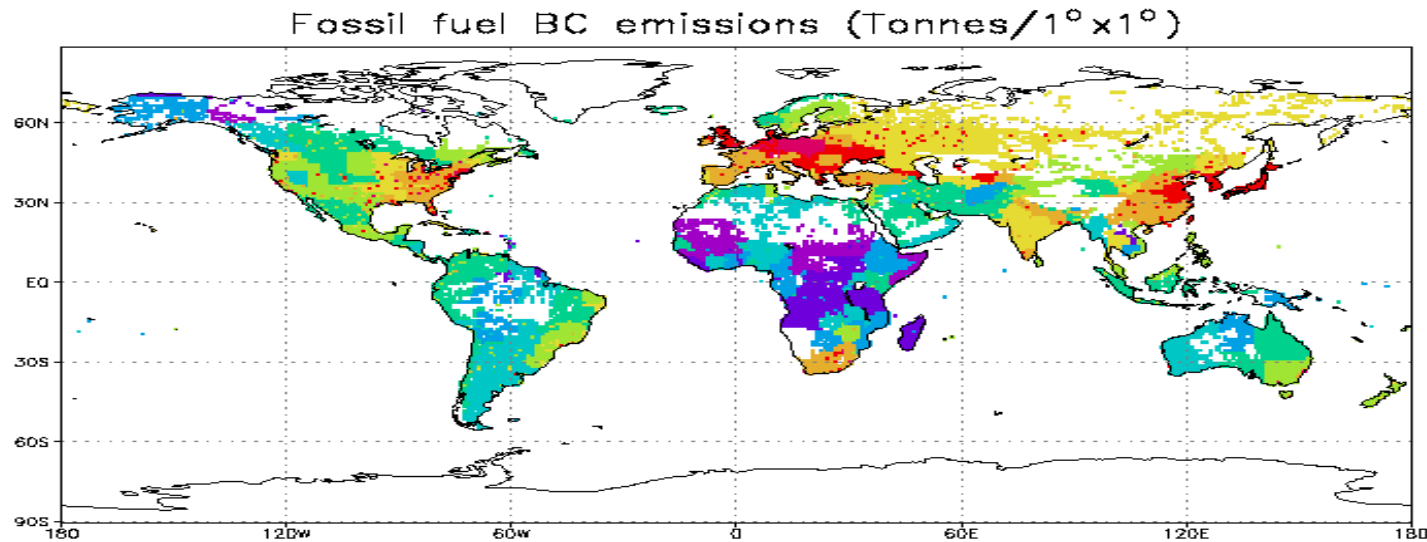
Burning's contribution to global emissions

Comparison of global emissions from biomass burning with emissions from all sources, including biomass burning (2).

Species	Biomass burning (Tg element/ year)	All sources (Tg element/ year)	Biomass burning, %
Carbon dioxide (gross)	3500	8700	40
Carbon dioxide (net)	1800	7000	26
Carbon monoxide	350	1100	32
Methane	38	380	10
Nonmethane hydrocarbons ^a	24	100	24
Nitric oxide	8.5	40	21
Ammonia	5.3	44	12
Sulfur gases	2.8	150	2
Methyl chloride	0.51	2.3	22
Hydrogen	19	75	25
Tropospheric ozone	420	1100	38
Total particulate matter	104	1530	7
Particulate organic carbon	69	180	39
Elemental carbon (black soot)	19	<22	>86

^aExcluding isoprene and terpenes.

Fossil Fuel vs. Biomass Burning



(GEIA,
2005)

Direct Impact of Biomass Burning

- **Contribute to global warming**
 - Production of greenhouse gases
 - Removal of CO₂ sink (vegetation)
 - Release of previously sequestered carbon within a short period of time
- **Affect global radiation budget and climate through emission of particulates**
- **Alter the oxidizing capacity of the atmosphere and cause tropospheric ozone production through emission of reactive gases**
- **Contribute to stratospheric ozone depletion through emission of methyl bromide**
- **Create regional and trans-boundary haze problems**

Other Indirect Impact

- Alter the biogeochemical cycling of nitrogen and carbon compounds from the soil to the atmosphere
- Change the hydrological cycle, i.e., run off and evaporation
- Affect the reflectivity and emissivity of the land
- Affect the stability of ecosystems and ecosystem biodiversity

Methodology of Estimating Biomass Burning Emissions

- **Direct measurement of emission concentration downwind of the plume**
 - Pros: direct reporting of pollutant concentration
 - Cons: no info on emission quantity per mass burned
- **Emission Factor (EF) Method**
 - Pros: report emission quantity per mass burned
 - Cons: high variation of estimated EFs
- **Emission Rate Method**
 - Pros: more consistent emission factors
 - Cons: requires more effort to obtain EFs

Better Data Quality



Biomass Burning Emission


$$Q(x) = M \times EF(x)$$

**Emission
Quantity
of Species
X (g)**


**Biomass
Burned
(kg)**

**Emission
Factor of
Species X
(g/kg)**

f (area burned,
burning efficiency,
biomass density,
etc...)



f (vegetation type,
burning conditions,
species, etc...)



Biomass Burned (M)

$$M = A \times B \times \alpha \times \beta$$

**Biomass
Burned
(kg)**



**Area
Burned
(m²)**

Seiler and
Crutzen (1980)

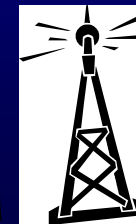
**Biomass
Density
(kg/m²)**



**Fraction
of Above
Ground
Biomass**



**Burning
Efficiency**



Emission Factor (*EF*)

$$EF(x) = ER_{X/CO_2} \times \frac{MW_X}{MW_{CO_2}} \times EF_{CO_2}$$

Emission
Factor of
Species X
(g/kg)

Emission
Ratio, CO₂
as reference

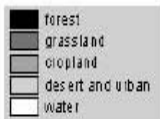
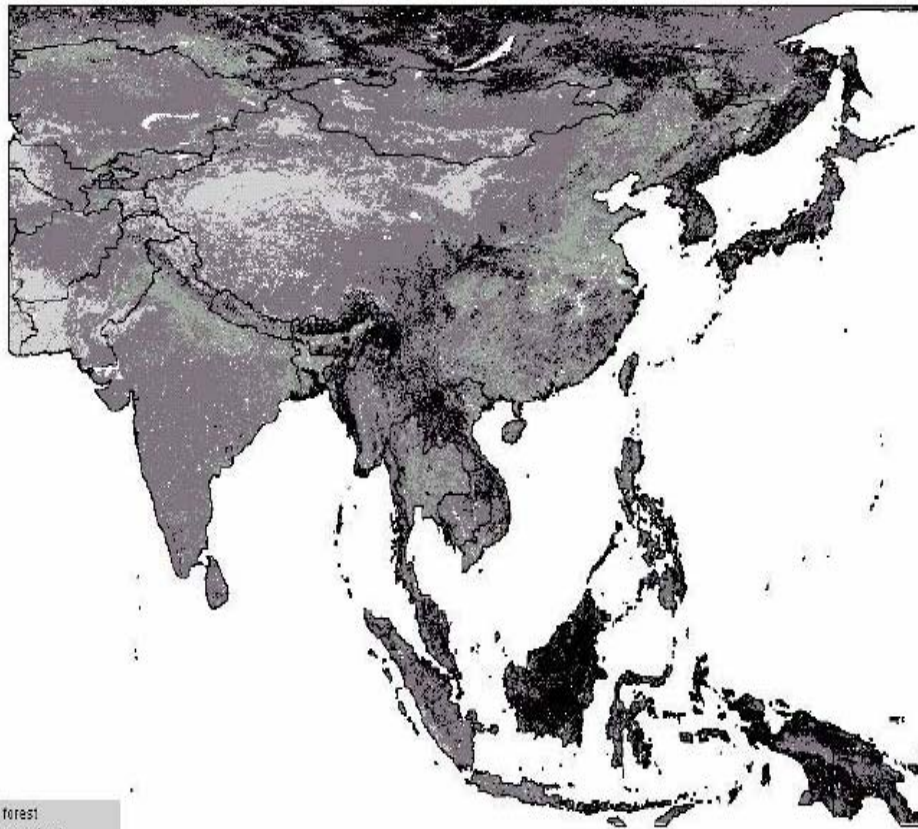
Molecular
Weight
Ratio

CO₂
Emission
Factor

$$ER_{X/CO_2} = \frac{X_p - X_b}{CO_{2p} - CO_{2b}}$$

p: within plume
b: the background

The Final Products ...

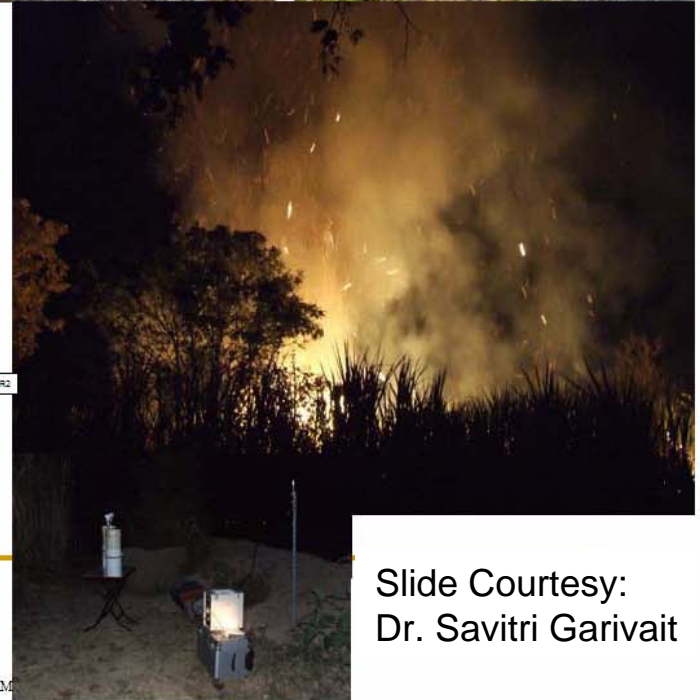
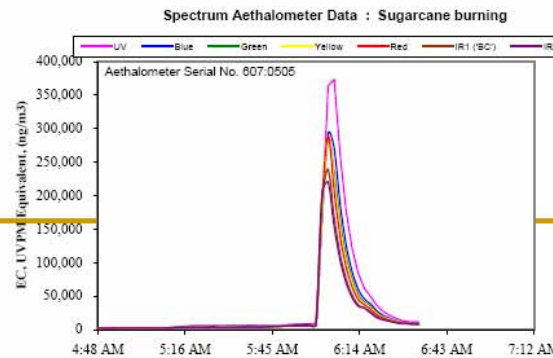
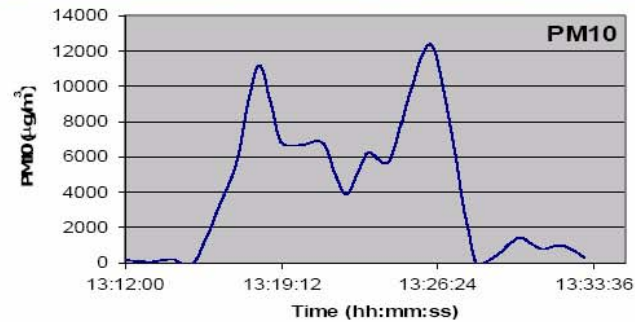
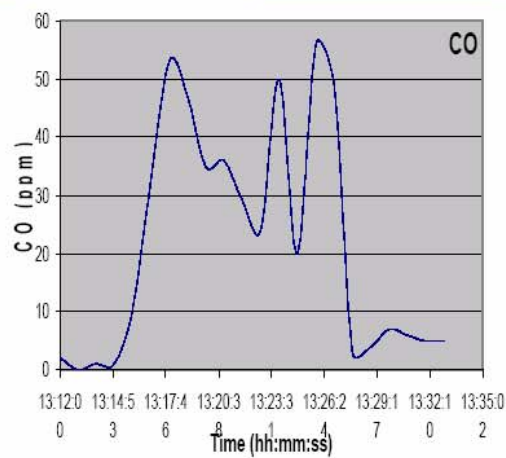


(Michel et al., 2005)

Vegetation Class	Biomass Density (g/m ²)	Burning efficiency
evergreen needleleaf forest	36700	0.25
evergreen broadleaf forest	23350	0.25
deciduous needleleaf forest	18900	0.25
deciduous broadleaf forest	20000	0.25
mixed forest	22250	0.25
woodland	10000	0.35
wooded grassland	3300	0.4
closed shrubland	7200	0.5
open shrubland	1600	0.85
grassland	1250	0.95
cropland	5100	0.6

Vegetation Class	EF(BC)	EF(OC)
evergreen needleleaf forest	0.6	6
evergreen broadleaf forest	0.7	6.4
deciduous needleleaf forest	0.6	6
deciduous broadleaf forest	0.6	6
mixed forest	0.6	6
woodland	0.61	5
wooded grassland	0.62	4
closed shrubland	0.61	5
open shrubland	0.62	4
grassland	0.62	4
cropland (g/kgdm)	0.725	2.1

Emission Uncertainty



Slide Courtesy:
Dr. Savitri Garivait

Comments on the Uncertainty

- Burning conditions (winds, RH, biomass moisture content, etc) strongly affect the emission factors.
- Difficulty in estimating burned biomass
- Laboratory measured emission factors may not be representative of field burning conditions

Repetitive, consistent measurements of biomass burning using well-defined methodology is critical !!!

Final Remarks

- Compiling emission inventory is a big job, using top-down approaches for a rough estimate is a good starting point
- Consider the emission inventory as a evolving datasets. Periodic review, update and careful documentation are necessary.
- Keeping data open to all stakeholders is important for detecting data gaps

**Finding emission inventories
is not a problem,...**

**Knowing how good they
are is another matter ...**

... David Streets