

# Historical emissions

a new 1860-2000 inventory  
of emissions of gases and particles

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## **Emissions of gases and aerosols from:**

→ technological emissions

→ biomass burning emissions

**What is missing/not well taken into account**

**What could be done over the next few months**

## Technological emissions:

General equation used to generate emissions:

$$\text{Emission} = \sum A_i EF_i P_{1i} P_{2i}$$

$A_i$  = Activity rate for a source

(ex: kg of coal burned in a power plant...)

$EF_i$  = Emission factor : amount of emission per unit activity

(ex: kg of sulfur emitted per kg burned)

$P_{1i}, P_{2i}, \dots$  = parameters applied to the specified source types and species

(ex: sulphur content of the fuel, efficiency, ...)

Emissions calculated for different categories of emissions

**Species : CO, CO<sub>2</sub>, NO<sub>x</sub>, NMVOCs, SO<sub>2</sub>, BC, OC<sub>p</sub>**  
**Period : 1860-2030**

**Anthropogenic sources included :**  
**fossil fuel and biofuel**  
**combustion sources**

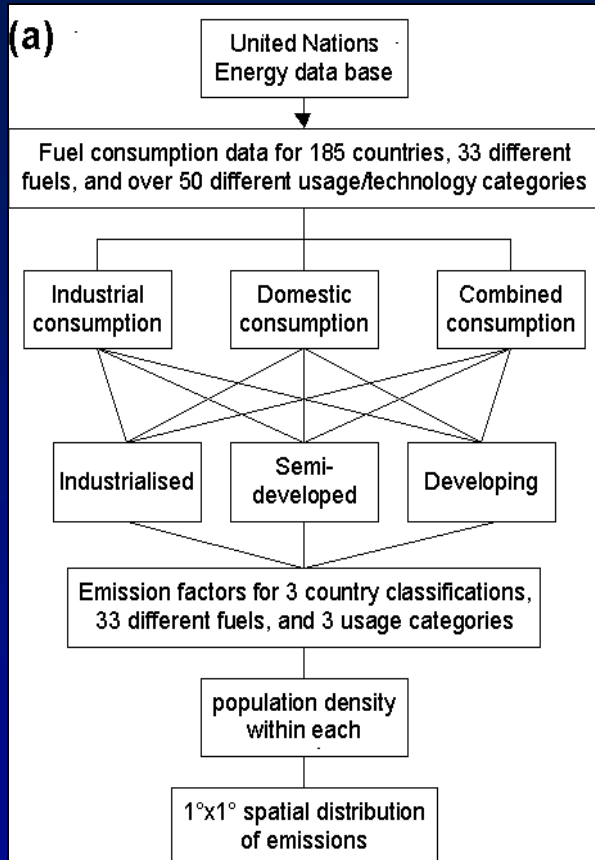
**☺ not included : ships, waste burning, solvent production and animals (could be taken from the RETRO inventory)**

**Bottom-up method used to derive emission inventories**  
**based on Junker and Lioussé, ACPD, 6, 4897, 2006**

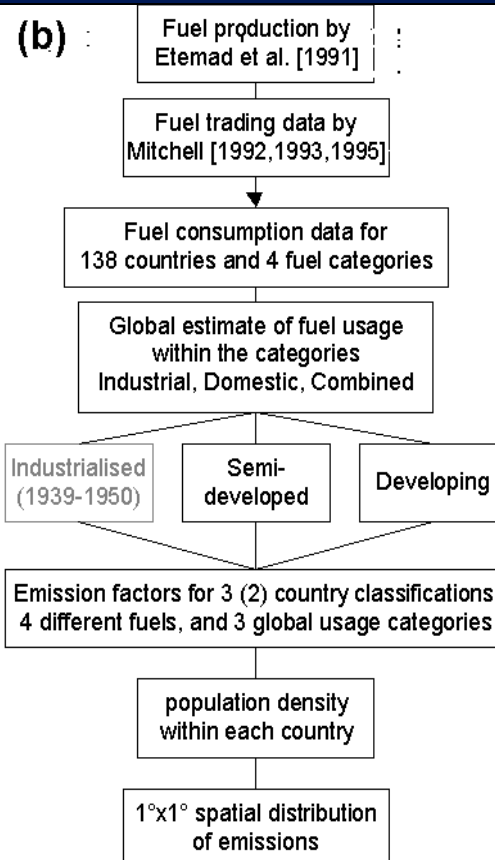
- Emissions provided country by country**
- Spatialization using GISS population map modified for large political changes**
- Different algorithms for 1860-1949, 1950-2003 and 2003-2030**

# Different algorithms for 1860-1949, 1950-2003

## 1950-2003



## 1860-1949



**Crude oil separated into Diesel and Gasoline**  
*extrapolation from UN data for each country group and activities)*

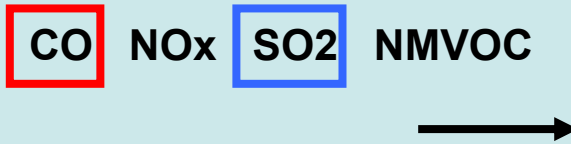
**Fuels over three sectors :**  
*extrapolation from UN data for each country group*

**Country classification**  
*<1940 : only 2 classes*

**See Table of EF values**

**NB : Data for Biofuel consumption for the 1860-1969 period :**  
*extrapolation from UN data and population trends for each country group and each activities*

# Still no agreement: Emission Factors



CO<sub>2</sub>  
↓

CO <sub>2</sub> (CO <sub>2</sub> g/kg)	All sectors
Solid fuel	2483 (a)
Fuelwood	1550 (b)
Charcoal	2611 (b)
Peat	2611
Aviation	3212 (a)
Diesel/Heavy fuel	3108 (a)
Motor gasoline	3168 (a)
Gas (Natural, GPL, É)	2435 (a)

**First step : gaseous  
EF constant over time**

	Co m	Do m	Ind	Co m	Do m	Ind	Co m	Do m	Ind	Co m	Do m	Ind
<b>Solid fuel</b>												
Develop.	13,6	45 <sup>a</sup>	4,1 <sup>a</sup>	3,85	2,02	7,34	16,3	14	19	0,29	1,7	0,05
Semi-Dev.	24,6	73,8	8,2	6,97	3,31	14,7	29	23	38	0,53	2,8	0,10
Developing	47,3	73,8	30,3	13,4	3,31	54,3	57	23	141	1	2,8	0,4
<b>Fuelwood</b>												
Develop.	20,7	63 <sup>d</sup>	6,8 <sup>d</sup>	1,84	1,1 <sup>a</sup>	3,1	0,4	0,2	0,75	3	7,3	1,25
Semi-Dev.	20,7	63	6,8	1,84	1,1	3,1	0,4	0,2	0,75	3	7,3	1,25
Developing	24,8	75,6	8,16	2,21	1,33	3,67	0,46	0,4	0,9	3,6	8,8	1,5
<b>Charcoal</b>												
Dévelop.	200	200 <sup>c</sup>	0	5,97	5,97	0	0,4	0,4	0.	2,7	2,7	0
Semi-Dev.	200	200	0	5,97	5,97	0	0,4	0,4	0.	2,7	2,7	0
Developing	200	200	0	5,97	5,97	0	0,4	0,4	0.	2,7	2,7	0
<b>Peat</b>												
Develop.	200	200	0	5,97	5,97	0	0,4	0,4	0.	4,9	4,9	0
Semi-Dev.	200	200	0	5,97	5,97	0	0,4	0,4	0.	4,9	4,9	0
Developing.	200	200	0	5,97	5,97	0	0,4	0,4	0.	4,9	4,9	0
<b>Aviation</b>												
Develop.	6 <sup>b</sup>	6	6	14 <sup>b</sup>	14	14	1	1	1	1,7	1,7	1,7
Semi-Dev.	6	6	6	14	14	14	1	1	1	1,7	1,7	1,7
Developing	6	6	6	14	14	14	1	1	1	1,7	1,7	1,7
<b>Diesel/Heavy fuel</b>												
Develop.	7,4 <sup>c</sup>	0,24	4	6,88	3,3 <sup>a</sup>	5	0,14	2,8	1,5	2,17	0,13	1,2
Semi-Dev.	14,8	0,31	5,8	13,8	4,29	7,25	0,29	3,64	2,2	4,3	0,17	1,74
Developing	37	1,2	13,3	34,4	16,5	16,6	0,72	14	5	10,8	0,65	4
<b>Motor gasoline</b>												
Develop.	9,76	4,55	4,55	9,76	4,55	4,55	0,5	0,5	0,5	17	8,4	8,4
Semi-Dev.	48,8	22,7	22,7	48,8	22,7	22,7	2,4	2,4	2,4	85	42	42
Developing	48,8	22,7	22,7	48,8	22,7	22,7	2,4	2,4	2,4	85	42	42
<b>Gaz (naturel, GPL...)</b>												
Develop.	3,02	2,29	3,98	3,02	2,29	3,98 <sup>d</sup>	8.e-4	1.e-4	7.e-3	0,63	1,66	0,24
Semi-Dev.	3,02	2,29	3,98	3,02	2,29	3,98	8.e-4	1.e-4	7.e-3	0,63	1,66	0,24

# EF(BC)...

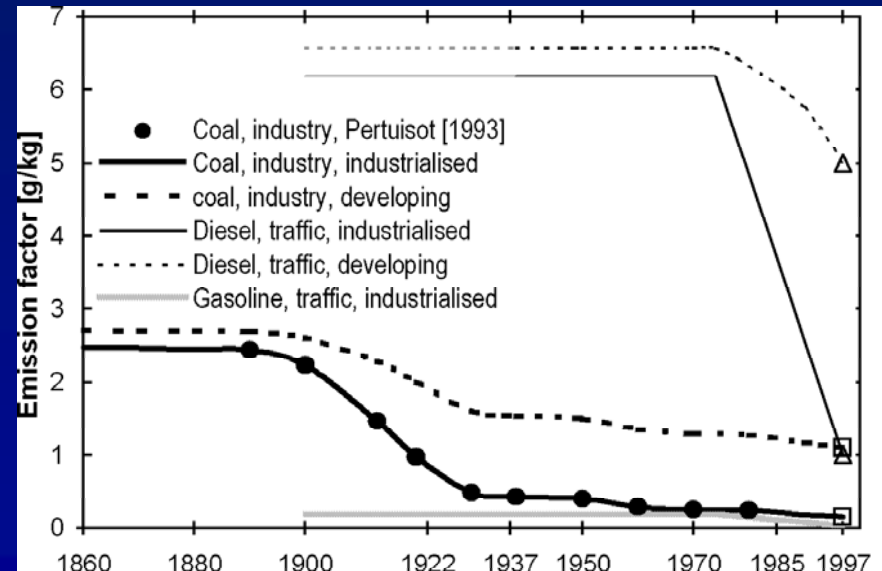
	Com	Dom	Ind	Com	Dom	Ind
<b>Coal</b>						
Develop.	0.46	1.39	0.07	0.66	2.92	0.15
Semi-Dev.	0.82	2.28	0.30	1.19	4.77	0.30
Developing	1.58	2.28	1.1	2.29	4.77	1.1
<b>Lignite</b>						
Develop.	0.46	1.39	0.07	1.35	4.09	0.21
Semi-Dev.	0.82	2.28	0.30	2.41	6.71	0.88
Developing	1.58	2.28	1.1	4.65	6.71	3.24
<b>Fuelwood</b>						
Develop.	0.67	0.75	0.6	2.02	2.25	1.8
Semi-Dev.	0.67	0.75	0.6	2.02	2.25	1.8
Developing	0.81	0.9	0.72	2.43	2.7	2.16
<b>Charcoal</b>						
Develop.	0.75	0.75	0.75	2.25	2.25	2.25
Semi-Dev.	0.75	0.75	0.75	2.25	2.25	2.25
Developing	0.75	0.75	0.75	2.25	2.25	2.25
<b>Peat</b>						
Develop.	0.3	0.67	0.13	2.71	6.07	1.21
Semi-Dev.	0.3	0.67	0.13	2.71	6.07	1.21
Developing	0.3	0.67	0.13	2.71	6.07	1.21
<b>Aviation</b>						
Develop.	0.1	0.1	0.1	1.15	1.15	1.15
Semi-Dev.	0.1	0.1	0.1	1.15	1.15	1.15
Developing	0.1	0.1	0.1	1.15	1.15	1.15
<b>Diesel</b>						
Develop.	1	0.07	0.2	0.5	0.05	0.15
Semi-Dev.	2	0.09	0.28	1	0.07	0.21
Developing	5	0.35	1	2.5	0.25	0.75
<b>Heavy fuel</b>						
Develop.	1	0.07	0.07	0.5	0.05	0.05
Semi-Dev.	2	0.09	0.09	1	0.07	0.07
Developing	5	0.35	0.35	2.5	0.25	0.25

# EF values: changing with time?

← Values for present

## Evolutionary EF for BC and OCp

EF (BC)



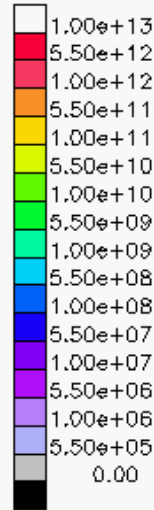
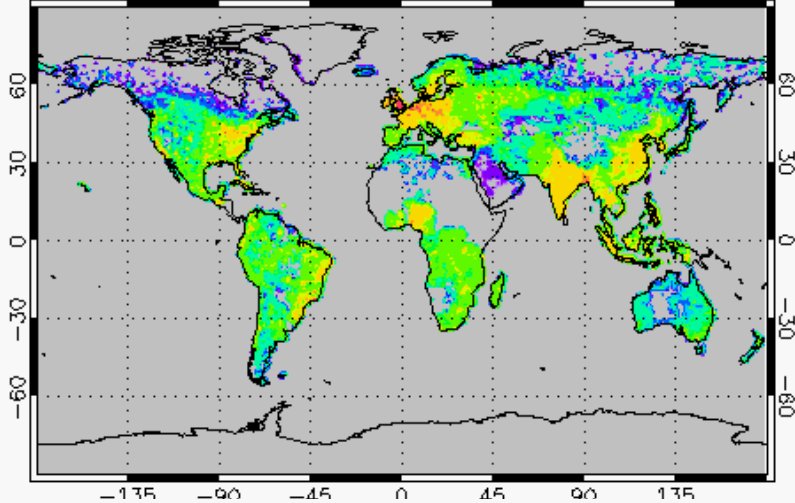
*Trends for Coal EF from trends of power plant efficiency*  
*Trends for Diesel from Yanowitz et al., 2000*

↘ EF (OCp)...

# Change in the distribution of anthropogenic emissions of CO from 1900 to 2000

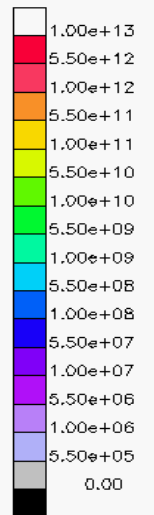
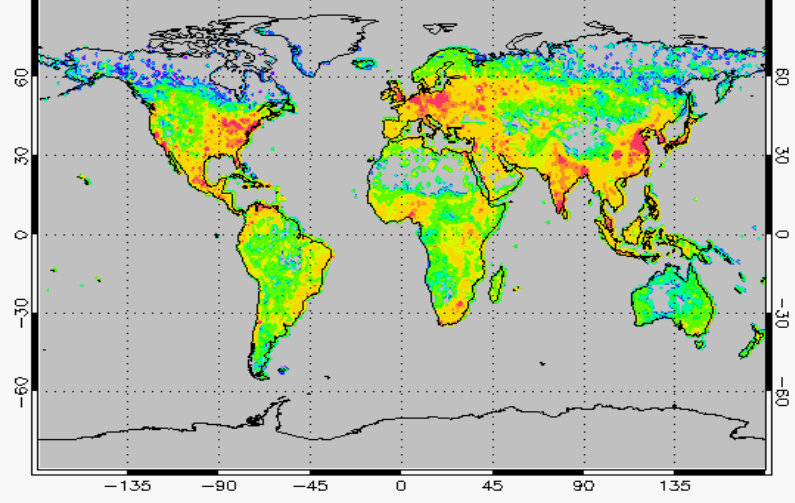
Emissions [Anthrop] 1900 [molec/cm2/s]

-135 -90 -45 0 45 90 135



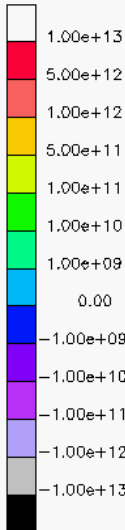
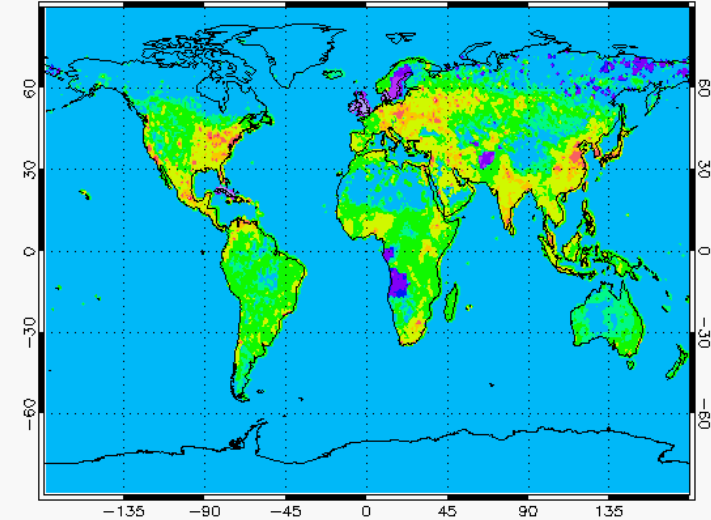
Emissions [Anthrop] 2000 [molec/cm2/s]

-135 -90 -45 0 45 90 135



Emissions [Anthrop] difference 2000-1900 [molec/cm2/s]

-135 -90 -45 0 45 90 135



/users/grunier/Desktop/work/bruno/ca\_2000.nc

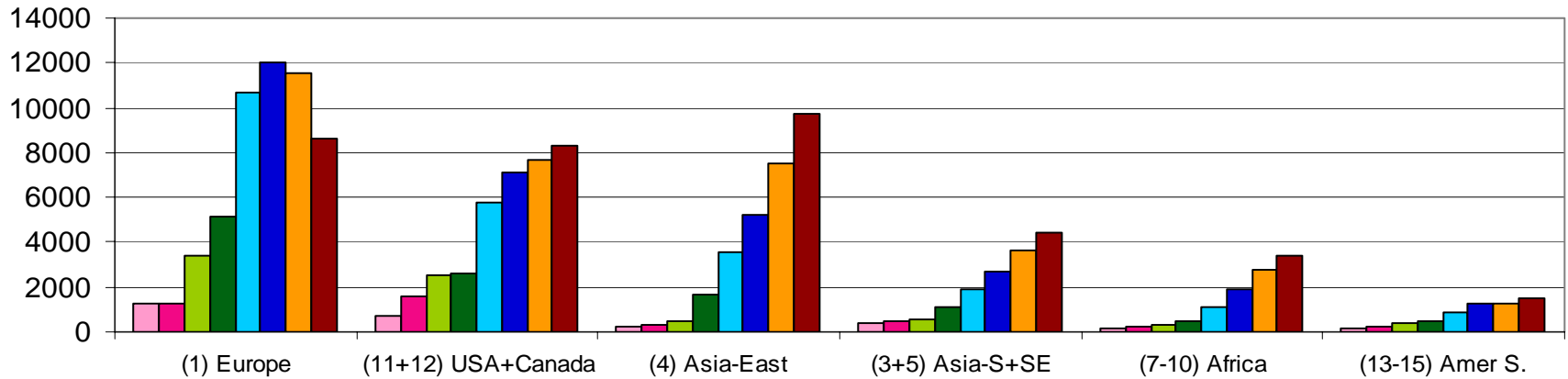
grunier 24.02.2007 16:04

/users/grunier/Desktop/work/bruno/ca\_2000.nc

grunier 24.02.2007 16:29

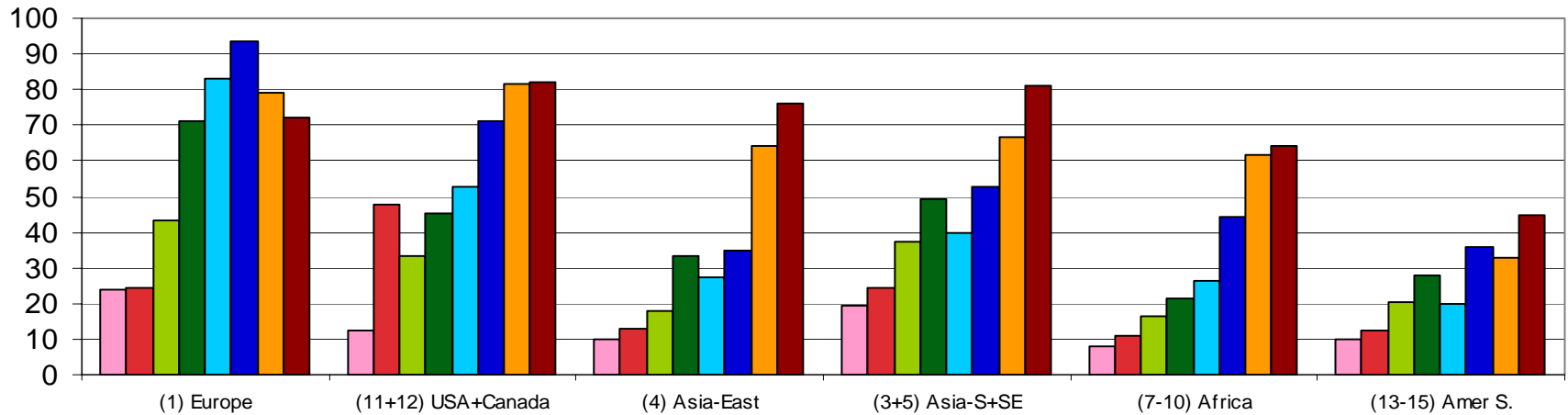
## CO2 anthropogenic emissions (Tg CO2/year)

1900 1922 1950 1960 1970 1980 1990 1997



## CO anthropogenic emissions (Tg CO/year)

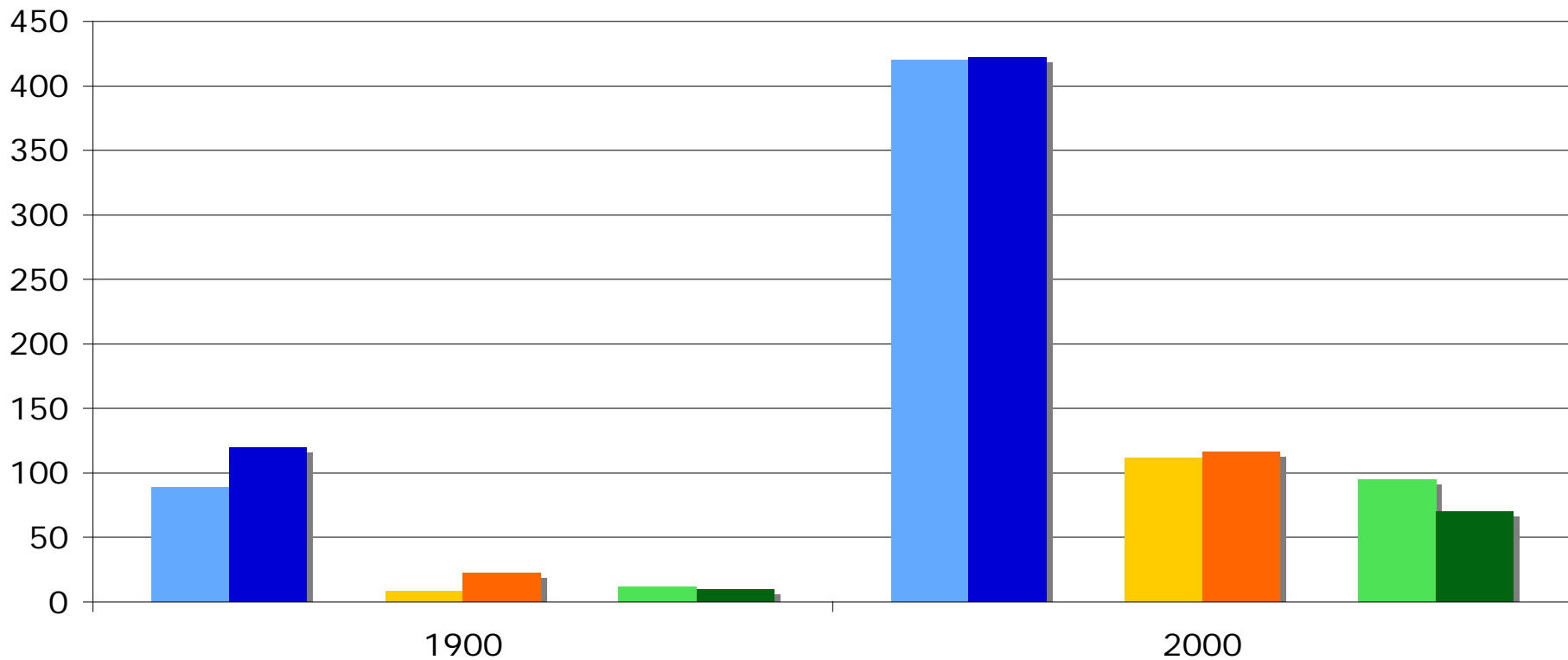
1900 1922 1950 1960 1970 1980 1990 1997



**Change in the anthropogenic emission of CO2 and CO for several large areas from 1900 to 1997.**

### Comparison with the HYDE-EDGAR inventory

CO CO\_Hyde NOx NOx\_Hyde SO2 SO2\_Hyde



In Tg/year

# What needs to be further evaluated

## 1. Impact of uncertainties on BC emissions factor

Table 1. (a) EF matrix for hard coal and diesel fuel and EF values given by Bond et al. (2004).

fuel type	level of development	fuel usage (this work)			Bond et al. (2004)	
		industrial	domestic	other/traffic	fuel usage	mean EF
hard coal	developed	0.15	1.39	0.46	power	0.006
	semi-developed	0.30	2.28	0.82	industry	0.610
	developing	1.1	2.28	1.58	traditional kiln	5.0
diesel	industrialised	0.6	0.07	1	standards in place	0.99
	semi-developed	0.87	0.09	2	standards beginning	2.31
	developing	2	0.35	5	superemitter	7.92

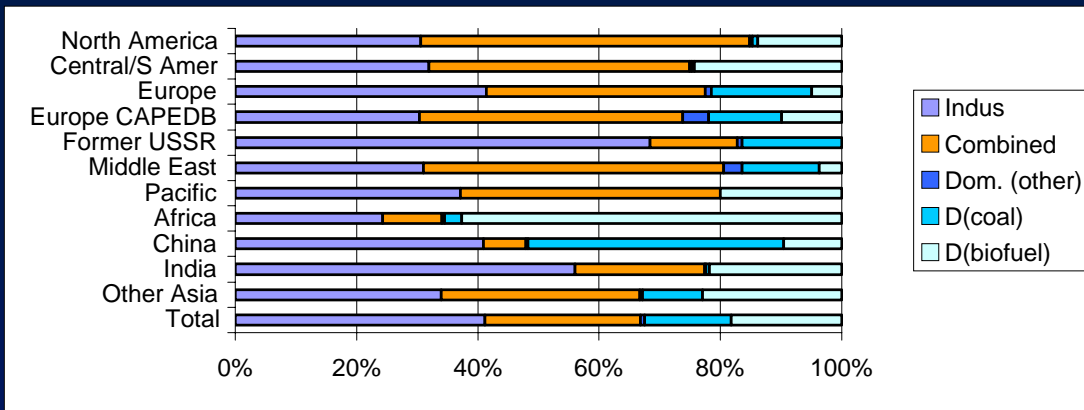


Emission factors from  
Cooke et al., JGR, 1999

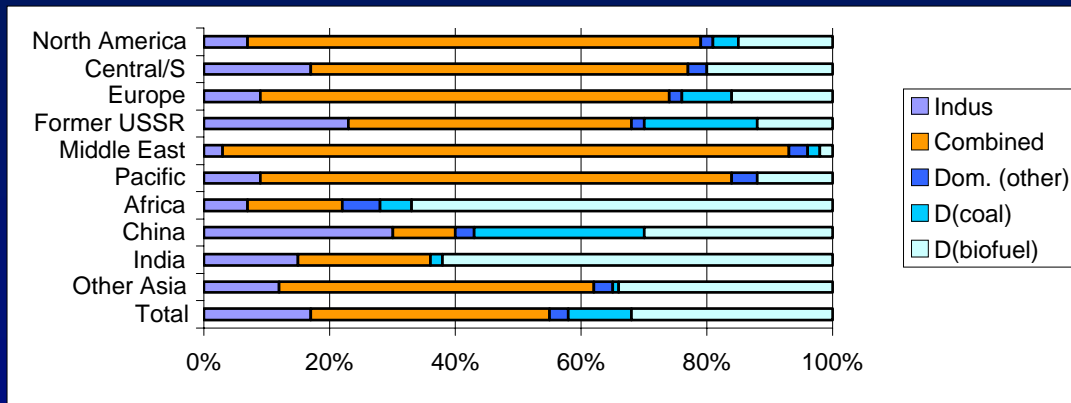


Emission factors from  
Bond et al., JGR, 1999

# Our inventory



# Using T. Bond Emission Factors



Large differences in spatial distribution

Total emitted:

Our inventory for BC: 4.8 Tg / year

T. Bond's inventory from AEROCOM: 4.7 Tg / year

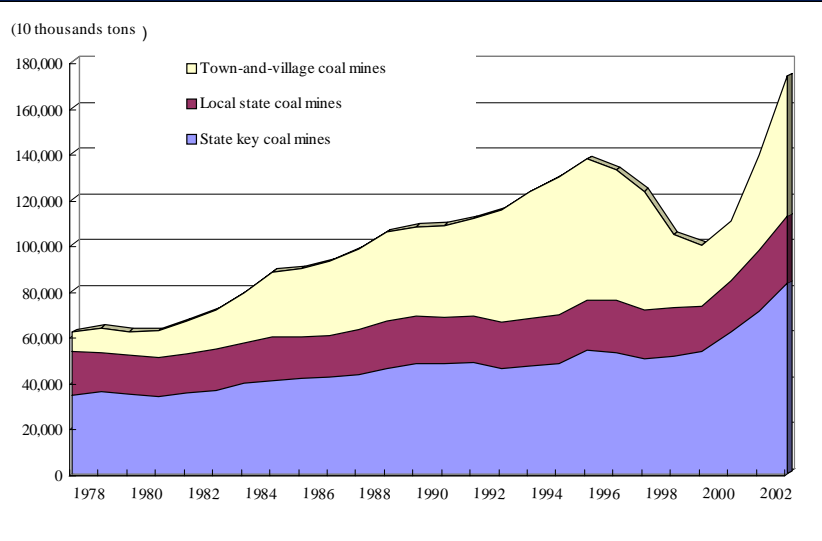
[Need to check that units are the same]



Detailed intercomparison of BC inventory for 2000

# What needs to be improved

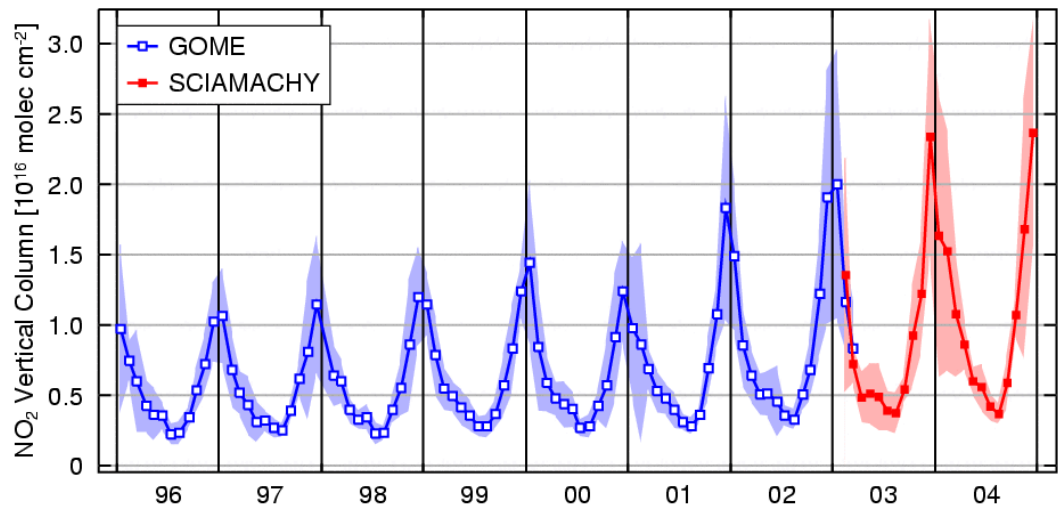
## 2. Emissions in China



**RAES 1995-2000 “corrected” inventory for China is now available: it will be used to update our current inventory (from Akimoto Frontier’s group)**

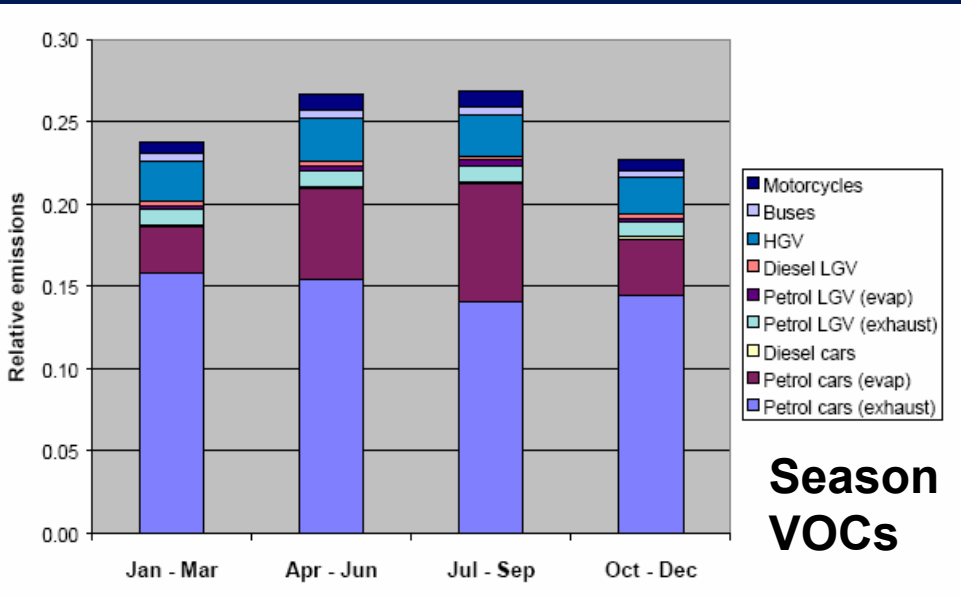
**NO<sub>2</sub> tropospheric column in China; From Richter, Burrows, Nuess, Granier and Niemeier, Nature, 2005**

**Coal production by types of coal**  
**Source: China Coal Industry Yearbook**

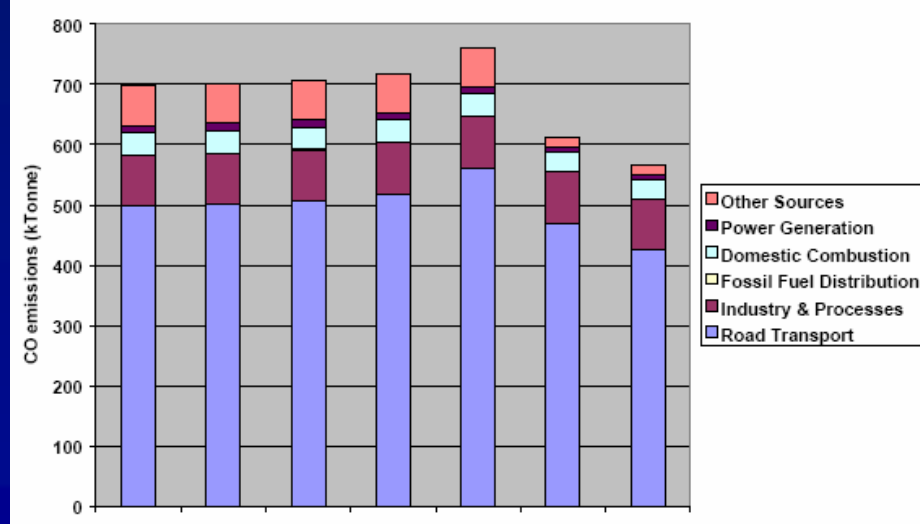
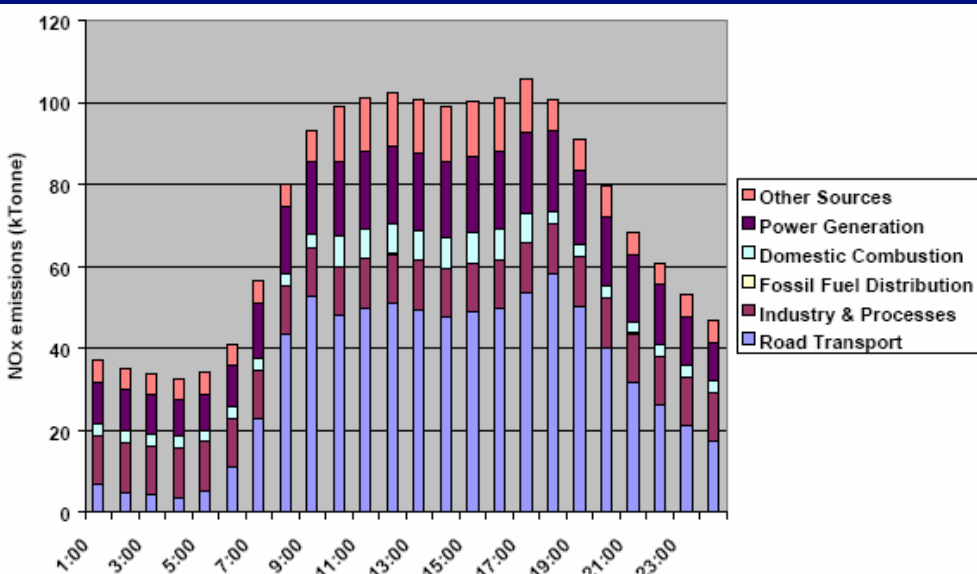


# What could be improved

## 3. Temporal variation

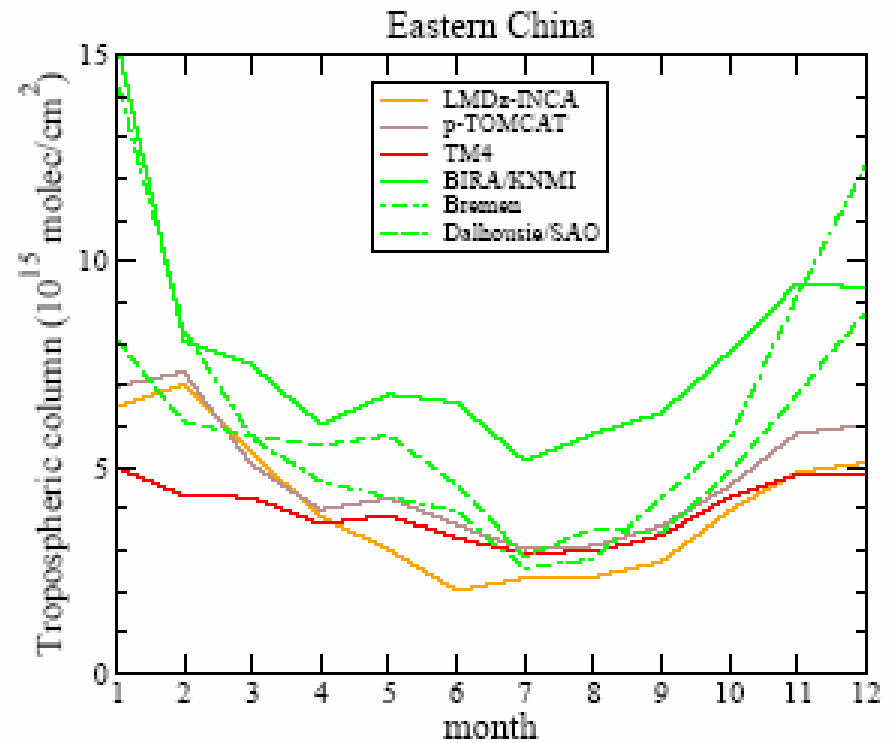
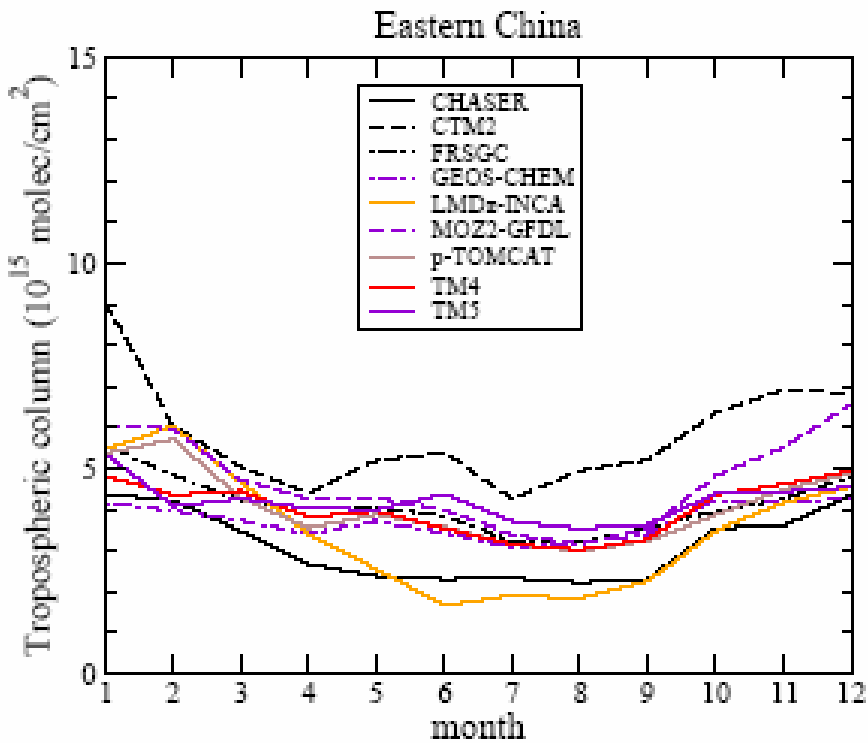


How to implement such temporal profiles?  
detailed data only easily and freely available for UK



CO weekly emissions

NOx diurnal emissions

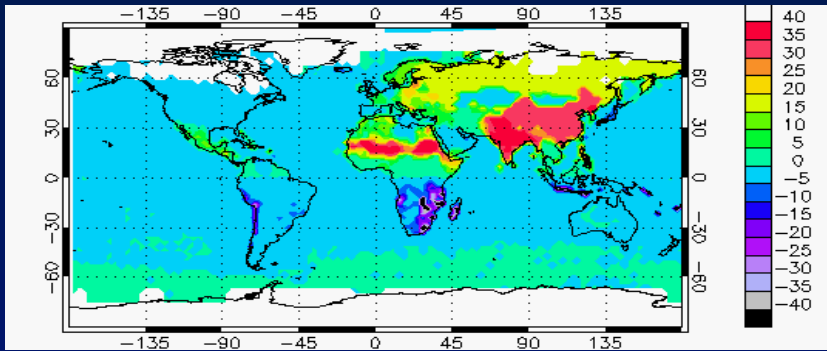


Use of NO<sub>2</sub> satellite data?

Significant differences between the 3 available retrievals from:

- University of Bremen
- KNMI, The Netherlands
- University of Nova Scotia

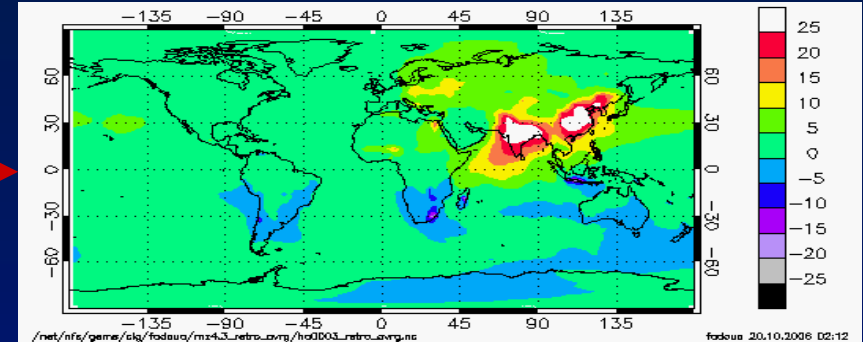
## CO surface emission



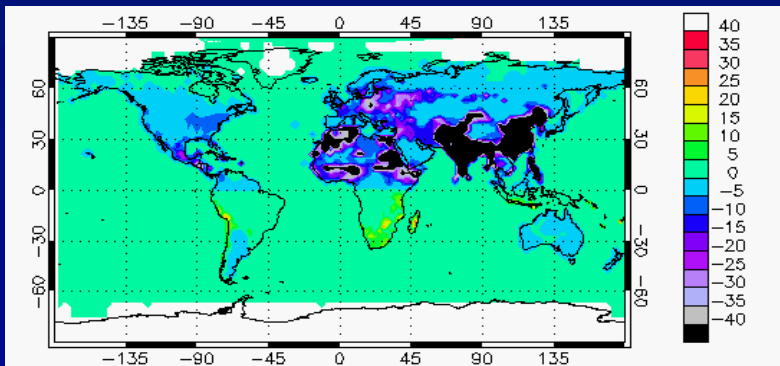
$$100 * (CO_{seas} - CO_{no\_season}) / CO_{seas}$$

## Surface CO

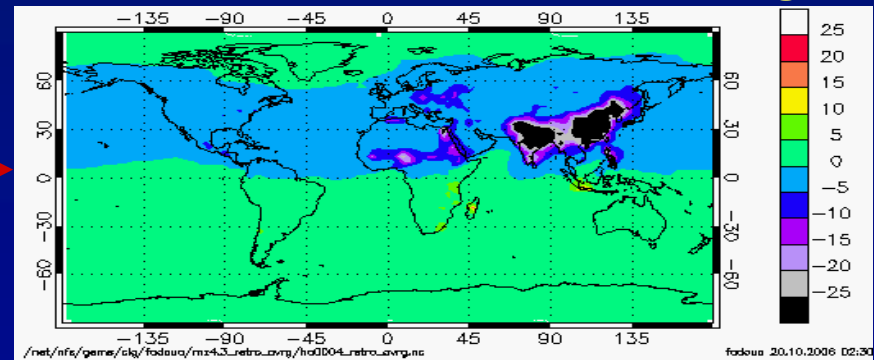
february



$$100 * (CO_{seas} - CO_{no\_season}) / CO_{seas}$$



$$100 * (CO_{seas} - CO_{no\_season}) / CO_{seas}$$

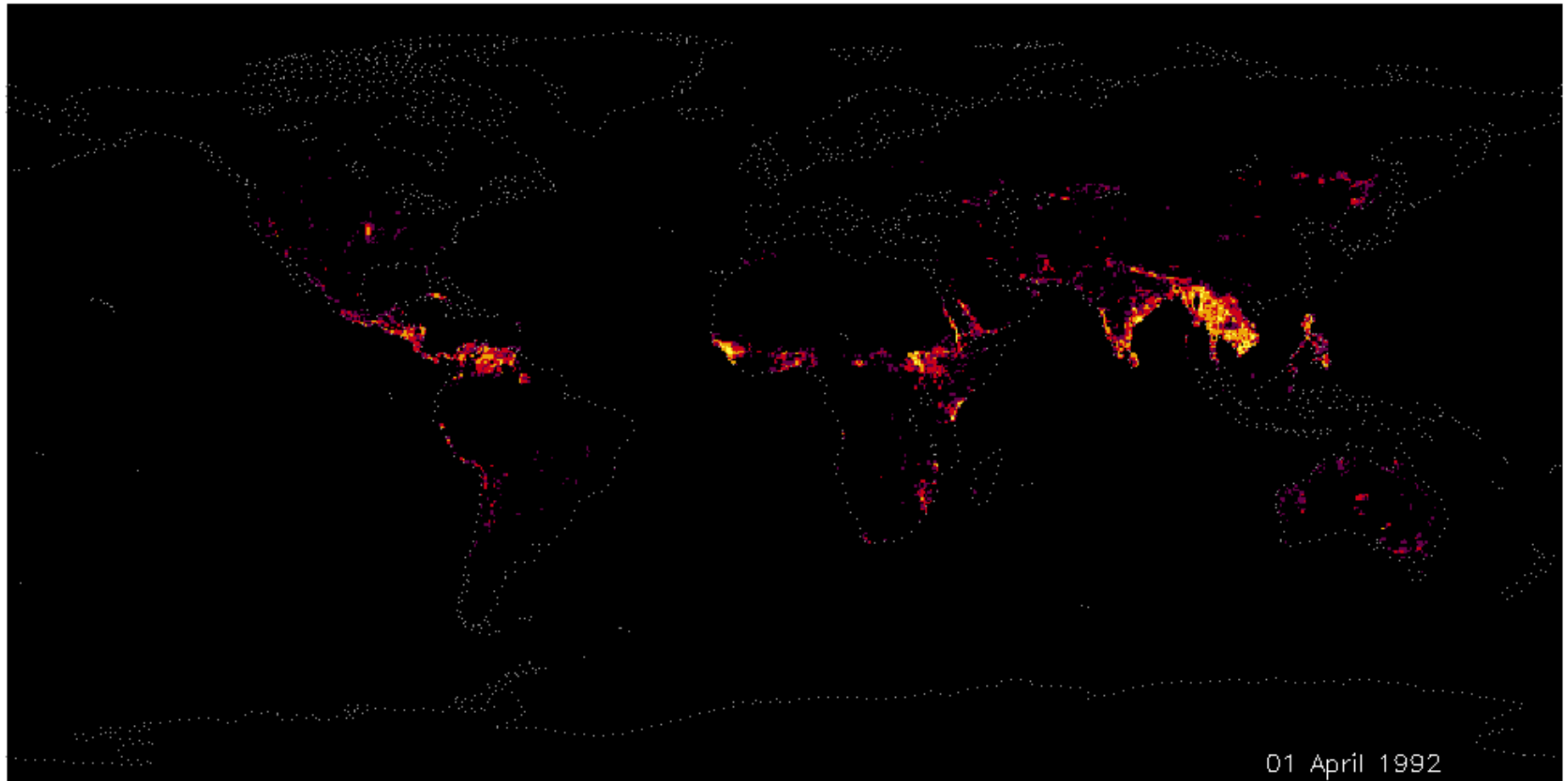


$$100 * (CO_{seas} - CO_{no\_season}) / CO_{seas}$$

**Importance of the seasonal variation of surface emissions on the seasonal variation of surface concentrations.**

The Global Distribution of Active Vegetation Fires as Derived from NOAA—AVHRR Satellite Data

Monitoring of Tropical Vegetation Unit, Space Applications Institute, Joint Research Centre of the European Commission, Ispra, Italy



Jan Feb Mar **Apr** May Jun Jul Aug Sep Oct Nov Dec 1992

**Biomass burning emissions: large contribution to total emissions**

# calculating the emissions per gridbox

$$M(X)_m = \sum_{k=1}^n EF_k(X) \times A_m \times \beta_k \times AFL_k$$

$M(X)_m$ : amount of species X emitted per month m

n: number of ecosystems (5)

$EF_k(X)$ : emission factor for species X per ecosystem

$A_i$ : area burnt per month

$\beta_k$ : combustion efficiency for ecosystem k

$AFL_k$ : available fuel load per ecosystem

$$AFL_k = \sum_{t=1}^9 fc_t \times \sum_{p=1}^5 \chi_{t,p} \times m_{t,p}$$

$fc_t$ : fractional cover of PFT t per gridbox

t: number of PFT's (9)

p: number of carbon pools (5)

$\chi_{t,p}$ : susceptibility factor

$m_{t,p}$ : dry matter per PFT and carbon pool

# 1900 – 2000 Biomass burning emissions

**Two steps:**

## **1. 1997-2003: Use of satellite data**

**For 2000:**

**GBA-2000 burned area product**

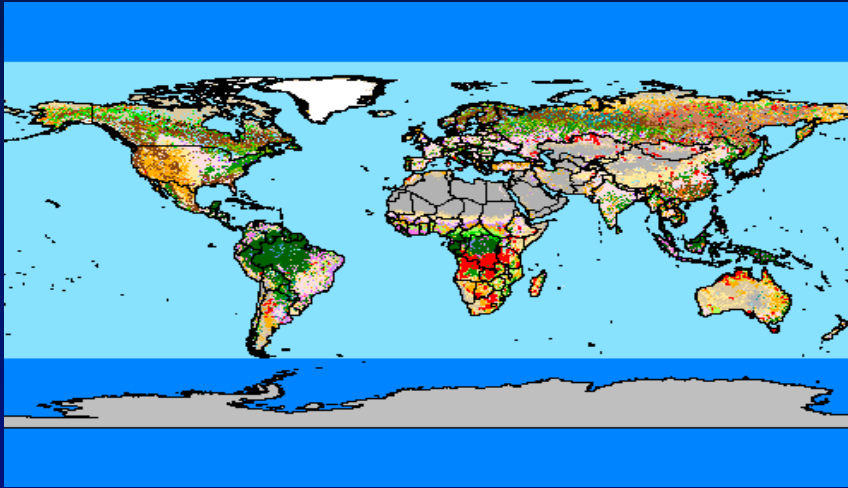
**GLC vegetation map**

**Both products developed by the JRC, Ispra, Italy**

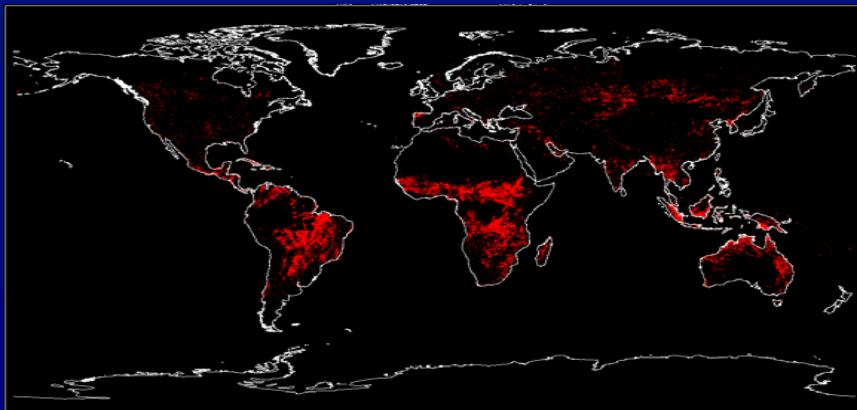
**Only available for 2000 [Burned area product are expected to be available for several years. When?]**

**For other years: use of active fires from ATSR**

# Methodology – biomass burning emissions 1997-2003

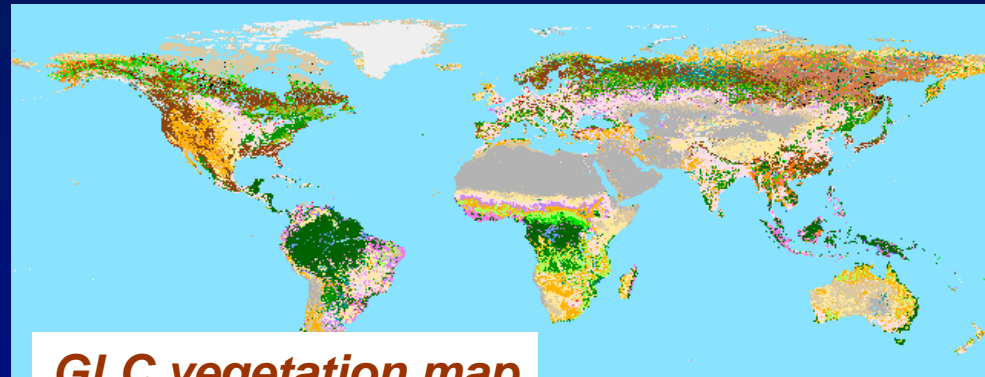


**GBA 2000 burnt areas for 2000**



**ATSR Fire Counts 1997 -2003**

## Data used

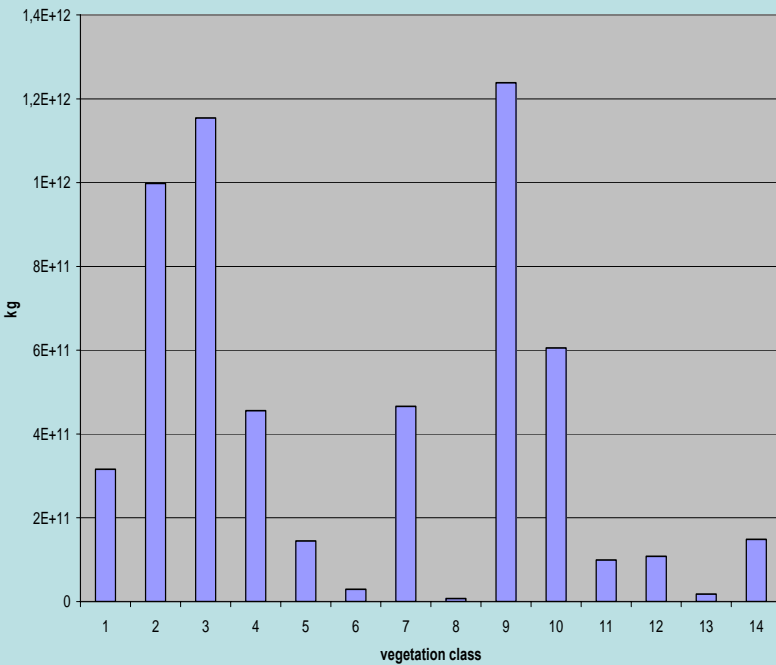


**GLC vegetation map**

GLC vegetation classes	Biomass density	Combustion	EF CO <sub>2</sub>	EF CO
	kg/m <sup>2</sup>	efficiency	g/kg	g/kg
1 Broadleaf evergreen GLC1	23.3	0.25	1580	104
2 Closed broadleaf deciduous GLC2	20	0.25	1569	107
3 Open Broadleaf deciduous GLC3	3.3	0.4	1613	65
4 Evergreen needleleaf forest GLC4	36.7	0.25	1569	107
5 Deciduous needleleaf GLC5	18.9	0.25	1569	107
6 Mixed leaf type GLC6	14	0.25	1569	107
7 Tree Cover, regularly flooded, fresh (-brackish) GLC	27	0.25	1580	104
8 Tree Cover, regularly flooded, saline, (daily variation)	14	0.6	1596	82
9 Mosaic : tree cover/other natural vegetation GLC9	10	0.35	1591	86
11 Shrub, closed-open, evergreen GLC11	1.2	0.9	1613	65
12 Shrub, closed-open, deciduous GLC12	3.3	0.4	1613	65
13 Herbaceous cover, closed open GLC13	1.4	0.9	1613	65
14 Sparse herbaceous or sparse shrub cover GLC14	0.9	0.6	1567	78
16 Cultivated and managed areas GLC16	0.4	0.6	1515	92
17 Mosaic : cropland/tree cover/other natural vegetatio	1.1	0.8	1594	70
18 Mosaic : cropland/shrub or grass GLC18	1	0.75	1580	74

# Methodology – biomass burning emissions 2000

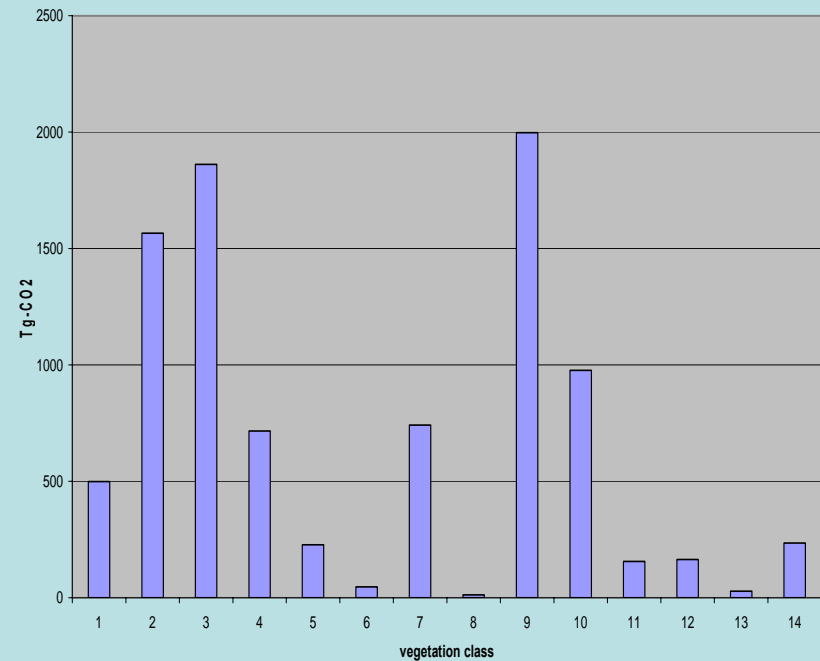
Burnt area per vegetation type



$\times \text{BD} \times \text{BE} \times \text{EF}$



CO2 emissions per vegetation type



**Other years:**

**scaling of ATSR fire counts, using 2000 as a basis**

## 2. 1900-1996 biomass burning emissions: Use of historical data

### Use of data compiled by Mouillot and Field:

Fire history and the global carbon budget: a 1x1 degree fire history reconstruction for the 20th century, *Global Change Biology* (2005) 11, 398–420.

Calculate CO<sub>2</sub> emissions for the 1990-2000 decade as the product :

$$\text{Emissions(CO}_2\text{)} = \text{BA} \times \text{BD} \times \text{BE} \times \text{EF(CO}_2\text{)}$$

BA = Burnt Area (from Mouillot et al. paper)

BD = Biomass Density

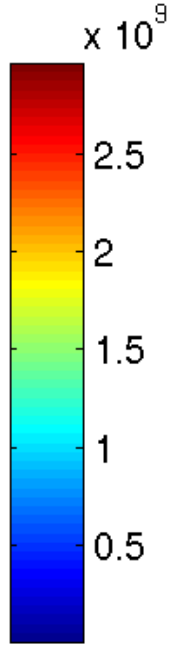
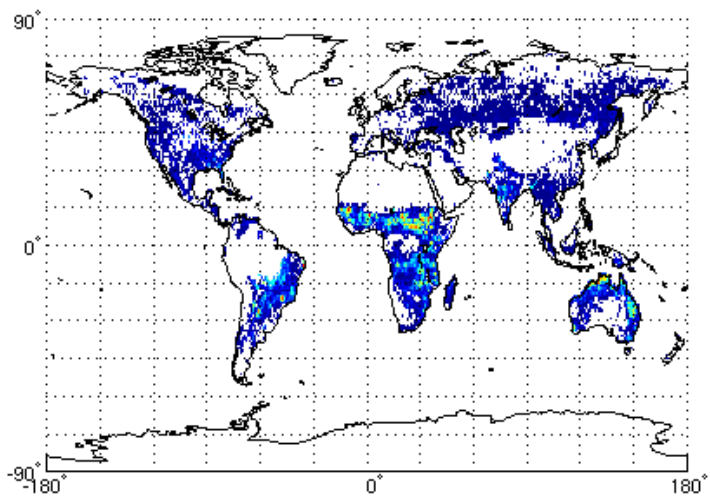
BE = Burning Efficiency (Use GLC 2000 map)

EF(CO<sub>2</sub>) = Emission Factor for CO<sub>2</sub> (from Andreae and Merlet, 2001)

Scale 1990-2000 CO<sub>2</sub> emissions from forest/savanna burning so that they equal the 1997-2003 previously calculated

Use the same scaling for all other decades considering forest and savanna burning separately

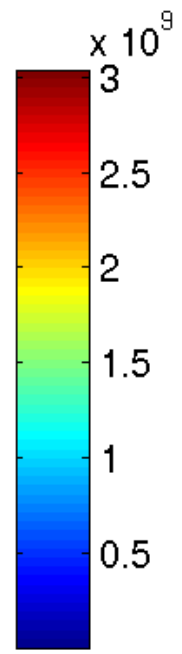
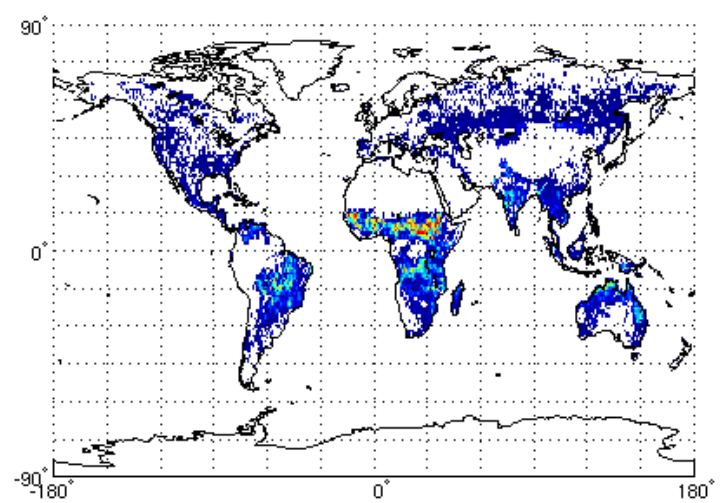
Historical burnt areas (m<sup>2</sup>) for the decade 1900-1910, regridded at 0.5°



**Burned areas (in m<sup>2</sup>)  
for the 1900-1910 and  
1990-2000 decades**

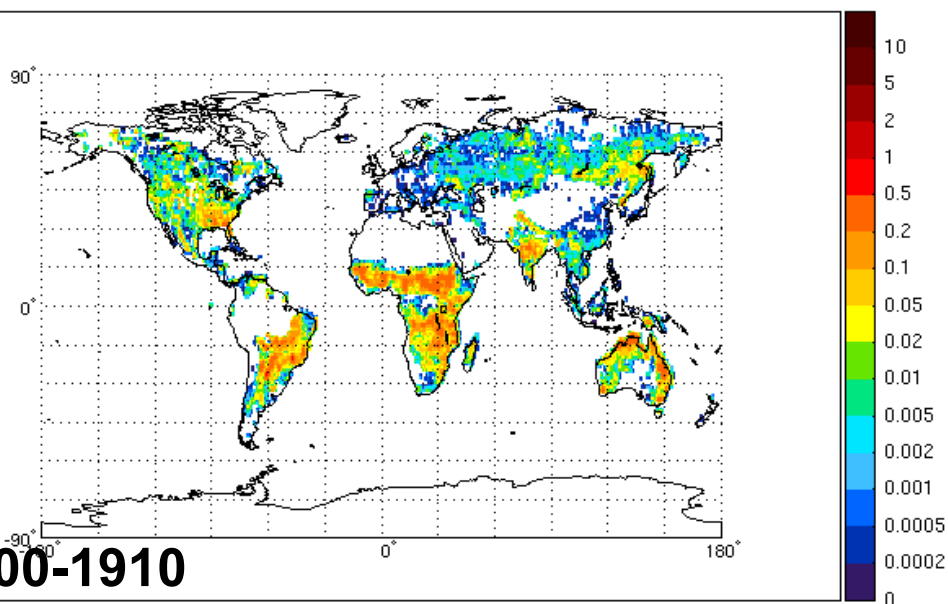
**1900-1910**

Historical burnt areas (m<sup>2</sup>) for the decade 1990-2000, regridded at 0.5°

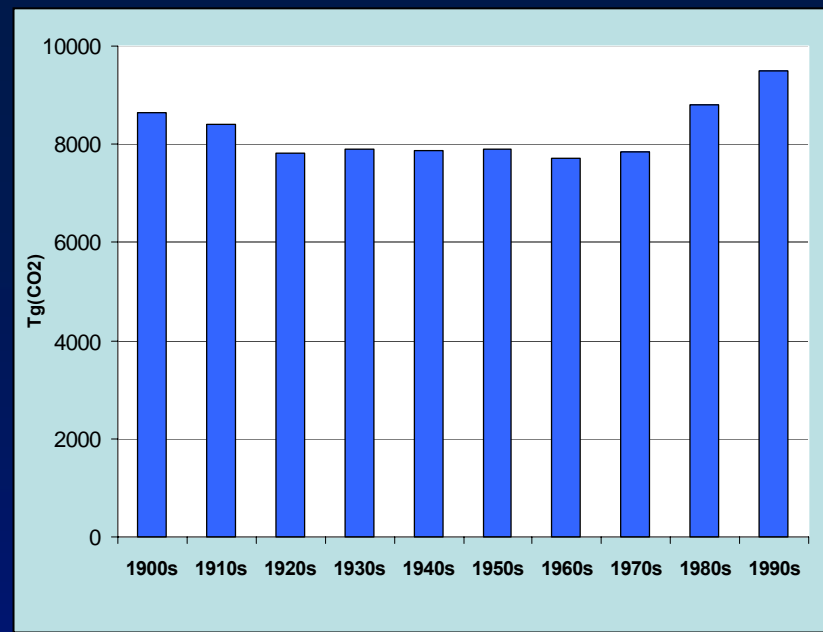


**1990-2000**

co2 emission flux from fires - 1900-1910, yearly average



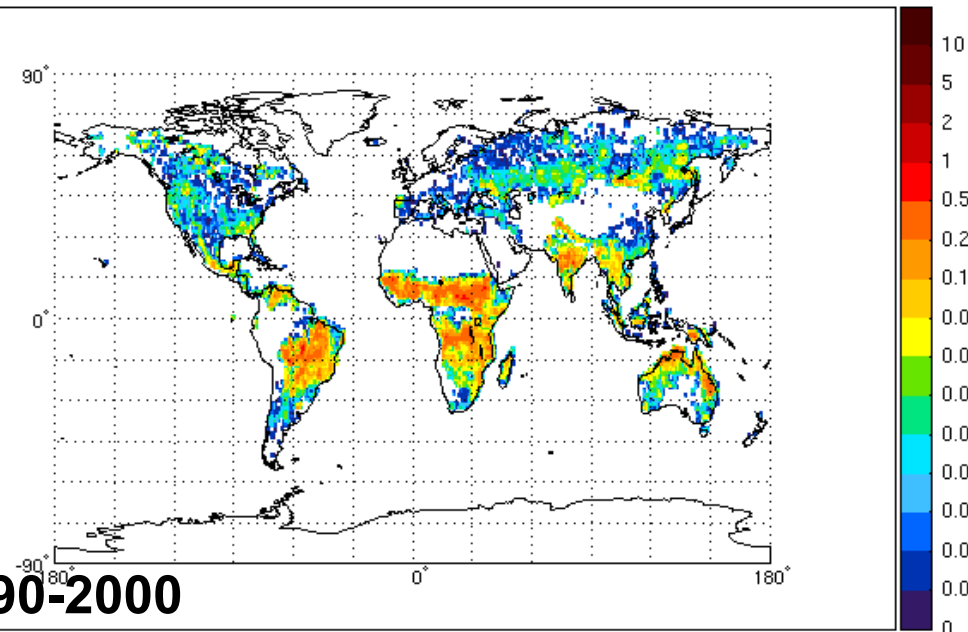
1900-1910



**CO2 emissions for the 1900-1910 and 1990-2000 decades (in 1.e13 molec/cm2/s)**

**Not taken into account: Change in vegetation distribution over the 20<sup>th</sup> century. Any existing data?**

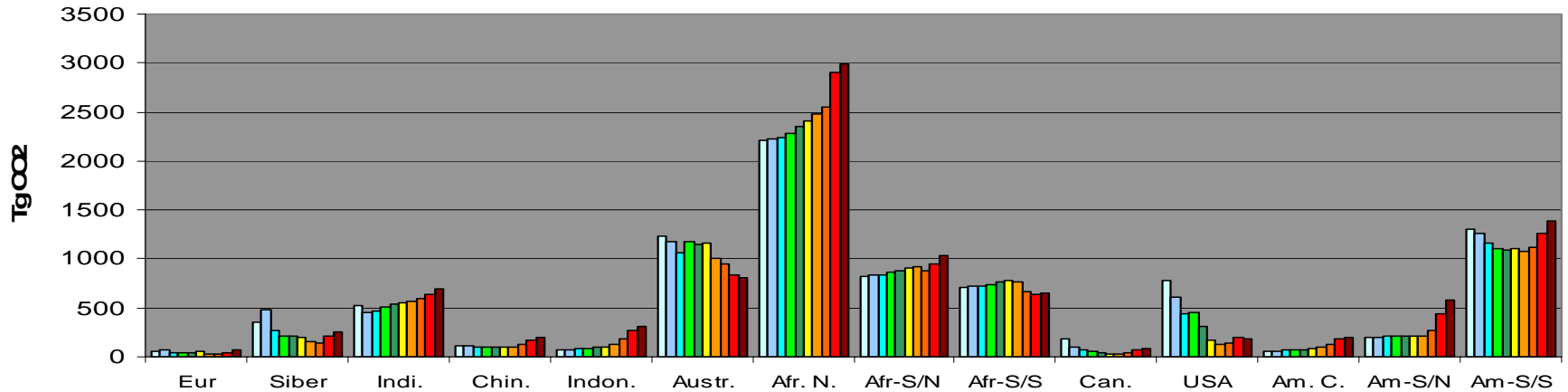
co2 emission flux from fires - 1990-2000, yearly average



1990-2000

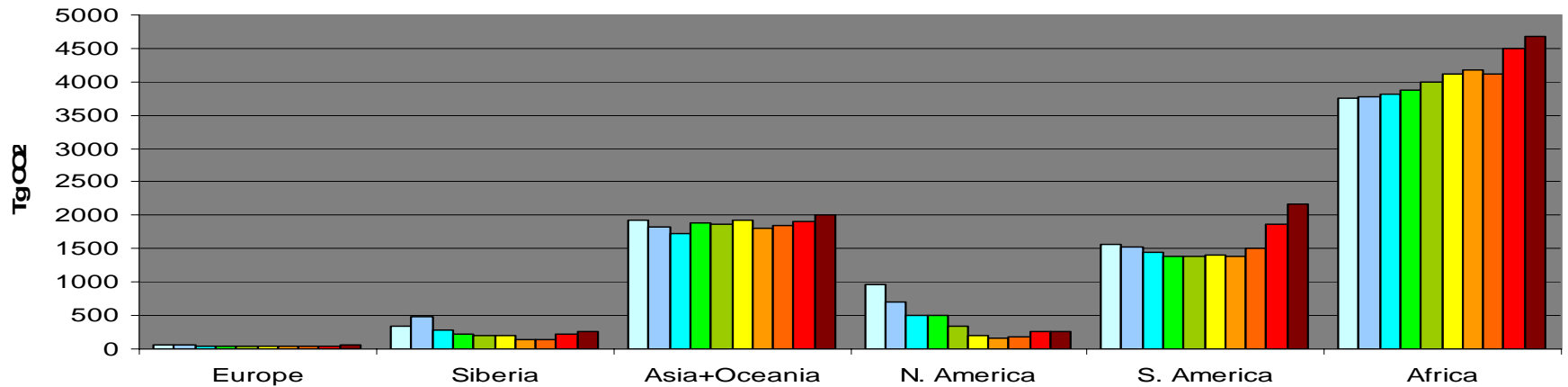
## CO2 emissions from biomass burning

1900-10 1910-20 1920-30 1930-40 1940-50 1950-60 1960-70 1970-80 1980-90 1990-2000



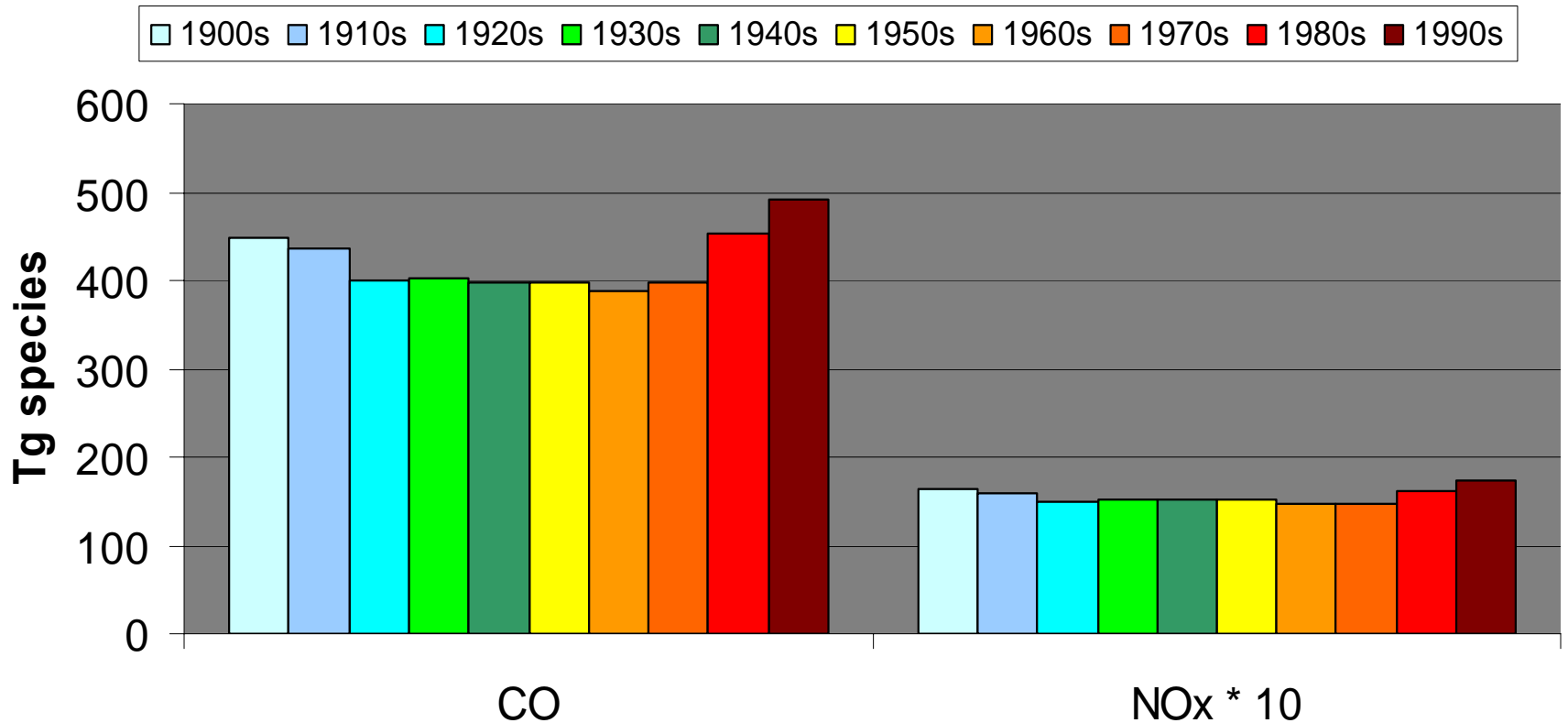
## CO2 emissions from biomass burning

1900-10 1910-20 1920-30 1930-40 1940-50 1950-60 1960-70 1970-80 1980-90 1990-2000



**CO2 emissions resulting from biomass burning during the 20<sup>th</sup> century**

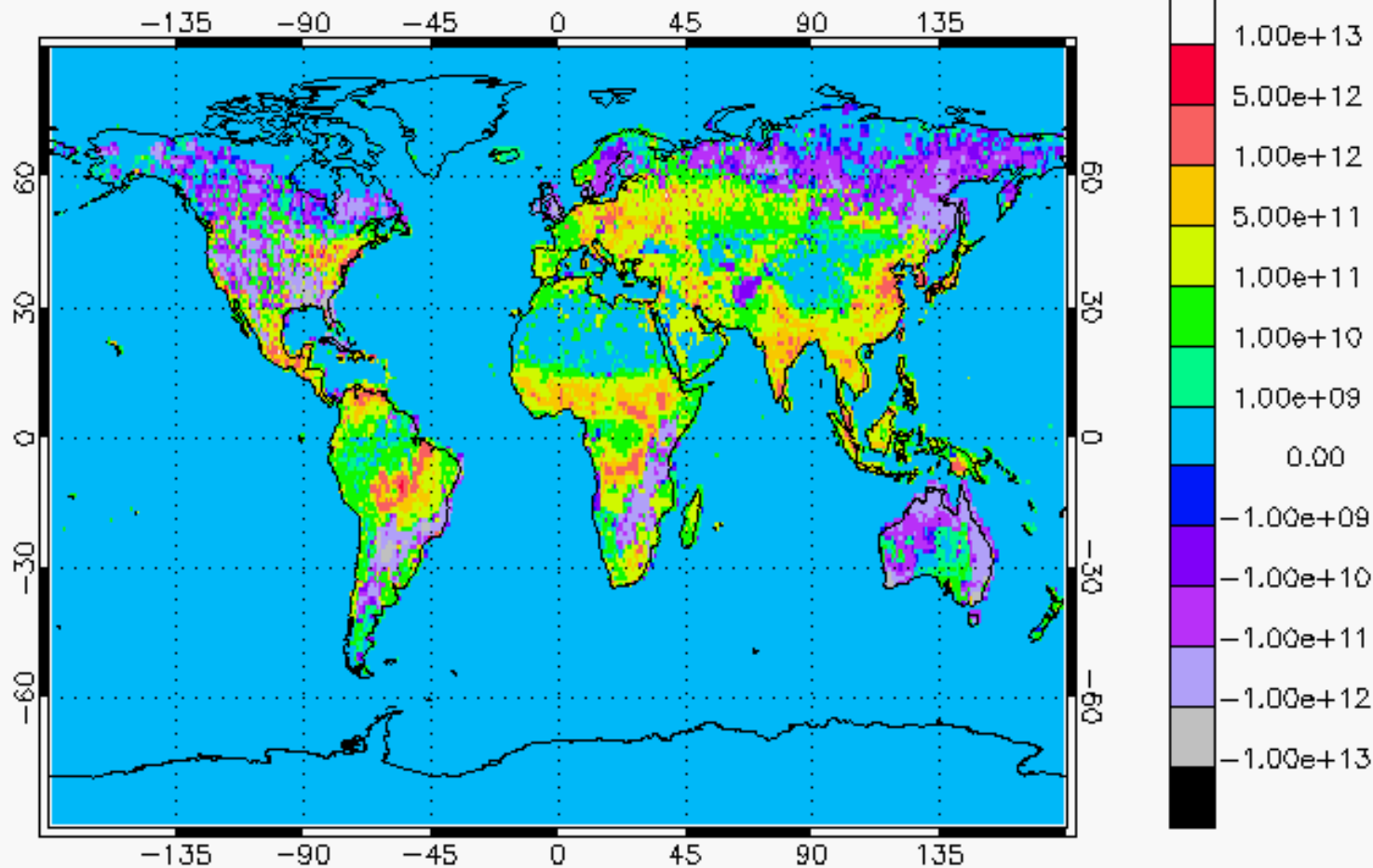
## CO and NOx biomass burning emissions



**CO and NOx emissions resulting from biomass burning during the 20<sup>th</sup> century**

# Summary: Difference in Anthrop+biomass burning emissions 2000-1900

Emissions [Anthrop+BB] difference 2000-1900 [mol/cm<sup>2</sup>/s]



## **1st version of the inventory**

**→ Simulations using these emissions will start this week  
1st set of simulations: steady-state, 1900 and 2000**

**→ Improvements/corrections planned, based on  
simulations results**

**First question we want to look at: are these new  
emissions compatible with the very low ozone  
concentrations measured at the beginning of the 20th  
century?**

**1st step: use MOZART-4**

**2nd step: use coupled model with dynamical vegetation/  
changing land use**

## What could also be developed using the same method: Future projections at the global scale for 2010-2030

New projections by using the **POLES** model including both **fossil fuel and biofuel emissions** (*Junker and Liousse, IGAC 2006*).

**Reference scenario** : Reflect the state of the world with what is actually (2000) embodied as environmental policy objectives

**CCC scenario** : Introduction of carbon penalties as defined by Kyoto for 2010 and a reduction of 37 Gt of CO<sub>2</sub> in 2030.

*First step :*

*- EF for gases constant over time*

*- BC and OCp :*

*EFs for the Reference scenario : equal to today's*

*Reduction of EF for the CCC scenario :*

*Developed countries : based on removal efficiency forecast by the IIASA Rains model*

*Semi-Developed countries : EFs of developed countries of 2000*

*Under-Developed countries : EFs of semi-developed countries of 2000*

**Also contributed to the development of the inventory:**

**Jean-Francois LAMARQUE, NCAR**

**Florent MOUILLOT, CEFÉ, Montpellier, France**

**Jean-Marie GREGOIRE, Joint Research Center, Ispra, Italy**

# Summer School

ESF - ACCENT - CNRS - GEIA

September, 11-20 2007  
île d'Oléron, France

*Surface emissions  
and  
prediction of atmospheric  
composition changes*

**Information:**

Contact: Claire Granier [[claire.granier@pero.jussieu.fr](mailto:claire.granier@pero.jussieu.fr)]

Web site: [www.geiacenter.org](http://www.geiacenter.org)

Application deadline: April, 20 2007

## Themes:

- Emissions
- Atmospheric chemistry
- Modeling
- Chemistry-climate interactions