Global emission inventories of gases and particles from combustion sources for the period 1860-2030 with tentative validations with carbonaceous aerosol TM4 global modeling

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Context :

-Climate change observed during the last century related to atmospheric composition change,

- Role of anthropogenic emissions is crucial, and especially from combustion sources:

Ozone : NOx, NMVOC,.. emissions

Sulfate, nitrates, SOA : SO2, NOx, NMVOC emissions

BC and OCp : primary emission inventories …

- Existing inventories either developed for gases or for particles (incoherence in the chosen proxidata…)

- Most recent studies, at regional or global scale, on pollution transport and on radiative forcing deal with both components (with aerosol module more or less complex including chemistry)

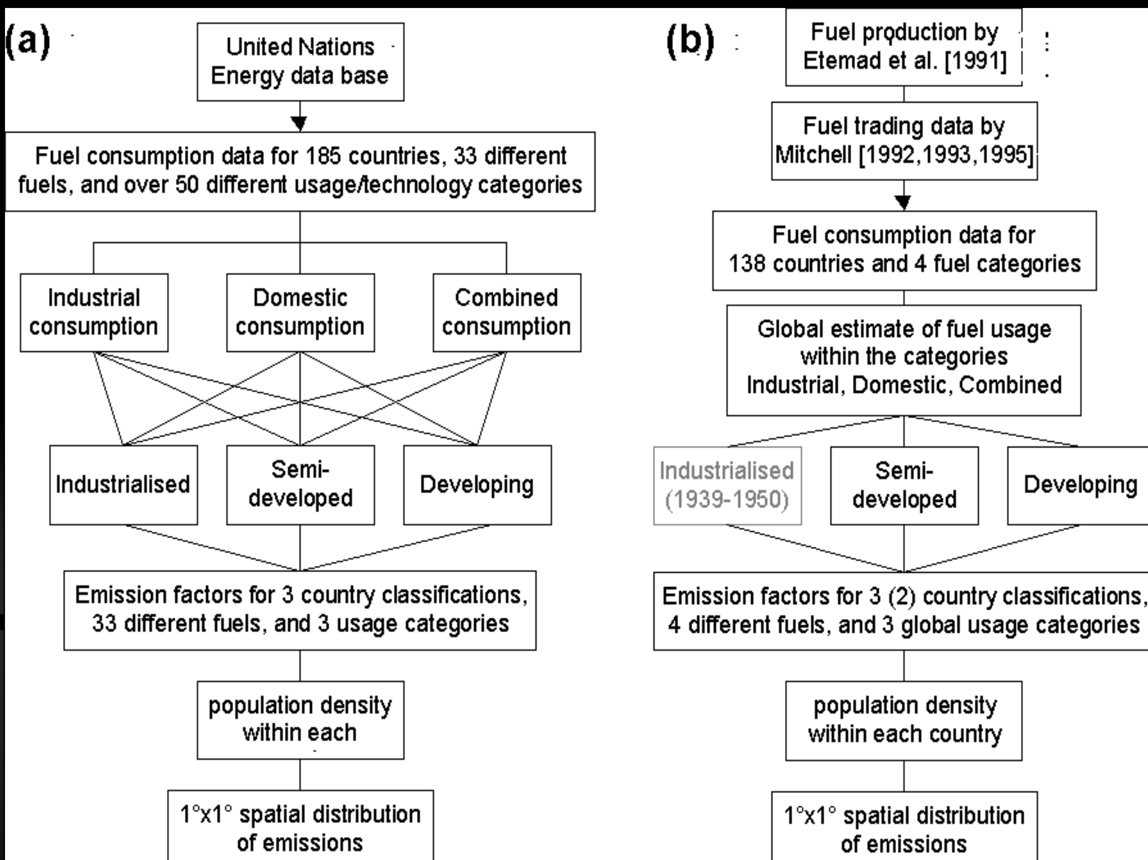
=> need to develop coherent and flexible inventories for gases and particles

Historical biofuel and fossil fuel emissions 1900-2000

Pollutants : CO, CO2, NOx, NMVOC, SO2, BC, OCp
Period : 1860-2030
Anthropogenic sources included : fossil fuel and biofuel combustion sources (not included : ships, waste burning, solvent production and animals)

Bottom-up method used to derive emission inventories (based on Junker and Liousse, 2008)
=> Emissions are provided country by country and spatialization is done by using the GISS population map modified for large political changes (2nd world war, USSR dismantlement..)
=> Different algorithms for 1860-1949, 1950-2003, 2000-2030 periods

1950-2003 1860-1949



2000-2030

New projections using the POLES model (Criqui 2002)

Reference scenario : Reflect the present state of the world

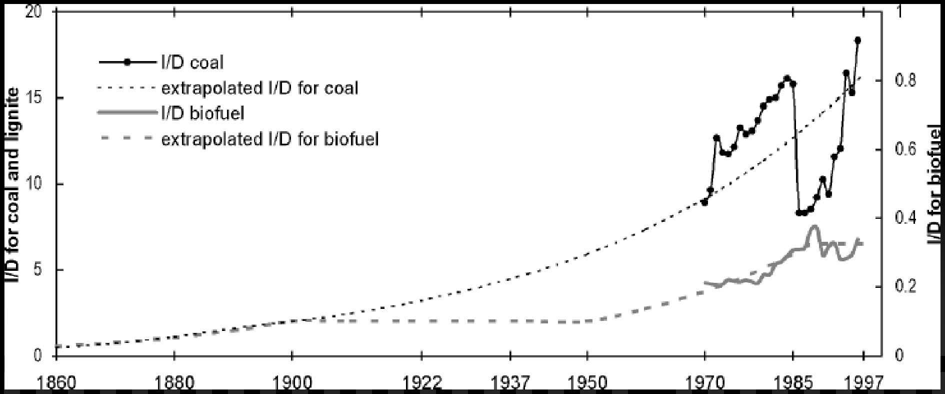
CCC scenario : Introduction of carbon penalties as defined by Kyoto for 2010 and a reduction of 37 Gt of CO2 in 2030.

Fuel consumptions are given for each scenarios, for each activity sectors and for each country groups.

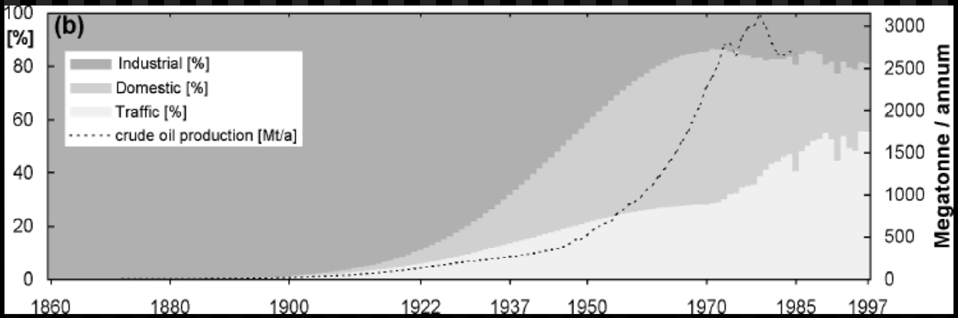
NB : Biofuel (1860-1969) : *extrapolation from UN data and population trends for each country group and activities)*

Past emissions : assumptions chosen to separate fuels into the 3 activities sectors => *for each country groups, UN data extrapolation*

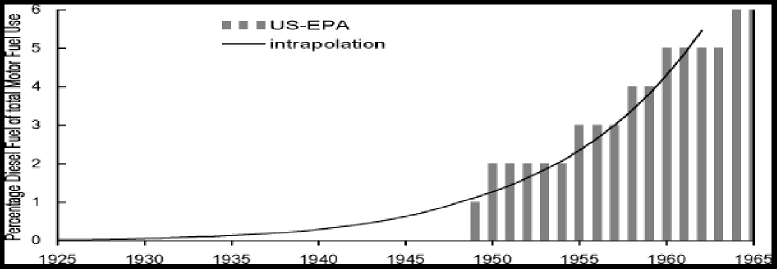
coal and biofuel



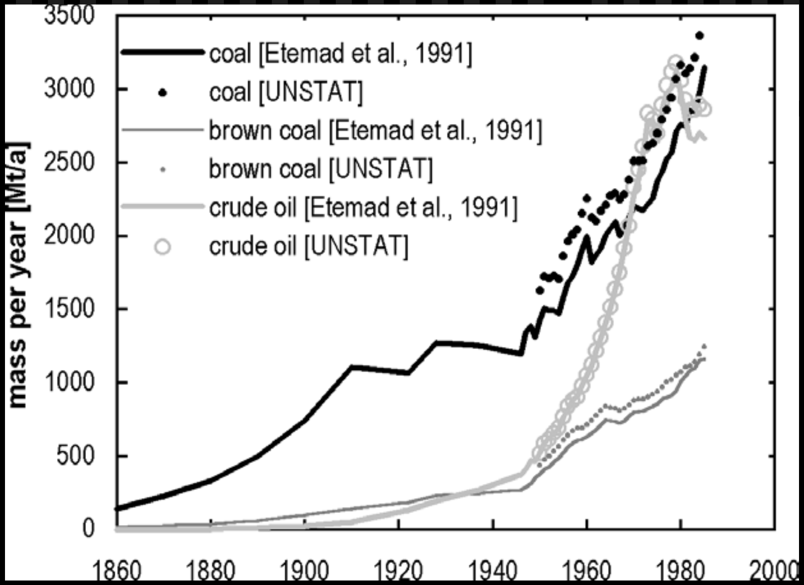
crude oil



diesel/motor gasoline



The 1950-1985 period is common between the two fuel consumption database : *a way to check the past data*.



What about EF values?

CO, NOx, SO2, NMVOC

CO2

CO2 (CO2 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 gazoline	3168 (a)
Gas (Natural, GPL, É)	2435 (a)

	Com	Dom	Ind	Com	Dom	Ind	Com	Dom	Ind	Com	Dom	Ind
Solid fuel												
Develop.	13,6	45 [a]	4,1[a]	3,85	2,02[a]	7,34[a]	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
Fuelwood												
Develop.	20,7	63[d]	6,8[d]	1,84	1,1[ad]	3,1[ad]	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
Charcoal												
Dˇvelop.	200	200[e]	0	5,97	5,97[e]	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
Peat												
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
Aviation												
Develop.	6[b]	6	6	14[b]	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
Diesel/Heavy fuel												
Develop.	7,4c	0,24[a]	4	6,88[c]	3,3[a]	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
Motor gazoline												
Develop.	9,76[c]	4,55[c]	4,55[c]	9,76[c]	4,55[c]	4,55[c]	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
Gaz (natural, GPLÉ)												
Develop.	3,02	2,29[d]	3,98[d]	3,02	2,29[d]	3,98[d]	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
Developing	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

Table 2: Emission factors for CO, NOx, SO2 and NMVOC for different uses ;
Comb = Combined (or traffic) ; Dom = Domestic ; Ind = Industrial
Ref : (a) http://www.aeat.co.uk/netcen/airqual/naei/annreport/annrep96
(b): http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/2_5_Aircraft.pdf
(c): http://www.ipcc-nggip.iges.or.jp/public/gl/guidelin/ch1ref4.pdf
(d): http://www.transport.govt.nz/business/multimodal/environment/vehicle/hapinz/28.php
(e): Andreae et Merlet, 2001

What about EF values?

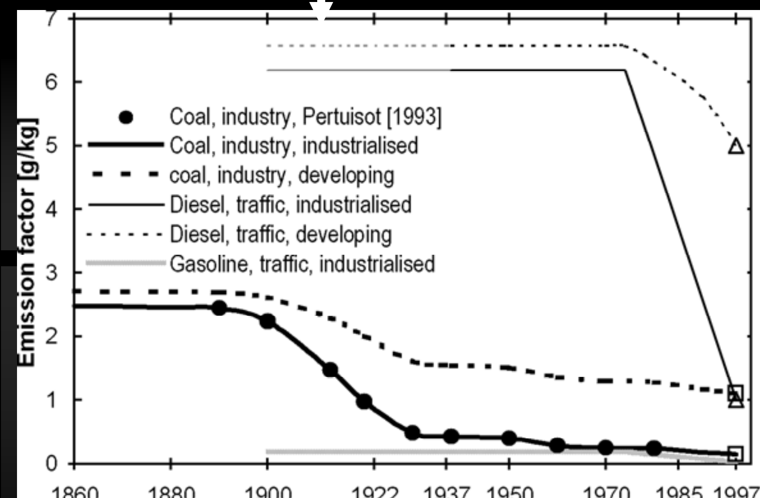
EF (BC) *EF (OCp)...*

Solid fuel						
Develop.	**0.46**	**1.39**	**0.15**	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
Fuelwood						
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
Charcoal						
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
Peat						
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
Aviation						
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
Diesel/Heavy fuel						
Develop.	**1**	**0.07**	**0.2**	0.5	0.05	0.42
Semi-Dev.	**2**	**0.09**	**0.28**	1	0.07	0.63
Developing	**5**	**0.35**	**1**	2.5	0.25	2.76
Motor Gazoline						
Develop.	**0.03**	**0.03**	**0.03**	0.07	0.07	0.07
Semi-Dev.	**0.15**	**0.15**	**0.15**	0.73	0.73	0.73
Developing	**0.15**	**0.15**	**0.15**	0.73	0.73	0.73
Gases (natural, GPL..)						
Develop.	**6.e-5**	**1.2e-4**	**1.e-5**	1.1e-4	5.8e-4	2.e-5
Semi-Dev.	**6.e-5**	**1.2e-4**	**1.e-5**	1.1e-4	5.8e-4	2.e-5
Developing	**6.e-5**	**1.2e-4**	**1.e-5**	1.1e-4	5.8e-4	2.e-5

Values for present

Evolutive 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

Values for EF in the scenarios for 2030 :

REF scenario : equal to today 's

Reduction of EF for the CCC scenario depending on each country group

Why these EF(BC) values ?

There are no wrong and right EF factors

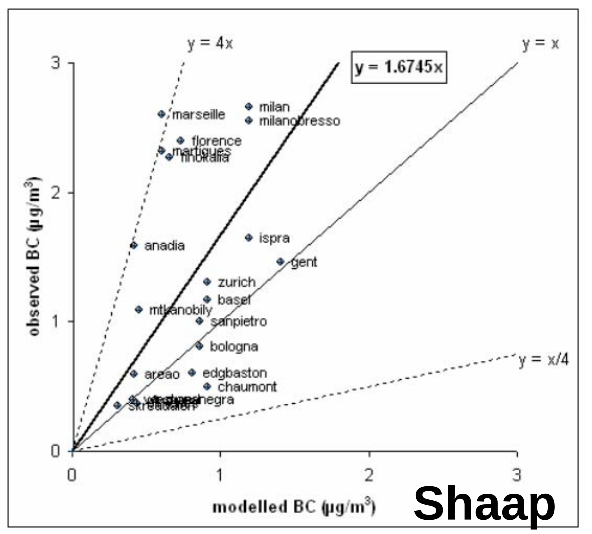
There are estimates due to the lack of measurements

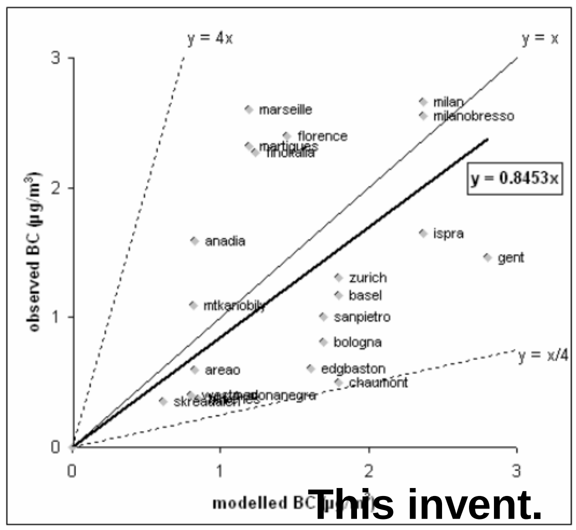
How do we check the consistency of our choices?

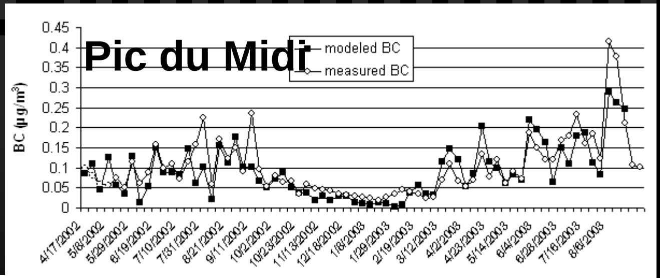
-by comparing with regional inventories *including technologies details (such as GF, FB, PC) : done for Europe (Guillaume and Liousse, 2008)*

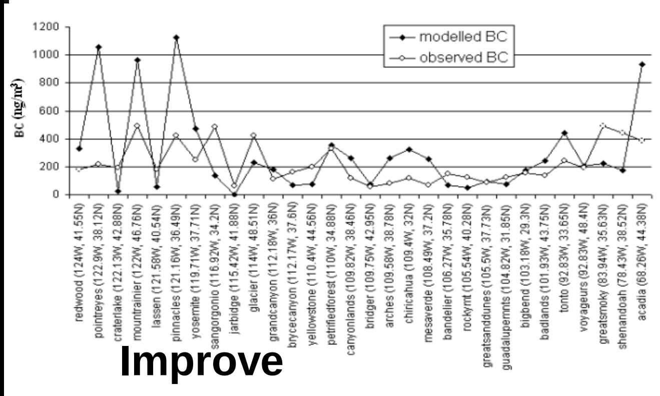
-by finding new theoretical *ways to derive* EF (BC/OC) *(ex with CO/CO2)*

-by including these inventories in models *and comparing modeled and measured BC concentrations*



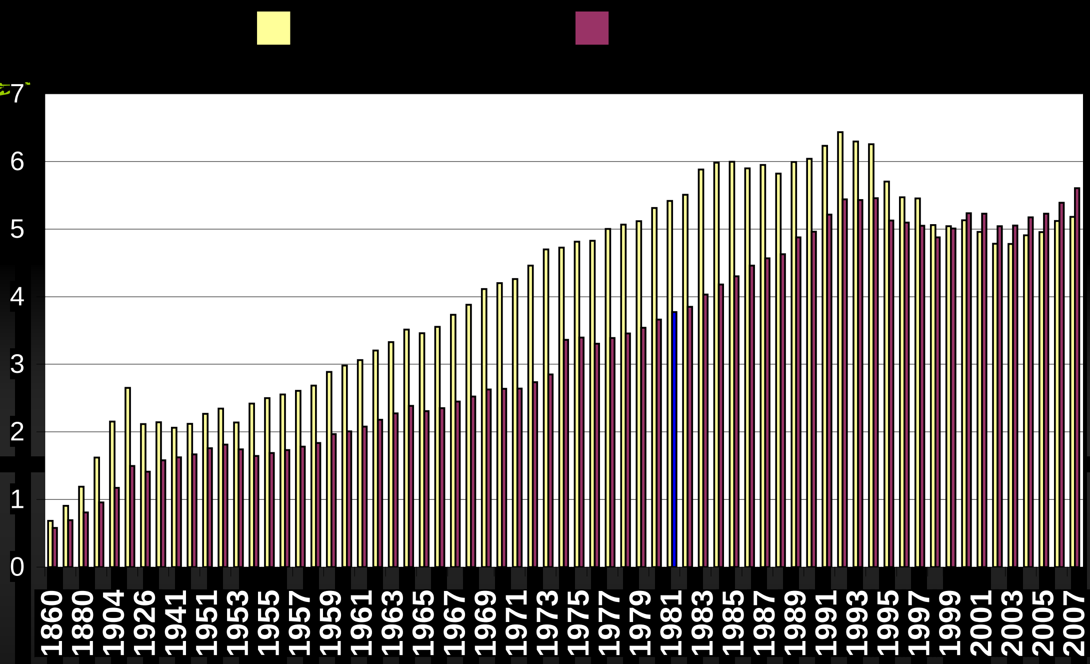






Guillaume et al., 2007, 2008

Past to present evolution of global BC emissions (Mt/yr)

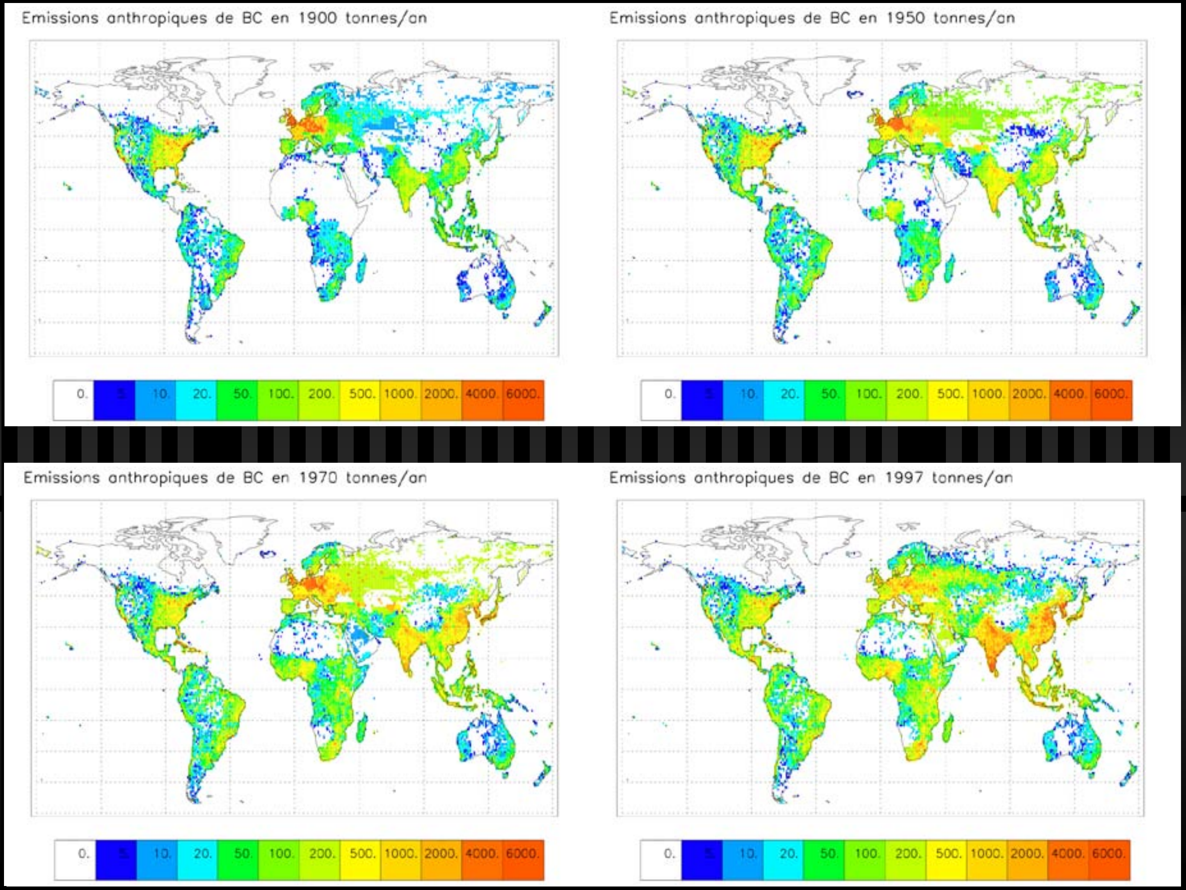


high impact of evolutive EF dataset

Past to present evolution of emission location

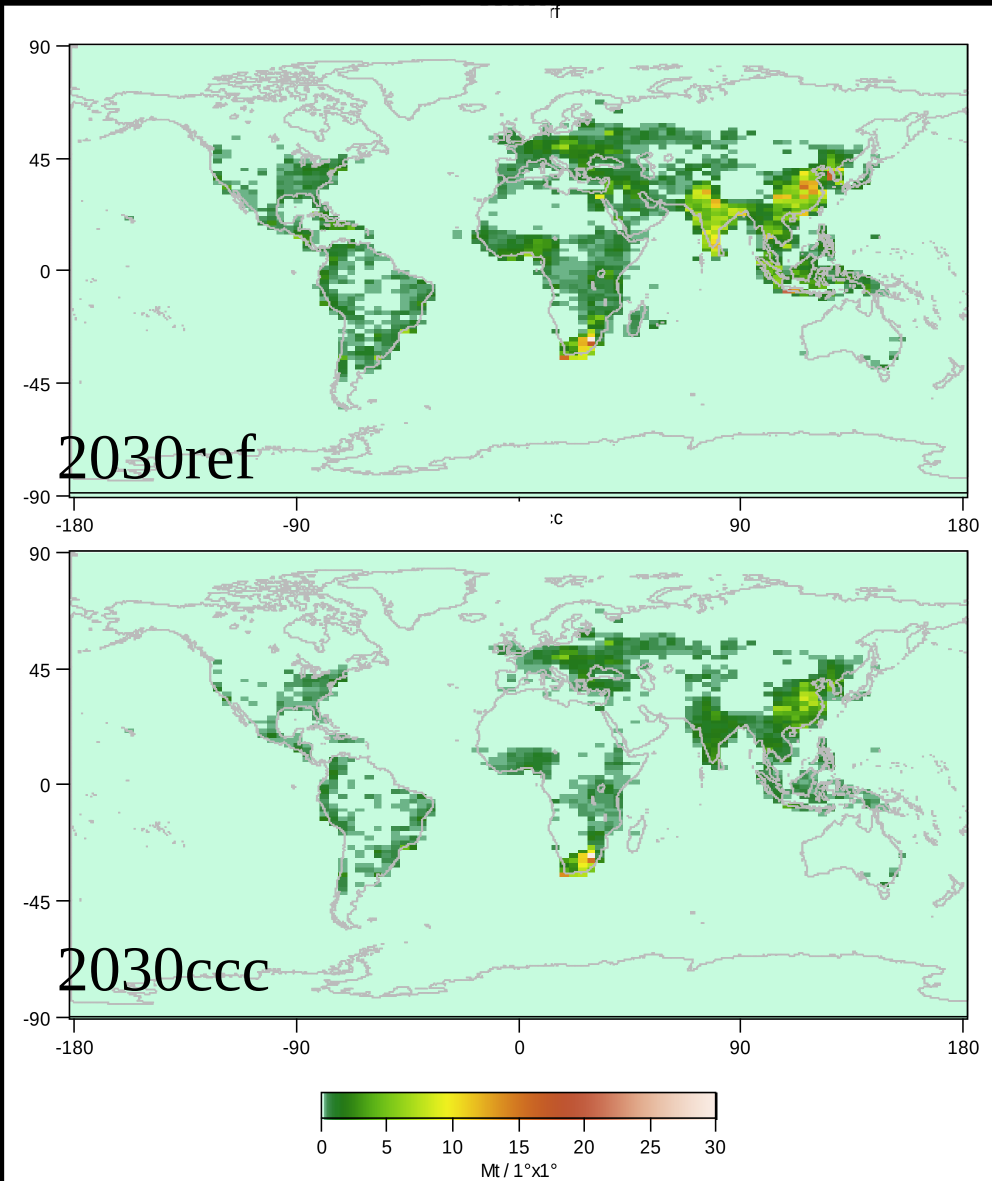
BC

1900 **1950**

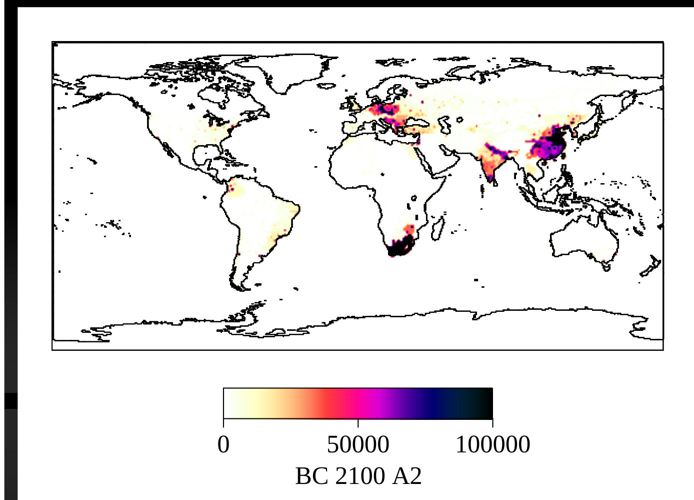


1970 **2000**

BC 2030 projections at global scale



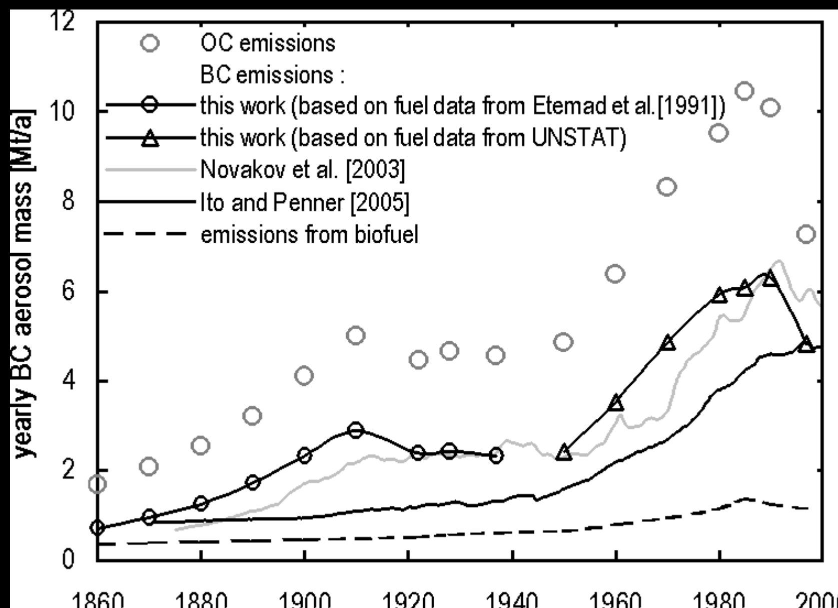
IPCC-2100A2



BC(TgC)	POLES,UN		IPCC
2000	4.76		
2030ref	14	2020A2	□25
2030ccc	7	2100 A2	100
2100 :	*next*	2100 B1	0.6

Liousse et al., in preparation

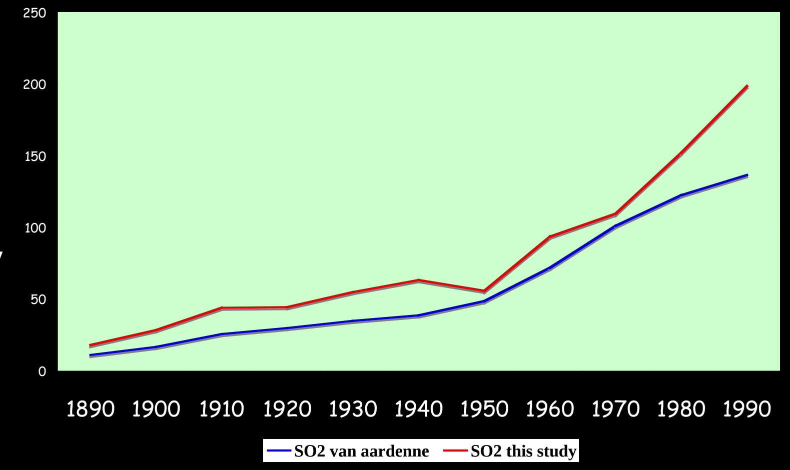
Comparison with previous historical BC emissions

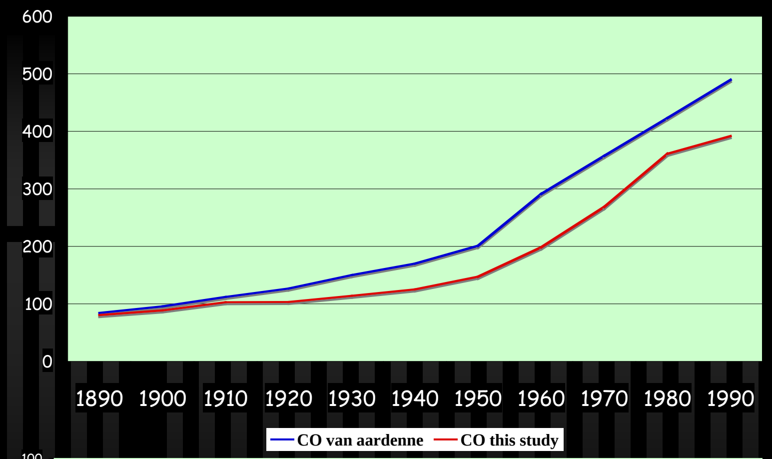


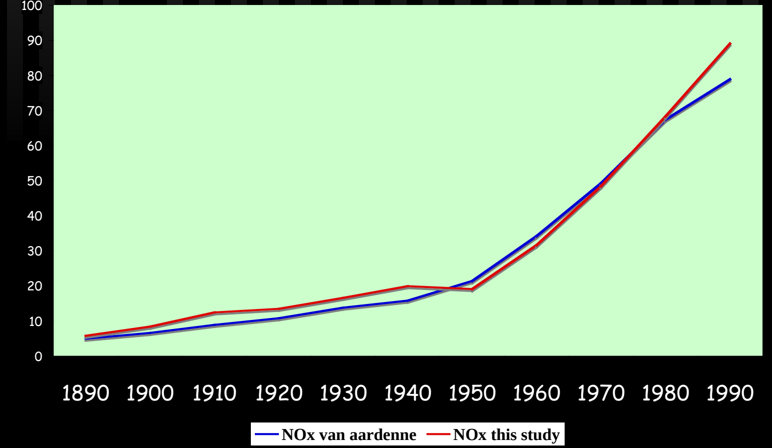
Our estimates are in the range of existing BC inventories

SO2, CO and NOX result

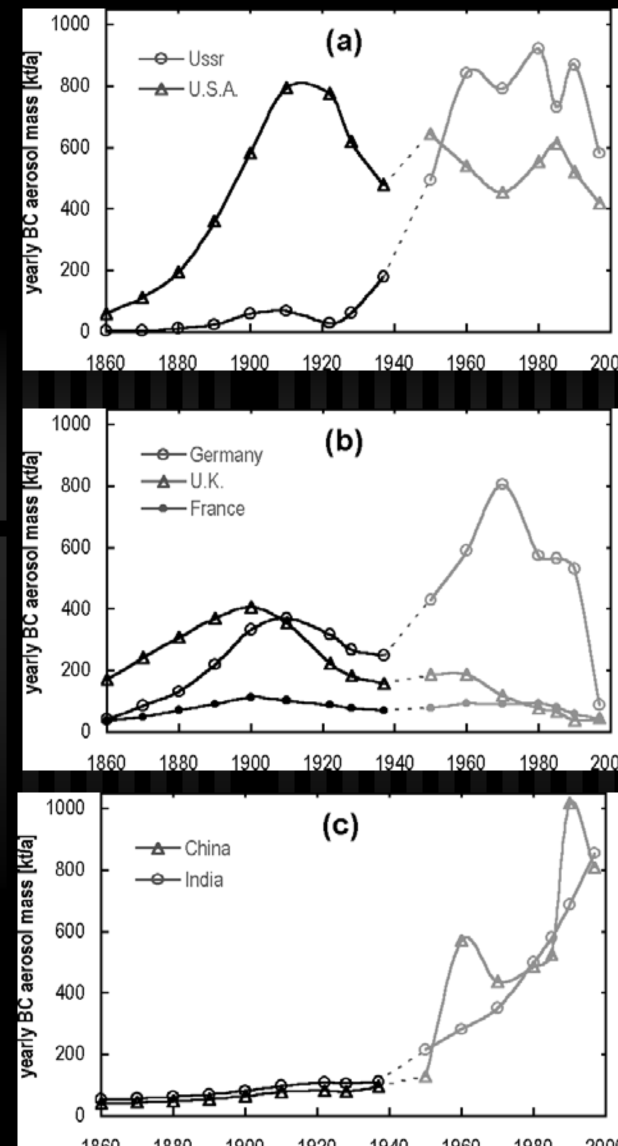
Comparison with previous global emission inventory







BC
Country by country…



Historical biomass burning emissions 1900-2000

=> a bottom up method based on satellite burned area maps and statistics

Pollutants : BC, OCp, OCtot, CO, CO_2, NOx, NMVOC, SO_2
and VOC by molecular species, as listed in Andreae and Merlet, 2004

Emissions = SB x GLCv x BEv x BDv x EFv

SB : burned area given on a 0.5x0.5 grid => for year 2000 : GBA 2000 product (0.5°x0.5°, monthly)

=> since 1900 every 10 year : data from Mouillot and Field, 2005

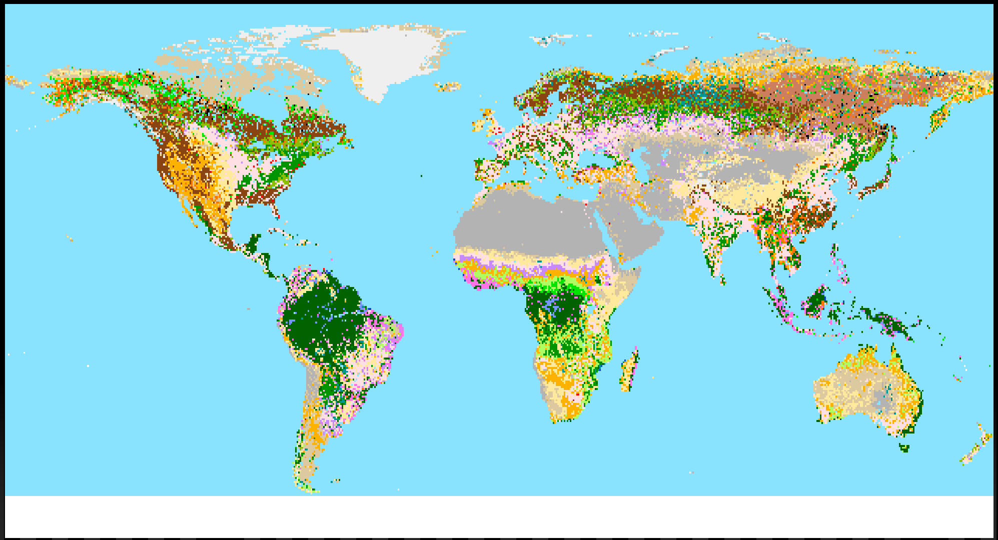
GLCv : quantity of vegetation v present in each grid cell (%) => GLC 2000 map

BEv,BDv : biomass density and burning efficiency, by vegetation type

EFv : emission factor by vegetation type

=> An important work based on Liousse et al., 2005, Michel et al., 2006 with inputs of Mayaux (Ispra) considering the GLC vegetation types

Mieville et al., 2008, Liousse et al., 2008



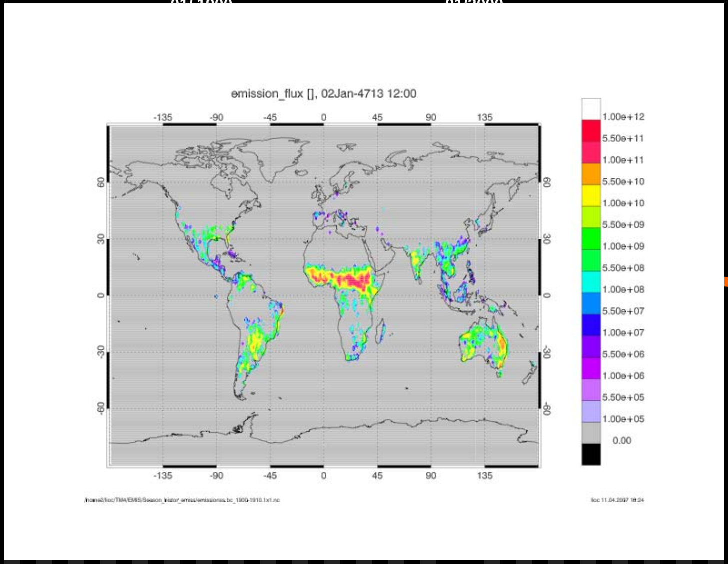
GLC 2000 map

GLC class	BD	BE	EF
GLC map	Density biomass (kg/m2)	Combustion efficiency	EFCO (g/kg)
Broadleaf evergreen GLC1	23,35	0,25	104
Closed broadleaf deciduous GLC2	20	0,25	107
Open Broadleaf deciduous GLC3	3,3	0,4	65
Evergreen needleleaf forest GLC4	36,7	0,25	107
Deciduous needleleaf GLC5	18,9	0,25	107
Mixed leaf type GLC6	14	0,25	106,9571
Tree Cover, regularly flooded, fresh (-brackish) GLC7	27	0,25	104,003
Tree Cover, regularly flooded, saline, (daily variation) GLC8	14	0,6	82,7543
Mosaic : tree cover/other natural vegetation GLC9	10	0,35	86
Shrub, closed-open, evergreen GLC11	1,25	0,9	65
Shrub, closed-open, deciduous GLC12	3,3	0,4	65
Herbaceous cover, closed open GLC13	1,425	0,9	65
Sparse herbaceous or sparse shrub cover GLC14	0,9	0,6	77,69
Cultivated and managed areas GLC16	0,44	0,6	92
Mosaic : cropland/tree cover/other natural vegetation GLC17	1,1	0,8	70
Mosaic : cropland/shrub or grass GLC18	1	0,75	73,812

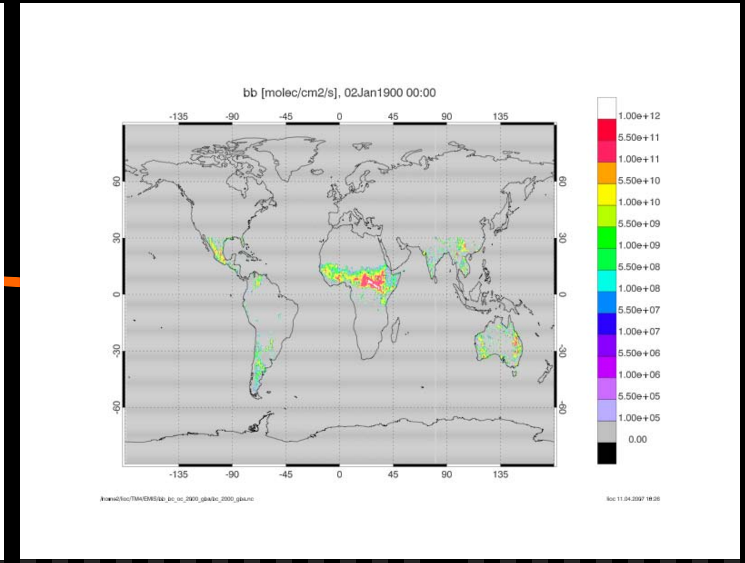
Mieville et al., 2008, Liousse et al., 2008

Historical biomass burning BC emissions in 1900 and 2000

01/ 1900



01/2000

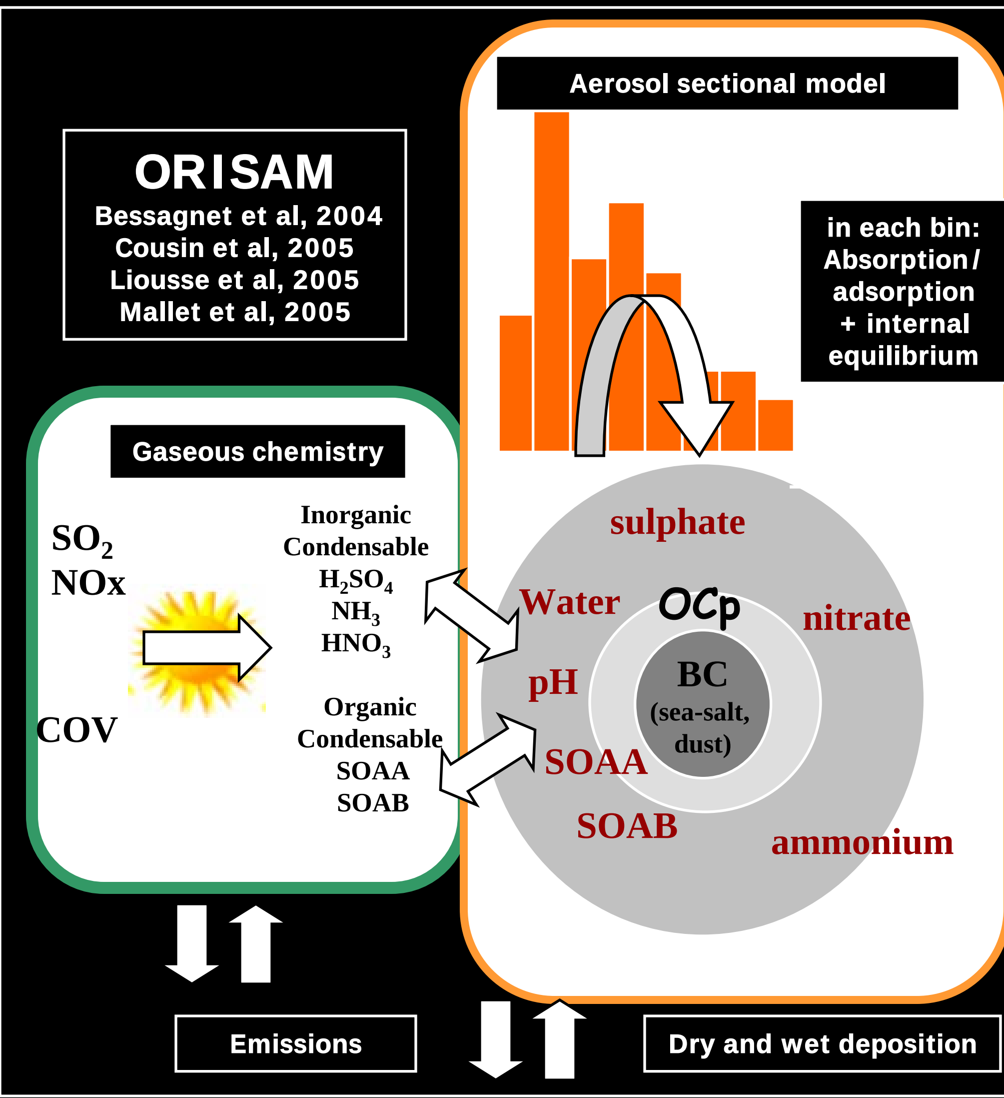


With this methodology : More intense BB Emissions in the Northern Hemisphere in 1900 than in 2000; same level of emissions in sub-Saharian fires.

Mieville et al., 2008

Testing our GICC emissions with ORISAM-TM4 global

ORISAM = ORganic and Inorganic Sectional Aerosol Model



COUPLING

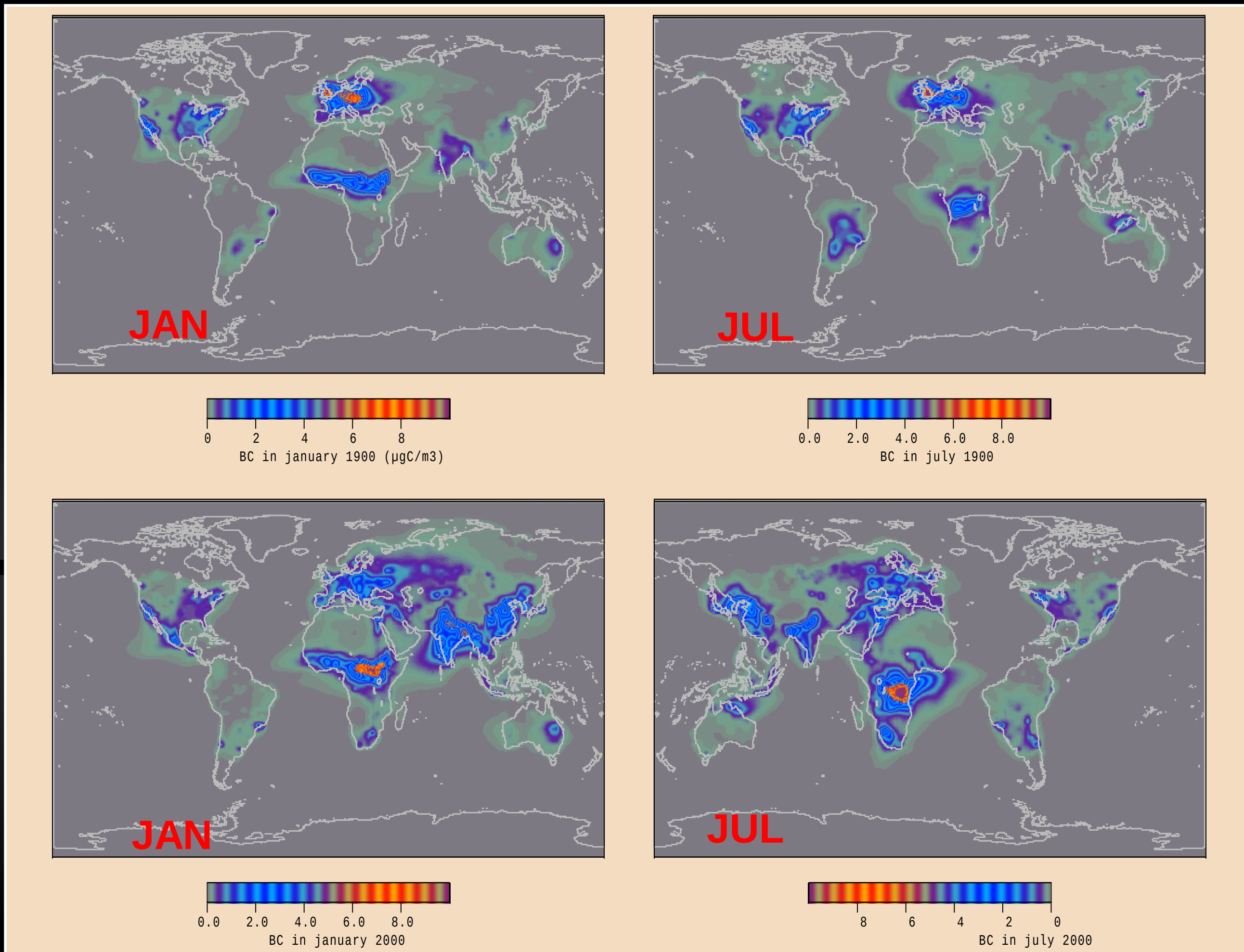
(Guillaume et al., 2007a)

TM4 (previous state)

(Van Velthoven et al., 1996):

- **-3°x2° horizontal,**
- **-31 vertical levels (jsq. 10hPa),**
- **- 38 gaseous components**
- **-(*+3 aerosol : sulfates, nitrates, ammonium without size distribution*)**
- **-Emission : EDGAR3, POET (COV),**
- **-ECMWF,**
- **-Dry and wet deposition**
- **-Gaseous chemistry (Houweling et al., 1998)**

GICC combustion emissions preliminarily tested in reduced model **TM4-BC**



1900
BC concentrations (in µg/m3) simulated with BB, FF and BF of 1900 ECMWF fields of 2000

2000
BC concentrations (in µg/m3) simulated with BB, FF and BF of 2000 ECMWF fields of 2000

- Same order of magnitudes for BC concentrations in 1900 and in 2000 ;
- BC 1900 > BC 2000 in US and over Northern Europe in 1900 than in 2000 ;
- BC 1900 < BC 2000 in Asia (essentially FF/BF increase) and in Africa .

On-going work:

Simulations with ORISAM-TM4 (here) and with MOZART model are on going to test our historical and future inventory for gases and particles (GICC inventory). Tentative validations will be performed with ground (inc. ice core) and satellite measurements for main species for past and present.

An international comparison exercise of past and present emission inventories for gases and particles is on going in the frame of the preparation of the next IPCC (Lamarque et al.).

In this context : A zoom on main differences especially for BC and OC particle emissions. The idea is to propose a coordinated inventory between the groups working on carbonaceous aerosol inventories.

Regional zoom : a regional anthropogenic emission inventory is in construction in Africa including african specificities (fuel consumption, emission factors ...) with a combined approach including experiments/modeling.