The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2256-5

Workshop on Aerosol Impact in the Environment: from Air Pollution to Climate Change

8 - 12 August 2011

Aerosol emission processes in Africa

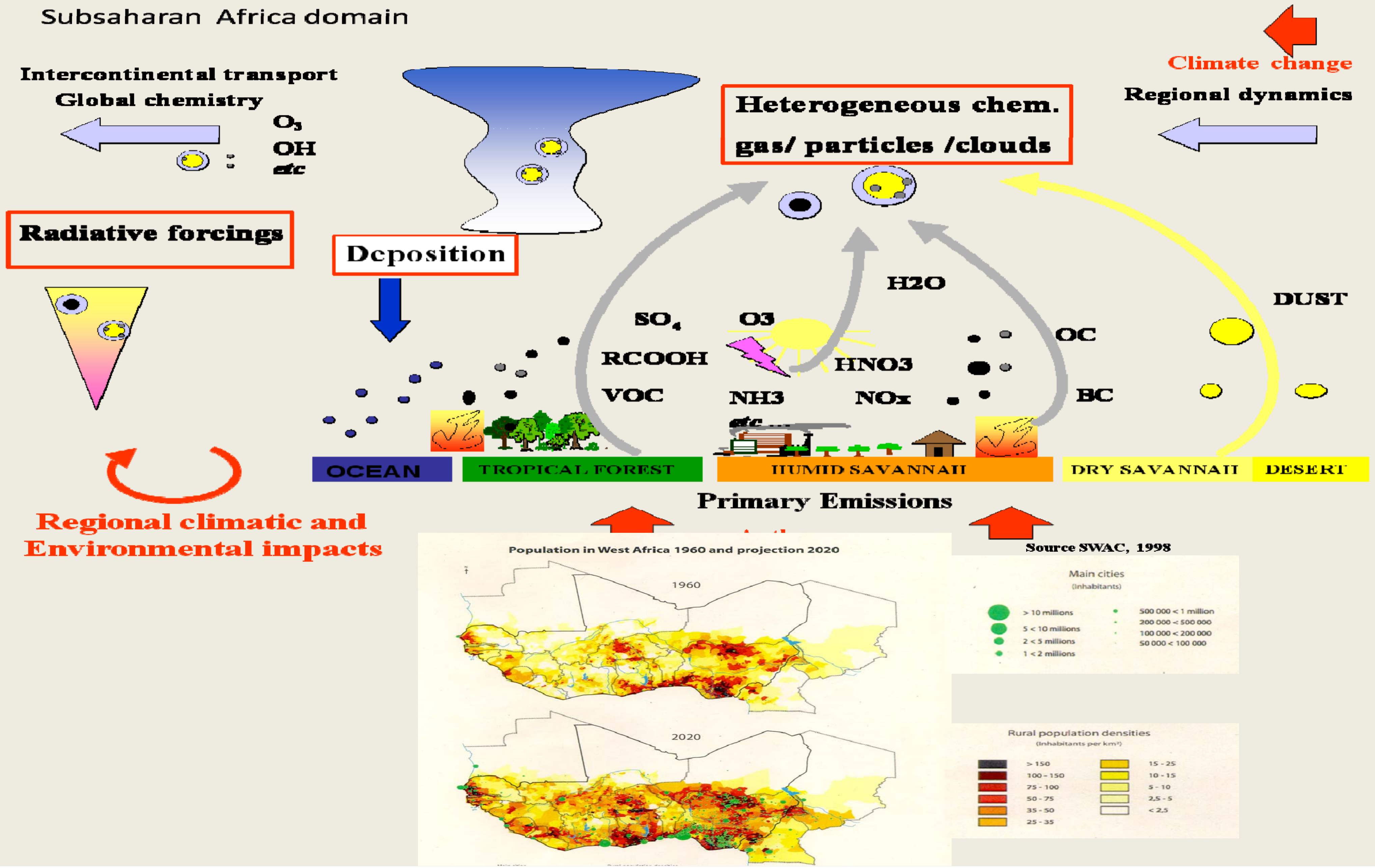
F. Solmon
ESP, ICTP, Italy

Important aspects of Aerosol emission modelling over Africa

F. Solmon (ESP, ICTP)

C. Liousse, E. Assamoi (LA, CNRS, Toulouse)
P. Nabat (Meteo France , Toulouse)

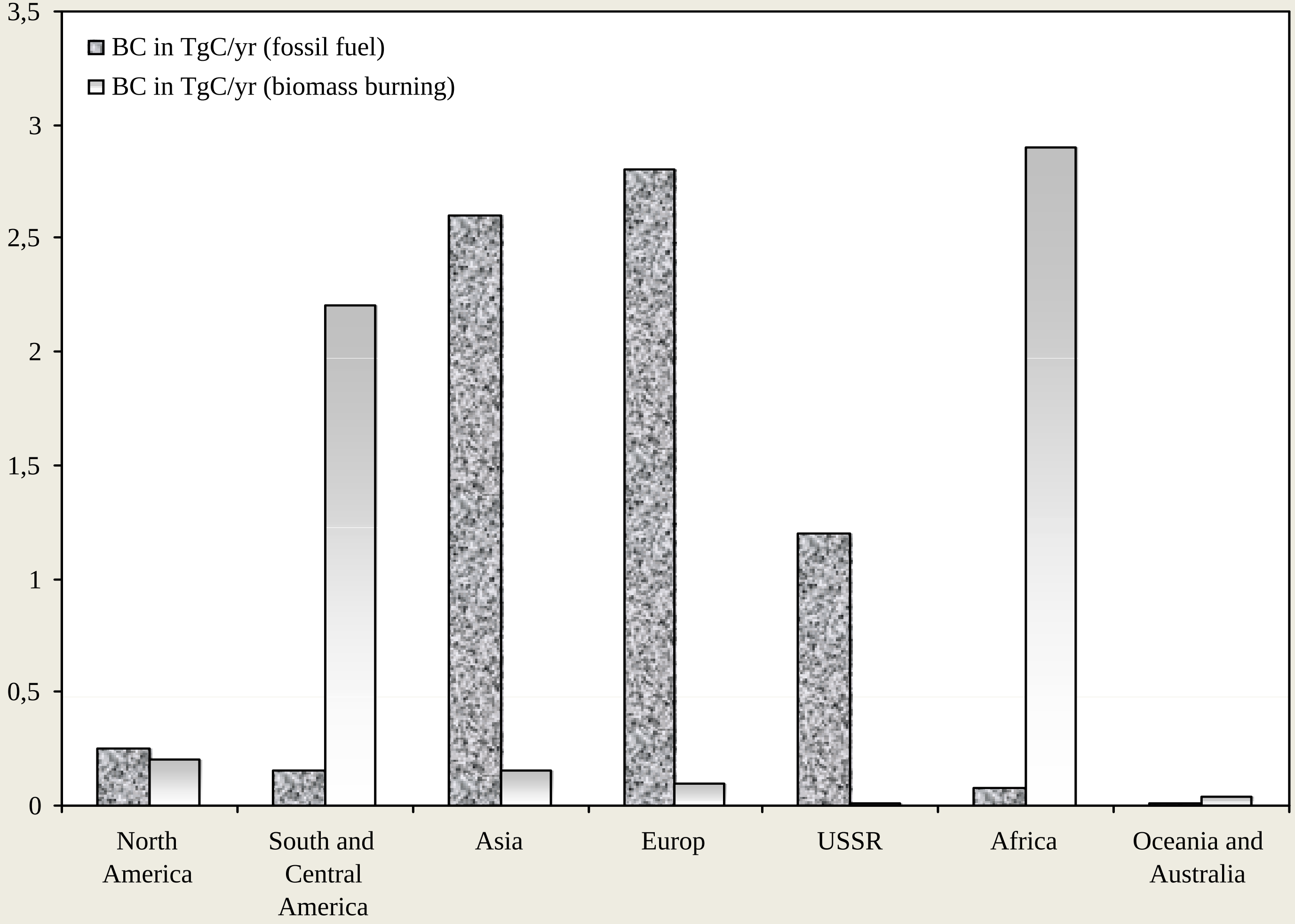
Interaction between atmospheric chemistry, climate, and biogeochemical cylces in a changing environment.



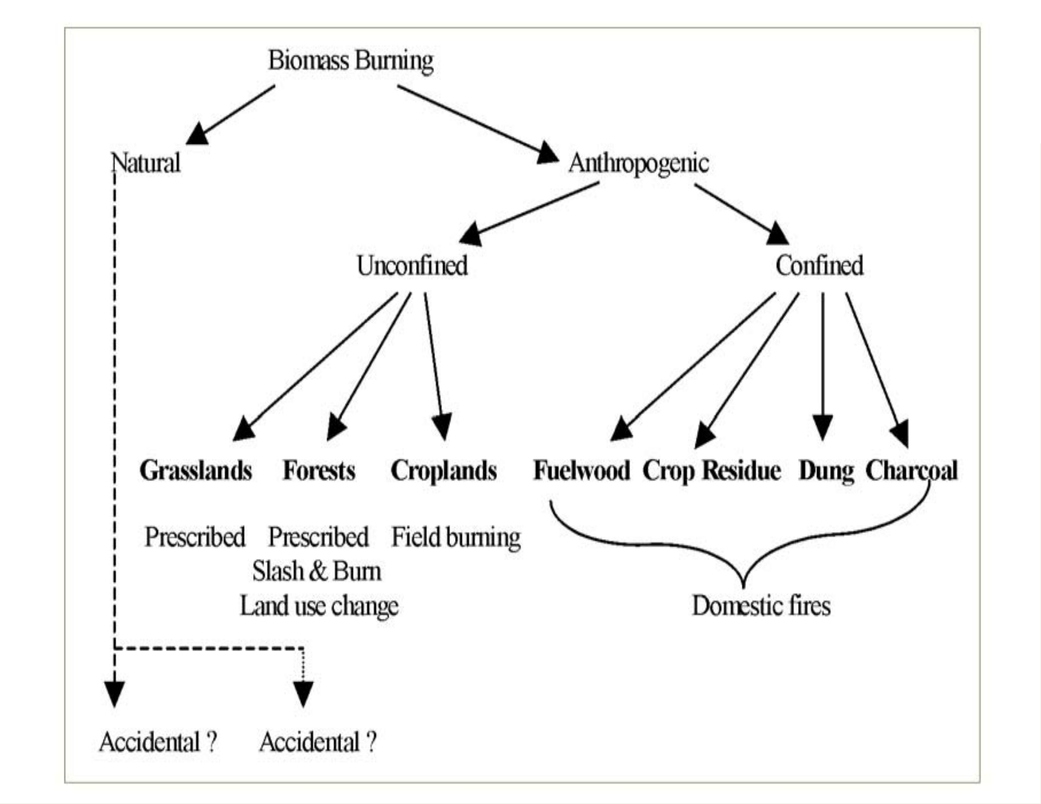
Biomass burning emissions

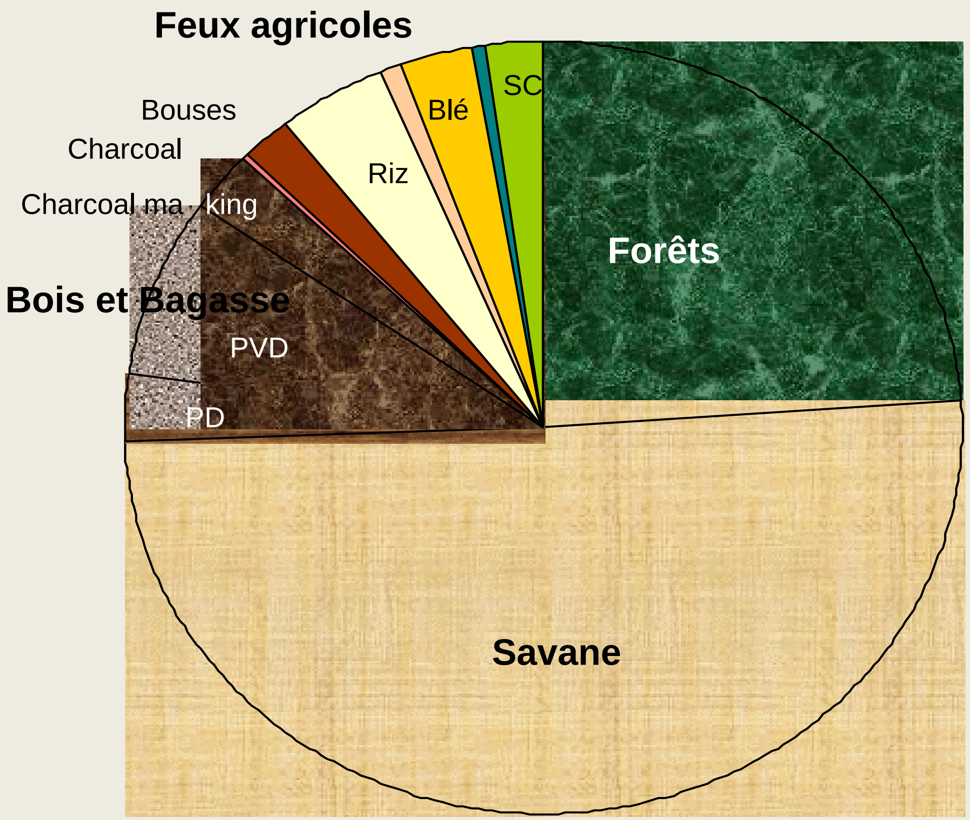
Photo H. Cachier

Relative contribution of Biomass Burning vs anthropogenic emissions for black carbon (BC) combustion tracer



Relative contribution of different biomass burning sources (5293 Tgdm /year)





Gas

Aerosols (carbonaceous BC / OC)

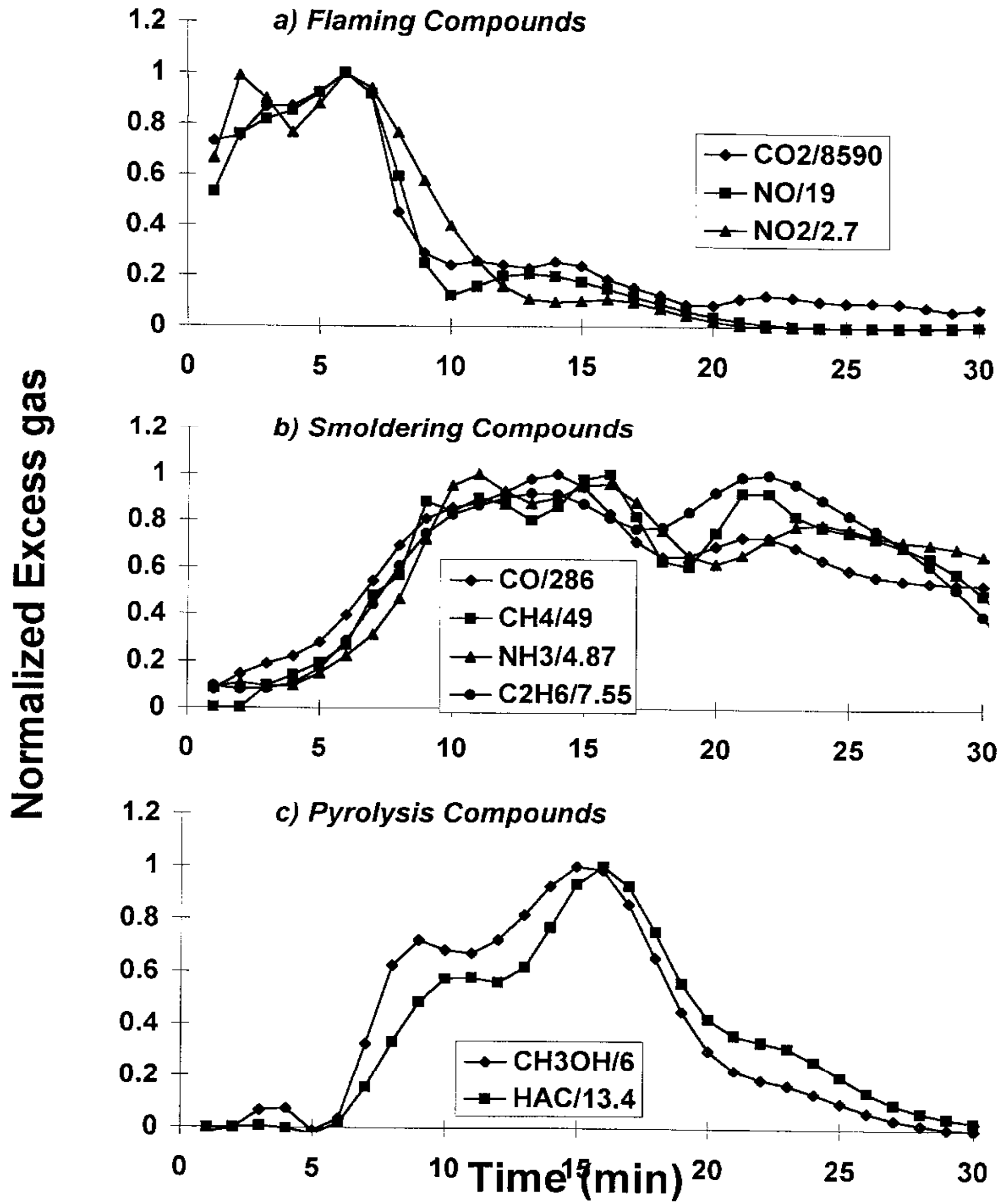
Combustion steps

- Drying
- Flaming + Glowing + Pyrolysis
- Glowing + Pyrolysis (Smoldering)
- Glowing
- Extinction

- **The quantity of burned fuel during each step depends on meteo, nature of the fuel**
- **However a same fire regime can be observed by ecosystem types**

- Drying
- Flaming + Glowing + Pyrolysis
- Glowing + Pyrolysis (Smoldering)
- Glowing
- Extinction

[from Yokelson et al. (1994)]



Biomass burning emissions

In most global and regional inventories gas and aerosols emissions are calcluated as :

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

•M is the biomass burned (kgdm/m2)

•EF(X) is the chemical species emission factor X in gX/kgdm

Emission Factor

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

- M_x = amount of a released compundsX
- $M_{biomass}$ = amount of biomass consumed
- M_C = mass of carbon emitted
- $[C]_{biomass}$ = carbon concentration of the burned biomass

- Emission estimation possible from the burned biomass
- Needs to measure the consumed fuel mass and the emitted mass of x: difficult measurements in the field !

Emission Factor
(often used approximation, Andreae and Merlet, 2001)

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

- Only concentrations are used.
- Still need to know the biomass carbon quantity effectively burned (variable parameter)

Emission Ratios

$$ER_x = \frac{\Delta[x]}{\Delta CO} = \frac{x_{smoke} - x_{ambiant}}{CO_{smoke} - CO_{ambiant}}$$

- Define ER from CO measurements

Estimation of EF by default

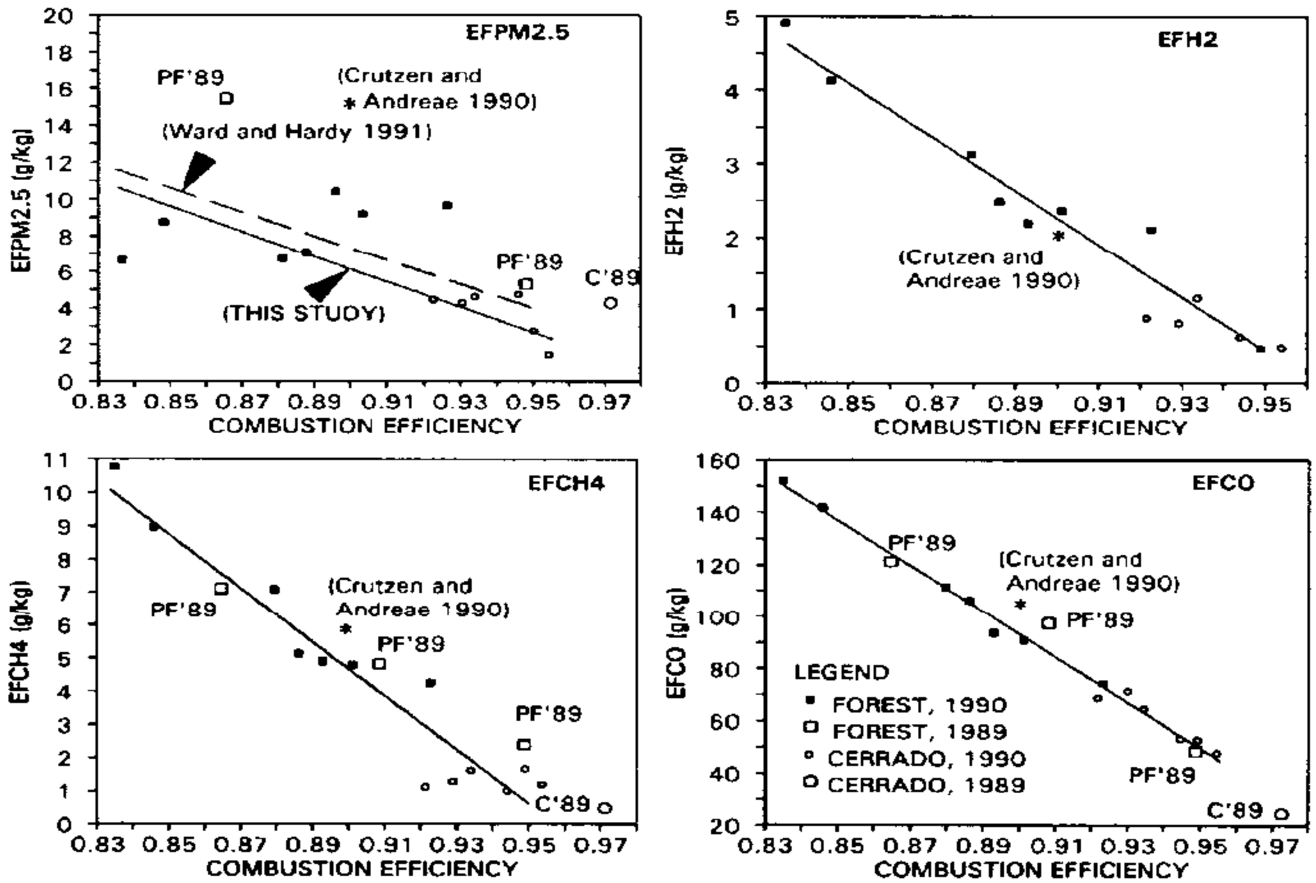


Fig. 7. Emission factor models for PM2.5, CH_4, H_2, and CO for the combined cerrado, primary forest, and second-growth forest emission data. The independent variable is combustion efficiency or the percent of carbon released in the form of CO_2.

EF(BC)g/kgdm	**Andreae**	**Liousse**	**Cooke**	**Streets**	**POM/BC in % (Liousse)**
Forest	0.66	1.53	1.1	- -	8.6
Savanna	0.48	0.81	0.5	- -	7.2
Biofuel wood	0.59	1.25	- -	1.0	5.7
Dung	- -	1.0	- -	- -	16.3
Charcoal making	- -	1.84	- -	- -	16.8
Charcoal burning	1.5	1.5	- -	- -	4.5
Agricul. fires on field	0.69	0.75	- -	0.75	4.1
Agricul. fires-biofuel	- -	0.95	- -	- -	6.8
Extratropical forest	0.56	0.75	0.5	- -	19.9

See also Andreae and Merlet , 2001, GBC

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

- M is the biomass burned
- EF(X) is the chemical species emission factor X en gX/kgdm

M? for savanah and forest fires

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

A is the burned area
B biomass density
α, biomass surface fraction
and β, combustion efficiency.

 Still big uncertainties for B, α et β

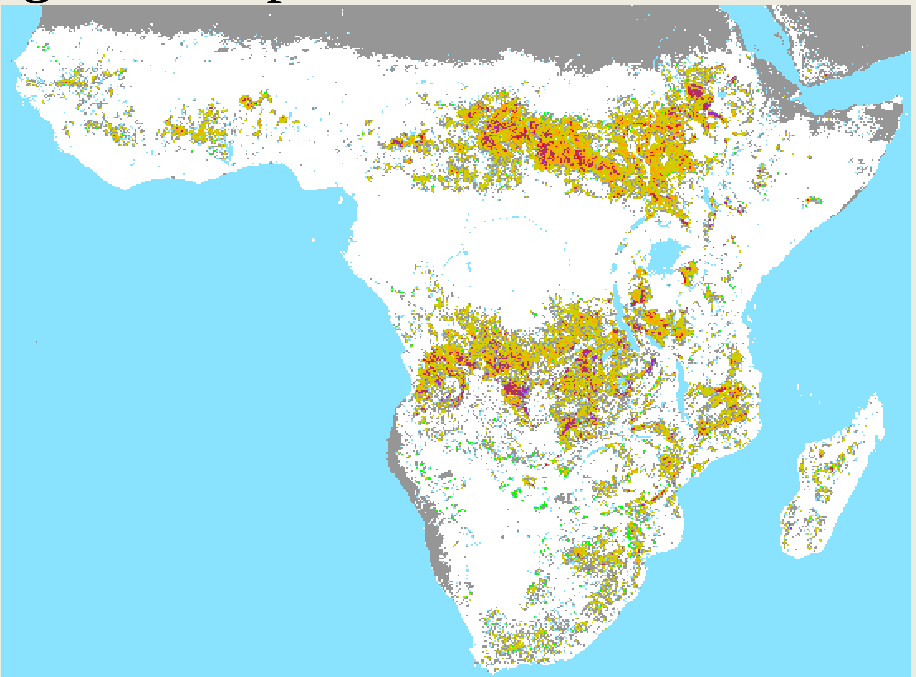
 Good progress for the determination of A

Biomass burning emissions: burned area

•Determination from statistic data (*Hao et al., 1991*) **=> uncertainty factor of 2 to 3 on A**

• Improvment in satellite detection of burned area, improvment of temporal variability of inventories

e.g.L3JRC product (Tansey et al.,2008)

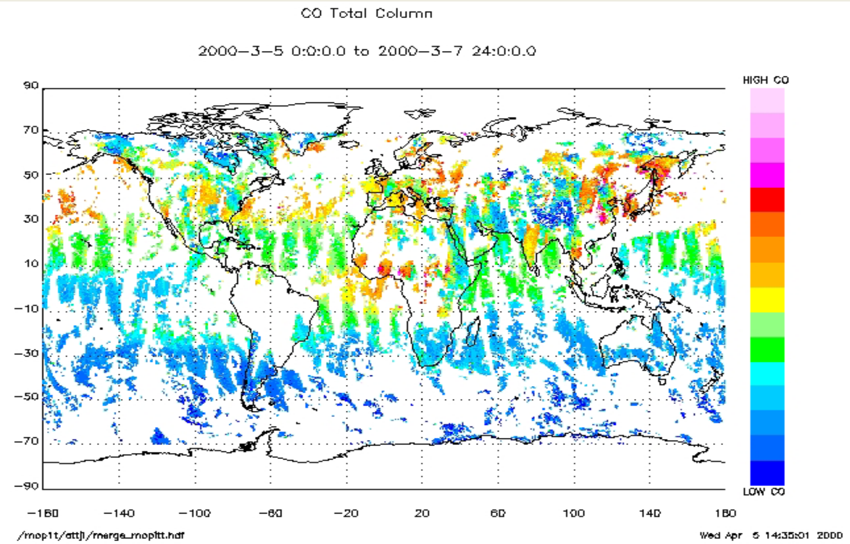


remaining uncertainties:

•There still might be an unburned fraction in the pixel
• Low injection fires are not seen by satellites (agricultural fires)

Indirect Methods to estimate sources

- Use of CO tracer
  - Biomass burning : important CO source
  - Existing data bases at the regional and global level
  - EF et ER(CO)
  - Good knowledge of CO sinks



	Emission estimate	*Inverse Model*
Global Total	750	663 - 807
Trop. Forest	139	483 - 633
Savanna	206	140 - 245
Burning at latitude > 30N	68	0 - 87

Bergamaschi et al., 2000

- Use of MODIS fire radiance to determine smoke emissions

(Ichoku And Kaufman 2005,)

Practically…available inventories ….

http://www.geiacenter.org/

GEIA
Global Emissions Inventory Activity

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ACCENT — Atmospheric Composition Change, The European Network of Excellence

GEIA-ACCENT emission data portal

- Project
- Emission Data portal
- Data manipulation tools
- ECCAD
- Workshops & meetings
- Contacts

Web links

- ACCENT web portal
- GEIA project
- Other Web links

Go to the LIST of SPECIES

Emission Data portal -

The GEIA /ACCENT data portal provides gridded emission data; emission data are usually separated into three main categories : anthropogenic emissions, biomass burning emissions, and natural emissions:

- anthropogenic emissions include emissions from fossil fuel and biofuel consumption, industry and agricultural sources.
- biomass burning emissions include emissions from forest fires, savannah fires, and sometimes large croplands fires.
- natural emissions include emissions from vegetation and oceans.

When using these data please acknowledge the authors of the datasets, as well as the GEIA/ACCENT data portal activity.

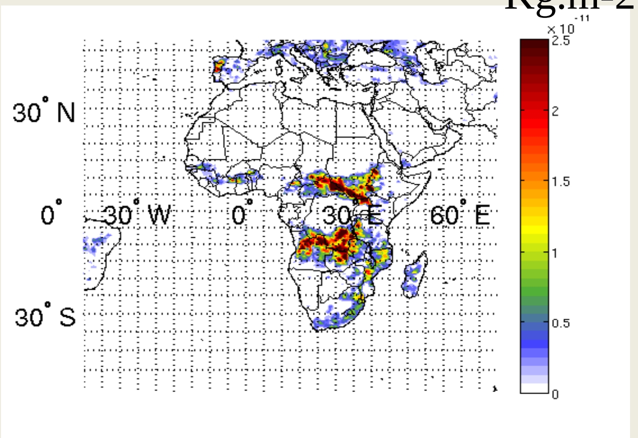
inventory (release year)	period covered	categories	temporal variability	grid size	provider
Global emissions					
ACCMIP (2010)	1850 -2000	anthropogenic biomass burning	-annual -annual	0.5 x 0.5	ACCMIP: Lamarque et al., 2010
RCPs (scenarios) (2010)	2000 -2100	anthropogenic biomass burning	-annual -annual	0.5 x 0.5	RCP database
EDGAR 3.2FT2000 (2005)	2000	anthropogenic biomass burning	-annual -annual	1 x 1	EDGAR
RETRO (2005)	1960 -2000	anthropogenic biomass burning	-monthly -monthly	0.5 x 0.5	RETRO
EDGAR-HYDE 1.3 (2001)	1890 -1990	anthropogenic	decadal	1 x 1	EDGAR
GFED3 (2010)	1997 - 2009	biomass burning	monthly	0.5 x 0.5	GFED
GFEDv2 (2005)	1997 - 2005	biomass burning	monthly 8 day (on GFEDv2 page)	1 x 1	GFED
GICC (2010)	1900 -2000 (decadal) 1997 -2005	biomass burning	monthly	1 x 1	LATMOS
MEGANv2 -biogenic (2009)	2000 decade	biogenic	monthly	0.5 x 0.5	NCAR
MEGANv2.1-CH3OH (2011)	2003-2009	biogenic	monthly	0.5 x 0.5	
GEIA v1	species dependent	anthropogenic biomass burning natural	species dependent	1 x 1	GEIA
Global emissions built for specific projects					
MACCity (2010)	1990 -2010	anthropogenic	-monthly	0.5 x 0.5	macc City Zen
POET (2003)	1990 -2000	anthropogenic biomass burning natural	-annual -monthly -monthly	1 x 1	POET GEIA
Global emissions providing specific species					
Andres -CO2 (2007)	1751 -2003	anthropogenic	annual	1 x 1	CDIAC
AMAP -Hg (2005)	1995, 2000	anthropogenic	annual	0.5 x 0.5	
Regional emissions					
AMMABB (Africa) (2009)	2000 -2006	biomass burning	-daily	0.5 x 0.5	
EMEP (Europe) (2007)	1970 -2020	anthropogenic	annual	0.5 x 0.5	emep
REAS (Asia) (2007)	1980 -2020	anthropogenic	annual	0.5 x 0.5	REAS
ABBI (Asia) (2005)	March-May 2000, March-May 2001	biomass burning	daily	1 x 1	

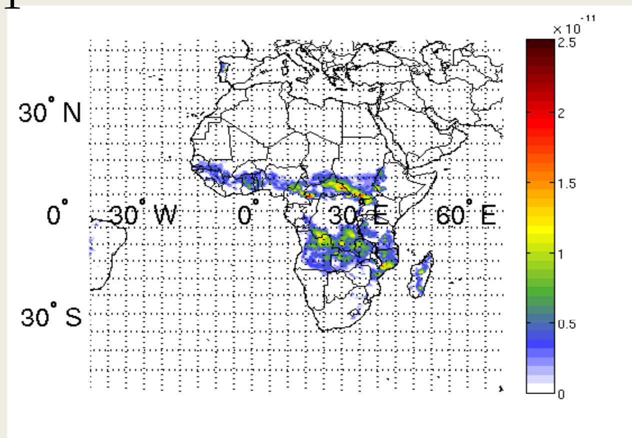
Comparison between recent inventories (year 2005 average)

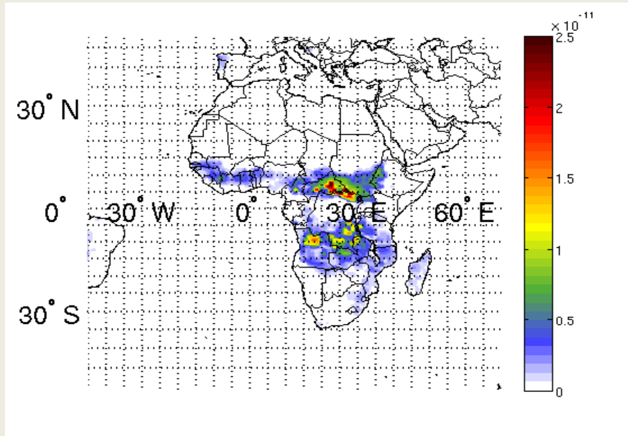
AMMABB (2005) | GFEDv3 (2005) | RCP26 (2000-decade)

BC

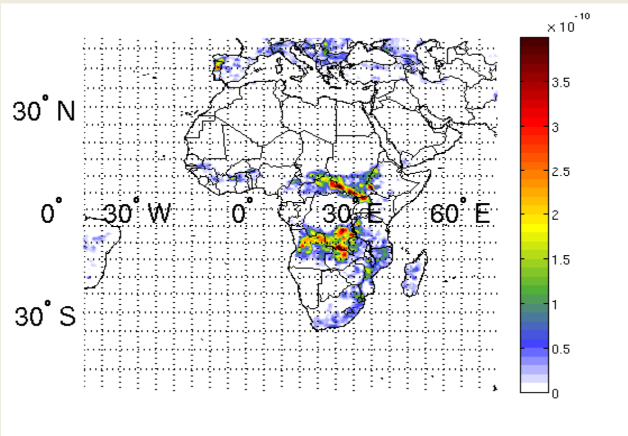
Kg.m-2.s-1

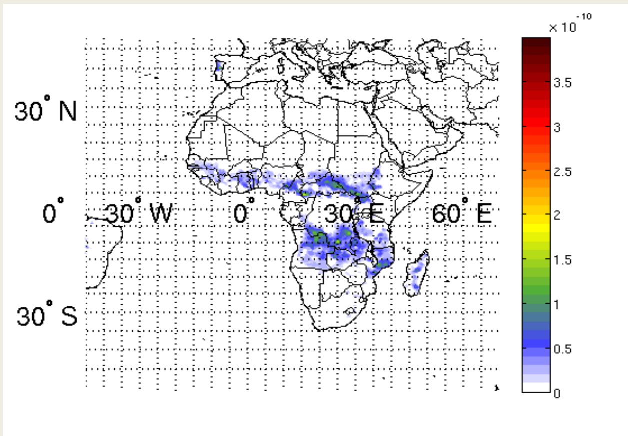


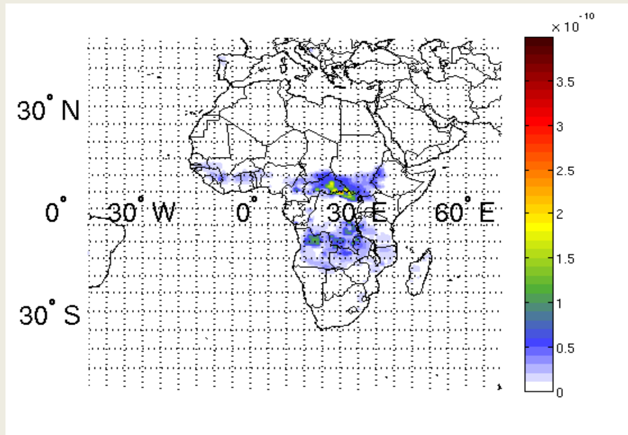




OC

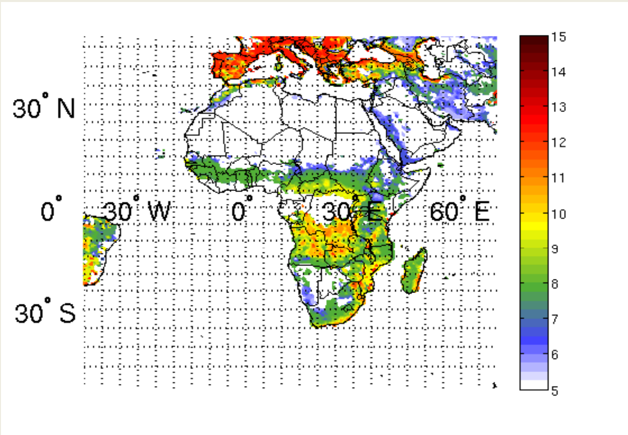


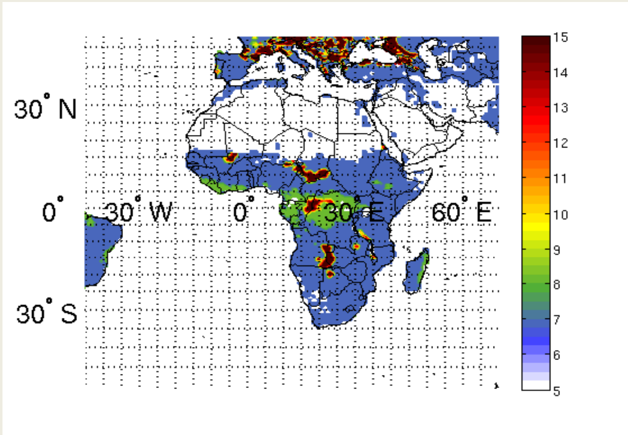


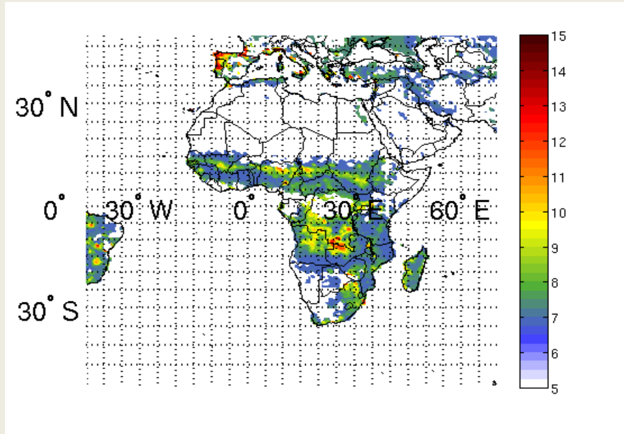


BC/OC emission ratios

AMMABB (2005) GFEDv3 (2005) RCP26 (2000-decade)







Impliactions for radiative forcing and climatic feedbacks (e.g.Tummon et al., 2010)

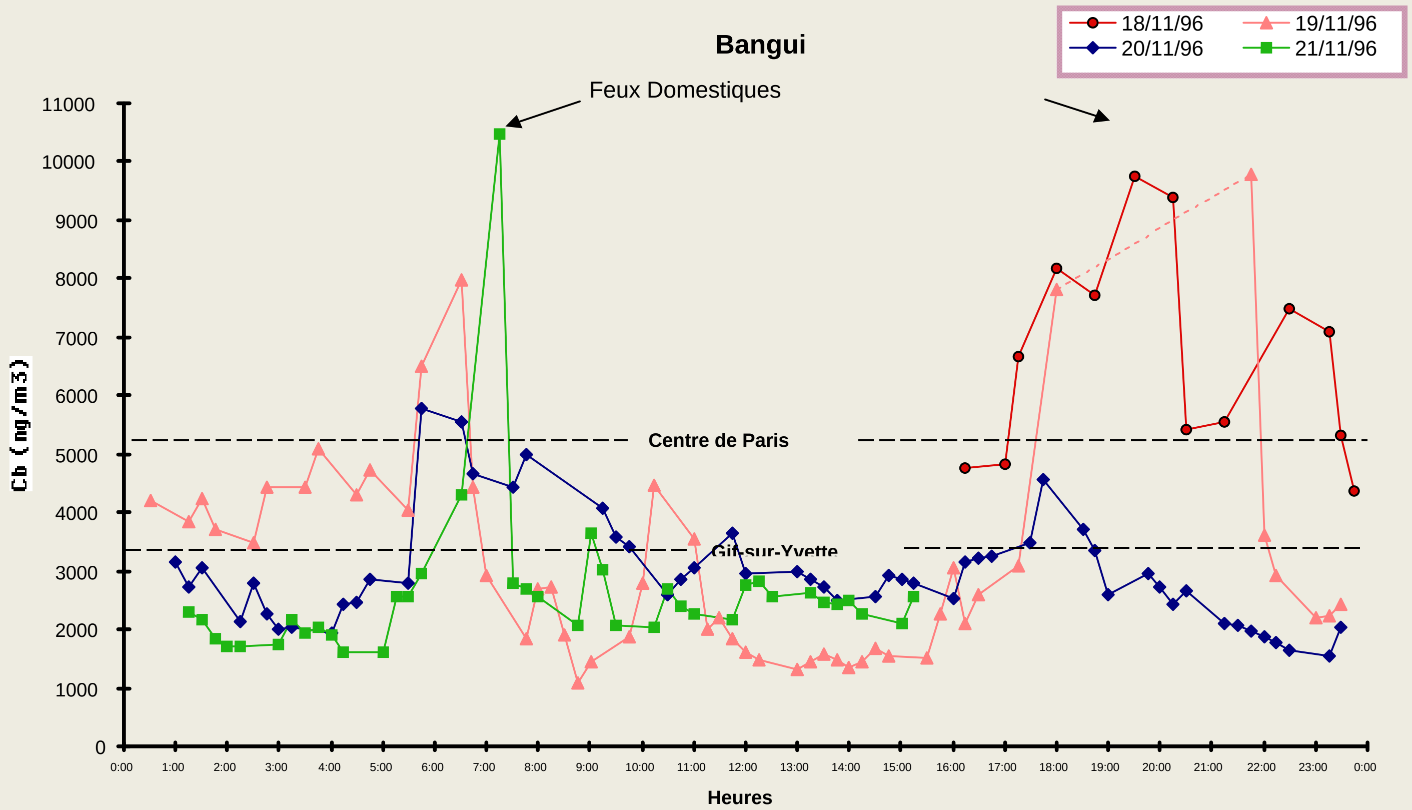
M? Other kind of tropical fires

Agricultural fires

M = P . W/P . Wf/W . Ce

P Harvest biomass quantity, W, waste fraction,
Wf, waste burned , Ce, combustion efficiency

Domestic fires : very important for Africa

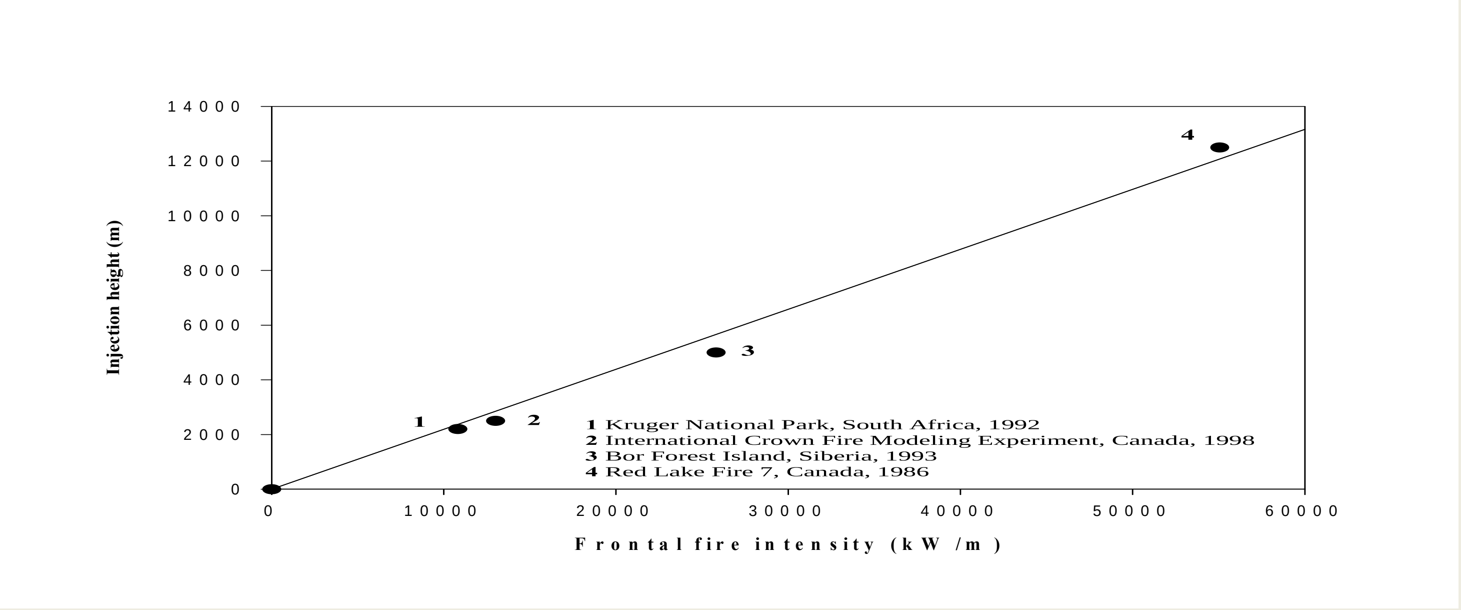


Injection Height

I=H.w.r.

where I : frontal intensity of a fire ; H, the fuel low heat of combustion ; w, the amount of fuel consumed and r, the rate of fire propagation on the ground

For boreal fires, relationship may be simplified as : Hi= 0.23.I (Lavoué et al., 2000)



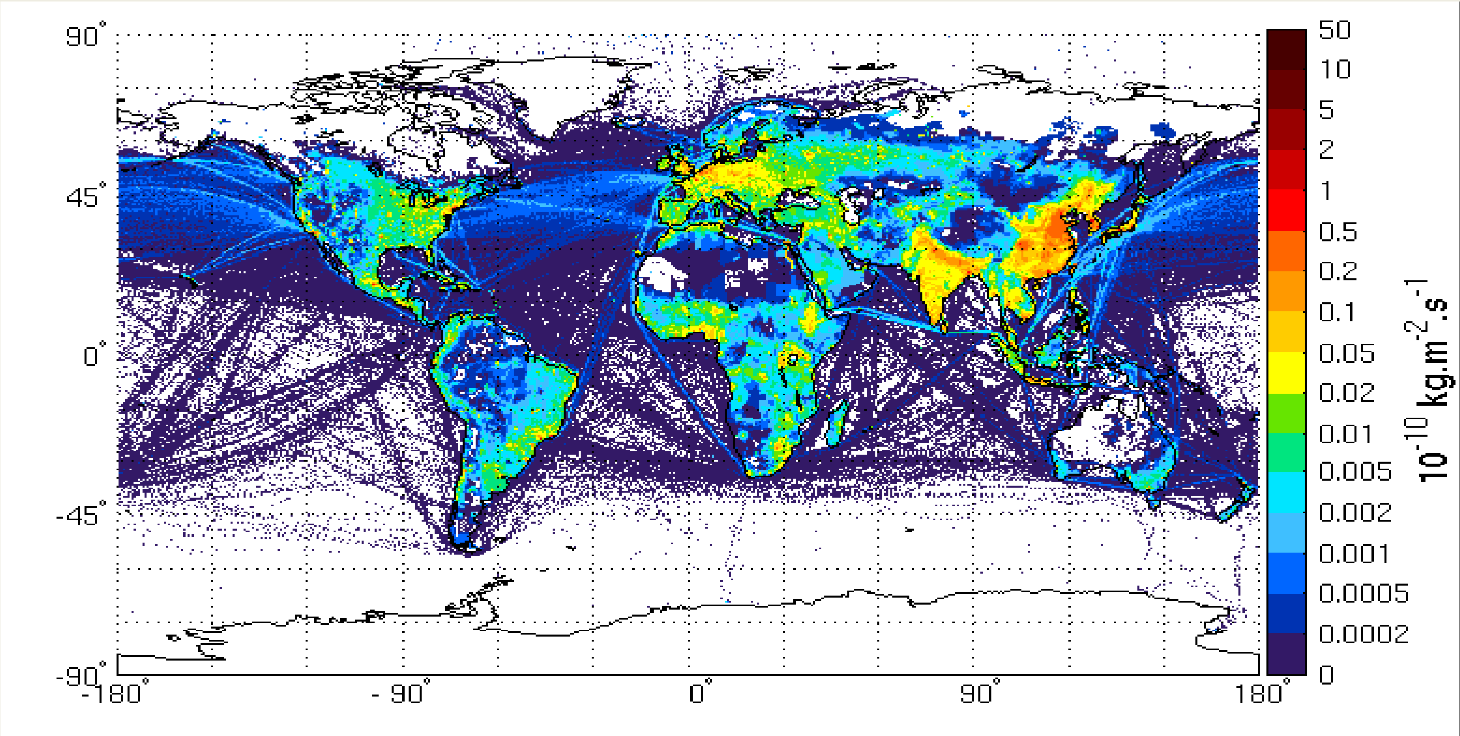
Explicit models: Freitas ?

Fossil fuel emissions

EF(X) = Consumed fuel x EF(X)

- Fuel data base (23 different types) (ONU, IEA..)
- Great complexity of emission factors EF : 9 EF by fuel type (function of development stage, specific fuel use ...)

Eg:
MACcity
BC ff
emission
2005



For Africa uncertainties as illustraed for example in Assamoi et al., 2010) study about the impact of two-wheel two-strokes engines in some west African cities

Junker and Liousse, global inventory (year 2002)

Junker and Liousse, Accouting for two wheels specific emissions

BC

OCp

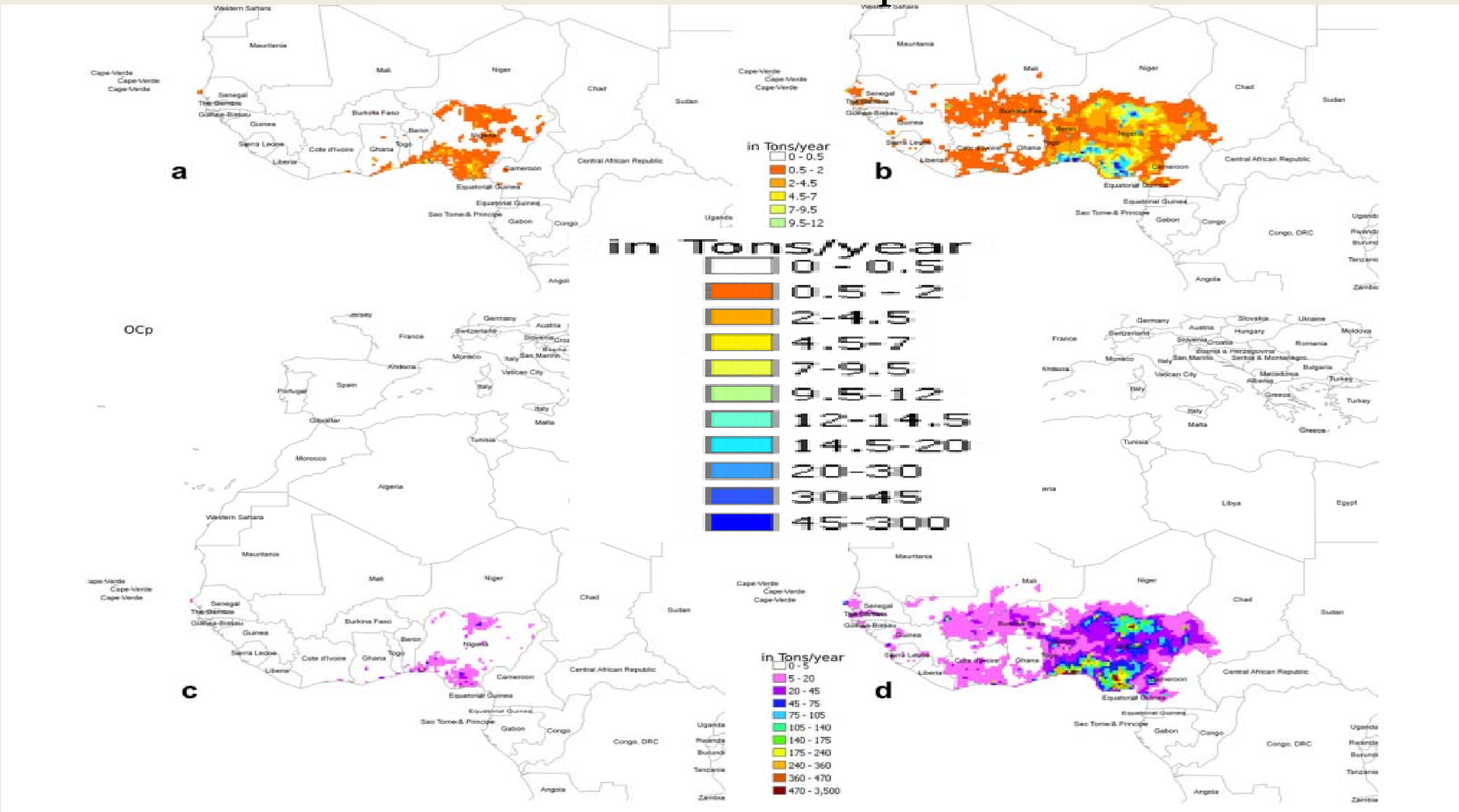
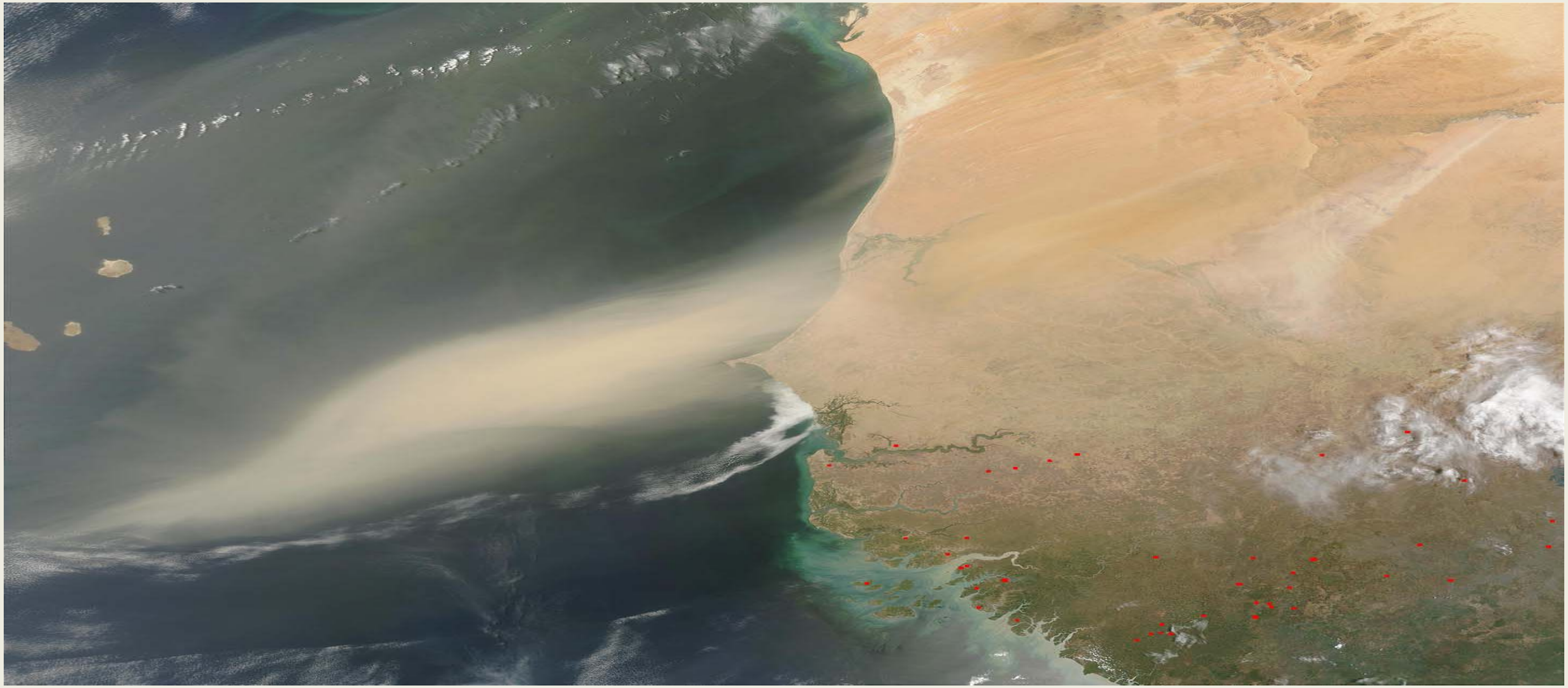


Fig. 7. BC and OCp emissions in West Africa in 2002. a and c: Junker and Liousse calculated for 2002. b and d: our maximum assumption for two-wheel vehicles added to Junker and Liousse calculated for 2002.

Dust emission



- Use of dust climatologies
- More and more climate models incorporates now on line dust emission schemes

Dust emission parameterization

Texture	Mode 1			Mode 2			Mode 3		
	n	MMD	σ	n	MMD	σ	n	MMD	σ
Sand	0.90	1000	1.6	0.10	100	1.7	0.00	10	1.8
Loamy Sand	0.60	690	1.6	0.30	100	1.7	0.10	10	1.8
Sandy Loam	0.60	520	1.6	0.30	100	1.7	0.10	5	1.8
Silt Loam	0.50	520	1.6	0.35	100	1.7	0.15	5	1.8
Silt	0.45	520	1.6	0.40	75	1.7	0.15	2.5	1.8
Loam	0.35	520	1.6	0.50	75	1.7	0.15	2.5	1.8
Sandy Clay Loam	0.30	210	1.7	0.50	75	1.7	0.20	2.5	1.8
Silty Clay Loam	0.30	210	1.7	0.50	50	1.7	0.20	2.5	1.8
Clay Loam	0.20	125	1.7	0.50	50	1.7	0.30	1	1.8
Sandy Clay	0.65	100	1.8	0.00	10	1.8	0.35	1	1.8
Silty Clay	0.60	100	1.8	0.00	10	1.8	0.40	0.5	1.8
Clay	0.50	100	1.8	0.00	10	1.8	0.50	0.5	1.8

Soil granulometry
10 µm – 10000 µm

Horizontal saltation flux (Marticorena and Bergametti, 1995):

$$G = E * \frac{\rho_a}{g} * U^{*^3} * \int_{D_p} \left(1 + \frac{U_t^*(D_p, Z_0, z_0)}{U^*}\right)\left(1 - \frac{U_t^*(D_p, Z_0, z_0)^2}{U^{*2}}\right) dS_{rel}(D_p) dD_p$$

$dS_{rel}(D_p)$: fraction of soil aggregate of diameter Dp / dtotal distribution

threshold friction velocity

$$u_t^*(D_p) = u_{ts}^*(D_p) \cdot f_{eff} \cdot f_w$$

Threshold friction velocity

Vitesse de vent nécesaire pour créer un flux de salatation horizontal, et donc un flux vertical de particules : dépend de la nature du sol caractérisé par sa granulométrie

Environment	Threshold wind (mph)
Fine to medium sand in dune covered regions	10-15
Sandy areas	20
Fine material, desert flat	20-25
Alluvial fans and crusted salt flats (dry lake beds)	30-35
Well developed desert pavement	40

Vertical dust emission flux

Physical approach (e.g. Alfaro and Gomes, 2001)

$$dF_{kin}(D_p) = \beta * dG(D_p).$$

$$dN_i(D_p) = dF_{kin}(D_p) * \frac{p_i(D_p)}{e_i}$$

$$F_i = \int_{D_p} \frac{\pi}{6} * \rho_p * D_i^3 * dN_i(D_p)$$

i refers to predefined log-normal emission mode characterized by cohesion energy ei

Gives a distributed emission flux. The distribution depends on wind intensity.

Estimation and mapping of the required parameters is difficult.

A more empirical approach (e.g Laurent et al, 2008)

$$\alpha = \frac{F}{G} = c_{alpha} \cdot 10^{0.134 \cdot \%clay - 6}$$

Does not give information on F size distribution

- Use of observed regional distribution (e.g. AMMA, **Crumeyrolle et al., 2009)**

Recently Kok (2011a, 2011b ACPD) proposed that dust emission is analogous to brittle fragmentation with a resulting invariant emission size distribution.

$$\frac{dV_d}{d\ln D_d} = \frac{D_d}{c_V}\left[1 + \operatorname{erf}\left(\frac{\ln(D_d/D_s)}{\sqrt{2}\ln\sigma_s}\right)\right]\exp\left[-\left(\frac{D_d}{\lambda}\right)^3\right]$$

$D_s = 3.4 \pm 1.9\mu m$ and $\sigma_s = 3.0 \pm 0.4\mu m$.

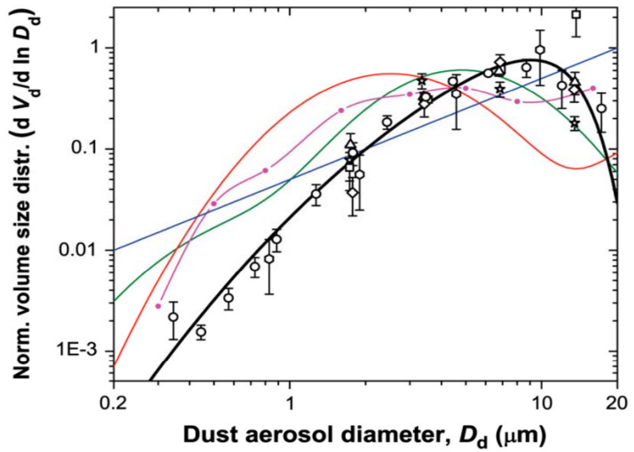
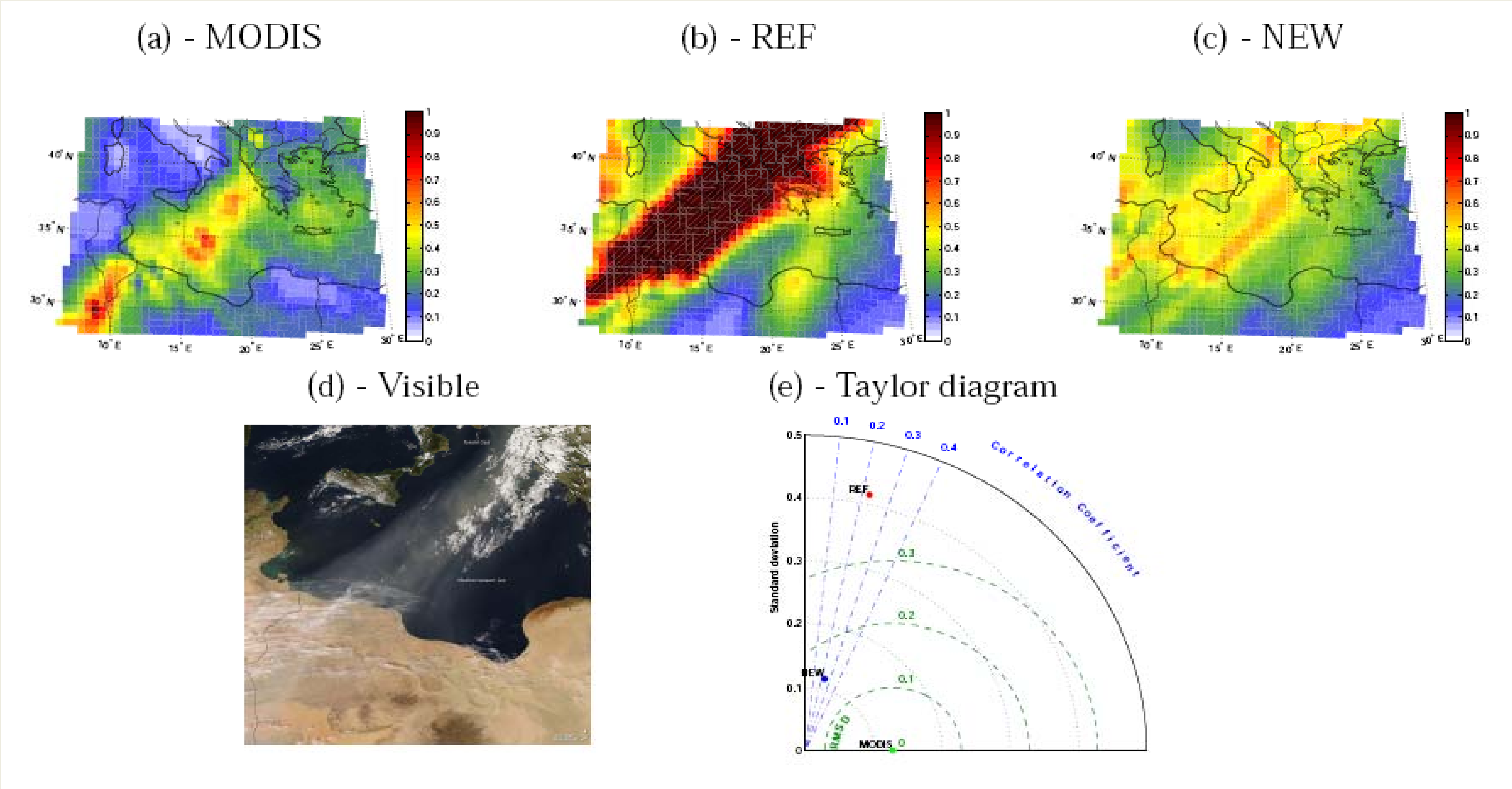
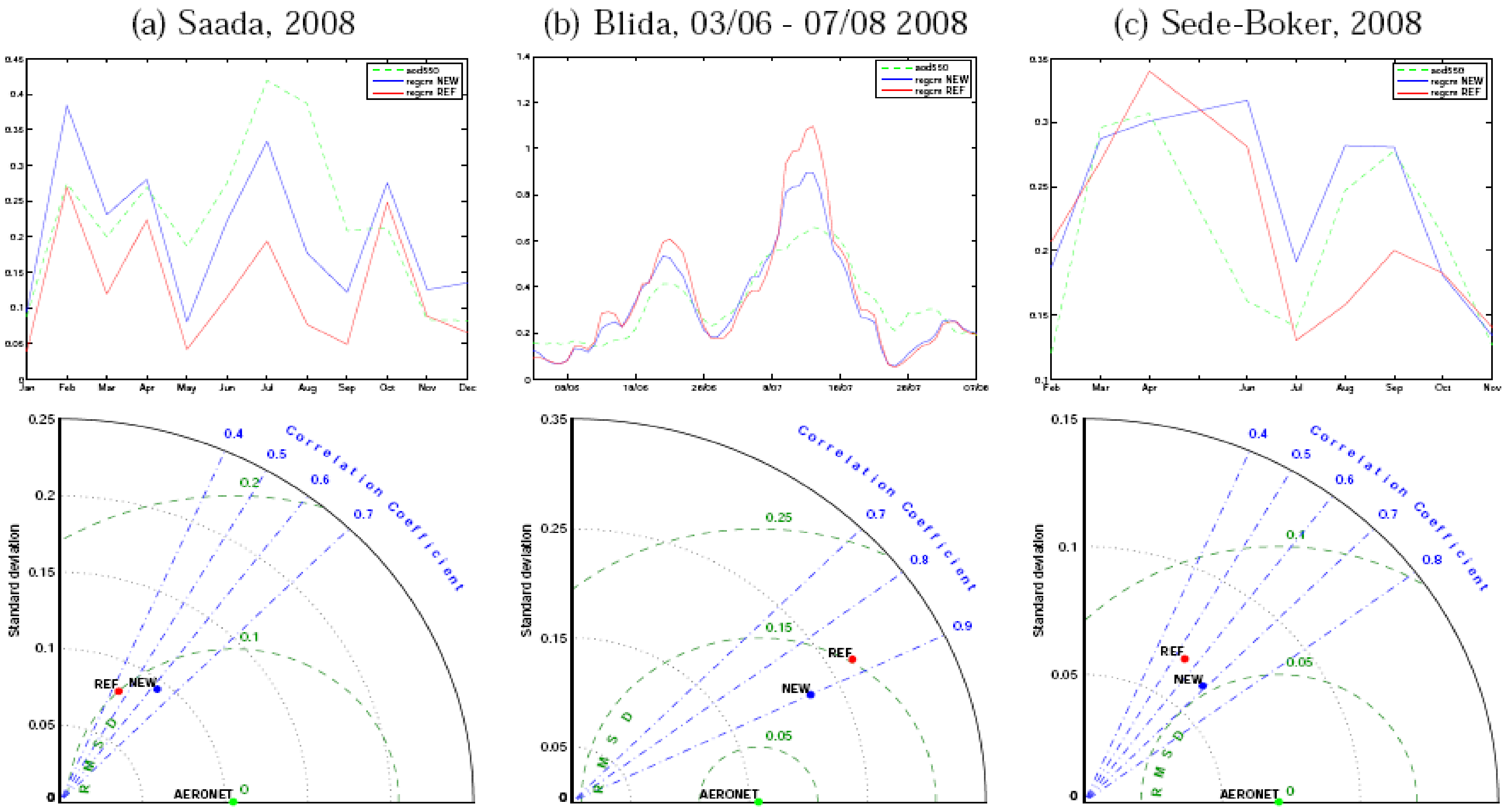


Fig. 3. The normalized volume size distribution of emitted dust aerosols used in 4 GCM studies [magenta line and circles (3), and blue (20), green (12), and red (13) lines]. The thick black line denotes the theoretical PSD of Eq. **6**, and symbols and error bars denote measurements as defined in Fig. 2.

Comparison of the two approaches using the RegCM model

REF = Alfaro and Gomes, 2006; NEW = Laurent et al., + Kok et al.





(a) Saada, 2008
(b) Blida, 03/06 - 07/08 2008
(c) Sede-Boker, 2008
aod550
regcm NEW
regcm REF
Standard deviation
Correlation Coefficient
RMSD
REF
NEW
AERONET

Conclusion

Still significant factor of uncertainties on anthropogenic emissions in Africa.

Biomass burning : significant progress have been made, using different approaches.

Other types of combustions (fossil fuel, domestic, waste burning ..) needs some basic data on emission factors (country and region specific).

Different inventories available for climate chemistry studies. This allows to perform sensitivity studies and ensemble simulations.

Calcul de la vitesse de seuil (Marticorena and Bergametti 1995)

$$u_t^*(D_p) = u_{ts}^*(D_p) \cdot f_{eff} \cdot f_w$$

Dp = diamètre de l'aggrégat

Vitesse seuil 'idéale' , issue d'expérience en soufflerie

$$u_{ts}^*(D_p) = \begin{cases} 0.129 \cdot K \cdot \left[1 - 0.0858 \cdot \exp\left\{-0.0617 \cdot \left(\mathrm{Re} - 10\right)\right\}\right] & \mathrm{R_e} > 10 \\ \dfrac{0.129 \cdot \mathrm{K}}{\left(1.928 \cdot \mathrm{Re}^{0.092} - 1\right)^{0.5}} & 0.03 < \mathrm{R_e} \leq 10 \end{cases}$$

$$R_e = aD_p^x + b$$

Reynolds number
caractérisantl'écoulement sur l'aggrégat

$$K = \sqrt{\frac{2.g.\rho_p.D_p}{\rho_a} \cdot \left[1 + \frac{0.006}{\rho_p.g.(2.D_p)^{2.5}}\right]} \cdot$$

Facteur de corrections (issus de lois empiriques)

$$f_{eff} = 1 - \left[\frac{\ln\left(\frac{z_m}{z_{0s}}\right)}{\ln\left(0.35\left(\frac{10}{z_{0s}}\right)^{0.8}\right)} \right]$$

rugosité

Humidité du sol

W’= f(% clay)

$$f_w = \begin{cases} \left[1 + A \cdot \left(w - w^{/}\right)^B\right]^{0.5} & \text{for } w > w^{/} \\ 1 & \text{for } w < w^{/} \end{cases}$$