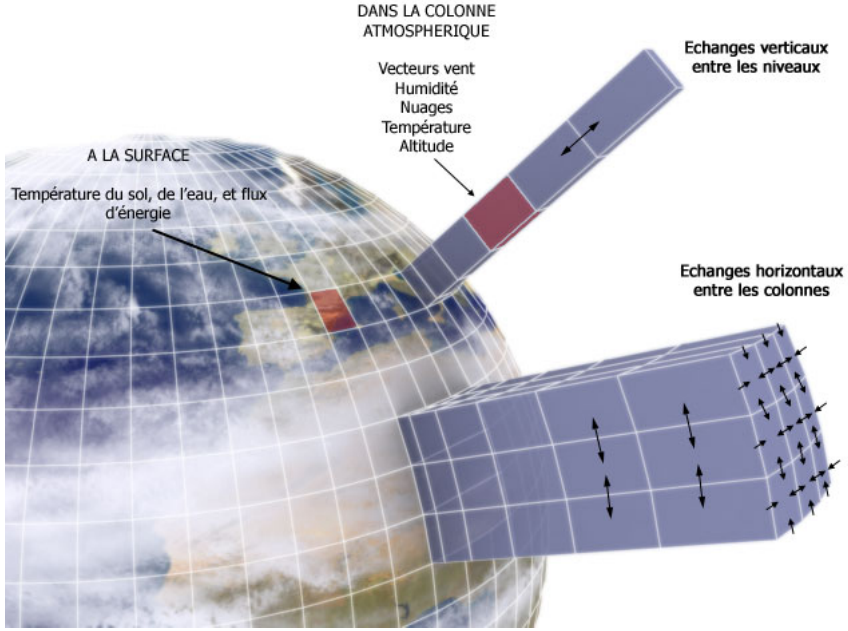
Modélisation des interactions chimie-aérosols / climat pour l'AR5

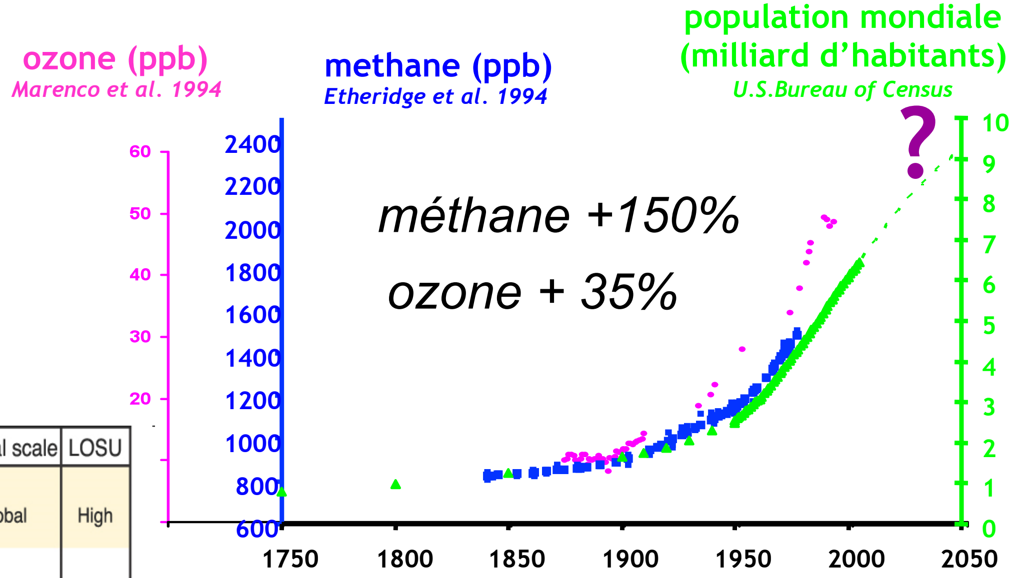
Sophie Szopa
Céline Déandreis, Yves Balkanski, Michael Schulz,
Anne Cozic, Nicolas Yan, Sébastien Denvil, David Cugnet,
Arnaud Caubel, Martial Mancip, Nathalie De Noblet …



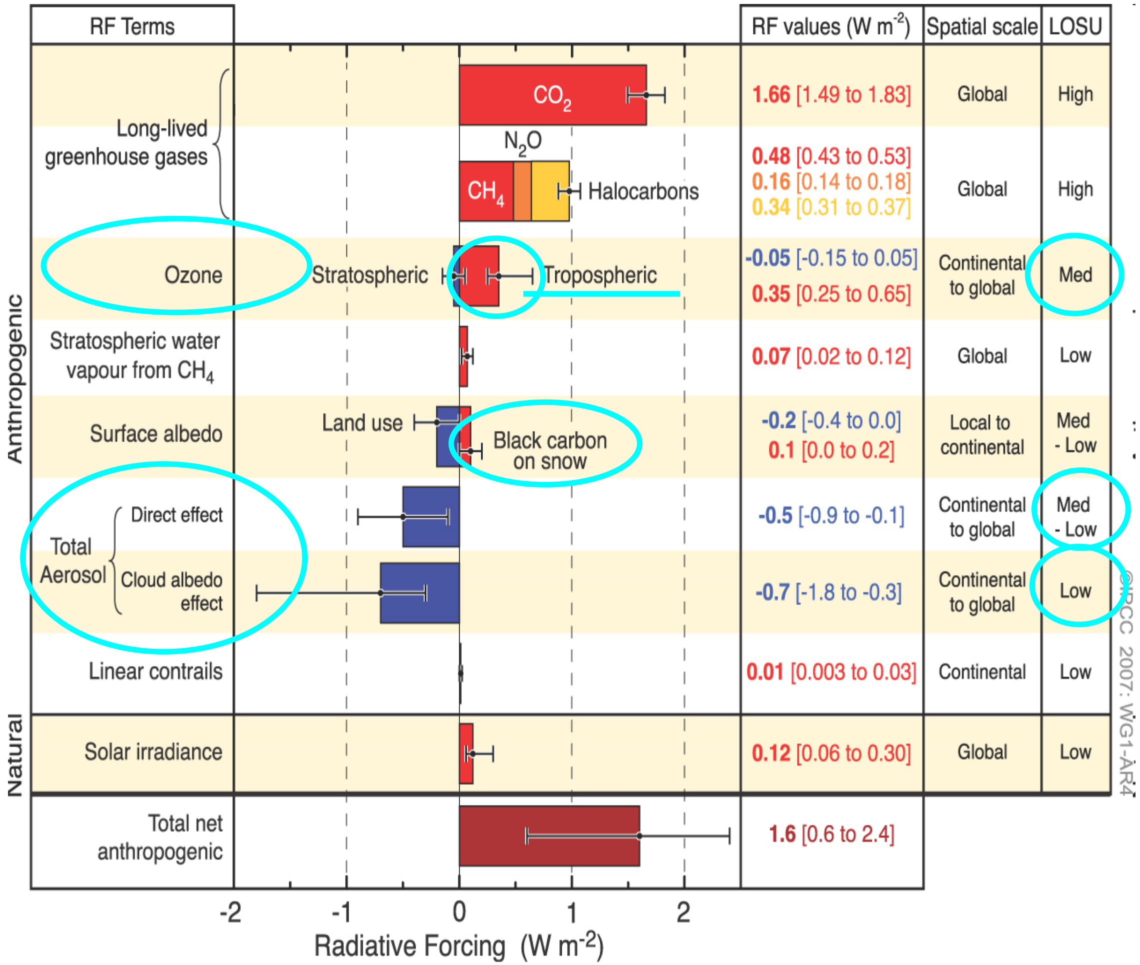
Animation Thème Modélisation – 13 avril 2010

Modélisation des interactions chimie-aérosols / climat pour l'AR5

Pourquoi?



CH_4=17%, O_3=13% de l'effet positif



Aérosols, effet négatif env 90% de effet du CO_2

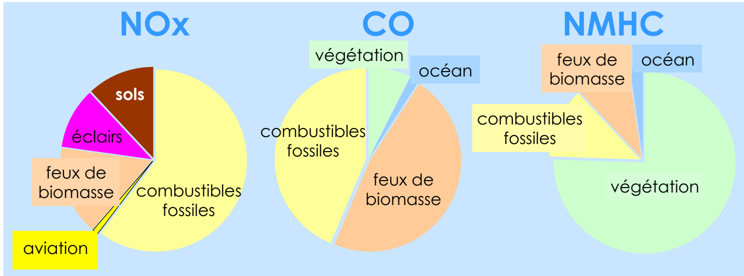
UNE INCERTITUDE ÉLEVÉE

Modélisation des interactions chimie-aérosols / climat pour l’AR5

Pourquoi cette grande incertitude?

Ozone et aérosols cachent de nombreuses espèces à documenter:
Ozone : plusieurs milliers de précurseurs représentés par quelques dizaines dans modèles
Aérosols : black carbon + sulphates + dust + nitrates + SOA en mélanges interne et externe (distributions en taille/masse complexes)

Des sources multiples (naturelles et anthropiques) et variables dans le temps (var saisonnière et interannuelle

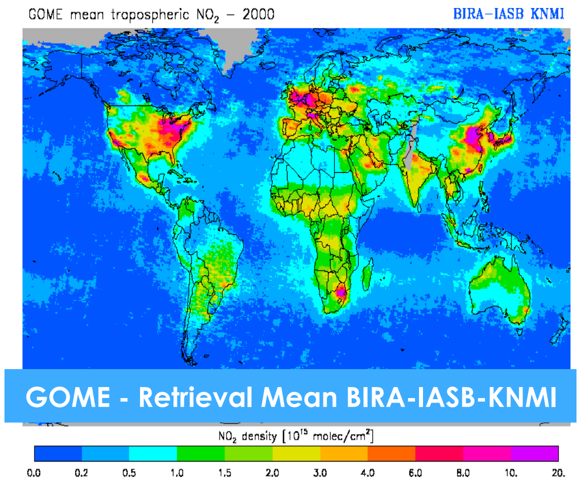


Des espèces réactives chimiquement (non linéarité)

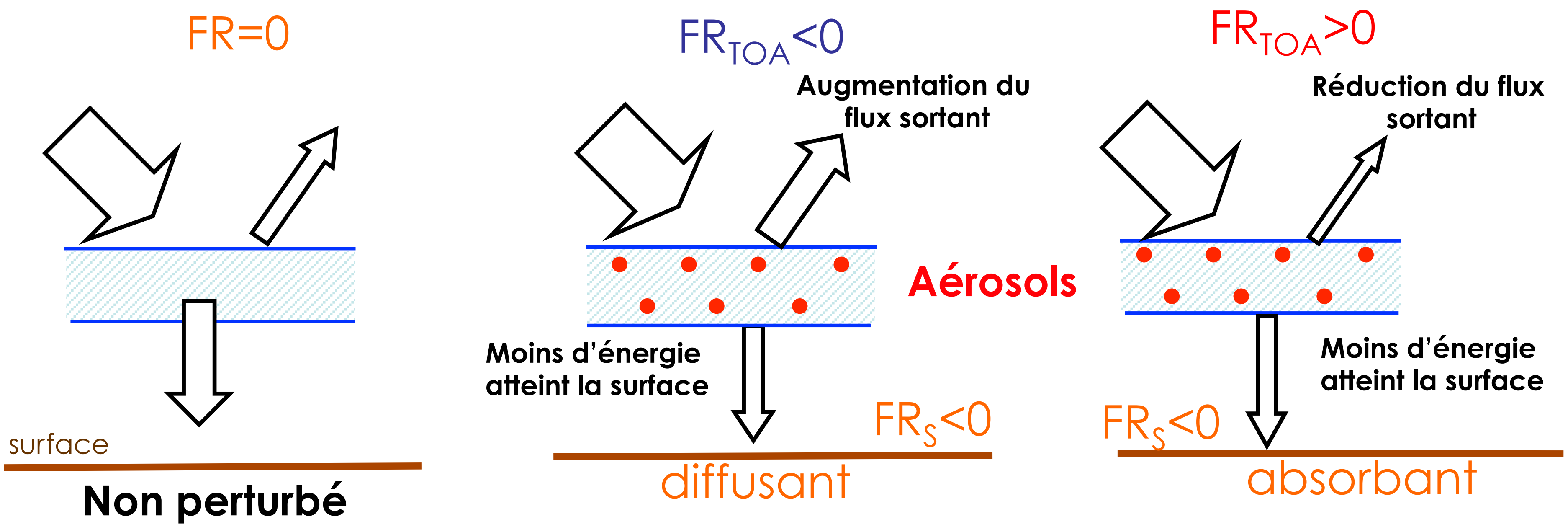
→ Forte variabilité spatiale et temporelle

→ Incertitude sur distribution horizontale et verticale présente (+ IAV)

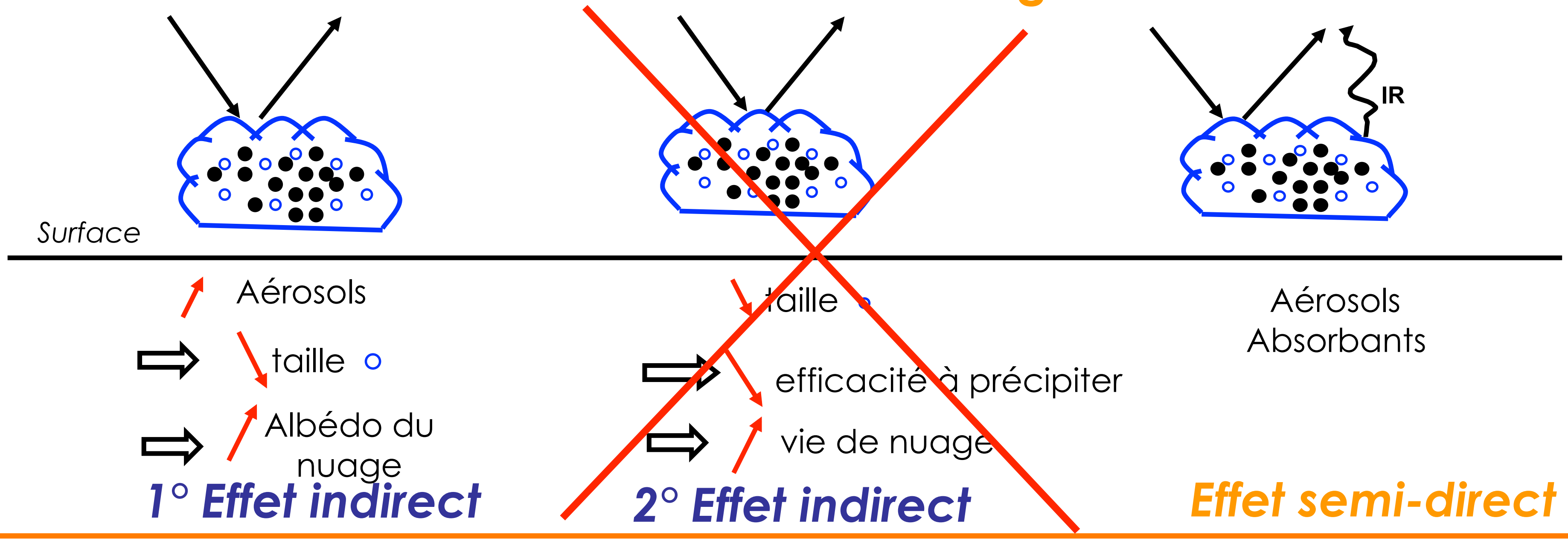
→ Très grande incertitude répartition passée



Les aérosols et le climat: Effet direct



Interactions avec les nuages



D'après thèse Céline Déandreis

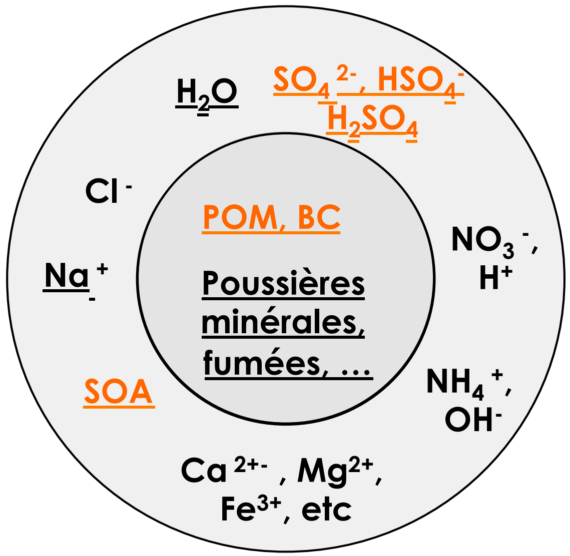
Modélisation des interactions chimie-aérosols / climat pour l'AR5

Pourquoi cette grande incertitude?

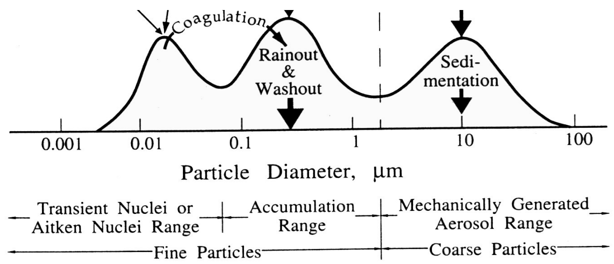
Difficulté à caractériser les propriétés optiques et hygroscopiques

→ **Incertitude sur effet indirect ?**

→ **Incertitude sur impact radiatif?**



Composition variée



Taille variée

Modélisation des interactions chimie-aérosols / climat pour l'AR5

Comment quantifier le forcage?

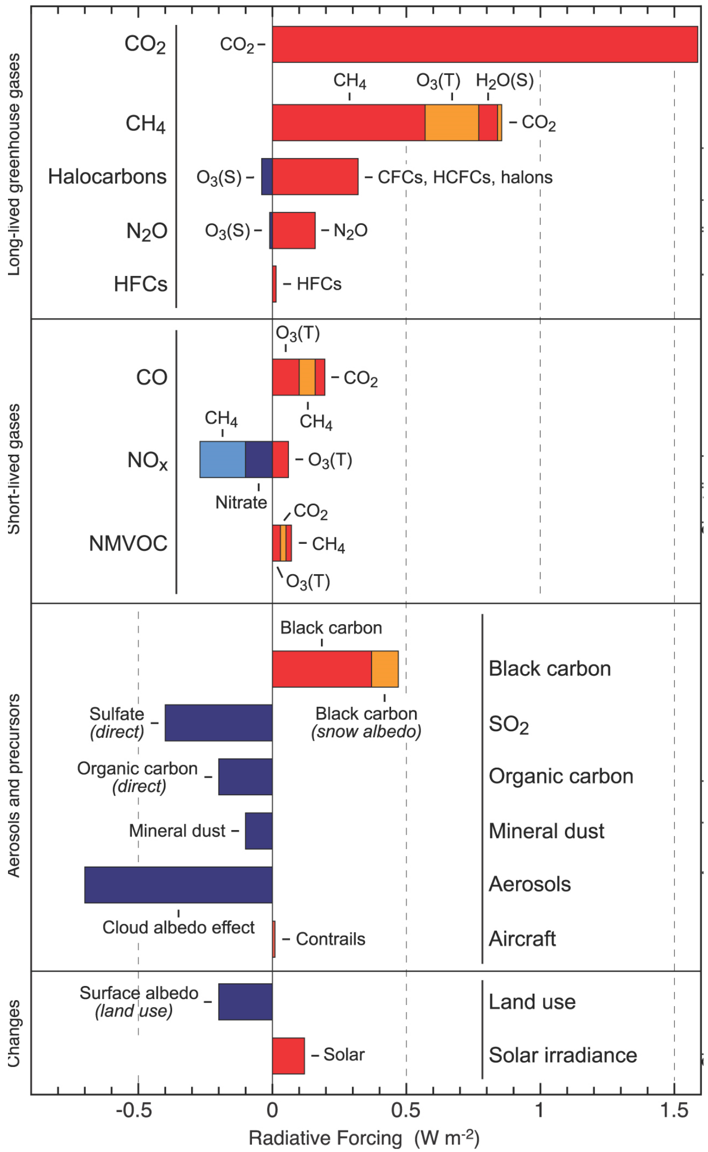
Modèles couplés système Terre car effets régionaux très élevés -> non linéarité (mais temps de calculs élevés)

Comment mieux caractériser la distribution des composés gazeux ou aérosols et discriminer les différents effets pour diminuer les incertitudes?

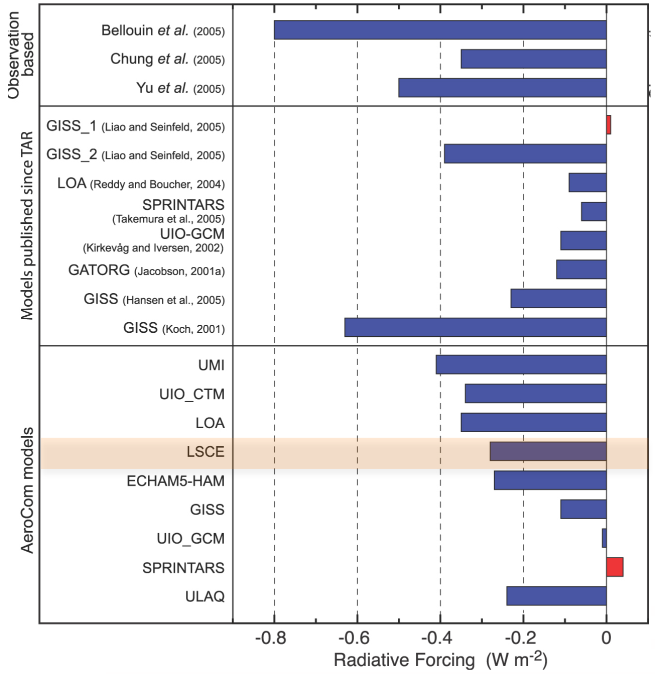
Modèles chimie-climat (type LMDzINCA) sous réserve de disponibilité d'inventaires d'émissions

AR4

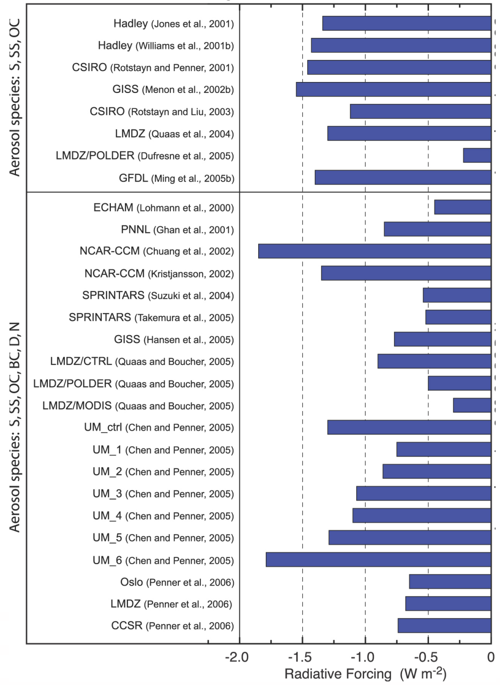
Components of radiative forcing for principal emissions



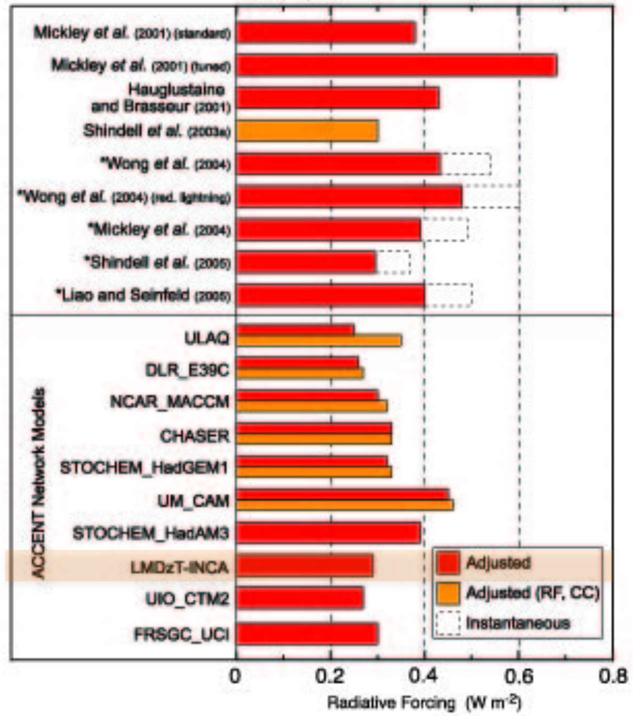
Aerosol Direct Radiative Forcing



Radiative Forcing from Cloud Albedo Effect



Radiative Forcing of Tropospheric Ozone Increases

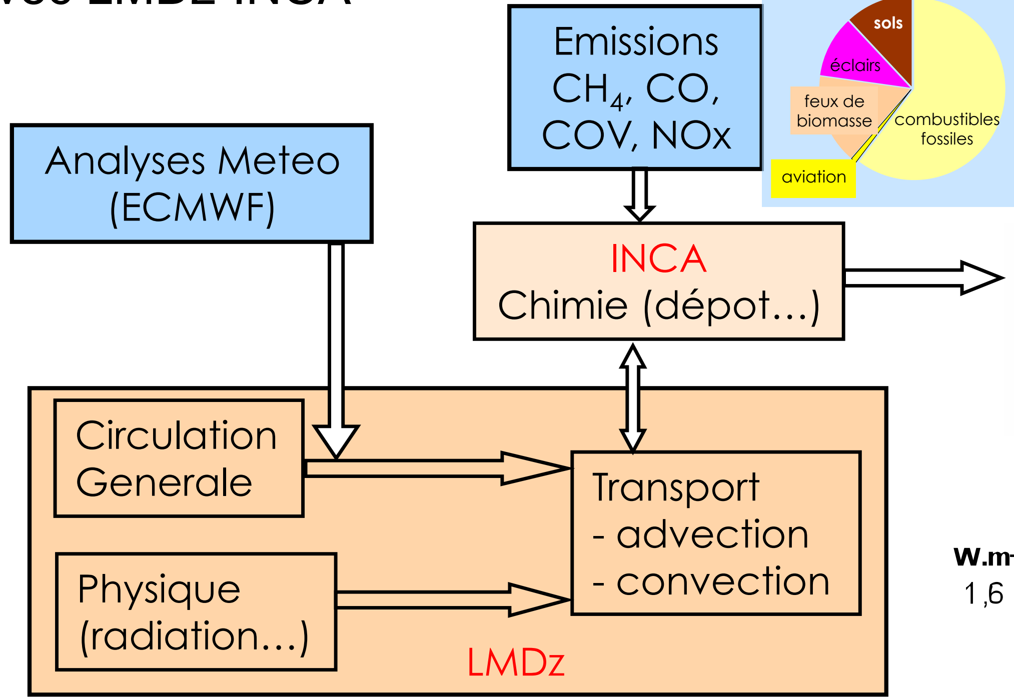


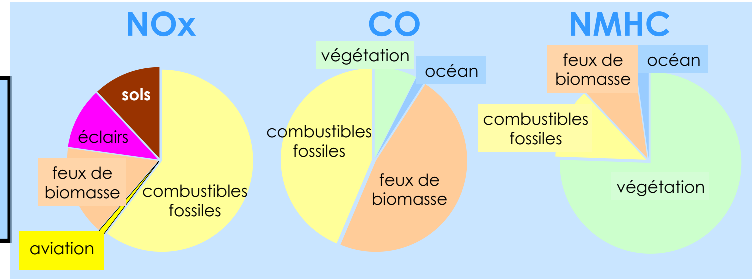
Modélisation des interactions chimie-aérosols / climat pour l'AR5

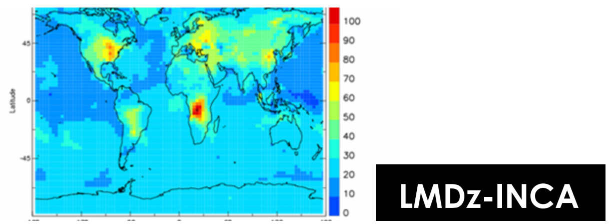
Pour l'AR4?

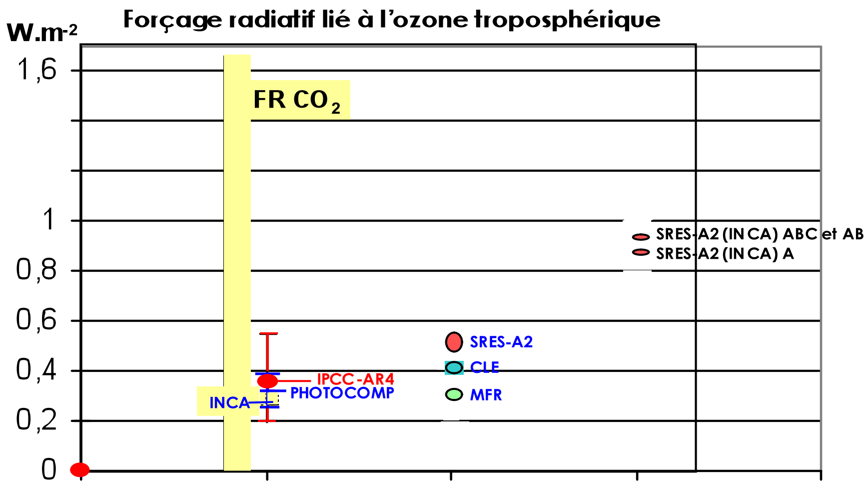
Coté chimie-aérosols

Avec LMDz-INCA









Exercice international
coordonné PHOTOCOMP
26 ctm
Seulement 10 gcm

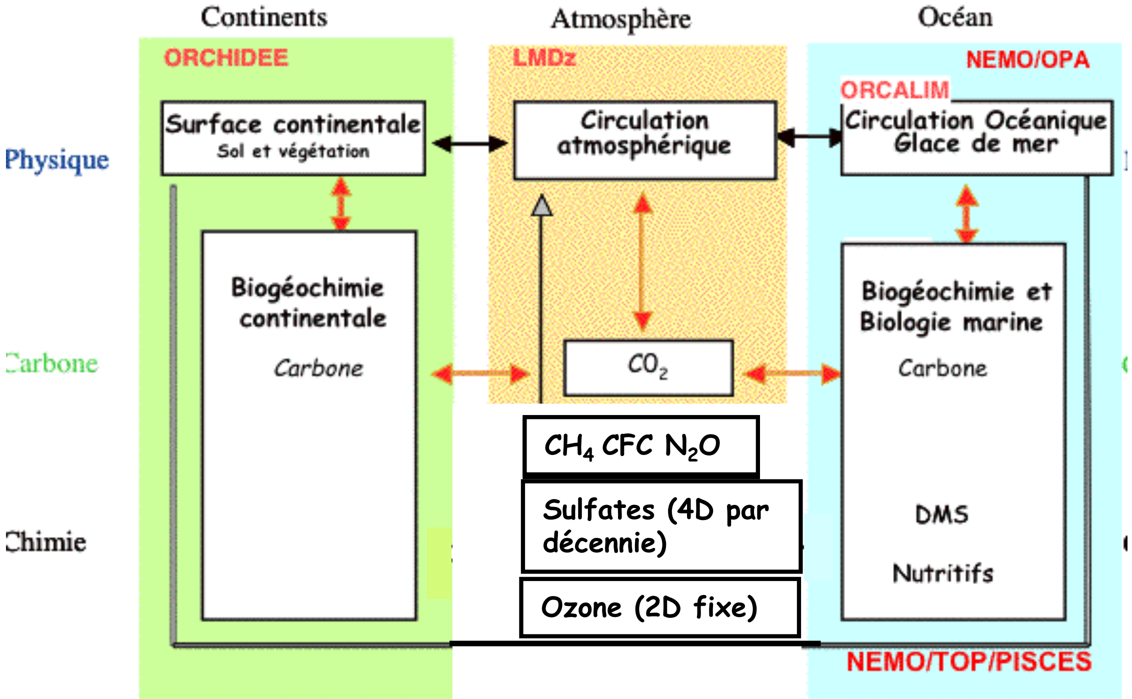
Snapshot preind/present/2030 (faute d'emissions et CPU [1an=~4.5heures])

Modélisation des interactions chimie-aérosols / climat pour l'AR5

AR4

Coté Climat

Dans le couplé IPSL

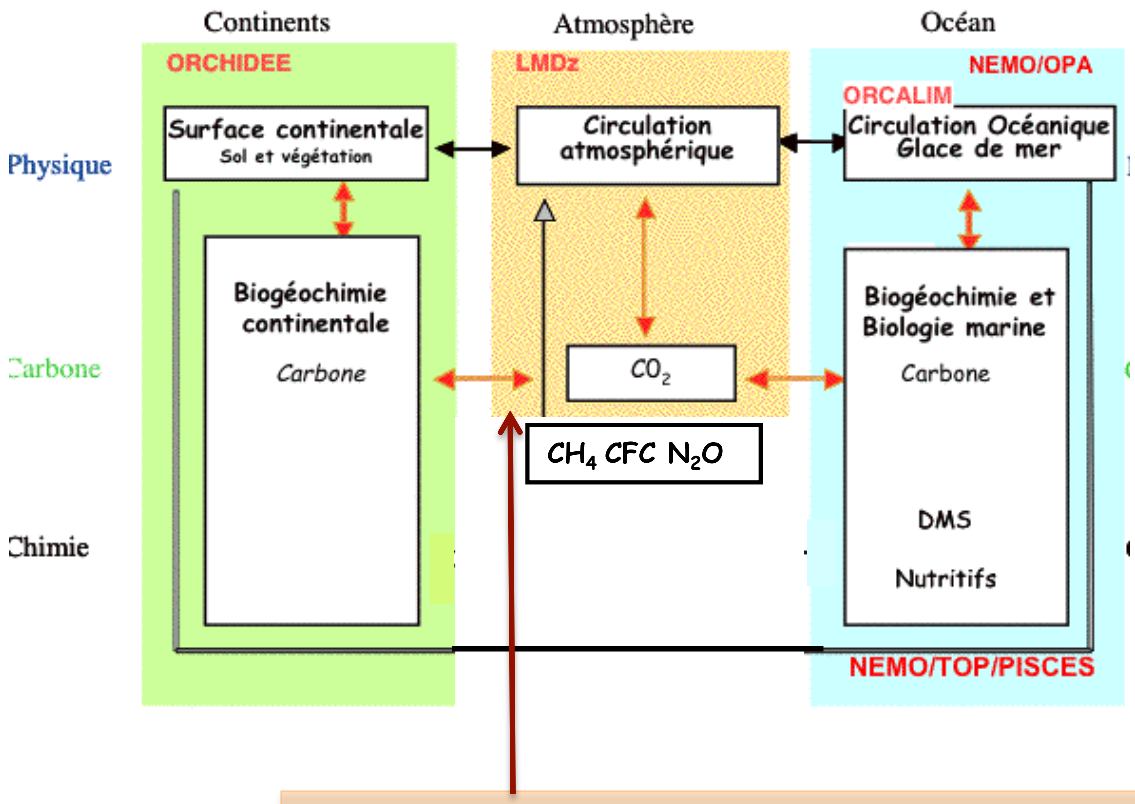


Modélisation des interactions chimie-aérosols / climat pour l'AR5

AR5

Coté Climat

Dans le couplé IPSL-CM5 A



Aérosols organiques
Black carbon
Sulphates
Dust
Sea Salt
Ozone tropo

Précalculés avec LMDz-INCA de 1850 à 2100

NB envoi a MeteoFrance de :

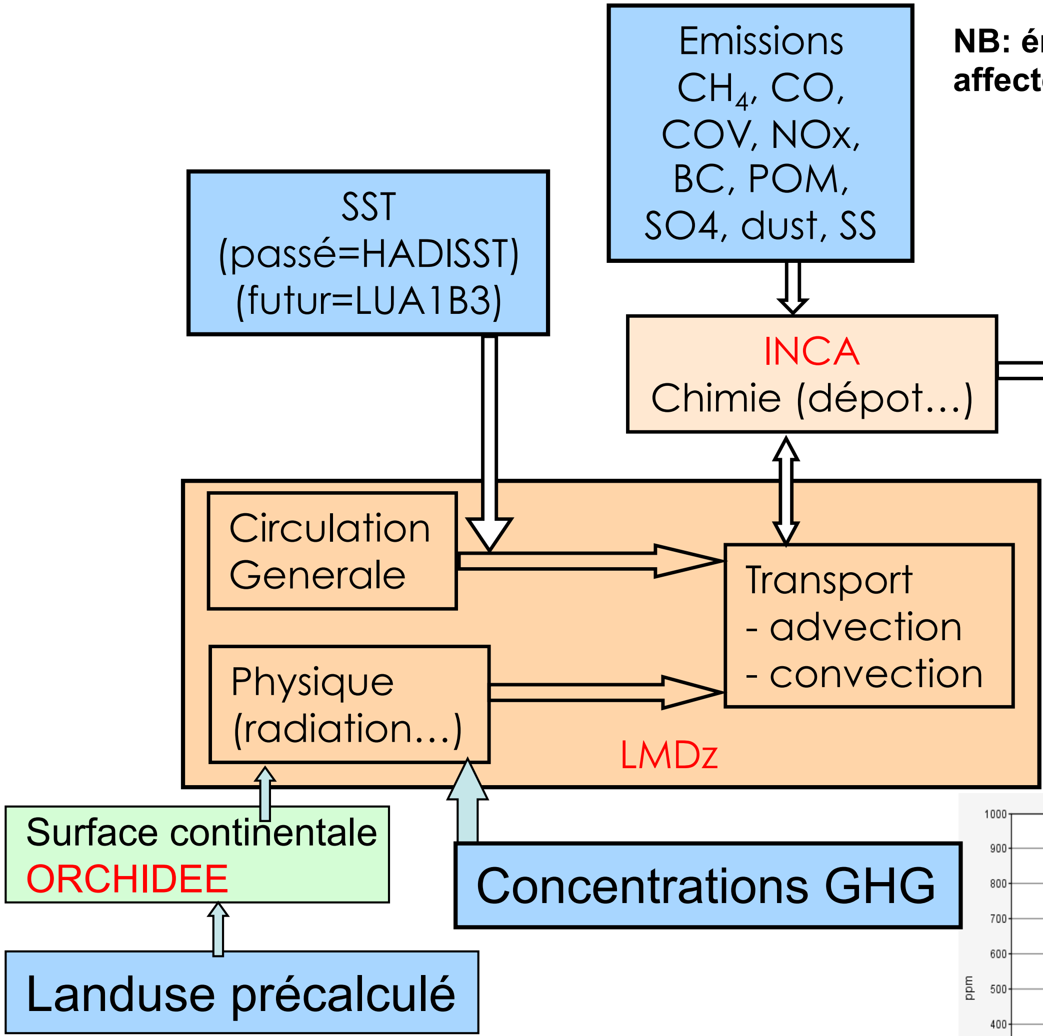
OD550_BCM	black carbon
OD550_POMM	particulate organic matter
OD550_SSM	sea salt
OD550_SO4M	sulfate
OD550_total	somme de tous

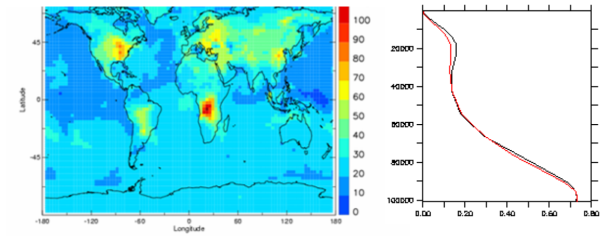
Modélisation des interactions chimie-aérosols / climat pour l'AR5

Préparation des forcages chimie-aérosols

Avec LMDz-INCA

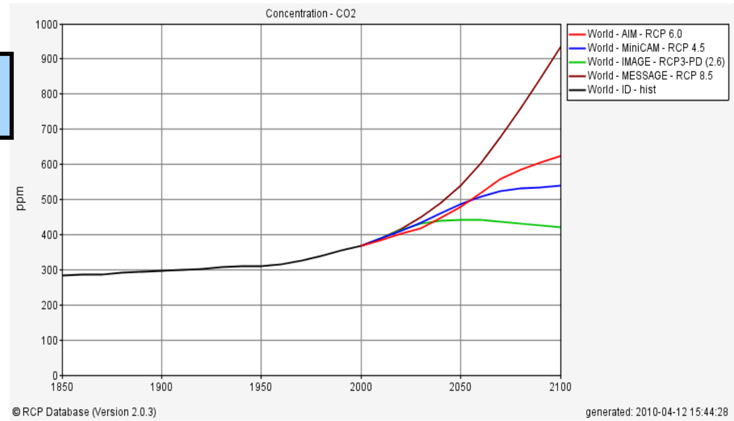
NB: émissions aérosols naturels (dust, sea salt) non affectées par changement climatique





Distribution horizontale et verticale

Évolution temporelle 1850-2100



Modélisation des interactions chimie-aérosols / climat pour l'AR5

Préparation des forcages chimie-aérosols

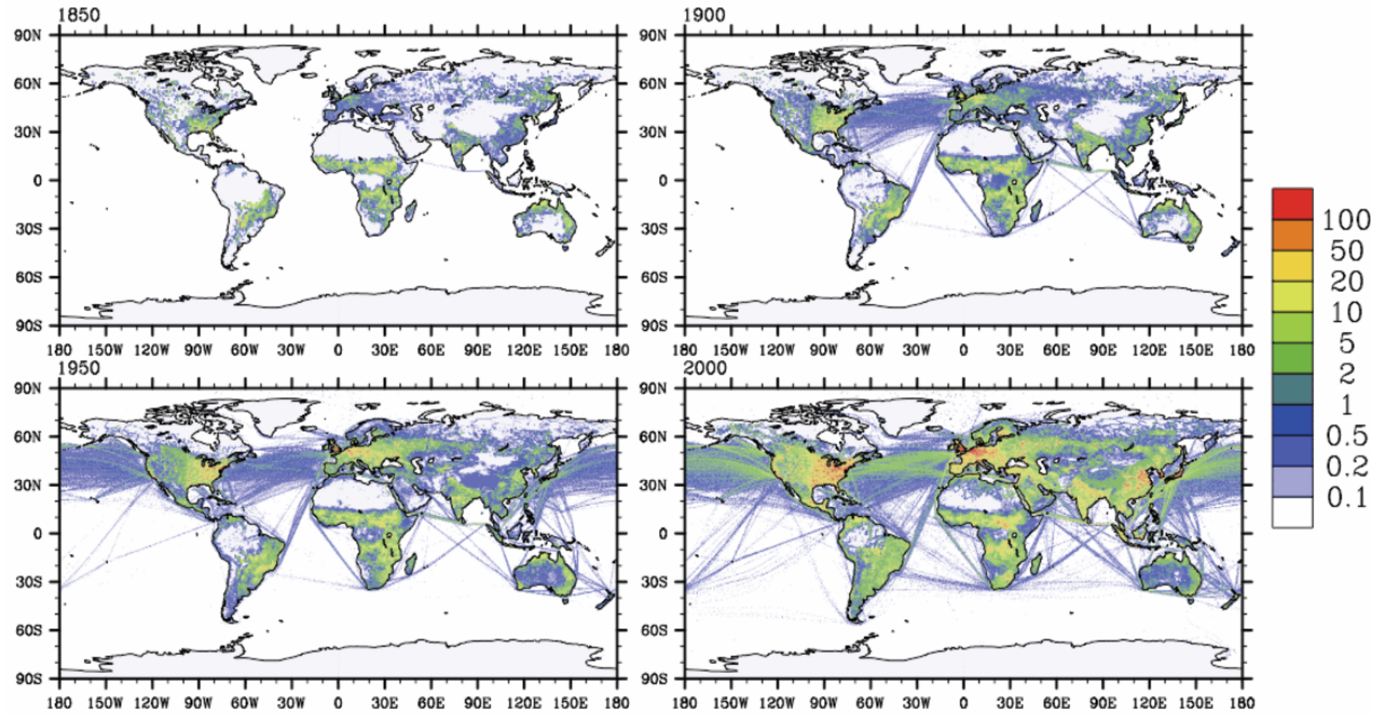
Quelles émissions?

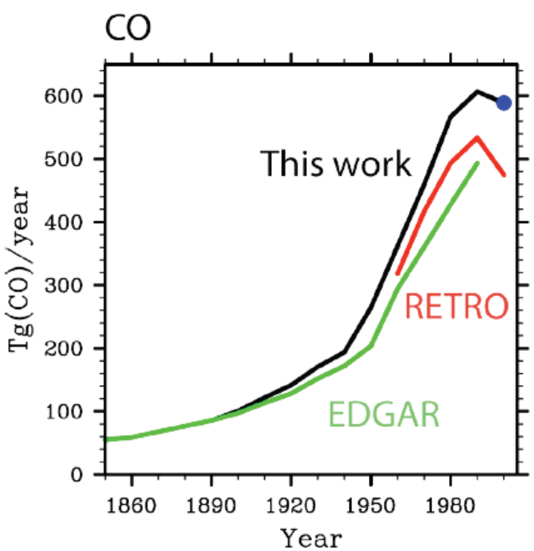
Historical (1850–2000) gridded anthropogenic and biomass burning emissions of reactive gases and aerosols: methodology and application
J.-F. Lamarque et al., ACPD, 2010

- consistent for chemistry model simulations needed by climate models for the CMIP5 in support of the IPCC-AR5

- 0.5x0.5° decadal

Total annual emissions (anthropogenic, shipping and biomass burning) of NOx





- for the year 2000 inventory represents a combination of existing regional and global inventories to capture the best information available at this point; 40 regions and 12 sectors are used to combine the various sources. The historical reconstruction of each emitted compound, for each region and sector, is then forced to agree with our 2000 estimate, ensuring continuity between past and 2000 emissions.

NMVOC speciation

name	molecular weight	comments
alcohols	46.2	assumed C_2H_5OH
ethane	30.0	
propane	44.0	
butanes	57.8	
pentanes	72.0	
hexanes and higher	106.8	
ethene	28.0	
propene	42.0	
ethyne	26.0	
other alkenes and alkynes	67.0	
benzene	78.0	
toluene	92.0	
xylene	106.0	
trimethyl benzenes	120.0	
other aromatics	126.8	
esters	104.7	surrogate species = $CH_3C(O)O(CH_2)nCH_3$
ethers	81.5	surrogate species = $CH_3CH_2O(CH_2)nCH_3$
chlorinates HC	138.8	
methanal (CH_2O)	30.0	
other alkanals	68.8	
ketones	75.3	
acids	59.1	
other VOC	68.9	use median *C* ratio of other compounds

Source types:

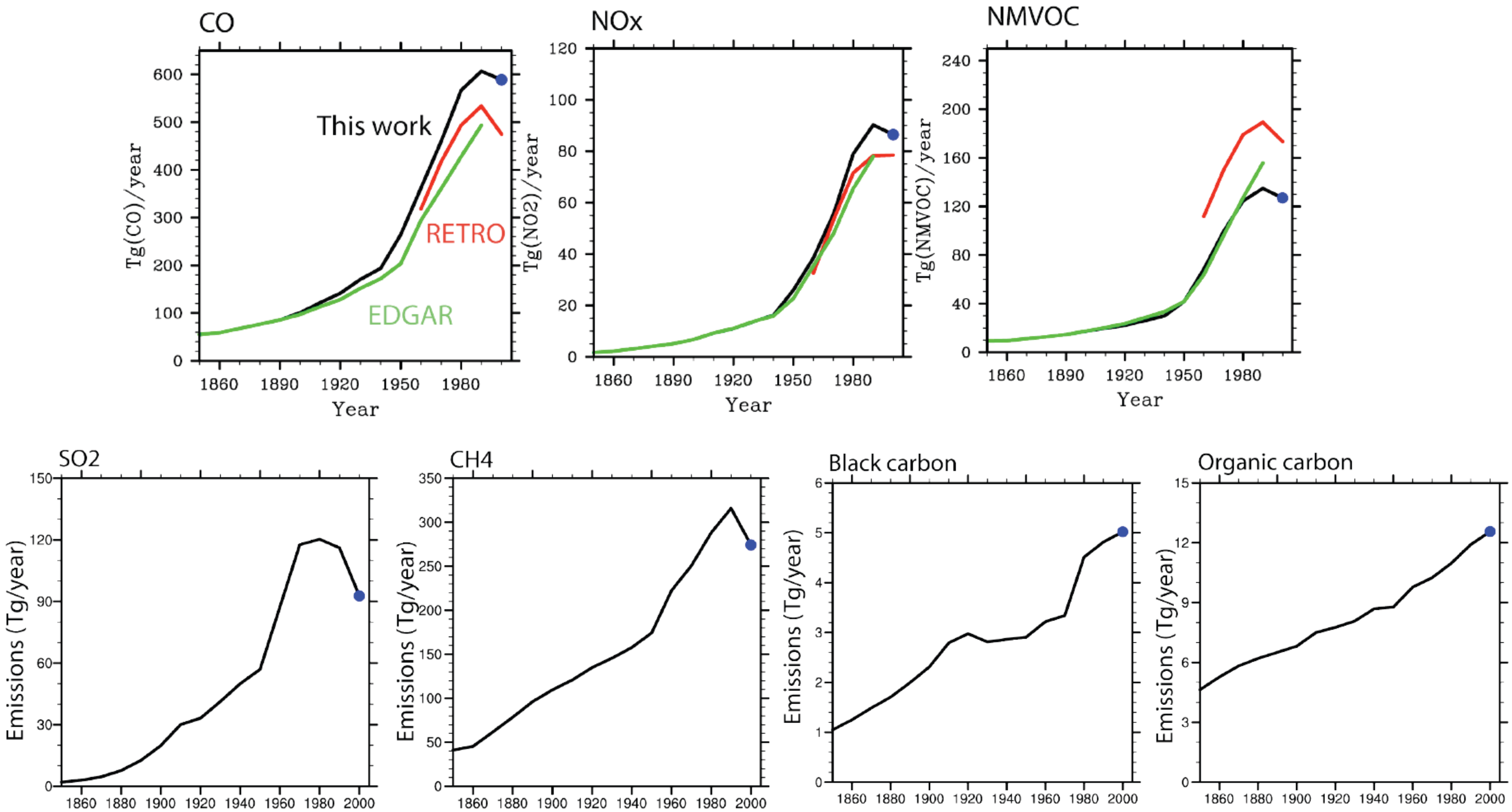
- Aircraft
- Anthropogenic
- Biomass burning
- Ship

+ black carbon
+ organic carbon
+ NH3
+ SO2
+ CH4

90 files per decades

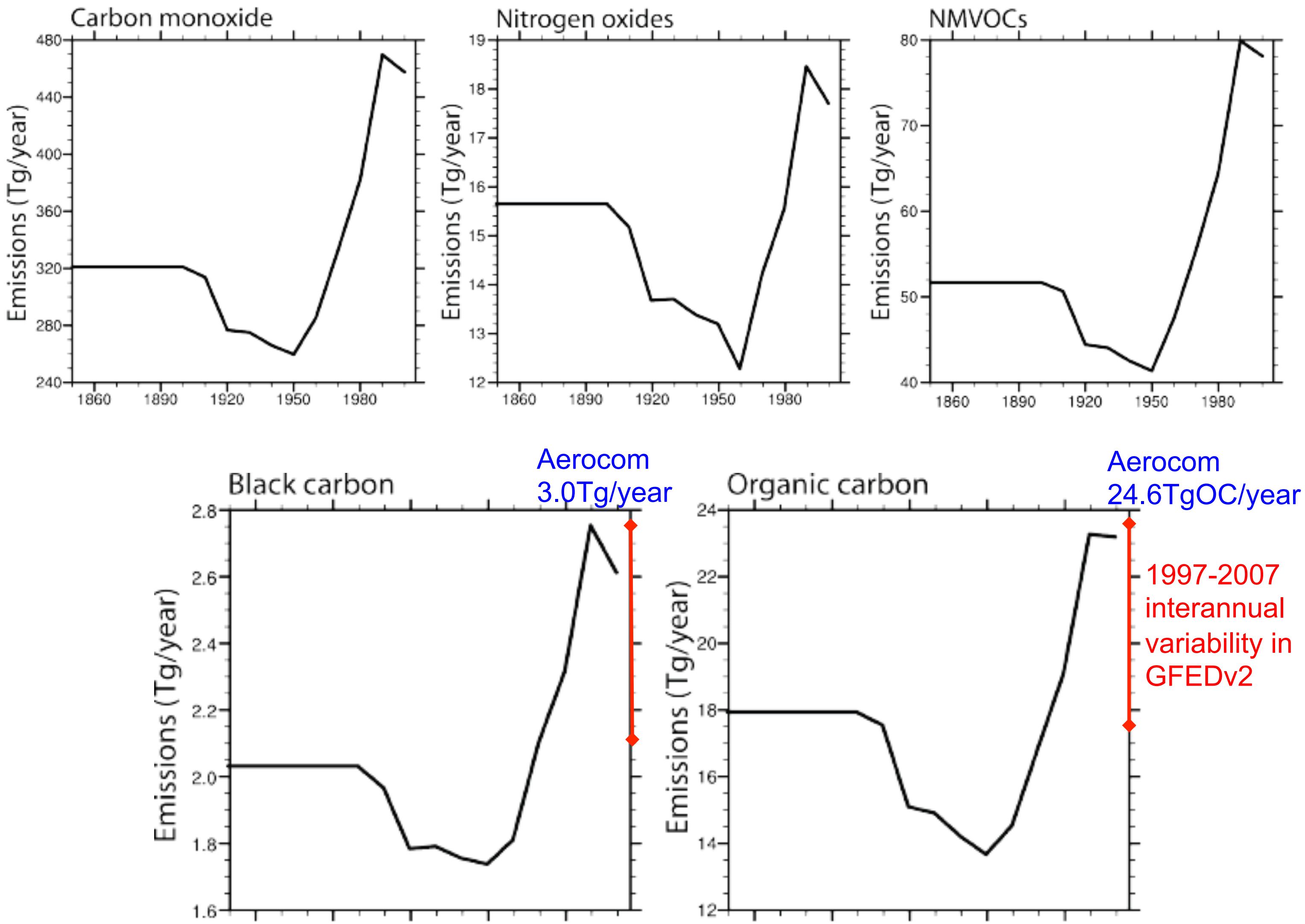
1350 fichiers (~60 Go) à

- regriller en 96x95
- sommer avec sources naturelles non fournies
- remettre dans les espèces spécifiques du schéma chimique d’INCA



Time evolution of the total (sum of all sectors) land anthropogenic emissions

Lamarque et al. 2010



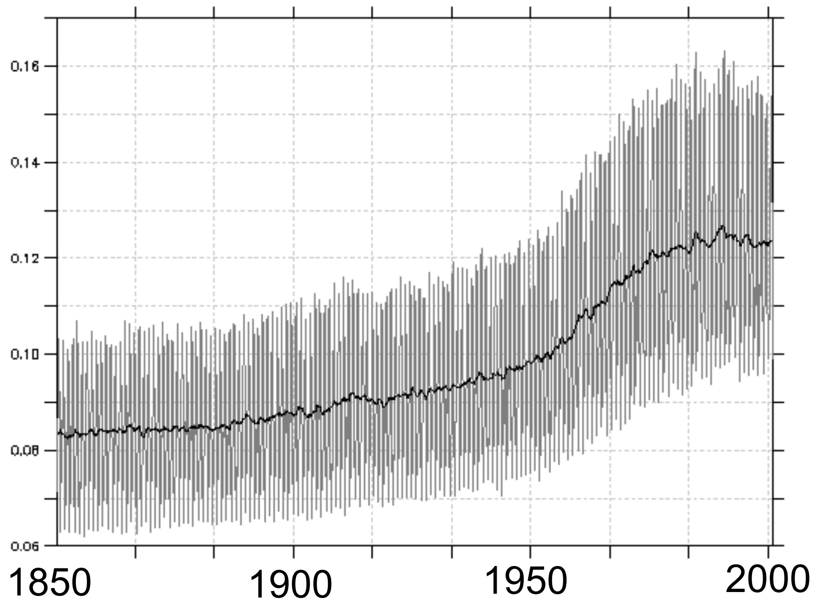
Time evolution of the total open biomass burning (forest and grassland) emissions

Lamarque et al. 2010

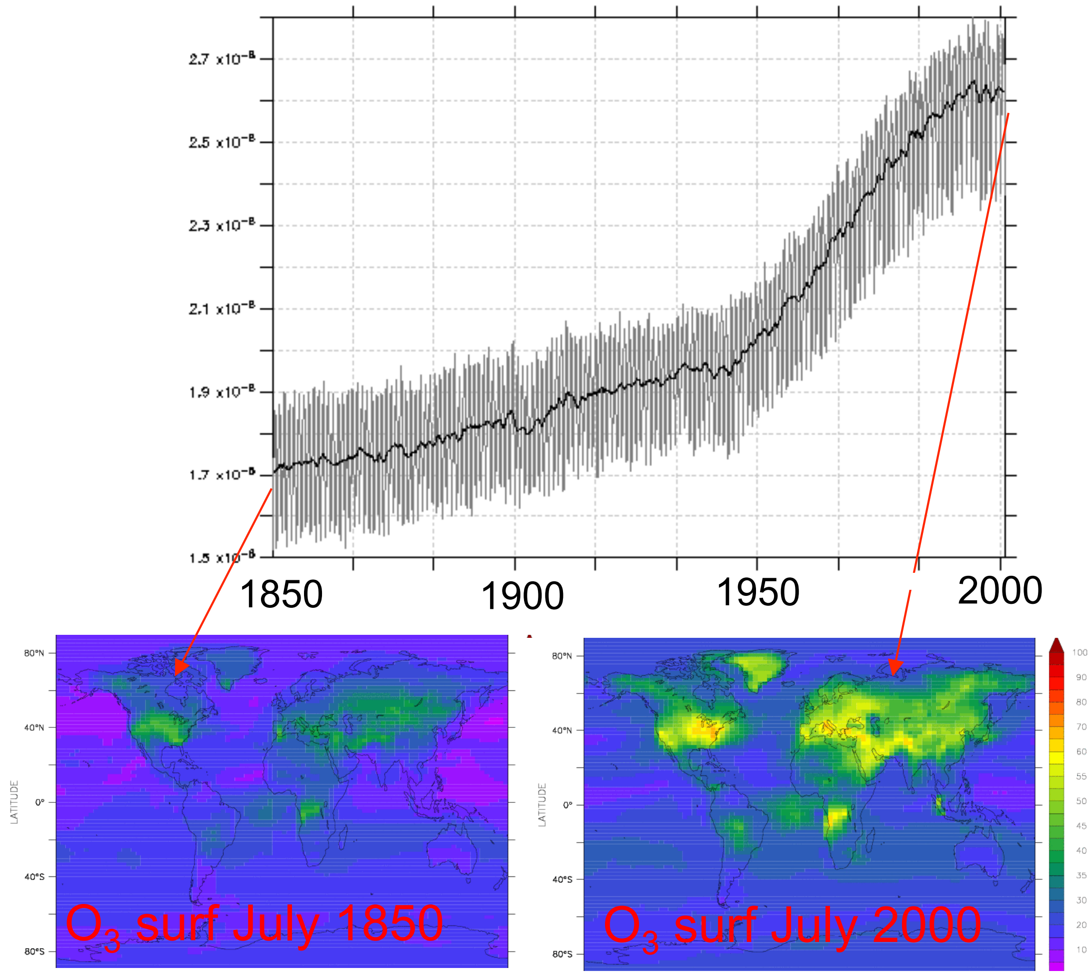
Modélisation des interactions chimie-aérosols / climat pour l'AR5

Run 1850-2000

Total aerosol optical depth (550nm)



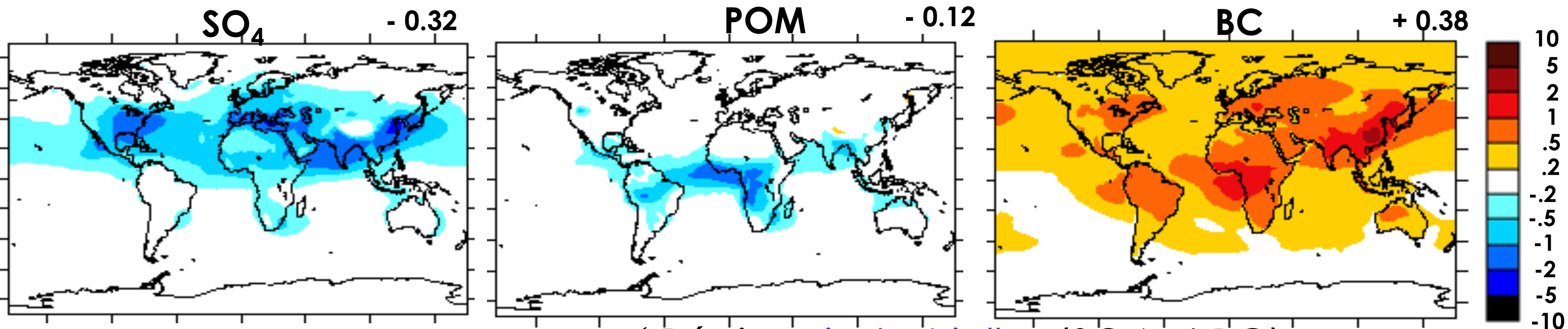
Surface ozone



Combiné avec O_3 strato de reprobus (en 2D) pour couplé

Distribution de l'effet direct

Forçage radiatif en $W.m^{-2}$:



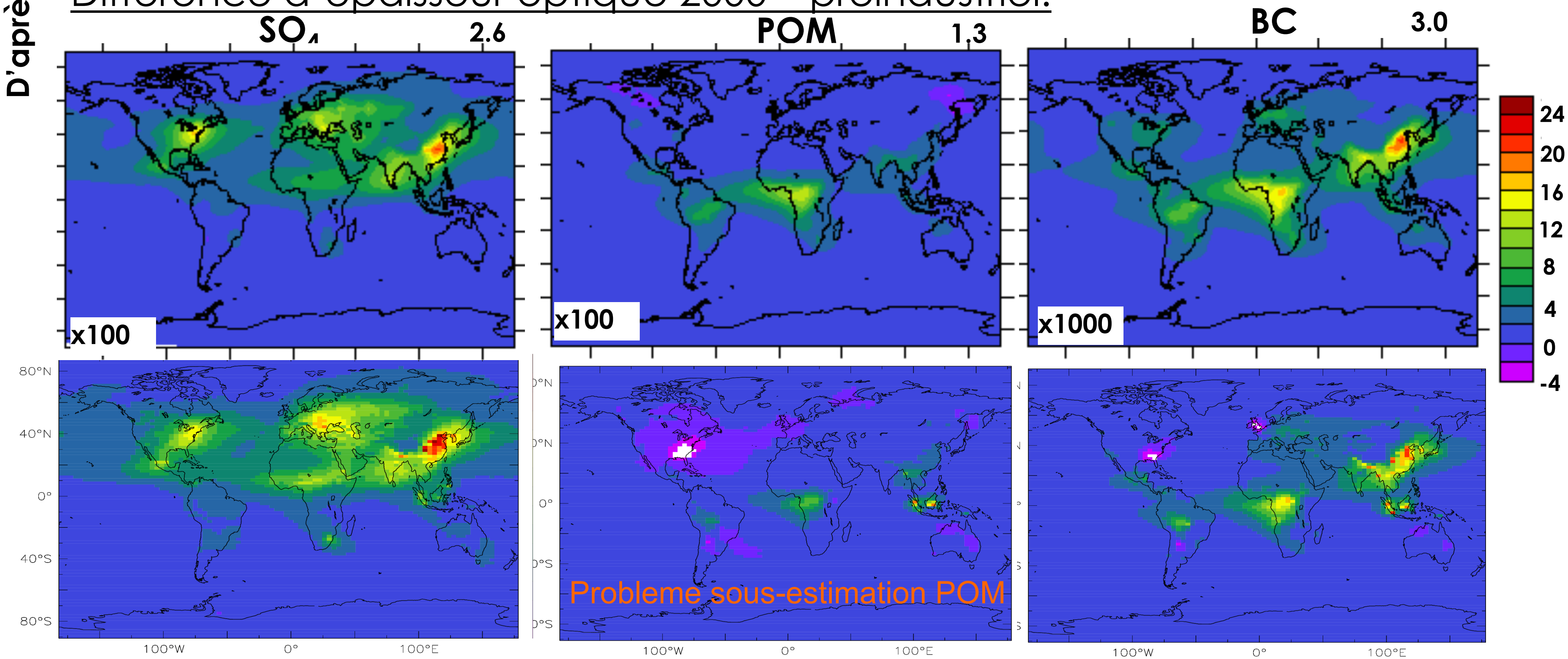
D'après thèse Céline Déandreis

Impact régional

✓ Régions industrielles (SO4 et BC)

✓ Régions de feux de biomasses (POM et BC)

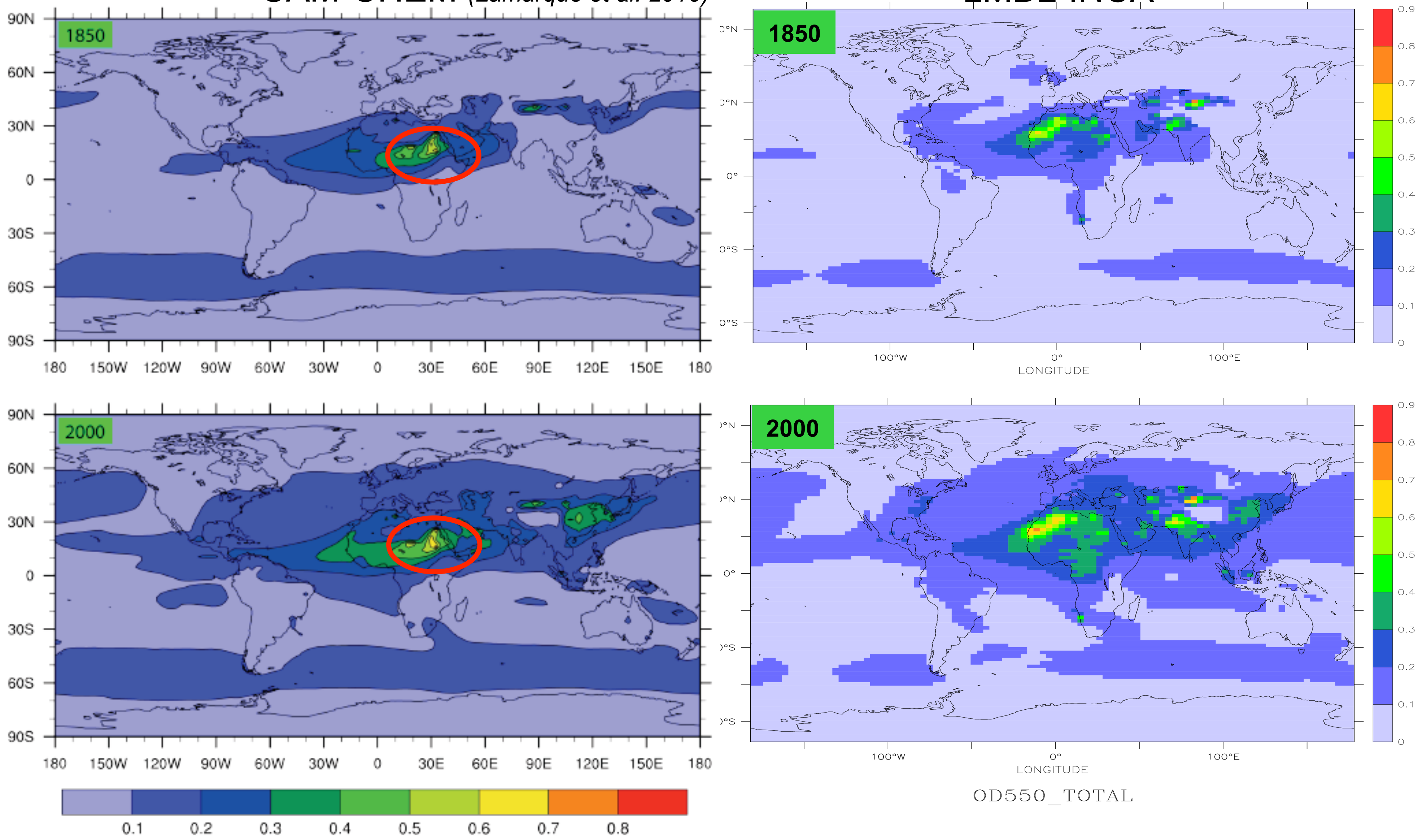
Différence d'épaisseur optique 2000 – préindustriel:



Dimin

Dimin

CAM-CHEM *(Lamarque et al. 2010)* LMDz-INCA



Total (natural and anthropogenic) aerosol optical depth at 550nm (decadal average) for 1850 and 2000.

Probleme dust dans CAM-CHEM??? papier Lamarque indique que c'est

Global burden for anthropogenically-perturbed aerosols

		1850	2000
Sulfate			
	Burden (mg(SO_4)/m^2)	1.55	3.65
		0.86	**3.10**
Black carbon			
	Burden (mg(C)/m^2)	0.09	0.24
		0.09	**0.23**
Organic carbon			
	Burden (mg(C)/m^2)	0.64	1.04
		1.34	**1.87**

CAM-chem simulation
LMDz-INCA simulation
(DMS différent et OH)

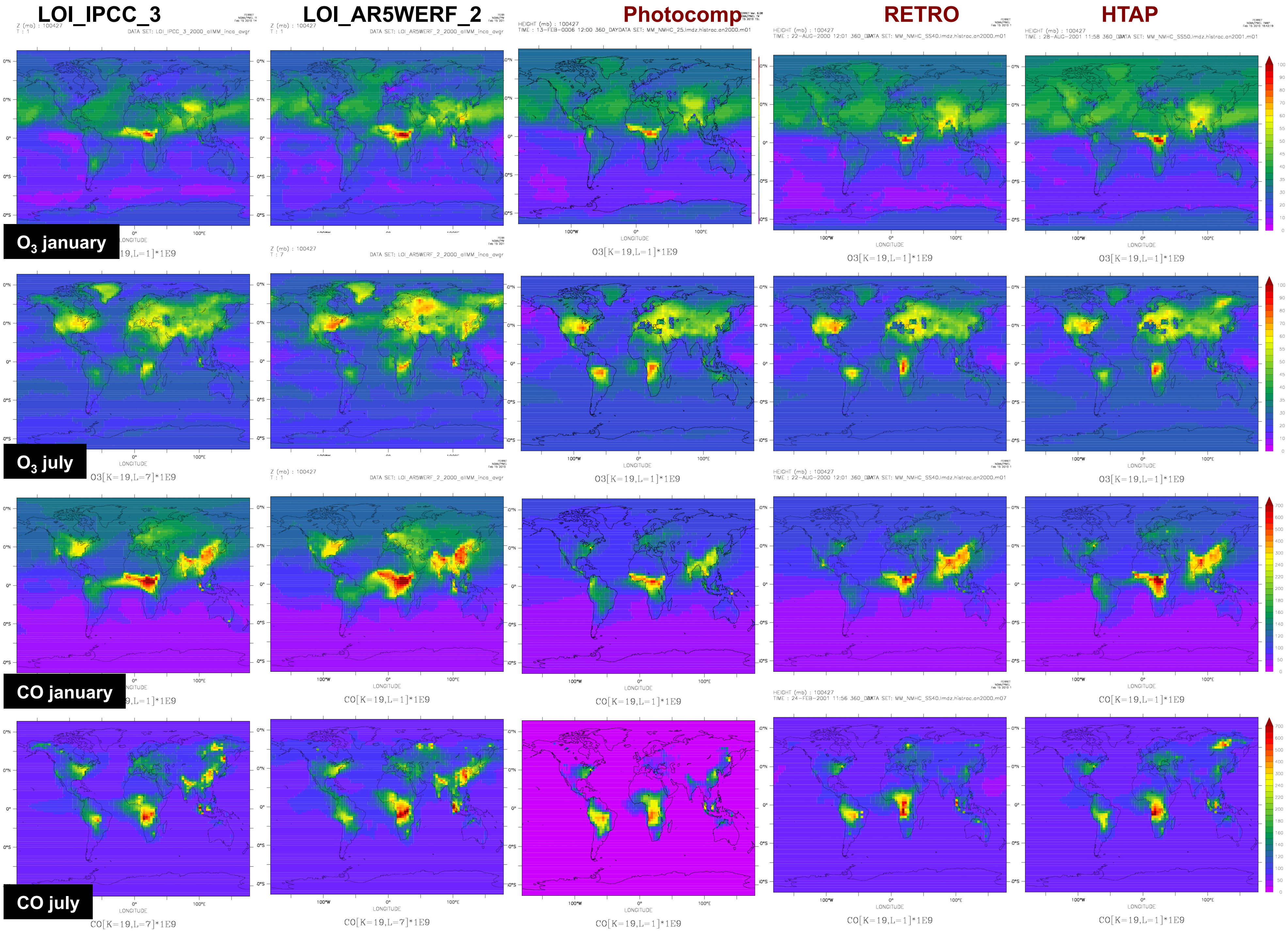
CAM-chem simulation
LMDz-INCA simulation

CAM-chem simulation
LMDz-INCA simulation *(ajout SOA prescrit dans aerocom)*

Quelle quantité de SOA est ajoutée dans nos émissions?? 10Tg/an sur les 50Tg/

Comparaisons pour 2000 avec d'autres runs

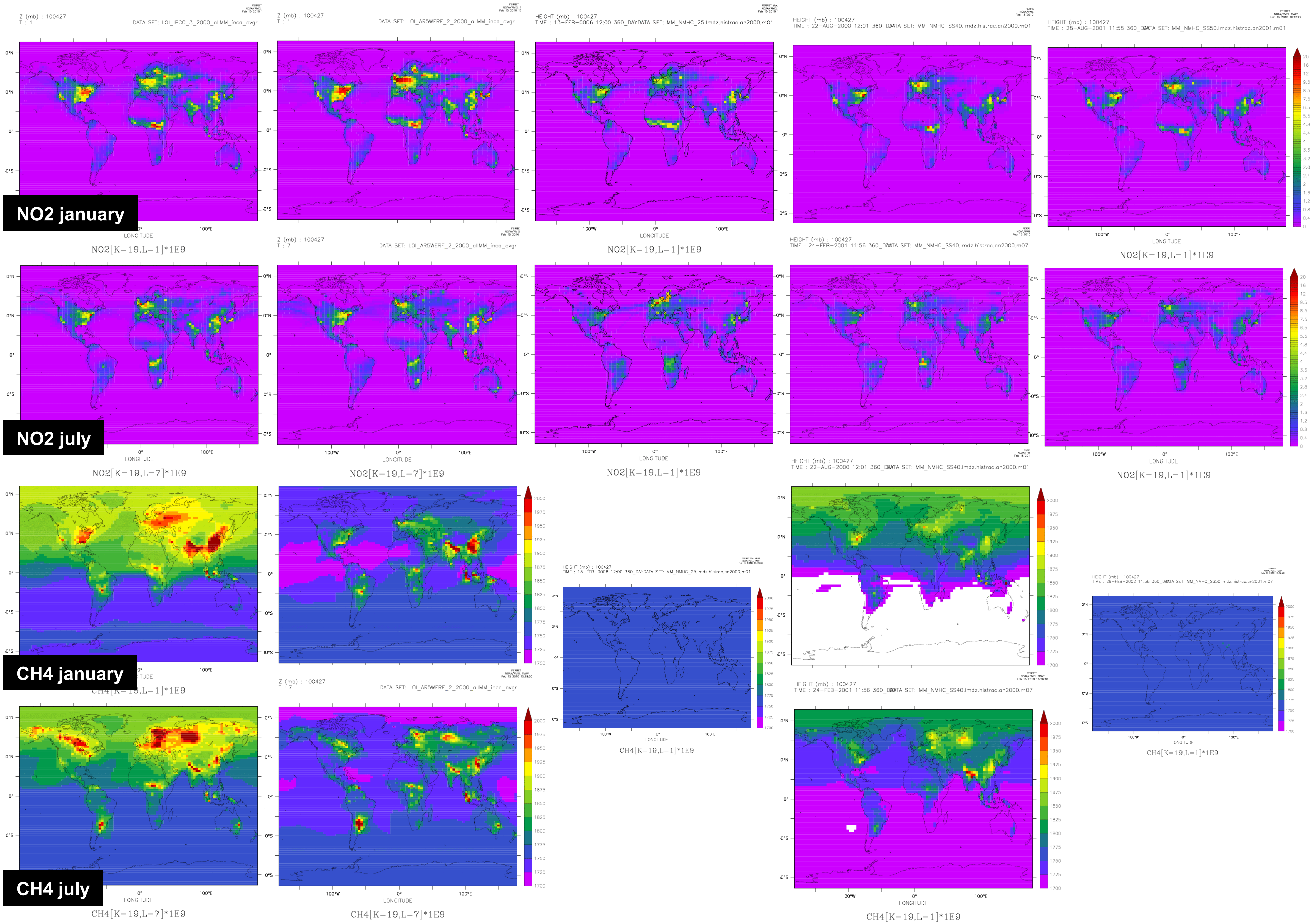
LMDz3 INCA2



Comparaisons en 2000 avec d'autres runs

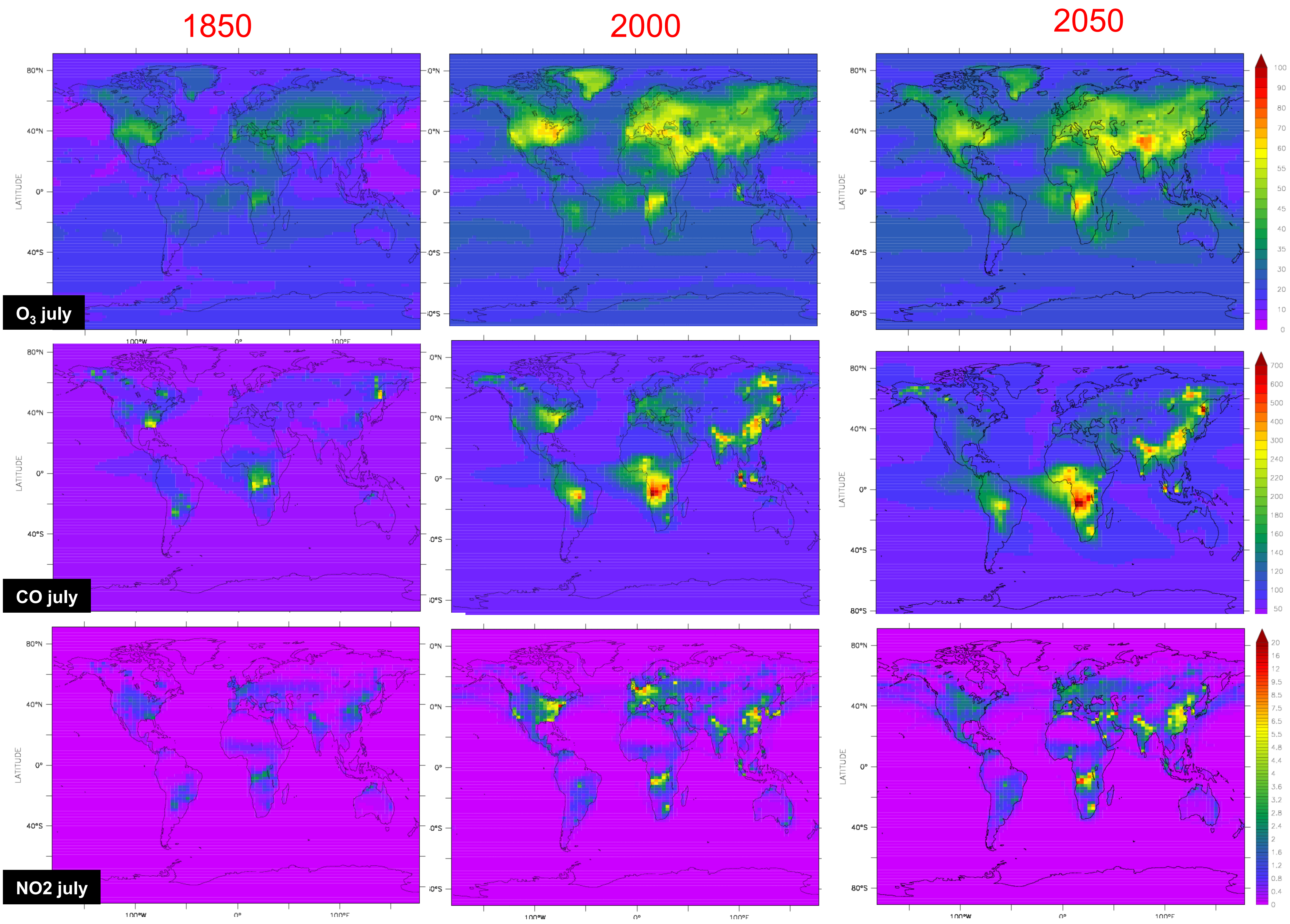
LMDz3 INCA2

LOI_IPCC_3 | **LOI_AR5WERF_2** | **Photocomp** | **RETRO** | **HTAP**

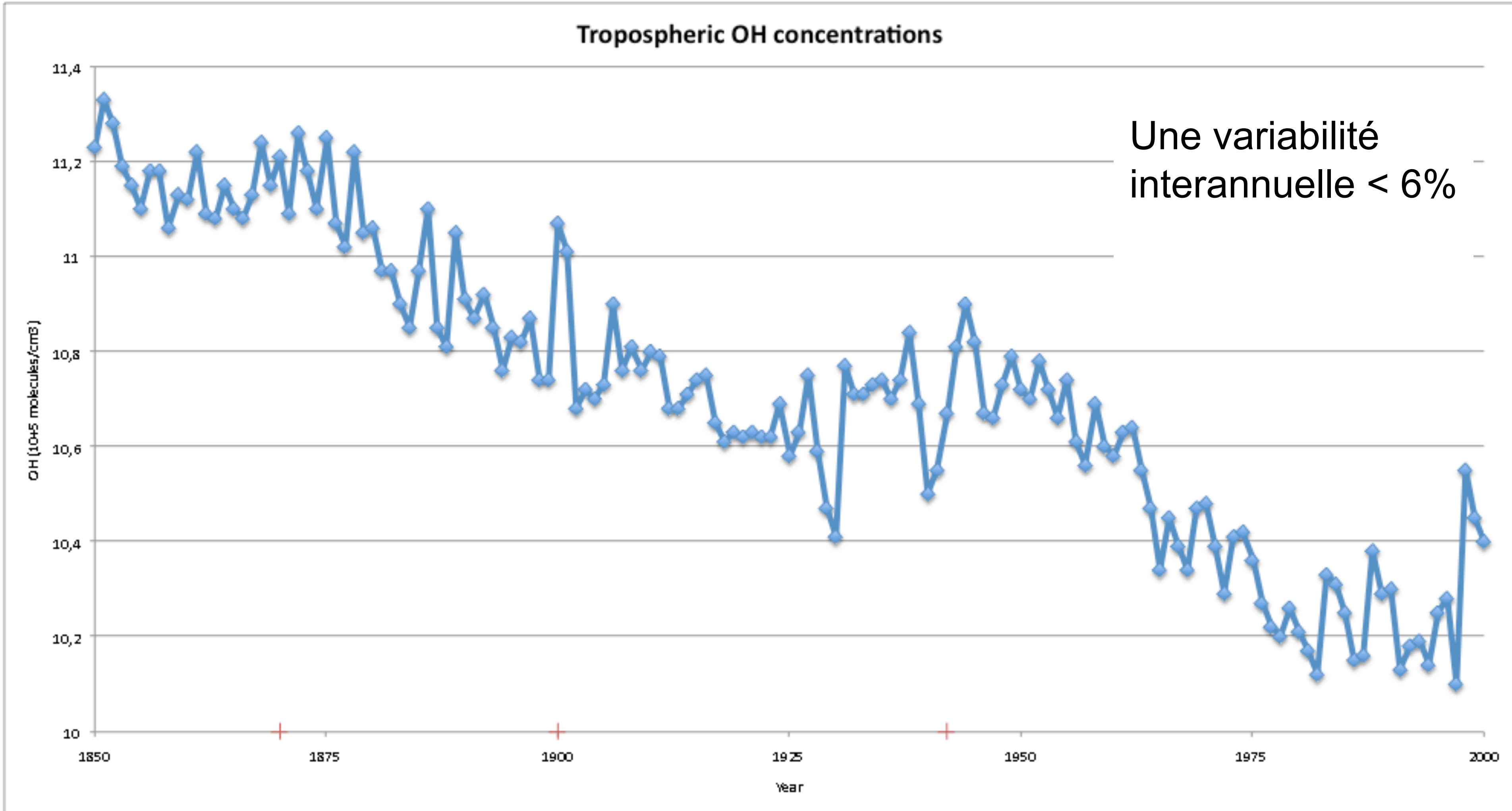


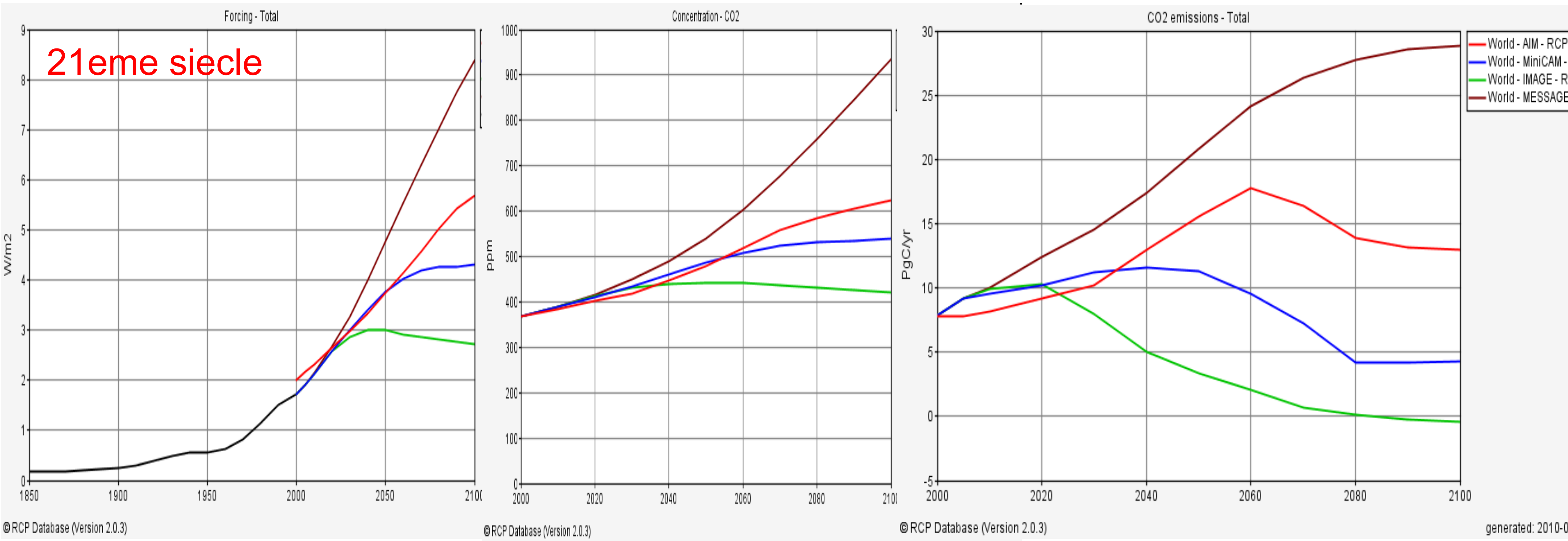
LOI_IPCC_3 puis RCP85

[O3] [CO] [NO2] en surface



Evolution de OH, puits chimique des hydrocarbures, du methane et du monoxyde de carbone





	Description[1]	Publication – IA Model
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m^2 in 2100.	Riahi et al. (2007) – MESSAGE
RCP6	Stabilization without overshoot pathway to 6 W/m^2 at stabilization after 2100	Fujino et al. (2006) and Hijioka et al. (2008) – AIM
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m^2 at stabilization after 2100	Clarke et al. (2007) – MiniCAM
RCP3-PD[2]	Peak in radiative forcing at ~ 3 W/m^2 before 2100 and decline	van Vuuren et al. (2006, 2007) – IMAGE

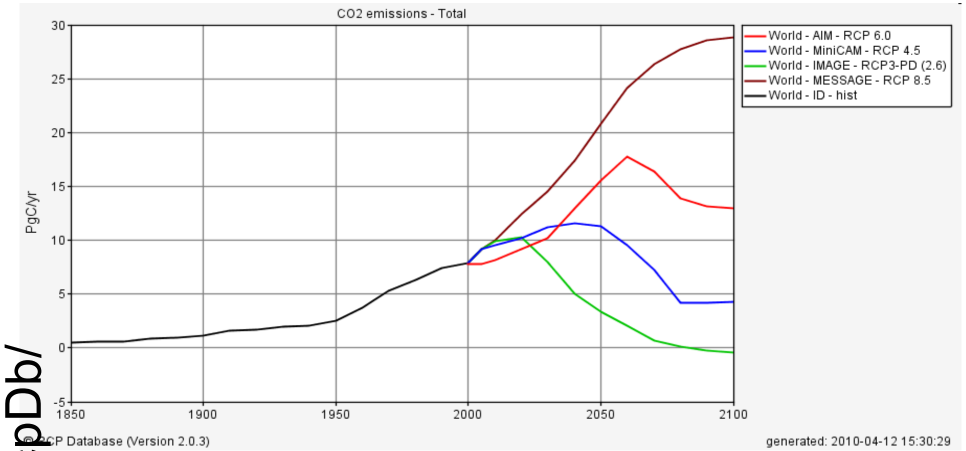
Notes:

[1] Approximate radiative forcing levels were defined as ±5% of the stated level in W/m^2 relative to pre-industrial levels Radiative forcing values include the net effect of all anthropogenic GHGs and other forcing agents.

[2] PD = peak and decline.

D'après http://www.iiasa.ac.at/web-apps/tnt/RcpDb/

D'après http://www.iiasa.ac.at/web-apps/tnt/RcpDb/

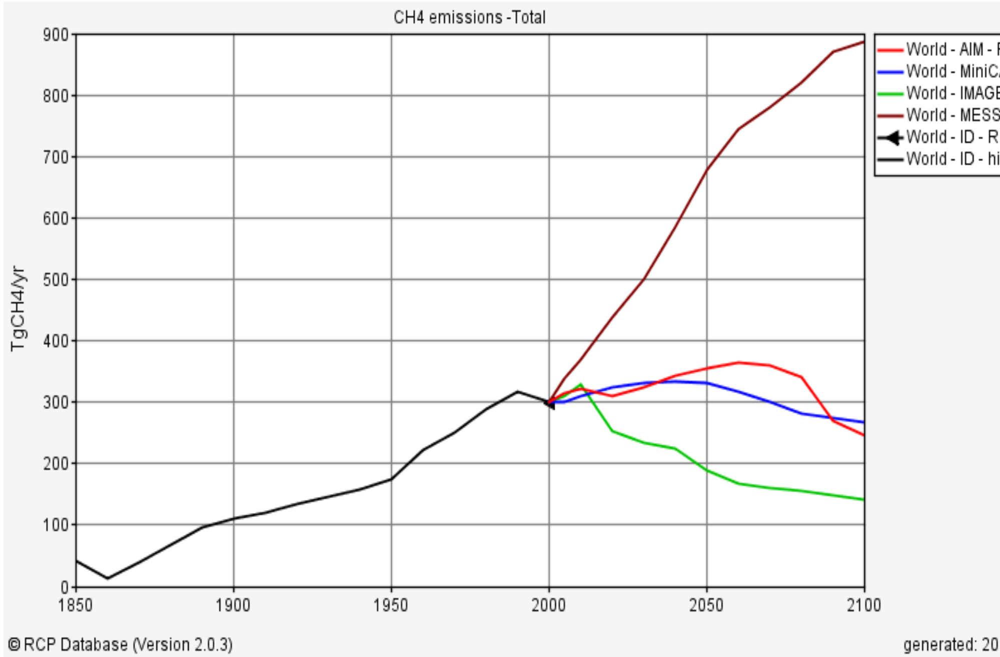


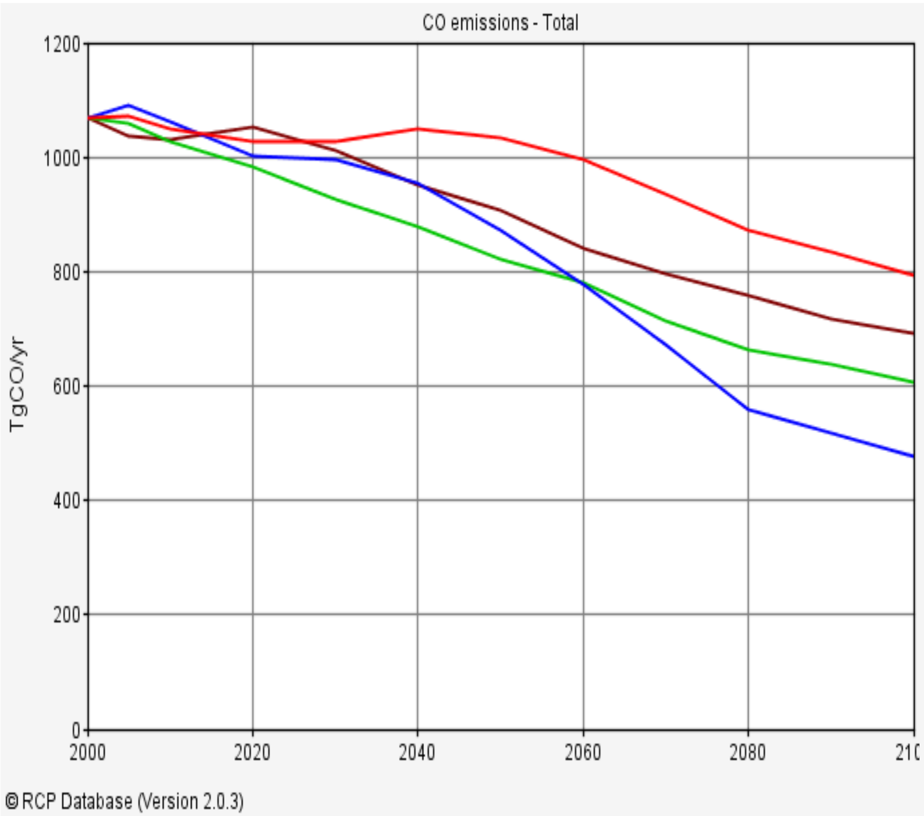
RCP85

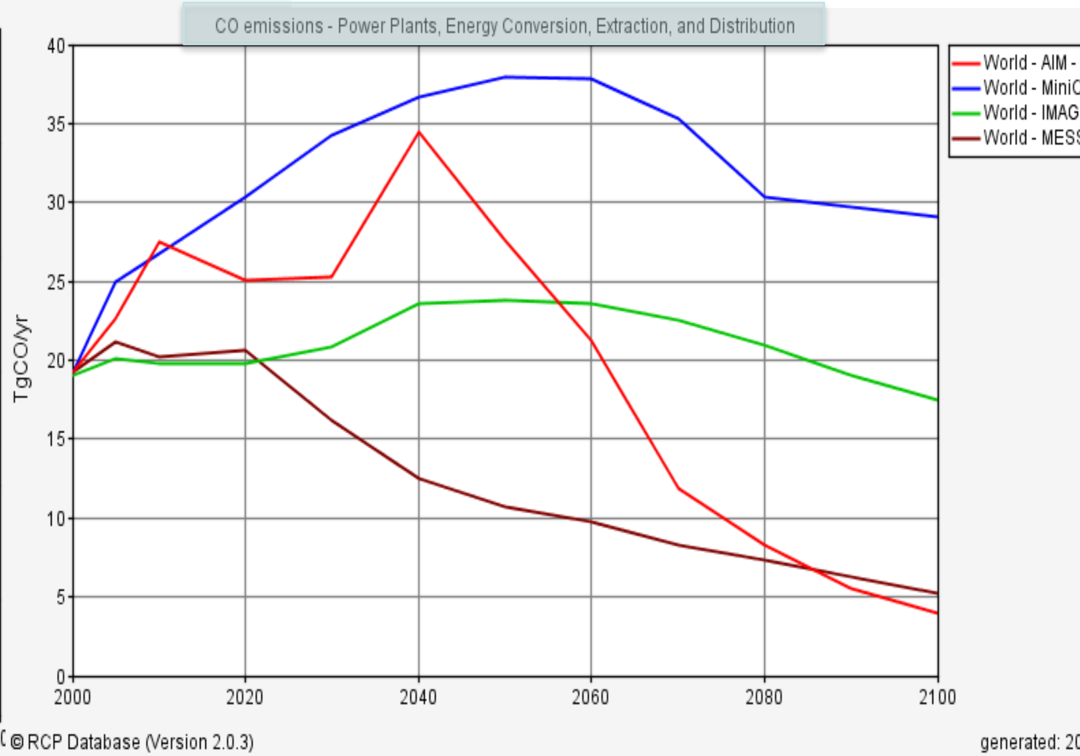
RCP45

RCP6

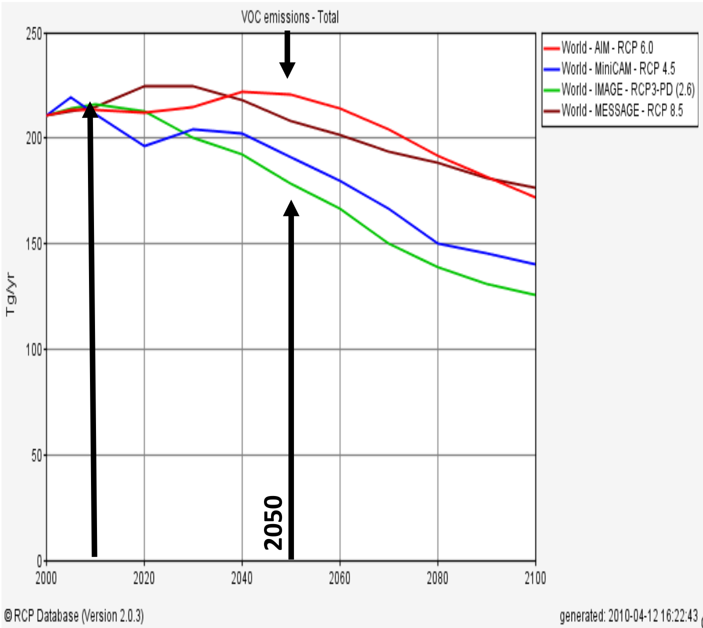
RCP3

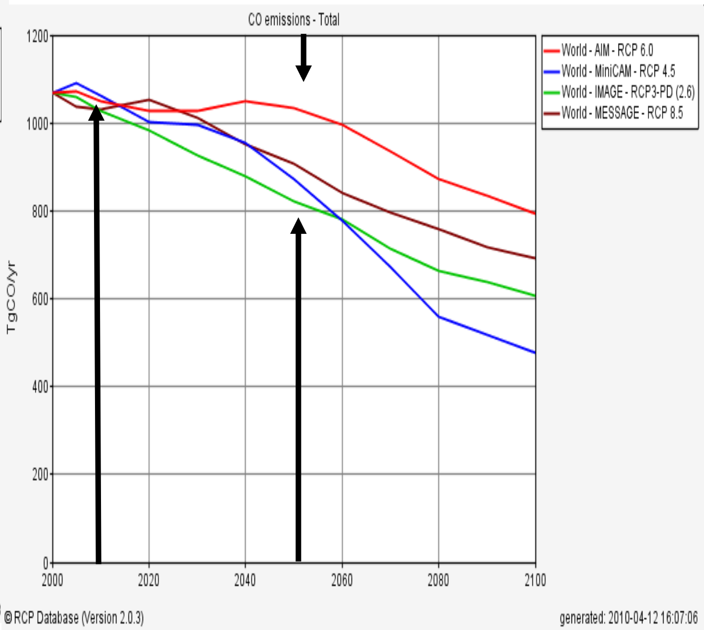


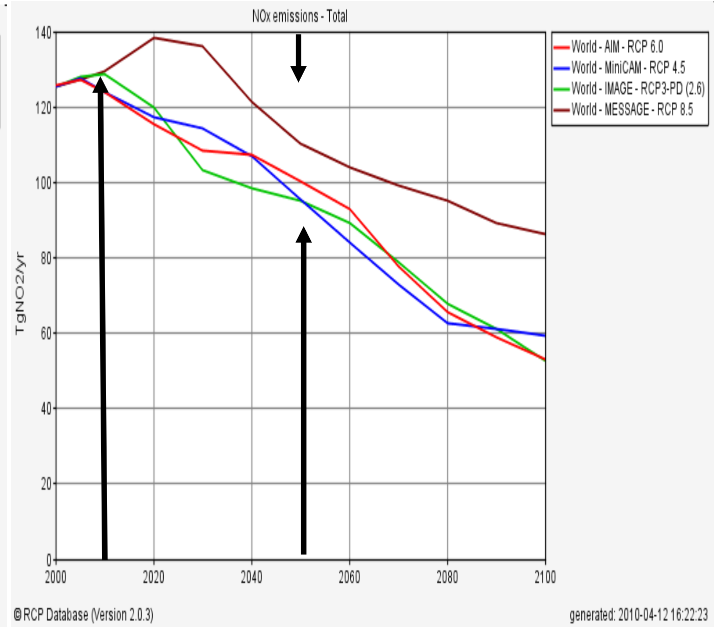




Evolution des Emissions mondiales des précurseurs d’ozone et d’aérosols pour les différents scénarios RCP

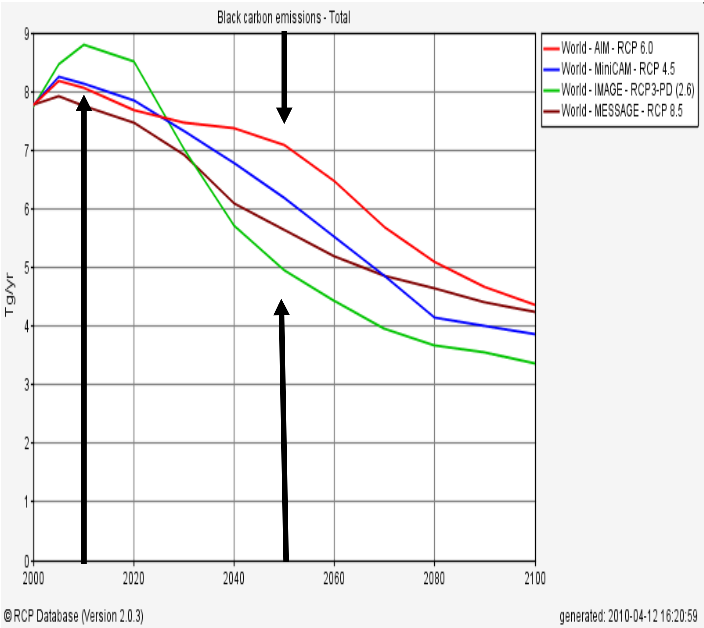


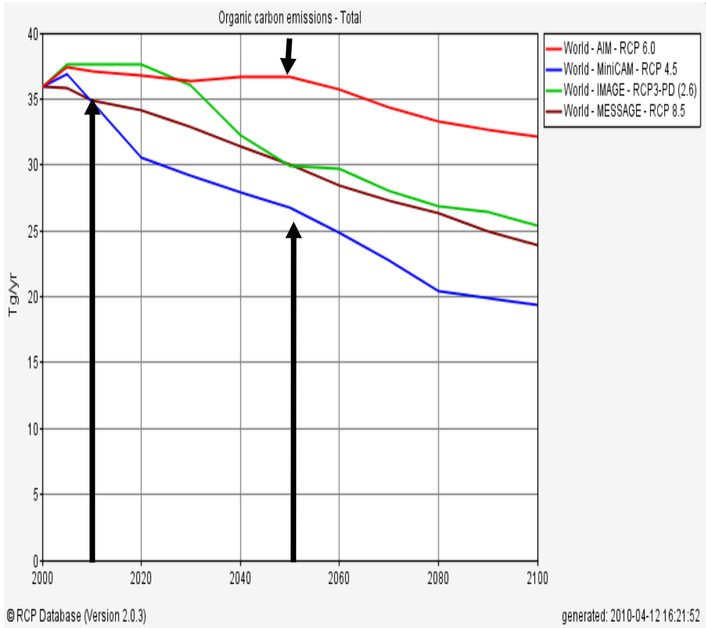


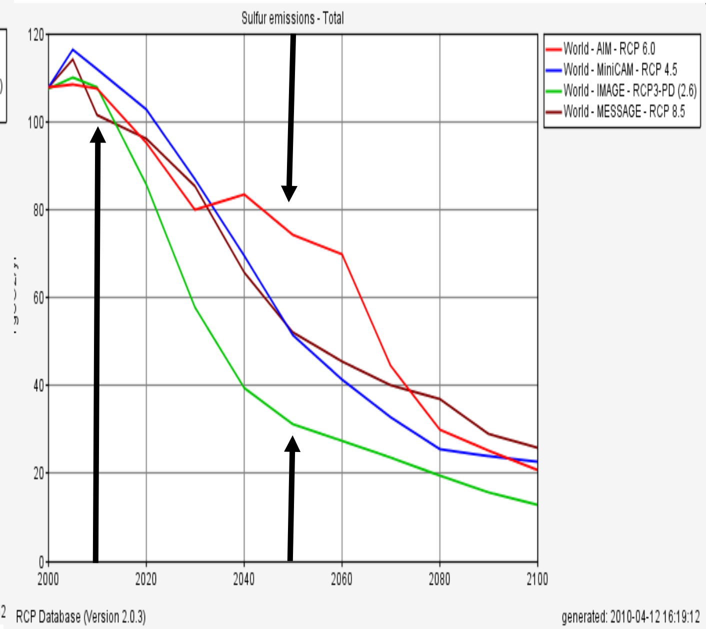


RCP85 | RCP6 | RCP45 | RCP3

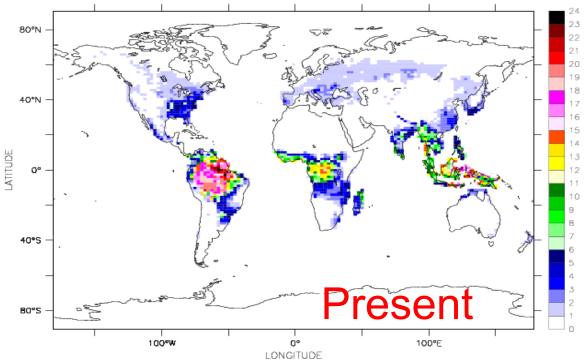
RCP6 : développement en Asie tres different
OC et BC diff inter scenario <20%
SO2 diff interscenario env. 50%





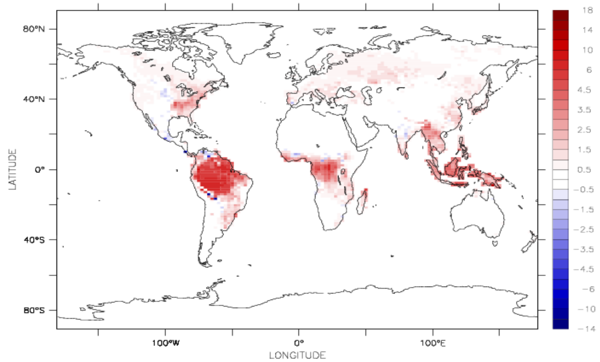


Biogenic emissions of isoprene (mgC/m²/h) ➔ [calculés avec ORCHIDEE]



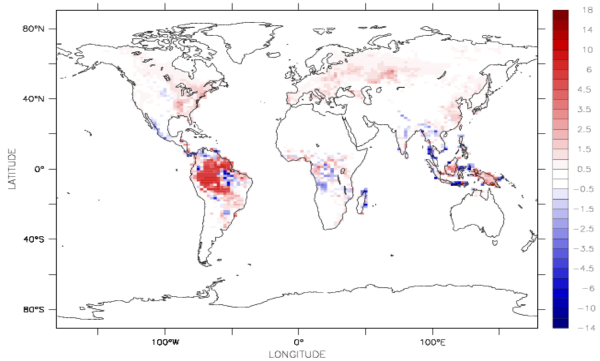
Effet des changements futurs (2050) sur les flux d'isoprène

2050 CLIMCO2



+33%

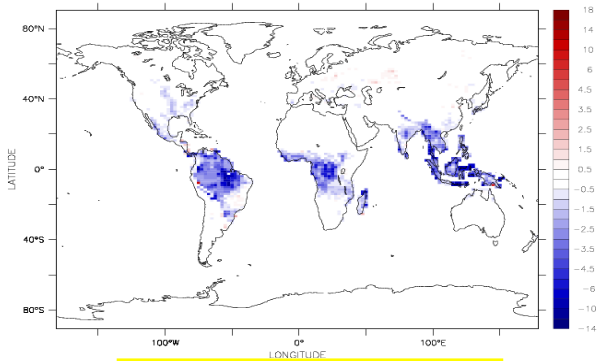
2050 CLIMCO2LU



+16%

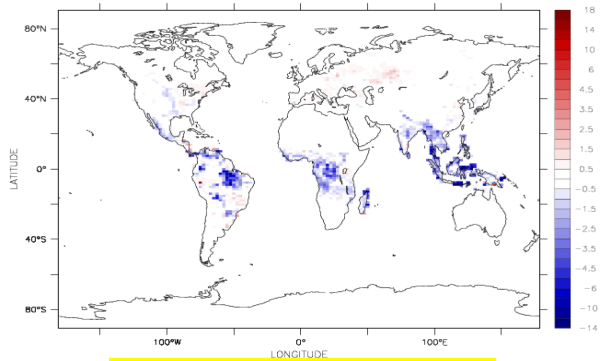
CO_2 inhibition effect (Possell et al. 2005 & Wilkinson et al. 2009)

2050 CLIMCO2LU + Poss



-25%

2050 CLIMCO2LU + Wilk



-10%

Travail en cours, Lathière et al.

Modélisation des interactions chimie-aérosols / climat pour l'AR5

Où en est-on?

1850-2000 fini
RCP8.5 en cours 2000-2095 (~2 ans/jour sur la SX9)

3 autres rcp : snapshots de 10 ans autour de 2050 et 2100

Runs futurs à refaire avec climat RCP cmip5 et/ou couplé aérosol/climat

Distribution? IPSL + MeteoFrance + AC&C MIP

Validation? AC&C MIP + outils AEROCOM

Au delà des objectifs de CMIP5?

- Regionalisation des impacts climat + chimie sur qualité de l'air en Europe *PRIMEQUAL-SALUTAIR*
- Etude des changements d'albedo lié au depot dans l'Himalaya *ANR-PAPRIKA*
- discrimination des effets des différentes sources des aérosols sur snapshots *EU COMBINE*
- Couplages chimie-vegetation *LEFE BOTOX*
- Effet chimie NH_3 et nitrates

FIN

Atmospheric Chemistry & Climate Model Intercomparison Project (ACC-MIP)

Groups that have agreed to participate thus far:
CCC (Canada), CCSR (Japan), DLR (Germany), ECHAM (Germany), Hadley Centre/Met Office (UK), LSCE/IPSL (France), NASA GISS (USA), NCAR (USA), NOAA GFDL (USA), MRI (Japan)

Experiment specifications

ACCMIP_1: Timeslice runs complementing CMIP5

Timeslice runs including detailed chemistry diagnostics and separating aerosol indirect effects. Each run 4 years with **prescribed SSTs taken from AR5 runs** (SSTs should ideally be decadal means around given years), 2-month initialization suggested.

8 historical times

5 future times

Total of 38 simulations, so ~158 model years (years not marked with I are second priority except 2000, as are year 2000 emissions/future SST runs, leaving those out gives 27 simulations).

For 2050 and 2100 (RCP 8.5), additional run with that year's SSTs/GHGs but 2000 emissions.

Historical simulations

Emissions/Configuration	1850	1890	1910	1930	1950	1970	1990	2000
Historical/with AIE	A	B	A	B	A	B	A	A
Historical/no AIE	A		A		A			A

Future simulations

Emissions/Configuration	2010	2030	2050	2070	2100
RCP 2.6/with AIE	A	B	A	B	A
RCP 2.6/no AIE	A		A		A
RCP 4.5/with AIE	A	B	A	B	A
RCP 4.5/no AIE	A		A		A
RCP 8.5/with AIE	A	B	A	B	A
RCP 8.5/no AIE	A		A		A
Year 2000/with AIE, RCP 8.5 SSTs/GHGs			B		B

A=required, B=second priority, blank=not requested

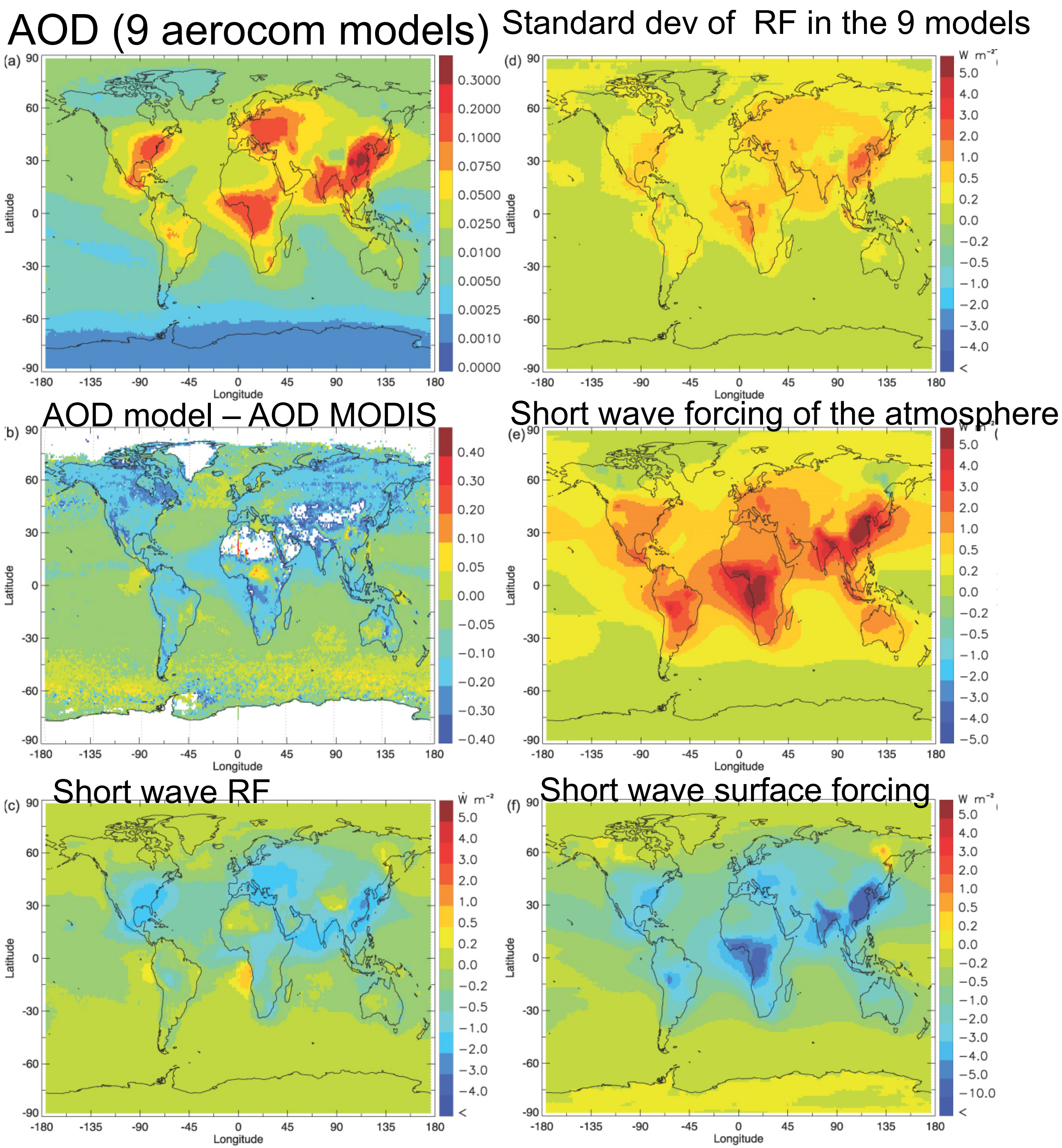
ACCMIP_2: Emission sensitivity studies

Run at year 2050 (SSTs from #1), 1 year runs (+2-month initialization), model's own distribution of given emission scaled uniformly:

2.1: +100 Tg isoprene
2.3 +20% biomass burning (all species)
2.4: +50 Tg methane (3 year run in this case, only applicable for models with sources/sinks of methane rather than prescribed)
2.5: +2 Tg N/yr lightning NOx

We assume the effects of varying dust, sea-salt and DMS emissions can be adequately accounted for with emission and removal diagnostics.
[total model years requested is 6.5]

Combined anthropogenic aerosol effect



Moyenne globale de l'effet direct

Simulation de contrôle 2000

Comparaison LMDZ-INCA / AEROCOM

LMDZ-INCA (noir)

AEROCOM (rouge), Schulz et al., 2006; *ACP*.

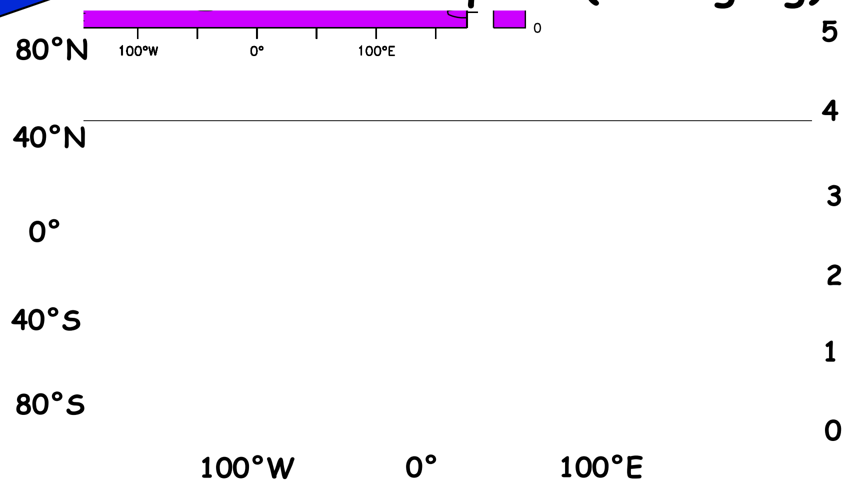
	Optical Depth at 550nm x100	Direct Radiative Forcing (W/m^2)
SO4	2.6 1.9 ± 0.9	-0.32 -0.35 ± 0.15
POM	1.3 0.8 ± 0.5	-0.12 -0.14 ± 0.05
BC	0.3 0.22 ± 0.12	+ 0.38 0.25 ± 0.08

SO4 et POM ⇒ LMDZ-INCA dans la gamme AEROCOM

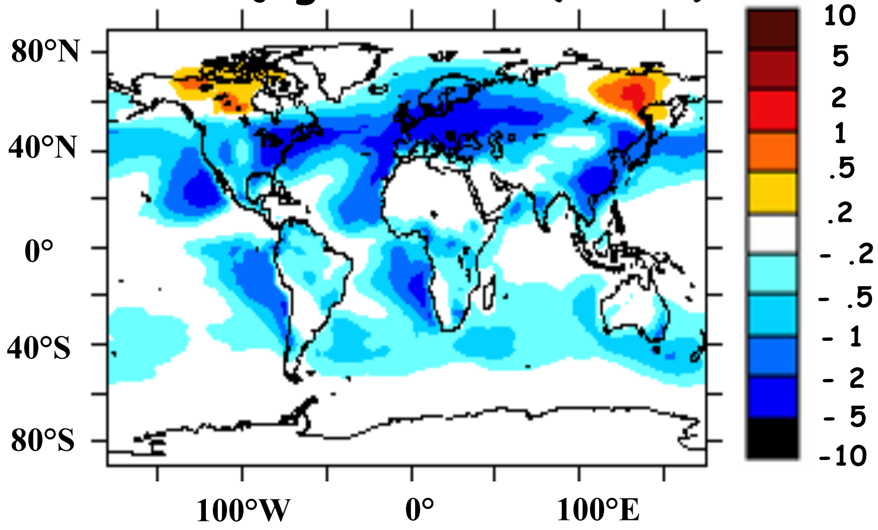
BC ⇒ surestimation du FR

Estimation du 1er effet indirect

contenu en eau liquide (10^5 kg/kg):

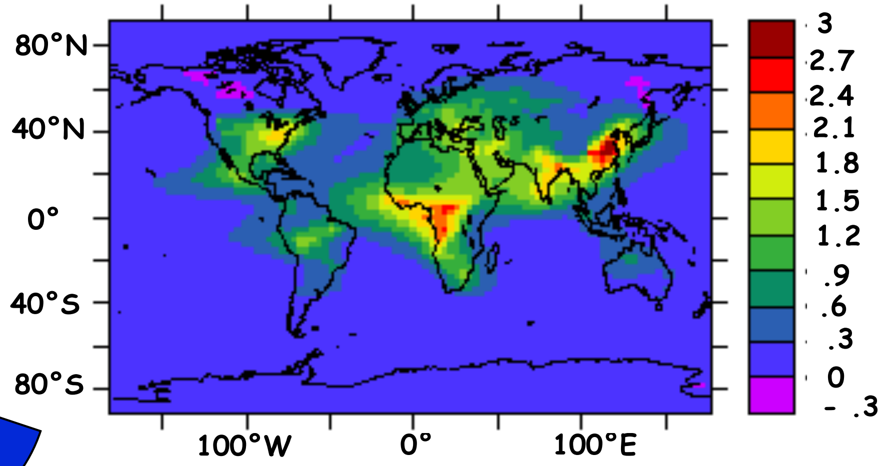


Forçage radiatif (W/m²)



Moyenne globale = - 0.46 W/m²

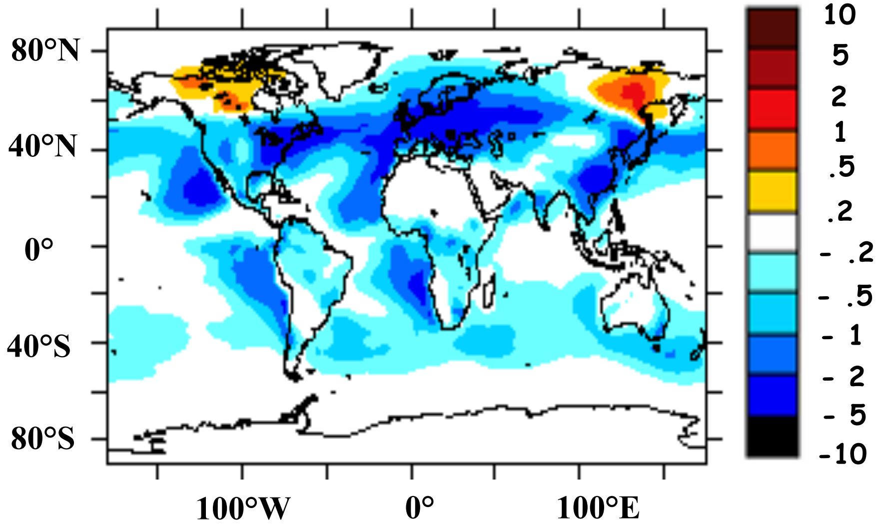
IPCC AR4: - 0.7 [-1.8 to -0.3] W/m²



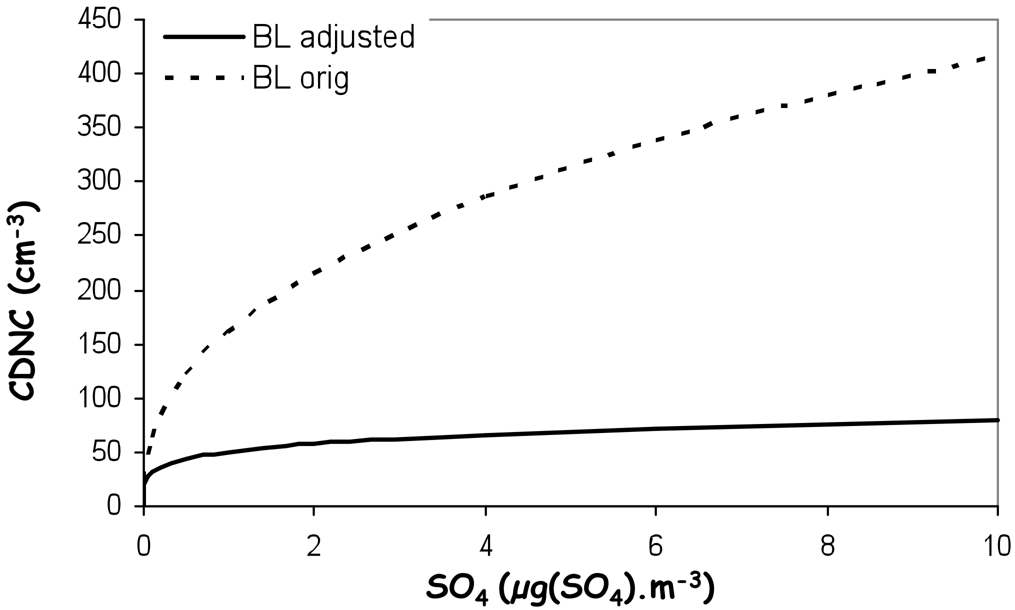
Différence de concentration d'aérosols 2000 -1750 (μg/m³)

Non linéarité du 1er effet indirect

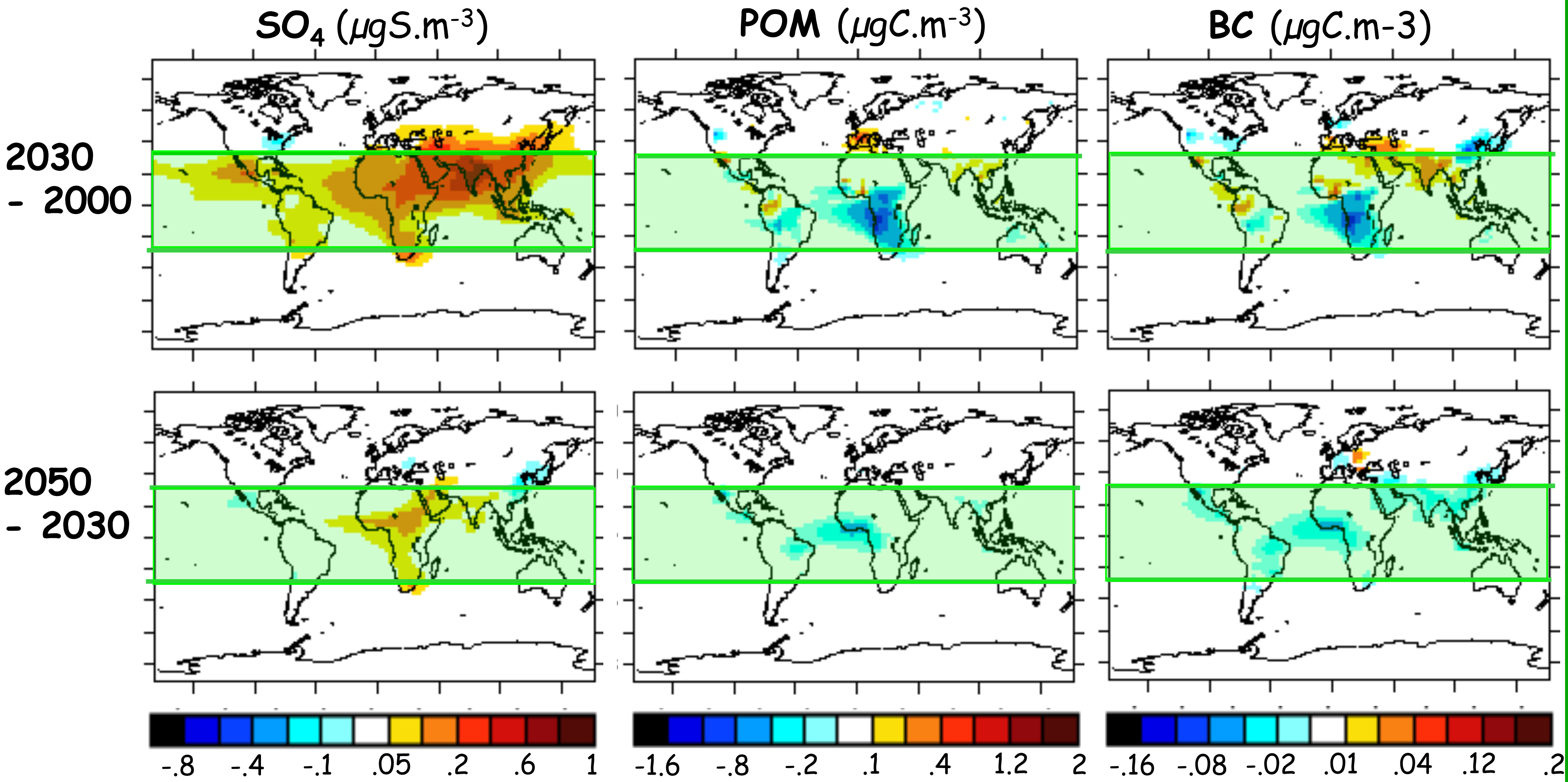
Forçage radiatif (W/m²)



Relation microphysique CDNC = f(m_a)

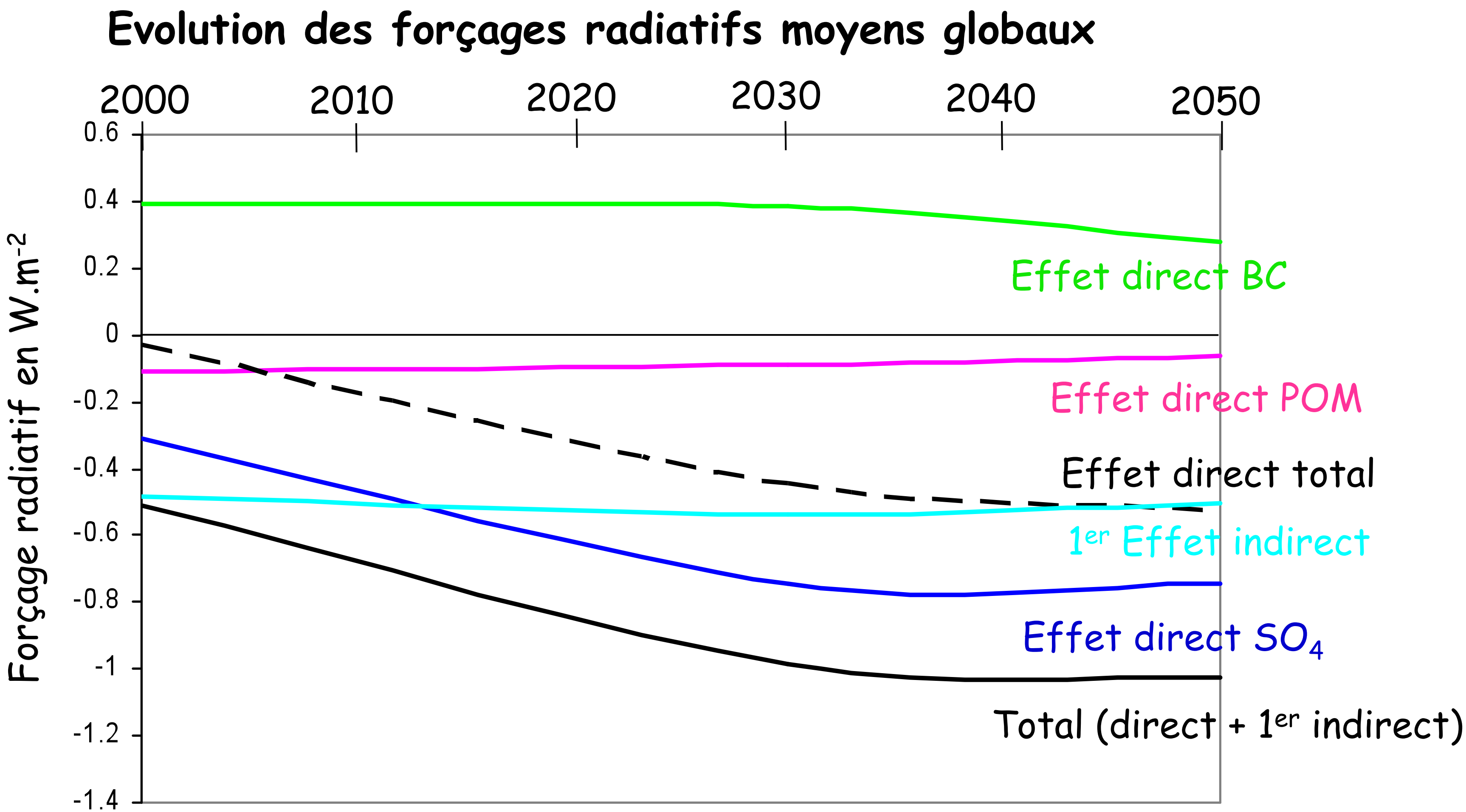


Distribution régionale du changement de concentrations en particules anthropiques



Régions tropicales fortement affectées

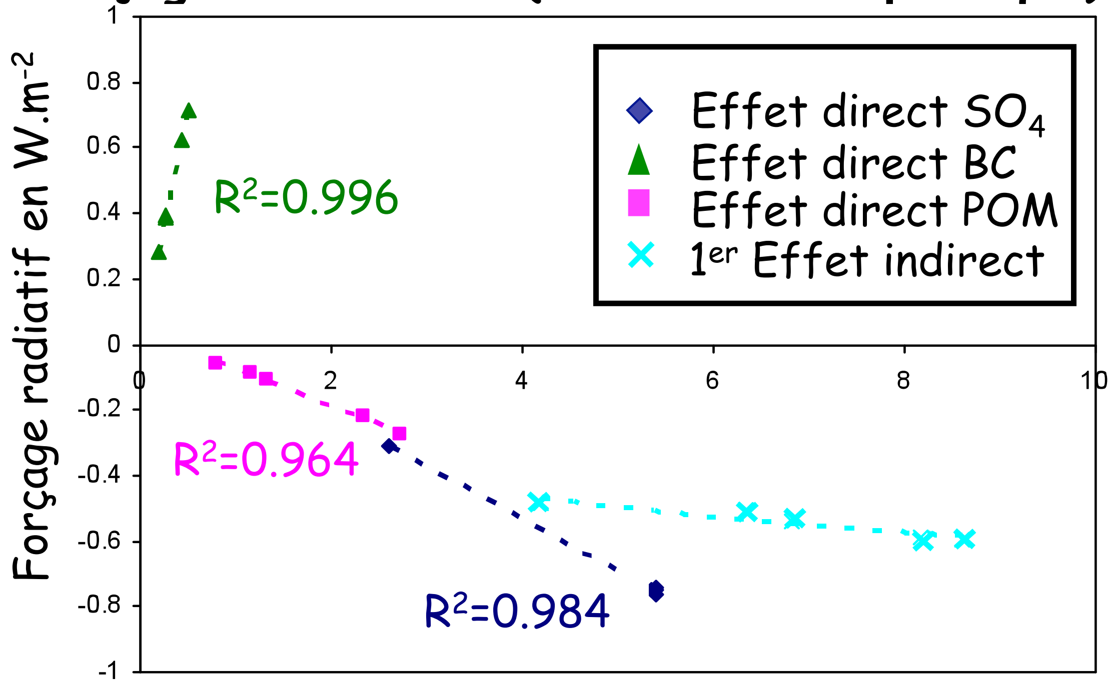
Evolution du forçage radiatif 2000-2050:



$\Delta FR_{total} \sim \Delta FR_{SO4}$ → **FAUX régionalement**

Corrélation entre forçages radiatifs et contenu atmosphérique

Forçage radiatif = f(contenu atmosphérique)



Contenu atmosphérique en TgS, TgC (effet direct) et Tg(C+S) pour le 1er effet indirect

Efficacité Radiative:

$$ER = \frac{FRdirect}{\text{contenu aérosol}}$$

Pente = efficacité radiative

Possibilité d'extrapoler l'effet direct à partir du contenu atmosphèrique

Pour le **1er effet indirect** on a un **effet de saturation**

Quoi de neuf pour les modèles utilisés?

CM3.1
ARPEGE-Climat
ISBA
- biophysique
OPA8
GELATO
TRIP

CM3.3
ARPEGE-Climat v4
-Nouvelle dynamique
-Effet indirect aérosols
-Volcans
-Schéma linéaire ozone
ISBA
-Utilisation des sols
-Conservation revue

Vers CM5
ARPEGE-Climat v5 (physique en cours définition)
SURFEX (surface externalisée)
NEMO3 1°
GELATO
TRIP

+ CERFACS pour projection décennales

2004-2006
AR4

2007-2008
ENSEMBLES

2009-2010
AR5

IPSLCM4

LMDZ3.3 96x71x19
-Sulfates lus
ORCHIDEE
- biophysique
ORCA2 (OPA9)
LIM2

LOOP

IPSL_CM4 +

ORCHIDEE
-carbone
PISCES
-Biogéochimie marine

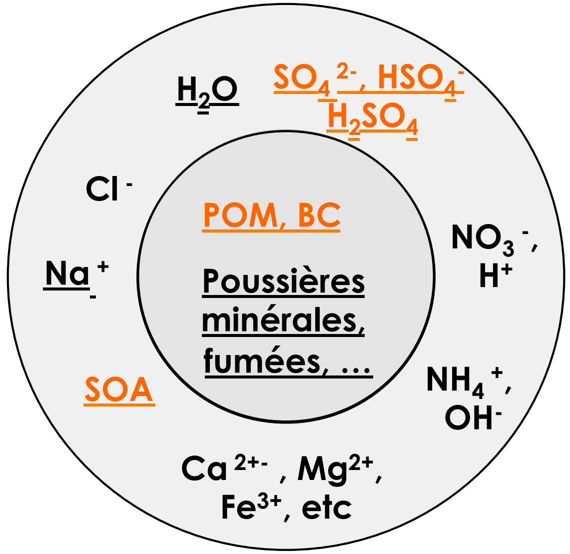
IPSLCM4_v2

LMDZ4 144x143x19
-Sulfates lus
-Volcans
-Cte solaire
ORCHIDEE
-Biophysique
-Utilisation des sols
+ conservation couplages revue

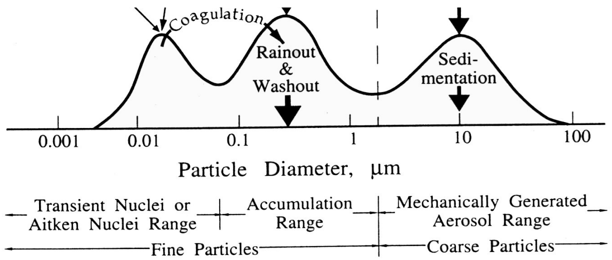
IPSLCM5
LMDZ4 96x95x39 et 144x143x39
-Version //
-Aérosols prescrits par INCA (SO4, BC, POM, poussières, sels de mer)
-Ozone prescrit par Reprobus
-Transport CO2
-ORCHIDEE1.9.4
-Utilisation des sols + carbone
-NEMO 2° tests physique en cours
-LIM2
+ quelques simulations aérosols interactifs
IPSLCM6 : nouvelle physique atmosphérique

Complexité liée à Diversité de taille, sources, composition

Origines diverses



Composition variée



Taille variée

Aérosol Carboné:

POM = Matière Organique Particulaire

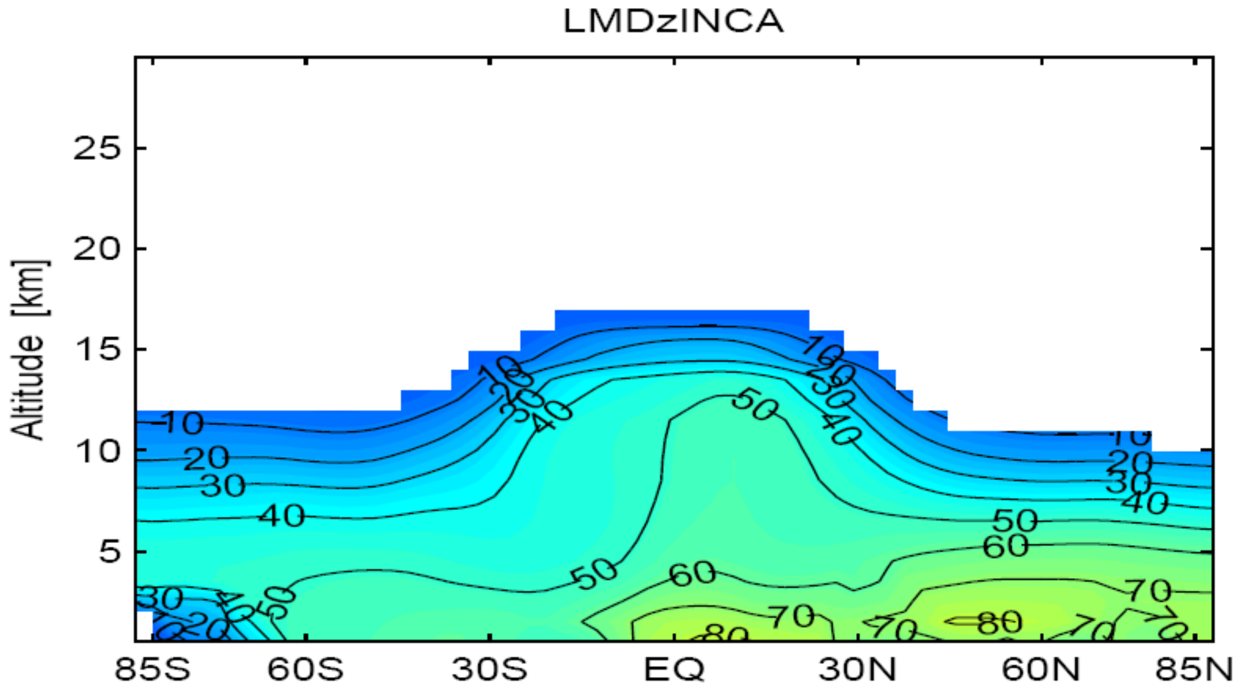
BC = Carbone graphite

SOA = Aérosol Organique Secondaire

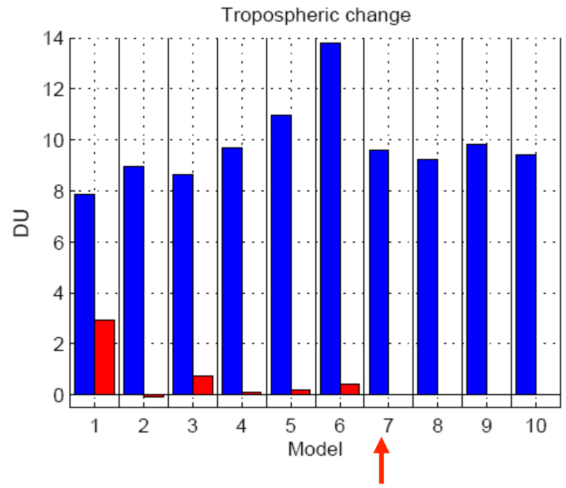
- **Propriétés optiques**
- **Hygroscopicité**

D'après thèse Céline Déandreis

Comparison with ozone changes between 1850 and 2000 investigated by Gauss et al. 2006



Annually averaged zonal-mean ozone change (%) between 1850 and 2000 when taking into account chemical change only



Change (DU) in the annual-mean **(a)** tropospheric ozone column between 1850 and 2000. Blue bars: “2 minus 1c”, reflecting chemical change. Red bars: “1c minus 1”, reflecting climate change only.

	“2 minus 1”		“2 minus 1c/1b”		“2 minus 1a”	
	DU T	DU S	DU T	DU S	DU T	DU S
ULAQ	10.8	−12.6	7.9	−17.5	−2.6	−18.3
DLR_E39C	8.9	−16.1	9.0	−23.5	−2.1	−17.9
NCAR_MACCM	9.4	−12.7	8.6	−20.1		
CHASER	9.8	−14.1	9.7	−14.1	−1.2	−14.8
STOCHEM_HadGEM1	11.1		10.9			
UM_CAM	14.2		13.8			
LMDzINCA			9.6			
STOCHEM_HadAM3			9.2			
UIO_CTM2			9.8	−28.6		
FRSGC_UCI			9.4	−24.4	2.2	−25.4

Annually averaged total ozone change for the differences “2 minus 1” (effect of both chemical and climate change), “2 minus 1c” (effect of chemical change only), and “2 minus 1a” (effect of chemical change in the stratosphere only). For LMDzINCA, UM CAM, and STOCHEM HadAM3 “2 minus 1b” is shown instead of “2 minus 1c”, since these models do not include stratospheric chemistry schemes.

Simulation LOI_IPCC_3 – 1850-1900

OH varie de moins de 3% lors des rattrapages de CH_4