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Institut  
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SAINT-QUENTIN-EN-YVELINES

# Interactions between Climate and atmospheric chemistry

## The gas-phase part of the story

Pr. Philippe BOUSQUET (LSCE, France)

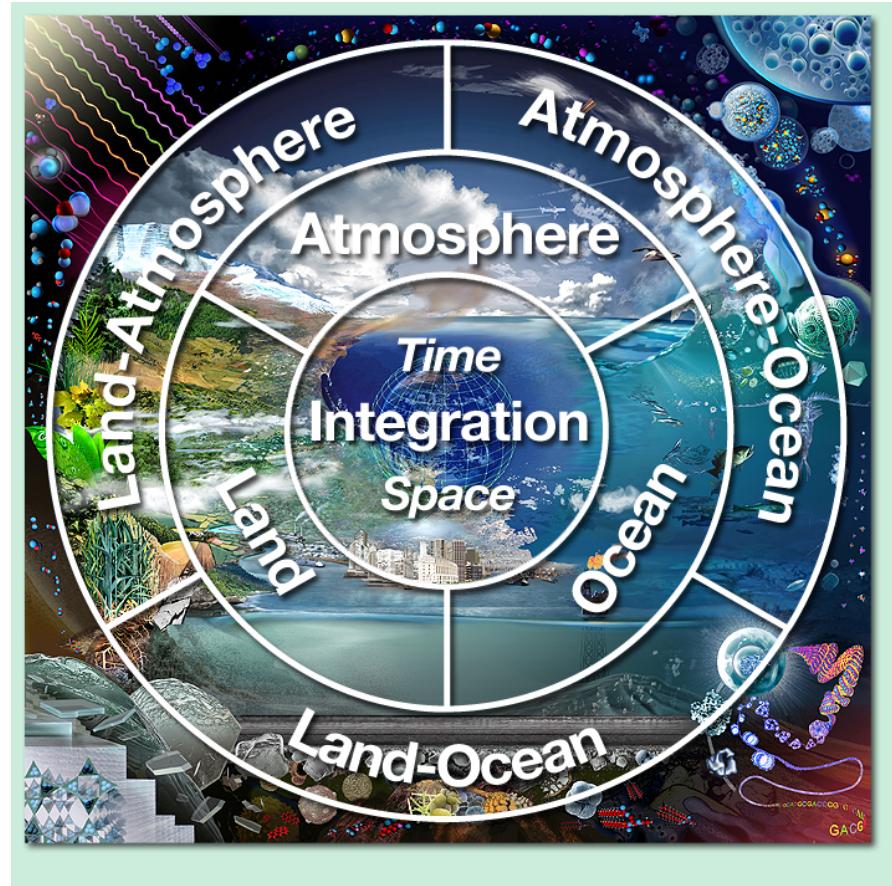
With the contributions from Dr. S. Szopa, Dr. M. Saunois, Dr. D. Hauglustaine



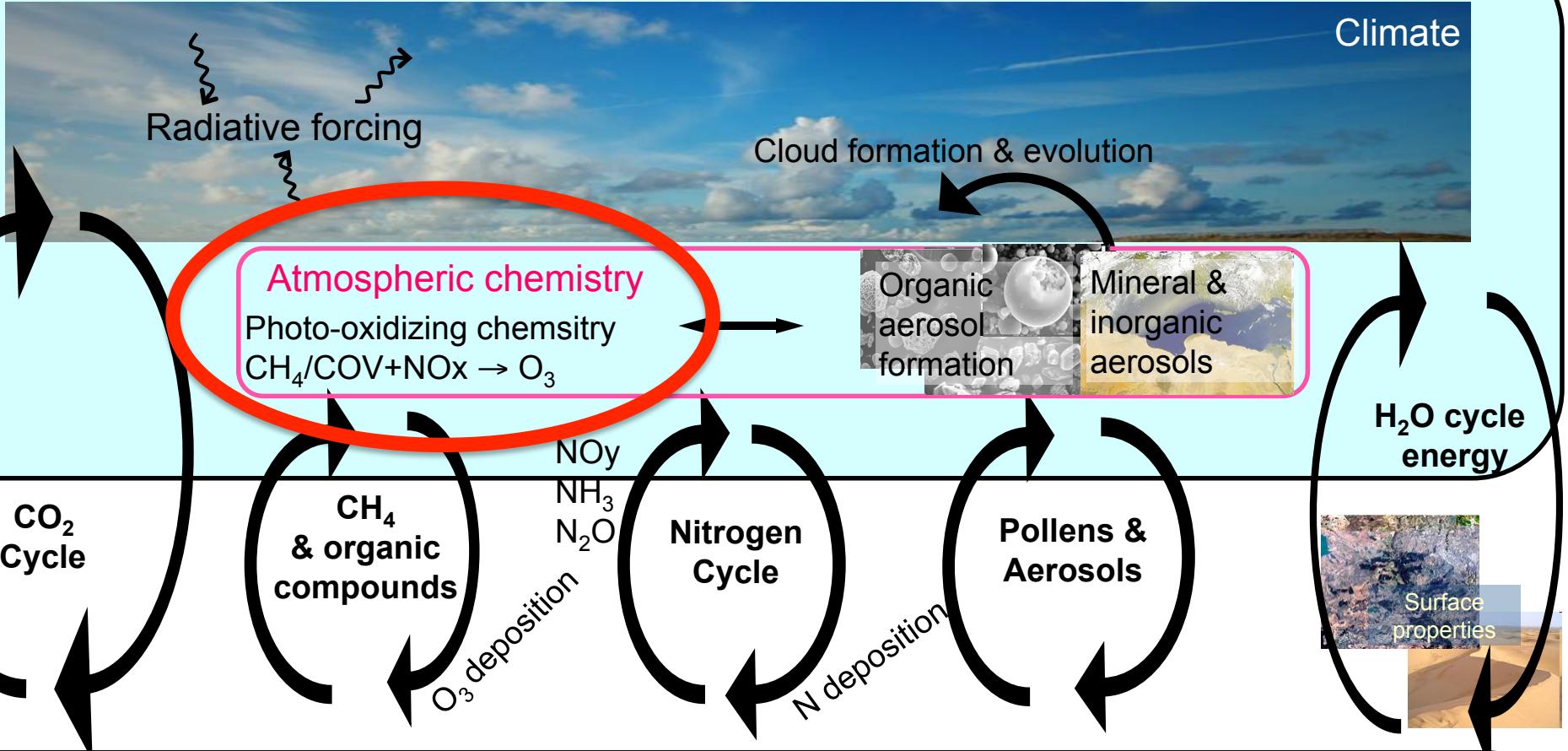
**First Winter School PKU-LSCE on Earth System Science, Feb 13-17 2012**



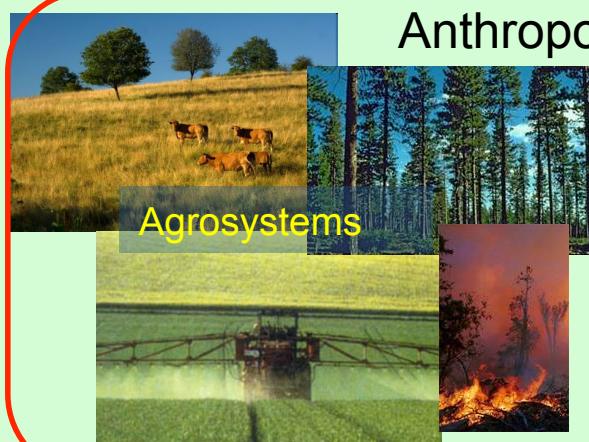
- Earth climate system is a multi component & complex system, with many coupling and feedbacks
- **Atmospheric chemistry** = one part of the Earth Climate system.
- Importance of the links between chemistry and climate



## Atmosphere



## Land biosphere



## Anthropogenic perturbation



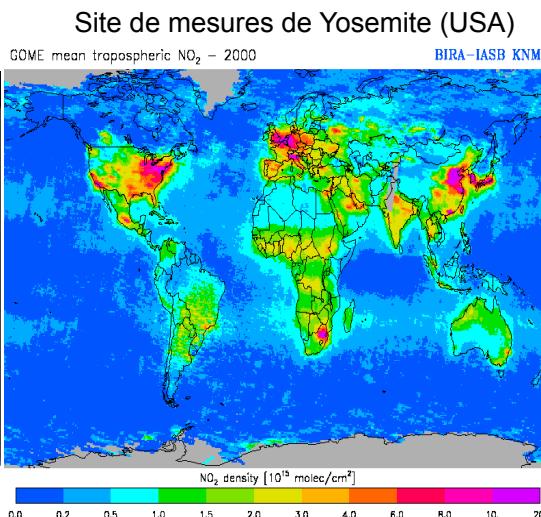
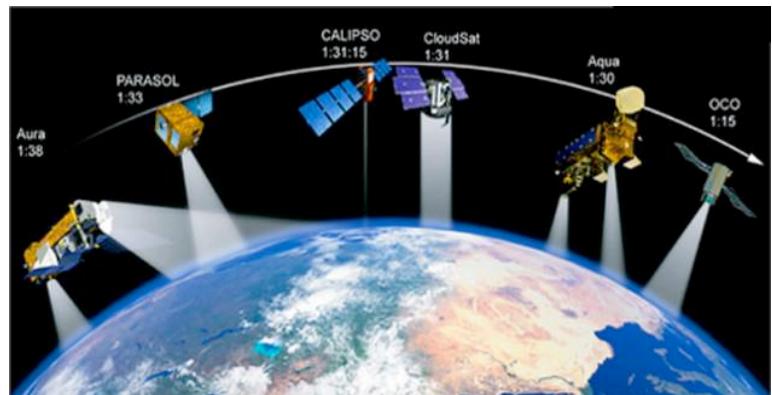
# Tools for understanding atmospheric chemistry



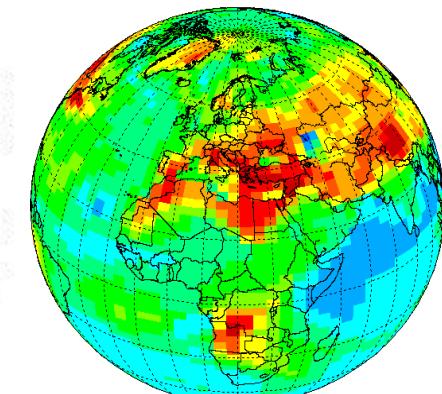
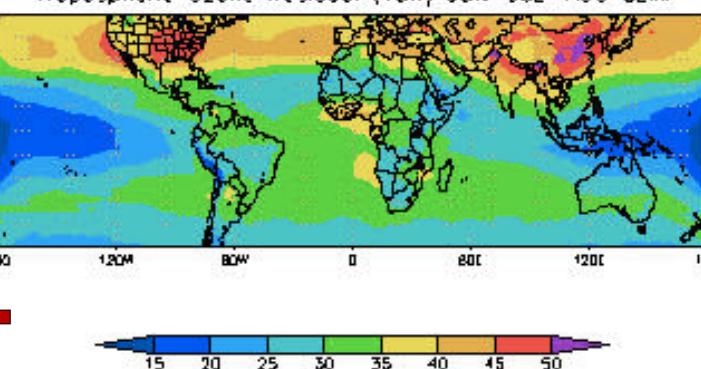
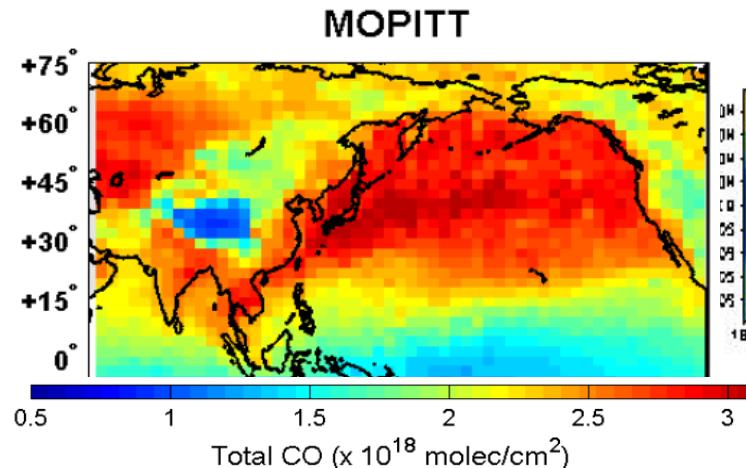
**In-situ measurements**  
**Satellite**  
**Intensive campaigns**  
**Observation simulators**  
**Models**



Lancement de ballon sonde depuis 1966 à Syowa

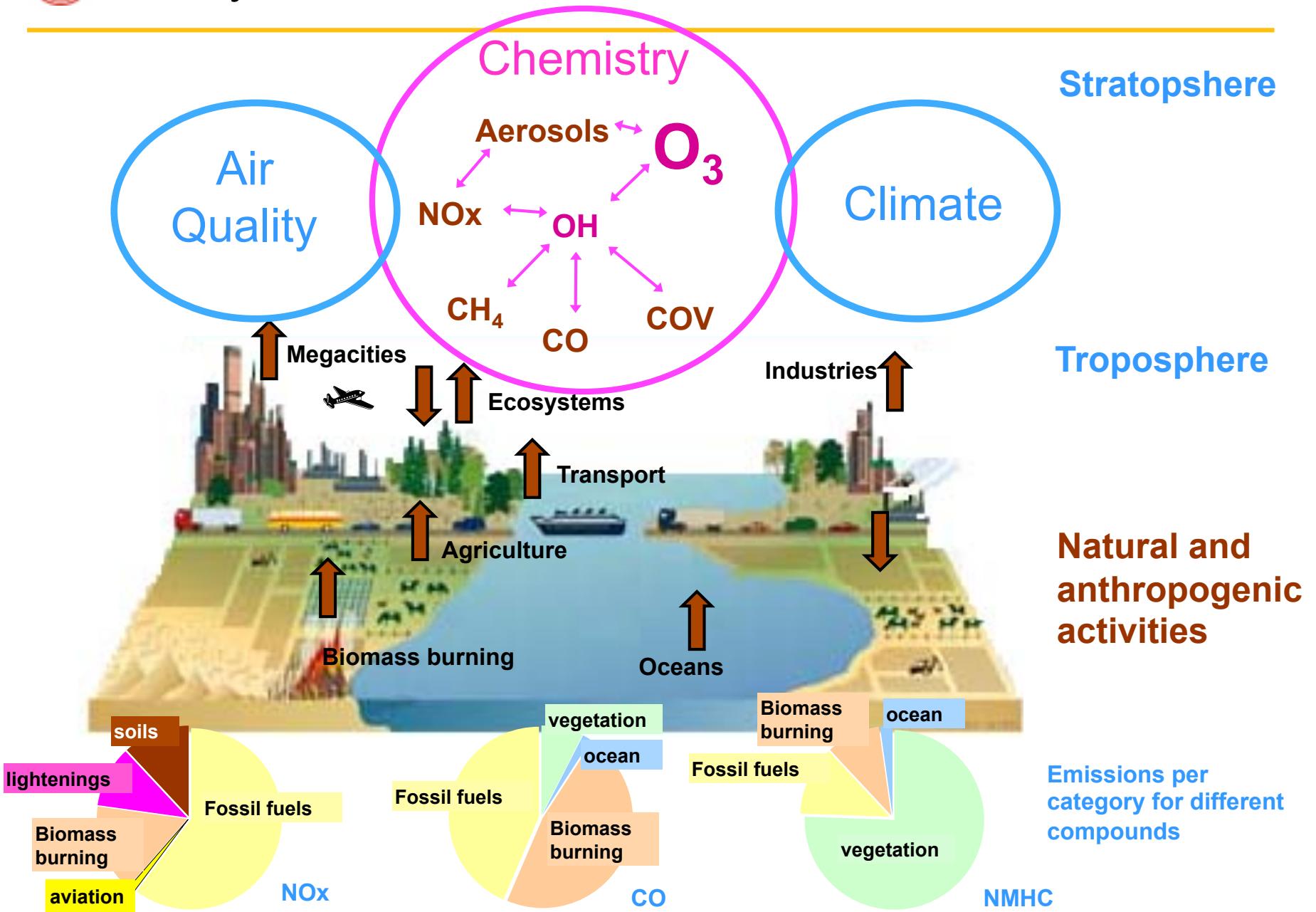


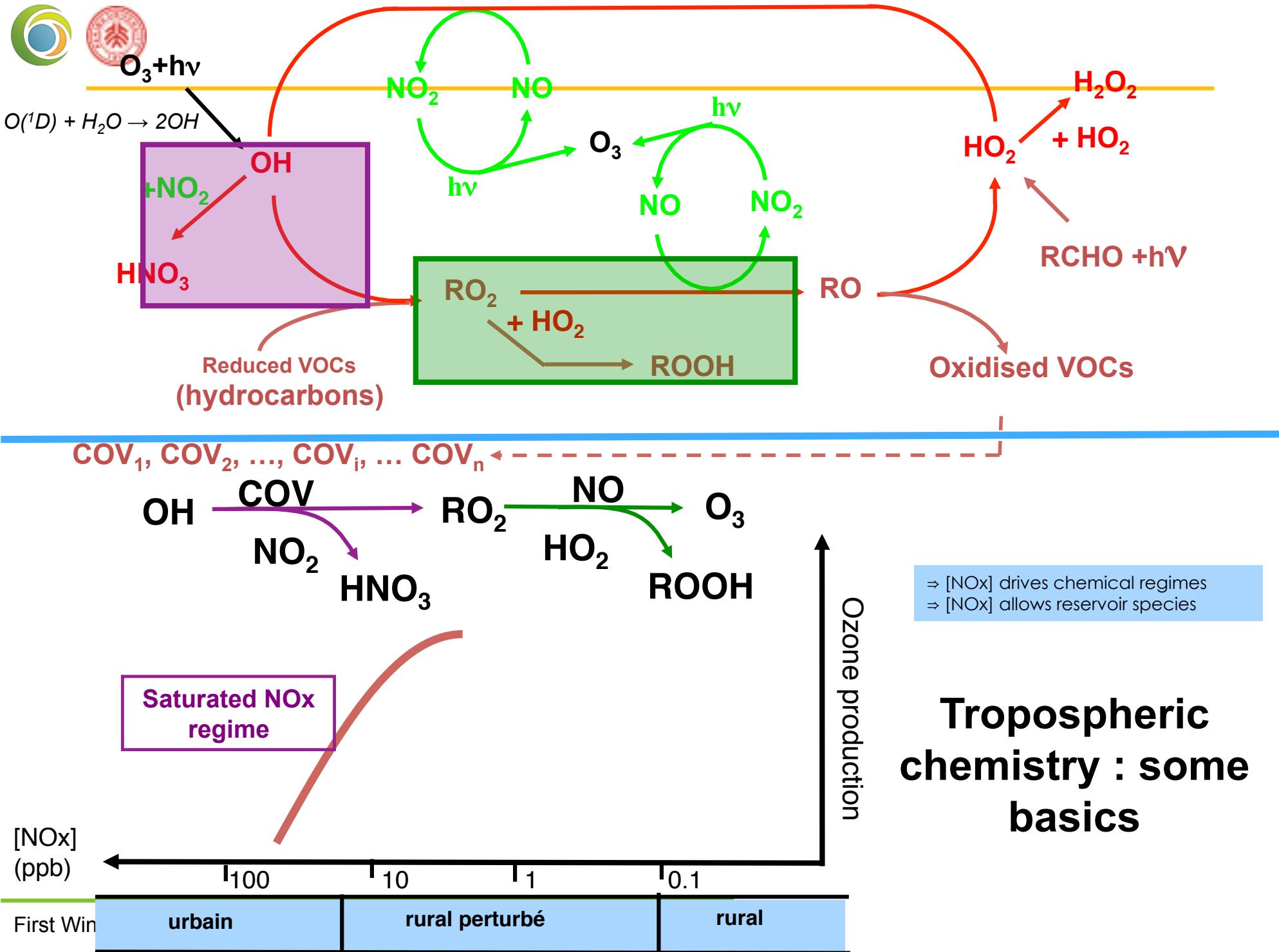
Chambre de simulation





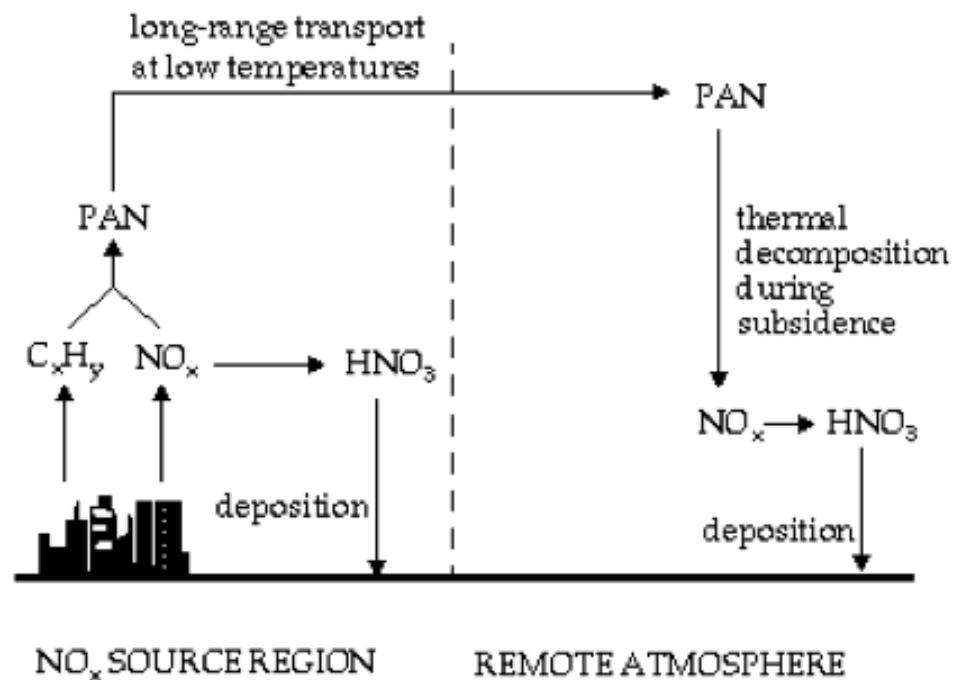
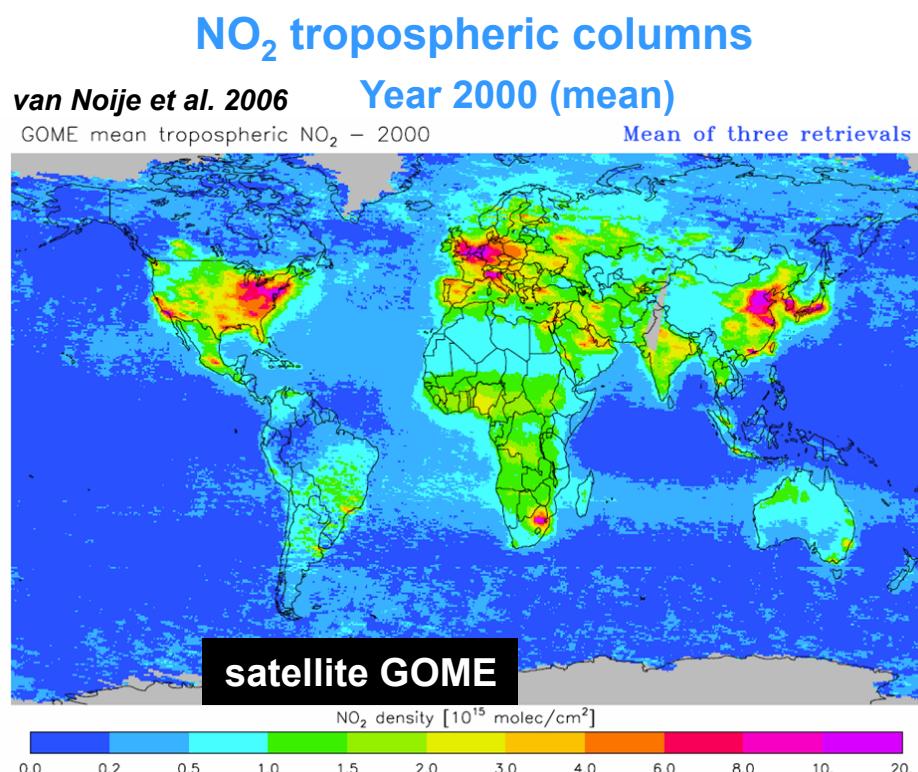
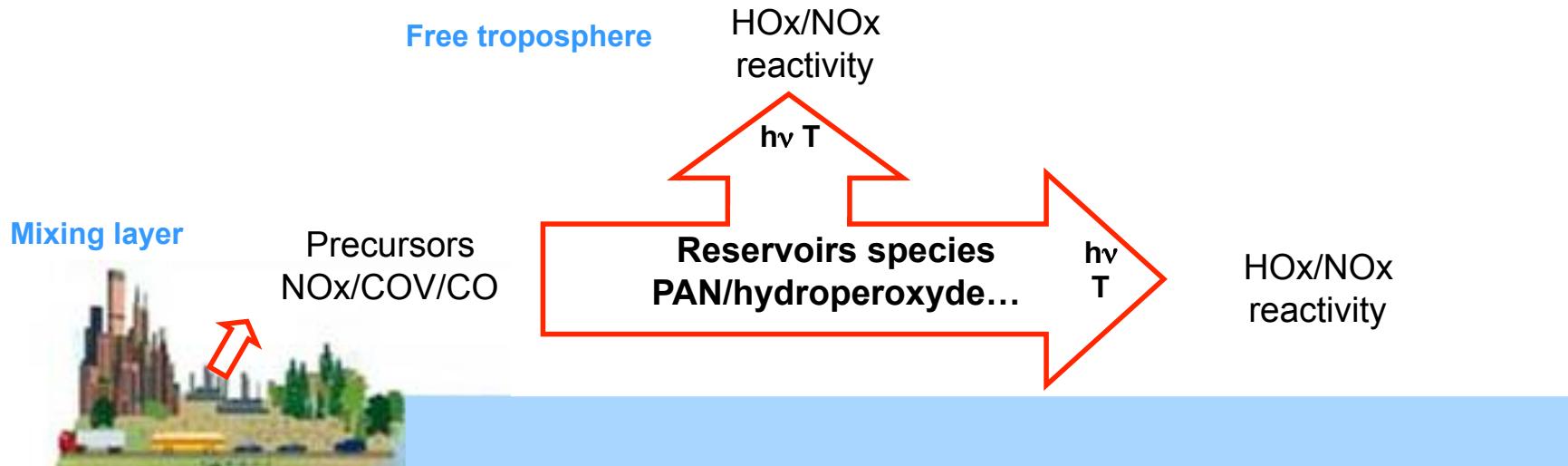
# Why ozone ?







# Tropospheric chemistry : Peroxy Acetyl Nitrate (PAN)

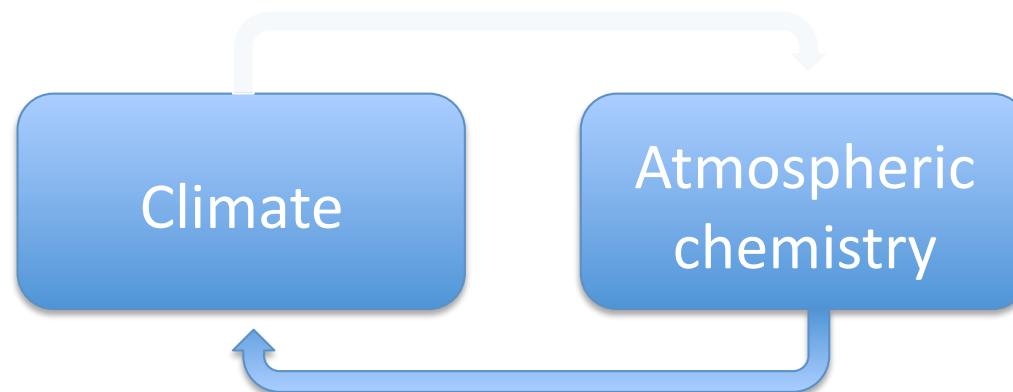


The lifetime of PAN is 1 hour at 295 K and several months at 250 K (strong T dependence).



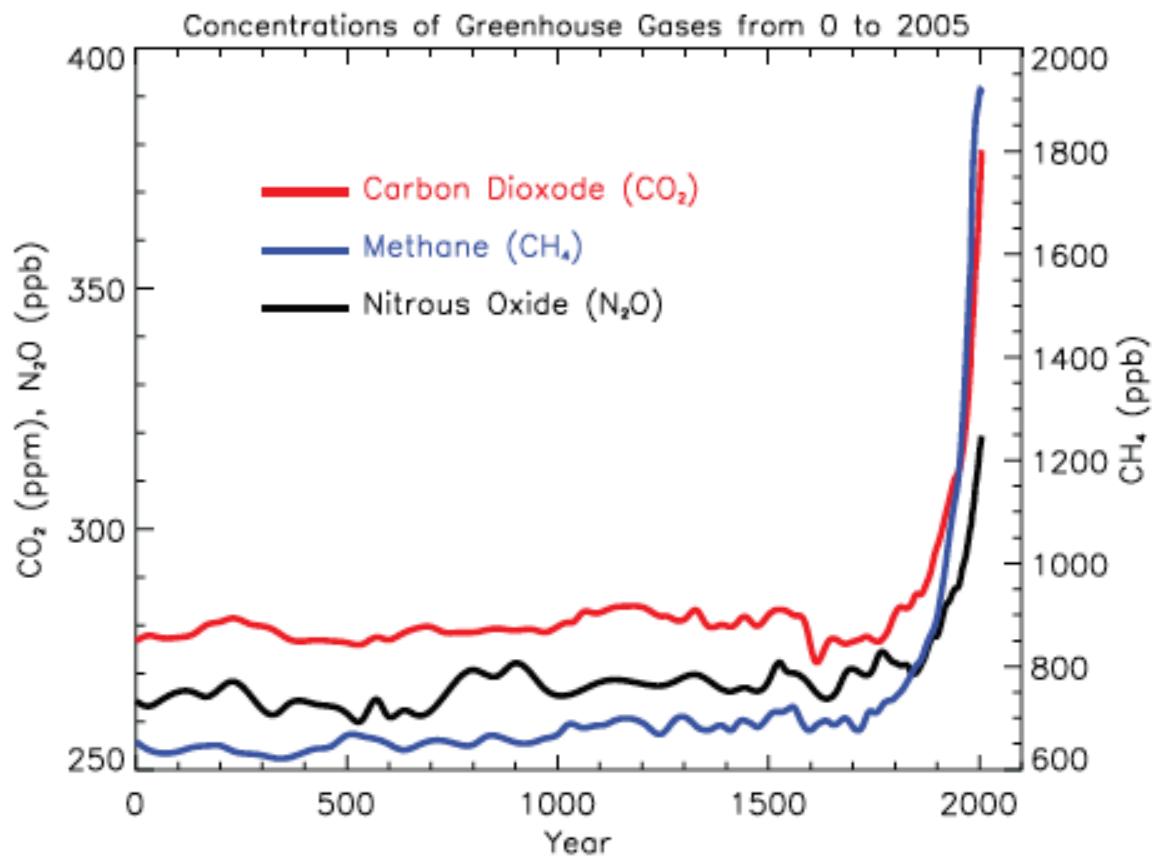
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Atmospheric chemistry can impact Climate





# Changes in greenhouse gases mixing ratios



**FAQ 2.1, Figure 1.** Atmospheric concentrations of important long-lived greenhouse gases over the last 2,000 years. Increases since about 1750 are attributed to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion air molecules, respectively, in an atmospheric sample. (Data combined and simplified from Chapters 6 and 2 of this report.)

## Tropospheric ozone

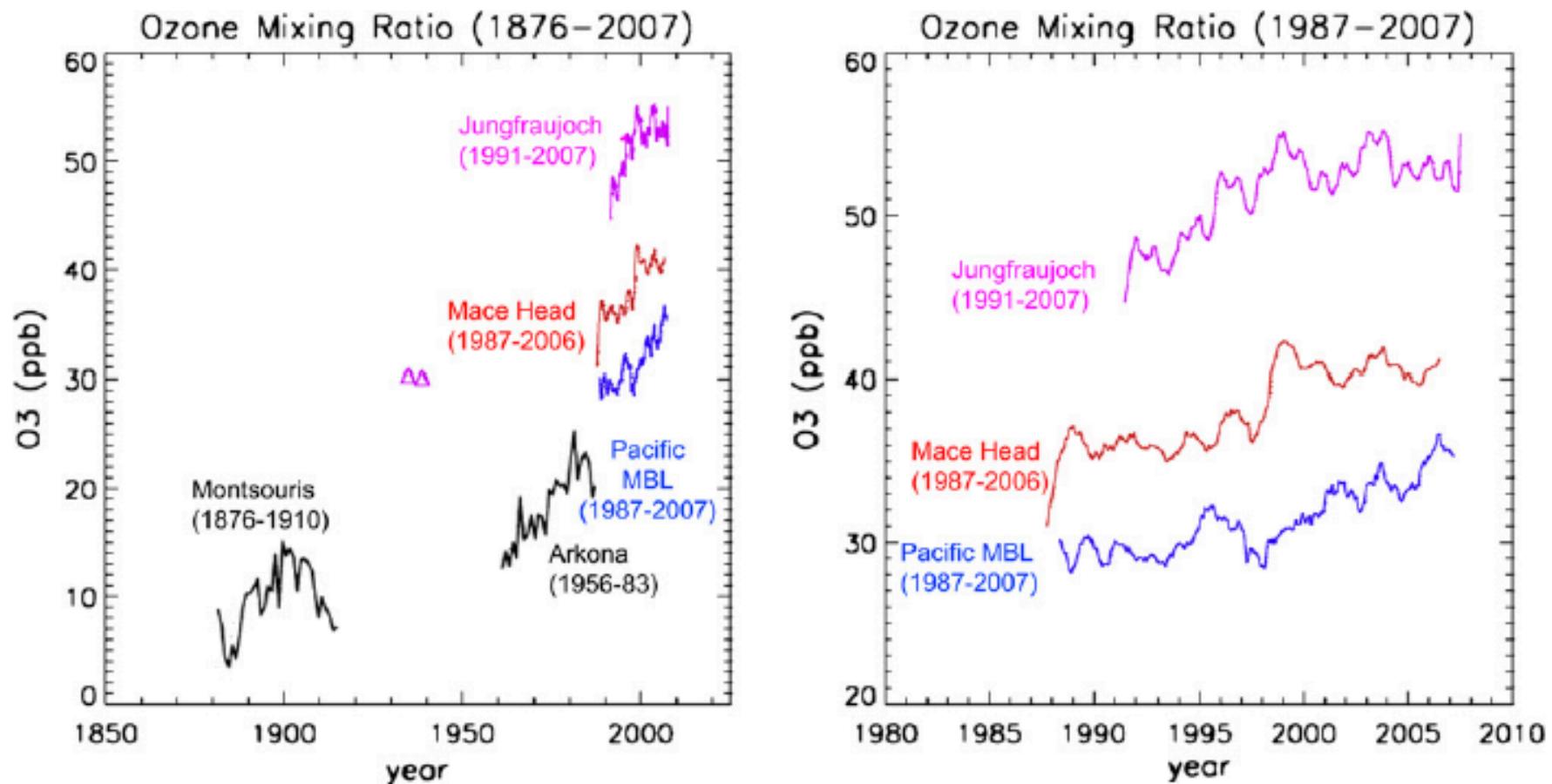


Fig. 15. Observed surface ozone at different Northern Hemispheric surface stations.

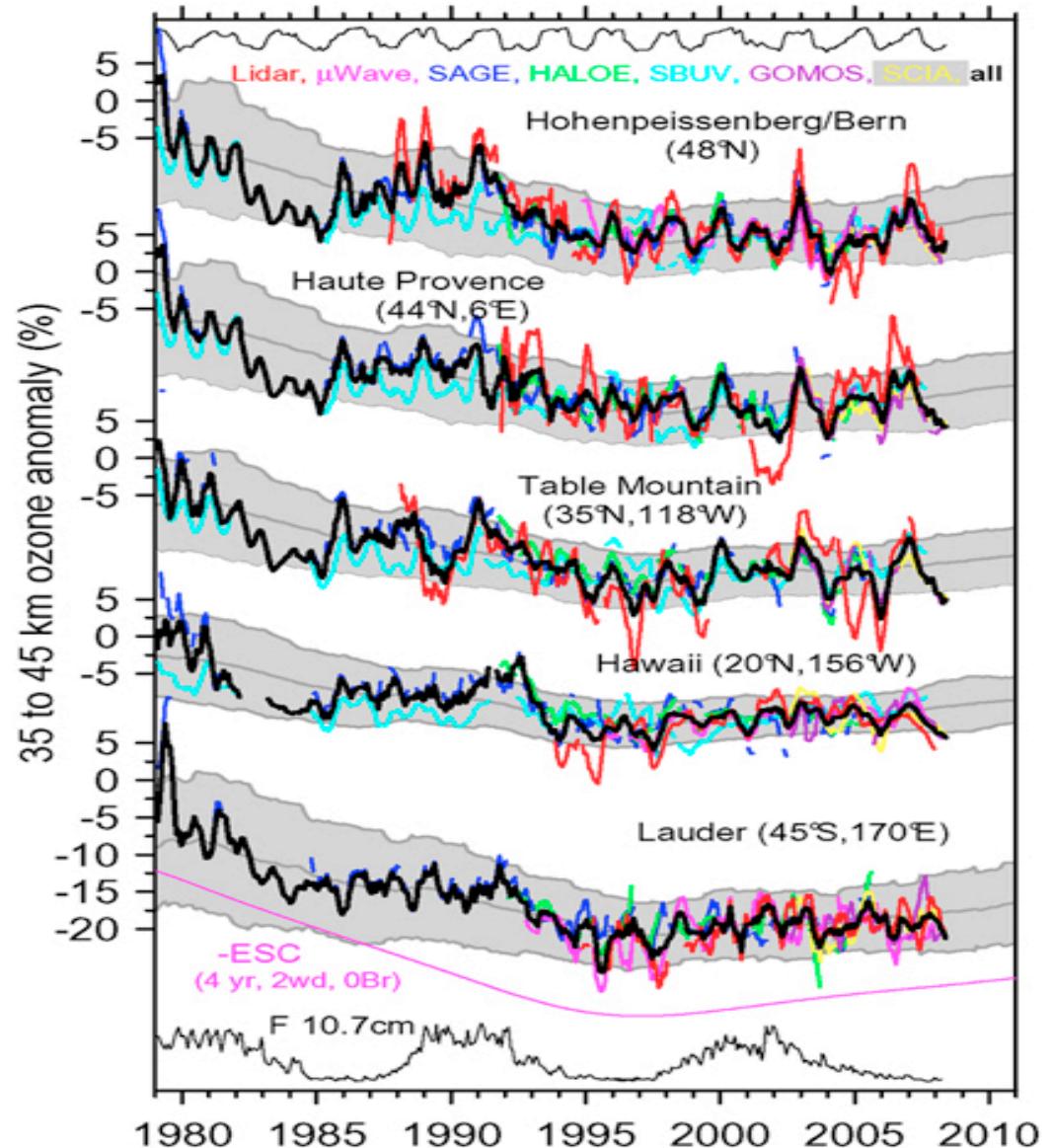


# Changes in greenhouse gases mixing ratios

Stratospheric ozone

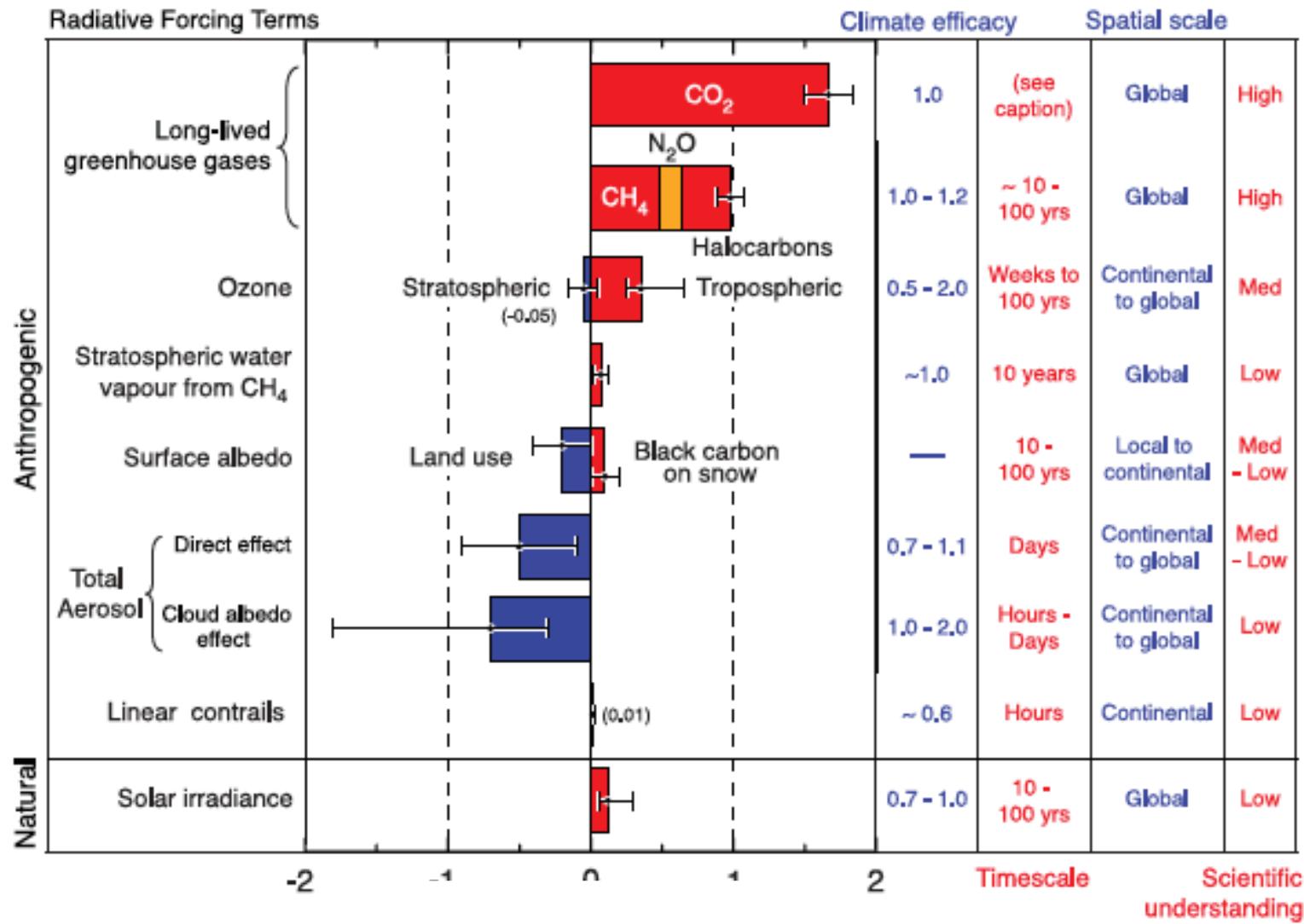
Montreal protocol

↓  
Towards recovering  
Ozone levels from the  
1970s (?)



# Radiative forcing for 1750-2005

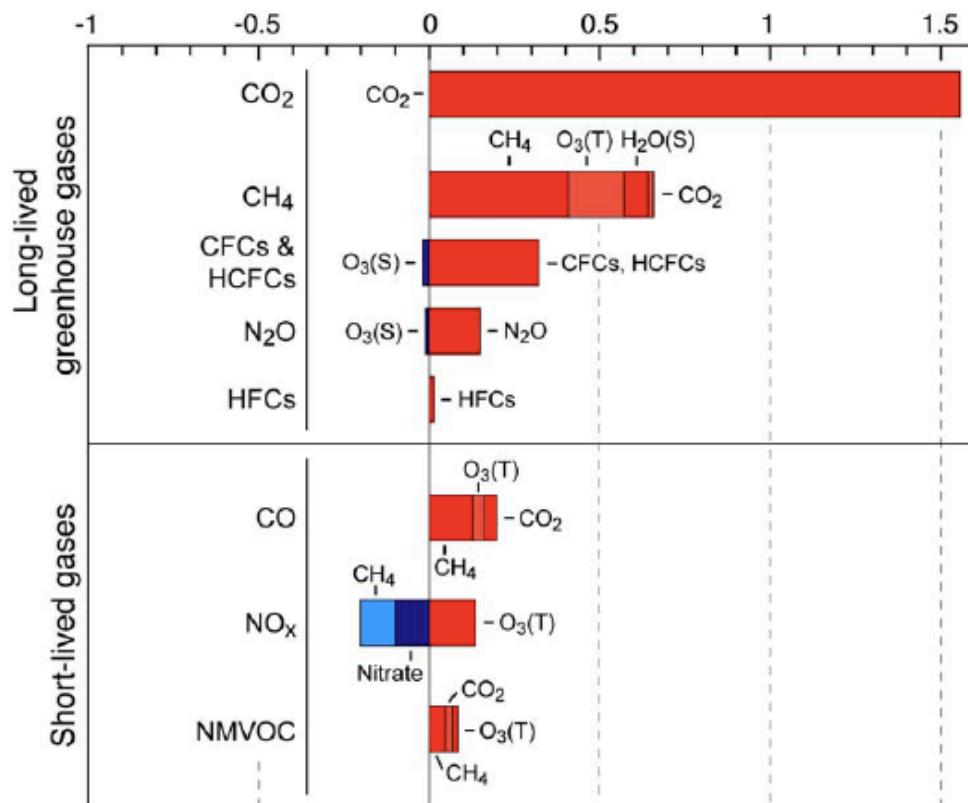
## Concentration-based point of view



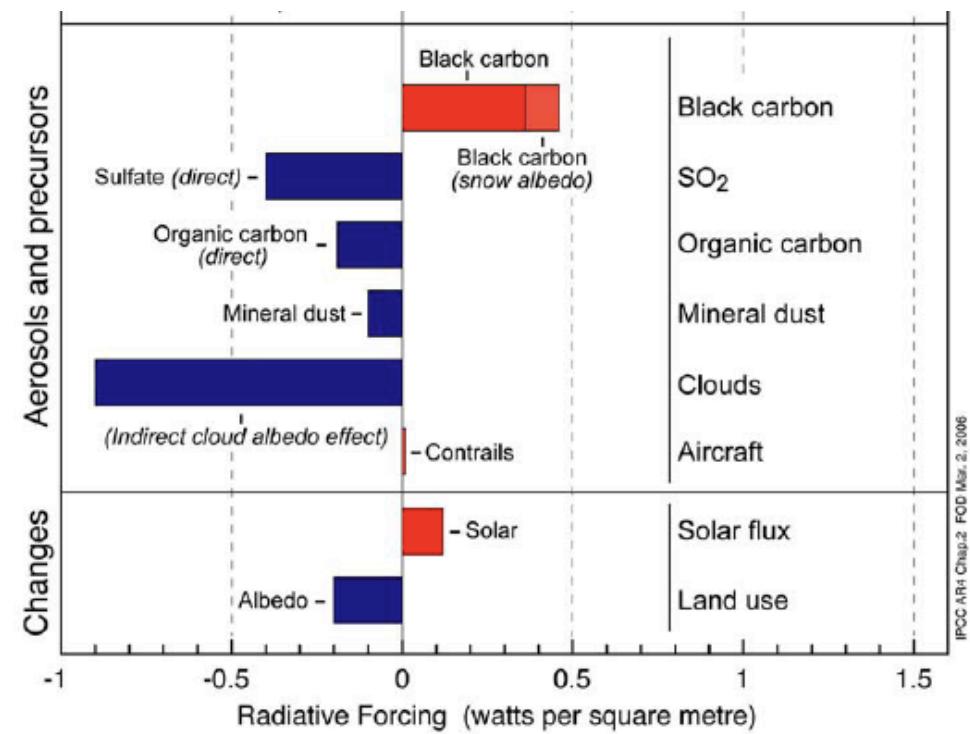
# Radiative forcing for 1750-2005

Emission-based point of view

## Atmospheric Gases



## Aerosols, Sun, Albedo



IPCC, 2007 ; Shindell et al., 2005



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Climate can impact atmospheric chemistry





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GEOPHYSICAL RESEARCH LETTERS, VOL. 32, L24807, doi:10.1029/2005GL024031, 2005

## **Future tropospheric ozone simulated with a climate-chemistry-biosphere model**

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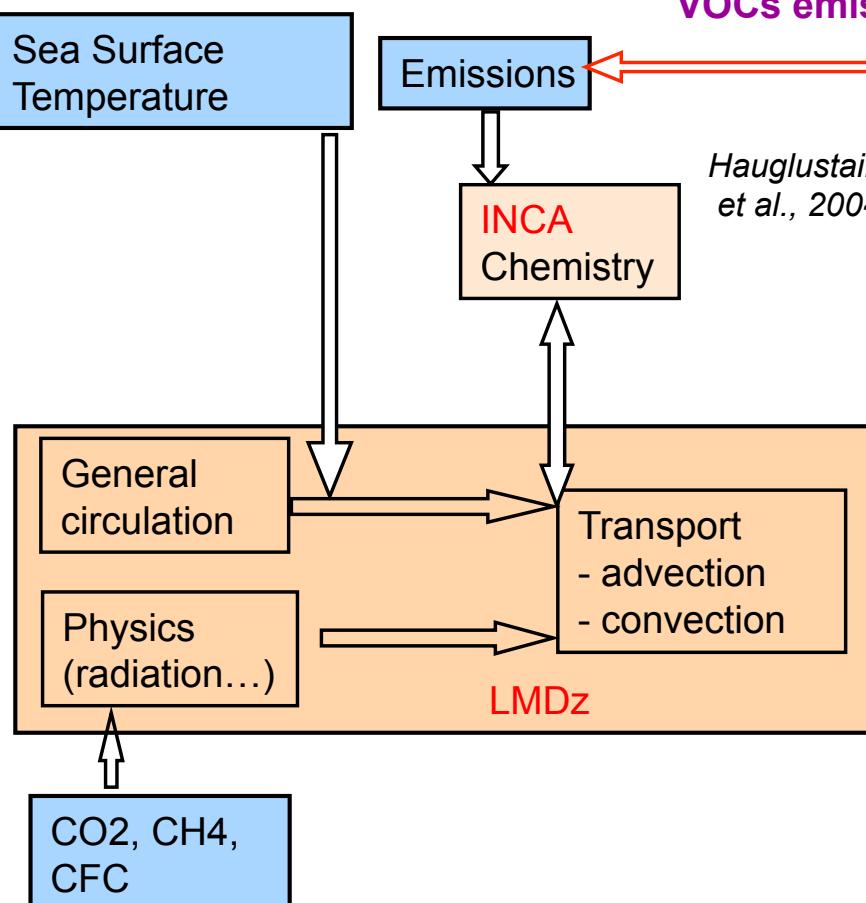
## What is the evolution of tropospheric ozone under a changing climate ?



# Evolution of tropospheric ozone under a changing climate

## Modelling tools

LMDZ – INCA - ORCHIDEE



Climate forcings →

STOMATE  
Carbon  
Nutriments

SECHIBA  
Radiative budget  
Hydrology  
Photosynthesis

VOCs emissions

Hauglustaine  
et al., 2004

ORCHIDEE

Dynamique LPJ  
Modèle de dynamique de la  
végétation

Krinner et al., 2005

Method :

4 simulations

2000

2100A : only anthropogenic emissions change

2100AB : changement A + biogenic emissions

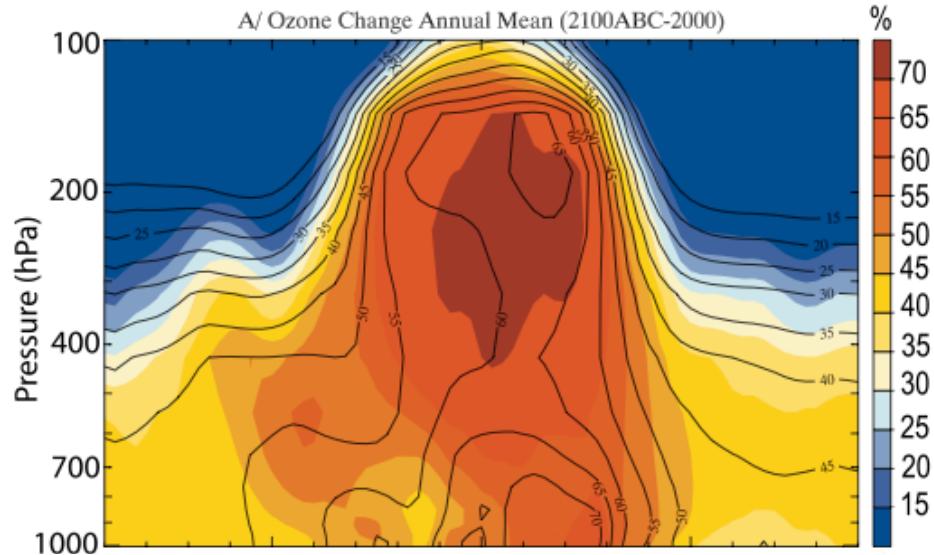
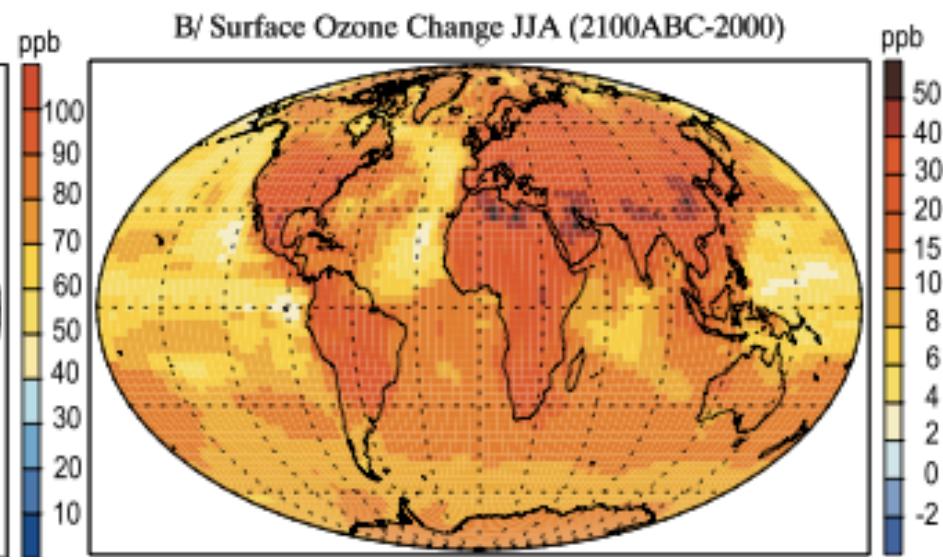
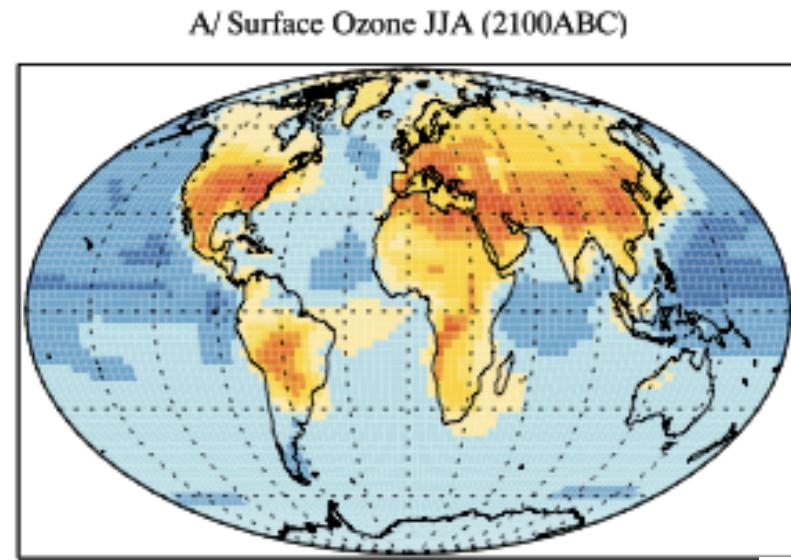
2100ABC idem + Realistic climate change

	2000	2100A	2100AB	2100ABC
NO <sub>x</sub> (surface+ aircraft)	45.4	122.6	124.4	124.4
CO	1199.9	2648.2	2648.2	2648.2
CH <sub>4</sub>	562.8	1128.6	1128.6	1128.6
Anthropogenic VOCs	175.4	322.8	322.8	322.8
Isoprene	402.0	402.0	637.9	637.9
Terpenes	130.8	130.8	265.3	265.3
Other BVOCs	163.2	163.2	287.8	287.8

NO<sub>x</sub> in Tg(N)/yr, CO and CH<sub>4</sub> in Tg/yr. VOC in Tg(C)/yr.



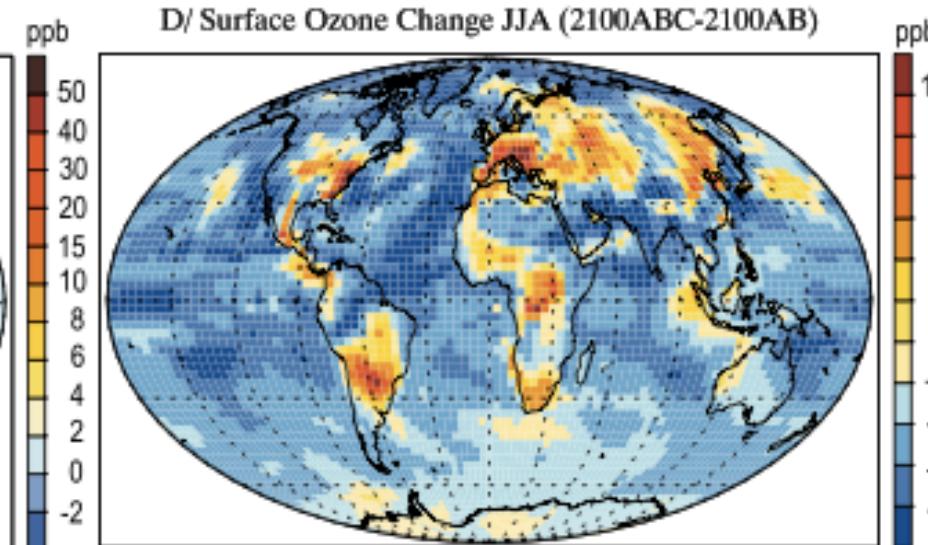
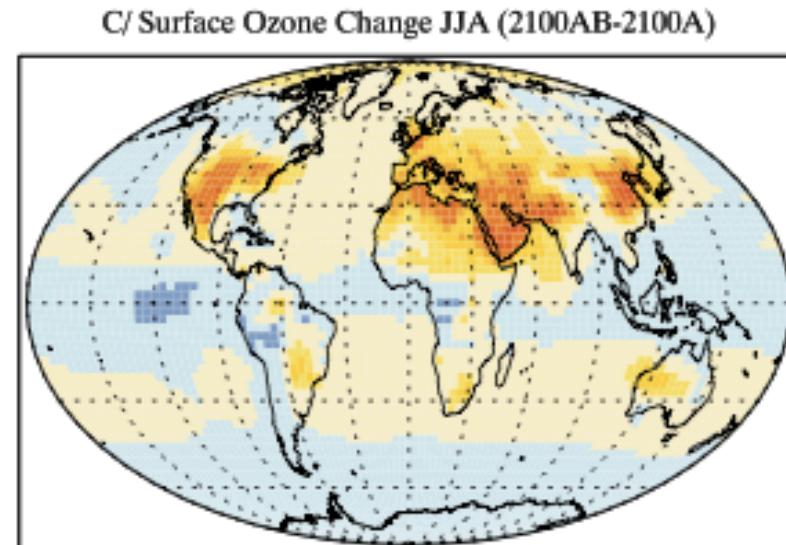
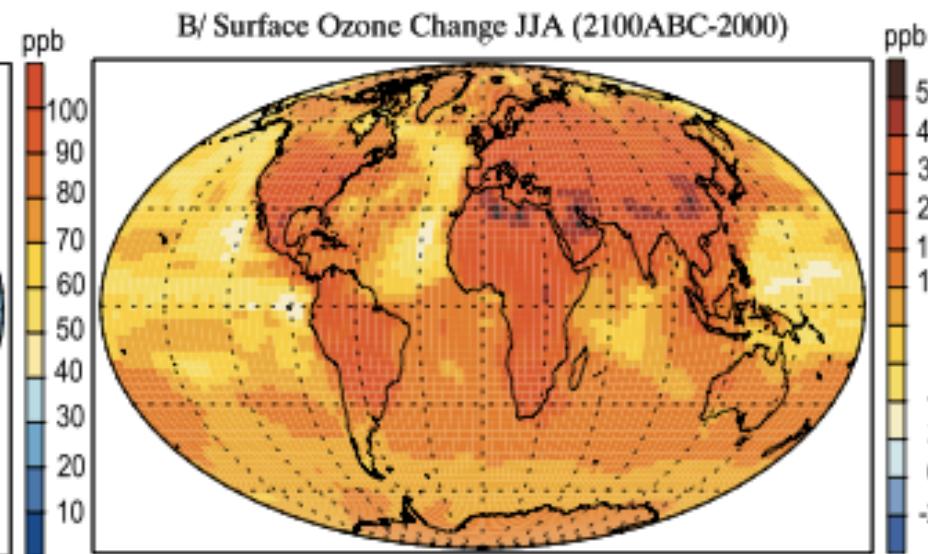
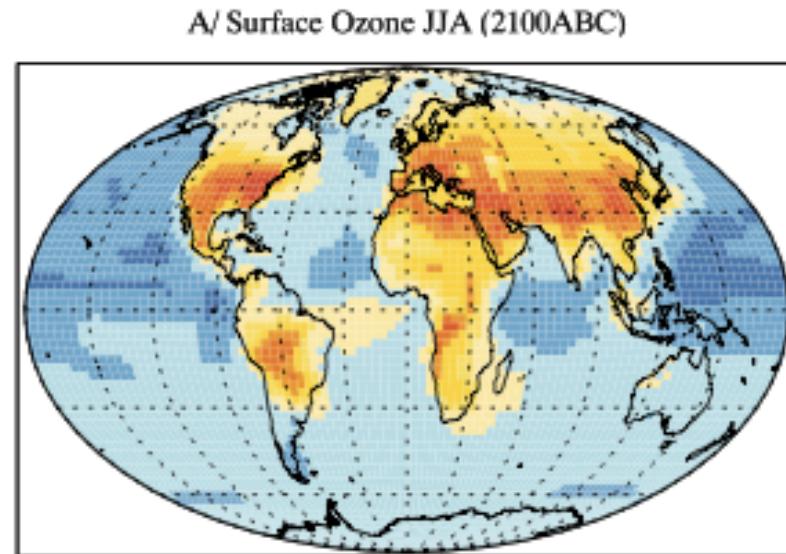
# Evolution of tropospheric ozone under a changing climate



**Ozone increases throughout the whole troposphere** with a maximum increase reaching 70% 2100ABC. In the lower troposphere, ozone increases by 60% in the tropics and by 40% at higher latitudes in exp. 2100ABC.



# Evolution of tropospheric ozone under a changing climate



Effects of Biogenic emission changes

Effect of climate change

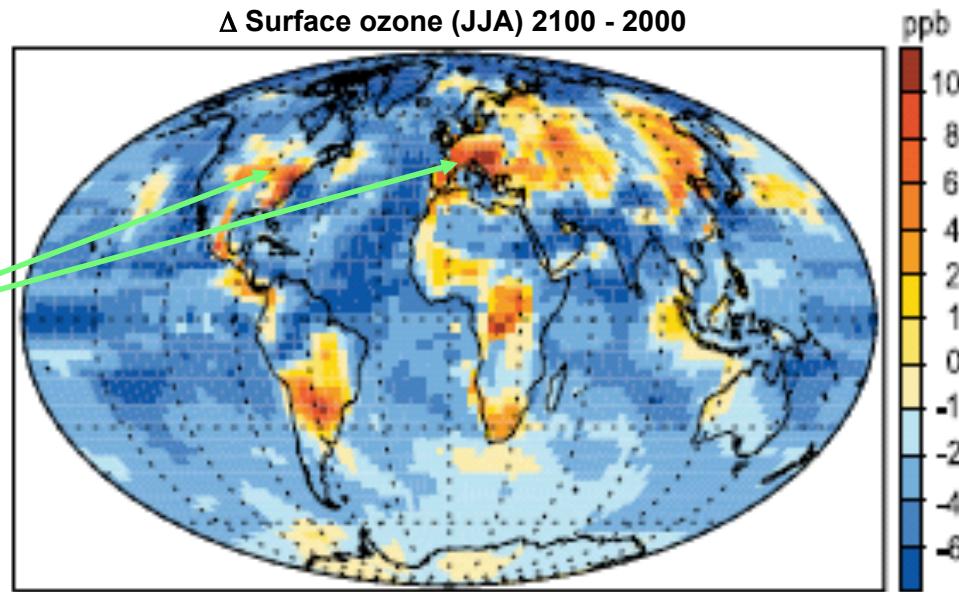


# Evolution of tropospheric ozone under a changing climate

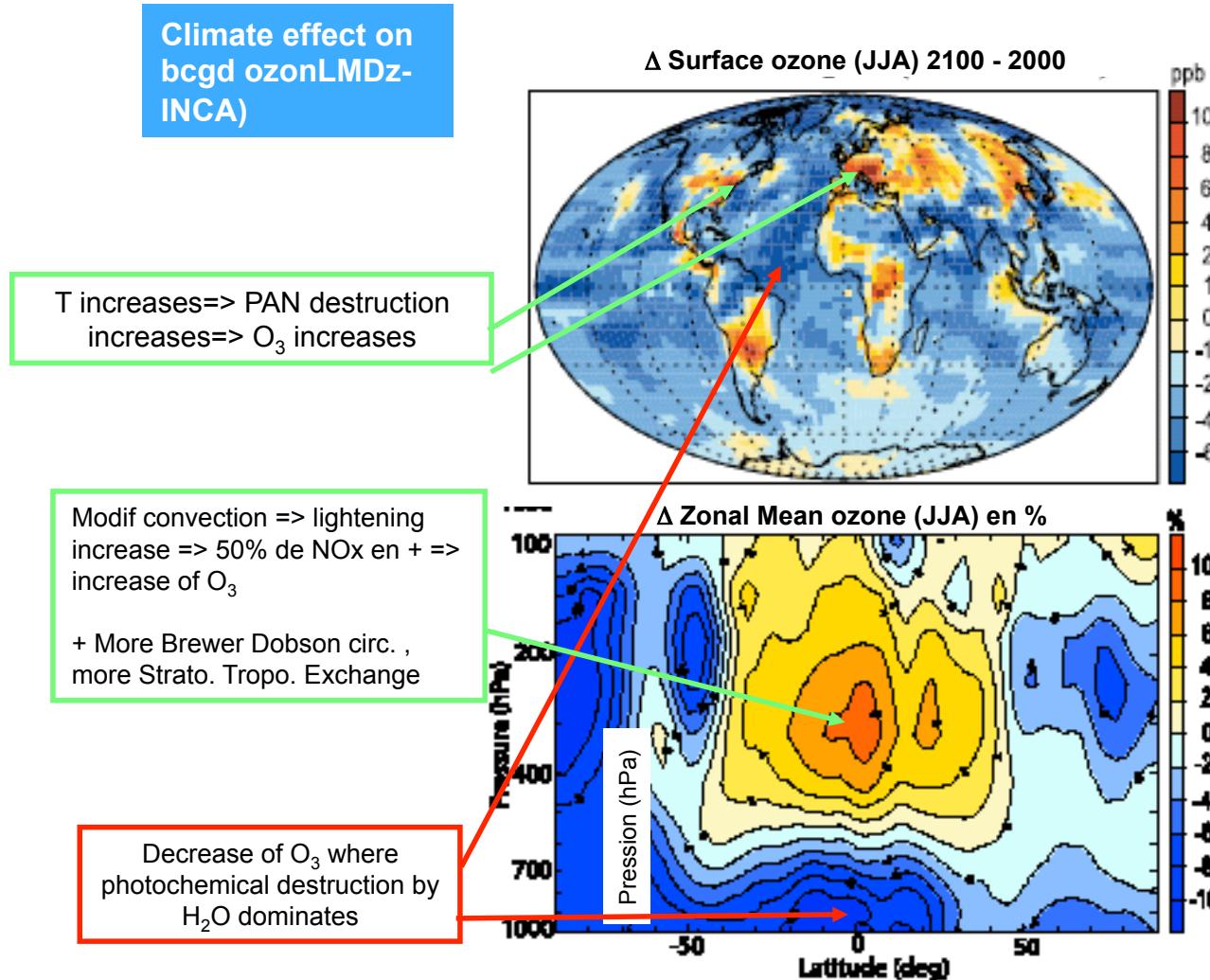
## Changes in background ozone and general circulation

Climate effect on  
bcgd ozonLMDz-  
INCA)

T increases=> PAN destruction  
increases=> O<sub>3</sub> increases



## Changes in background ozone and general circulation



The impact of climate change is to increase both the ozone photochemical production and destruction terms. Overall, the increased destruction dominates and the net chem prod is reduced by 308 Tg/yr from exp. 2100AB to 2100ABC.

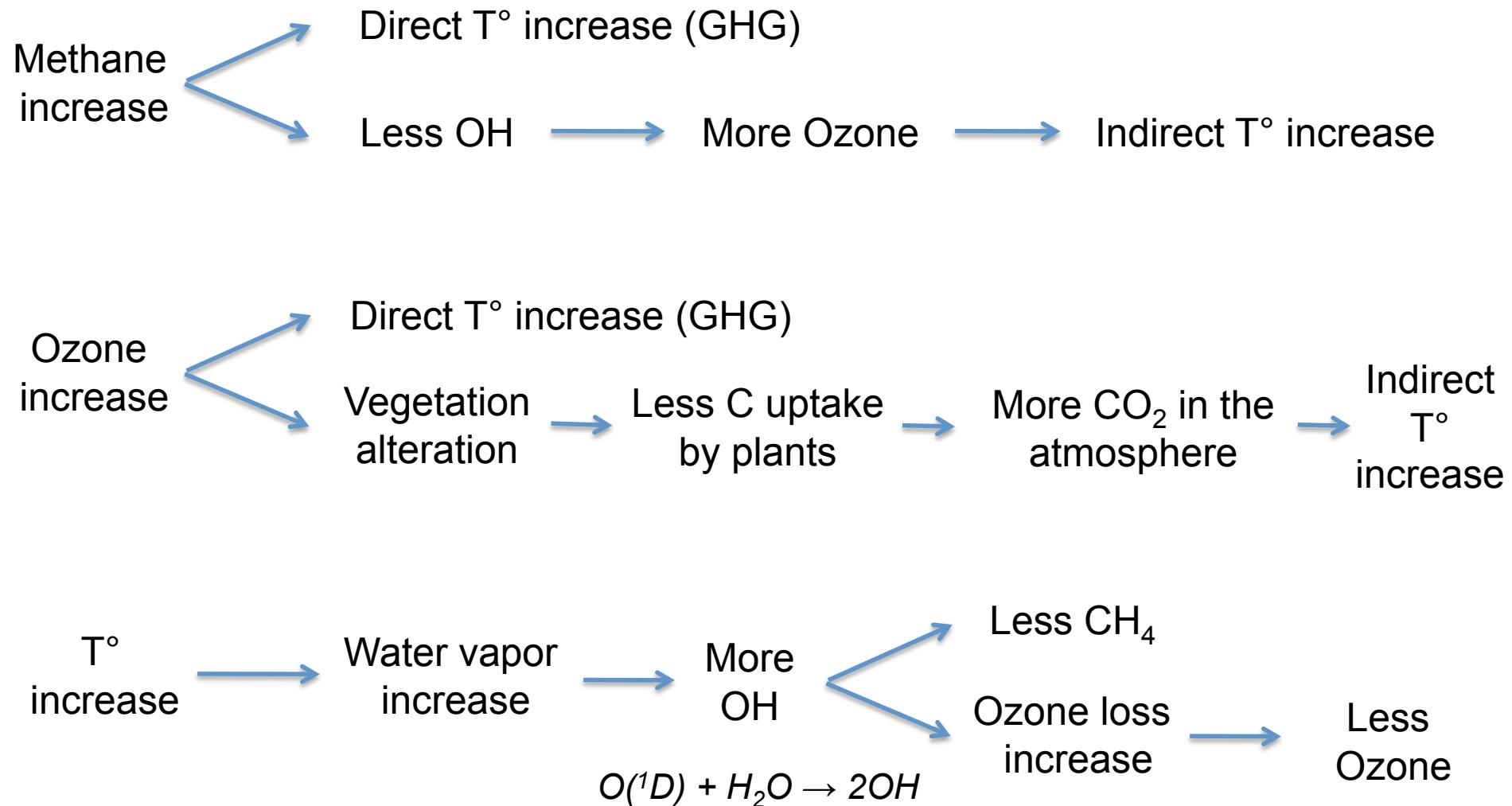


# Evolution of tropospheric ozone under a changing climate

- **Increased precursor emissions** : ozone increase in the whole troposphere.
- **Climate change** : warmer and wetter climate enhanced ozone photochemical destruction and tends to **decrease ozone** and offsets the emissions related increase below about 500 hPa.
- **BUT Climate change** : more intense Brewer-Dobson circulation causes the stratospheric ozone influx to increase by 35% and a more vigorous convective activity induces an increase of lightning NO<sub>x</sub> emissions from 5 to 7.5 Tg(N)/yr. In the upper troposphere, ozone is **further increased** between 50 S–50 N when climate change is considered.
- As a result, **climate change slightly decreases the global tropospheric ozone burden**.
- **Tropospheric ozone net radiative forcing from the present to 2100**  
**0.521 W.m<sup>-2</sup>** due to anthropogenic emissions (exp. 2100A).  
**0.581 W.m<sup>-2</sup>** accounting for the impact of biogenic emissions (exp. 2100AB)  
**0.585 W.m<sup>-2</sup>** considering the climate change (exp. 2100ABC)
- Radiative forcing increases even if the ozone burden is reduced by 6 Tg from exp. 2100AB to 2100ABC. CC increases ozone in the upper troposphere where the impact on the forcing is enhanced.
- **Increased biogenic emissions play an important role in the future development of ozone pollution.**  
Their contribution increases surface ozone by 30 – 50% in northern continental regions during summer.



## Uncertainties, coupling & feedbacks makes it more complicate





# Impact of Climate Change on tropospheric ozone

Process/activity	Impact on global tropospheric ozone resulting from climate change	
	Impact	sign
Human activity-fossil fuel related emissions	Small	o
Biomass burning	Medium to large	±
Soil NO <sub>x</sub>	Medium	o
Lightning NO <sub>x</sub>	Medium-to-large	+
Natural CH <sub>4</sub> emissions	Medium-to-Large	+
Natural VOC emissions	Medium-to-large	+
Oceanic emissions of sulphur containing gases	Small	o
Heterogeneous chemistry on sea-salt	Medium	-
Heterogeneous chemistry on mineral dust	Small-medium	-
Organohalogens	Unknown	-
Changes in dry deposition	Medium	o
Changes in wet deposition	Small-medium	-
Effect of meteorology on O <sub>3</sub> production and loss	Large	-
Cloudiness	Small	-
Climate induced changes in stratosphere-troposphere exchange	Large	+
Changes in weather patterns	Unknown	o



# What about the next IPCC report ?

**Scenario Driving Forces**

**Population** (Past Population Trends, Population Scenarios , Aging and Urbanization)

**Economic and Social Development** (Historical Trends , Scenarios of Economic Development)

**Energy and Technology** (Energy Use and Emissions by Major Sectors, Energy Resources, Energy Supply Technologies)

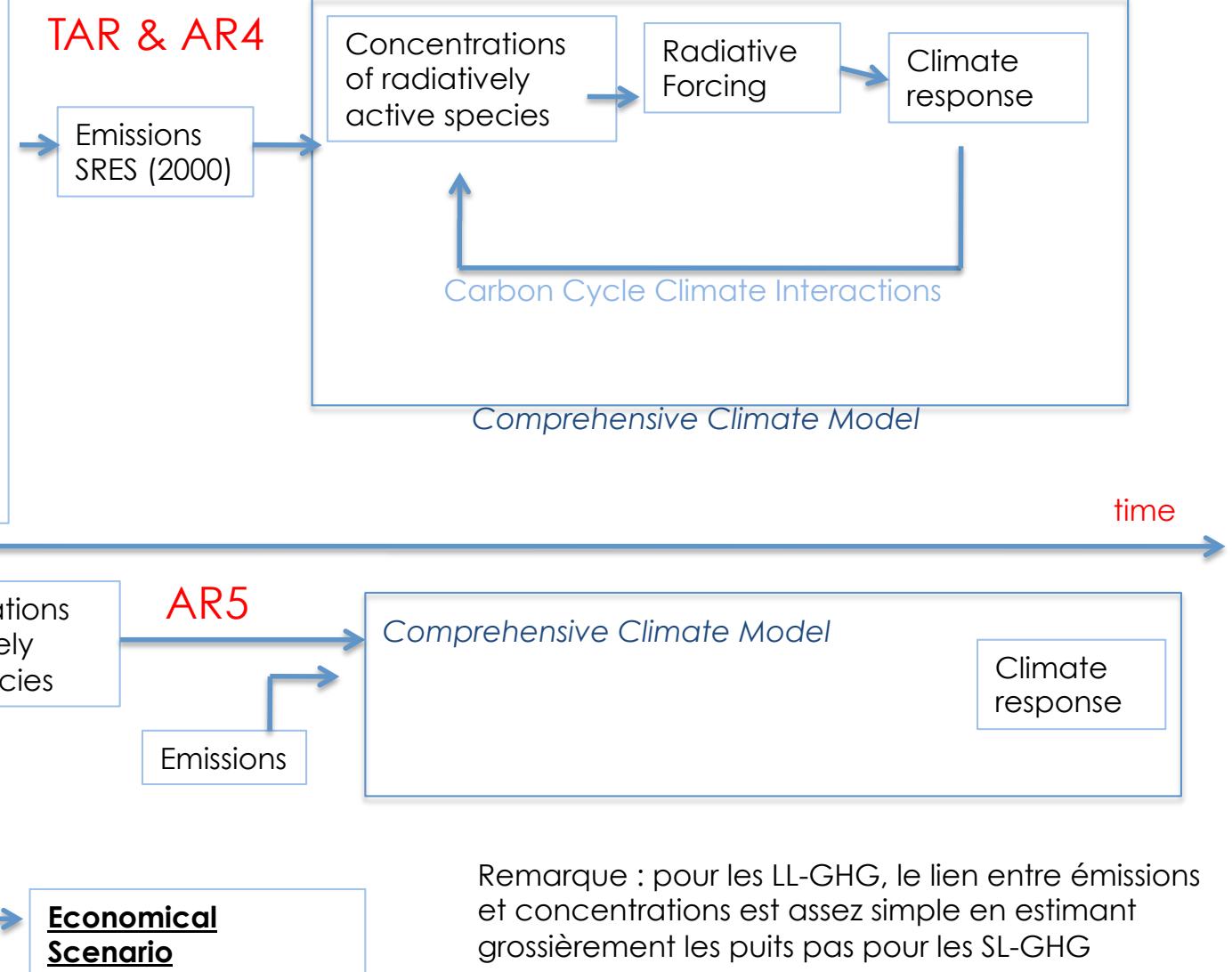
**Agriculture and Land-Use**

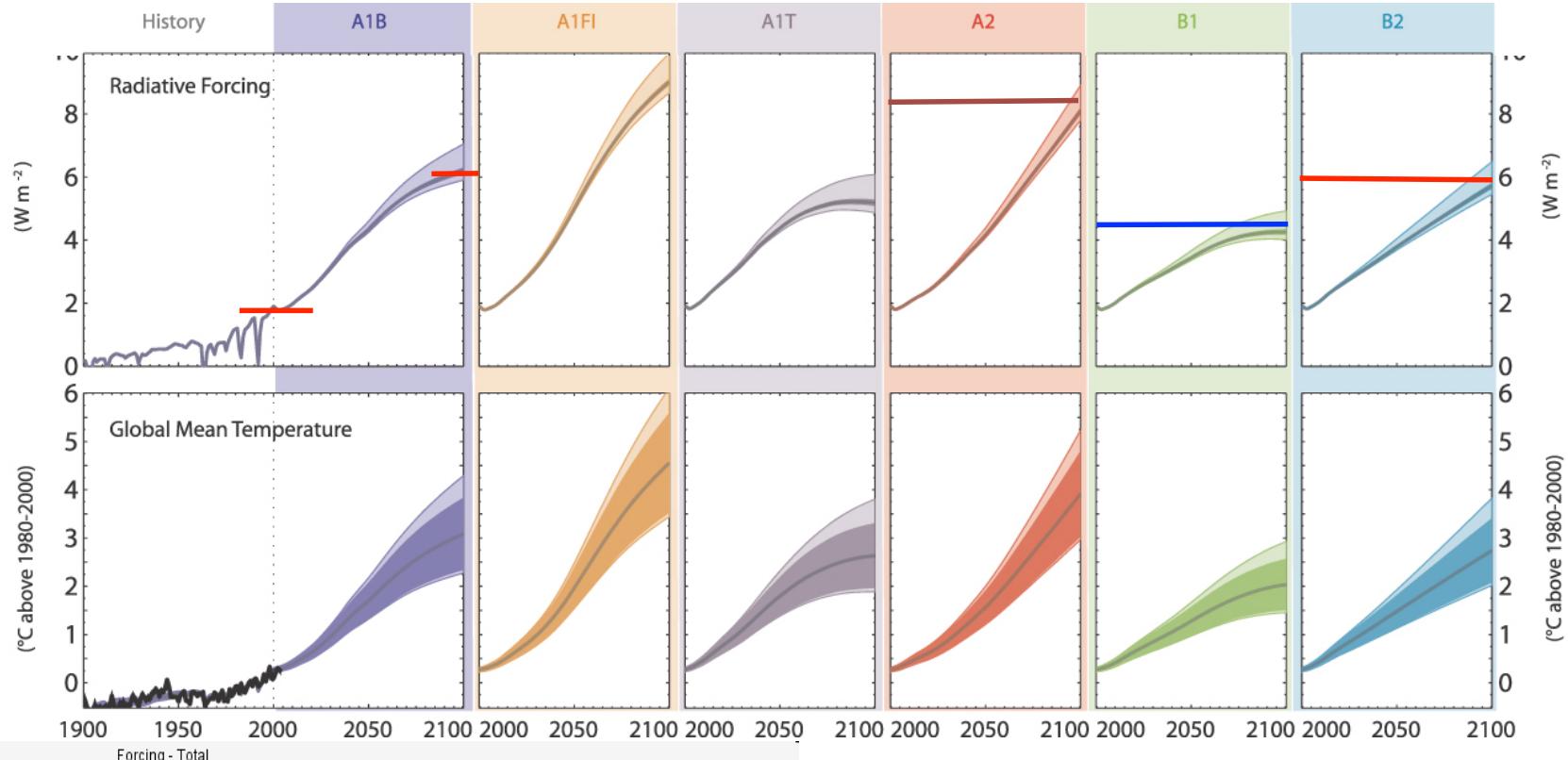
**Emissions**

**Other Gas Emissions**

**Policies**

## Climate scenarios : AR4 versus AR5

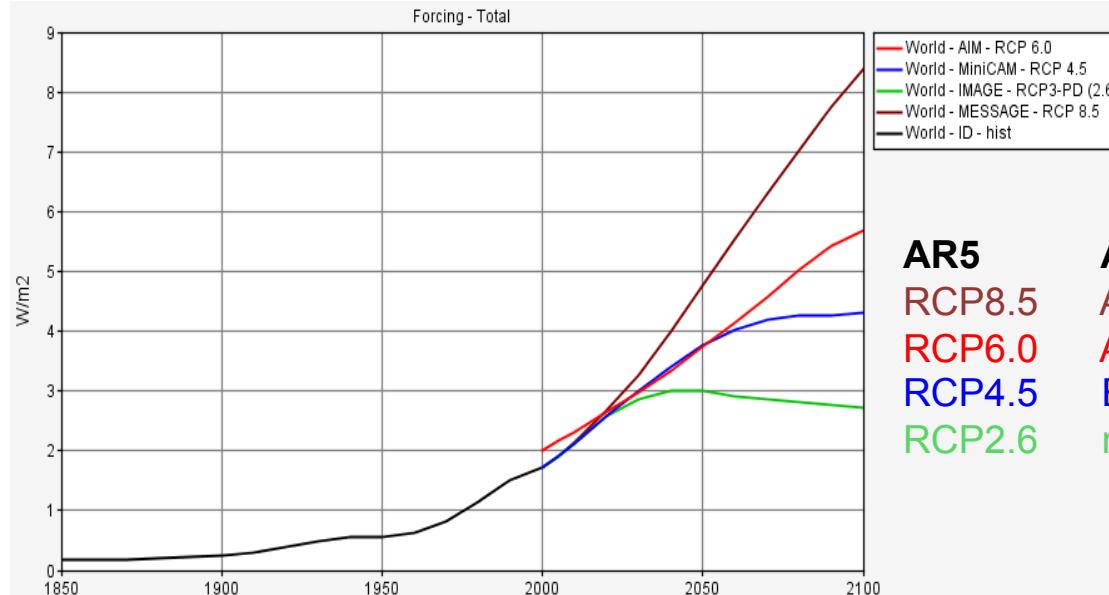




## Scenario correspondances

**AR5**

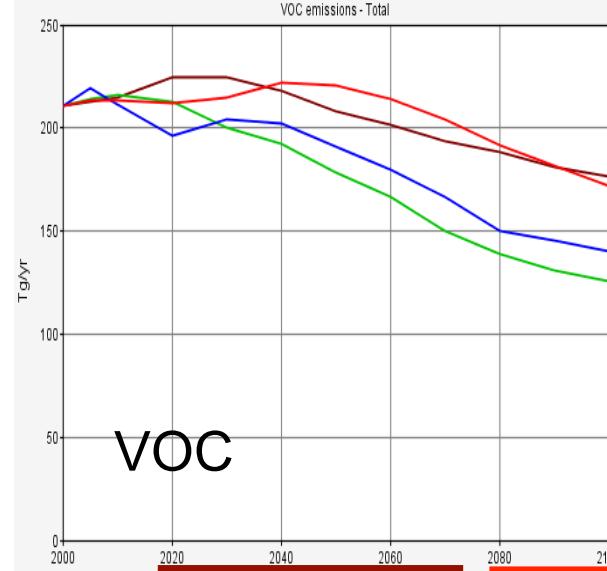
RCP8.5	A2 (ou A1F1)
RCP6.0	A1B ou (B2)
RCP4.5	B1 ou A1T
RCP2.6	non (E1 de ENSEMBLE)



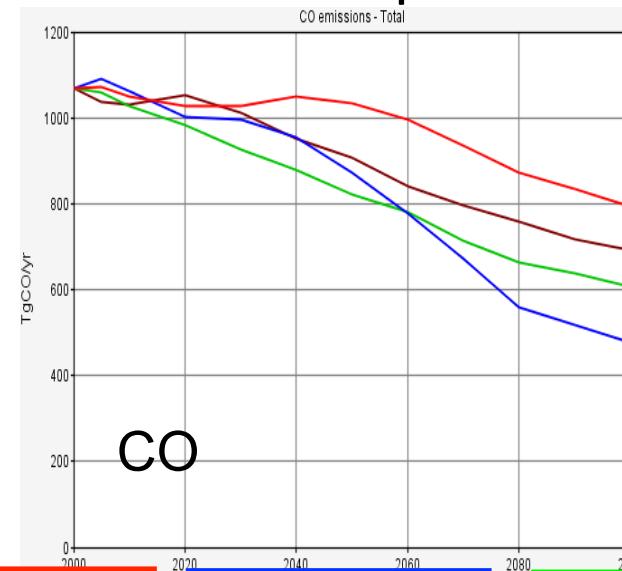


# Anthropogenic emissions

## Global emission evolution for ozone precursors and aerosols in RCPs

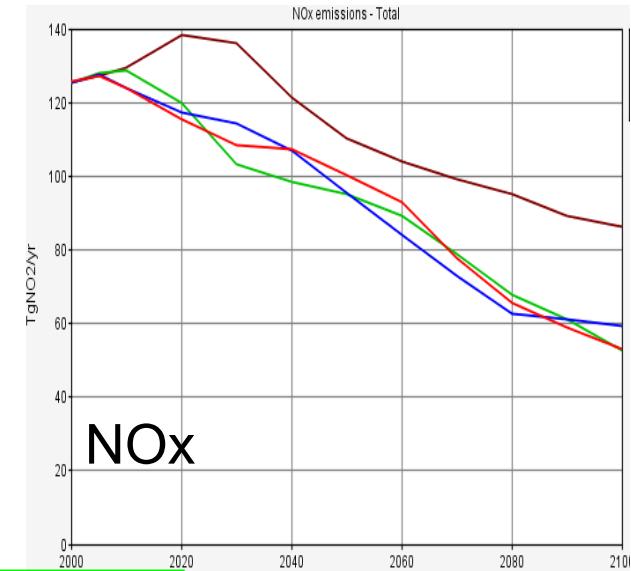


RCP85

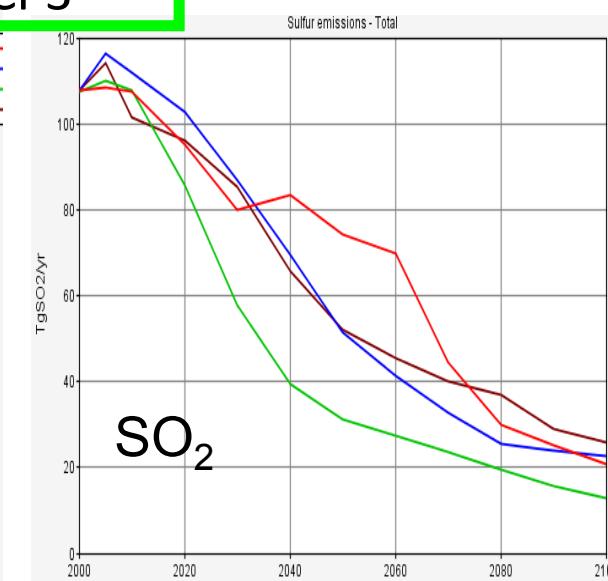
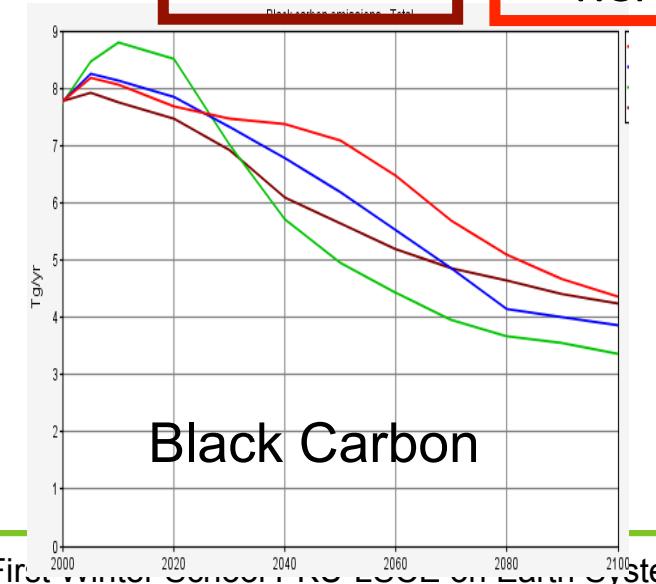


RCP6

RCP45



RCP3

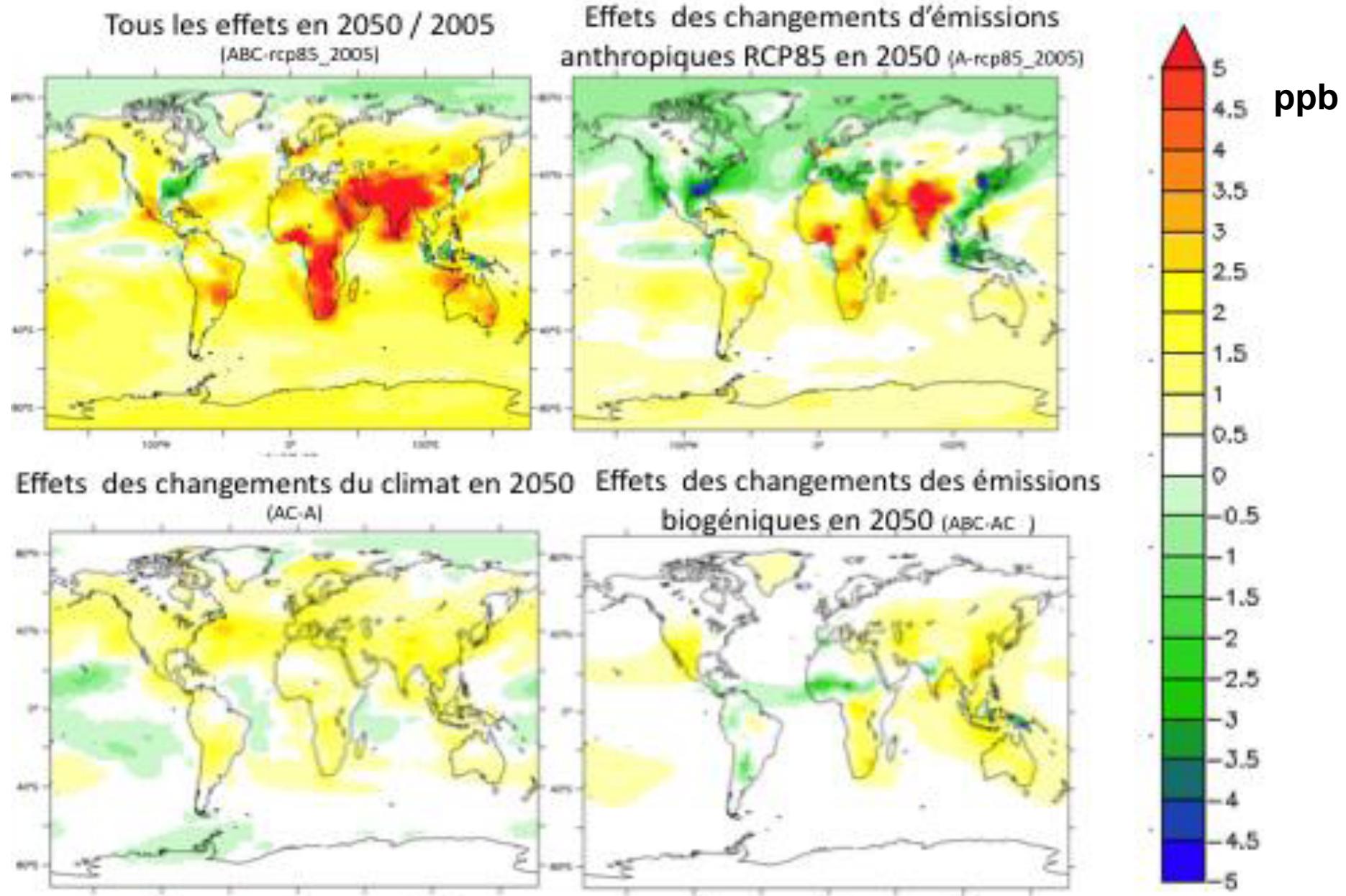


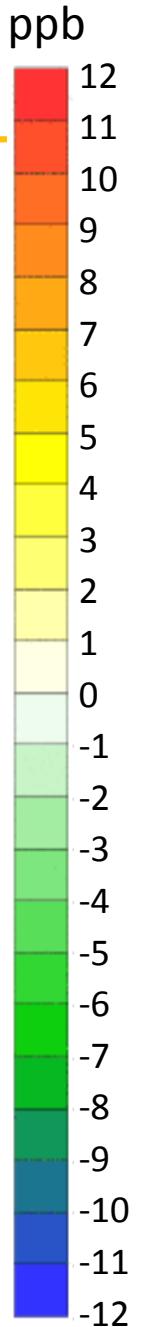
SO<sub>2</sub>

Fires, Volcanoes, Subsidence, Land-use, Emissions



# Effect discrimination (for surface Ozone)

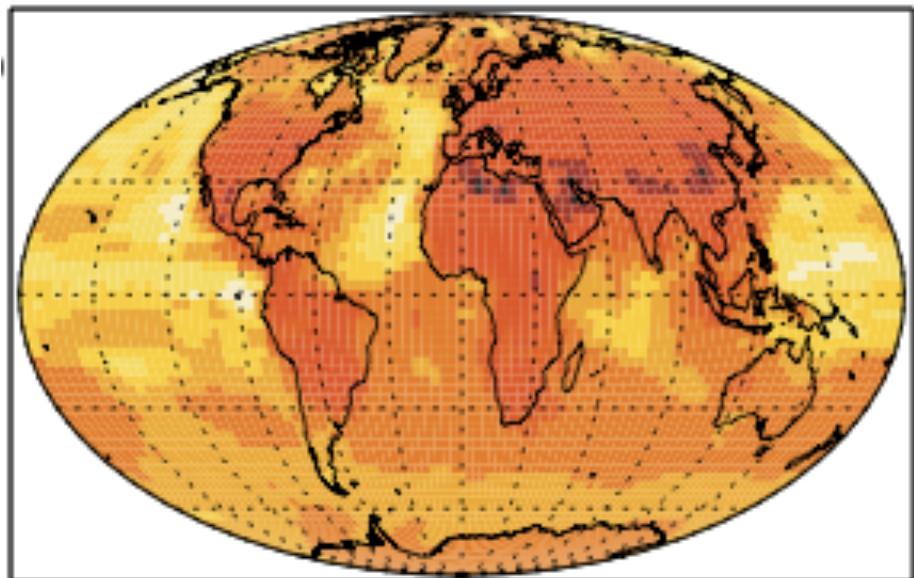




AR4

AR5

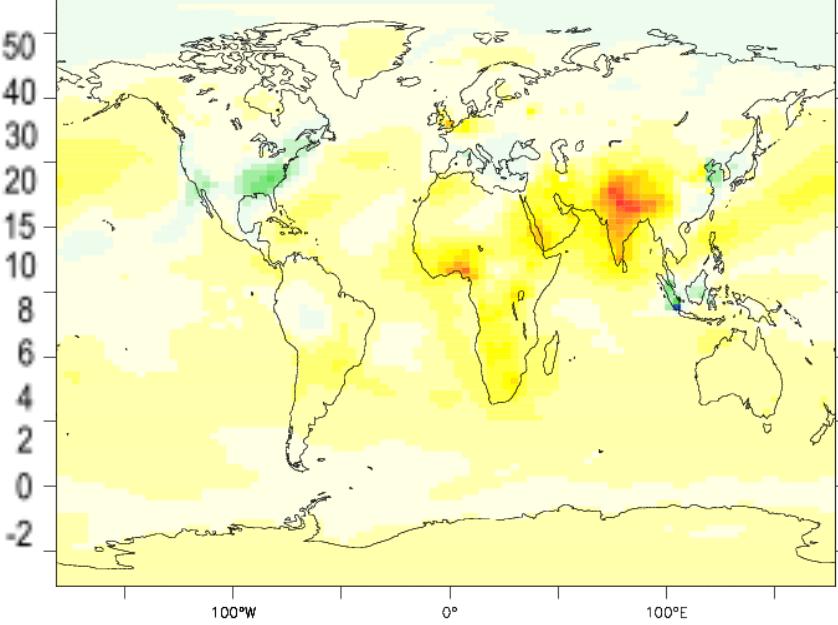
B/ Surface Ozone Change JJA (2100ABC-2000)



Hauglustaine et al. 2005,

RCP85

ppb



(2050, ~cte after )

Szopa et al., 2012

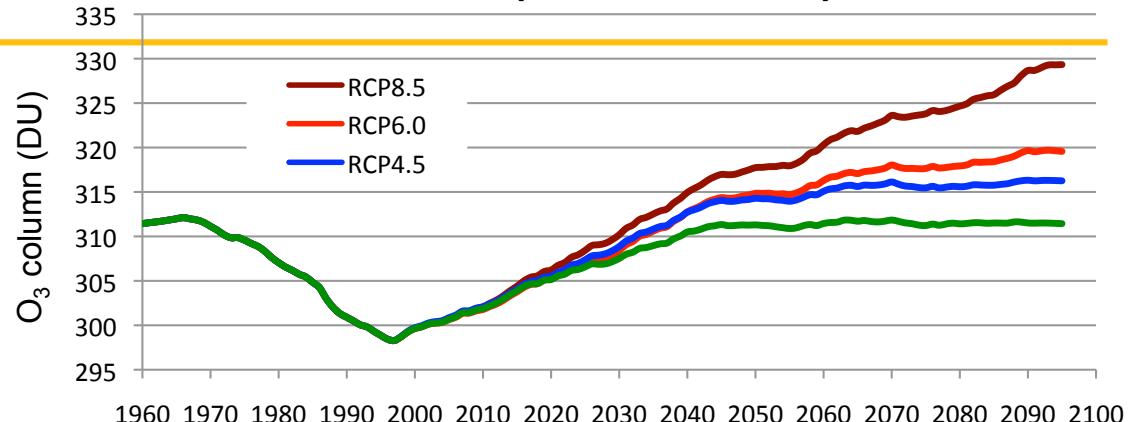
Work in progress ...



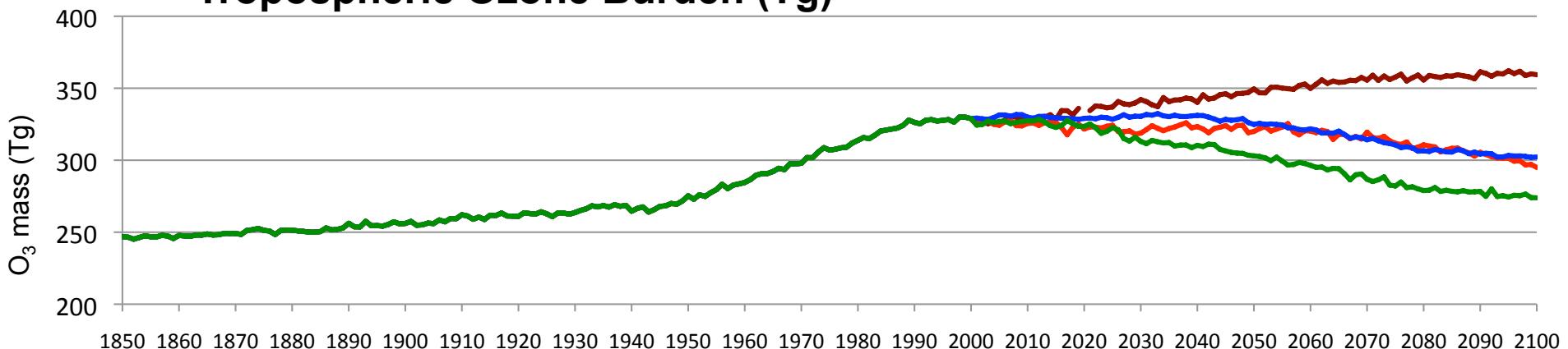
# Ozone evolution

Szopa et al., 2012

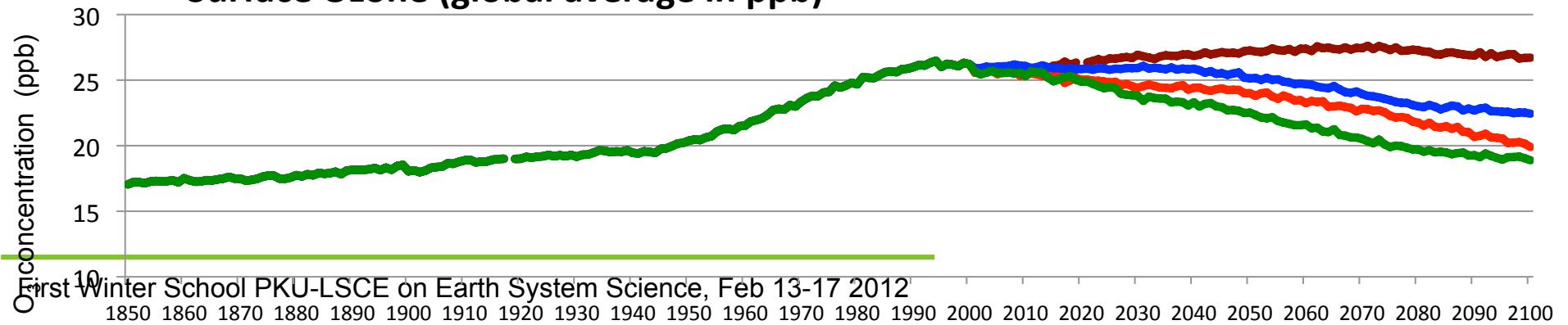
## Total ozone (Dobson Unit)



## Tropospheric Ozone Burden (Tg)



## Surface Ozone (global average in ppb)





## Take-home messages

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- Atmospheric chemistry is non-linear & complex. Atmospheric composition impacts climate and is impacted by climate. Uncertainties are still large !
- Tropospheric and stratospheric ozone play a central role in atmospheric chemistry
- Progresses have been made in the recent years concerning the :
  - quantification of emissions (NOx, VOCs, CO, CH4, ...) through various approaches (inverse modelling, inventories, process-based models)
  - changes in OH from temperature and humidity perturbations,
  - changes in tropospheric ozone through STE exchange and changes in stratospheric ozone
- *Continued growth in emissions favors impact from the short-lived compounds. However, it is likely that in the future the relative contribution from the chemically active climate compounds become smaller compared to the contribution from CO<sub>2</sub>, but probably with large regional contrasts (from Isaksen et al., 2009)*
- We are only starting to account for the complexity of the interactions between climate and chemistry in earth system models