Synergies entre qualité de l'air et changement climatique :

Quelques exemples sur base du modèle global LMDz-INCA

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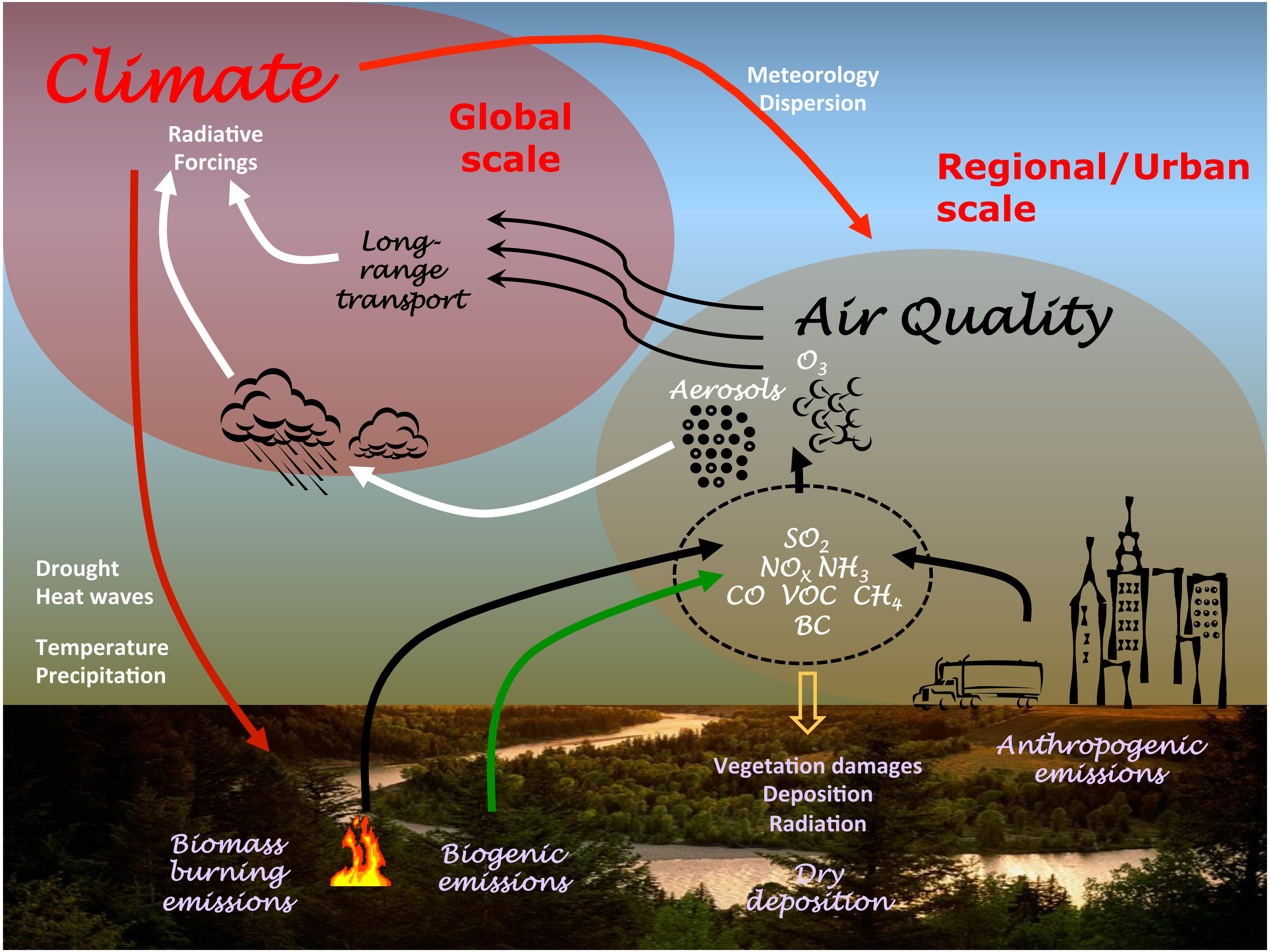
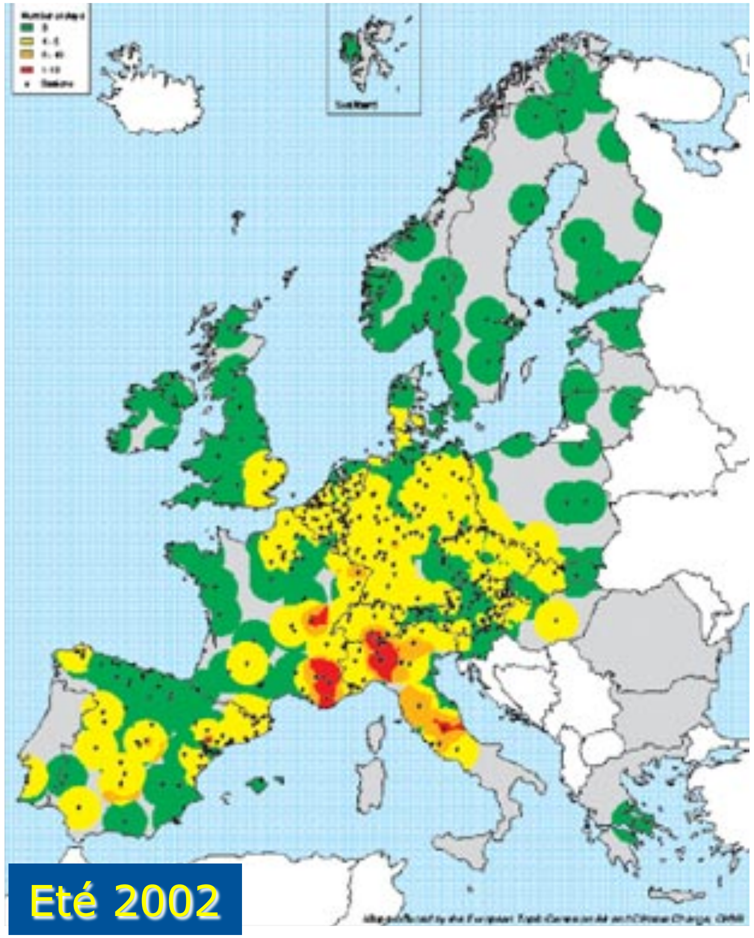
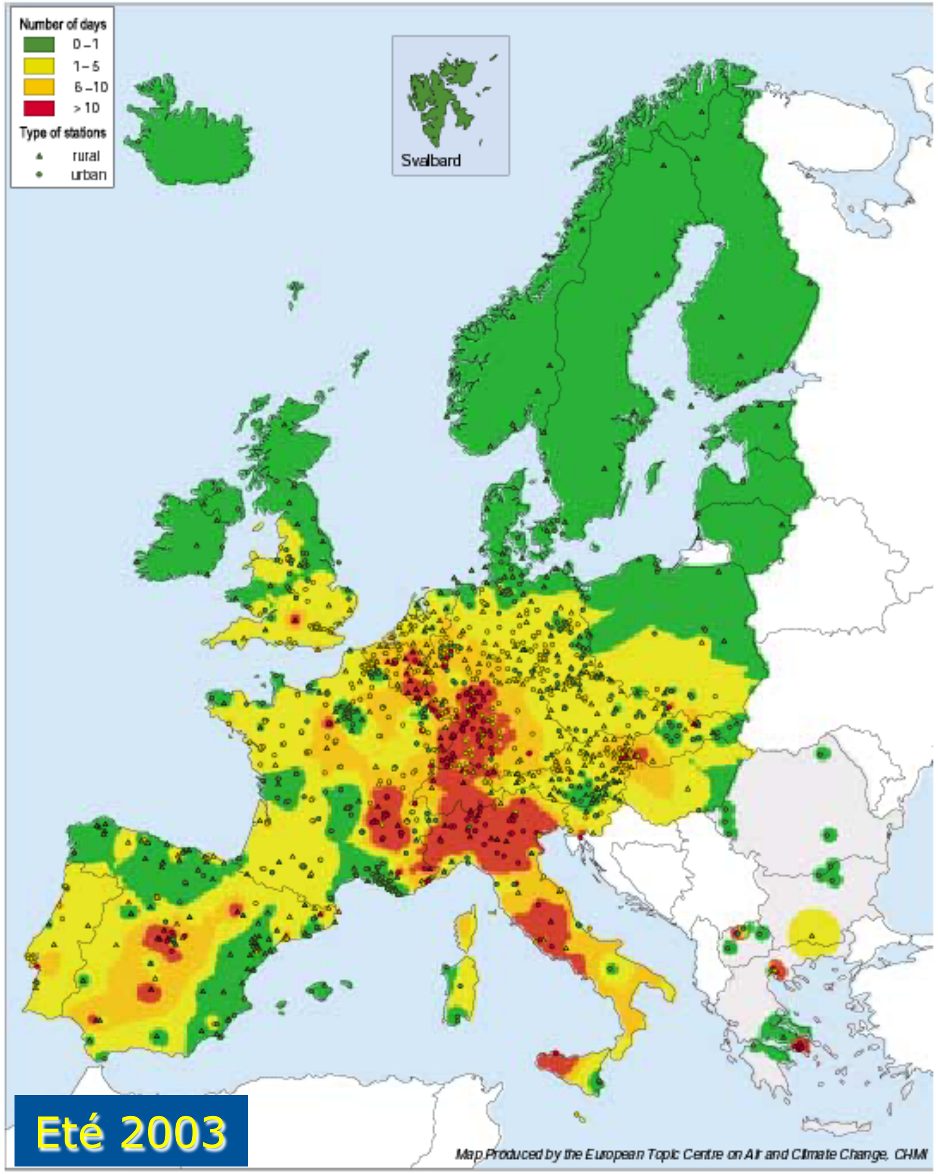


Climate
Global scale
Radiative Forcings
Meteorology Dispersion
Regional/Urban scale
Long-range transport
Air Quality
O_3
Aerosols
SO_2
NO_x NH_3
CO VOC CH_4
BC
Drought
Heat waves
Temperature
Precipitation
Vegetation damages
Deposition
Radiation
Anthropogenic emissions
Biomass burning emissions
Biogenic emissions
Dry deposition

Influence du climat sur la qualité de l’air

Nombre de jours durant lesquels l’ozone a dépassé le seuil de 180 µg/m^3





Dépendance de la qualité de l'air avec les principales variables météorologiques

Variable	Ozone	PM
Température	++	-
Conditions anticycloniques	++	++
Vitesse du vent	-	-
Turbulence	=	-
Humidité	=	+
Couverture nuageuse	-	-
Précipitations	=	--

Jacob & Winner, 2009

Enjeu des mesures prises pour limiter l'augmentation future de CH_4 (O_3) et BC

- Plus de 400 mesures de contrôle des émissions de gaz et particules considérées.

- 14 mesures gardées améliorant à la fois la qualité de l'air et la lutte contre le changement climatique et agissant sur CH_4 (et donc O_3) et BC.

- Les mesures agissant seulement sur le CO_2 ne permettent pas de limiter le réchauffement à 2°C à l'échelle du XXIe siècle à cause du long temps de résidence de ce gaz.

- Agir à la fois sur le CO_2 et sur les agents à plus court temps de résidence permet d'atteindre cet objectif et de limiter à 2°C.

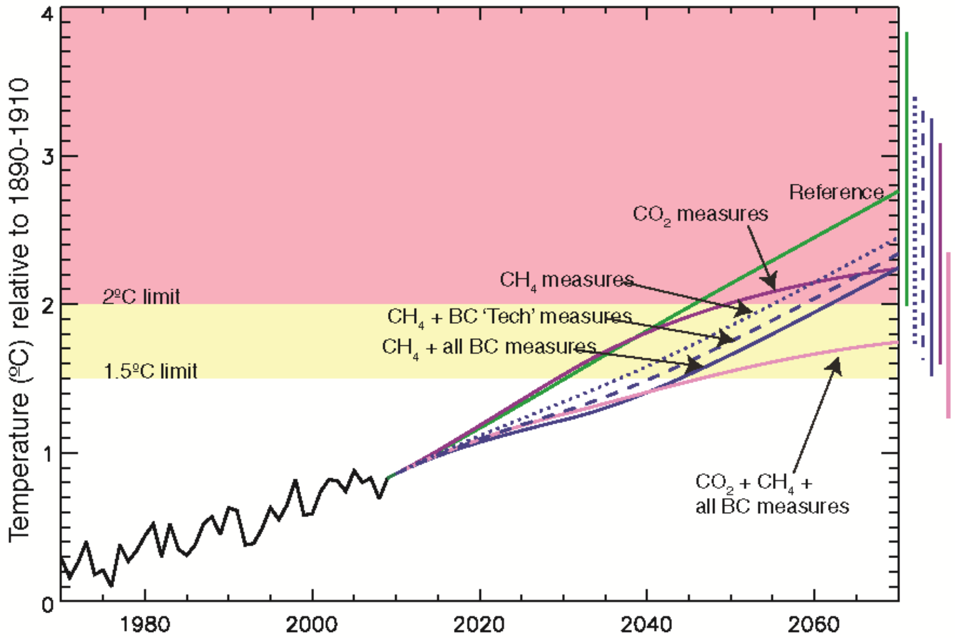


Fig. 1. Observed temperatures (*42*) through 2009 and projected temperatures thereafter under various scenarios, all relative to the 1890–1910 mean. Results for future scenarios are the central values from analytic equations estimating the response to forcings calculated from composition-climate modeling and literature assessments (*7*). The rightmost bars give 2070 ranges, including uncertainty in radiative forcing and climate sensitivity. A portion of the uncertainty is systematic, so that overlapping ranges do not mean there is no significant difference (for example, if climate sensitivity is large, it is large regardless of the scenario, so all temperatures would be toward the high end of their ranges; see www.giss.nasa.gov/staff/dshindell/Sci2012).

UNEP, 2011

Synergies entre qualité de l’air et changement climatique

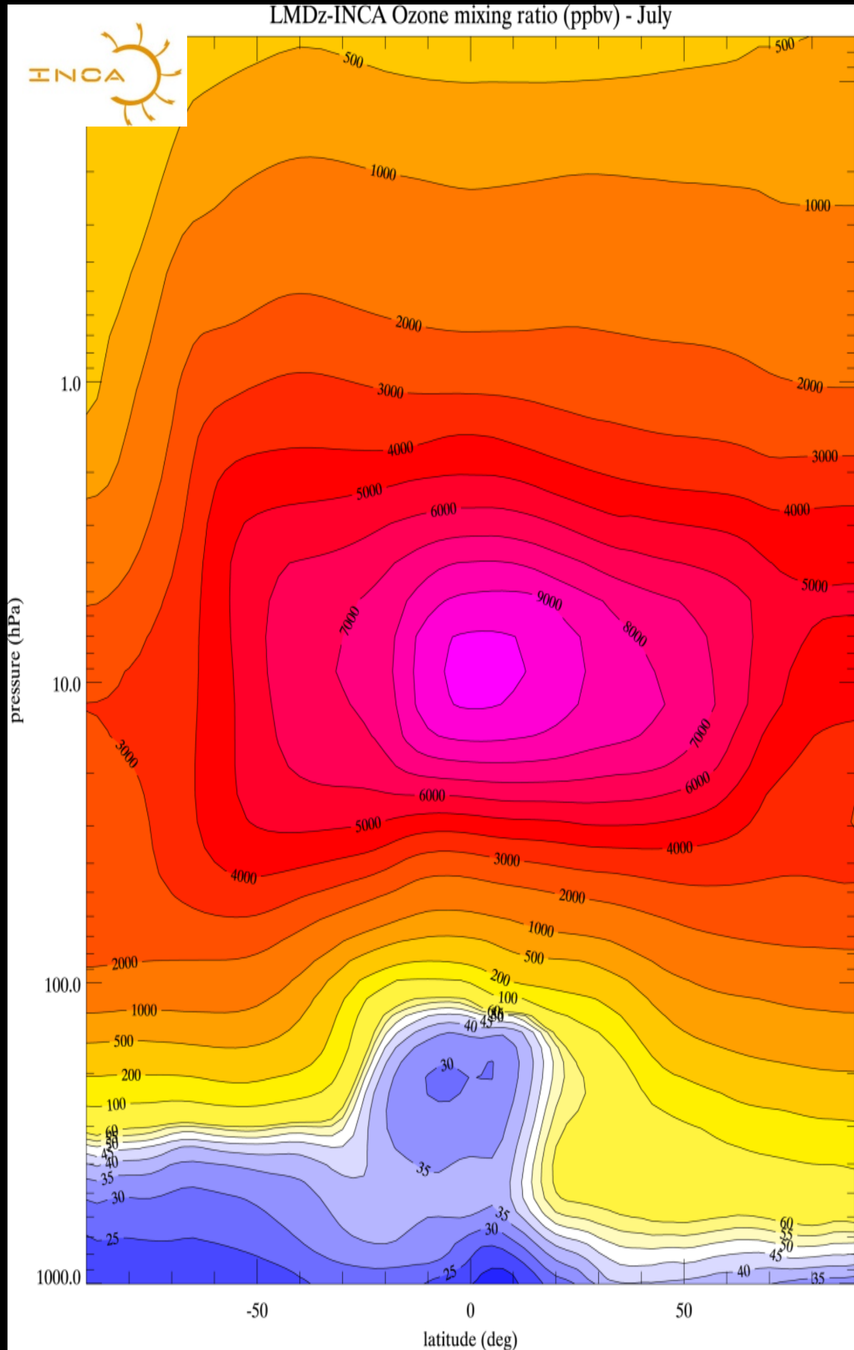
Exemple 1. Impact de la pollution sur le climat

LMDz5-INCA4 chemistry-climate model

- On-line chemistry model in LMDz GCM
- Resolution: 2.5°-3.75° long. x 1.27°-1.9° lat (39-79 levels)
- NMHC tropospheric gas phase chemistry (about 100 tracers) (Hauglustaine et al., 2004) and stratospheric chemistry (about 50 tracers).
- Different aerosol types (BC, OC, SOA, SO4, NO3, dust, seasalt) and interactions with gas phase chemistry.
- Interactive dry deposition scheme
- Van-Leer (1977) advection; K. Emanuel convection; Louis (1972) boundary layer mixing).

ORCHIDEE Dynamical Vegetation model

- Dynamical global vegetation model: seasonal phenological cycle - carbon cycle, latent and sensible heat fluxes. Dynamical vegetation model (Krinner et al., 2004)
- Biogenic NMHC emission parameterization (LAI, PFT emissivities, temperature, PAR, leaf age, CO_2) (Lathière et al., 2006; Messina et al., 2016)
- NO and NH_3 soil emissions (soil temperature and moisture, precipitation pulses, fertilizers)



Application à la pollution en Chine (1/2)

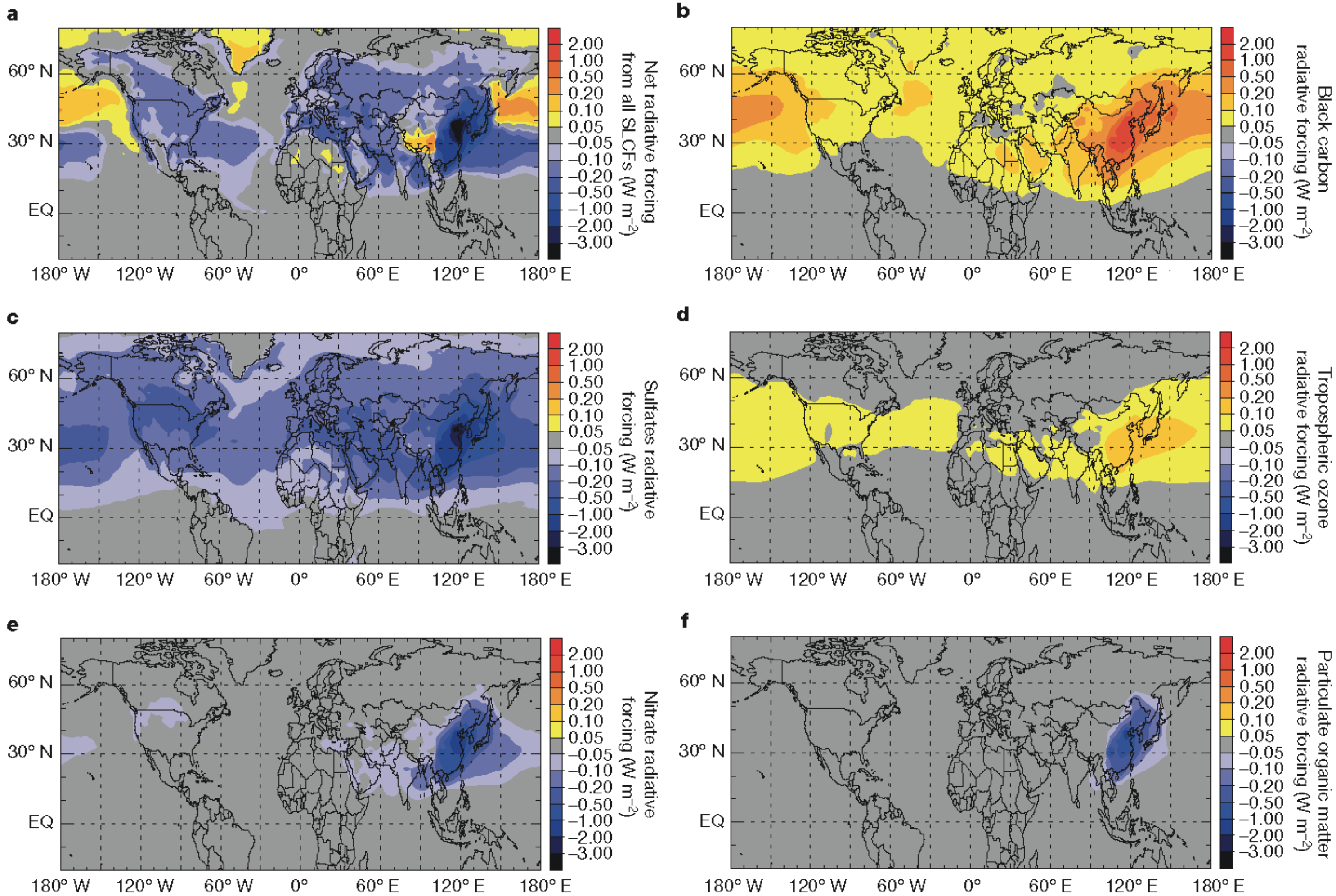
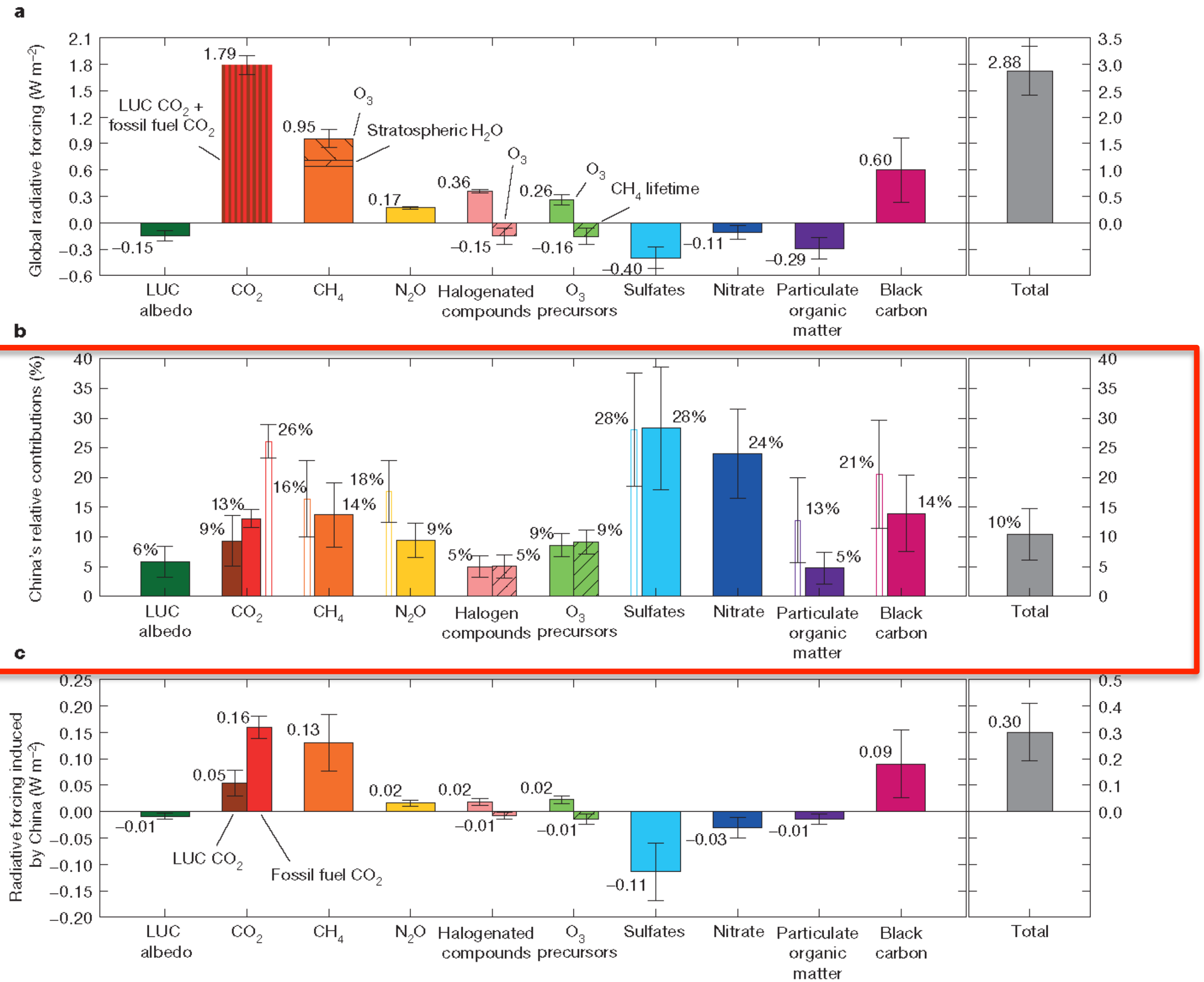


Figure 3 | Spatial distribution of RFs from China-induced SLCFs. All-sky RF of the SLCFs induced by China through emission of short-lived pollutants and precursors in 2010. These RFs are direct outputs from the LMDz-INCA model. **a**, The net RF of all the SLCFs combined. **b–f**, The RFs from black carbon, sulfates, tropospheric ozone, nitrate and particulate organic matter, respectively.

Li et al., 2016

Application à la pollution en Chine (2/2)



China contributes for 26% to the global CO_2 emissions but only for 10% to the total anthropogenic climate forcing since the preindustrial.

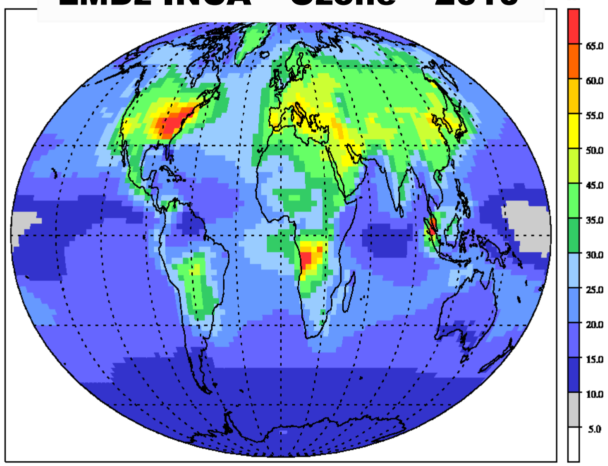
Li et al., 2016

Synergies entre qualité de l’air et changement climatique

Exemple 2. Evolution future de la composition chimique à différentes échelles

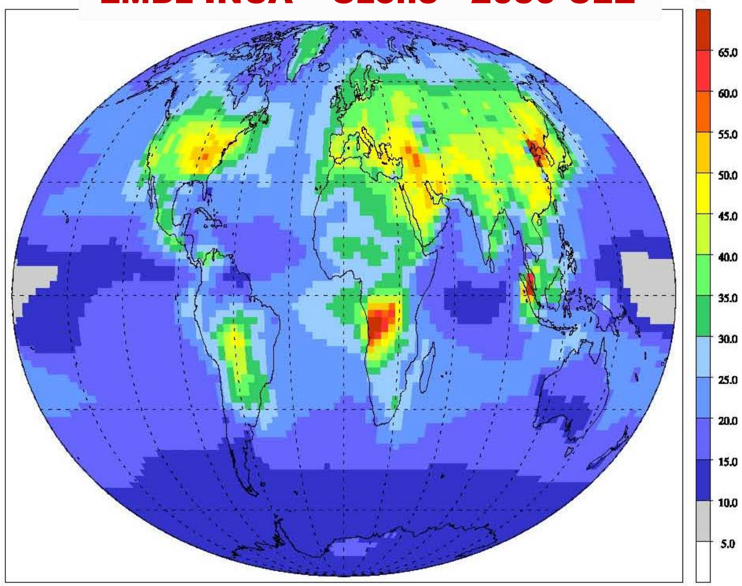
Evolution of future surface ozone at the global scale ...

LMDz-INCA – Ozone – 2010

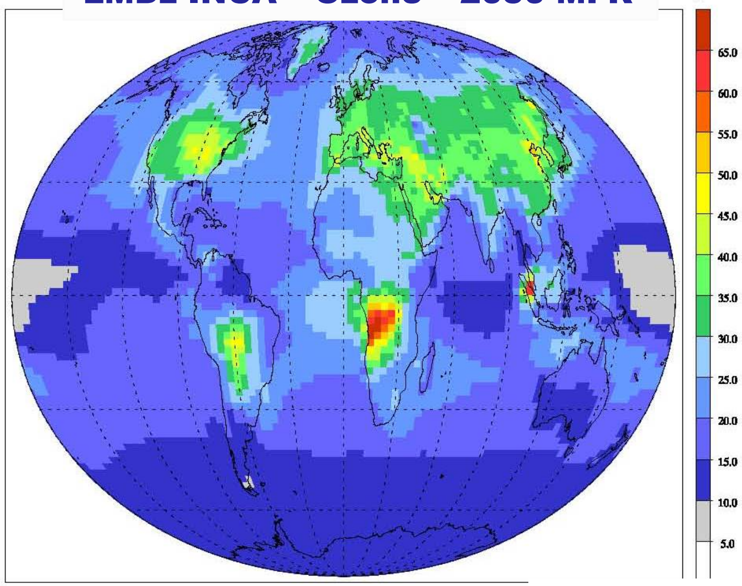


Modélisation de la composition chimique à différentes échelles avec le système LMDz-INCA-CHIMERE. Application dans le cadre du projet ACHIA pour l'étude de l'évolution de la composition chimique en 2050 sous l'effet des émissions et du climat et de son impact sur la santé.

LMDz-INCA – Ozone - 2050 CLE

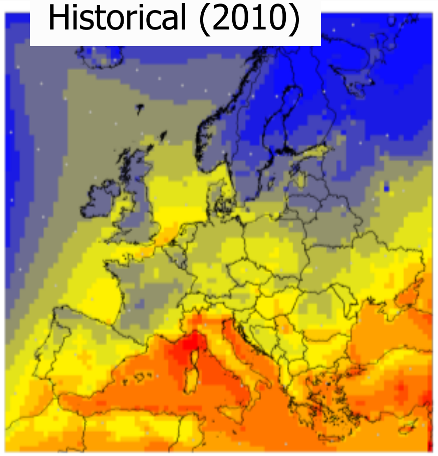


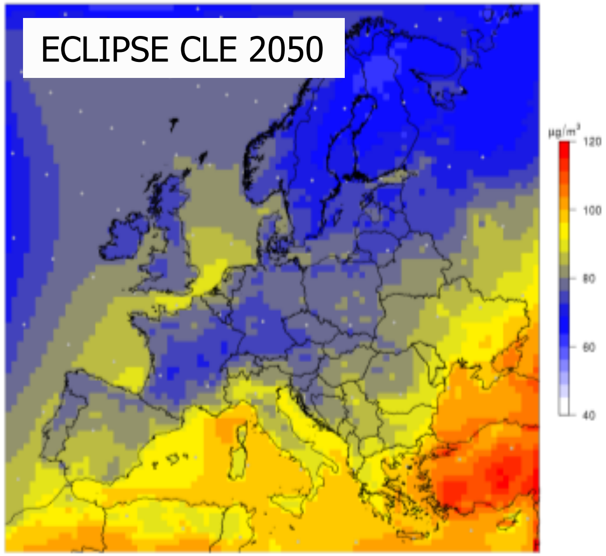
LMDz-INCA – Ozone – 2050 MFR



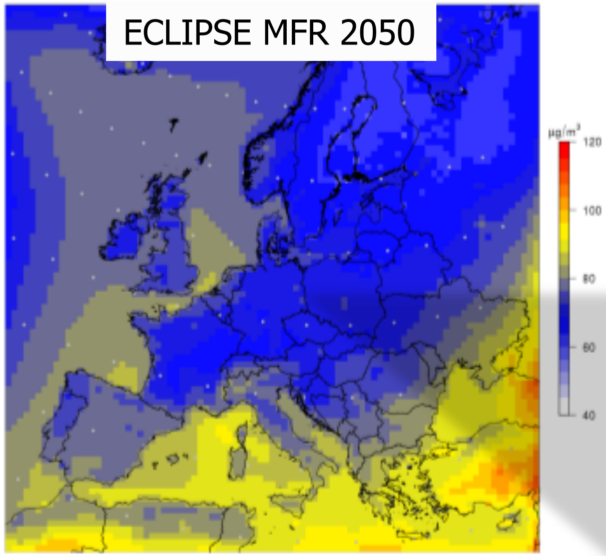
Likhvar et al., 2015

... and at the regional and city scales.

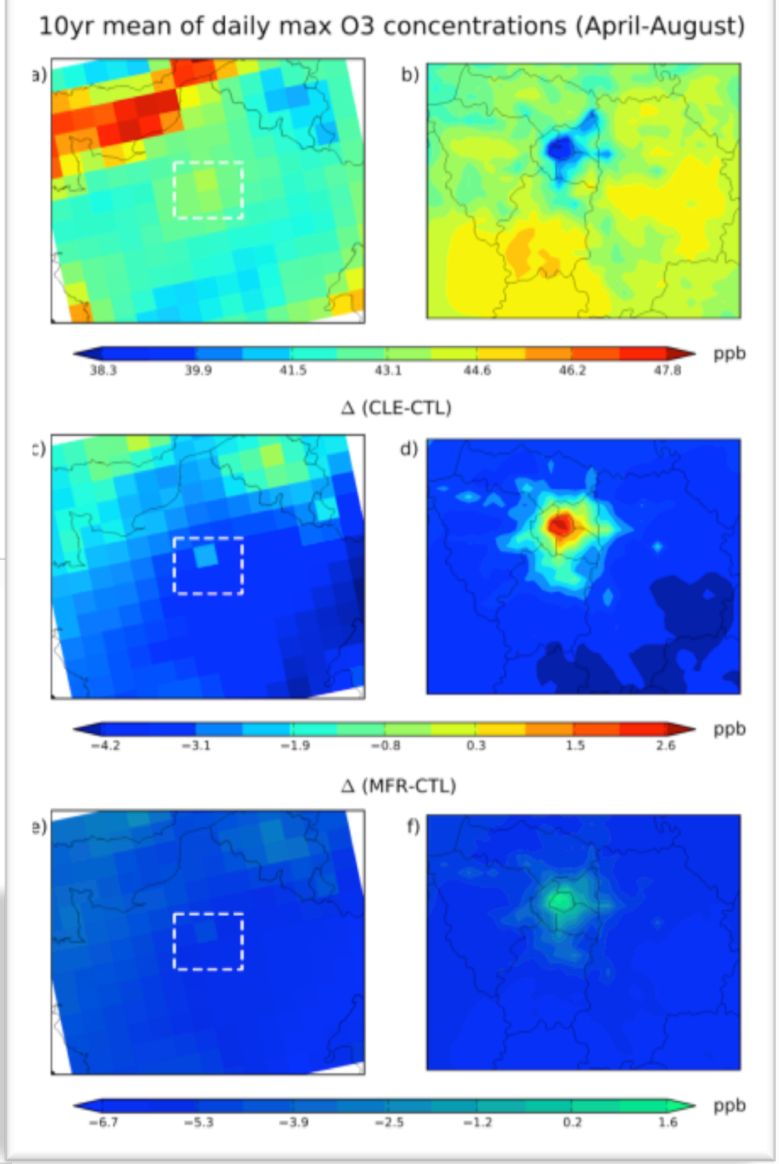




50km x 50km



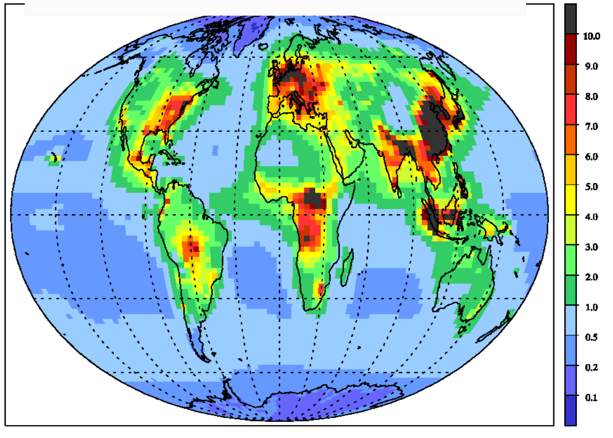
4km x 4km



Likhvar et al., 2015

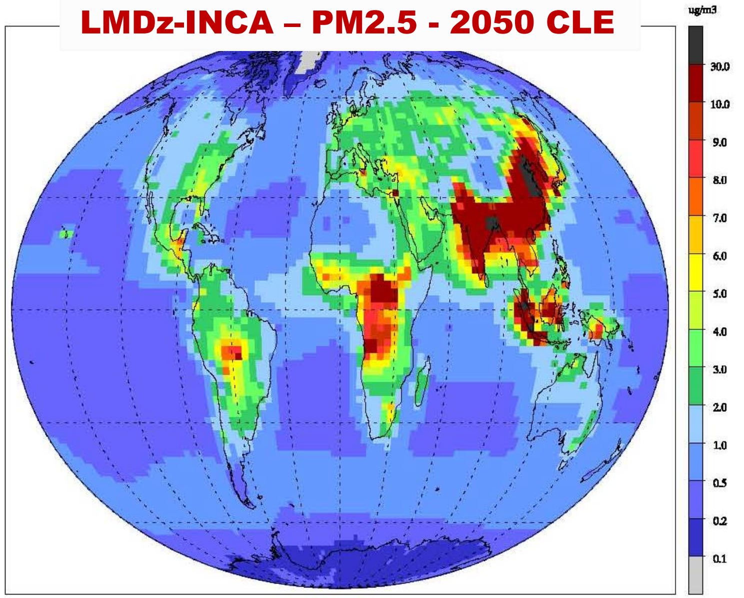
Evolution of PM2.5 surface concentration at the global scale ...

LMDz-INCA – PM2.5 - 2010

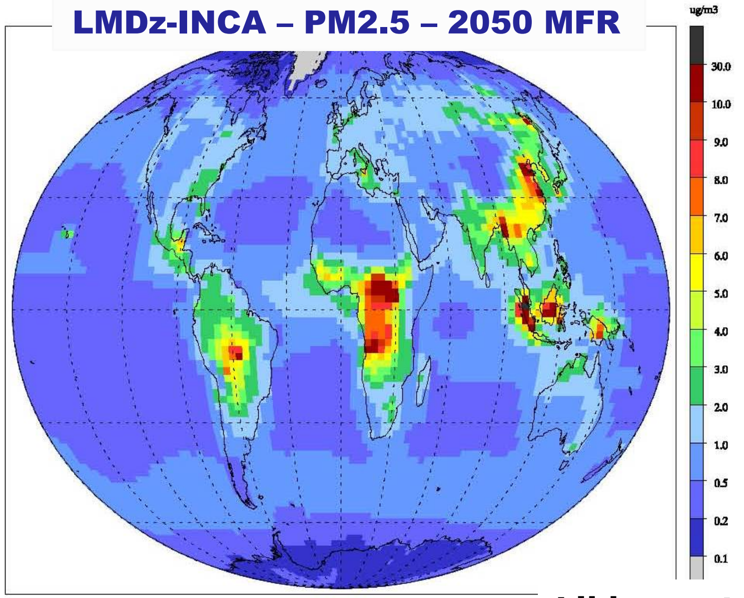


Modélisation de la composition chimique à différentes échelles avec le système LMDz-INCA-CHIMERE. Application dans le cadre du projet ACHIA pour l'étude de l'évolution de la composition chimique en 2050 sous l'effet des émissions et du climat et de son impact sur la santé.

LMDz-INCA – PM2.5 - 2050 CLE



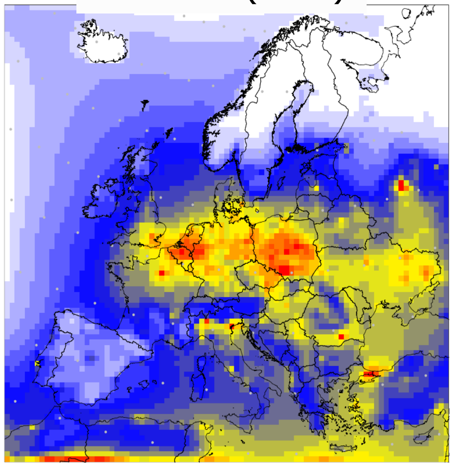
LMDz-INCA – PM2.5 – 2050 MFR



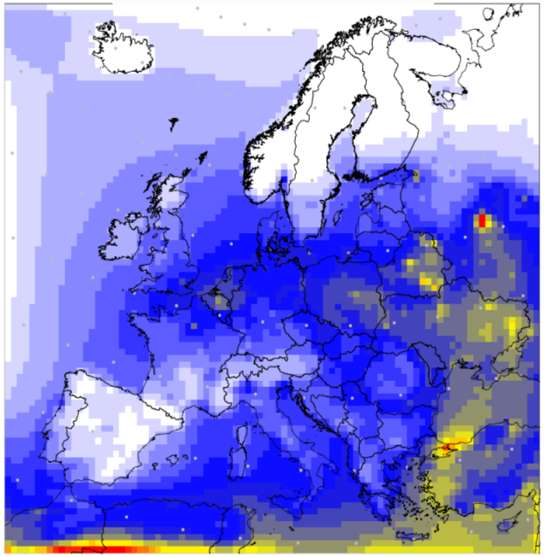
Likhvar et al., 2015

... and at the regional and city scales.

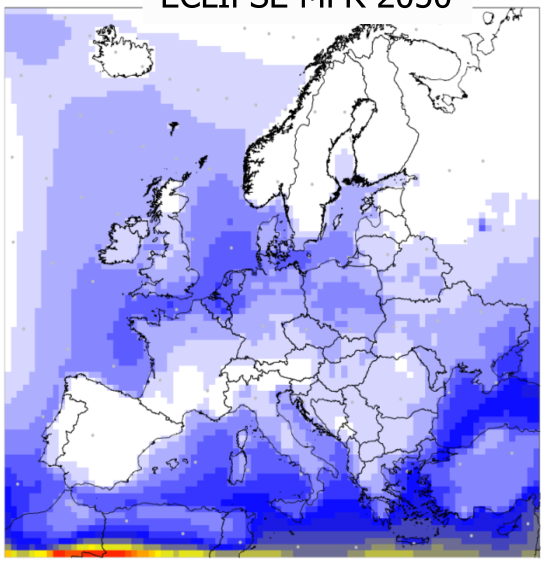
Historical (2010)

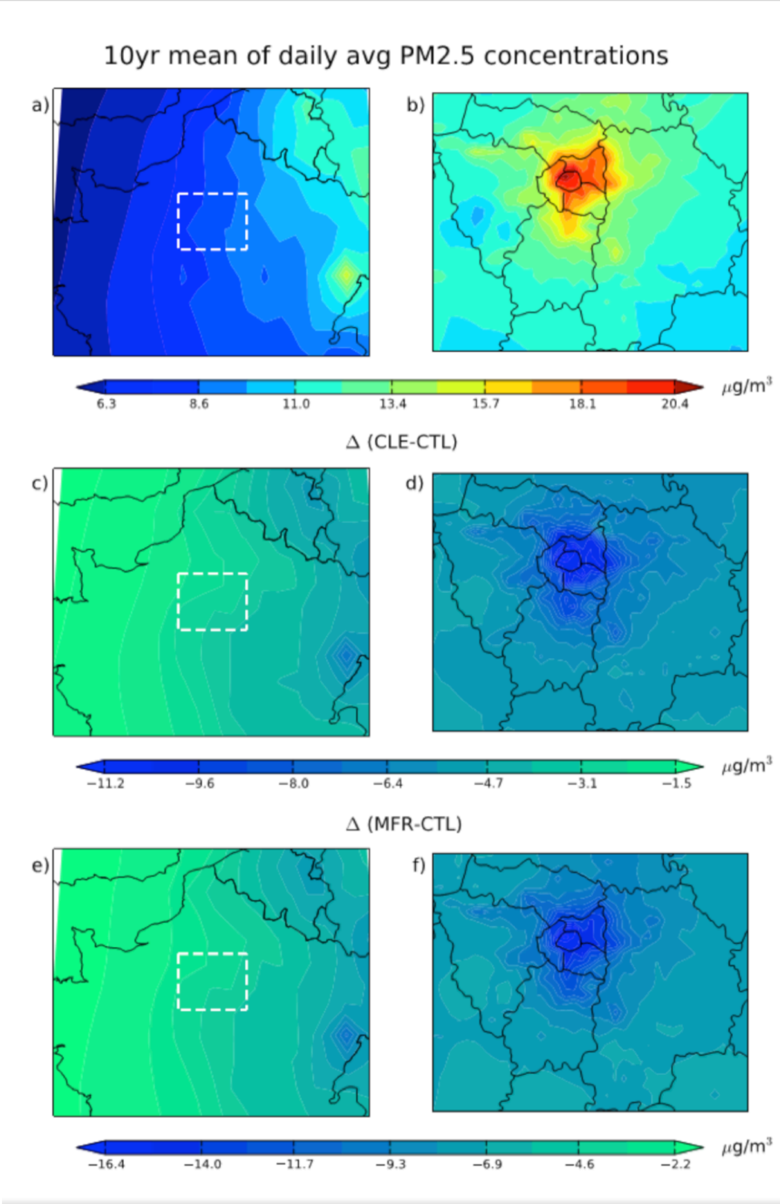


ECLIPSE CLE 2050



ECLIPSE MFR 2050





Likhvar et al., 2015

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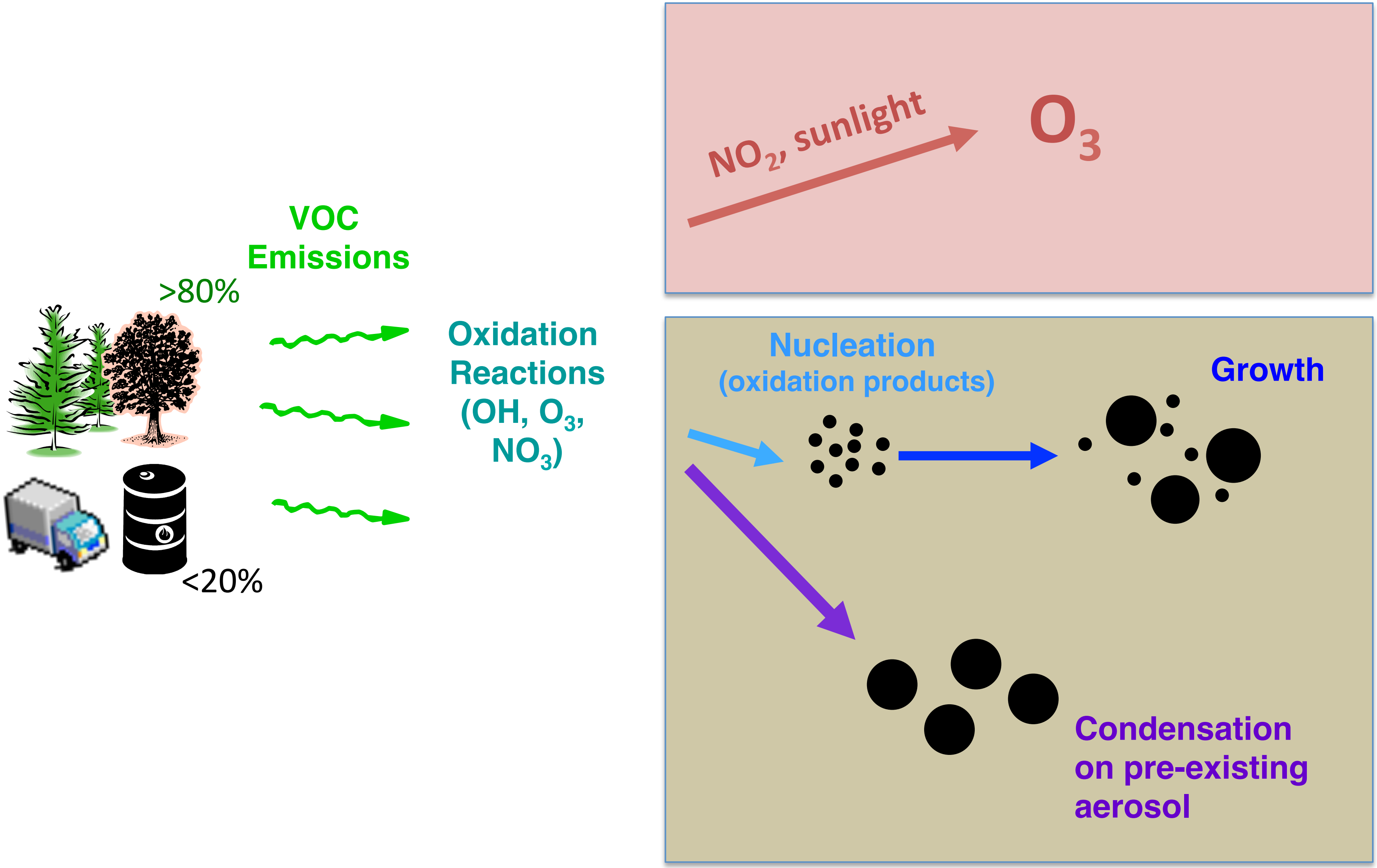
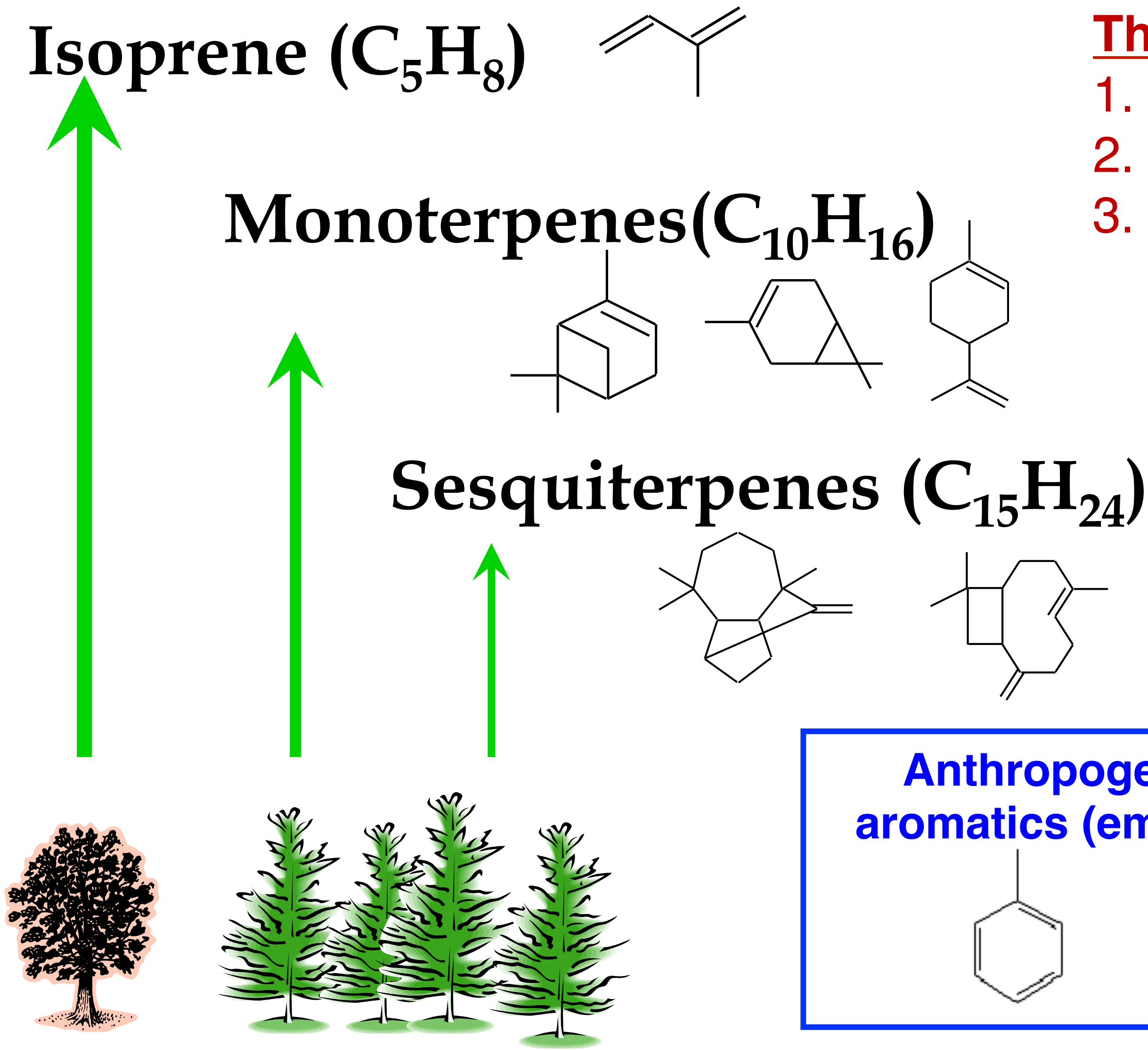
Exemple 3. Rôle des émissions biogéniques de COV

Ozone and Secondary Organic Aerosol production



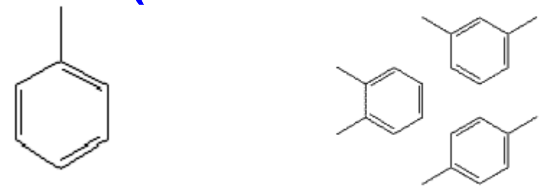
Biogenic VOCs are important SOA precursors



<u>Three factors:</u>

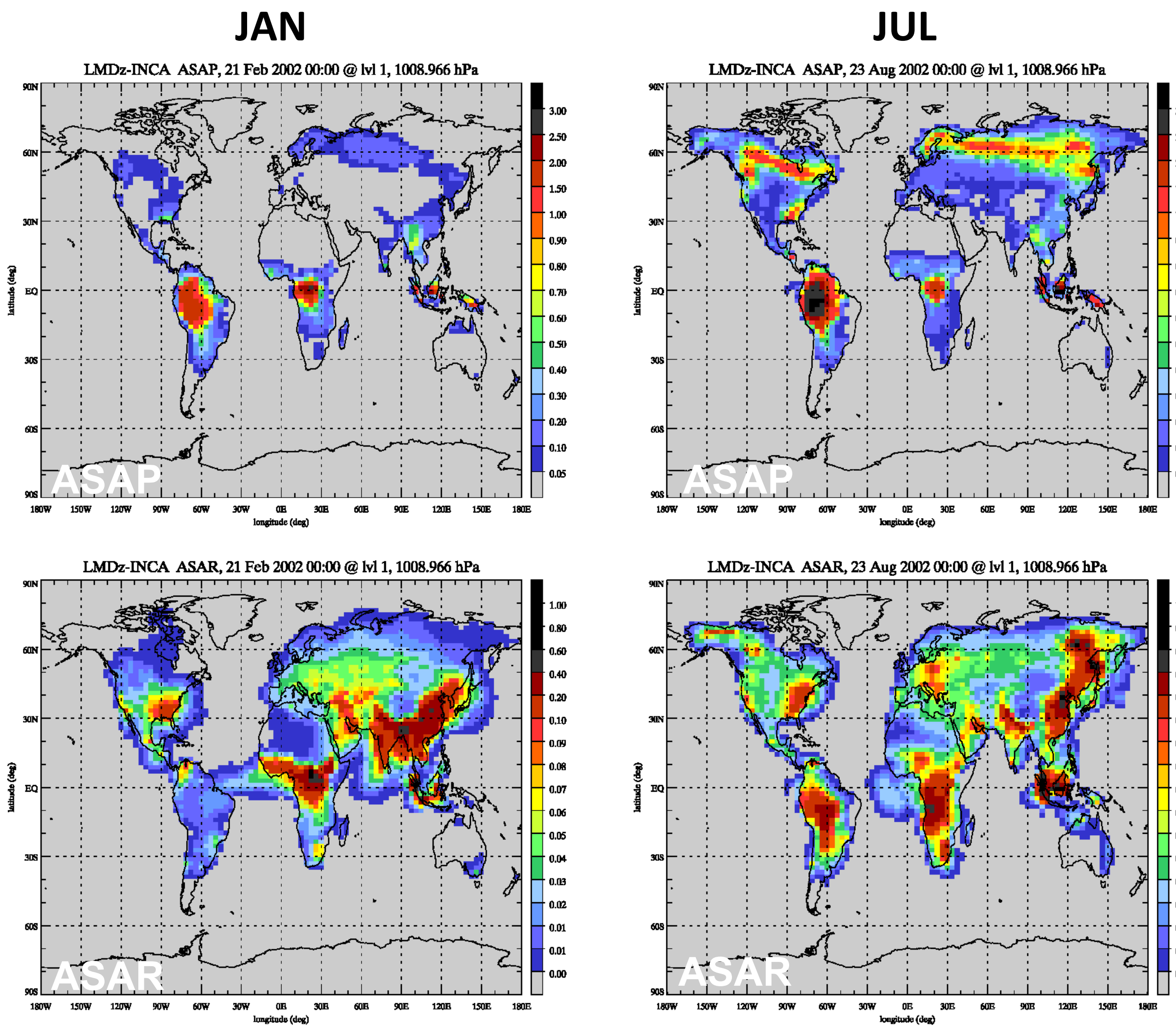
1. Atmospheric Abundance
2. Chemical reactivity
3. The vapour pressure (or volatility) of its products

Anthropogenic SOA-precursors = aromatics (emissions are 10x smaller)



Aérosols organiques secondaires dans INCA

- **SOA formation introduced in the INCA model based on Tsigaridis and Kanakidou (2003).**
- **Four different types of SOA are considered depending on the parent HC and on the volatility.**
- **ASAP from biogenics; ASAR from anthropogenic aromatics.**



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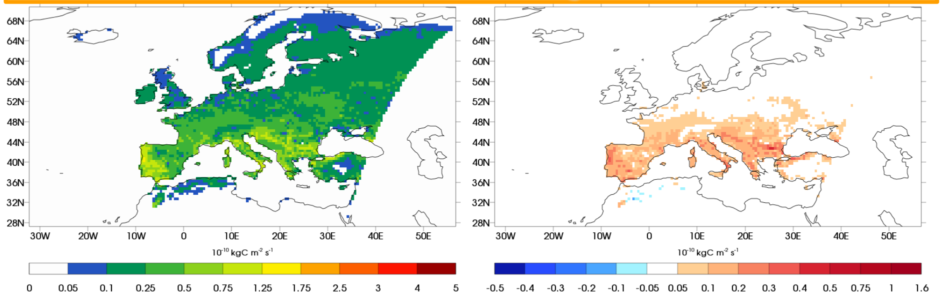
Futrure biogenic emissions at the European scale

5.9 → 7.1 TgC/y

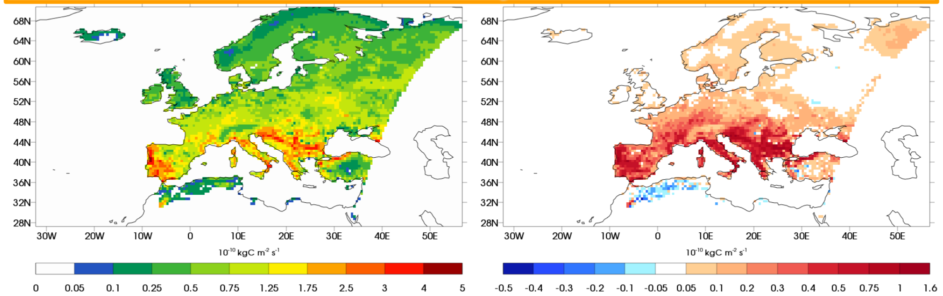
Isoprene

+ 17 %

Future | **Annual average** | Diff Future-Present



Future | **July** | Diff Future-Present



10^{-10} kgC m^{-2} s^{-1}

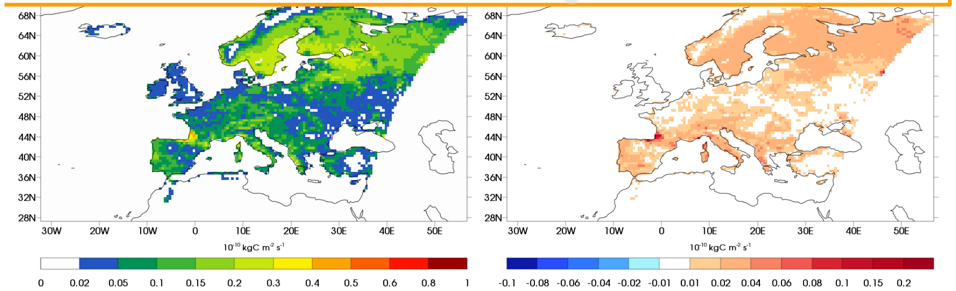
10^{-10} kgC m^{-2} s^{-1}

2.2 → 2.6 TgC/y

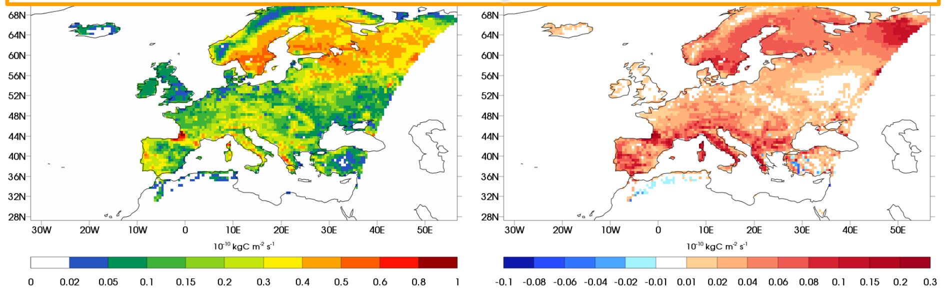
Monoterpenes

+ 15 %

Future | **Annual average** | Diff Future-Present



Future | **July** | Diff Future-Present

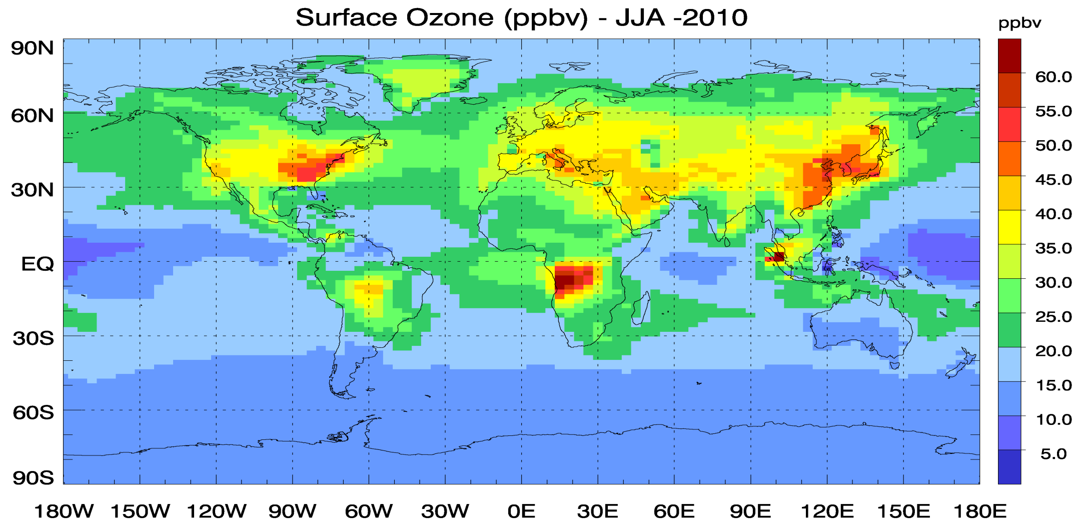


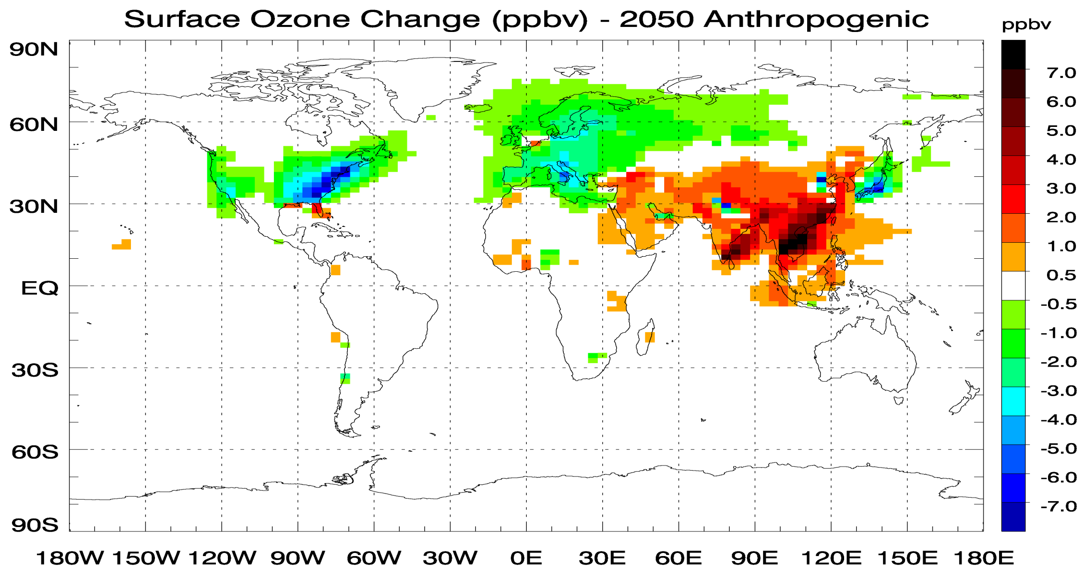
10^{-10} kgC m^{-2} s^{-1}

10^{-10} kgC m^{-2} s^{-1}

In general **increase** of **BVOC emissions** for whole Europe, the **largest increment** occurs in the months of **June, July** and **August**.

Impact of future BVOC emissions on tropospheric chemistry (1/2)





These emissions have been used in the LMDz-INCA model in order to assess the relative importance of future anthropogenic and biogenic emissions on atmospheric chemistry. Simulations are performed for 2010 and 2050 conditions with ECLIPSE CLE anthropogenic emissions. As an example of these changes in atmospheric composition, the figure shows the surface ozone calculated in June-July-August for 2010 and the changes in 2050 due to anthropogenic emissions.

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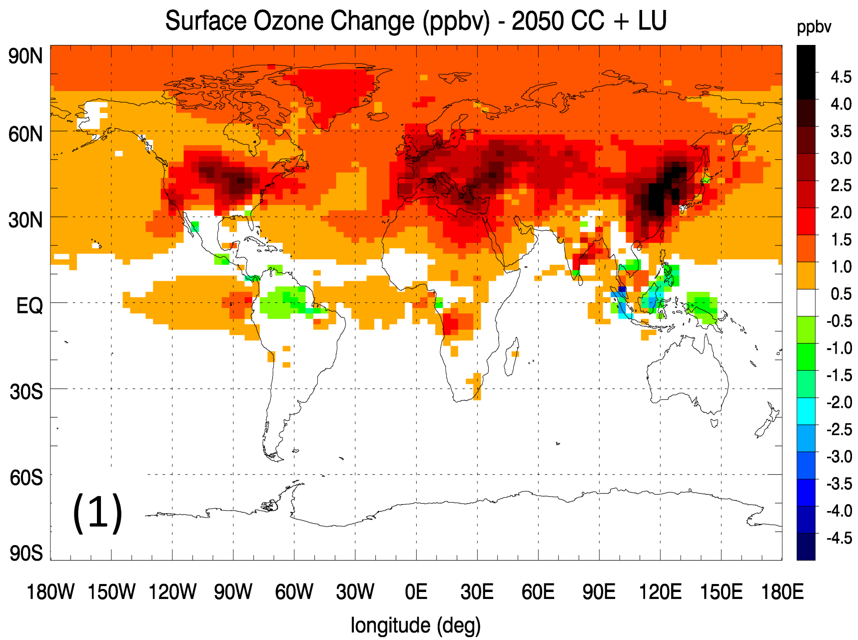
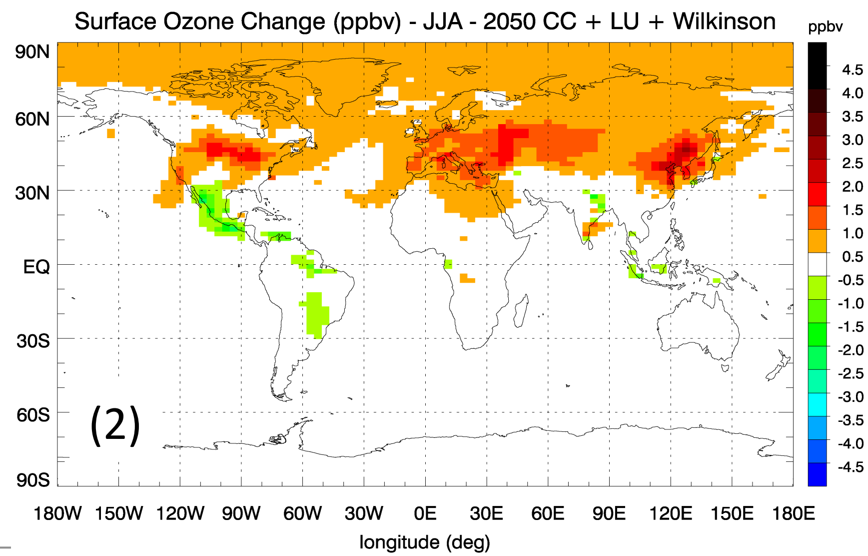
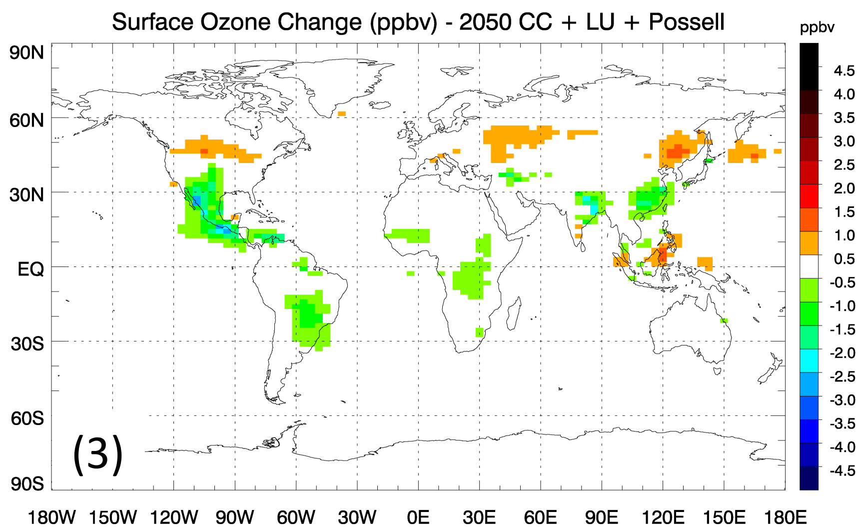
Impact of future BVOC emissions on tropospheric chemistry (2/2)



Changes in surface ozone in 2050 relative to the simulation with present-day biogenic emissions due to future biogenic emissions (ppbv). (1) climate change including CO_2 fertilization (CC) and land-use (LU) changes considered for future BVOC emissions; (2) CC + LU + CO_2 inhibition for isoprene from Wilkinson; (3) CC + LU + CO_2 inhibition from Possell.





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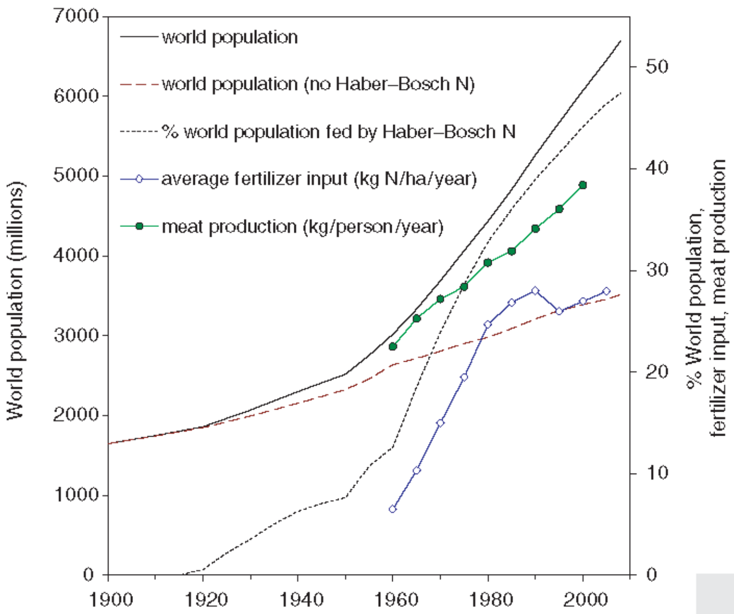
Exemple 4. Le rôle des nitrates

Nitrogen cycle in the atmosphere

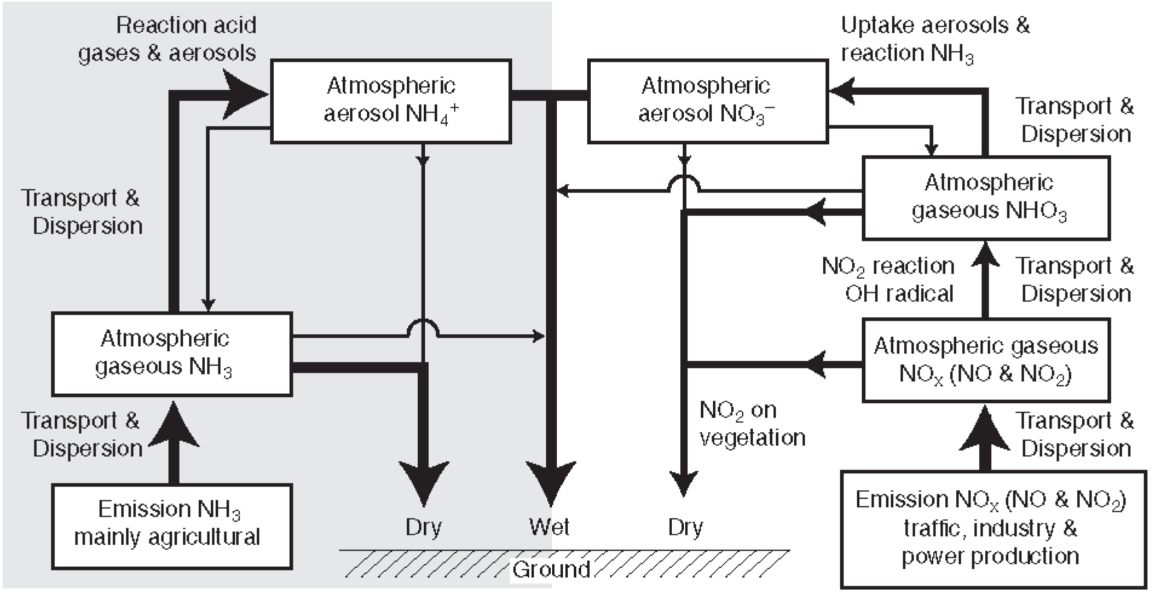


European Nitrogen Assessment, 2011

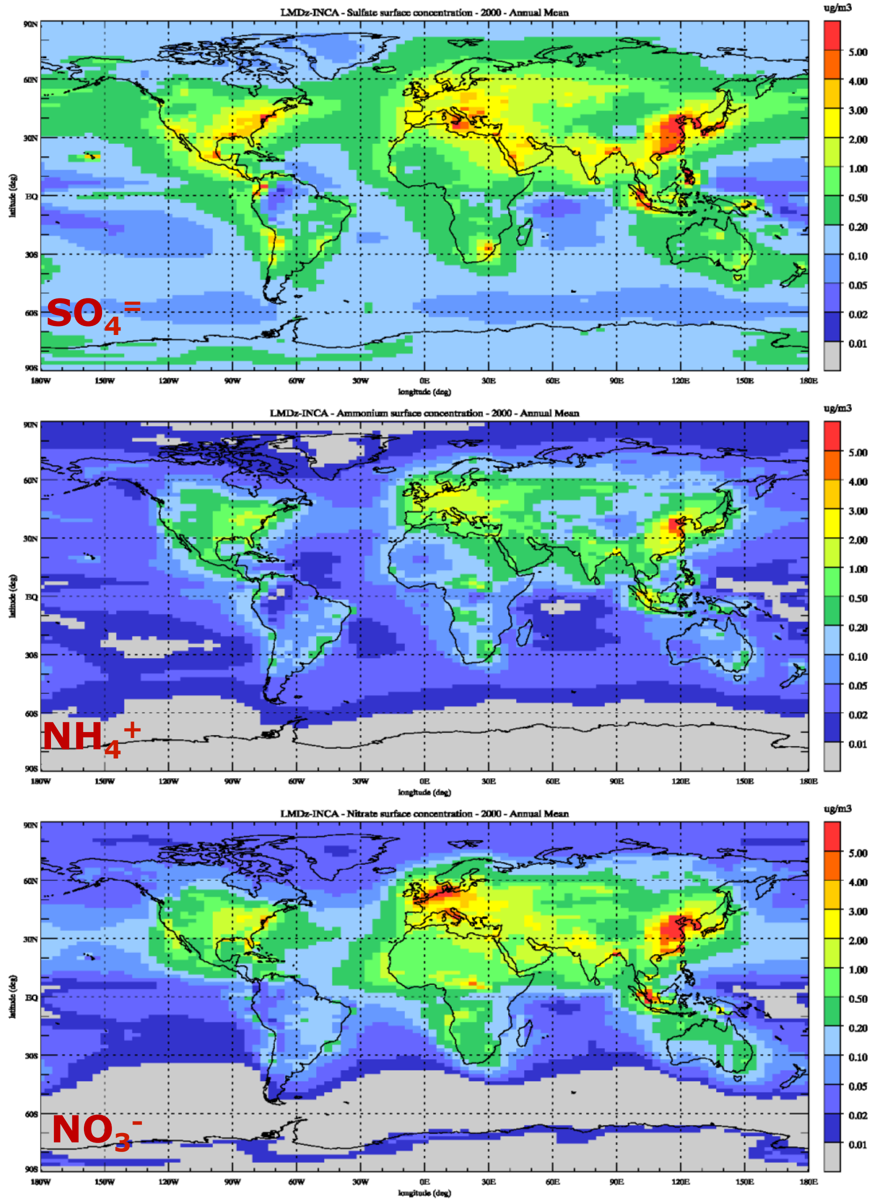
Following the invention of the Haber-Bosch process (1908), it has been possible to produce ammonia in large quantities and relatively cheaply from N_2. The use of synthetic fertilizers supports about 50% of the world population. In particular, the widespread use of ammonia and its derivative as agricultural nitrogen fertilizers has substantially increased emissions of ammonia in the atmosphere.

Nitrate particle formation

The formation of nitrate particles in the atmosphere arises from the reaction of reduced (left) and oxidized (right) nitrogen compounds involving both agricultural (NH_3) and fossil fuel burning (NO_x) emissions.



NH_3 cycle and nitrate formation in LMDz-INCA



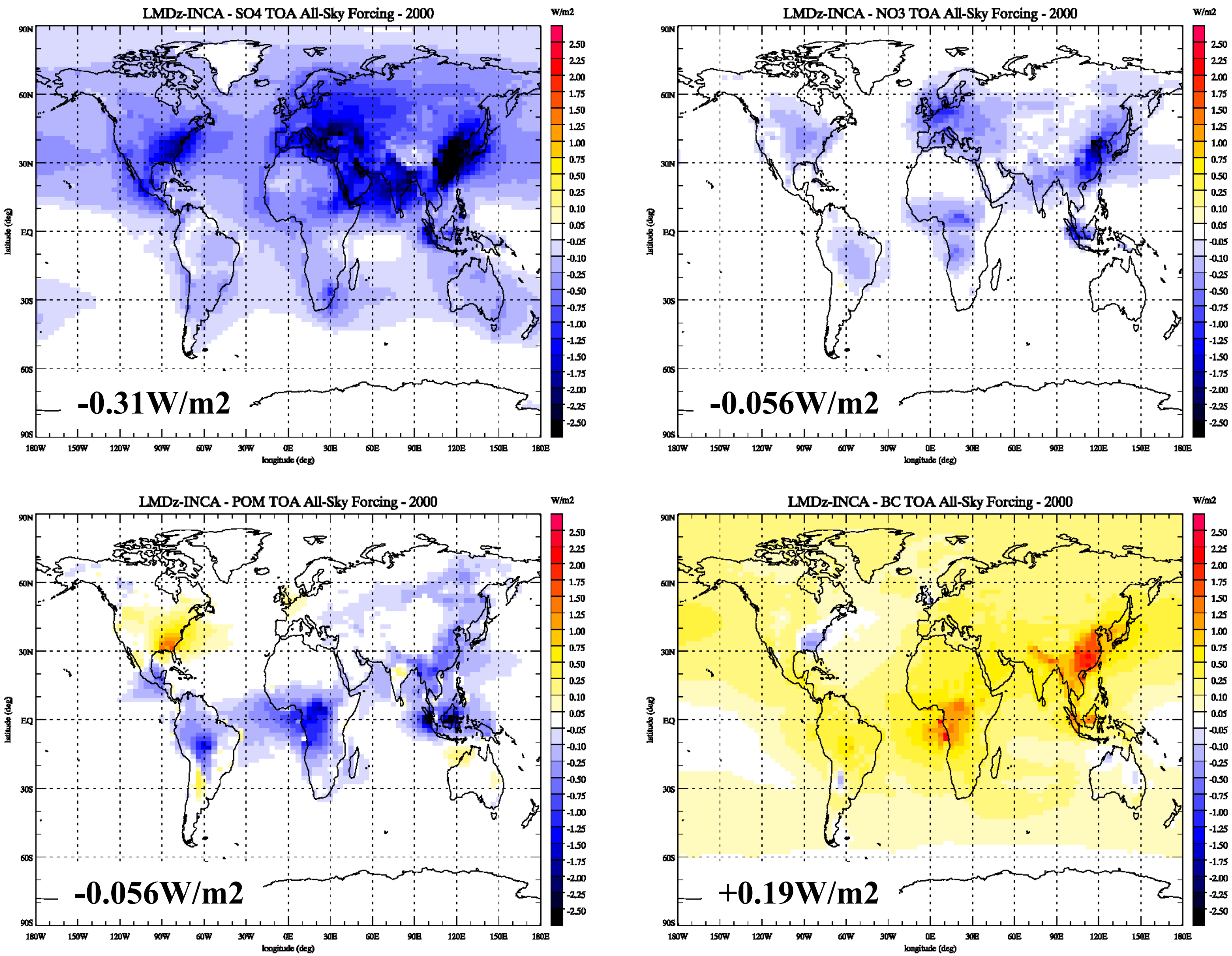
NH_3 emissions based on ACCMIP and RCP scenarios (Lamarque et al., 2010, 2011). Natural emissions from GEIA. Gas phase chemistry of NH_3 and deposition processes.

In the atmosphere NH_3 condenses on preexisting sulfate particles to form ammonium sulfate $(NH_4)_2SO_4$ or $(NH_4)_3H(SO_4)_2$ or NH_4HSO_4.

It can also react in the gas phase with HNO_3 to form new particles of NH_4NO_3. Equilibrium concentration calculated based on Seinfeld and Pandis (1998).

First order heterogeneous reactive uptake of HNO_3 to form coarse nitrates particles on preexisting dust and sea-salt particles.

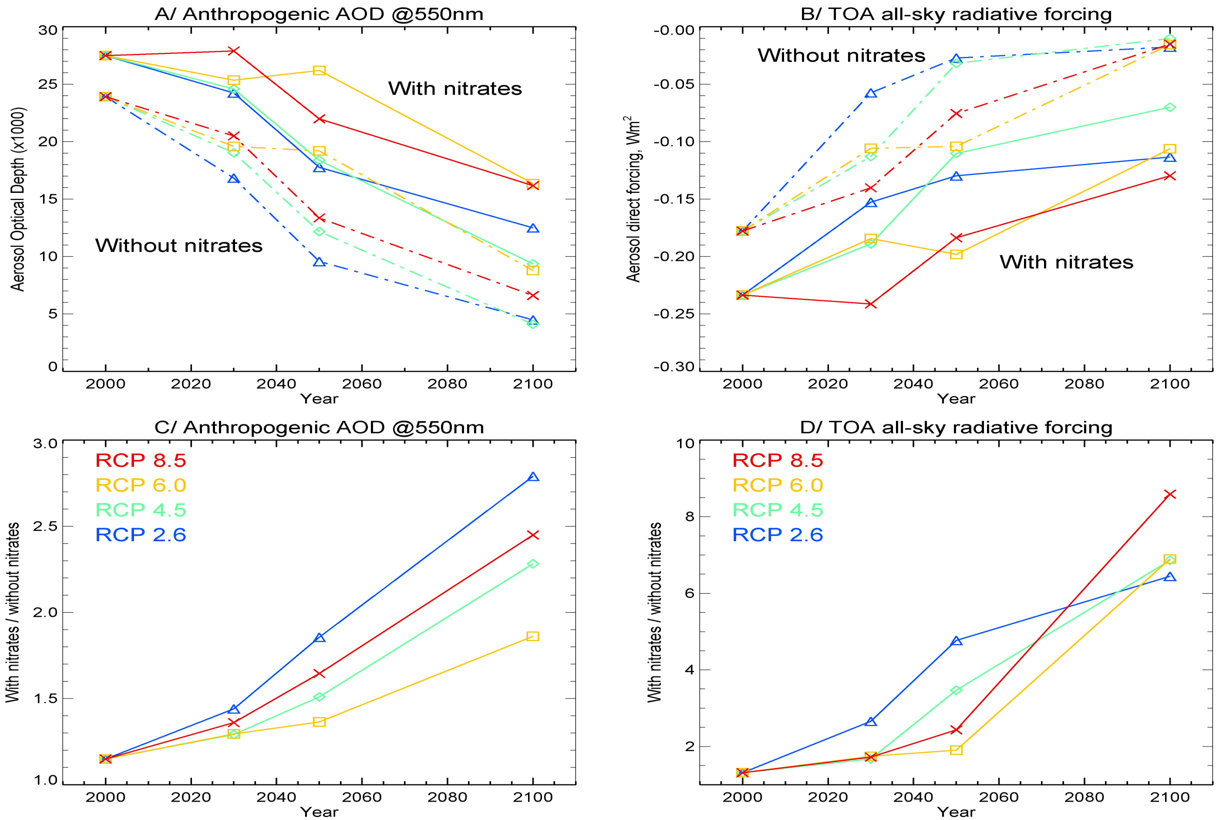
Aerosol direct radiative forcings (W/m²) – 1850-2000



Hauglustaine et al., 2014.

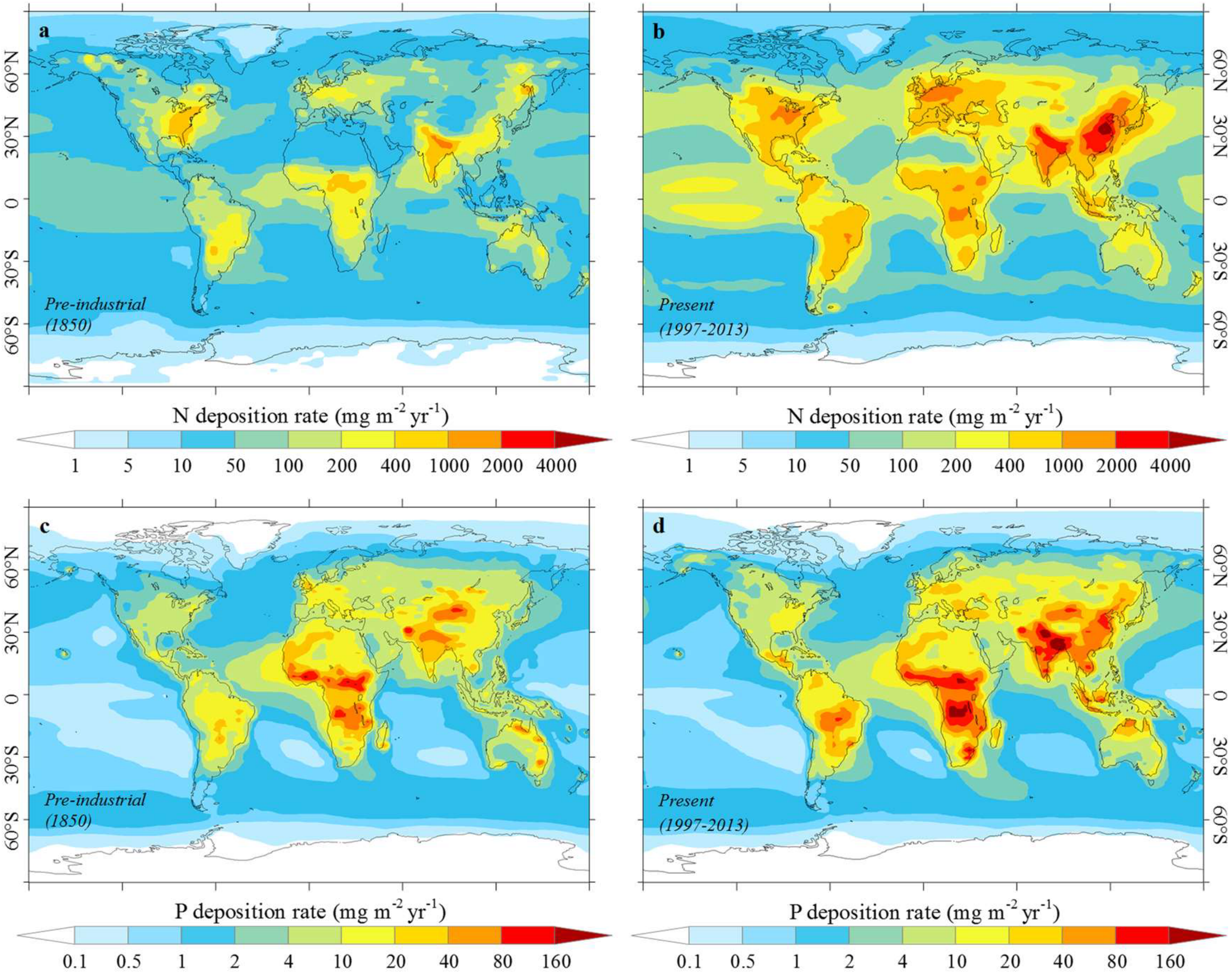
Present and future nitrate aerosols and their direct radiative forcing of climate

Evolution of A/ the aerosol anthropogenic optical depth at 550nm (X1000) and B/ all-sky top of the atmosphere direct radiative forcing (W/m^2) for the four RCP scenarios and from present-day to 2100; RCP8.5 (red), RCP6.0 (yellow), RCP4.5 (green) and RCP2.6 (blue) Solids lines: nitrates included; dashed lines: nitrates excluded. Corresponding fractional contribution of nitrates to the C/ anthropogenic aerosol optical depth and D/ direct radiative forcing.



Hauglustaine et al., 2014

Nitrogen and phosphorous surface deposition in 1850 and 1997-2013



Wang et al., 2017.

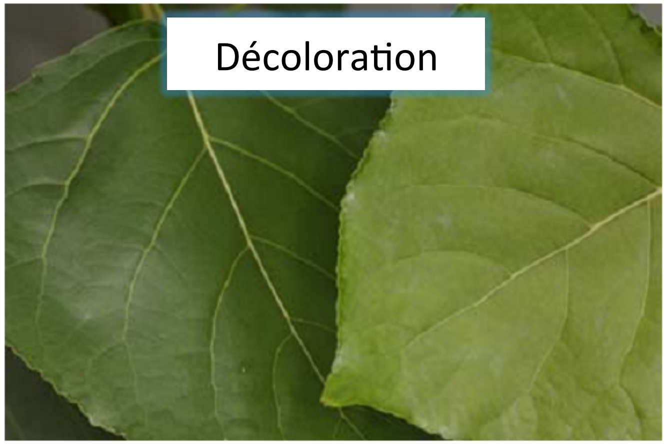
Synergies entre qualité de l'air et changement climatique

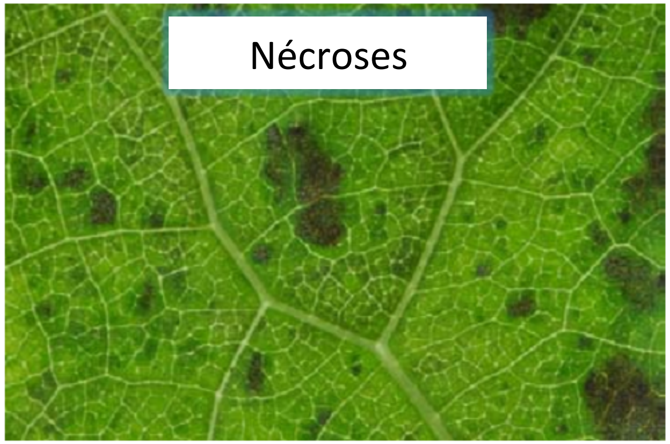
Exemple 5. Impact de l'ozone sur la végétation

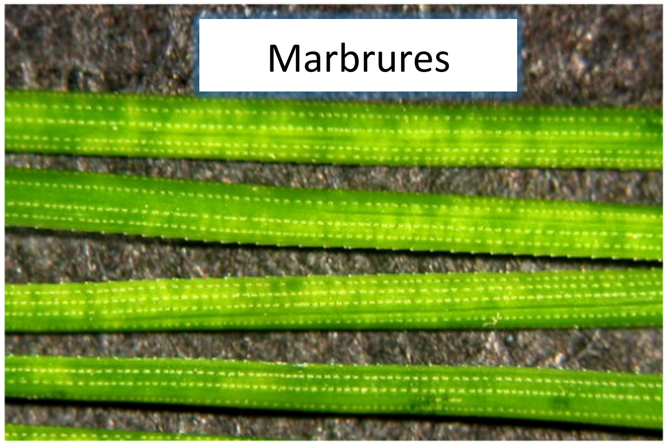
Impact de l'ozone sur la végétation

Dommages visibles à l'échelle foliaire

Symptômes foliaires spécifiques lors d'exposition à des [O_3] très élevées



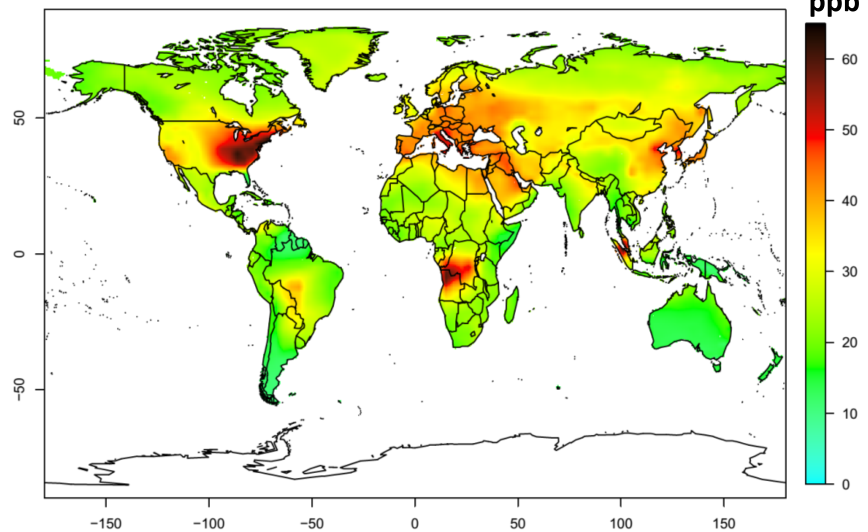




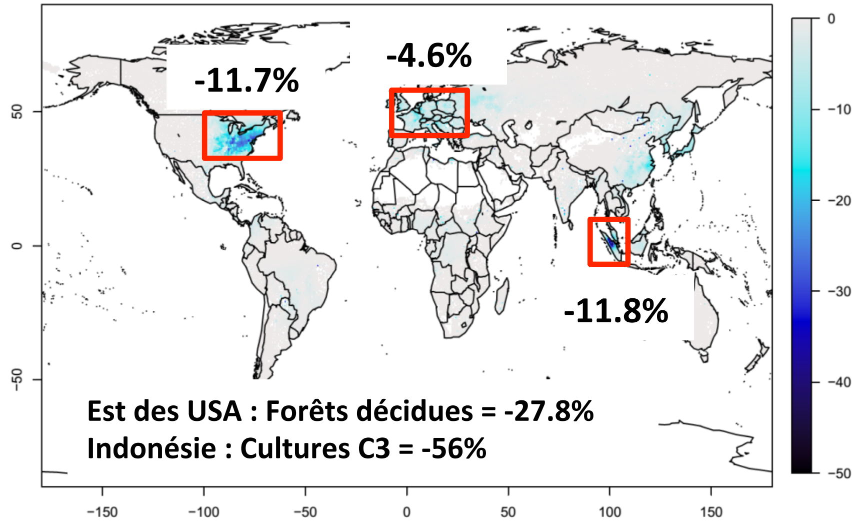
Symptômes d'une réponse des plantes à l'O_3 = ***stress oxydatif interne***

Impact de l'O_3 sur la végétation actuelle

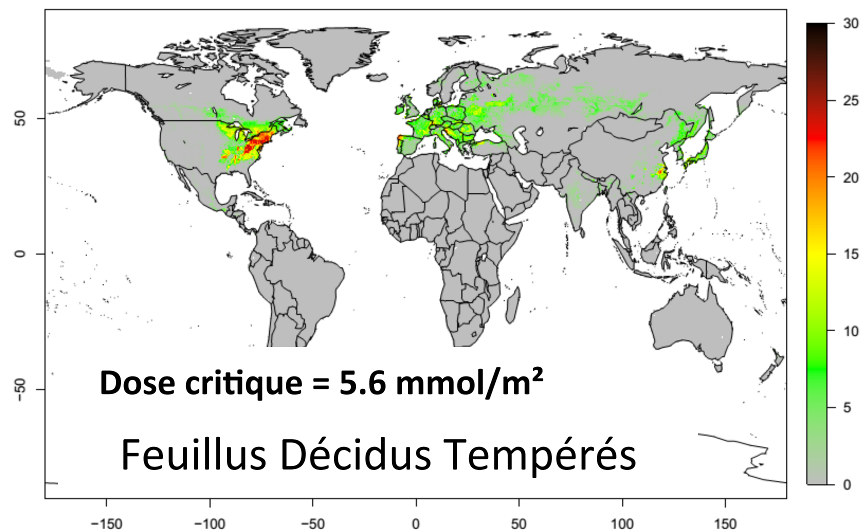
[O_3] (ppb) juin-juillet-aout



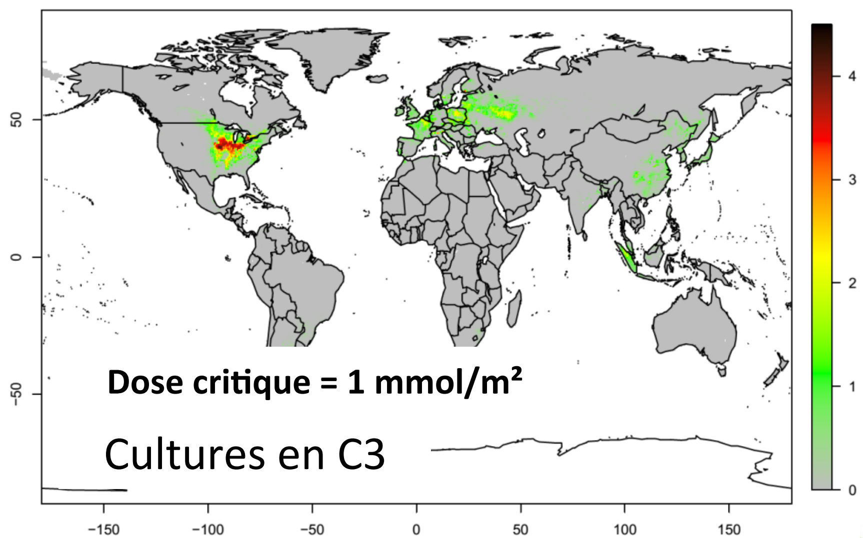
Impact annuel (%) sur la production nette totale



Dose phytotoxique POD6 (mmol/m²)



Dose phytotoxique POD1 (mmol/m²)



T. Verbeke, 2015

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Synergies entre qualité de l'air et changement climatique

Exemple 6. Co-bénéfices climat - santé

Impact de la qualité de l'air sur la santé : rôle de l'ozone et des particules

International Agency for Research on Cancer

World Health Organization

PRESS RELEASE
N° 213

12 June 2012

IARC: DIESEL ENGINE EXHAUST CARCINOGENIC

Lyon, France, June 12, 2012 – After a week-long meeting of international experts, the International Agency for Research on Cancer (IARC), which is part of the World Health Organization (WHO), today classified diesel engine exhaust as **carcinogenic to humans (Group 1)**, based on sufficient evidence that exposure is associated with an increased risk for lung cancer.

Background
In 1988, IARC classified diesel exhaust as *probably carcinogenic to humans* (Group 2A). An Advisory Group which reviews and recommends future priorities for the IARC Monographs Program had recommended diesel exhaust as a high priority for re-evaluation since 1998.

There has been mounting concern about the cancer-causing potential of diesel exhaust, particularly based on findings in epidemiological studies of workers exposed in various settings. This was re-emphasized by the publication in March 2012 of the results of a large US National Cancer Institute/National Institute for Occupational Safety and Health study of occupational exposure to such emissions in underground miners, which showed an increased risk of death from lung cancer in exposed workers (1).

Evaluation
The scientific evidence was reviewed thoroughly by the Working Group and overall it was concluded that there was *sufficient evidence* in humans for the carcinogenicity of diesel exhaust. The Working Group found that diesel exhaust is a cause of lung cancer (*sufficient evidence*) and also noted a positive association (*limited evidence*) with an increased risk of bladder cancer (Group 1).

The Working Group concluded that gasoline exhaust was possibly carcinogenic to humans (Group 2B), a finding unchanged from the previous evaluation in 1989.

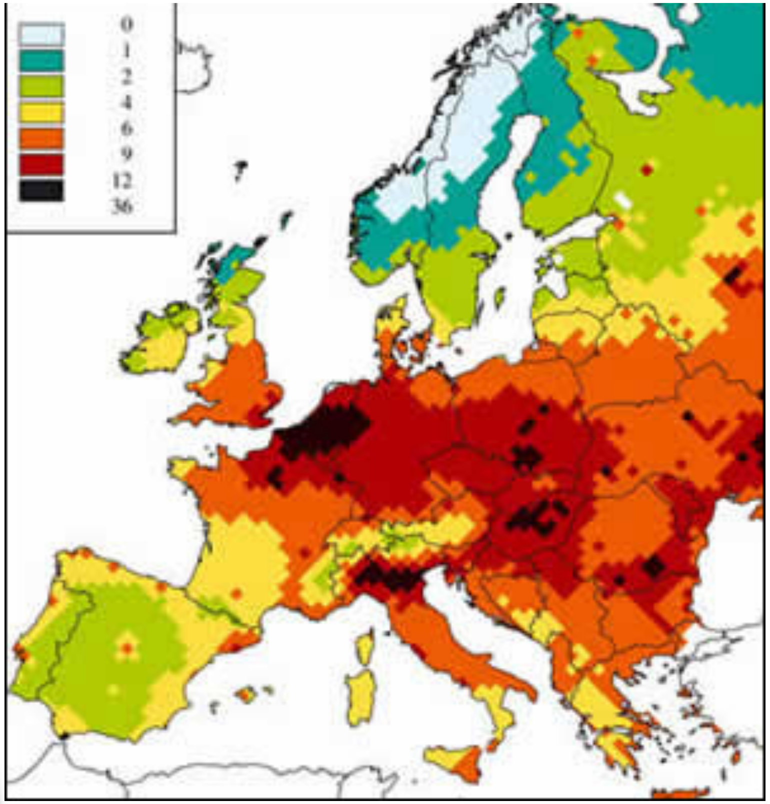
Public health
Large populations are exposed to diesel exhaust in everyday life, whether through their occupation or through the ambient air. People are exposed not only to motor vehicle exhausts but also to exhausts from other diesel engines, including from other modes of transport (e.g. diesel trains and ships) and from power generators.

Given the Working Group's rigorous, independent assessment of the science, governments and other decision-makers have a valuable evidence-base on which to consider environmental standards for diesel exhaust emissions and to continue to work with the engine and fuel manufacturers towards those goals.

Increasing environmental concerns over the past two decades have resulted in regulatory action in North America, Europe and elsewhere with successively tighter emission standards for both diesel and gasoline engines. There is a strong interplay between standards and technology – standards drive technology and new technology enables more stringent standards. For diesel engines, this required changes in the fuel such as marked decreases in sulfur content, changes in engine design to burn diesel fuel more efficiently and reductions in emissions through exhaust control technology.

However, while the amount of particulates and chemicals are reduced with these changes, it is not yet clear how the quantitative and qualitative changes may translate into altered health effects; research into

400.000 morts prématurées en Europe



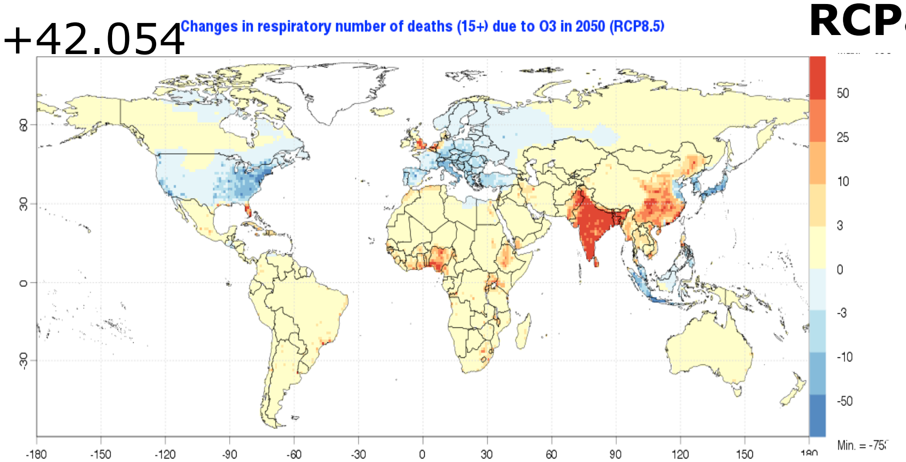
Co-bénéfices climat-santé des espèces à courte durée de vie

Synergies et co-bénéfices: la mitigation du changement climatique à un effet sur les émissions de SLCP et donc sur la qualité de l’air et la santé. Variation du nombre de morts prématurées en 2050 associées à O_3 et PM dans LMDz-INCA pour RCP8.5 et 2.6.

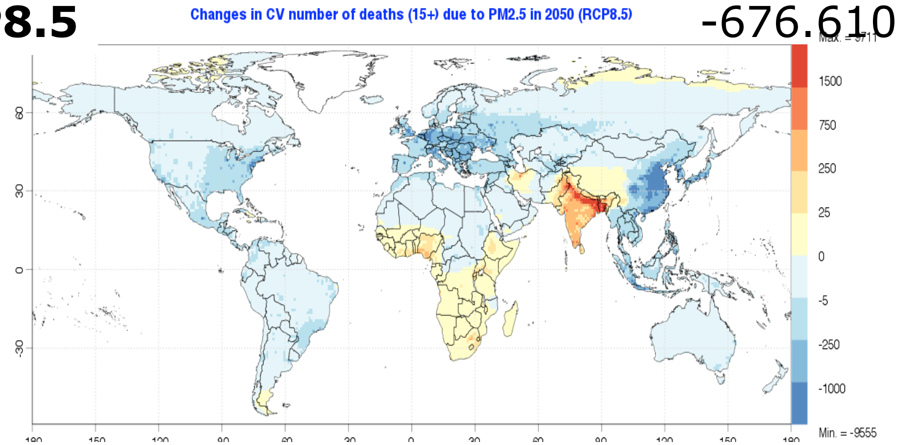
Ozone | **PM2.5**

RCP8.5

+42.054

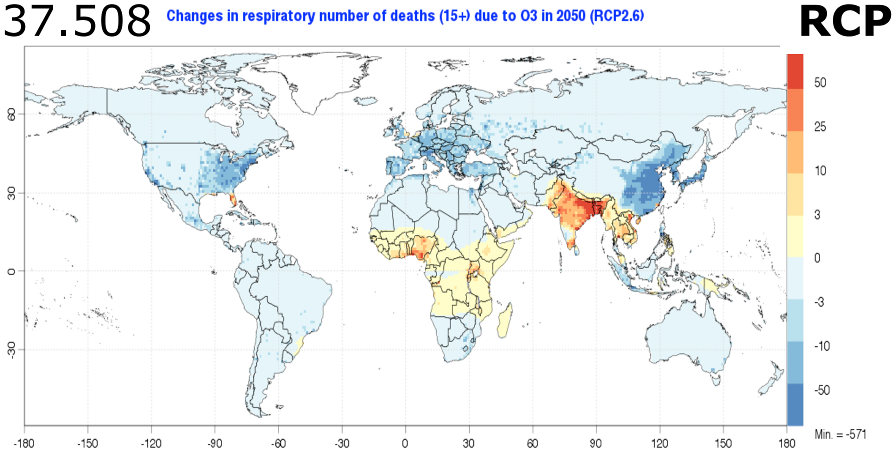


-676.610

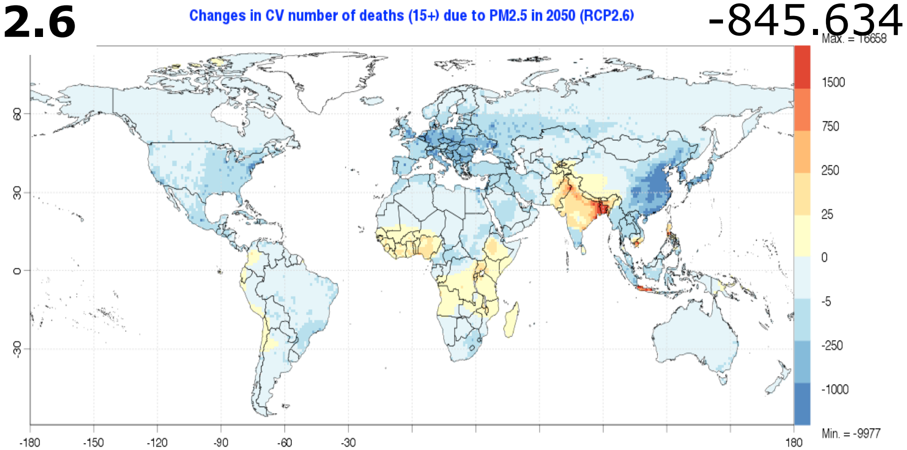


RCP2.6

-37.508

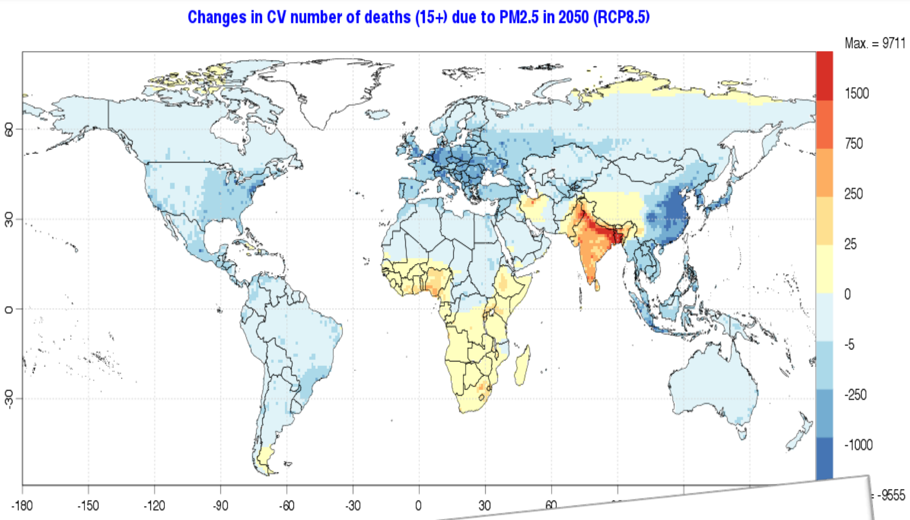


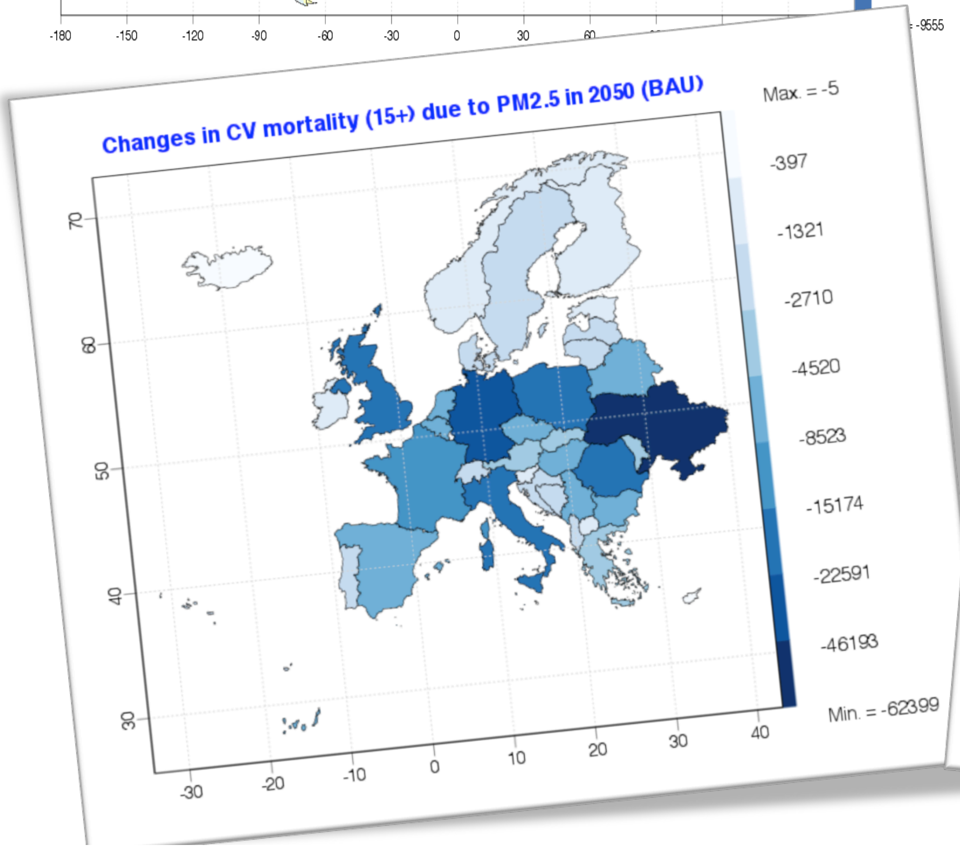
-845.634

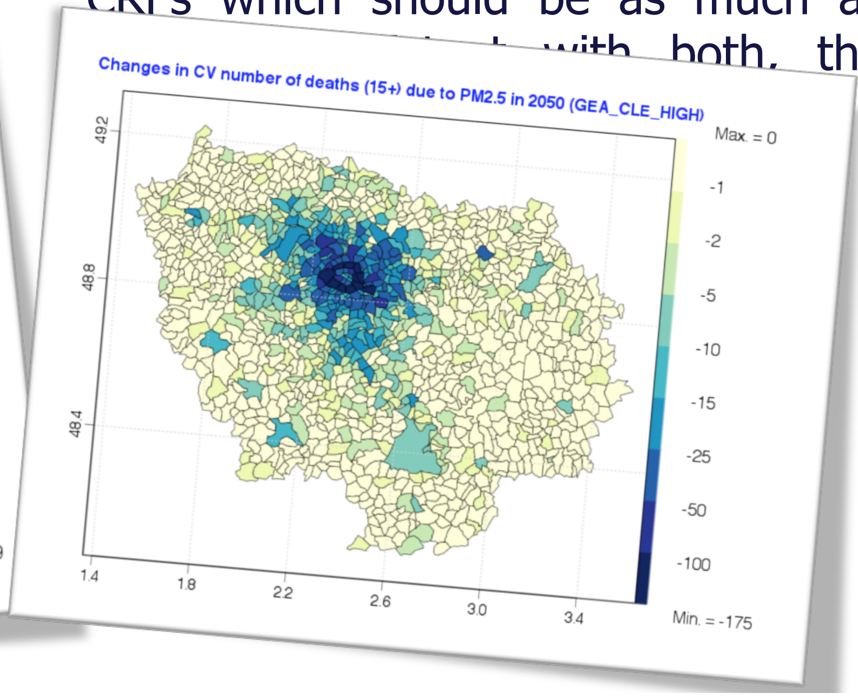


Likhvar et al., 2015

Impact sur la santé à différentes échelles







We applied HIA methods to estimate the long-term impacts of PM2.5 on total and cardiovascular mortality, and of ozone and respiratory mortality.

To ensure consistency on each scale, several decisions were made regarding availability and quality of health data, air quality modeling capabilities and the choices for the CRFs which should be as much as ... with both, the