Institut Pierre Simon Laplace

IPSL Climate Modelling Centre

LMD

Projection of future climate change at the global scale

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IPSL Climate Modeling Center
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Paris, 12 November 2013

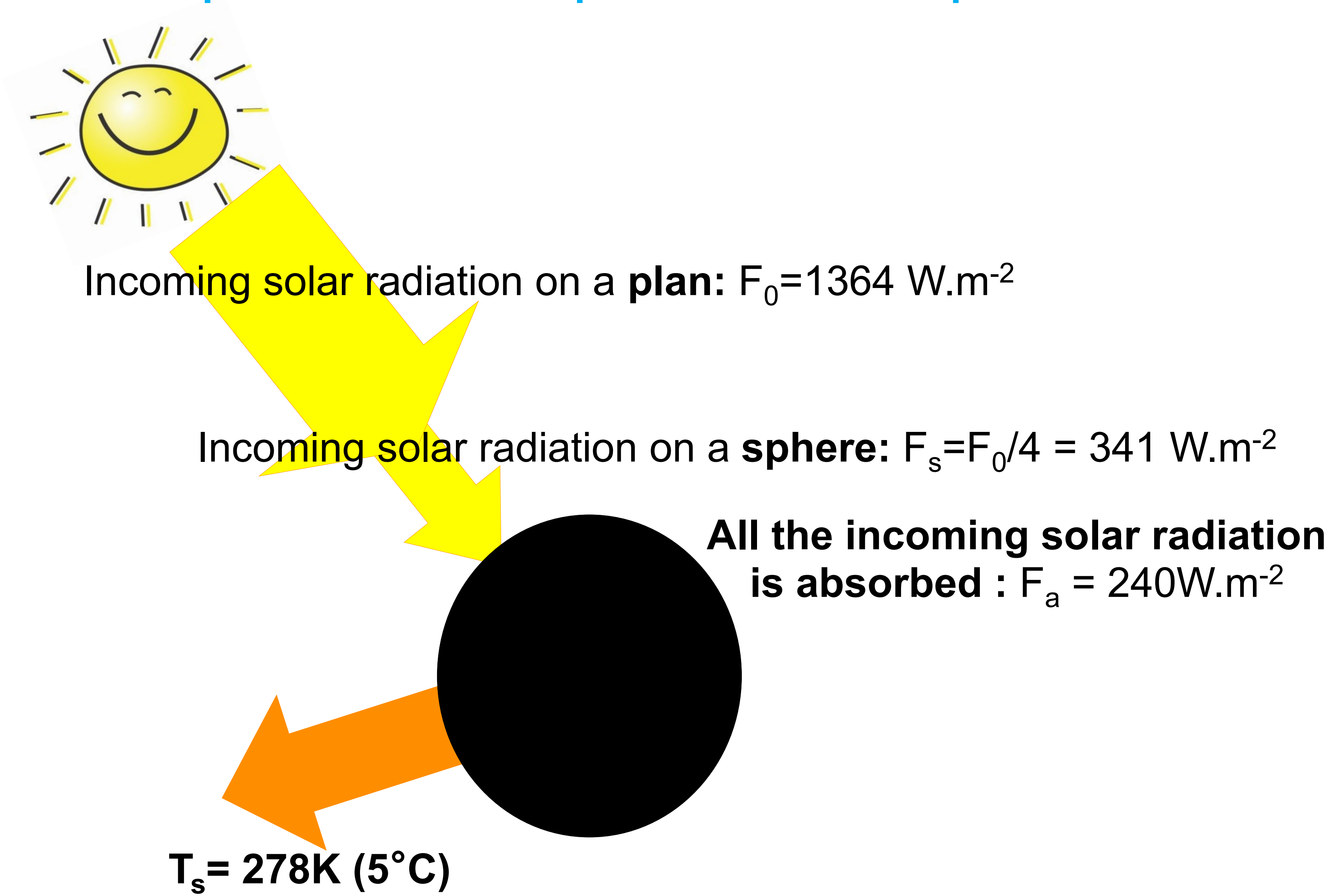
Outlook

I. Basic of climate change: greenhouse effect, forcing and feedbacks

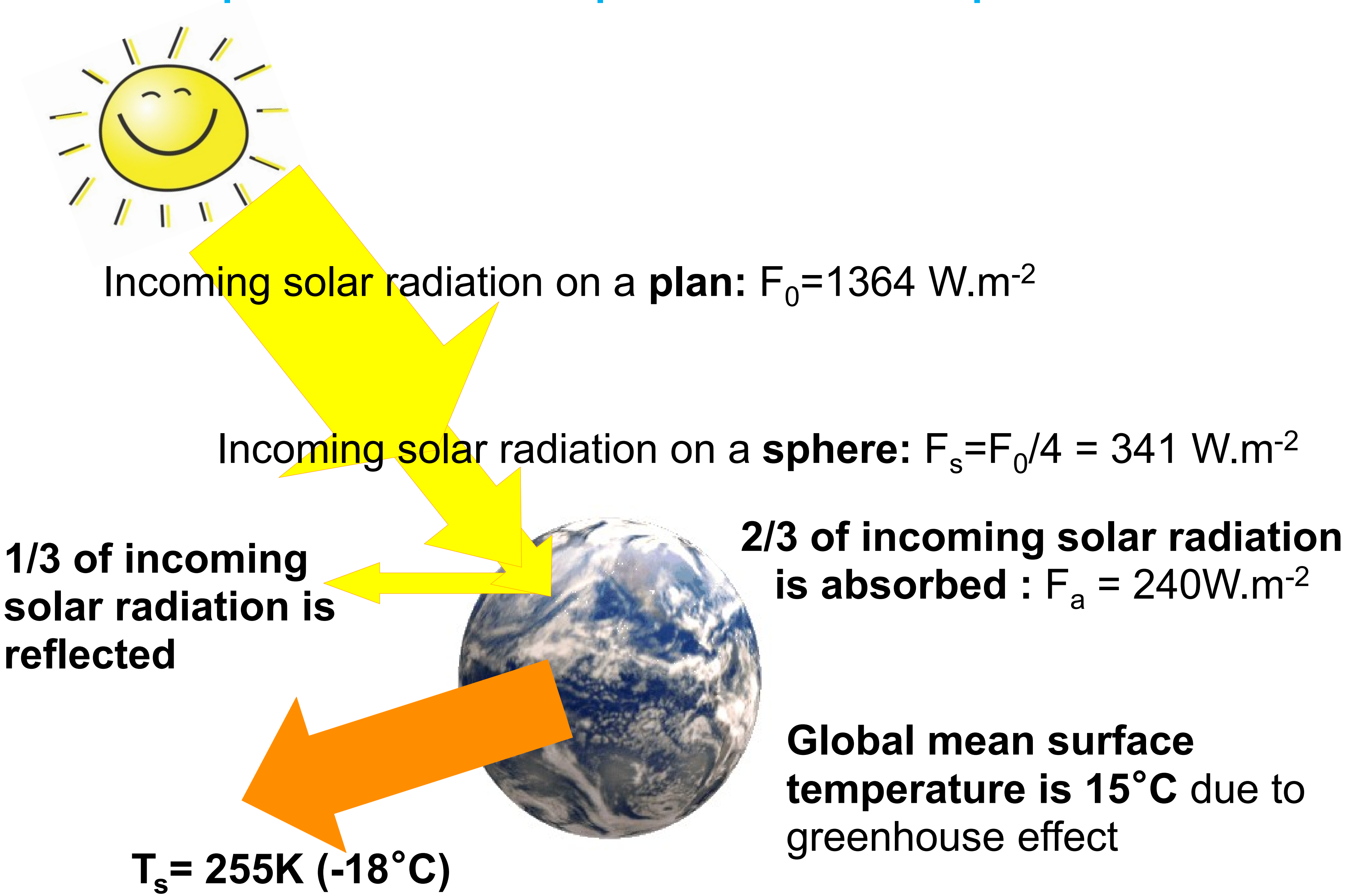
II. Scenarios and forcings for climate change projections

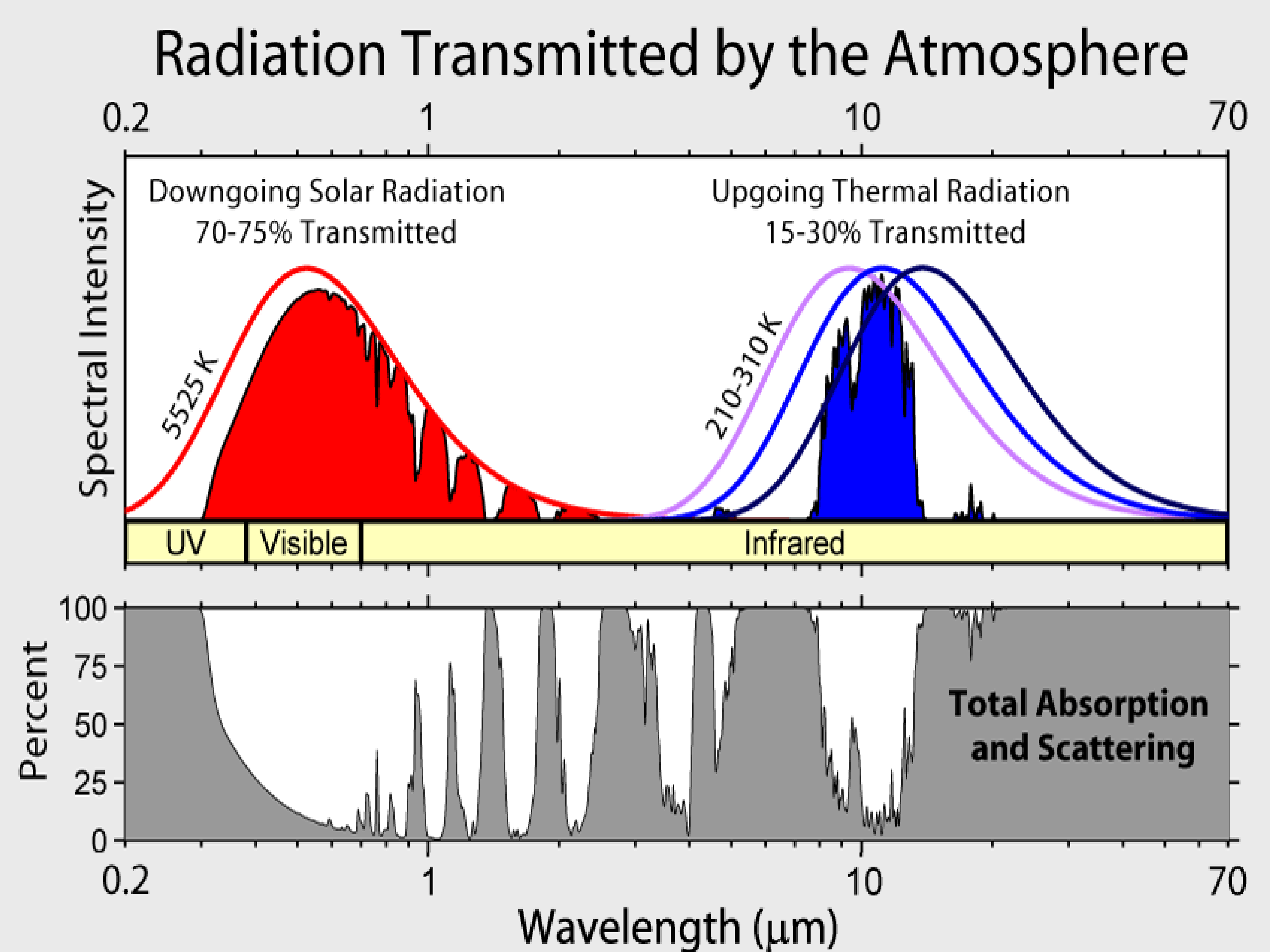
III. Climate change projections at global scales

Equilibrium temperature of a planet

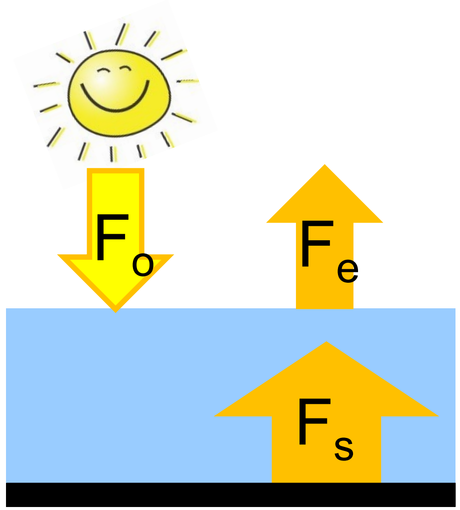


Equilibrium temperature of a planet

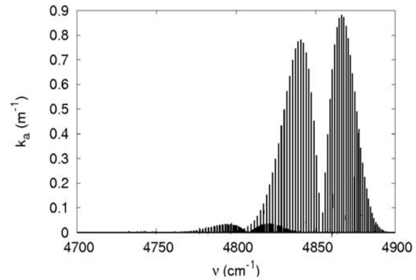



Radiation Transmitted by the Atmosphere
0.2
1
10
70
Downgoing Solar Radiation
70-75% Transmitted
Upgoing Thermal Radiation
15-30% Transmitted
5525 K
210-310 K
Spectral Intensity
UV
Visible
Infrared
100
75
50
25
0
Percent
Total Absorption
and Scattering
0.2
1
10
70
Wavelength (μm)

What radiation heat transfer theory tell us



Greenhouse effect: $G=F_s-F_e$



Gas radiative properties

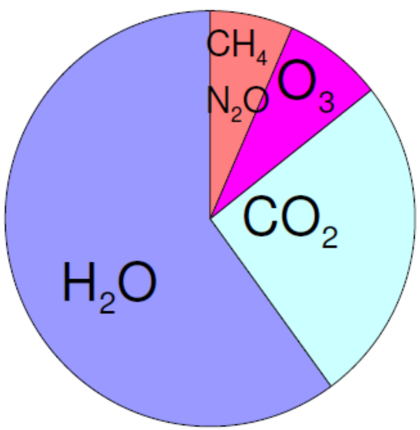
Atmospheric characteristics

Computation of the radiative fluxes and the greenhouse effect

Current greenhouse effect: G ≈ 150 $W.m^{-2}$

Contribution of atmospheric gases (clear sky)

Water vapour	60%
CO_2	26%
Ozone O_3	8%
N_2O + CH_4	6%



For a doubling of CO_2 concentration, green house effect increases by **≈ 3.7 $W.m^{-2}$**

From radiative transfer computation to climate modelling

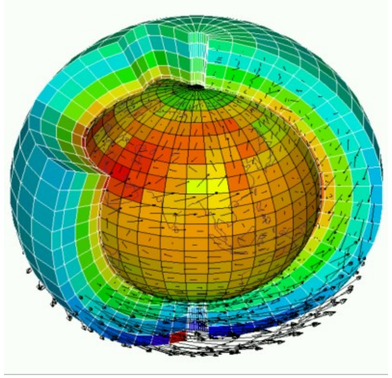
For a doubling of the CO_2 concentration:

- the green house effect increases by 3.7 $W.m^{-2}$
- the temperature increases by ≈ 1.2 K, if nothing change except the temperature

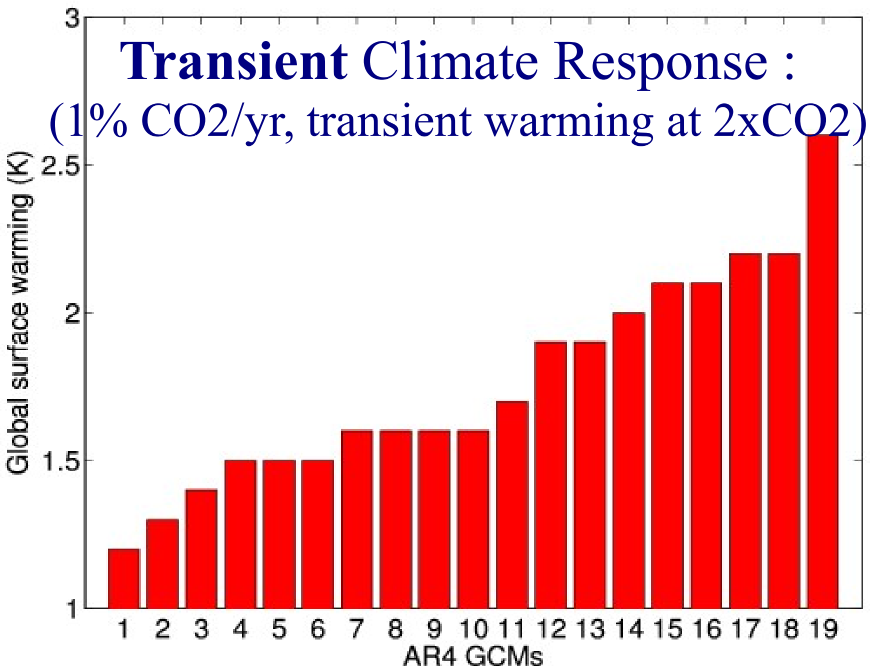
But feedbacks exist:

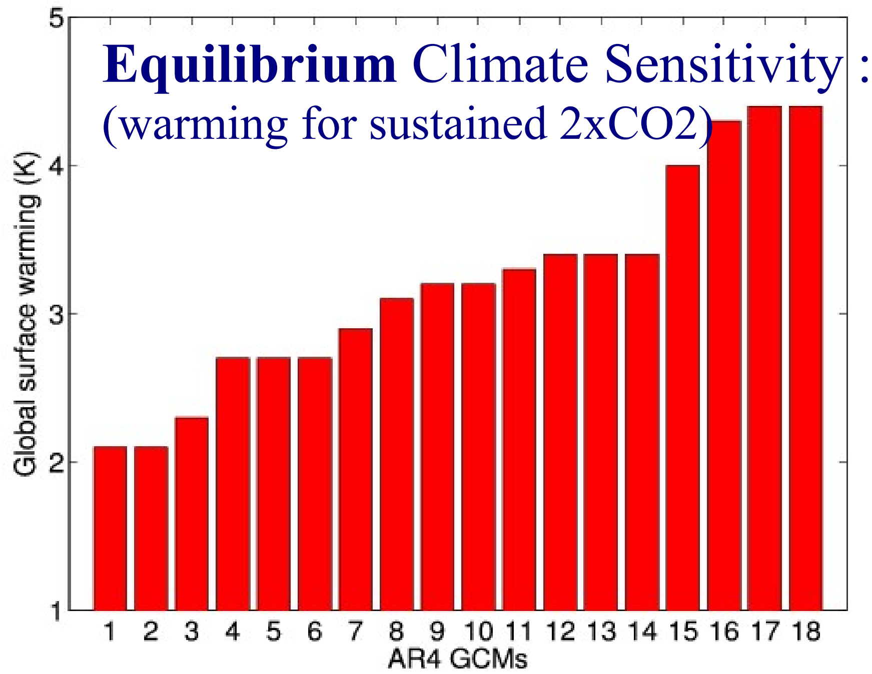
- Snow and sea ice reflect solar radiation; if they decrease, more solar energy will be absorbed ⇒ positive feedback
- Water vapour is the main greenhouse gas; if it increases, the greenhouse effect will be enhanced ⇒ positive feedback
- Clouds reflect solar radiation and contribute to the greenhouse effect; if they change, the energy budget will be modified ⇒ positive or negative feedback

Need of 3D numerical climate models



Climate sensitivity estimates from CMIP3 GCMs (IPCC-AR4)





[IPCC, 2007]

Climate sensitivity and TCR estimates depend on :

- radiative forcing
- climate feedbacks
- ocean heat uptake (transient only)

How do these different components contribute to inter-model differences in climate sensitivity ?

Climate feedback

$$\Delta R = \Delta Q + \lambda \Delta T_s$$

- ΔR: flux at TOA change
- ΔQ: radiative forcing
- λ: "feedback parameter"
- ΔT_s: Global average surface temperature change

When a new equilibrium is reached, ΔR=0

$$\Delta T_s^e = \frac{-\Delta Q_t}{\lambda}$$

$$\lambda = \lambda_P + \lambda_w + \lambda_L + \lambda_c + \lambda_\alpha$$

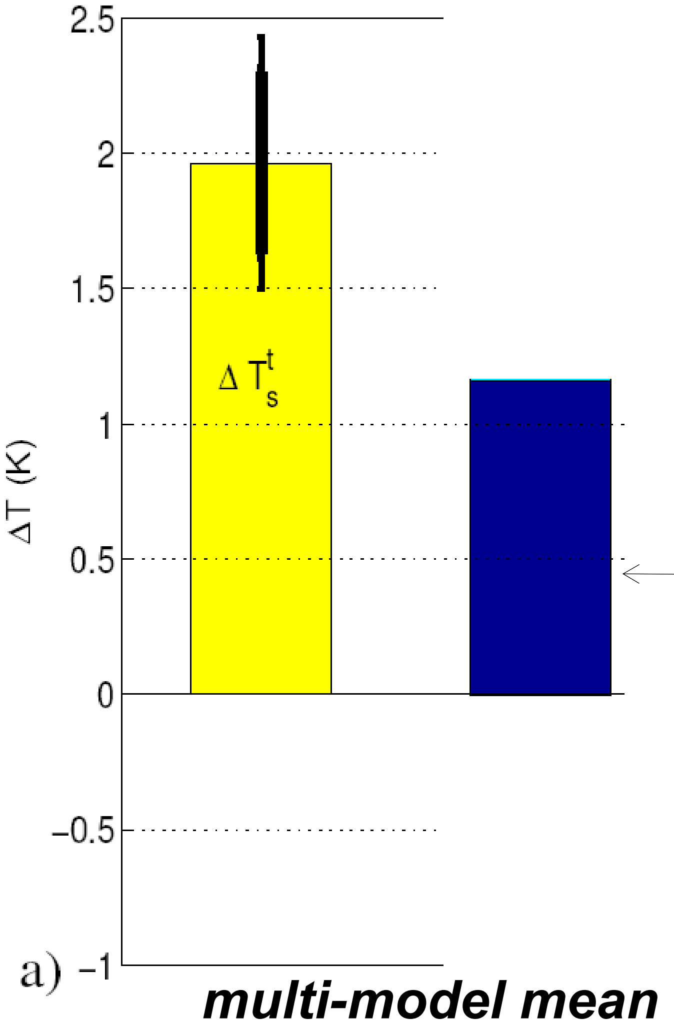
Planck, water vapor, lapse rate, clouds, surface albedo

$$\lambda = \frac{\partial R}{\partial T_s} = \sum_x \frac{\partial R}{\partial x} \frac{\partial x}{\partial T_s}$$

λ can be diagnosed from model results with different technics

Transient temperature response to a CO_2 doubling

(CO_2 increase 1%/year, 70 years)

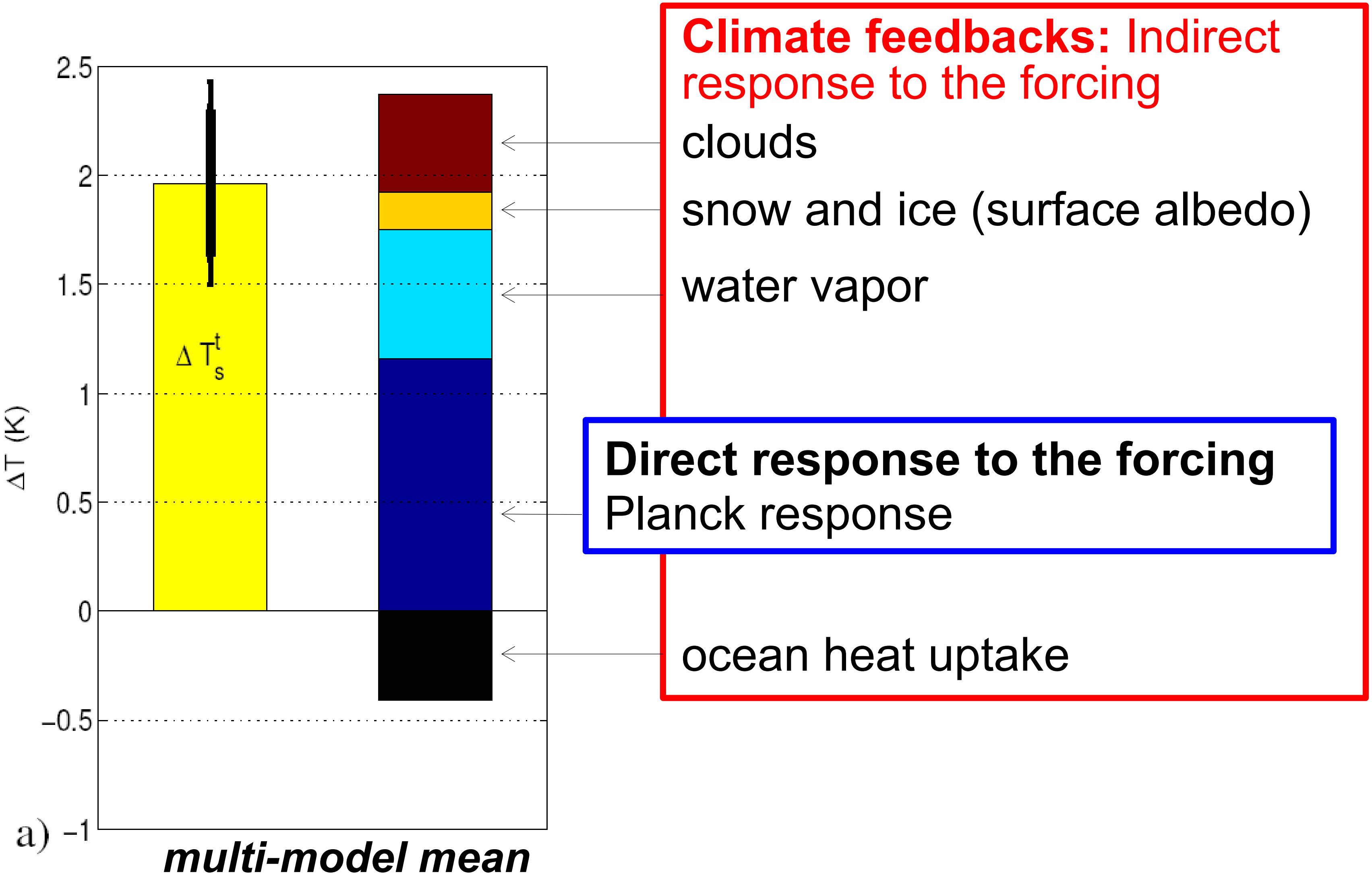


Direct response to the forcing
Planck response

(Dufresne & Bony, 2008)

Transient temperature response to a CO_2 doubling

(CO_2 increase 1%/year, 70 years)



(Dufresne & Bony, 2008)

Transient temperature response to a CO_2 doubling

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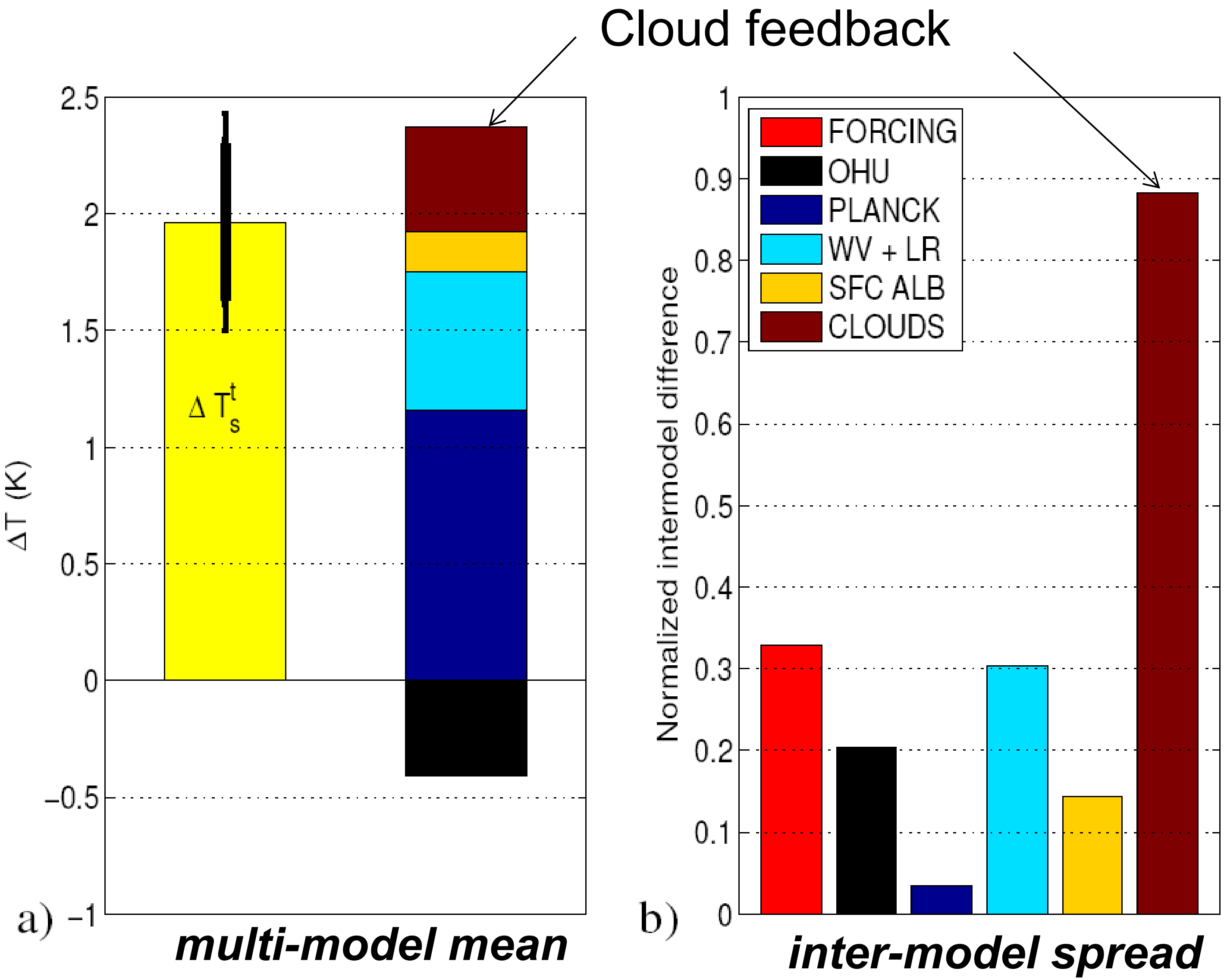

(Dufresne & Bony, 2008)

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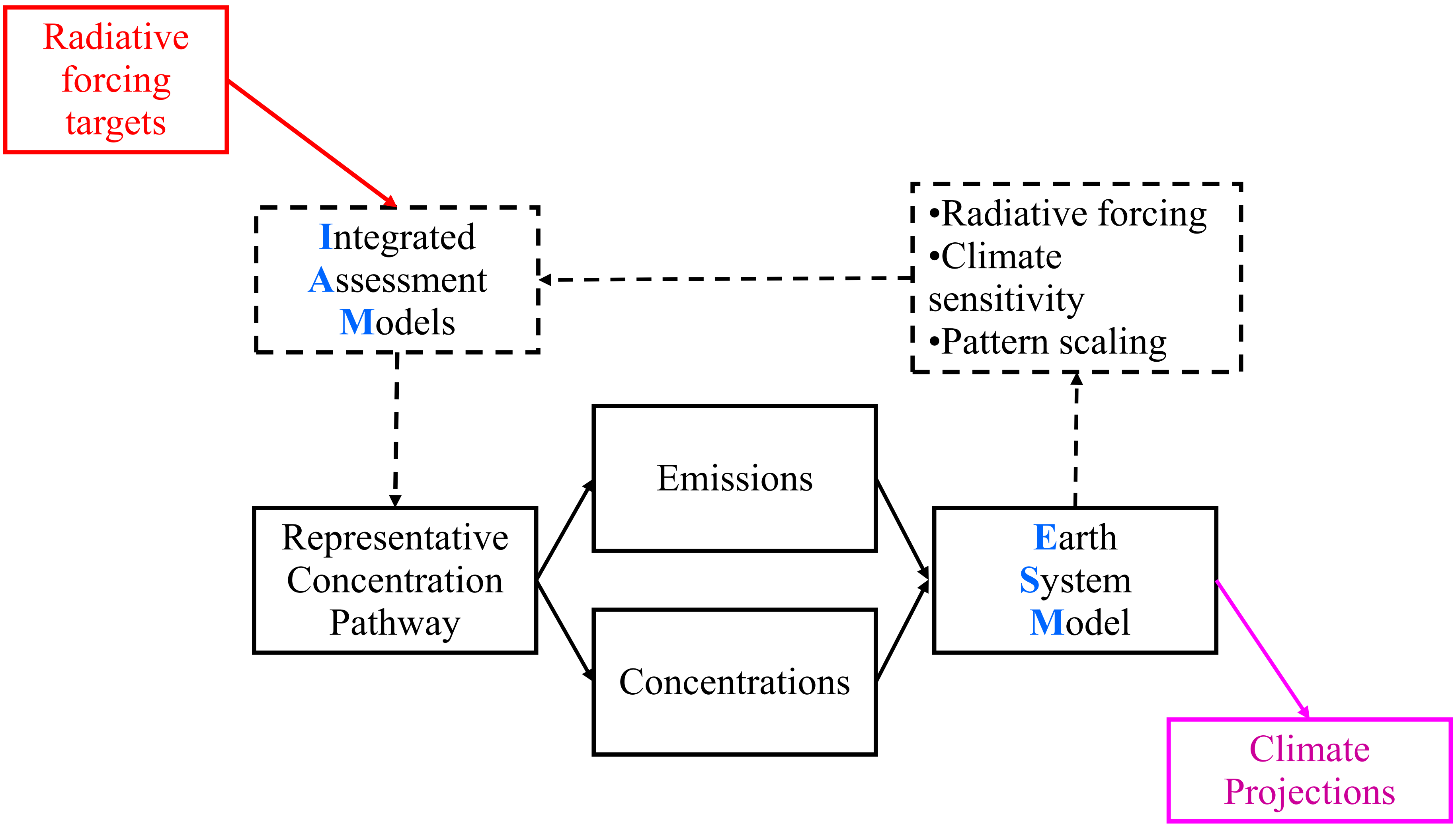
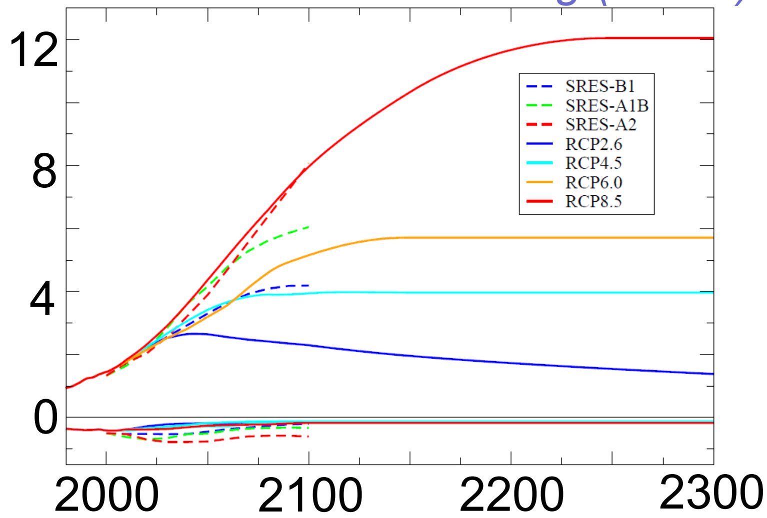
Scenario for future climate change projections

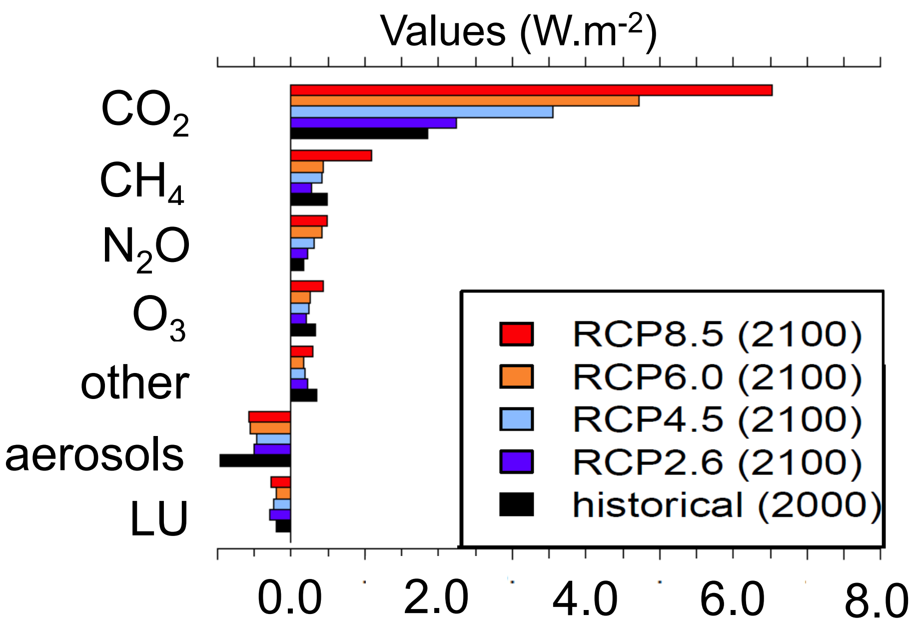


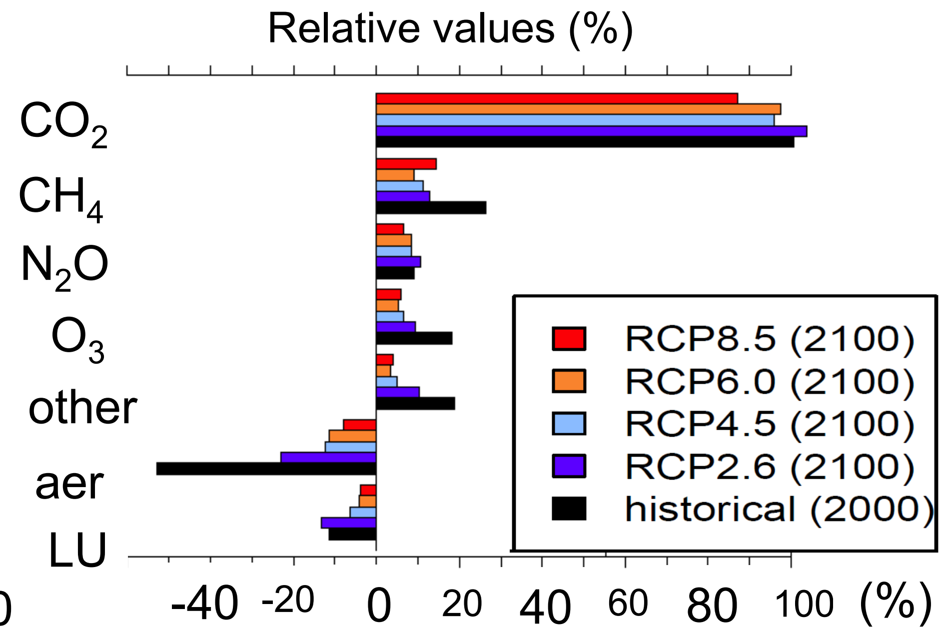
Radiative forcing of future scenarios

Total radiative forcing ($W.m^{-2}$)



Contribution of individual forcings to total forcing relative to ***1850***





Radiative forcing of future scenarios

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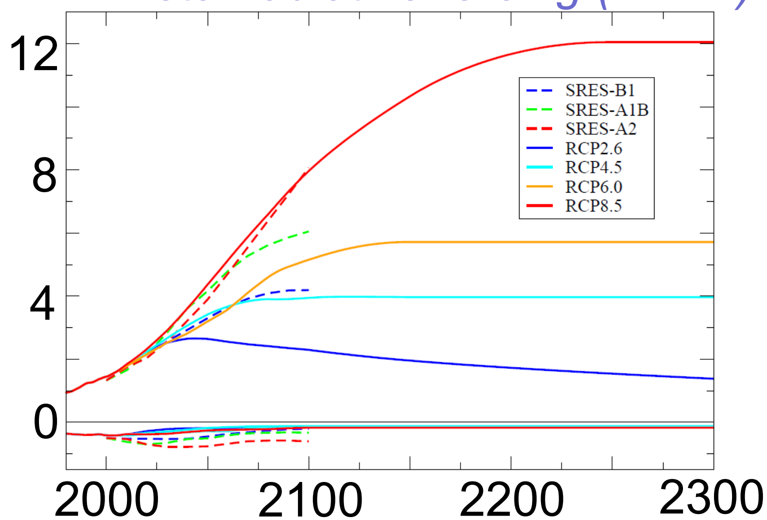
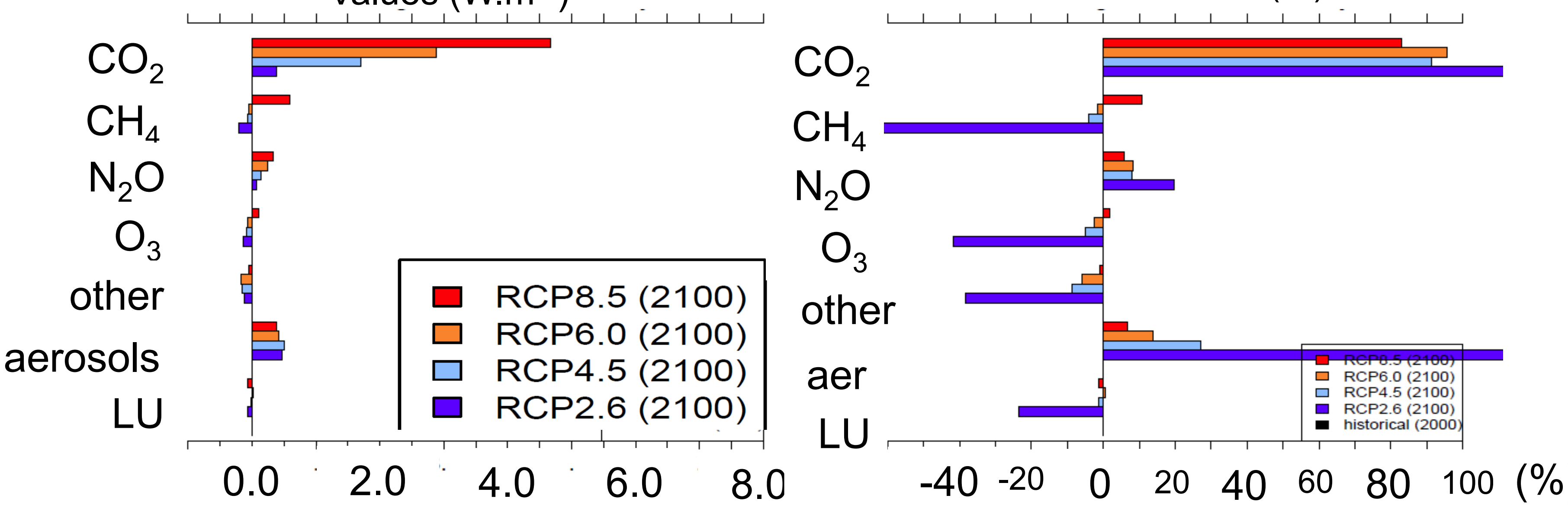
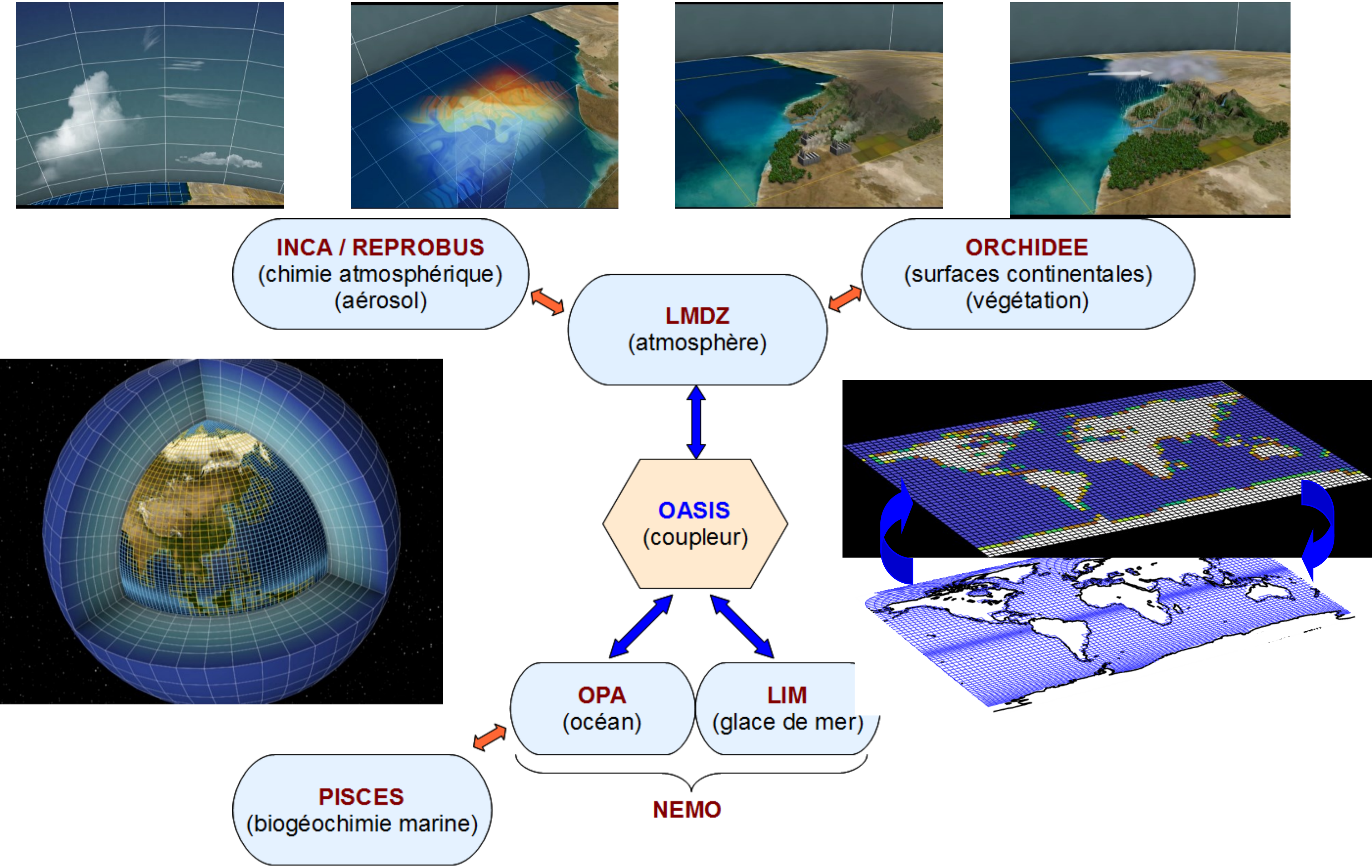


Contribution of individual forcings to total forcing relative to ***2000***

Values (W.m^{-2}) | Relative values (%)



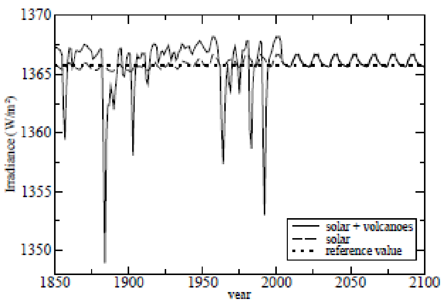
The IPSL Earth System Model



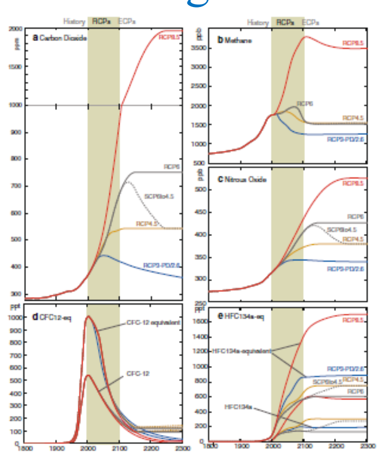
The IPSL Earth System Model

Natural and anthropogenic forcings

Solar and volcanoes

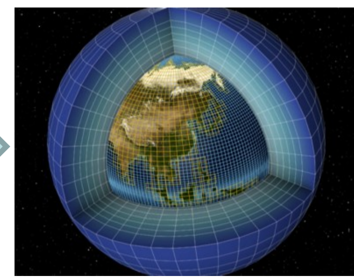


Green house gases and active gases

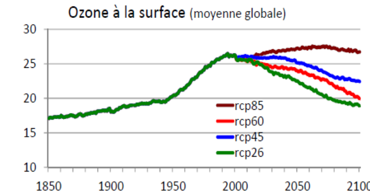


CO_2 concentration

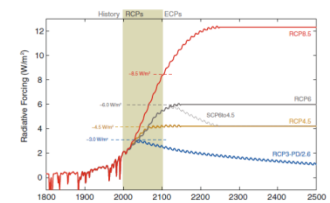
IPSL-CM5A-LR



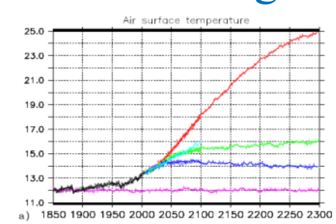
Atmospheric composition



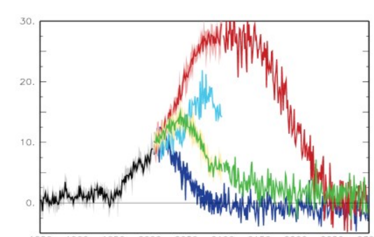
Radiative forcings



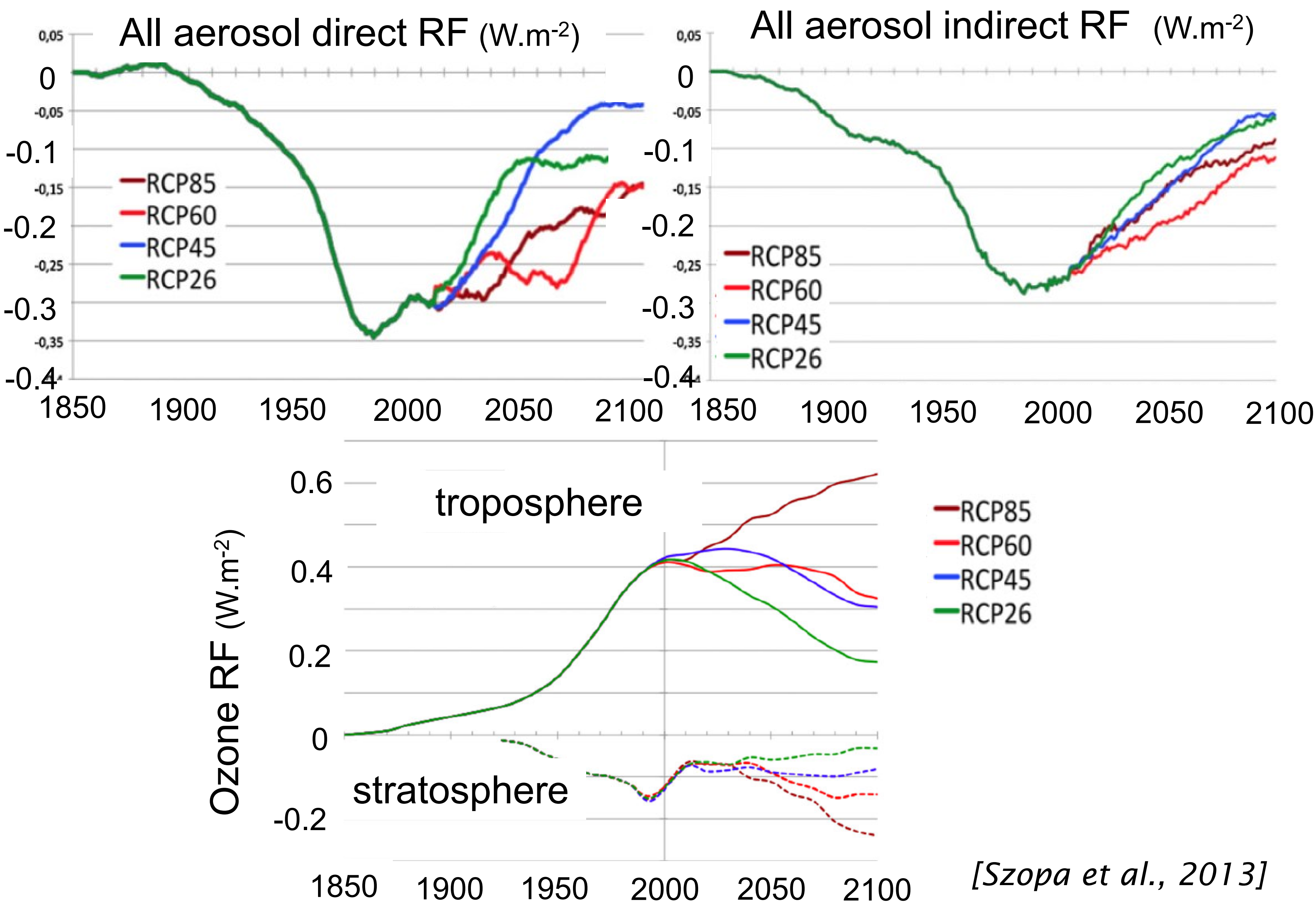
Climate changes



Authorized CO_2 emissions

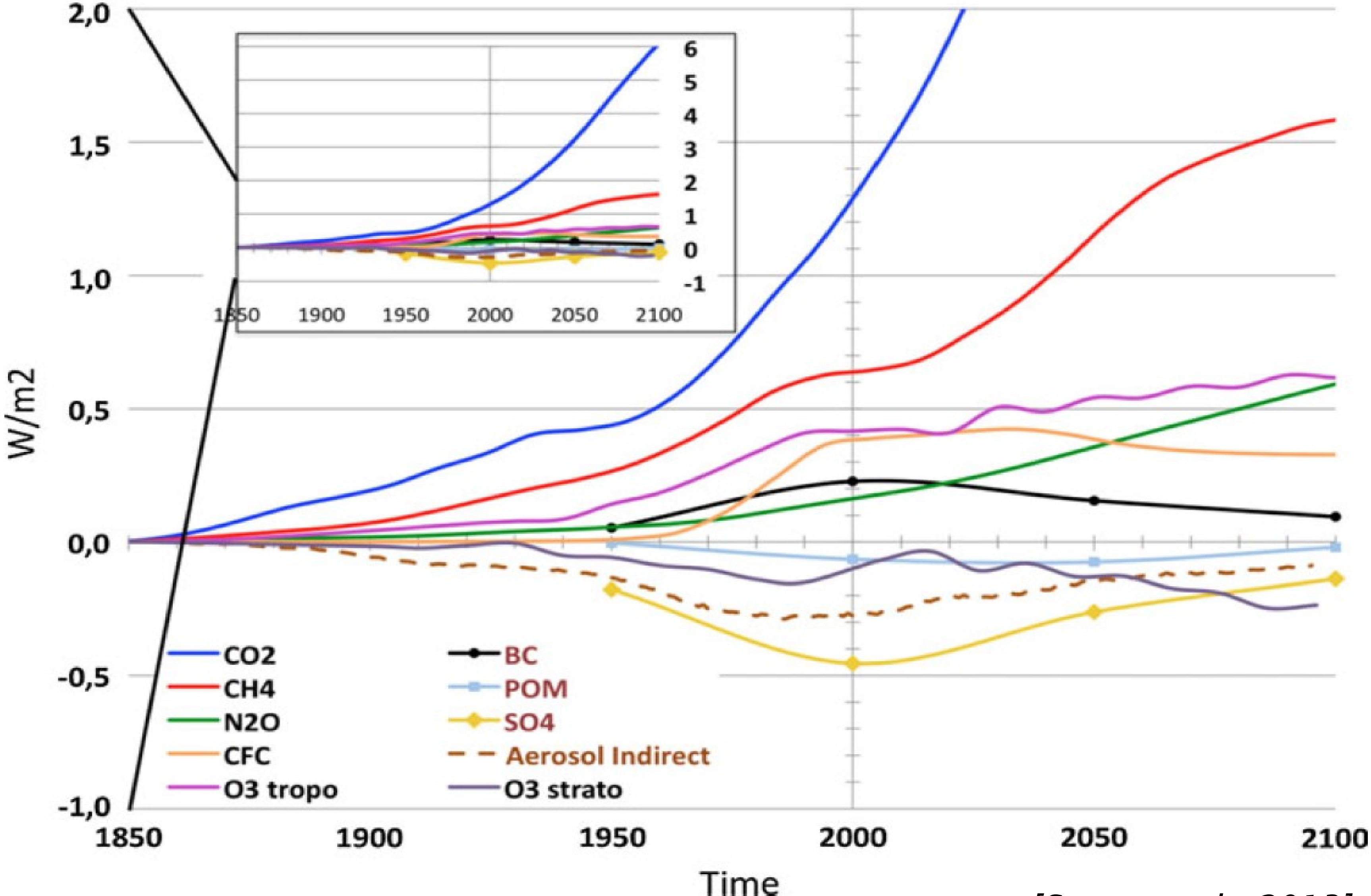


Ozone and aerosols computations (IPSL-CM5A-LR model)



[Szopa et al., 2013]

Radiative forcings for the historical period and the future
RCP8.5 scenario (IPSL-CM5A-LR model)



[Szopa et al., 2013]

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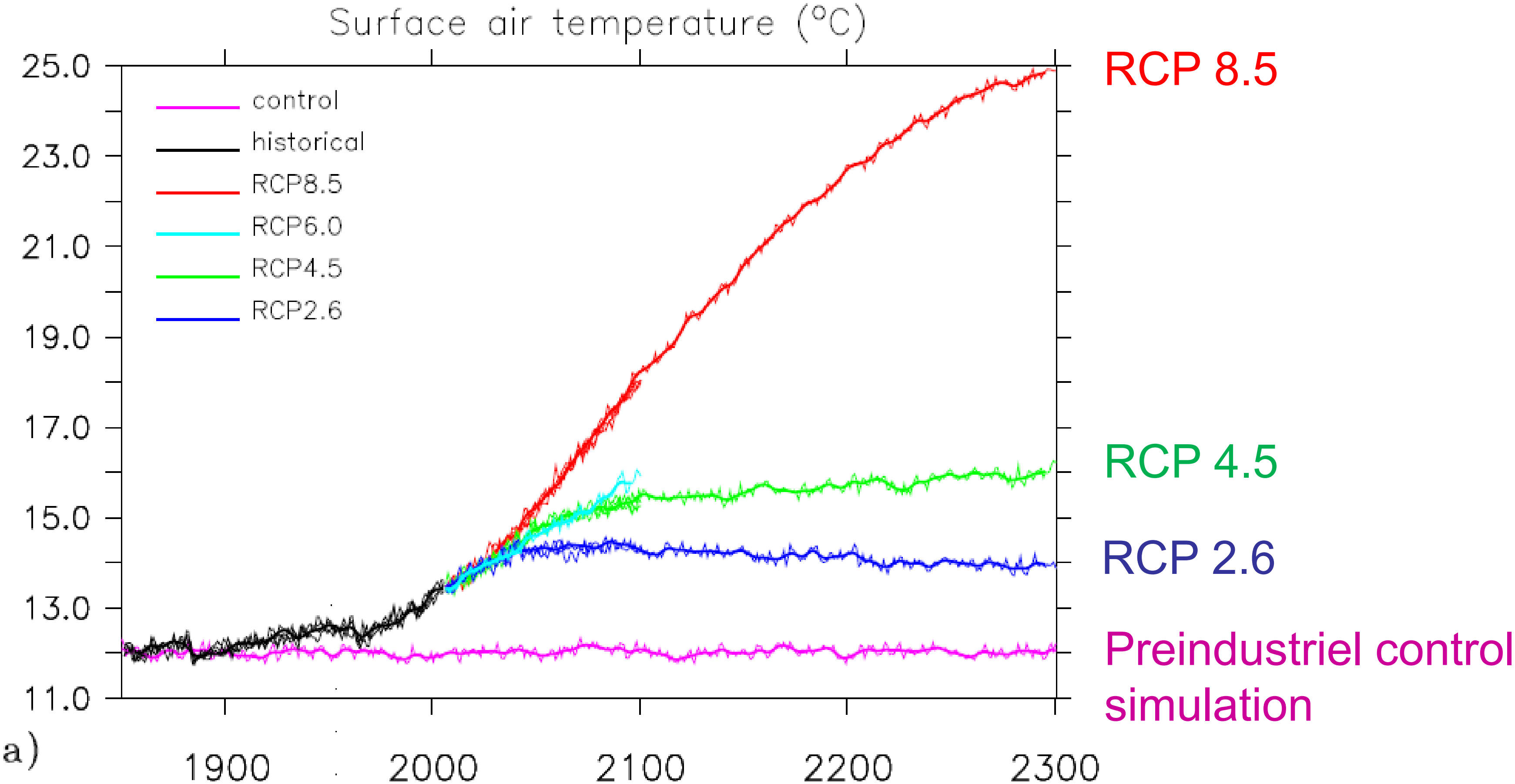
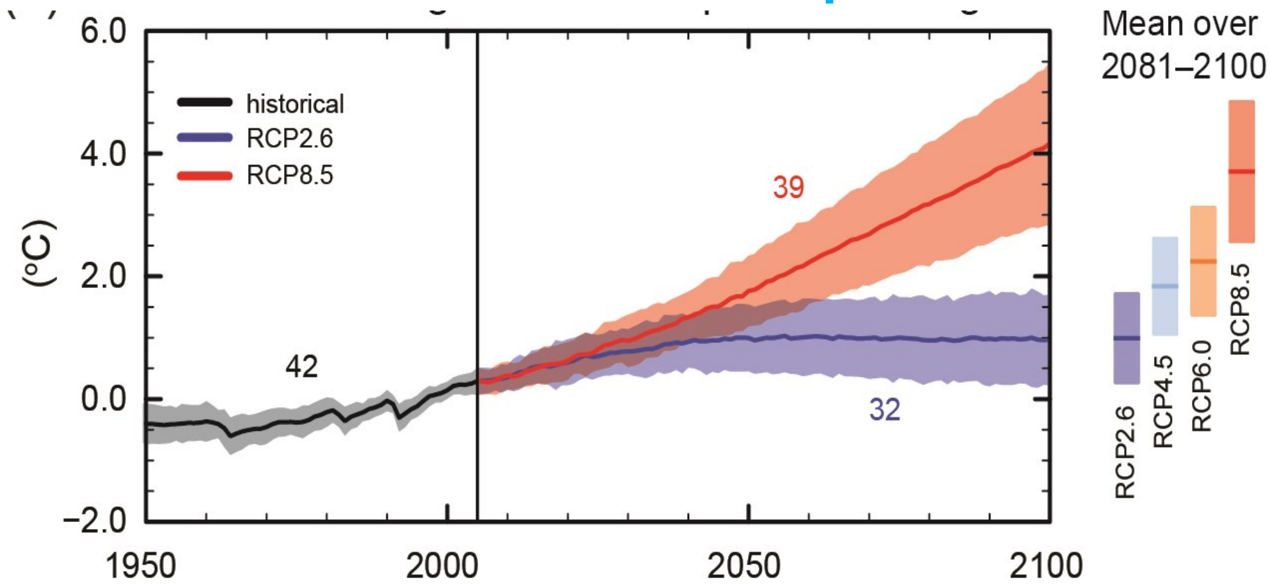
Global mean surface temperature

1850 to 2300
IPSL-CM5A-LR model



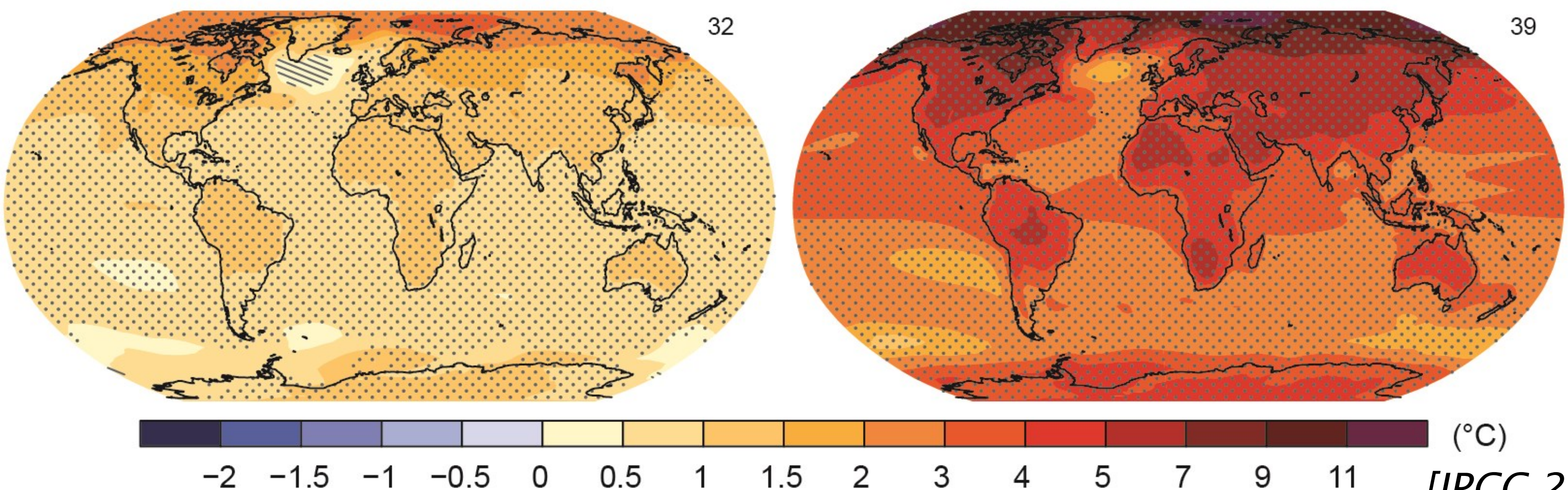
[Dufresne et al., 2013]

Global mean surface temperature change



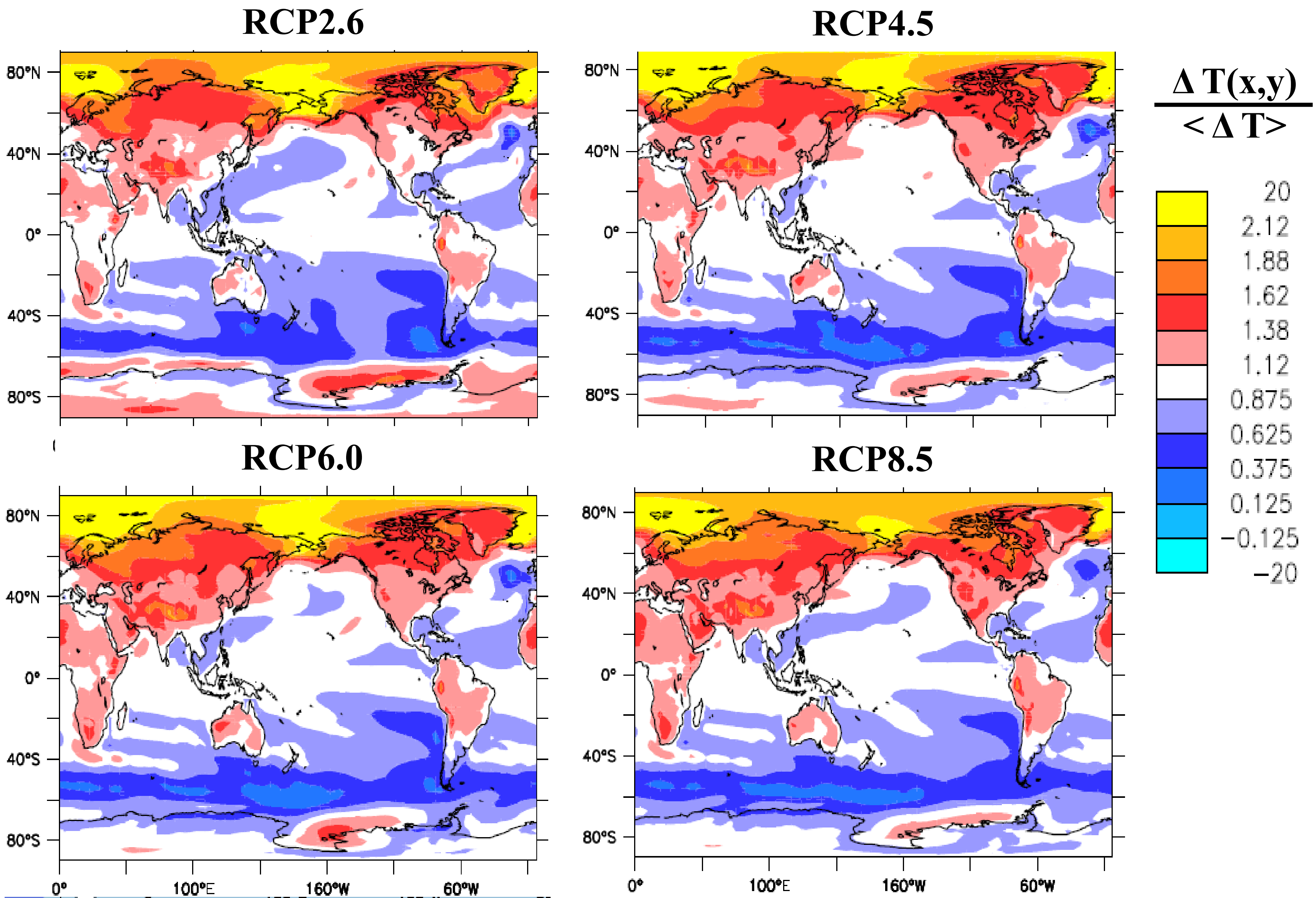
RCP 2.6 **RCP 8.5**

Change in average surface temperature (1986−2005 to 2081−2100)



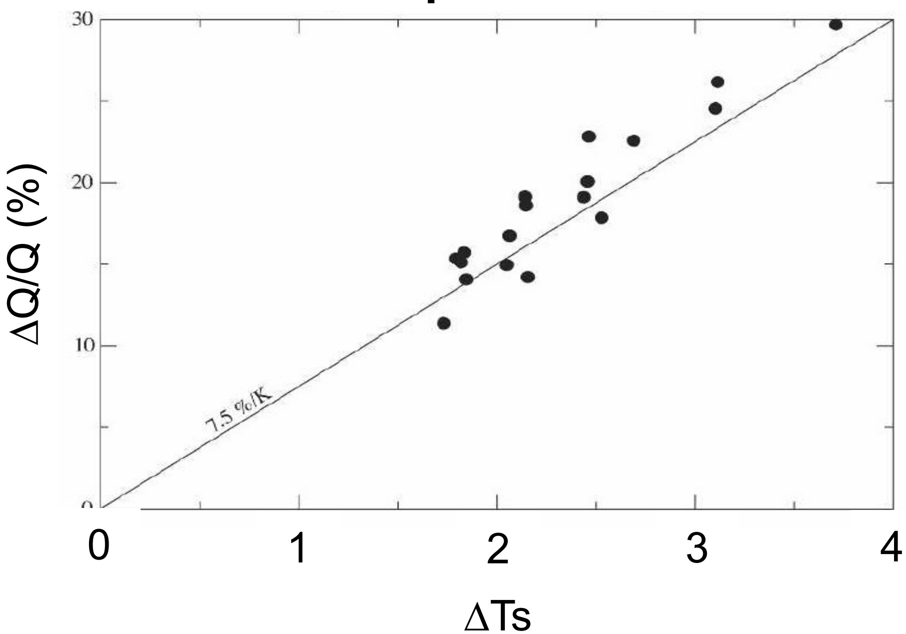
[IPCC 2013]

Spatial distribution of the normalized air surface temperature change Δ T(x,y)/<Δ T> in 2100



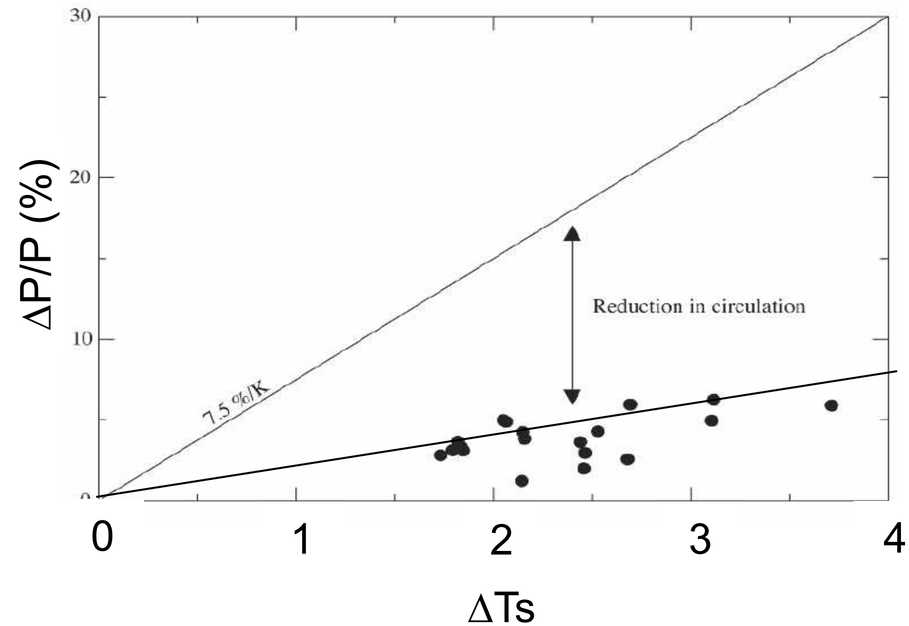
Precipitation changes

Change of the amount of **water vapor** $\mathbf{H_2O}$ vs change of the average surface **temperature**



$\Delta Q/Q\ (\%) \approx 7.5\ \Delta Ts$

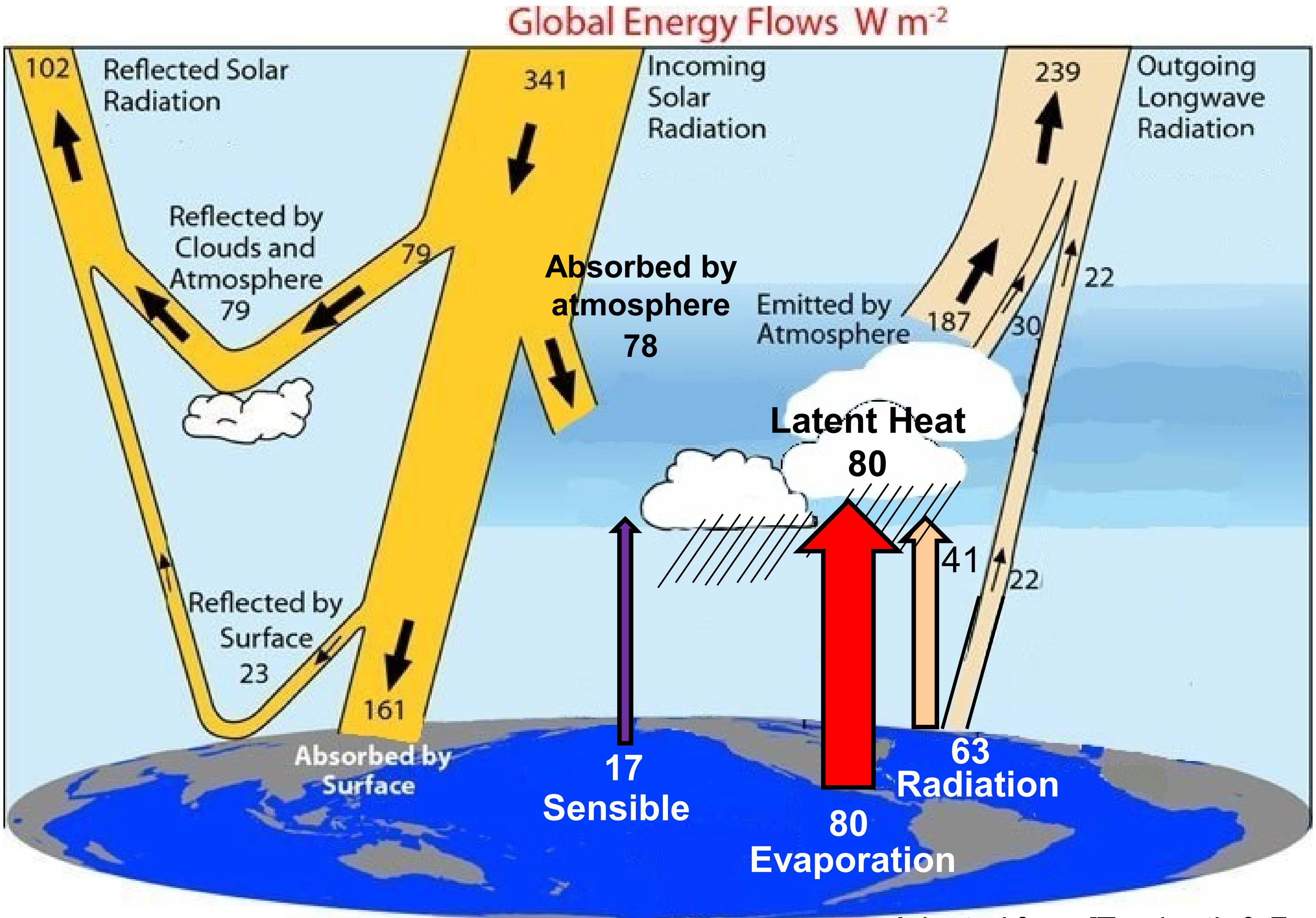
Change of **precipitation** vs change of the average surface **temperature**



$\Delta P/P\ (\%) \approx 1.5\ \Delta Ts$

The change of the global average precipitation does not depend directly from the change of global average water vapor

(Vecchi & Soden, 2007)

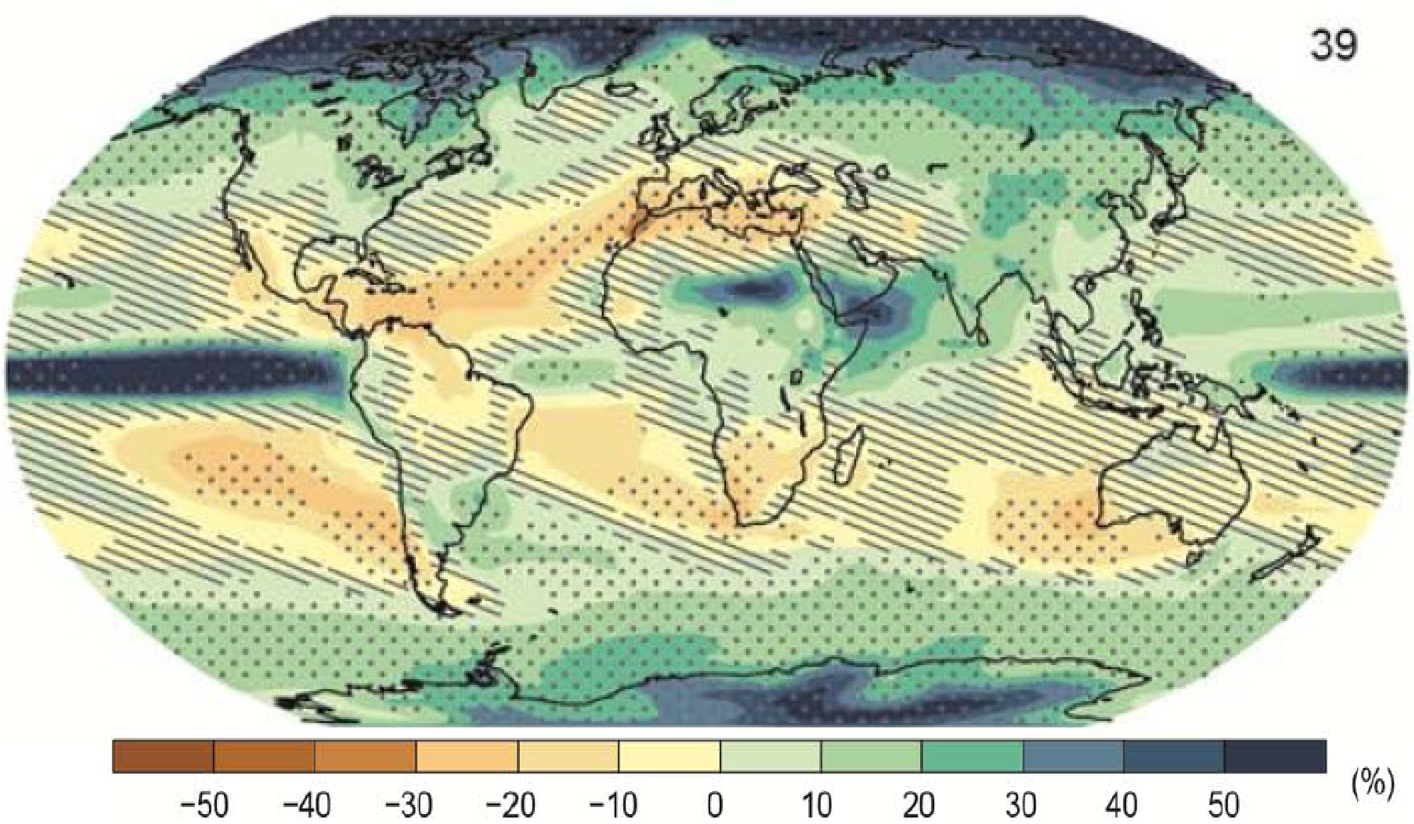


Adapted from [Trenberth & Fasullo, 2012]

*The **change of the global average precipitation** is constrained by the **radiative cooling** of the atmosphere*

Precipitation changes: Geographical distribution

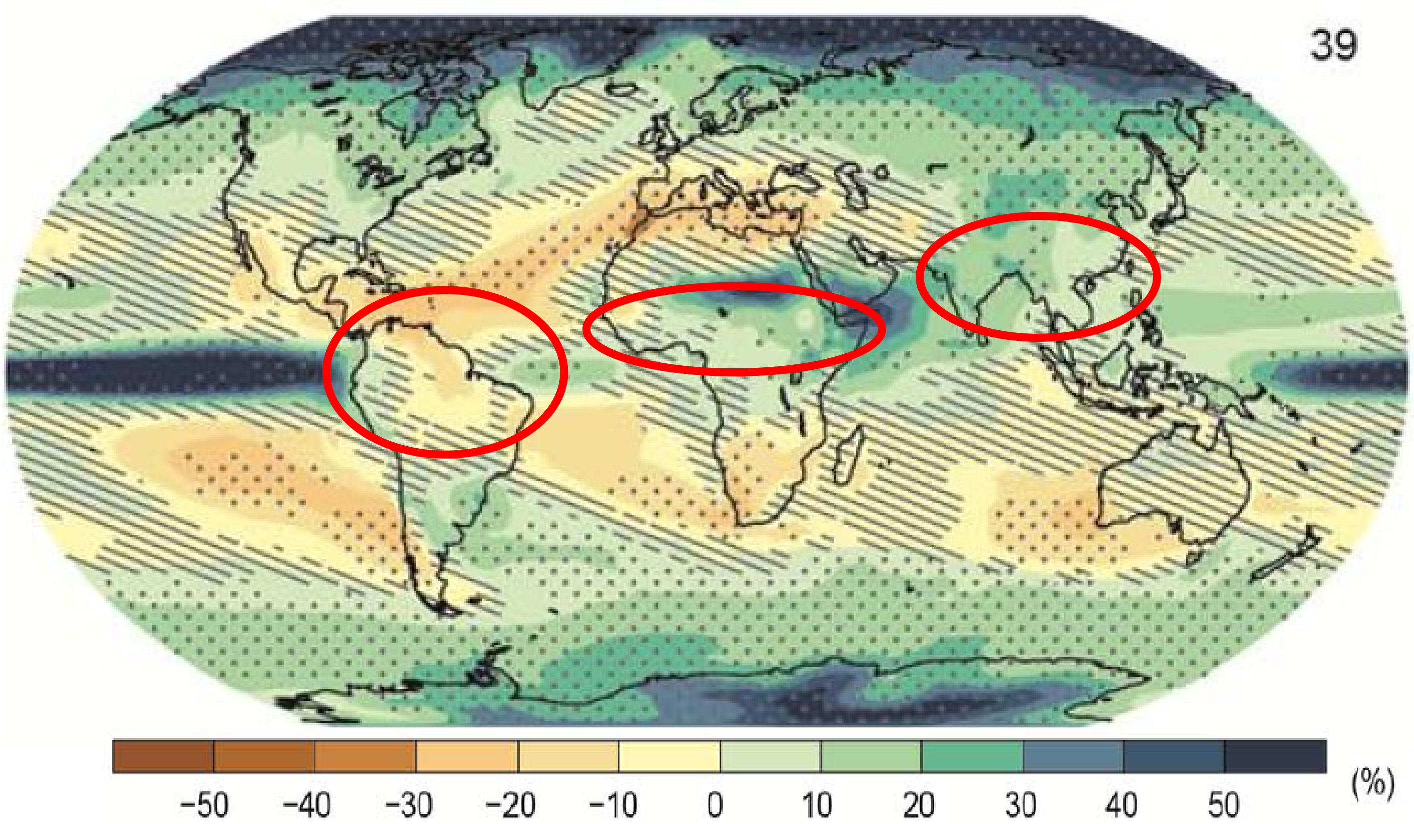
Relative change in average precipitation, RCP8.5 scenario (2081-2100)



[IPCC 2013]

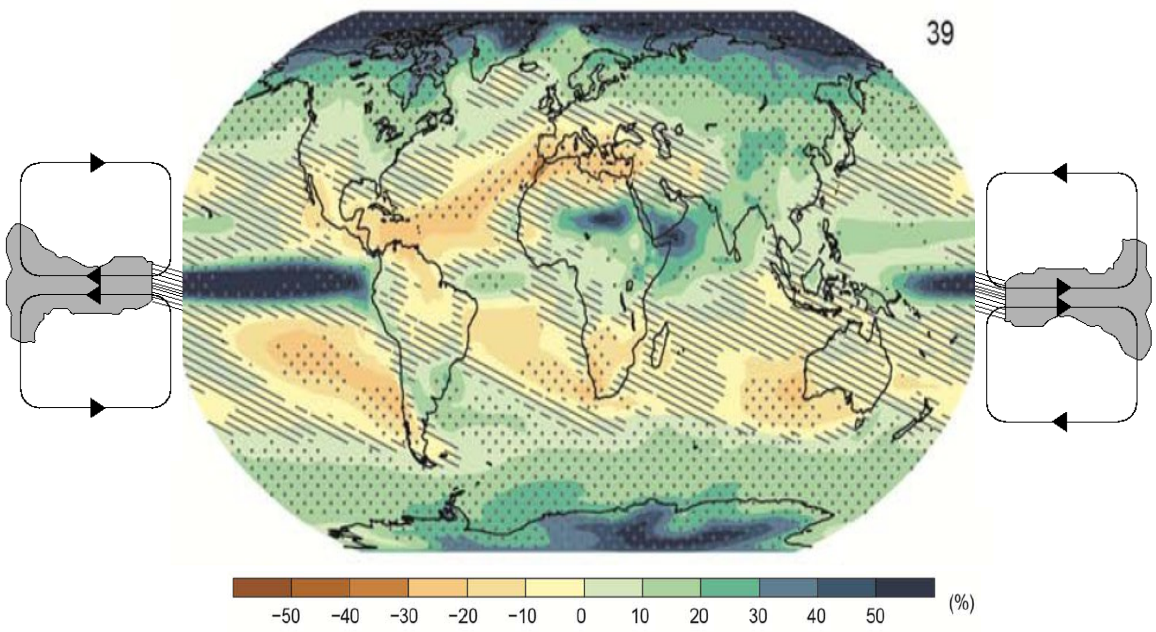
Precipitation changes: Geographical distribution

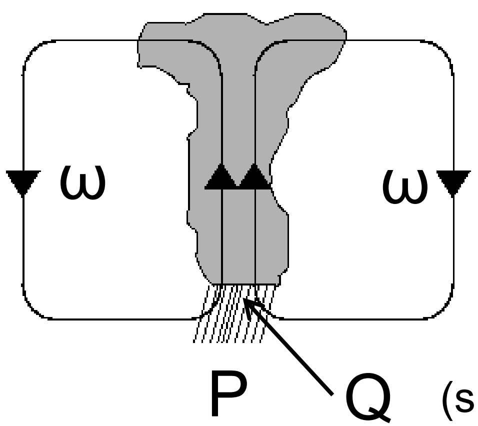
Relative change in average precipitation, RCP8.5 scenario (2081-2100)



[IPCC 2013]

Precipitation changes





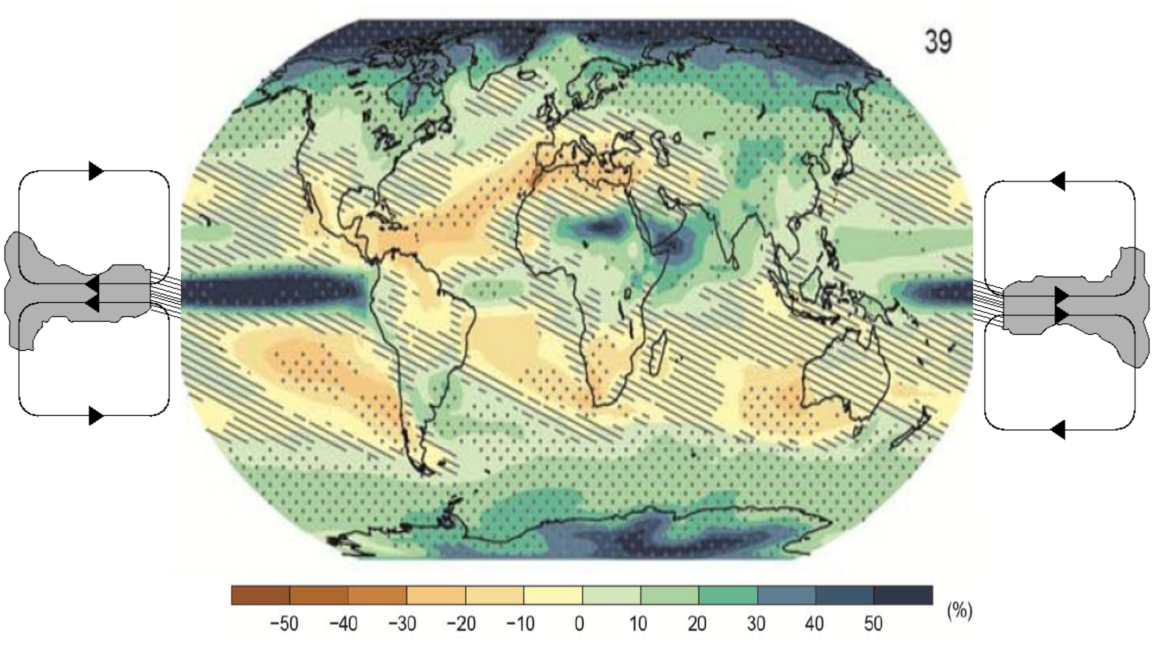
(specific humidity)

Precipitations changes $\Delta P \approx \omega\, \Delta Q + Q\, \Delta\omega$

Thermodynamic response

Dynamic response

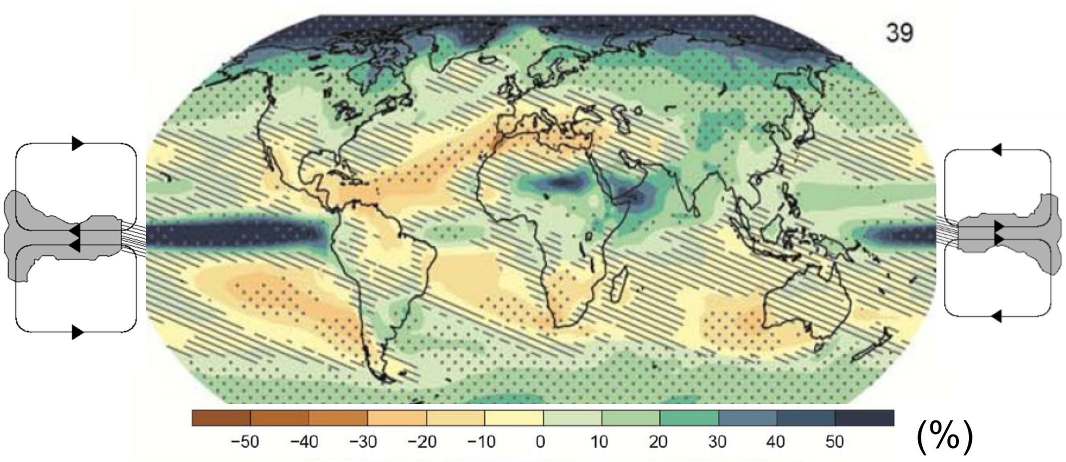
Precipitation changes



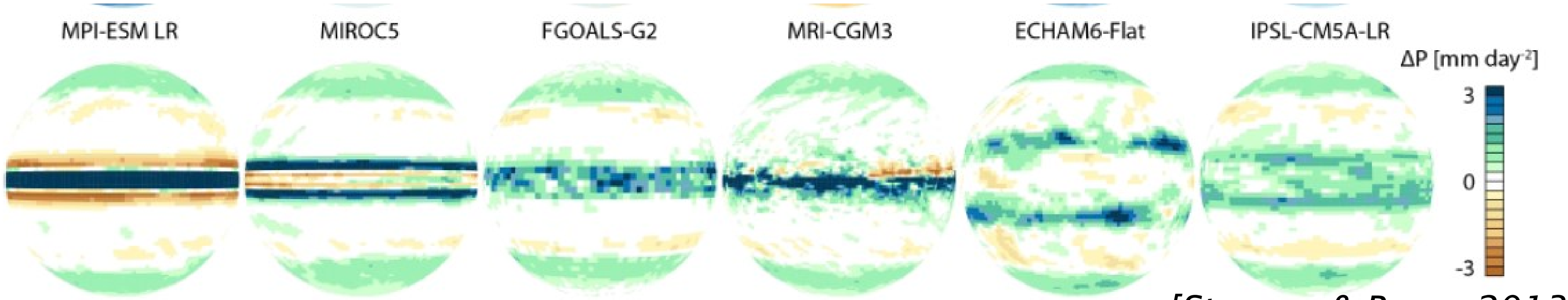
At the global scale:

- Precipitation increases in some regions while deceasing in others
- the contrast between wet and dry regions is expected to increase
- same with the contrast between wet and dry seasons

Precipitation changes



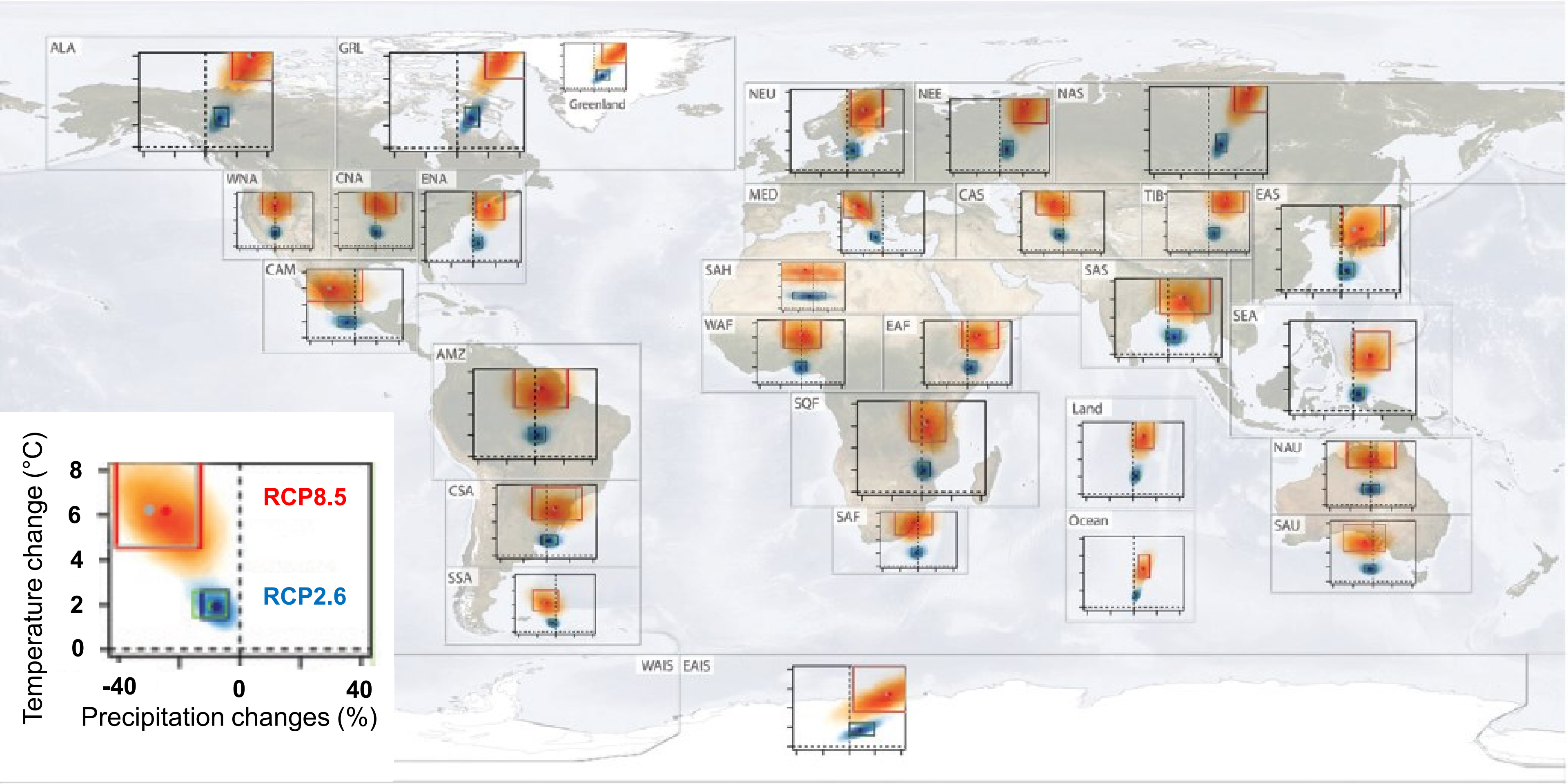
And in a simpler world? Precipitation changes in response **to a uniform increase of temperature** of 4K for **aqua-planets**



[Stevens & Bony, 2013]

A large fraction of the spread in precipitation changes originates from fundamental problems in water-vapor-temperature-circulation interactions

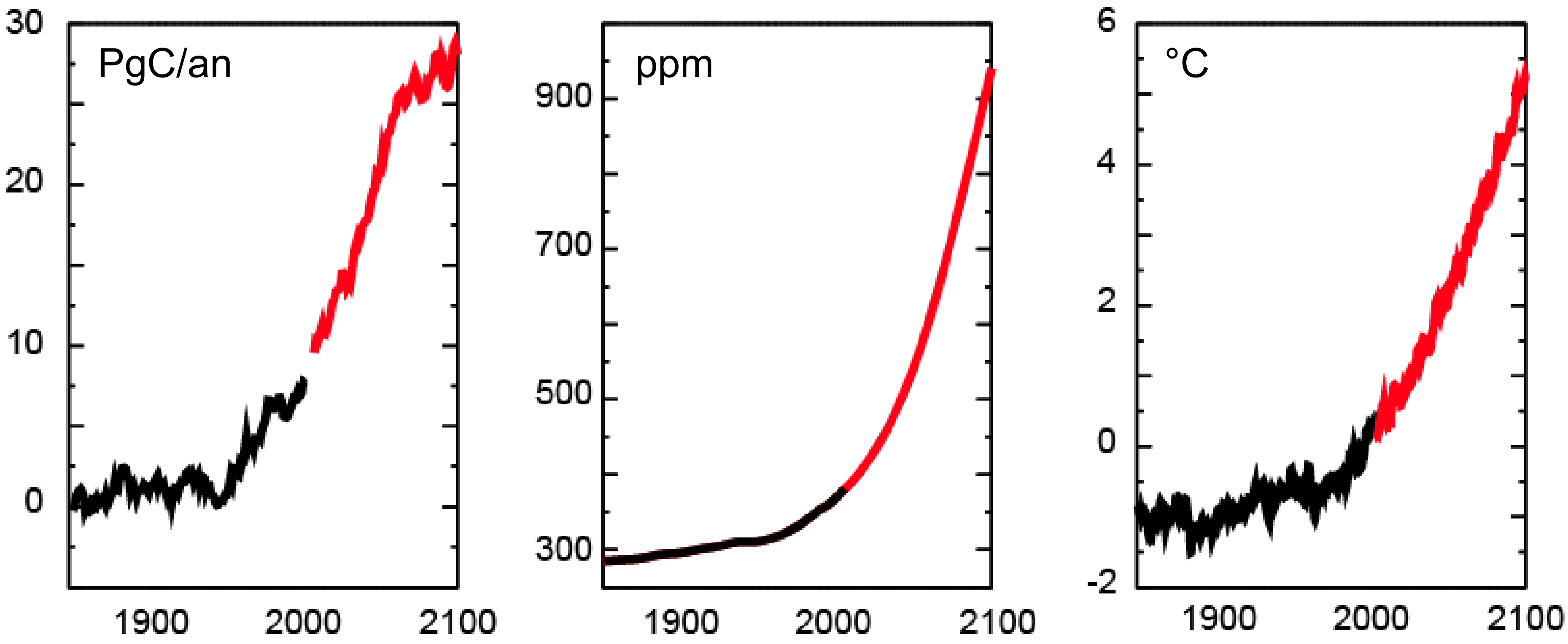
Regional precipitation changes using a scaling approach



[Frieler et al., 2012]

Carbone emission, CO_2 concentrations and global temperature: time constants

Higher scenario : emissions, concentration and temperatures continue to grow

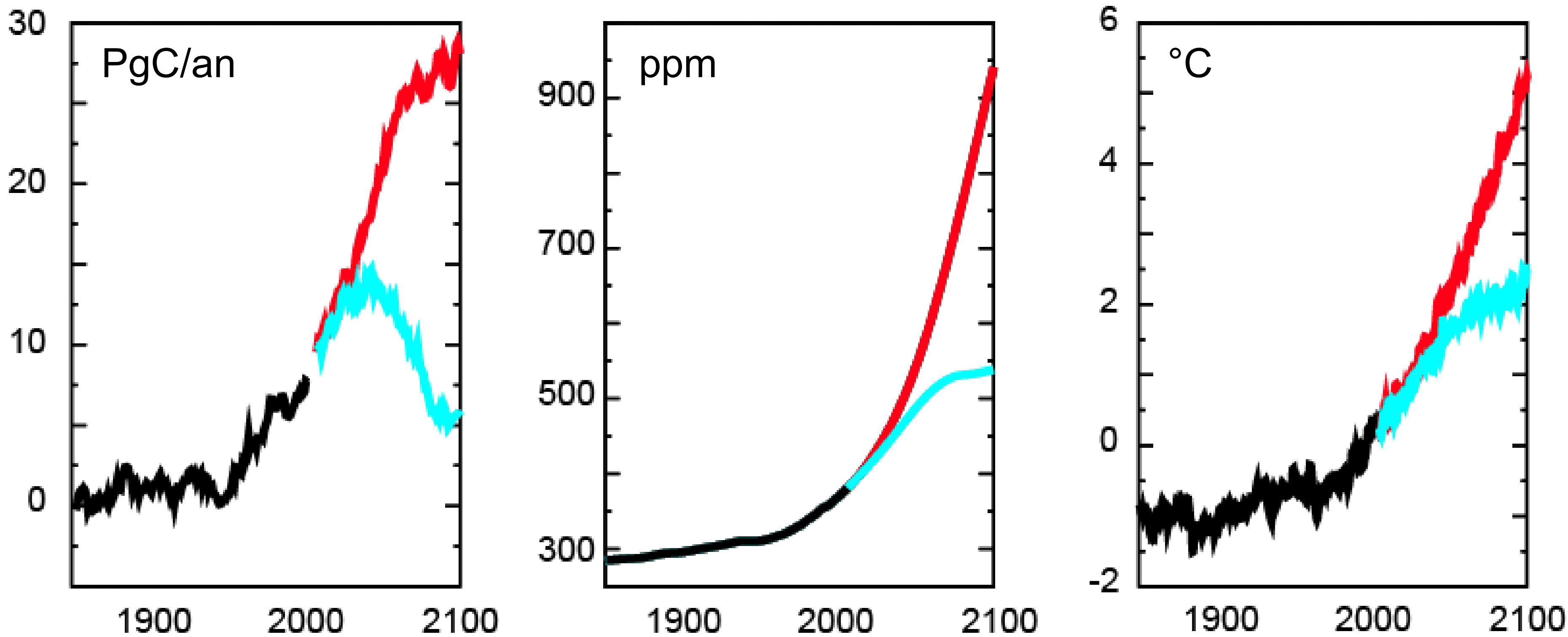


Courtesy L. Bopp

Carbone emission, CO_2 concentrations and global temperature: time constants

Higher scenario : emissions, concentration and temperatures continue to grow

Medium scenario : to stabilize CO_2 concentration 550 ppm, emissions need to be strongly reduced. However, temperature will continue to increase



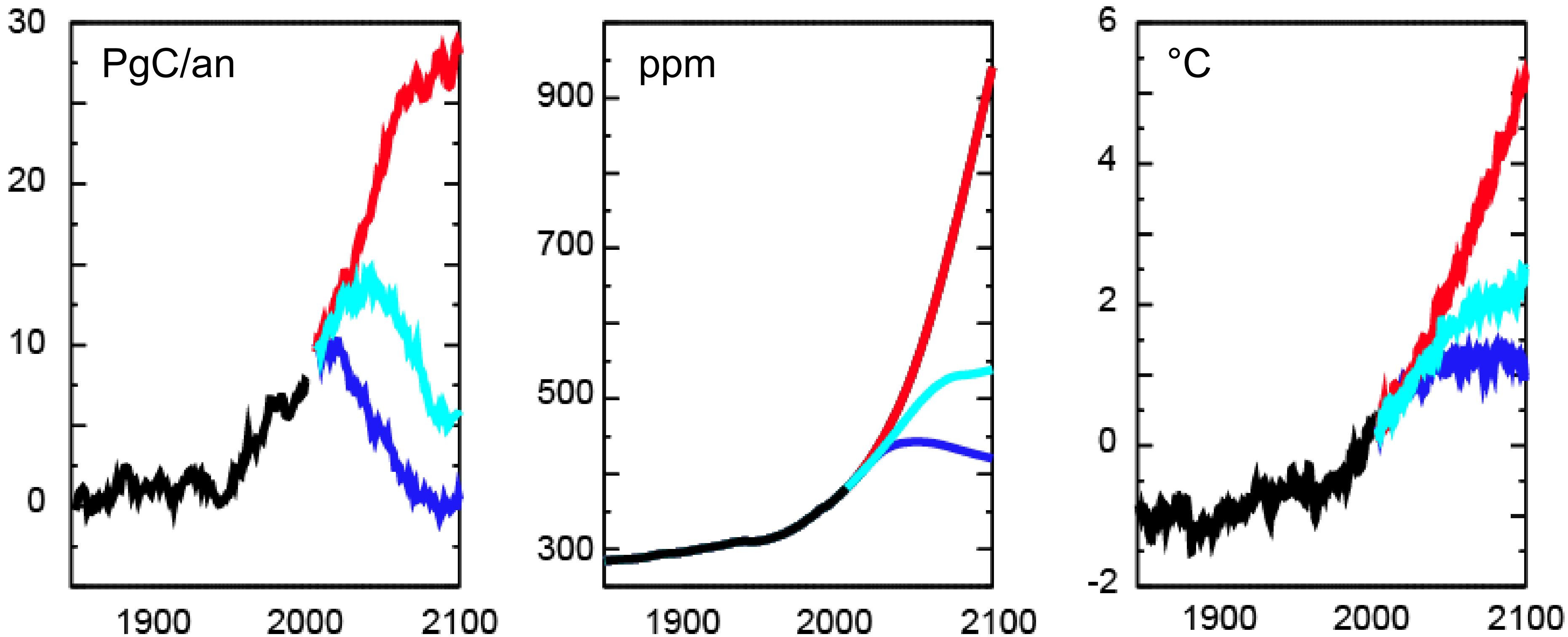
Courtesy L. Bopp

Carbone emission, CO_2 concentrations and global temperature: time constants

Higher scenario : emissions, concentration and temperatures continue to grow

Medium scenario : to stabilize CO_2 concentration 550 ppm, emissions need to be strongly reduced. However, temperature will continue to increase

Lower Scenario : to limit a 2° global warming, CO_2 concentration has to be limited to less then 450 ppm, and emissions need be to be 0 before the end of the century



Courtesy L. Bopp


Thank you for your attention