Laboratoire de
Météorologie
Dynamique

LMD

Institut Pierre Simon Laplace

Sciences de l'environnement

Climate change due to CO_2 increase

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Climate change:
a theoretical prediction

J. Fourrier

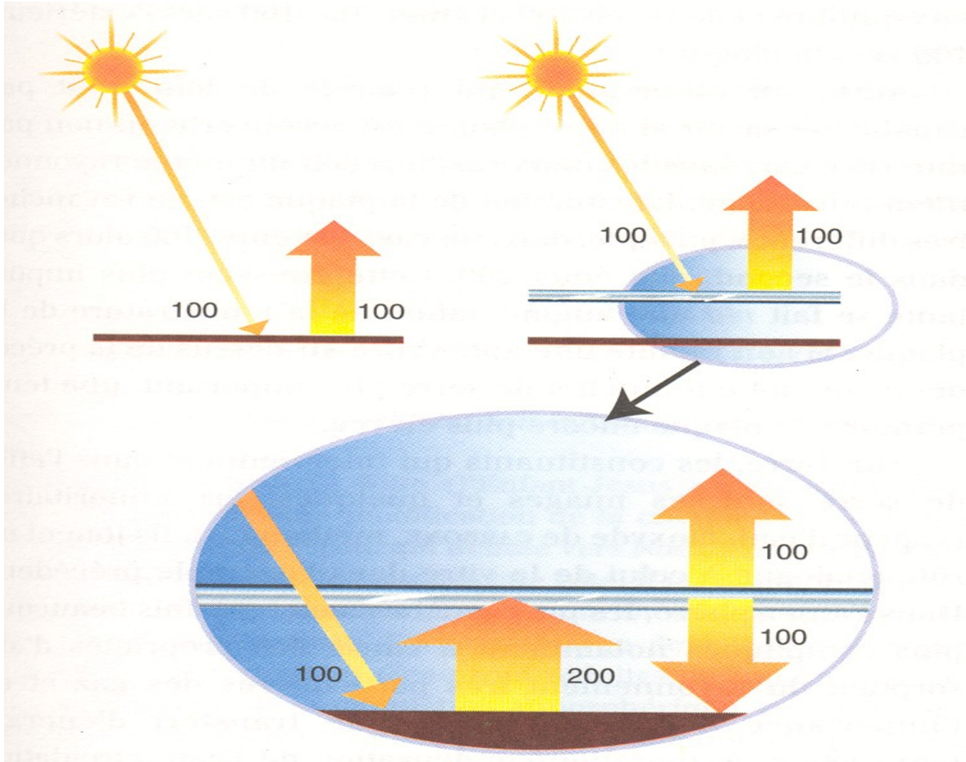
***19th Century*:** the discovery of infrared radiation and of the atmospheric 'greenhouse effect'

Beginning of the 20th Century: hypotheses:

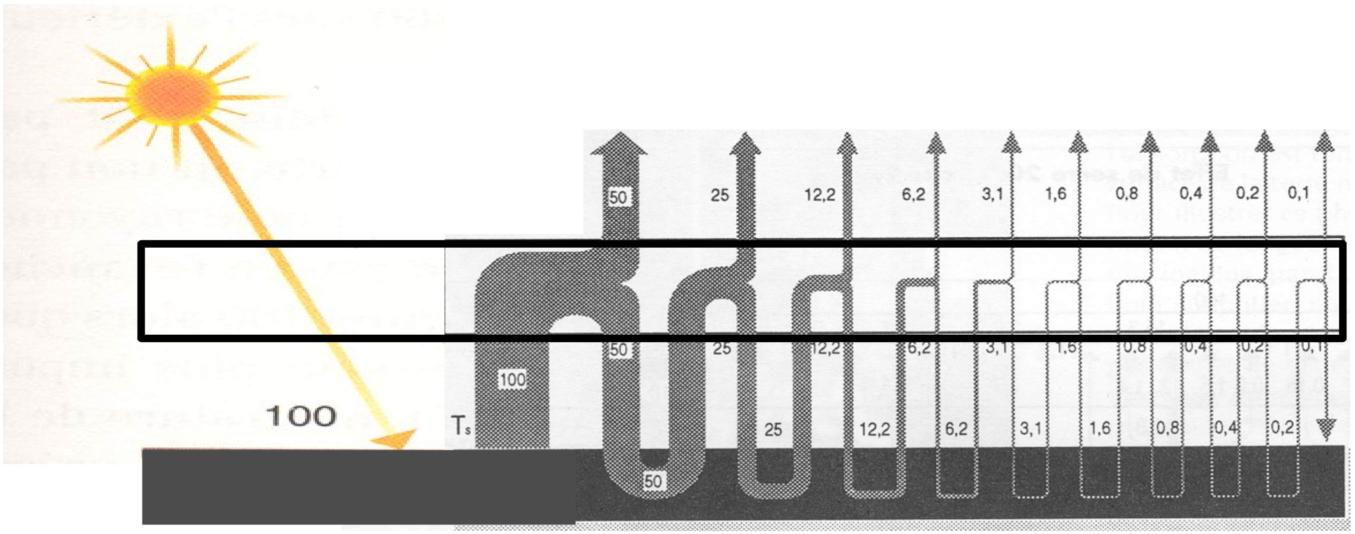
- CO_2 changes have influenced the climate in the past
- anthropogenic activities can cause an increase in CO_2 in the atmosphere, which would modify the climate

S. Arrhenius

The greenhouse effect



A sheet of glass opaque to infrared radiation covers a surface exposed to sunlight

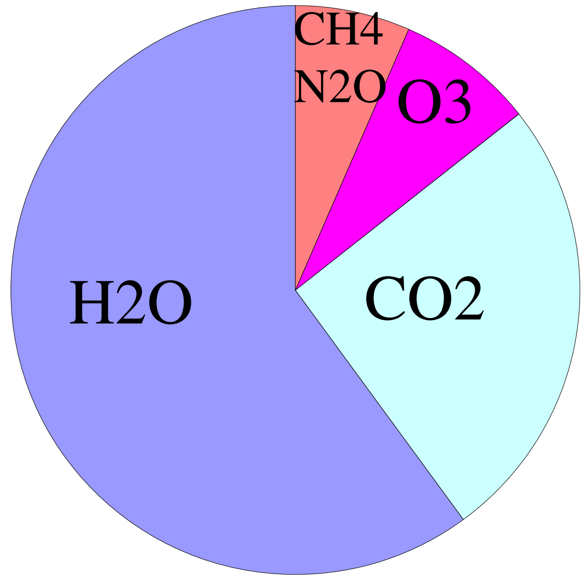


Main greenhouse gases

Greenhouse effect ($W.m^{-2}$):

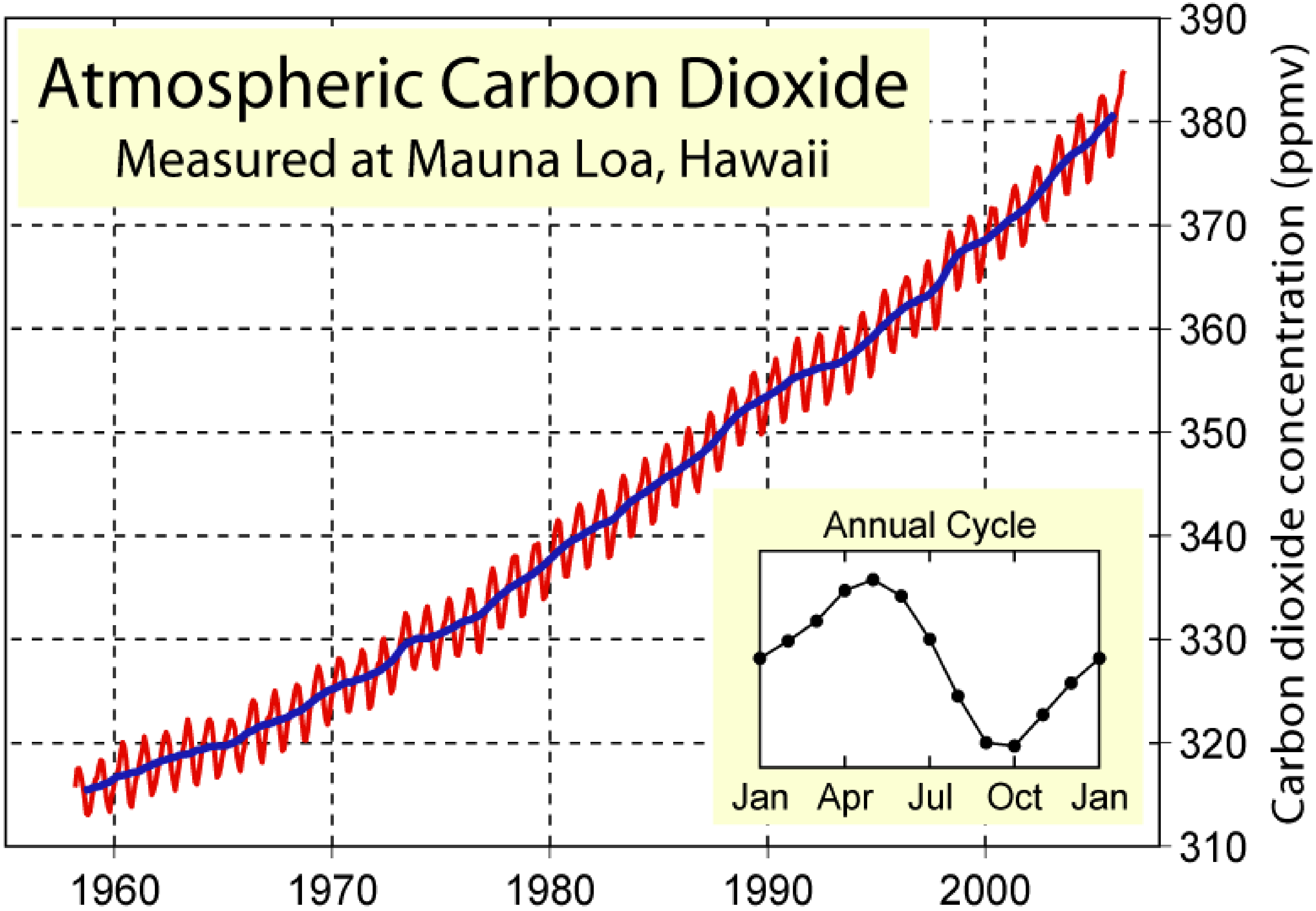
Water vapour	75	60%
CO_2	32	26%
Ozone	10	8%
N2O+CH4	8	6%

Greenhouse gaz contribution

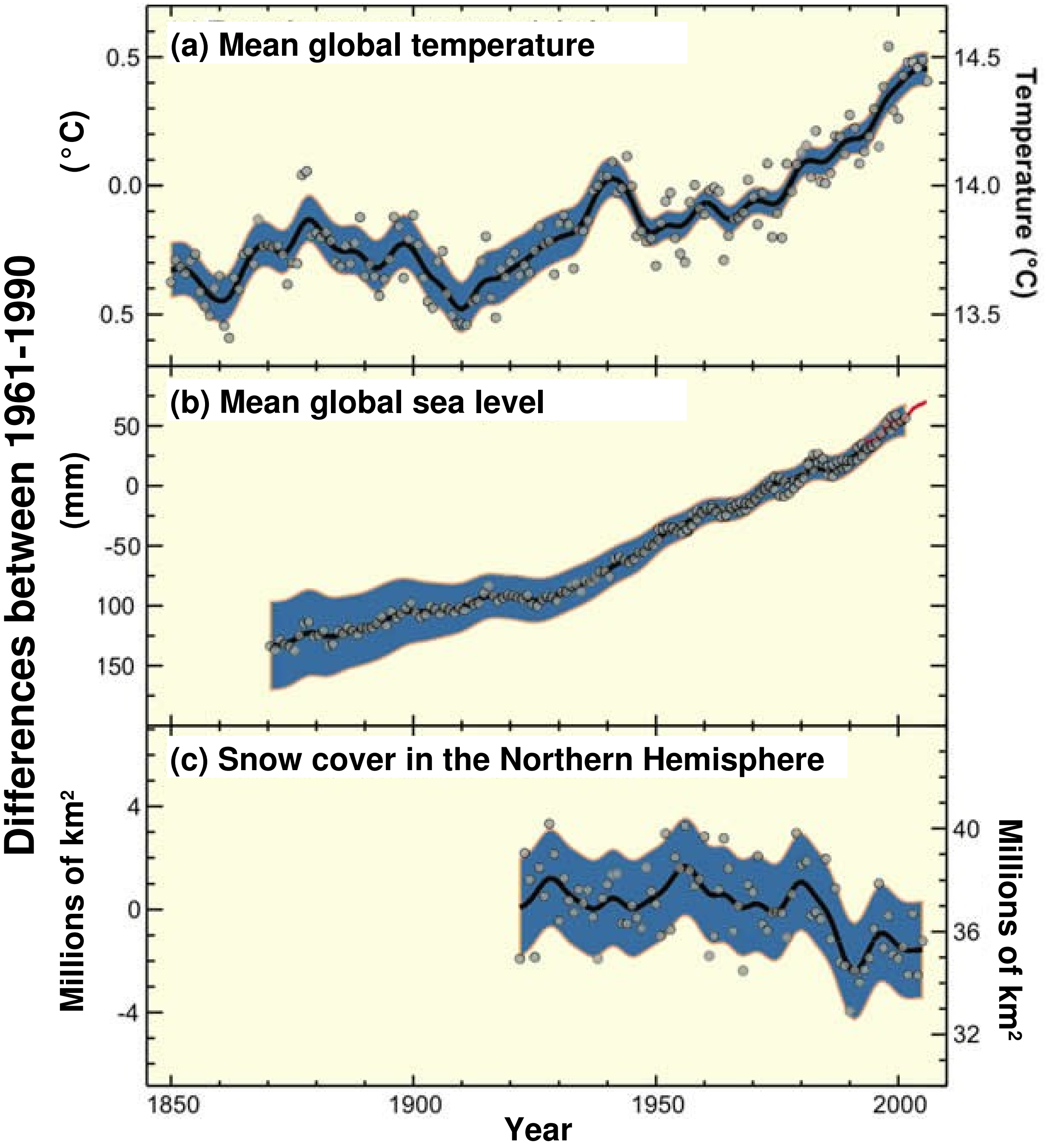


Source: Meehl and Trenberth, 1997

Anthropogenic changes: a recent observation



Climate variations on a global scale



Source: IPCC 2007

Anthropogenic aerosols

Aerosols:

- Reflect solar radiation
- Modify the size of cloud droplets
- Modify the formation of precipitation?

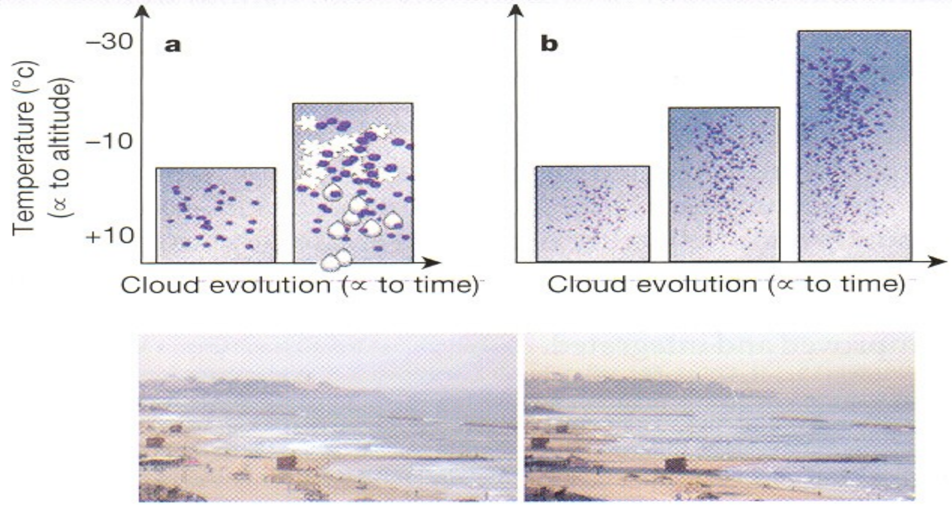
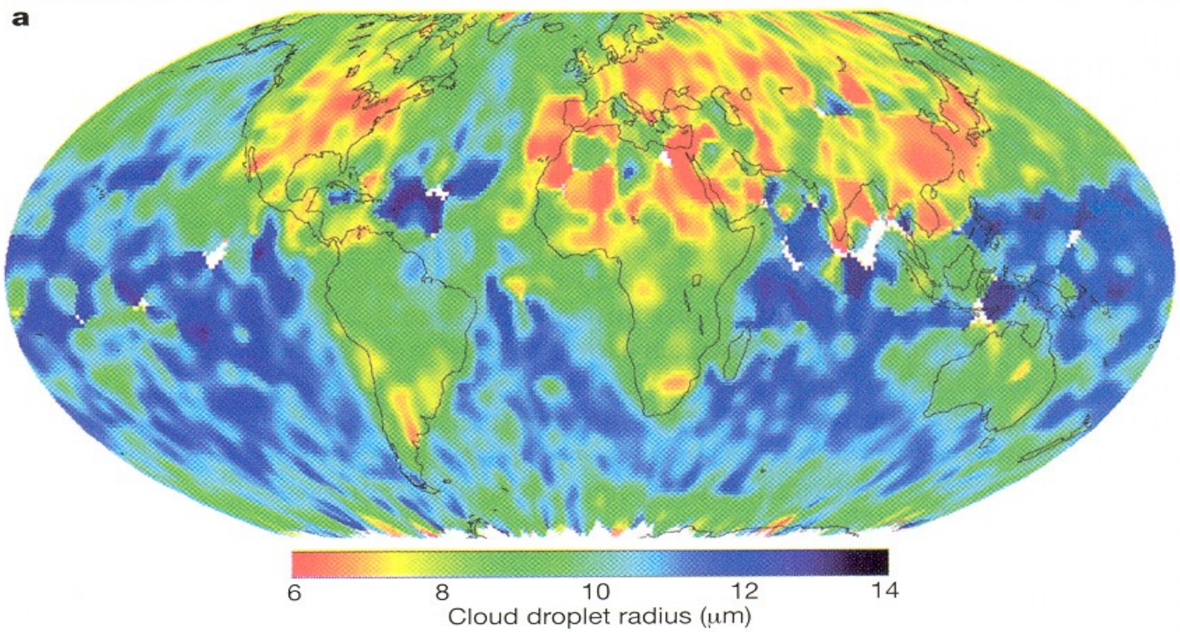


Figure 6 Schematic diagram of cloud formation in a clean and polluted atmosphere. **a**, In a clean atmosphere, the cloud droplet size increases with cloud development until liquid precipitation or glaciation and precipitation take place. **b**, In polluted clouds, the availability of cloud condensation nuclei decreases cloud droplet development. In clouds with strong updrafts the developed cloud can be supercooled with no glaciation down to −37.5 °C. The filled circles show the location of droplets of varying size, the asterisks show the location of ice crystals, and the oval shapes indicate rain drops.

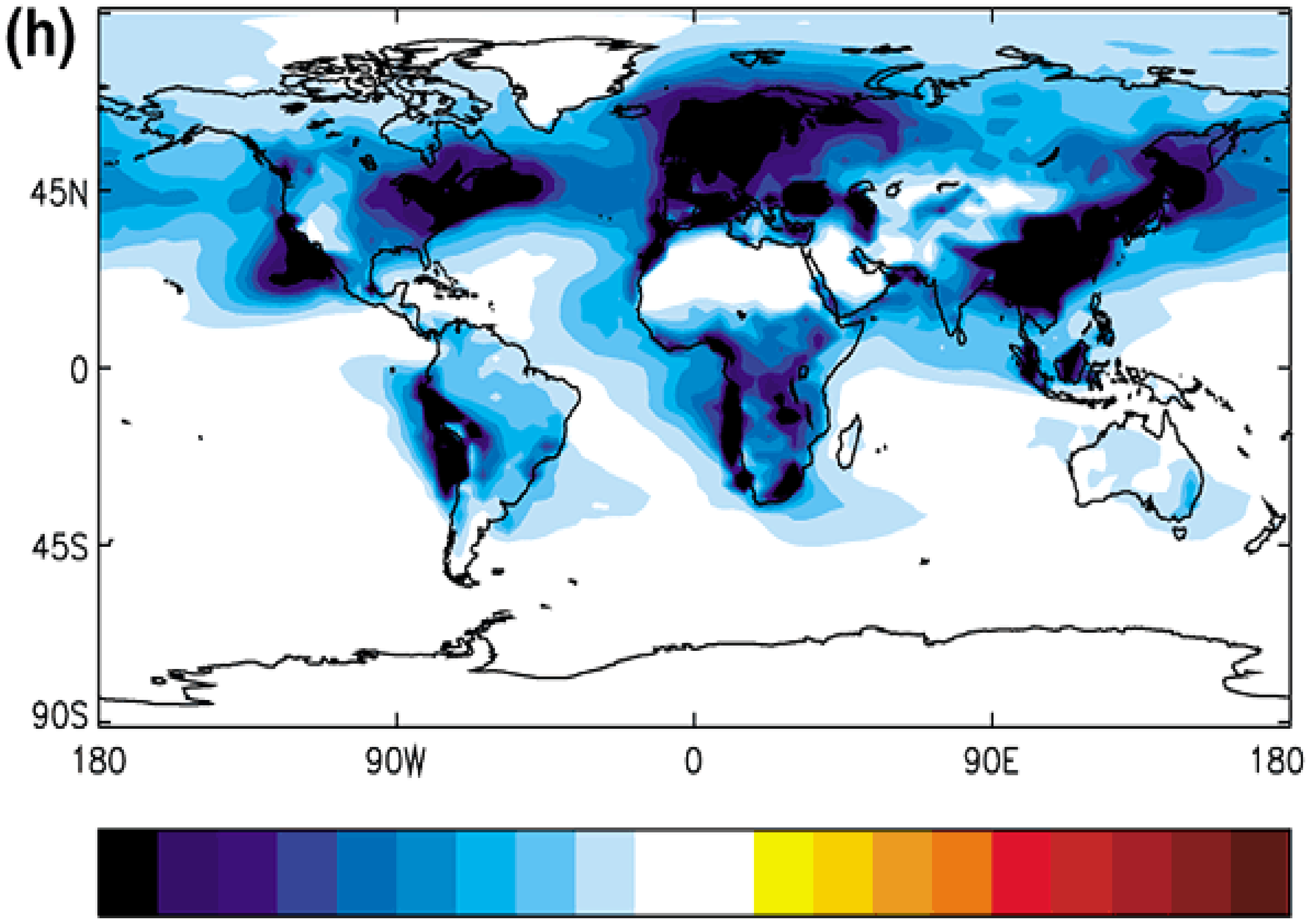
Figure 7 Effect of aerosol on cloud droplet and reflectance derived from POLDER and AVHRR spaceborne measurements. **a**, Seasonal (March–May 1997) average droplet size in liquid water clouds estimated from the POLDER measurements[31]. **b**, The dependence of the droplet size on the aerosol index, also derived from POLDER over land (red) and ocean (blue). **c**, Analysis of AVHRR data for the dependence of the droplet size (purple) and cloud reflectance (brown and red) on aerosol optical thickness over the Amazon Basin during the dry burning season of 1987 (refs 16, 19). The reflectance of low-level clouds (brown) with reflectance of 0.35 increases with the aerosol concentration and the reflectance of bright clouds (red) decreases.



Source: Kaufman et al. 2002, Bréon et al. 2002

Anthropogenic aerosols

Radiative effect of sulfate aerosols (direct and indirect)

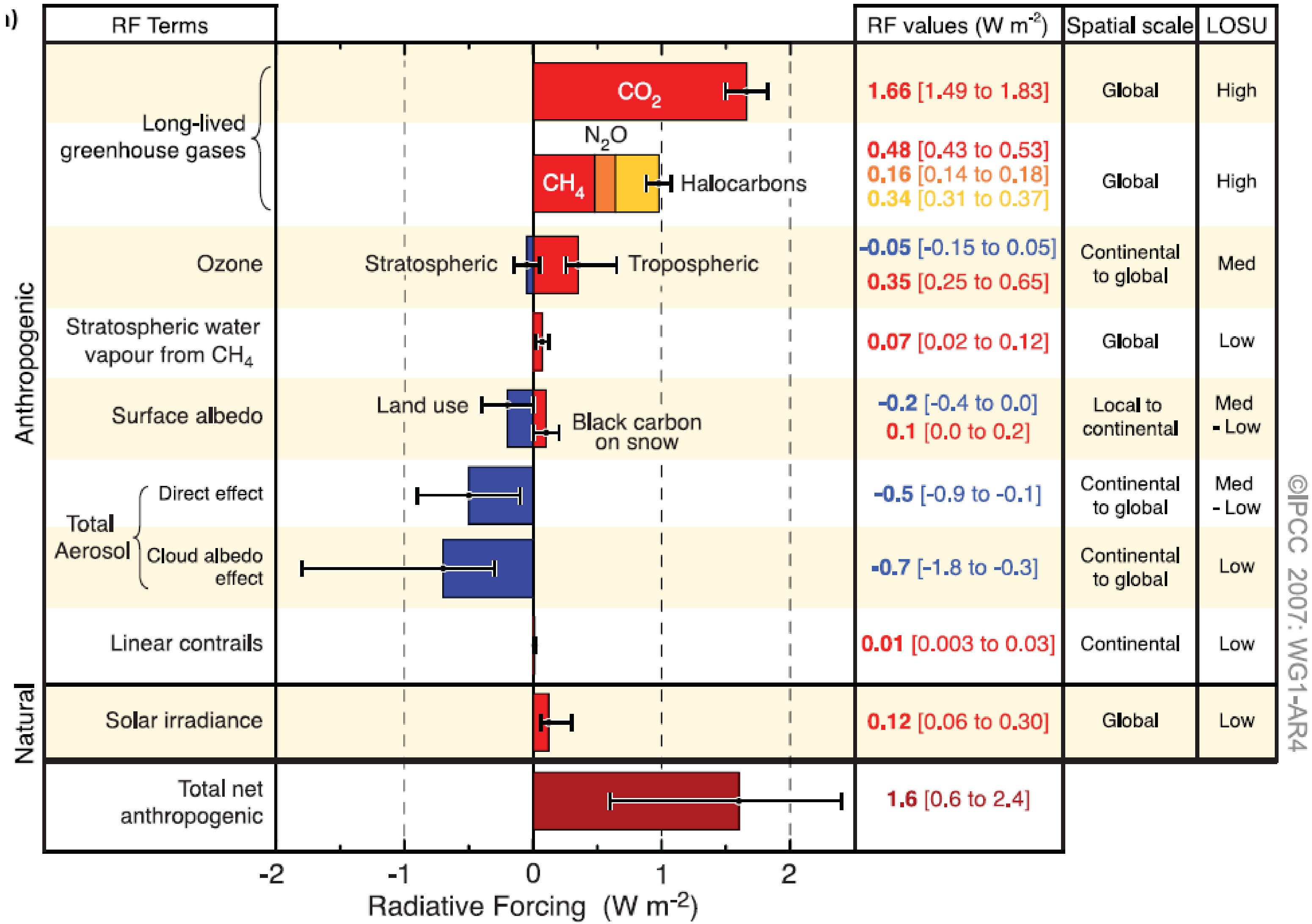


(W/m^2)

But also carbon soot, mineral dust, and so on.

Source: GIEC 2001

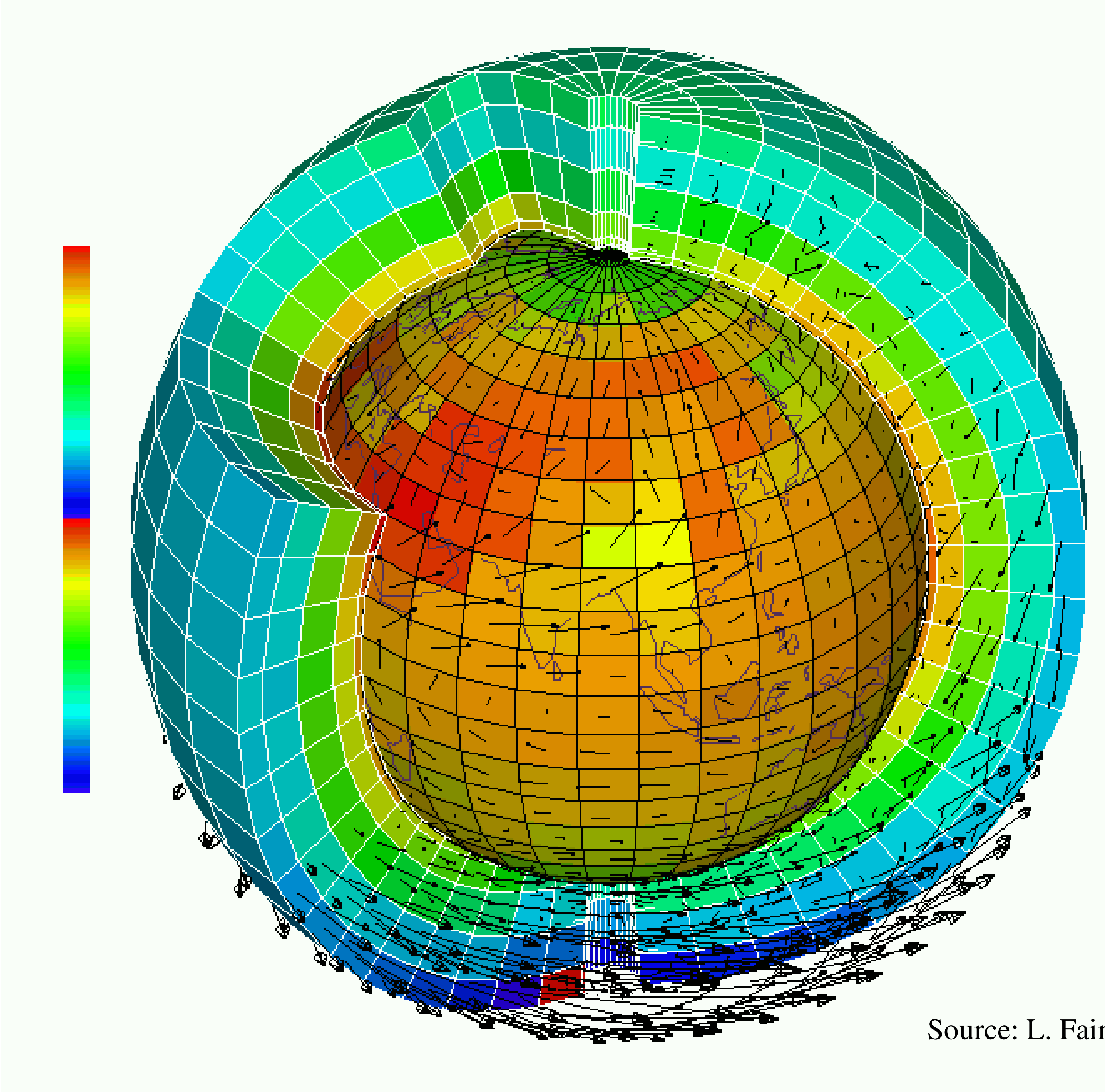
Global mean radiative forcings



Currently, aerosols mask between 1/3 and ½ off the radiative forcing due to greenhouse gases increase. It will not be the case in the future any more

Source: IPCC 2007

3D numerical climate model

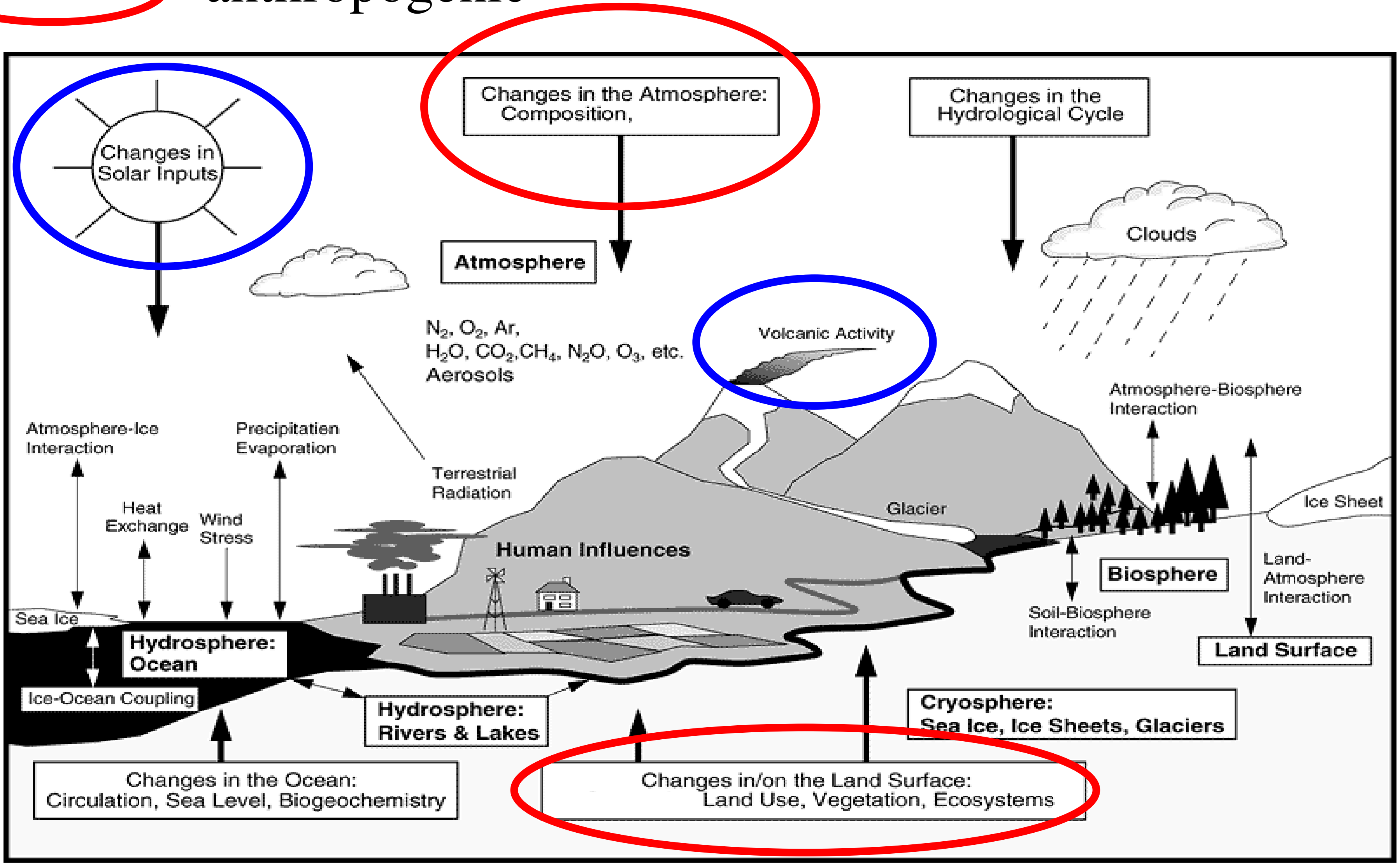


Source: L. Fairhead, LMD/IPSL

Climate forcings

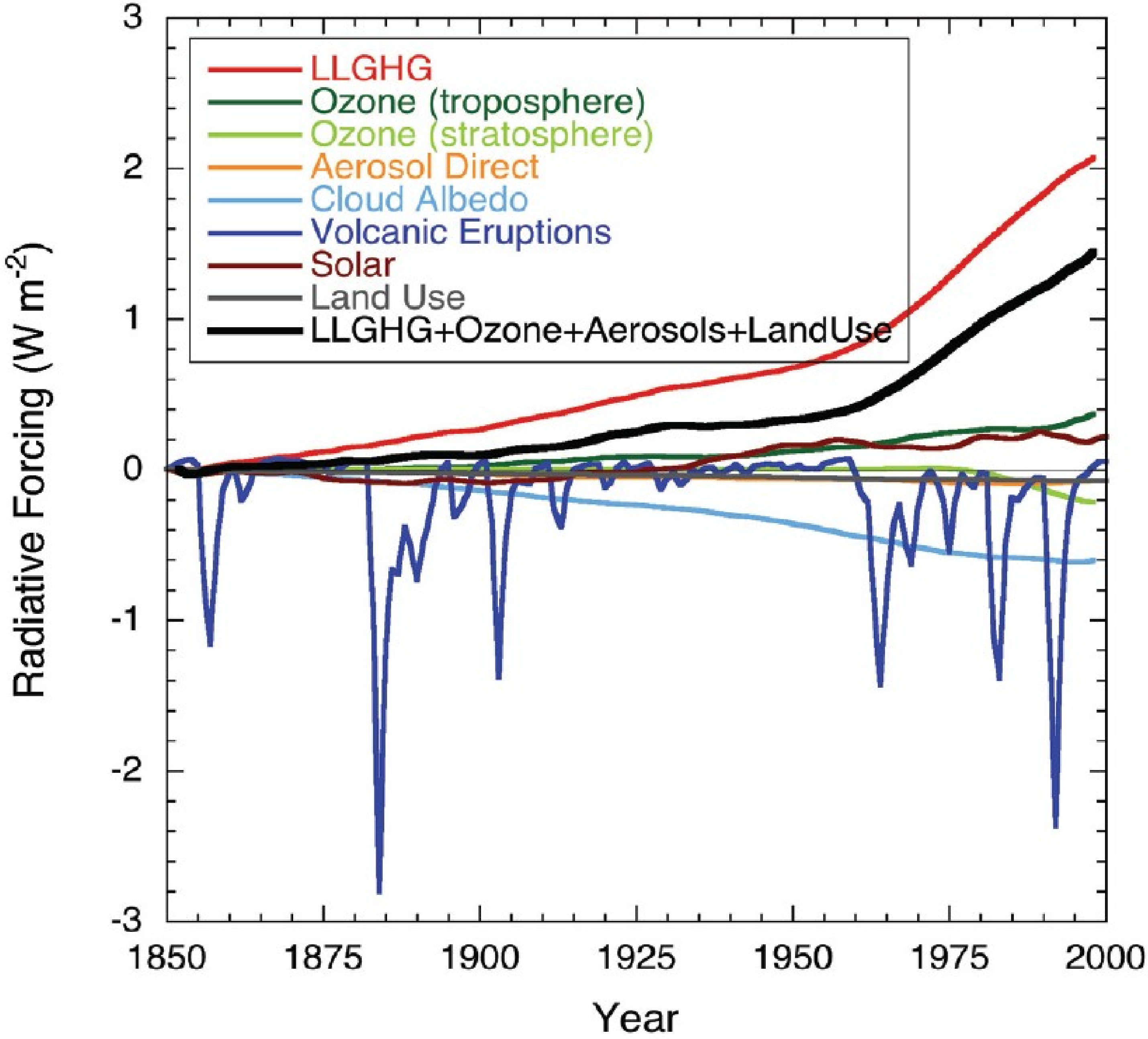
natural

anthropogenic



Source: IPCC, 2001

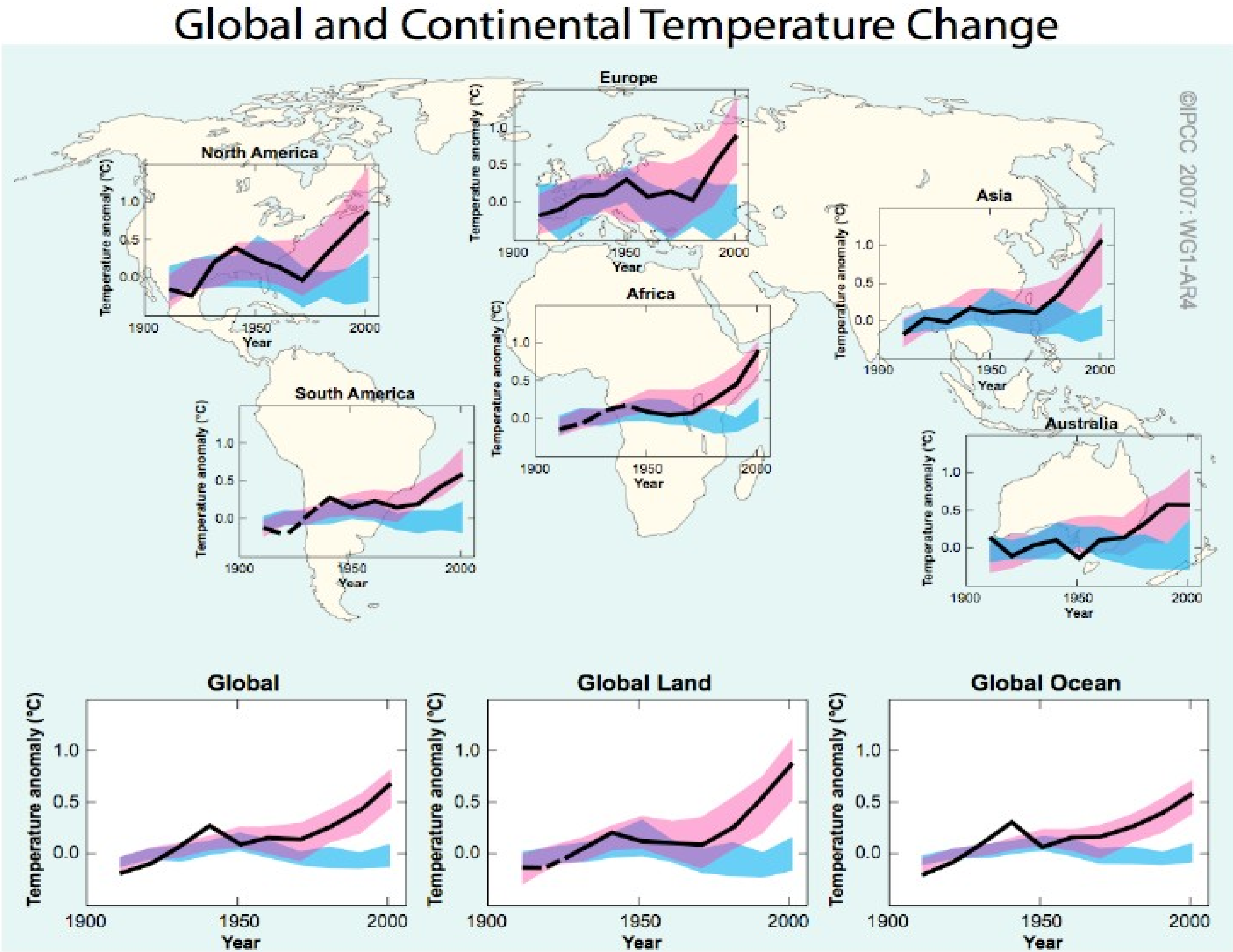
Radiative forcings over the 20th century



Added to solar "forcing" (240 W/m2)

Source: IPCC 2007

Has human activities already changed the climate?



Black: observations; blue: natural forcing; magenta: anthropogenic+natural forcing

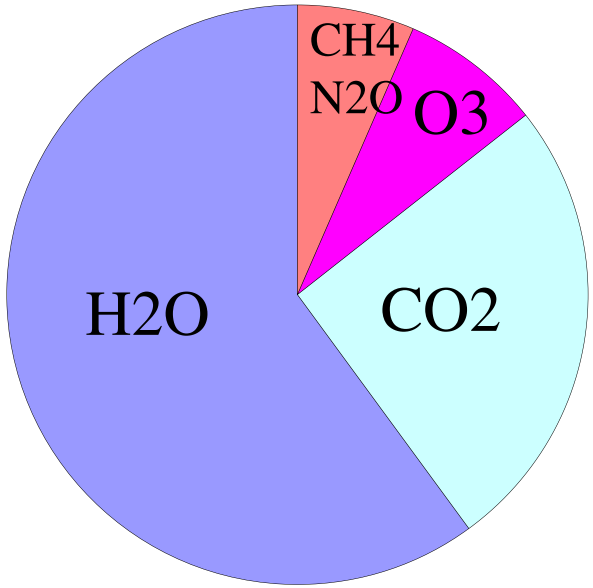
Source: IPCC 2007

Contributions to the greenhouse effect

Greenhouse effect ($W.m^{-2}$):

water vapour	75	60%
CO2	32	26%
ozone	10	8%
N2O+CH4	8	6%

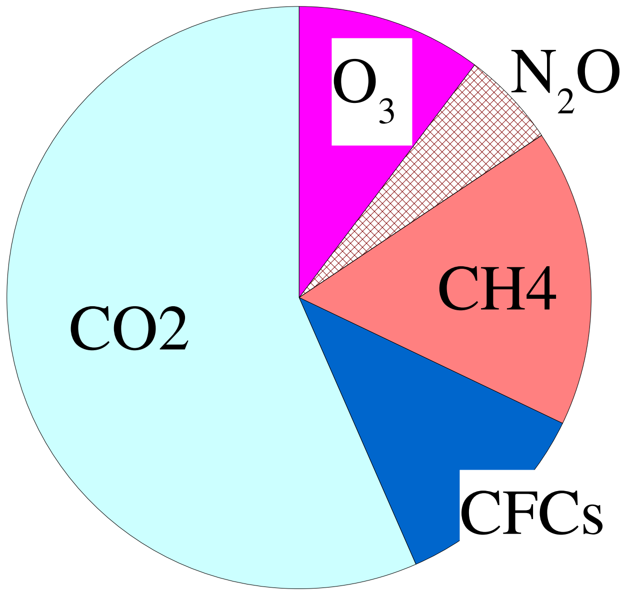
Greenhouse gaz contribution



Additional greenhouse effect, due to anthropogenic activities:

- CO2 56%
- CFCs 12%
- methane (CH_4) 16%
- ozone (O_3) 11%
- N_2O 5%

Anthropogenic greenhouse increase

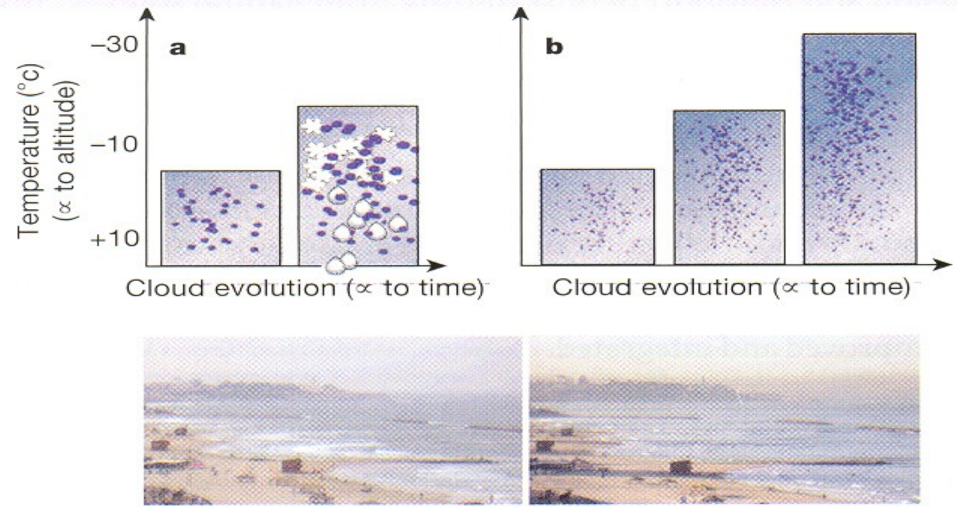


Source: IPCC 2007

Anthropogenic aerosols

Aerosols:

- reflect solar radiation
- change the size of droplets in clouds
- change the way precipitation forms?



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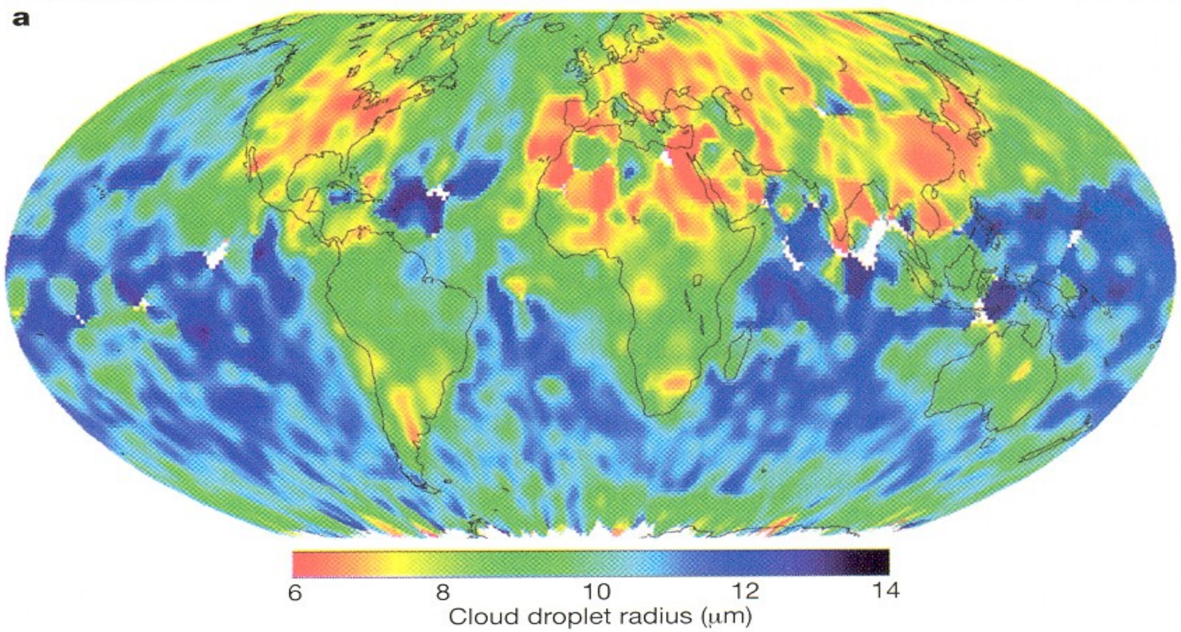
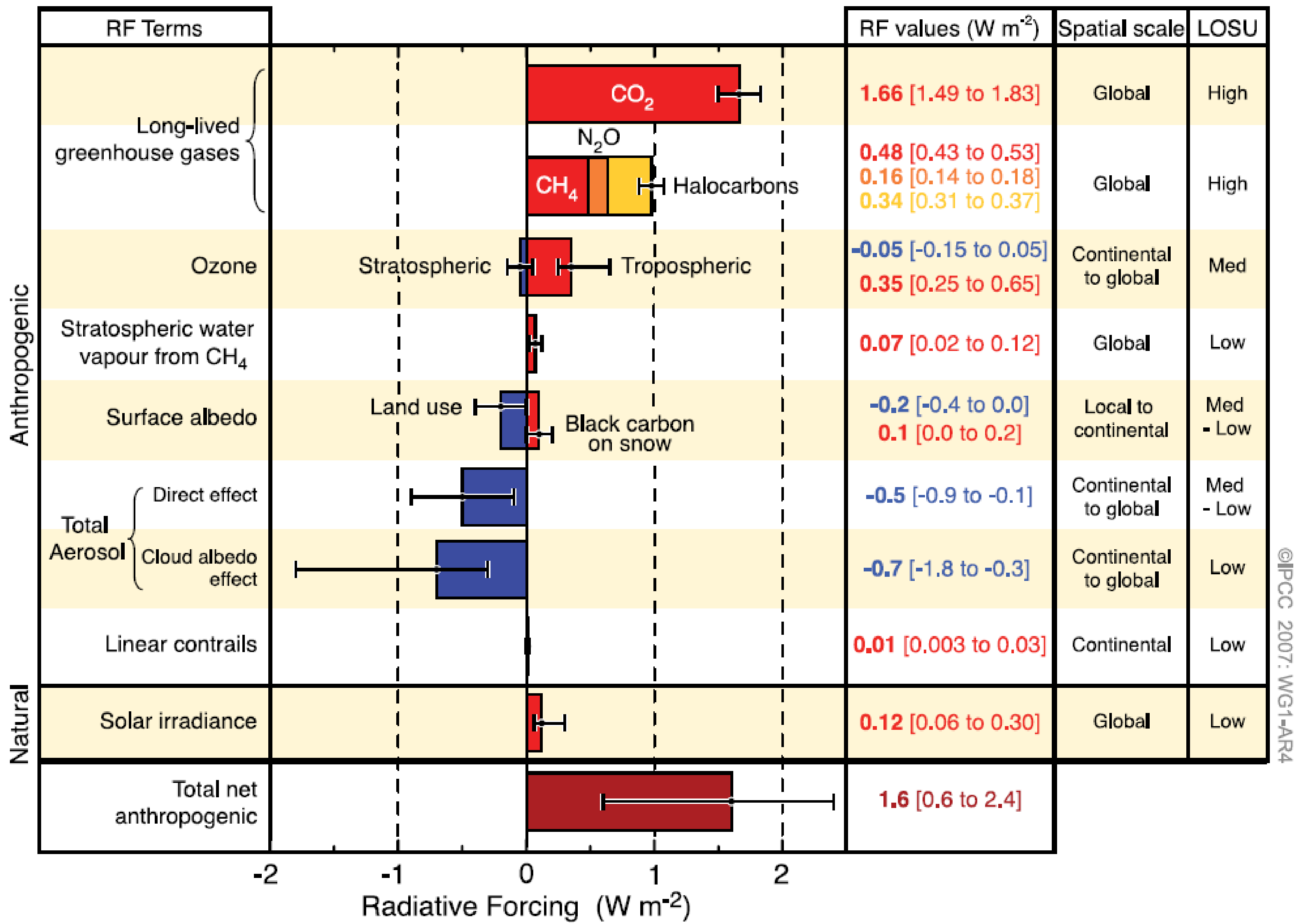


Source: Kaufman et al. 2002, Bréon et al. 2002

Radiative forcing over the last 150 years

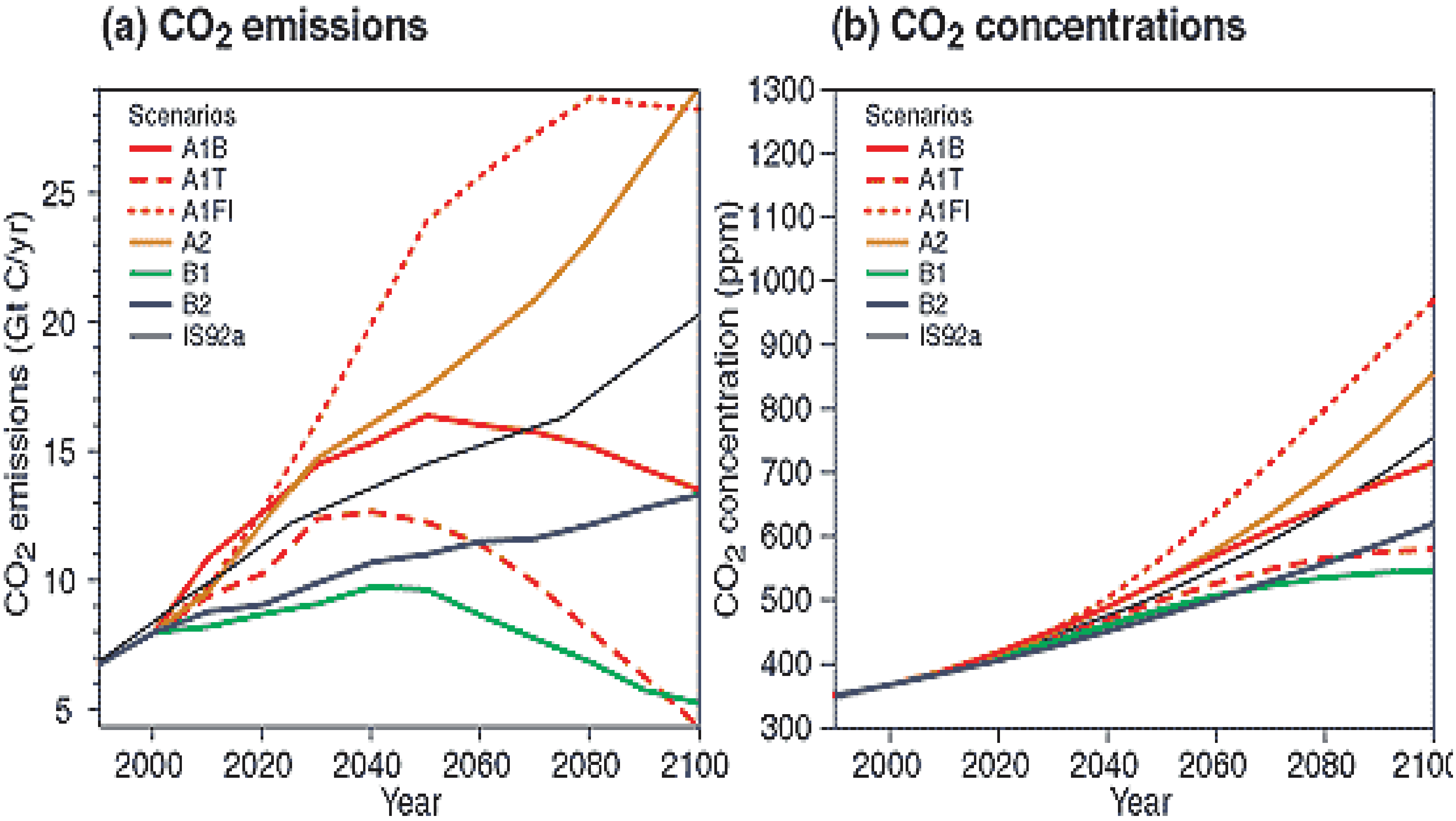


Aerosols now mask 1/3 to 1/2 of the additional greenhouse effect and their actual effect is uncertain.

Source: IPCC 2007

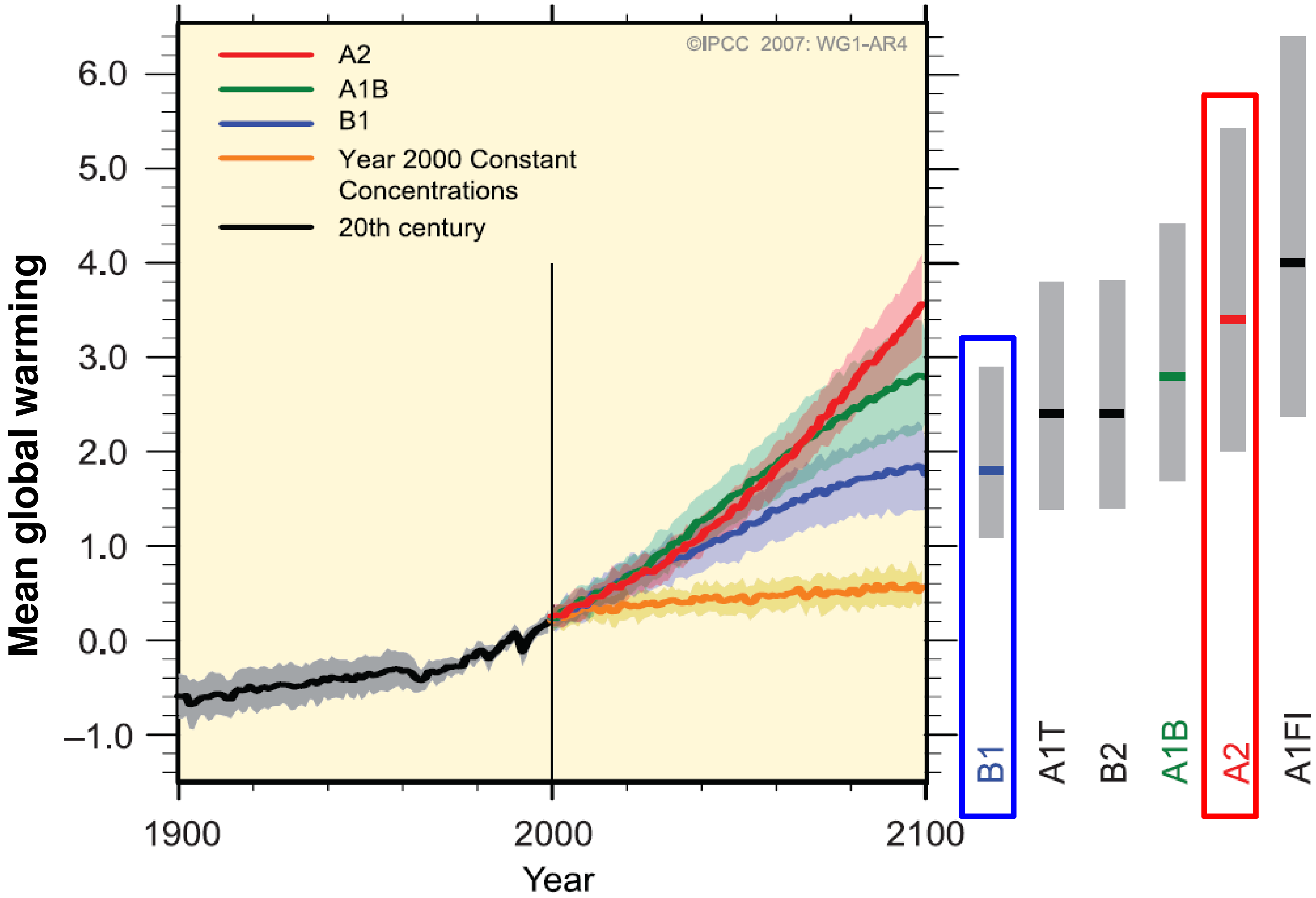
Future climate change

Emissions and concentrations of CO_2: using different scenarios



Source: IPCC 2001

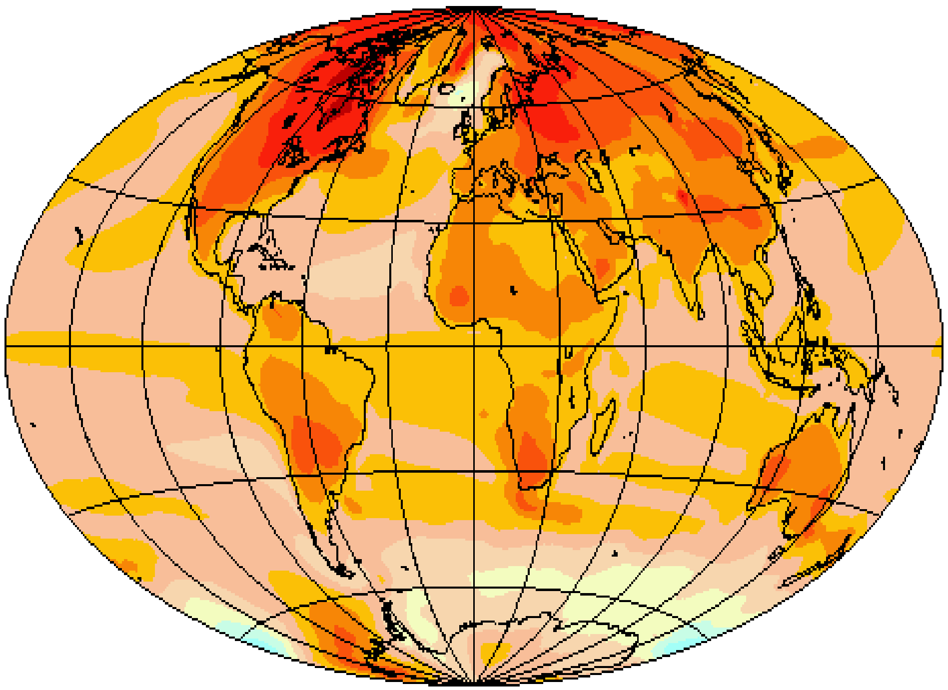
Changes in global temperature



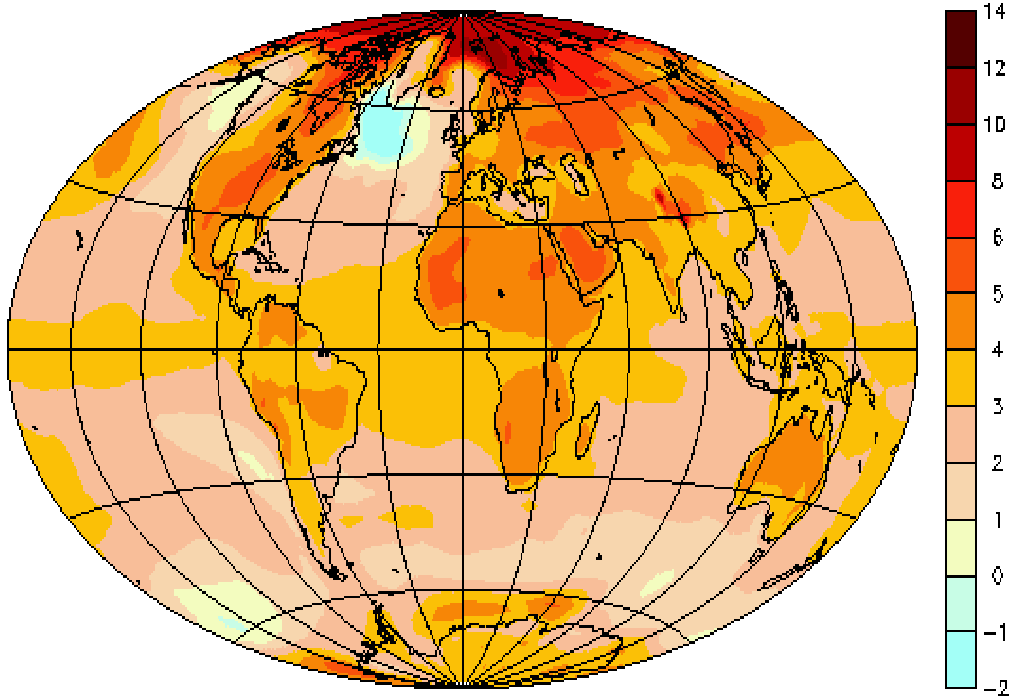
Source: IPCC 2007

Projecting forward to 2100

Changes in temperature for the A2 scenario



IPCC / IPSL – SRESA2 scenario – Temperature anomalies (deg. C)
(2090-2099) compared to (2000-2009)

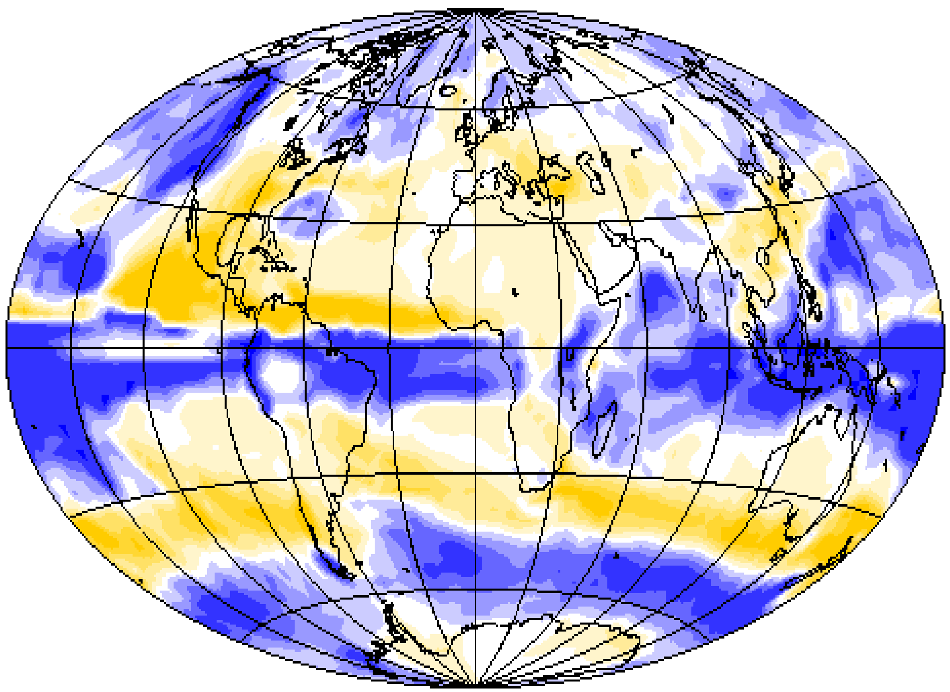


IPCC / CNRM – SRESA2 scenario – Temperature anomalies (deg. C)
(2090-2099) compared to (2000-2009)

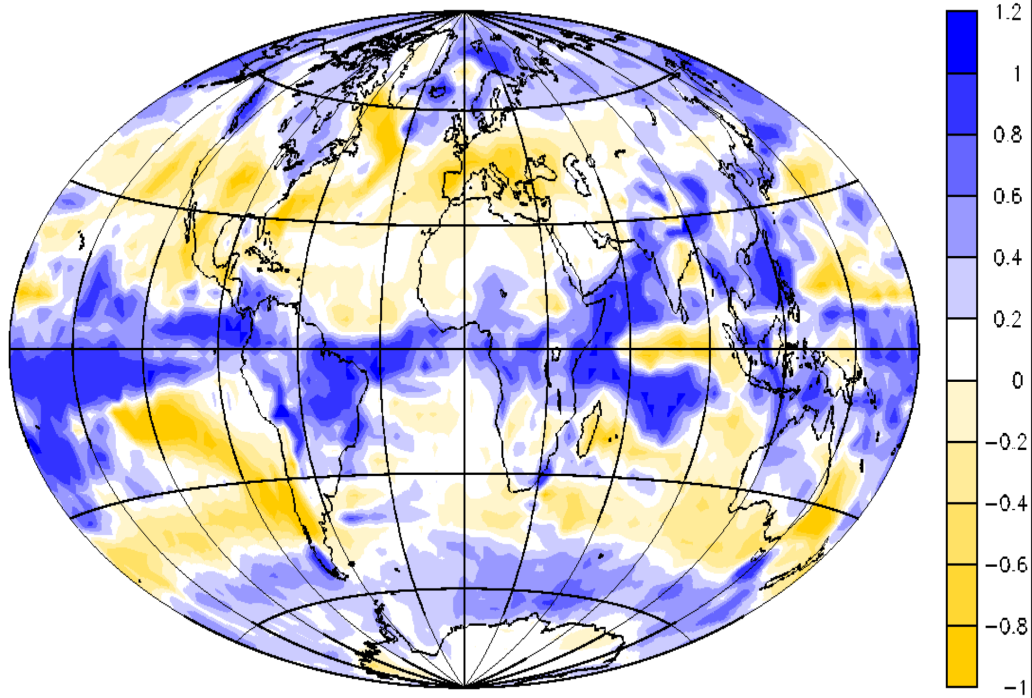
Source: CNRM et IPSL, 2006

Projecting forward to 2100

Changes in precipitation for the A2 scenario



IPCC / IPSL – SRESA2 scenario – Precipitation anomalies (mm/day)
(2090-2099) compared to (2000-2009)



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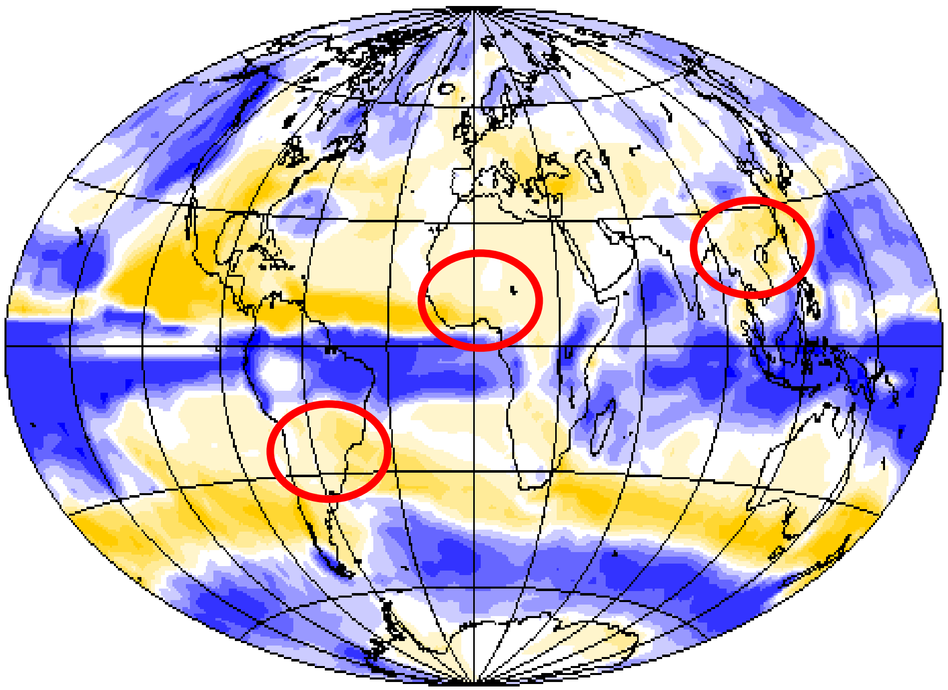
Changes in precipitation for the A2 scenario



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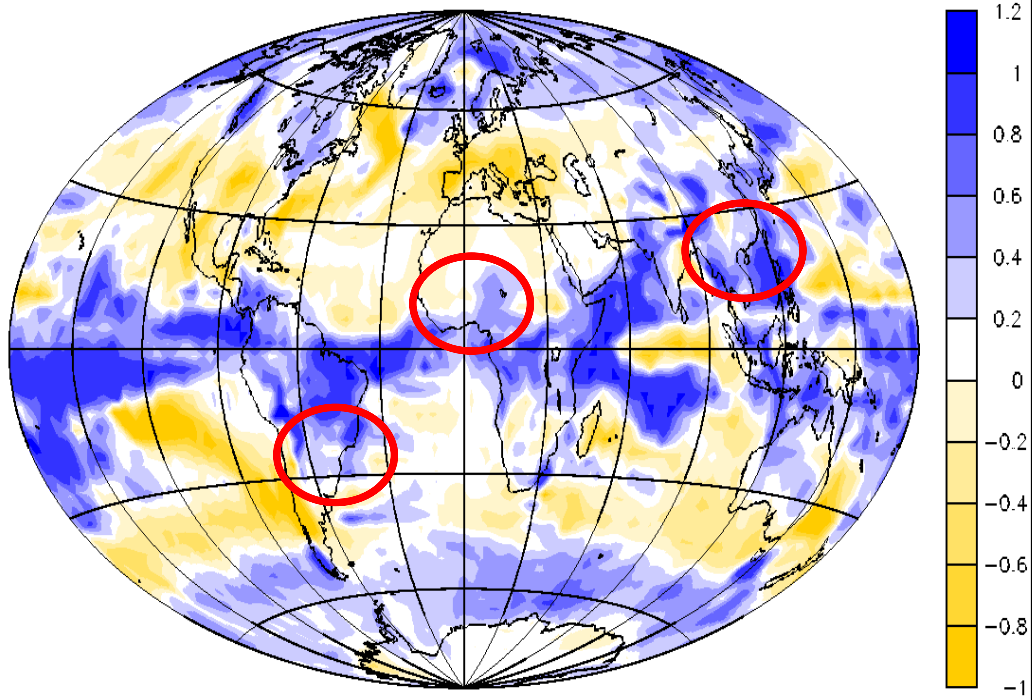


IPCC / CNRM – SRESA2 scenario – Precipitation anomalies (mm/day)
(2090-2099) compared to (2000-2009)

Source: CNRM et IPSL, 2006

Projected Patterns of Precipitation Changes

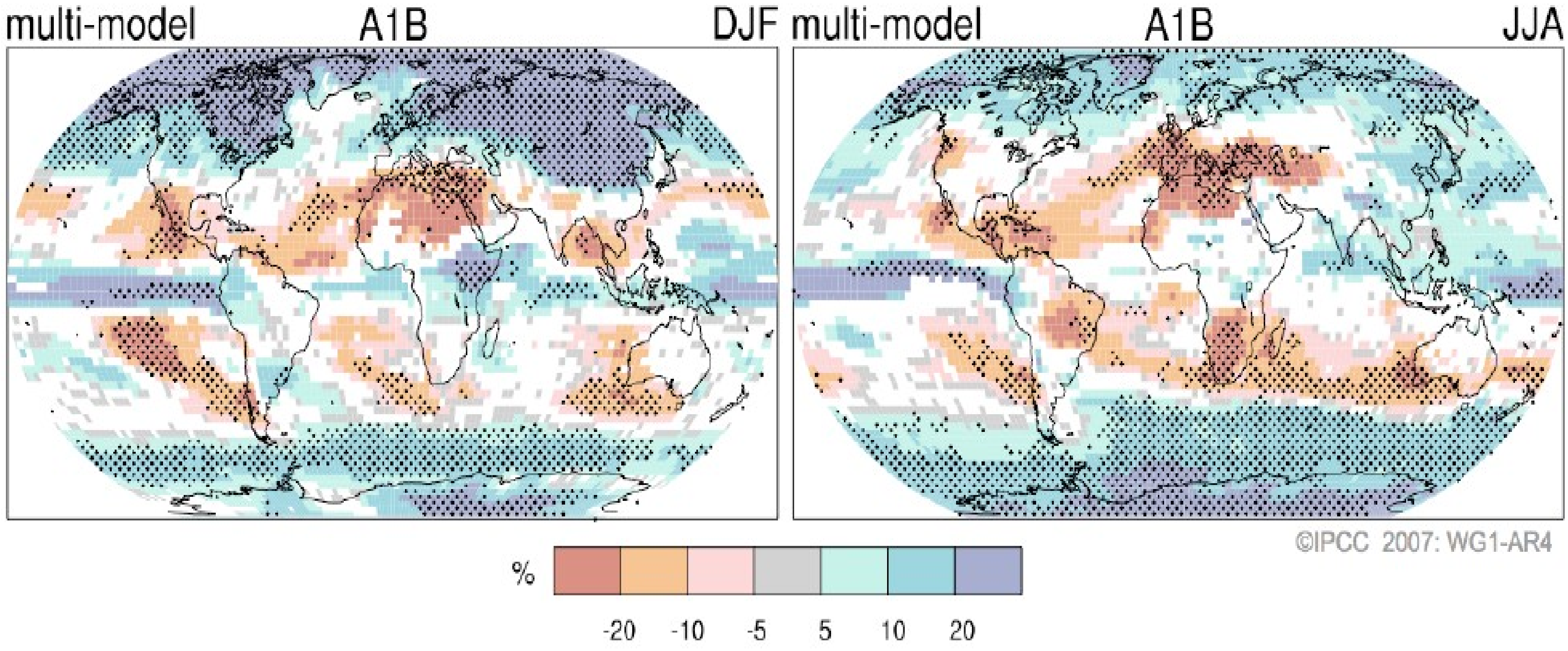


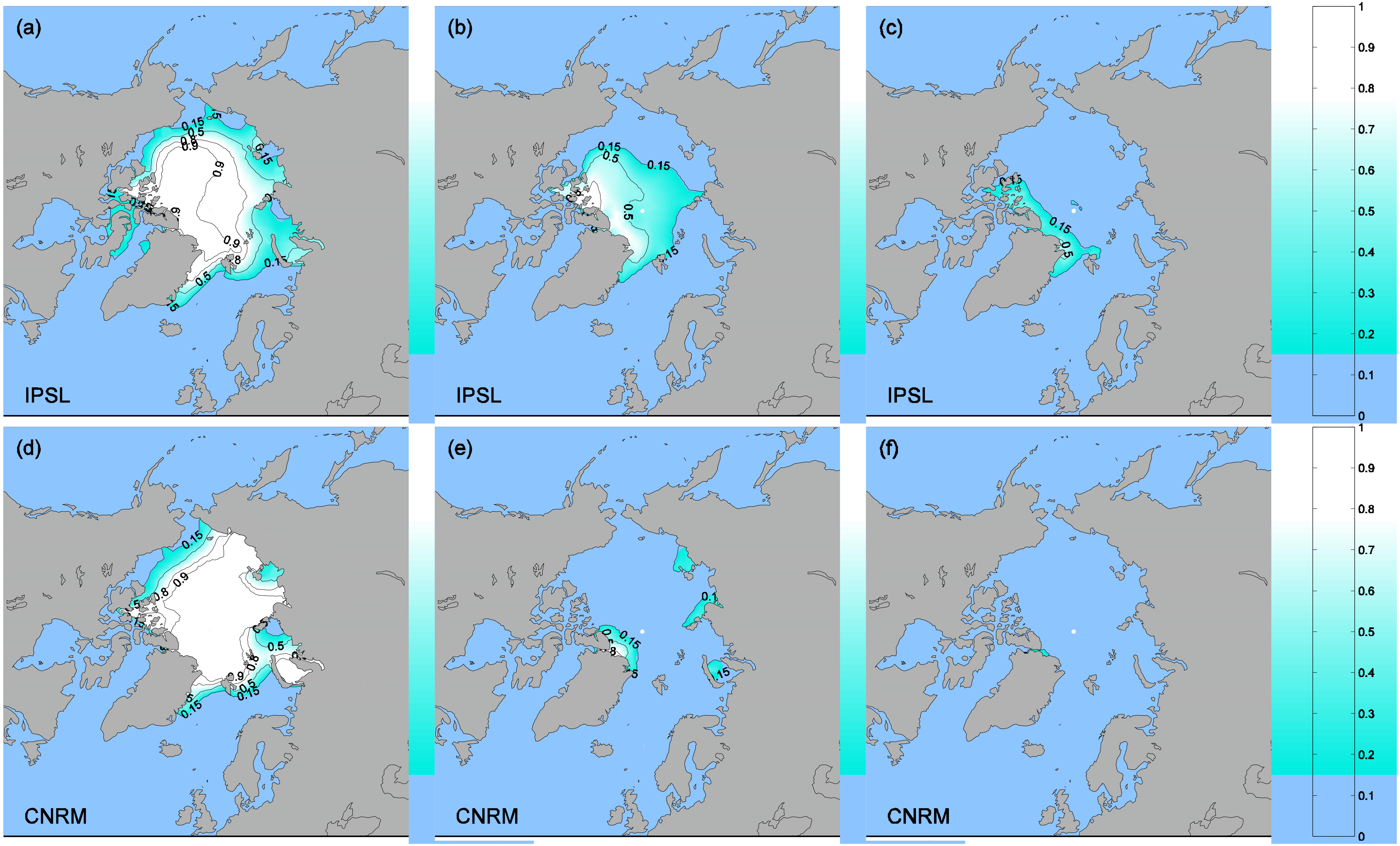
FIGURE SPM-6. Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. {Figure 10.9}

Source: IPCC 2007

Minimal extent of the sea-ice (summer)

IPSL

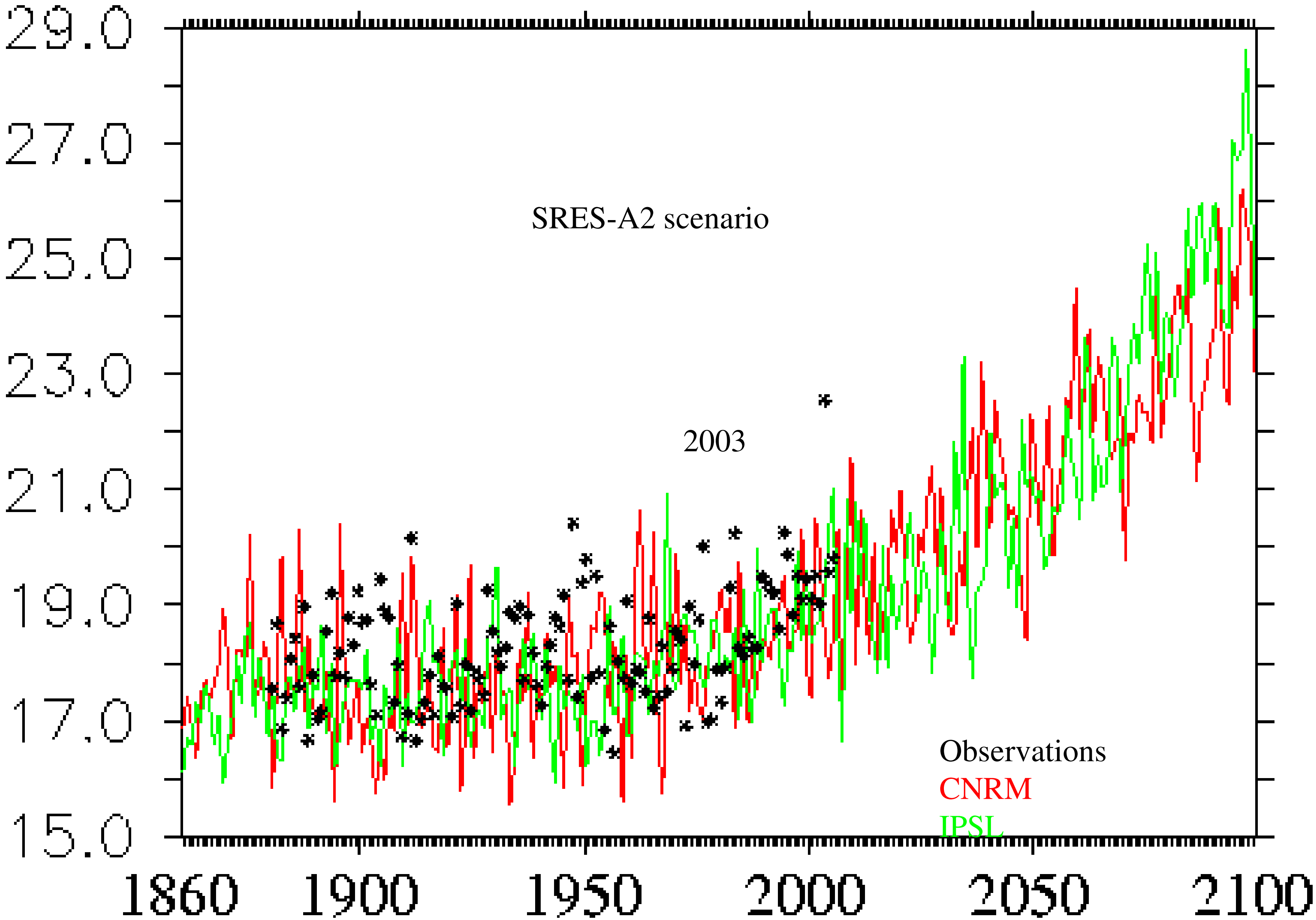
CNRM



1960-1989 | 2070-2099; B1 | 2070-2099; A2

[Dufresne et al., 2006]

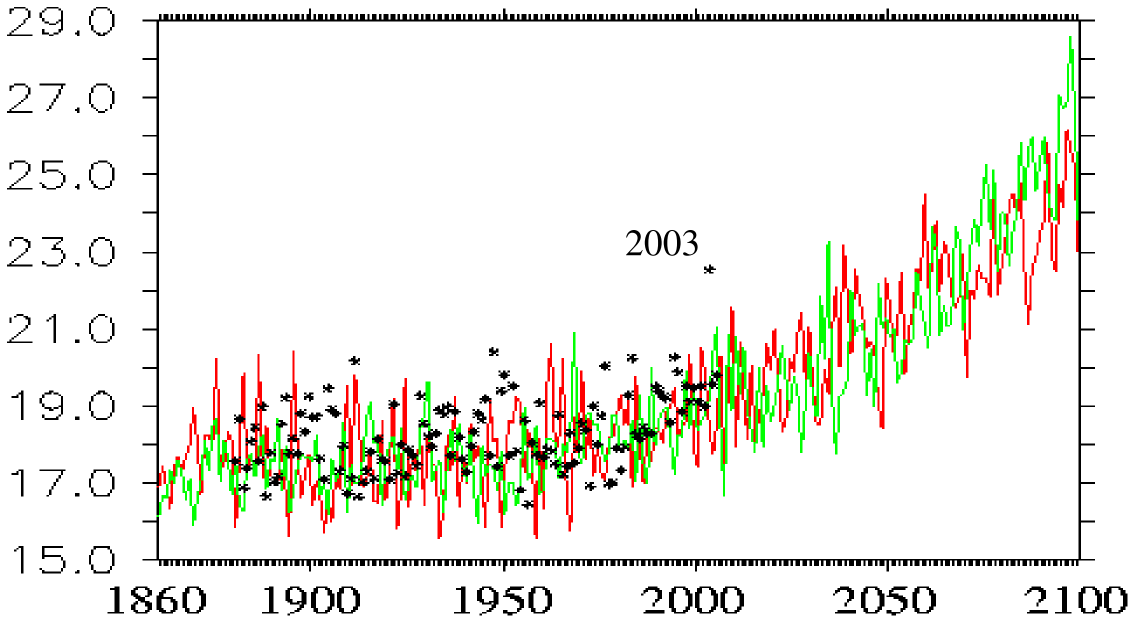
Mean summer temperatures for France, from 1860 to 2100



Source: Dufresne et al., 2006

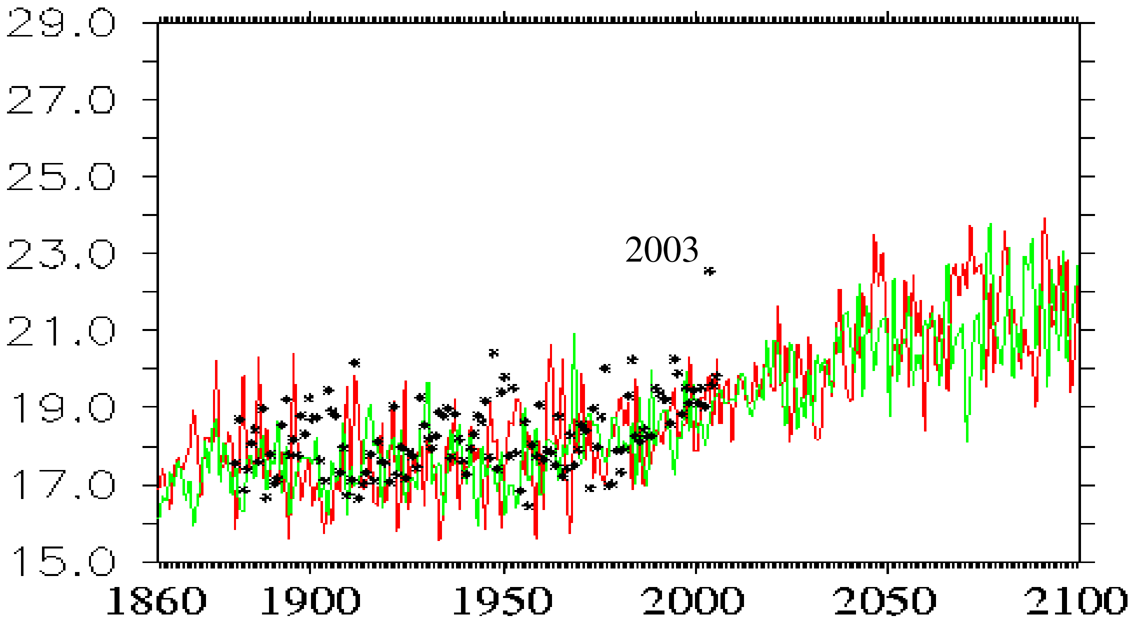
Mean summer temperatures for France, for two scenarios

SRES-A2



Observations
CNRM
IPSL

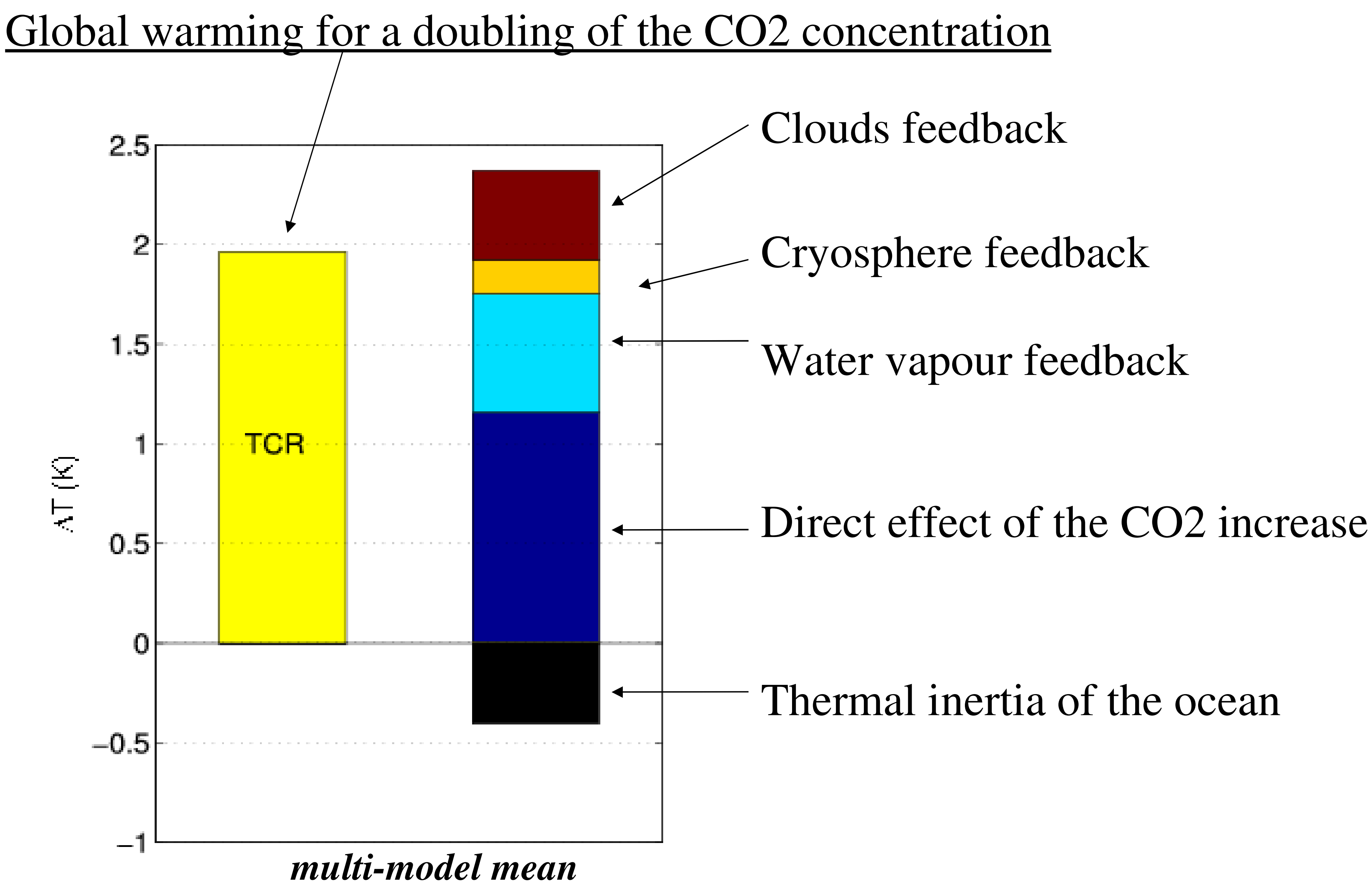
SRES-B1



Observations
CNRM
IPSL

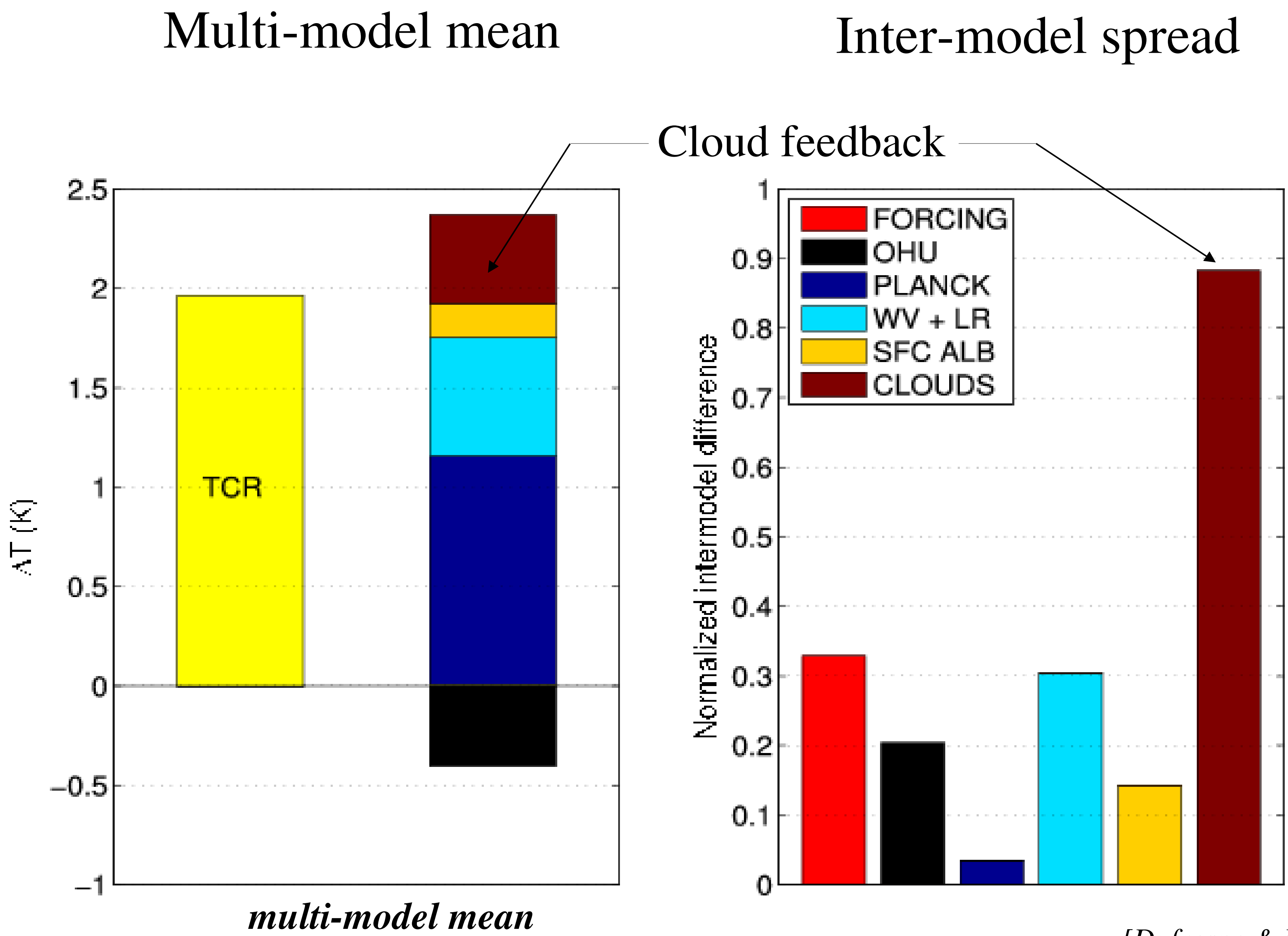
Source: Dufresne et al., 2006

Uncertainties: the importance of feedback loops



[Dufresne & Bony 2008]

Uncertainties: the importance of feedback loops



[Dufresne & Bony 2008]

Conclusions

- The climate is going to change significantly if emissions of CO_2 and other gases are not reduced.
- The geographical distribution of temperature changes is fairly well known.
- This is not the case for precipitation.
- Water stress in plants will increase (as evaporation increases).
- Seasonal cycles of water availability will change.
- Sea-levels will rise.
- Hurricanes? Thunderstorms? Rainstorms?
- Will the oceans and the Earth's vegetation continue to up-take half of human's CO_2 emissions?