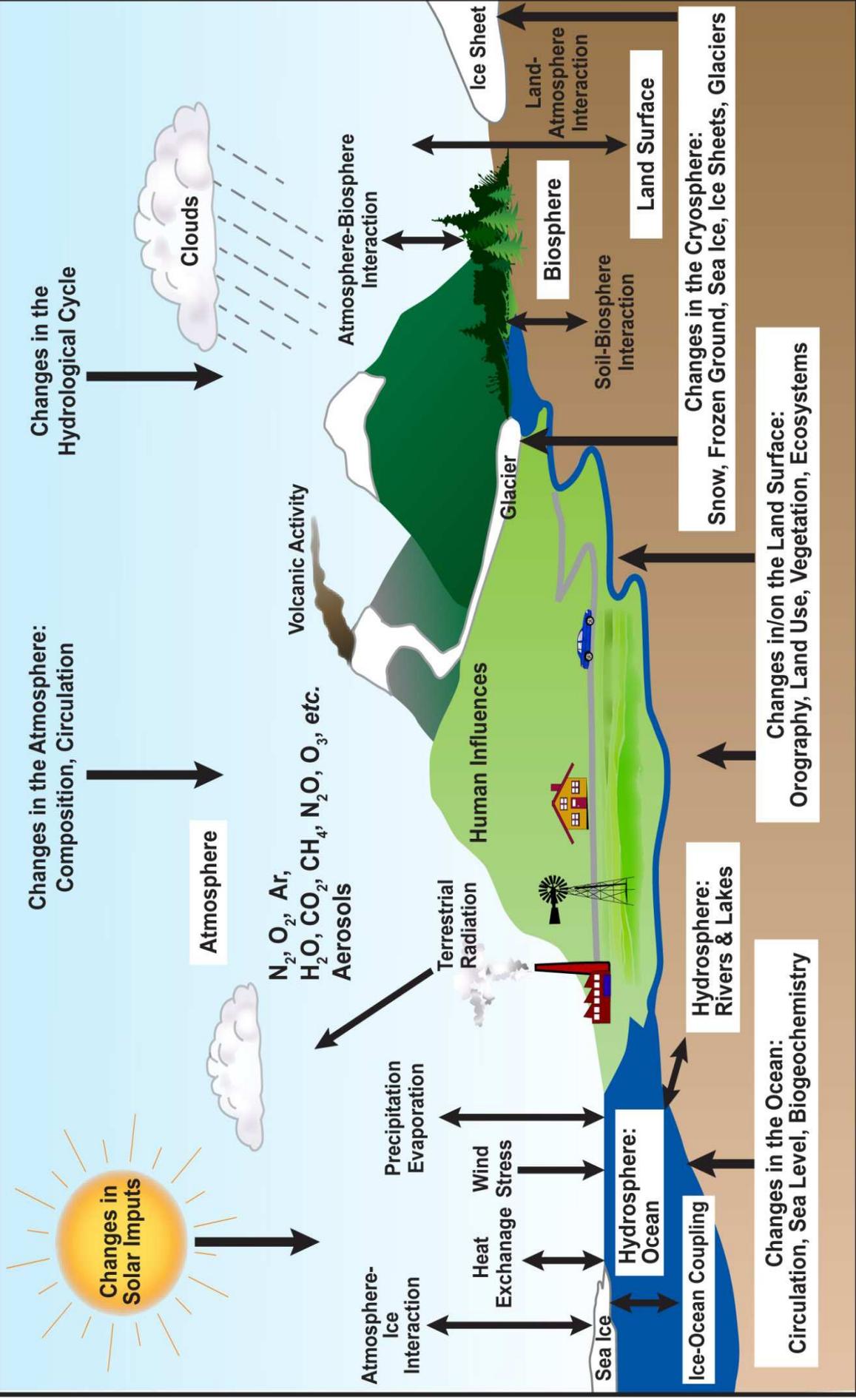


# *Changements climatiques: nouveaux enjeux*

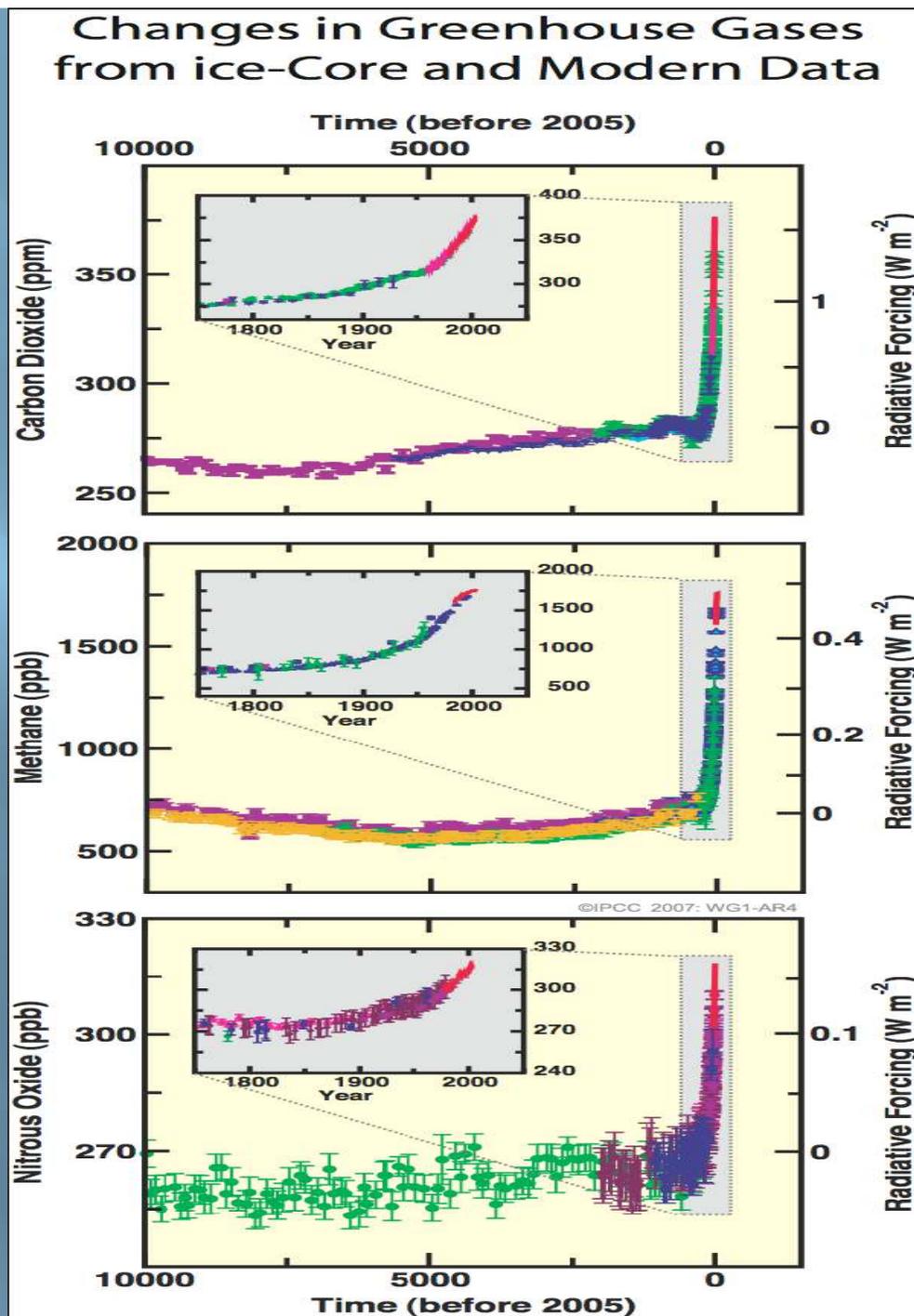
*Hervé Le Treut*

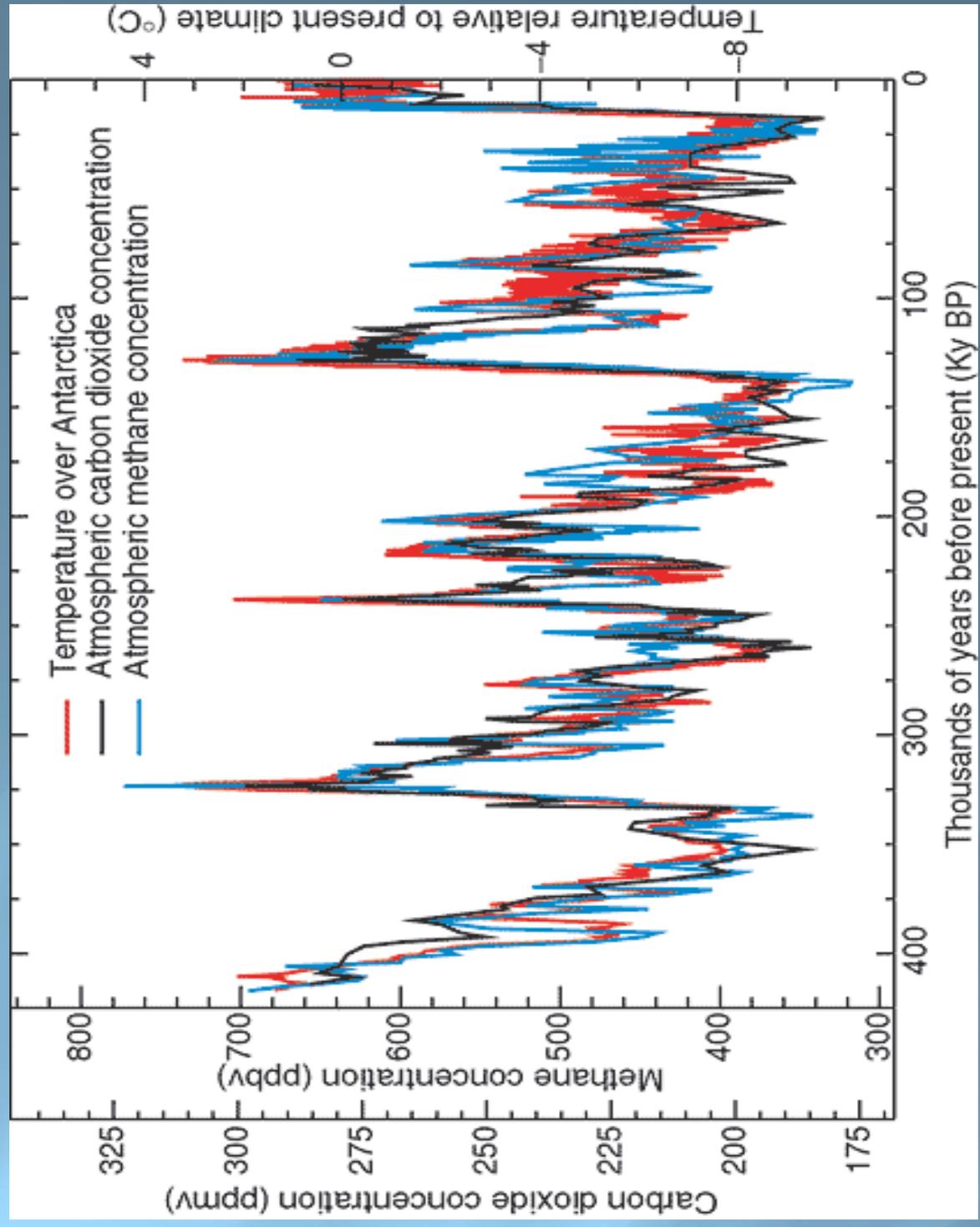


Le climat dans lequel  
se sont développés nos  
civilisations: une situation  
très particulière

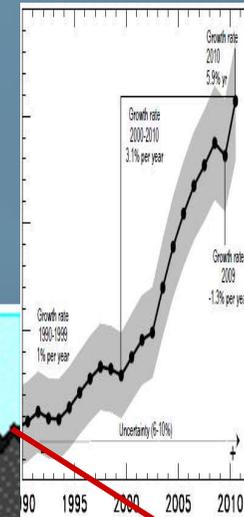
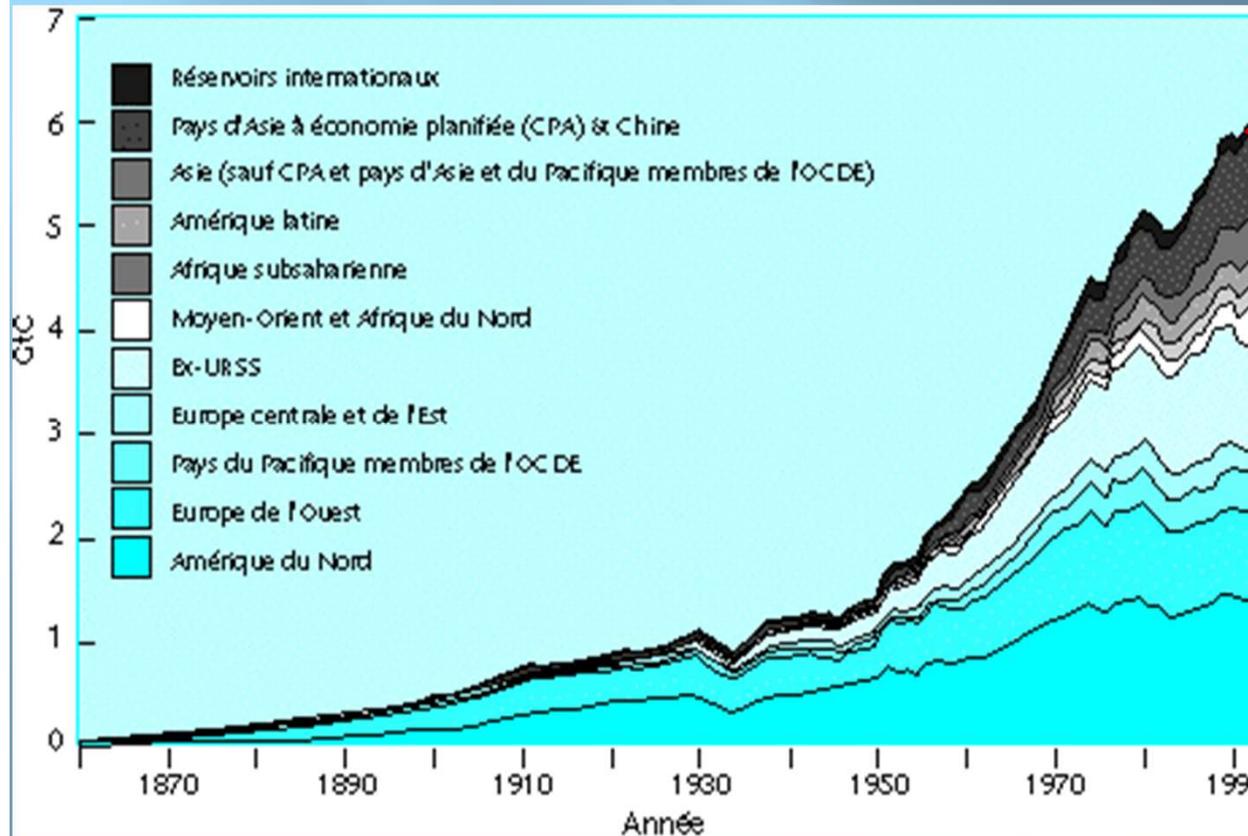
10 000 ans  
de « quasi-stabilité »  
et quelques décennies de  
changement

IPCC, 2007



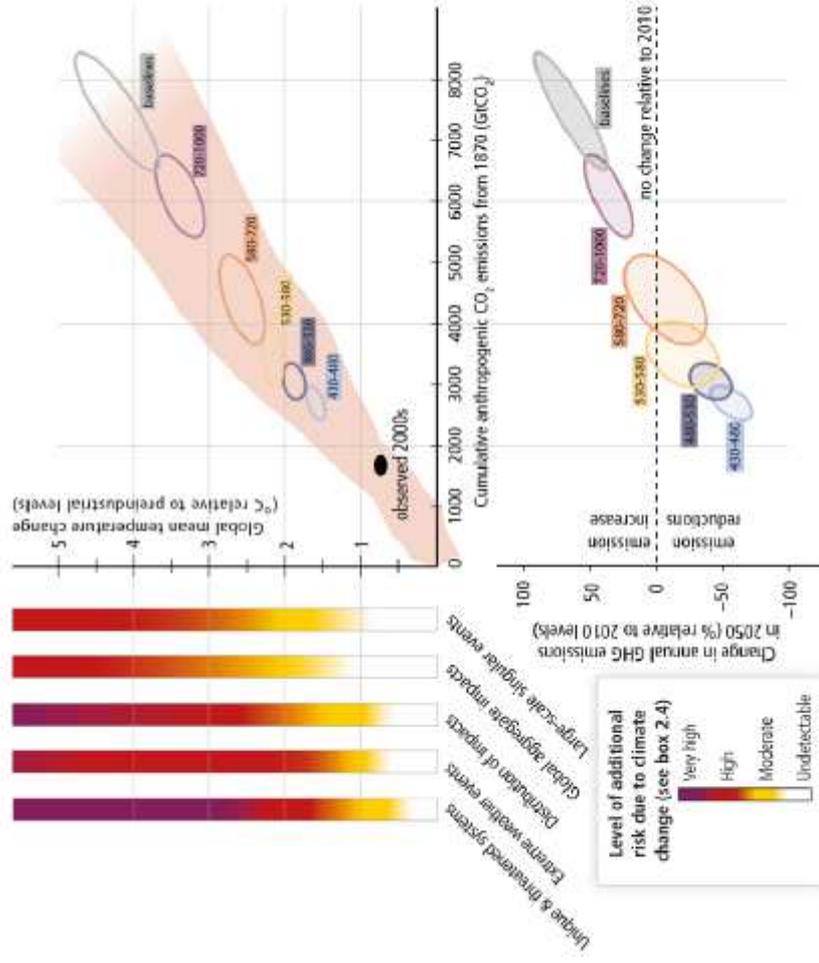


**Le contexte** : les émissions de CO<sub>2</sub> liées à la combustion des hydrocarbures ne diminuent pas (en milliards de tonnes de carbone par an)



**Sommet de la Terre  
Rio 1992**

(A) Risks from climate change... (B) ...depend on cumulative CO<sub>2</sub> emissions...



(C) ...which in turn depend on annual GHG emissions over the next decades

Figure SPM.10: The relationship between risks from climate change, temperature change, cumulative CO<sub>2</sub> emissions, and changes in annual GHG emissions by 2050. Limiting risks across Reasons For Concern (panel A) would imply a limit for cumulative emissions of CO<sub>2</sub> (panel B), which would constrain annual GHG emissions over the next few decades (panel C). (A) reproduces the five Reasons For Concern (Box 2.4). (B) links temperature changes to cumulative CO<sub>2</sub> emissions (in GtCO<sub>2</sub>) from 1870. They are based on CMIP5 simulations (pink plume) and on a simple climate model (median climate response in 2100), for the base-lines and five mitigation scenario categories (six ellipses). Details are provided in Figure SPM.5. (C) shows the relationship between the cumulative CO<sub>2</sub> emissions (in GtCO<sub>2</sub>) of the scenario categories and their associated change in annual GHG emissions by 2050, expressed in percentage change (in percent GtCO<sub>2</sub>-eq per year) relative to 2010. The ellipses correspond to the same scenario categories as in Panel B, and are built with a similar method (see details in Figure SPM.5). (Figure 3.1)

# The Human Perturbation of the CO<sub>2</sub> Budget (2000-2009)

7.7 ± 0.5 PgC y<sup>-1</sup>



1.1 ± 0.7 PgC y<sup>-1</sup>



+

2009)  
4.1 ± 0.1 PgC y<sup>-1</sup>

47%



2.4 PgC y<sup>-1</sup>

27%

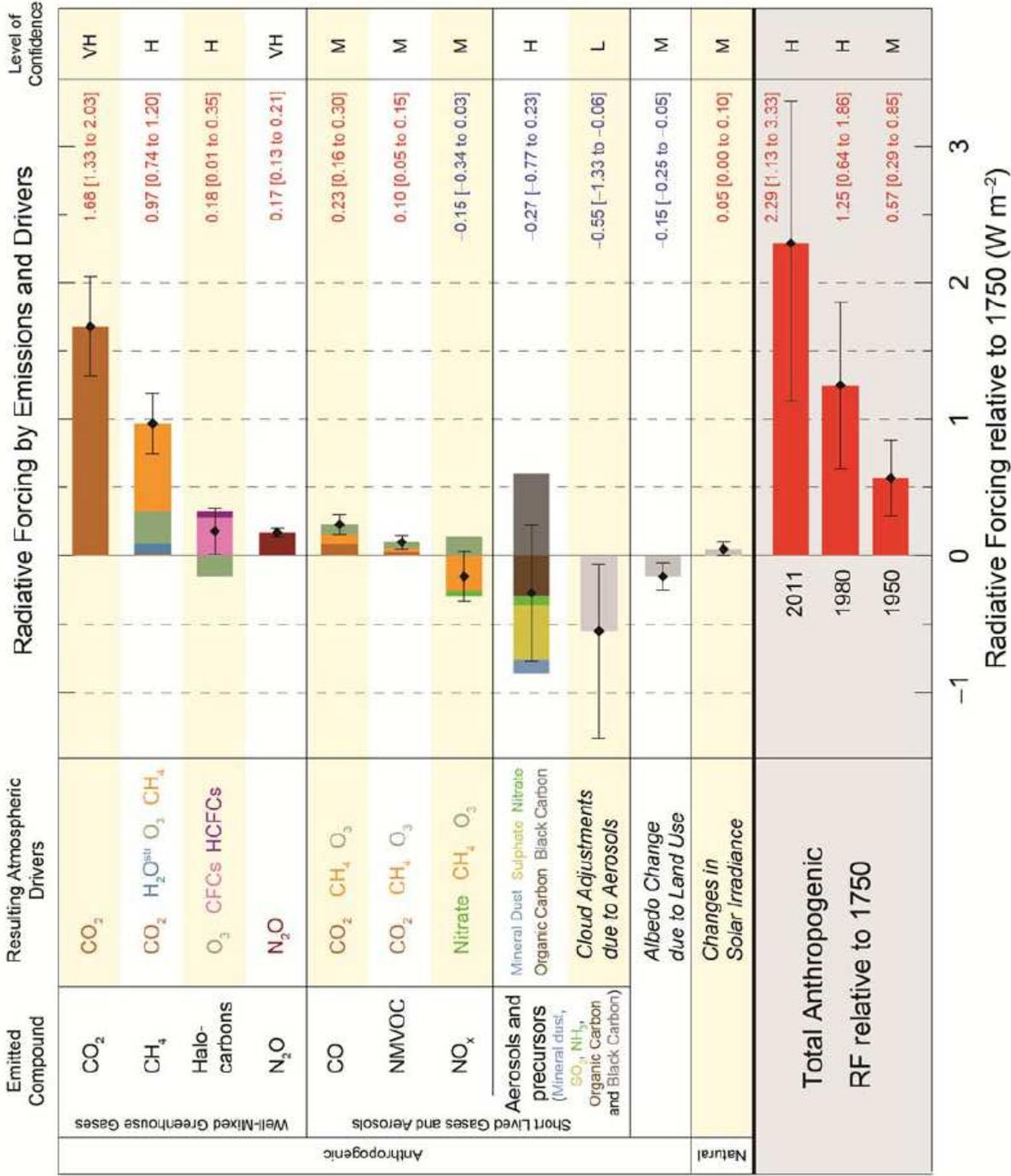
Calculated as the residual



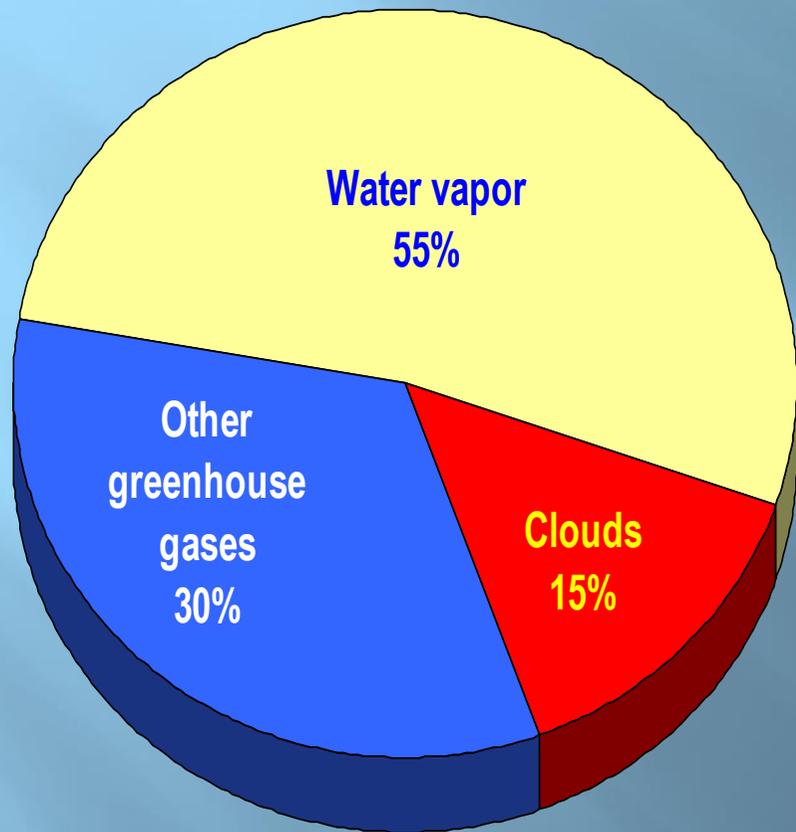
26%

2.3 ± 0.4 PgC y<sup>-1</sup>

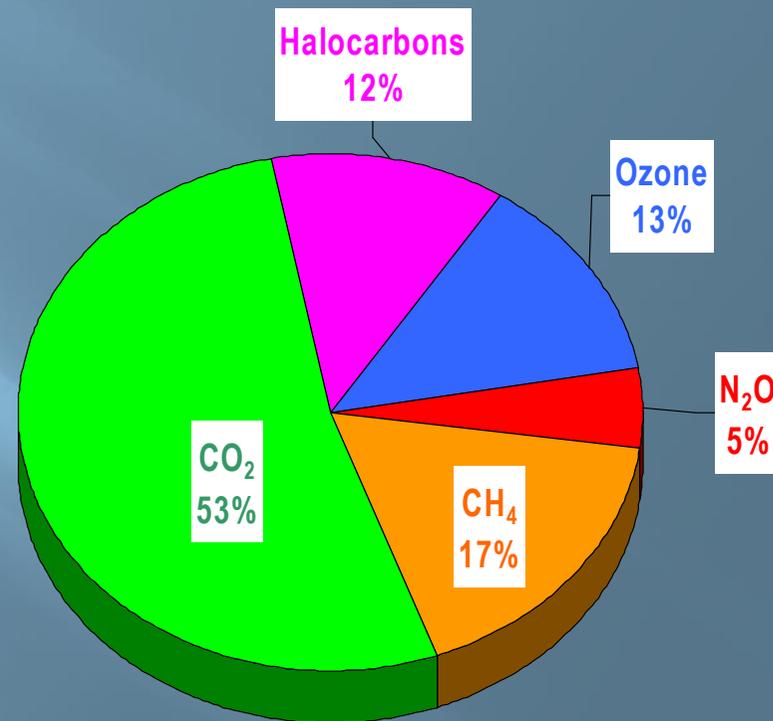




# Principaux constituants atmosphériques contribuant à l'effet de serre

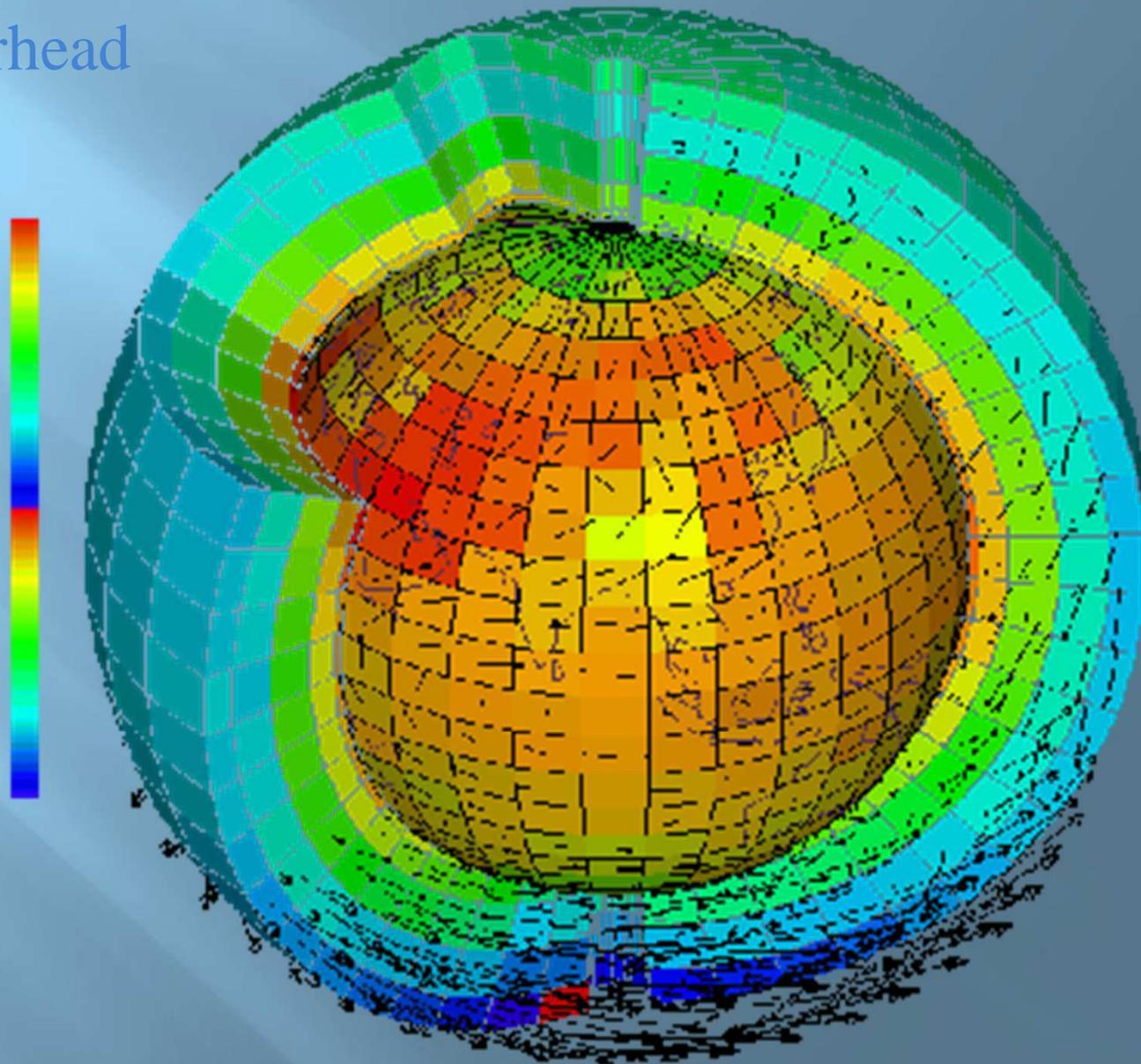


**Naturel**  
**(155 W/m<sup>2</sup>)**

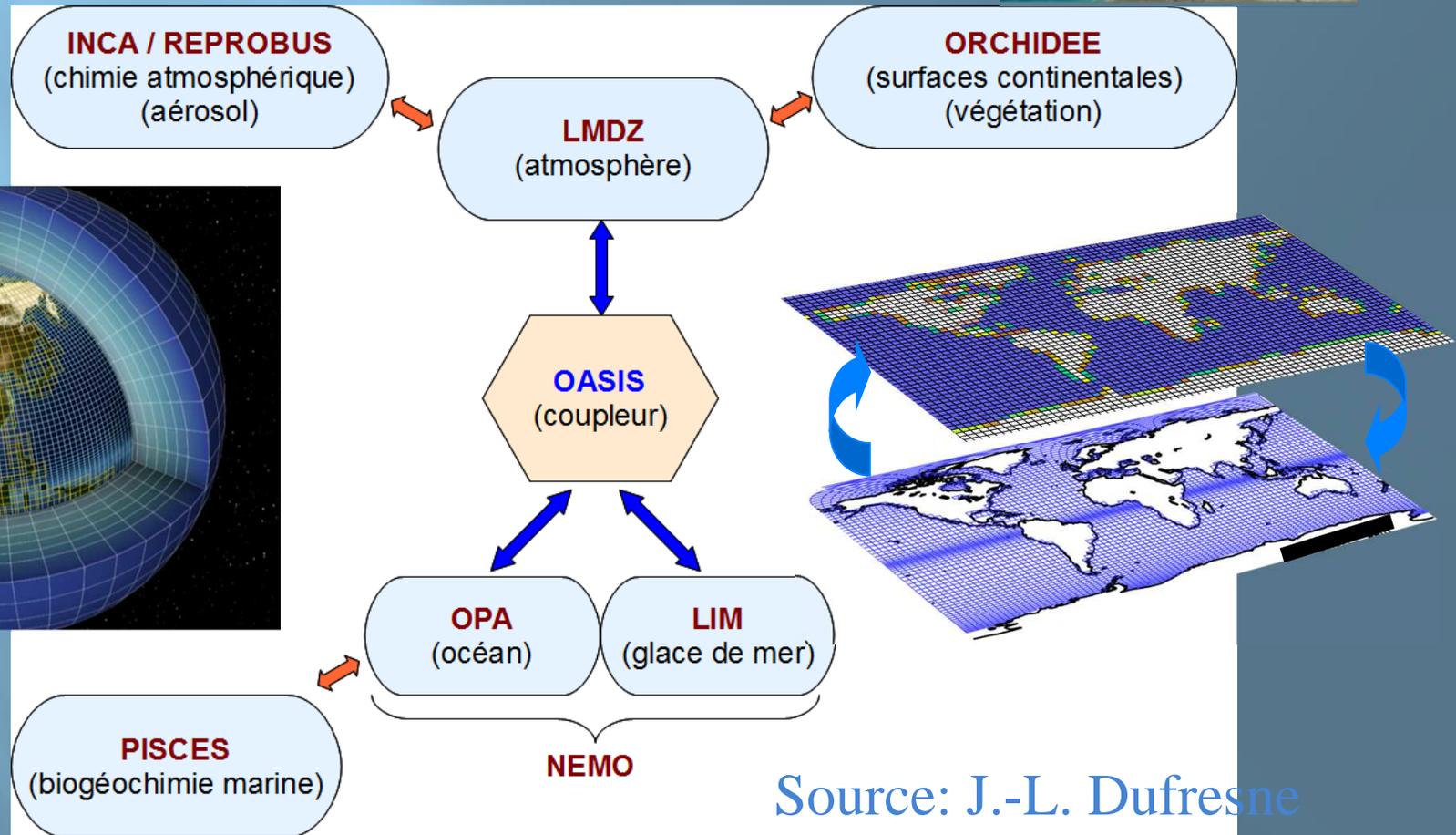
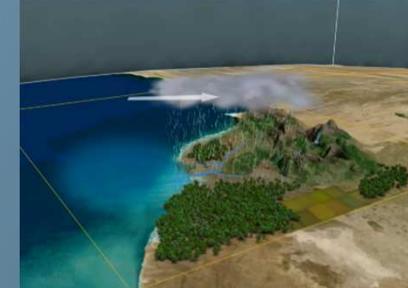
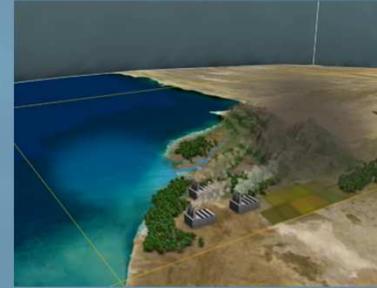
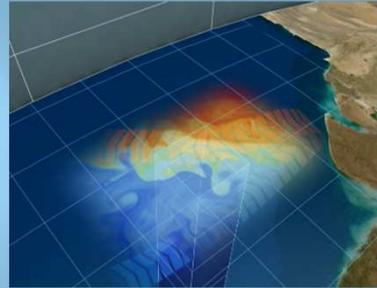
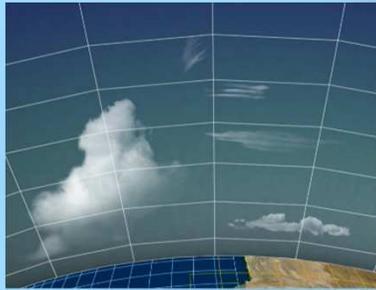


**Additionnel**  
**(2.8 W/m<sup>2</sup>)**

L. Fairhead



# Le modèle couplé "Système Terre" de l'IPSL



Source: J.-L. Dufresne

# Des lois de la mécanique des fluides déjà anciennes:

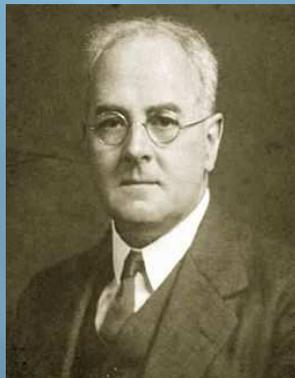
*Henri Navier (1785-1836)    George Gabriel Stokes (1819 – 1903)*

Equation de Navier-Stokes (1845):

$$\frac{D\mathbf{U}}{Dt} = -2\mathbf{\Omega} \wedge \mathbf{U} - \nabla\Phi - \frac{1}{\rho}\nabla P + \mathbf{F}$$

*Première application directe?*

*Lewis Fry Richardson (1922)*



# Simulations proposées par CMIP-5

(co-chairs: S. Bony, G. Meehl)

Thématiques d'intérêt pour l'IPSL

**Climat-carbone**

(C4MIP)

**Nuages**

(CFMIP)

**Paléoclimat**

(PMIP)

**Aérosols**

(AEROCOM)

**Emissions**

(GEIA)

**Ozone**

(CCMVal)

Évolution du climat au 20e siècle

Évolution du climat au 21e siècle

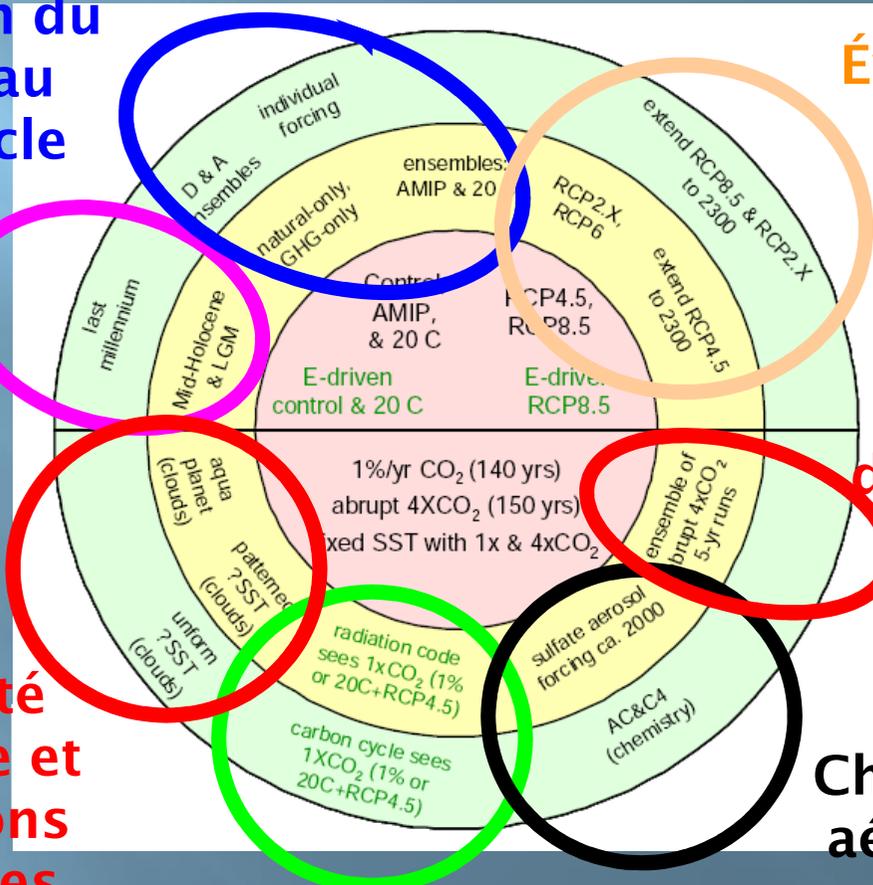
Paléo-climats

Estimation des forçages radiatifs

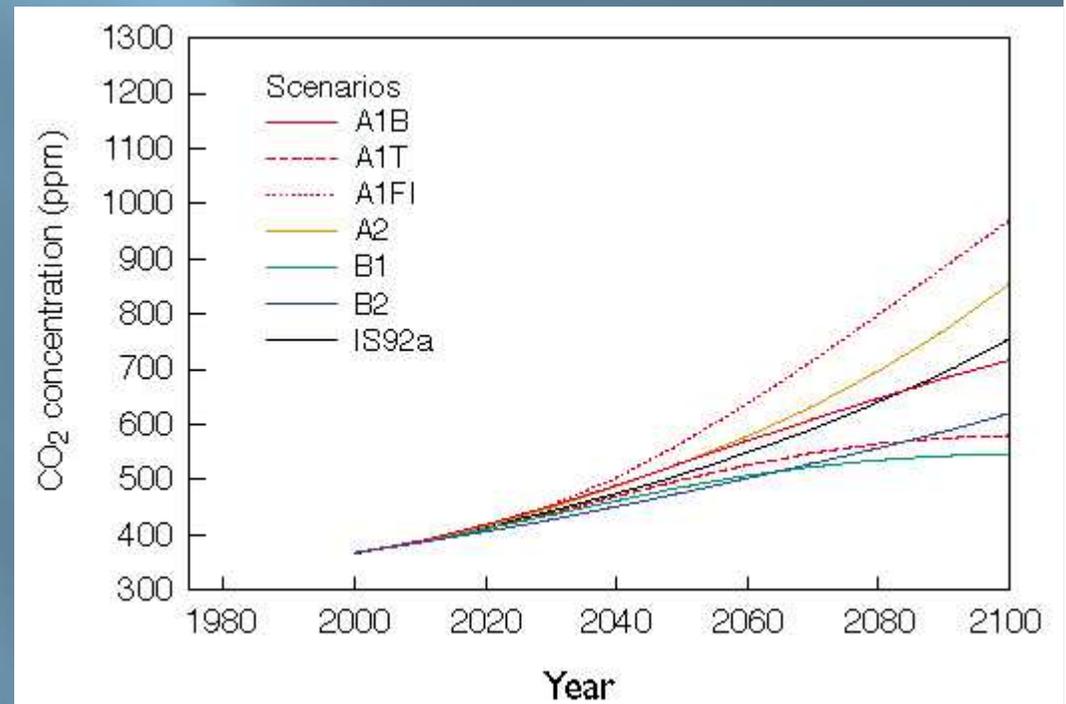
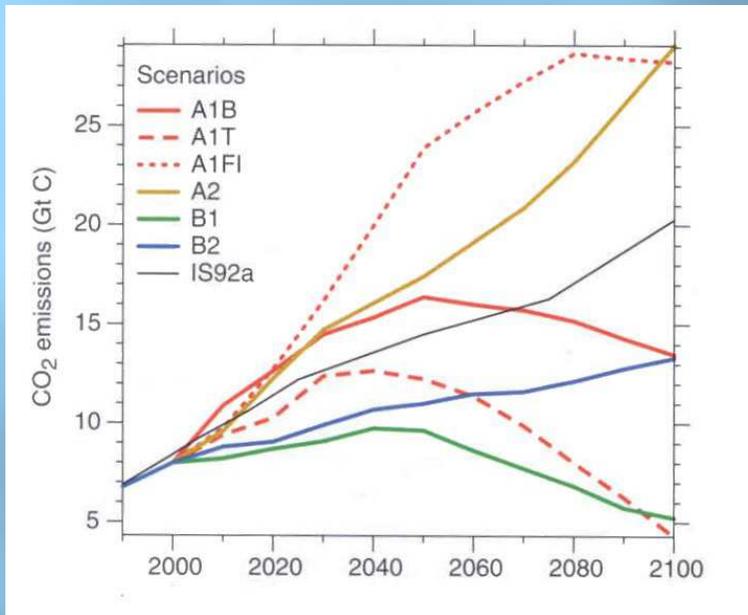
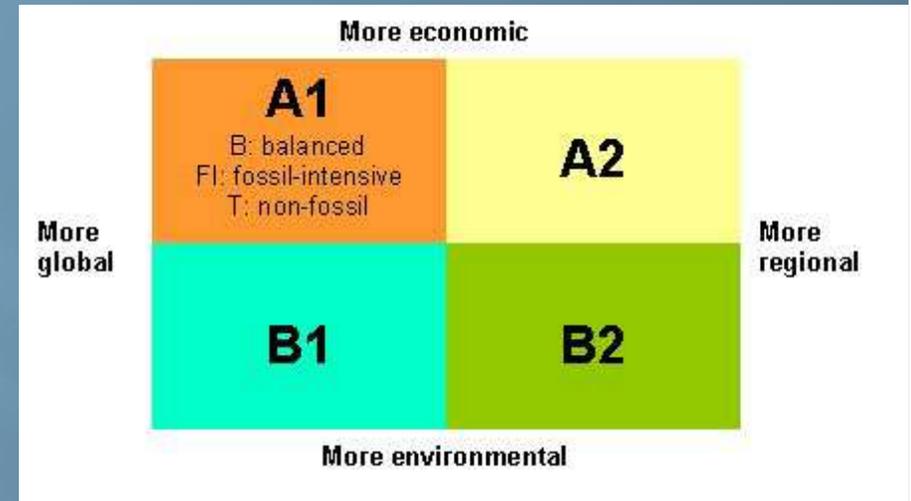
Sensibilité climatique et rétroactions des nuages

Chimie et aérosols

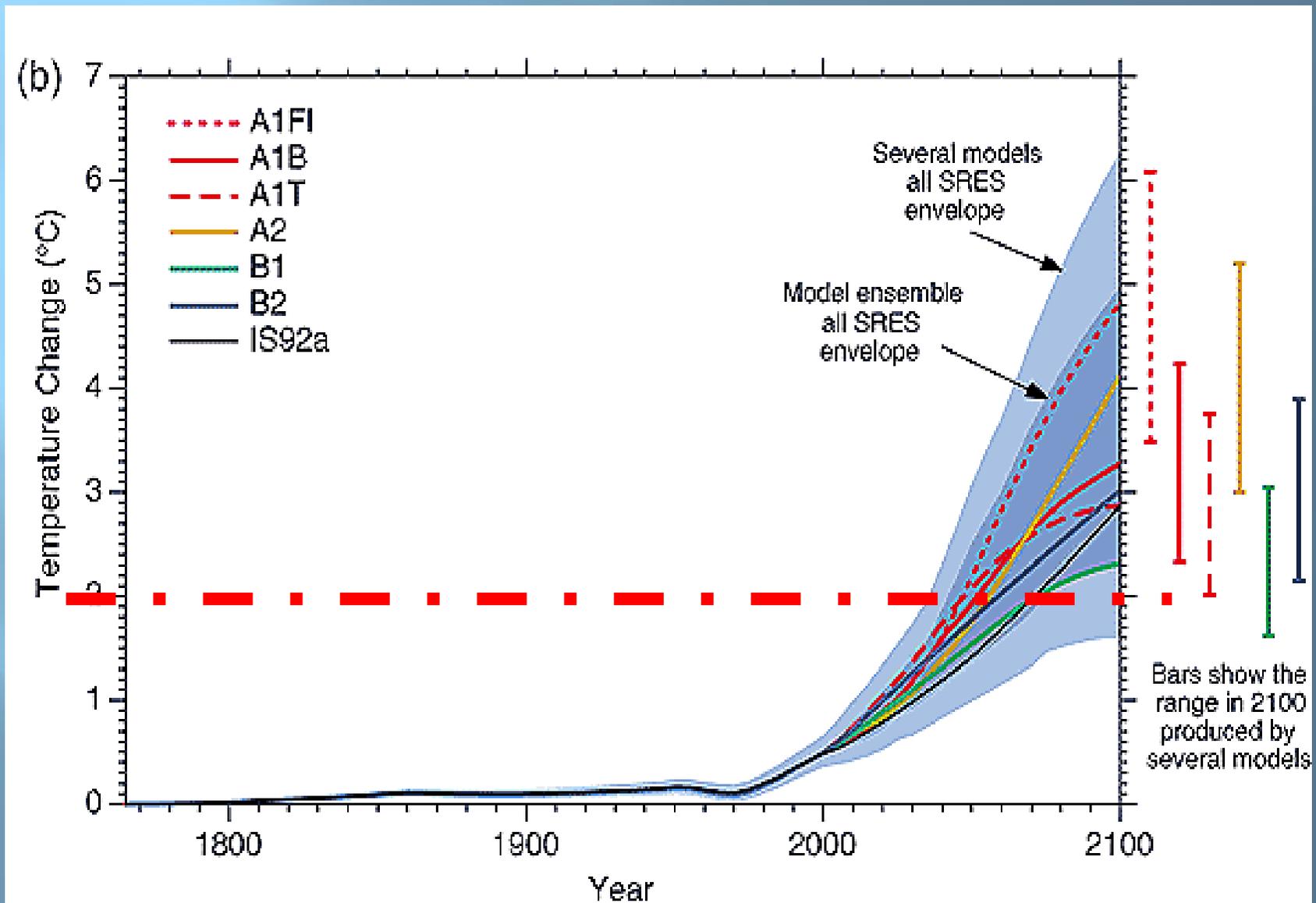
Couplage climat-carbone



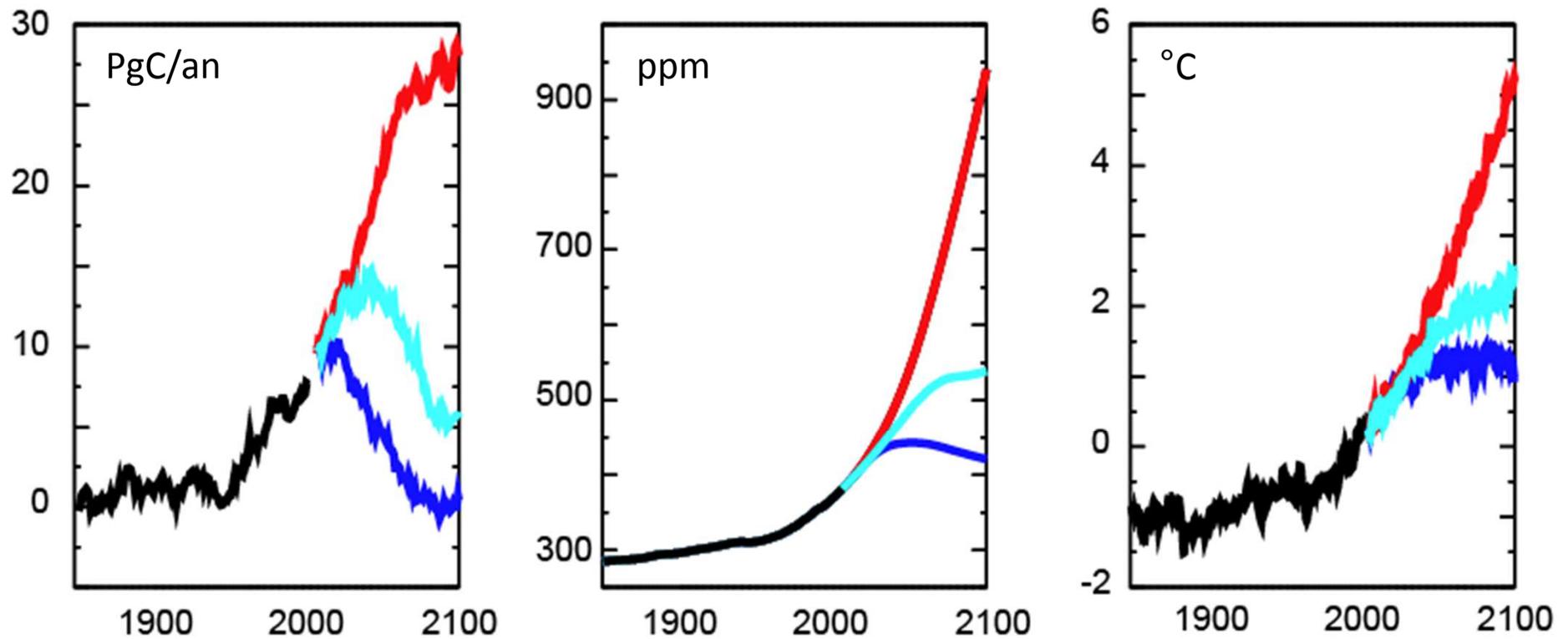
# Les scénarios du GIEC en 2001 et 2007: le « SRES »



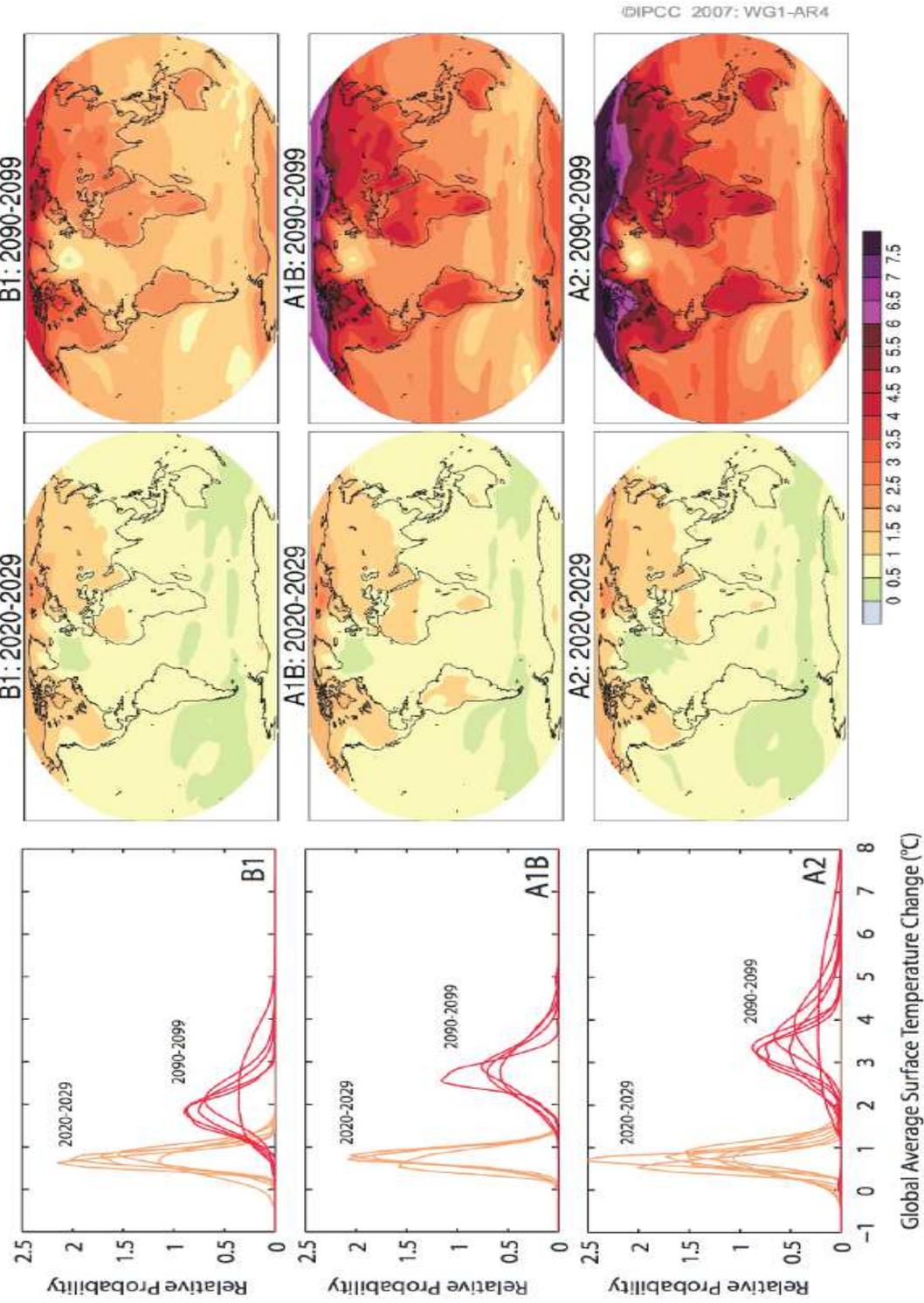
# Un exercice collectif de « scénarisation » des températures futures toujours valide (GIEC, 2001)



## Porteurs d'implications très lourdes (Carbone Emissions, CO<sub>2</sub>, Mean Température)



# AOGCM Projections of Surface Temperatures

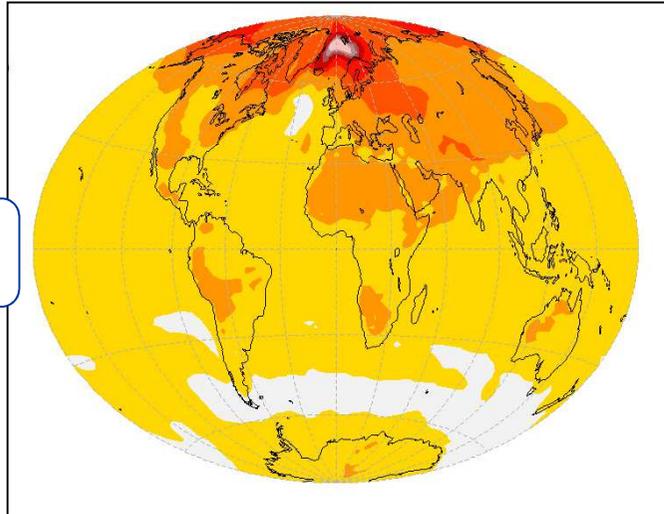


# Changement de température de surface

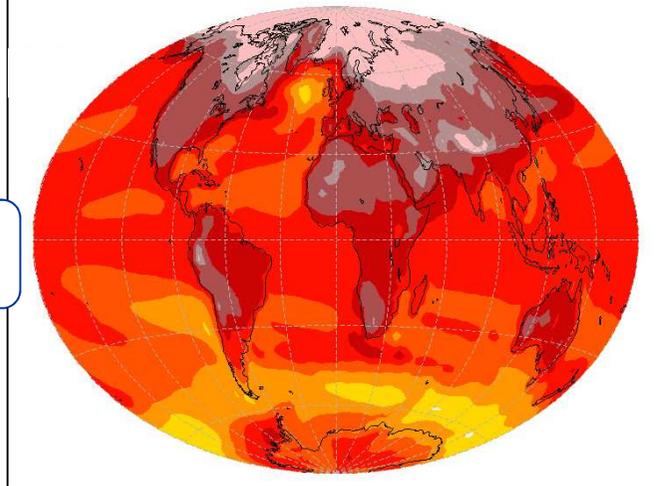
Différence entre **2100** et **1990**

IPSL-CM5A-LR

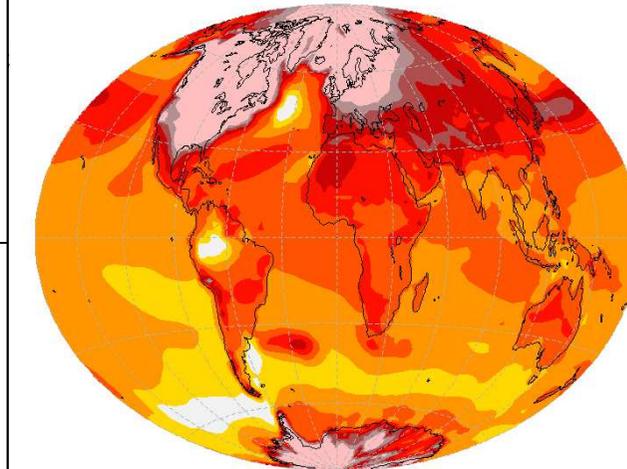
**RCP2.6**



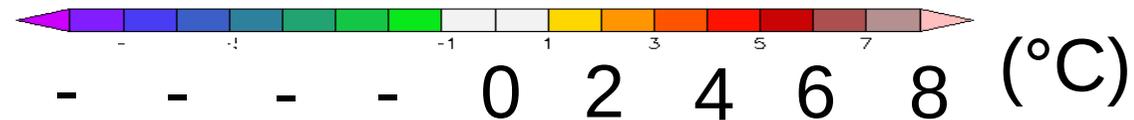
**RCP8.5**



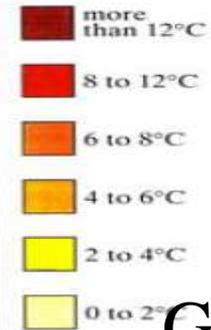
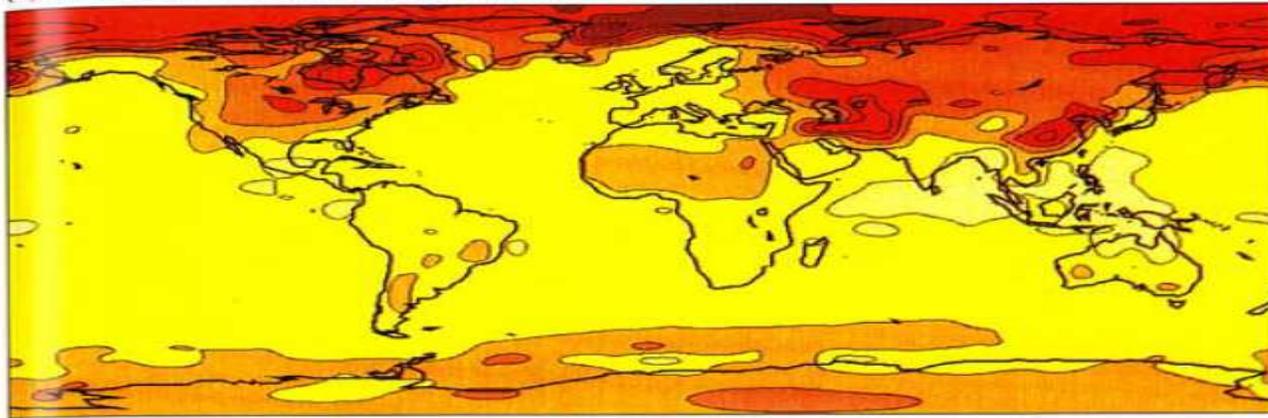
Entre **préindustriel** et  
**glaciaire**



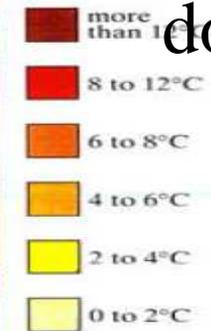
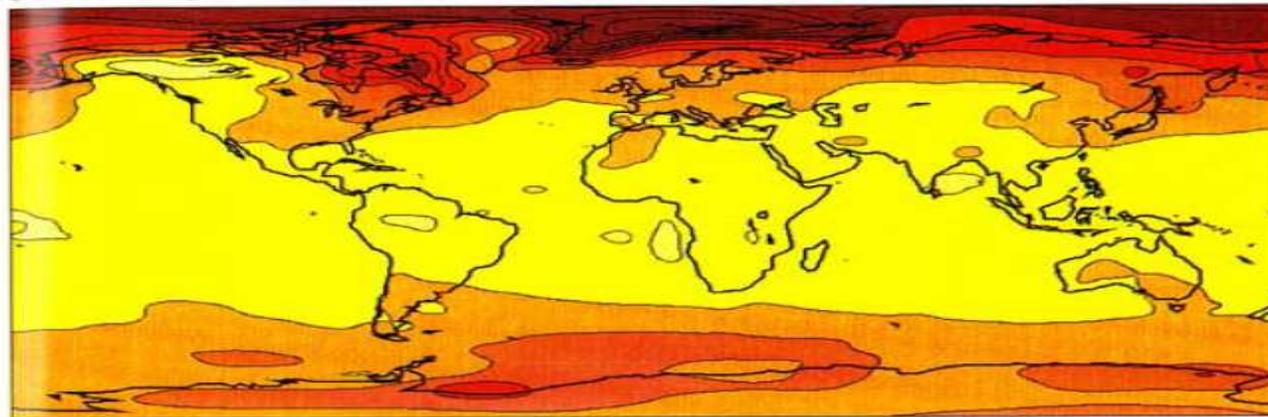
**Glaciaire**



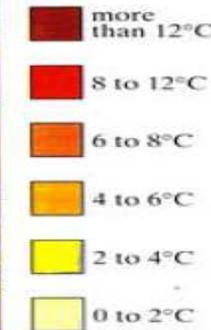
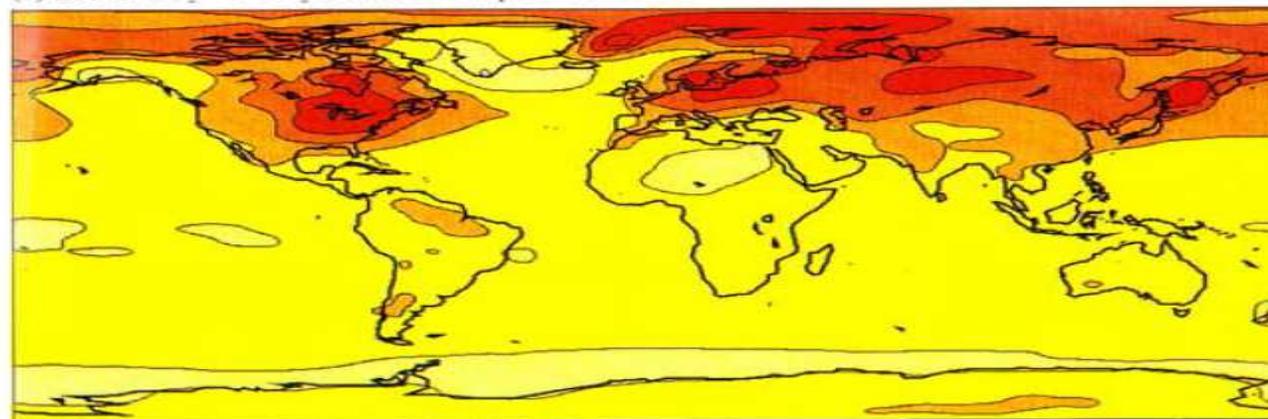
(a) DJF  $2\times\text{CO}_2 - 1\times\text{CO}_2$  surface air temperature: CCC



(b) DJF  $2\times\text{CO}_2 - 1\times\text{CO}_2$  surface air temperature: GFHI



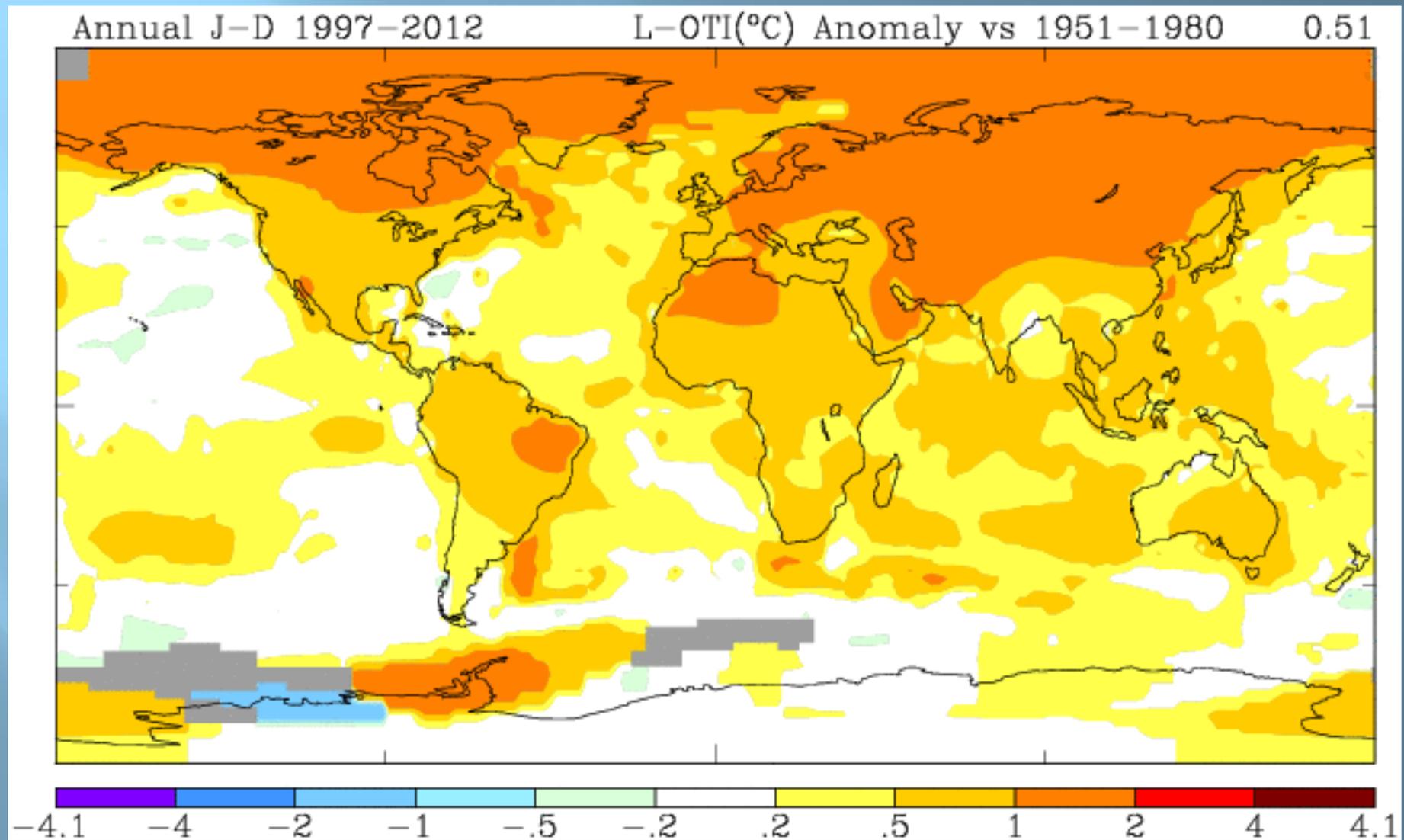
(c) DJF  $2\times\text{CO}_2 - 1\times\text{CO}_2$  surface air temperature: UKHI

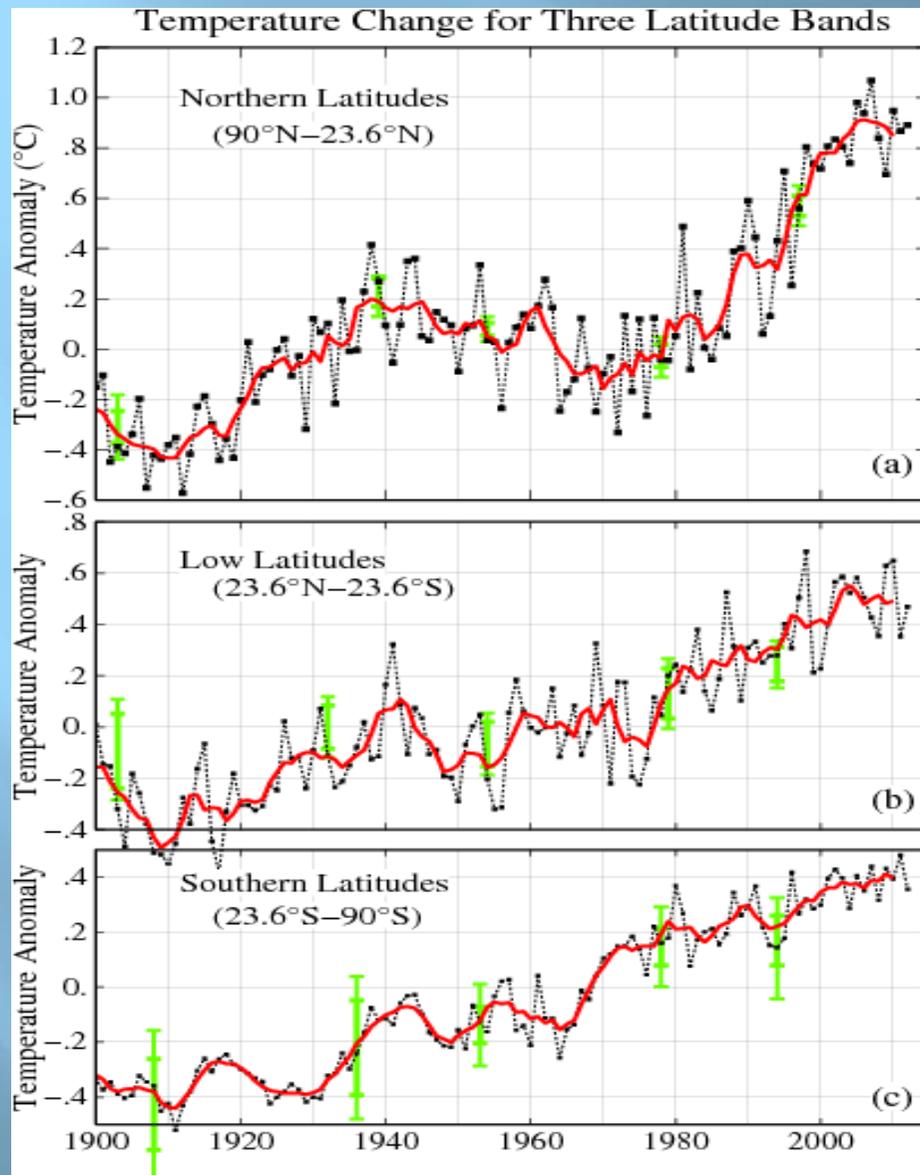


GIEC 90  
3 modèles  
doublement  
du  $\text{CO}_2$

Hiver

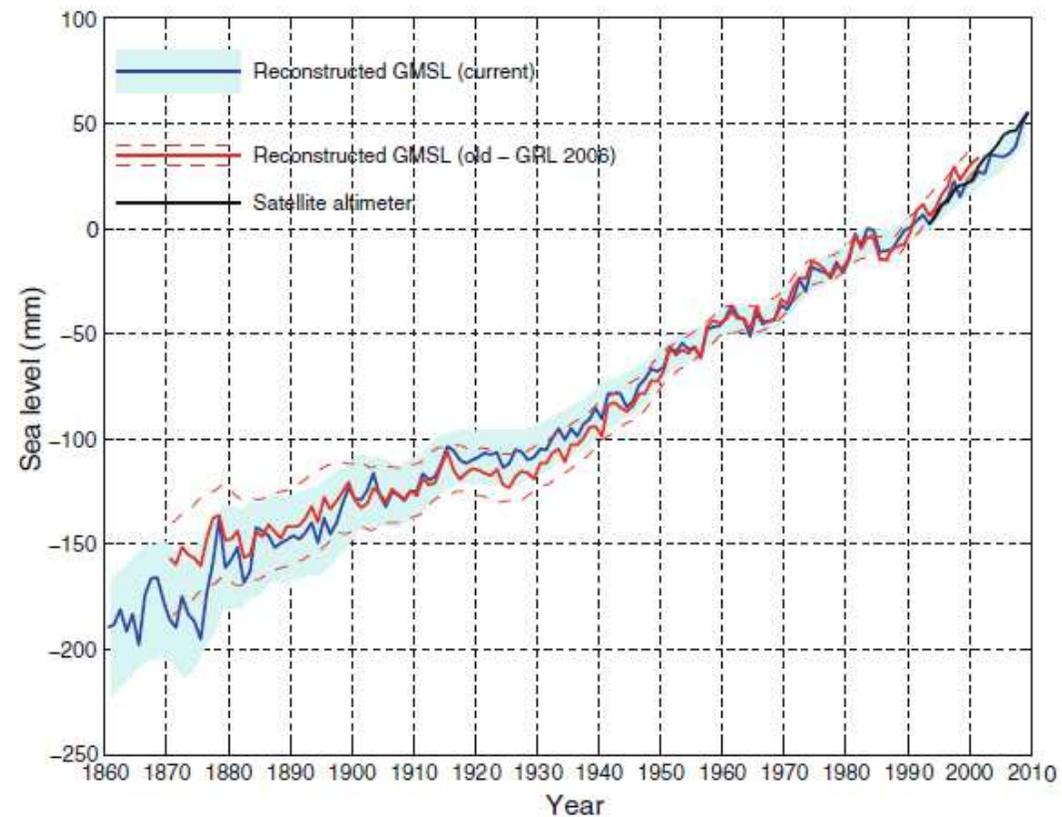
# Les changements observés confirment les prévisions





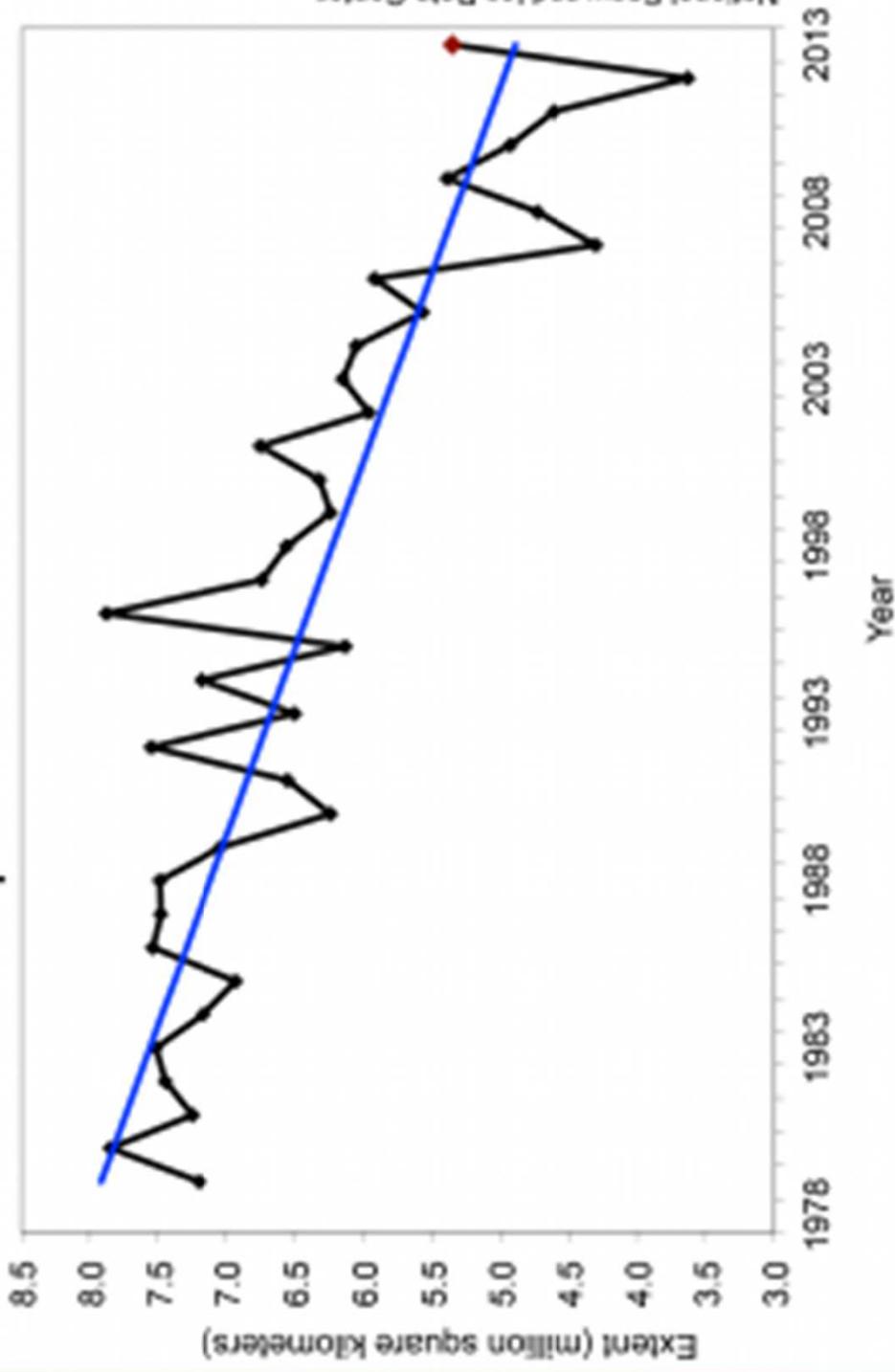
**Variabilité naturelle et  
action de l'homme se  
superposent**

## Le relèvement du niveau de la mer



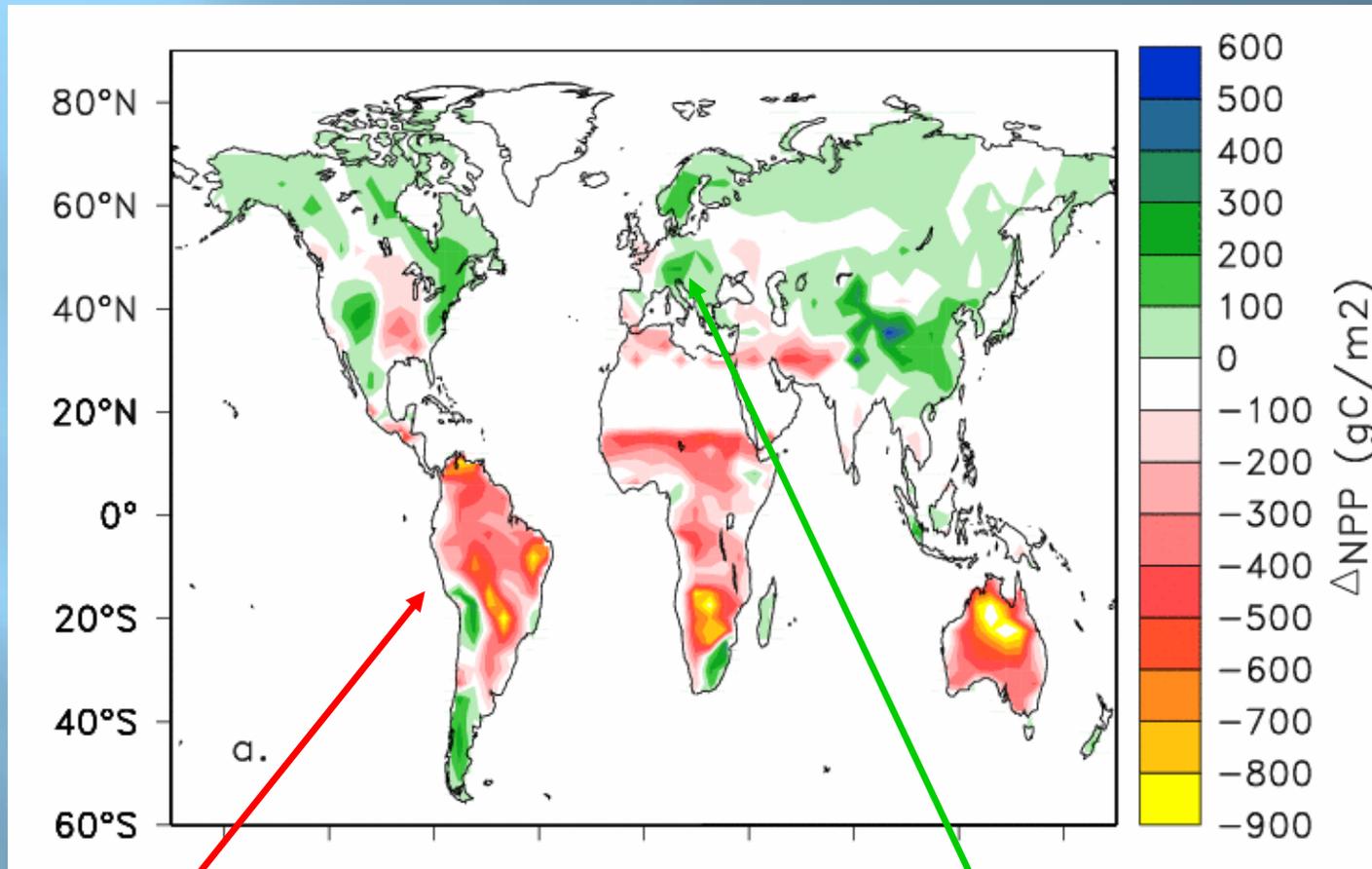
**Fig. 5** Global average sea level from 1860 to 2009 as estimated from the coastal and island sea-level data (*blue*). The one standard deviation uncertainty estimates plotted about the low passed sea level are indicated by the *shading*. The Church and White (2006) estimates for 1870–2001 are shown by the *red solid line* and *dashed magenta lines* for the 1 standard deviation errors. The series are set to have the same average value over 1960–1990 and the new reconstruction is set to zero in 1990. The satellite altimeter data since 1993 is also shown in *black*

# Average Monthly Arctic Sea Ice Extent September 1979 - 2013



National Snow and Ice Data Center

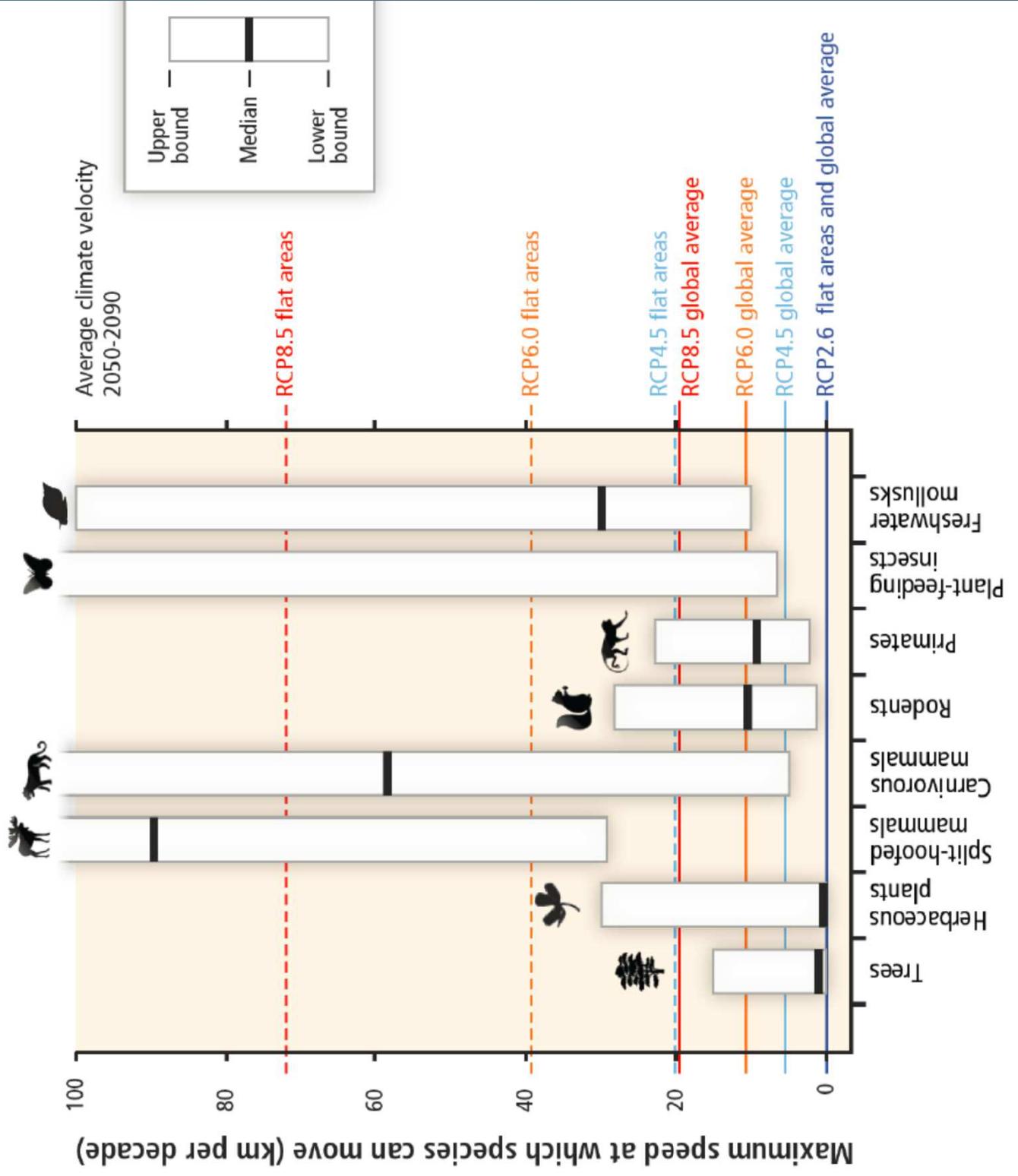
# La production primaire nette: dépendance au climat



Increase in  
soil aridity

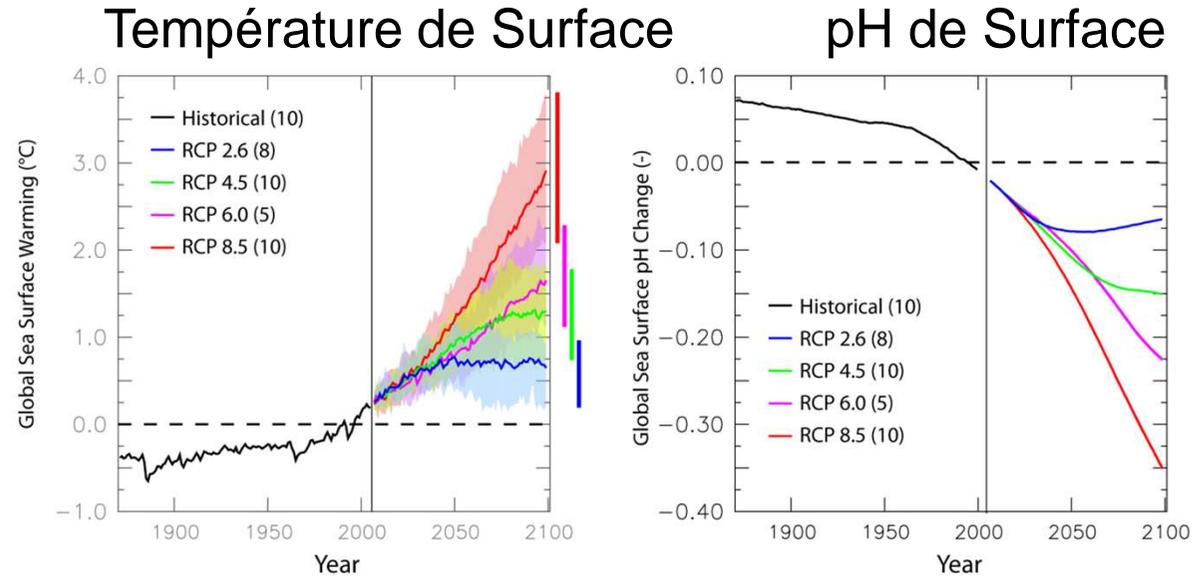
Extension of the  
growing season

Berthelot et al., 2002

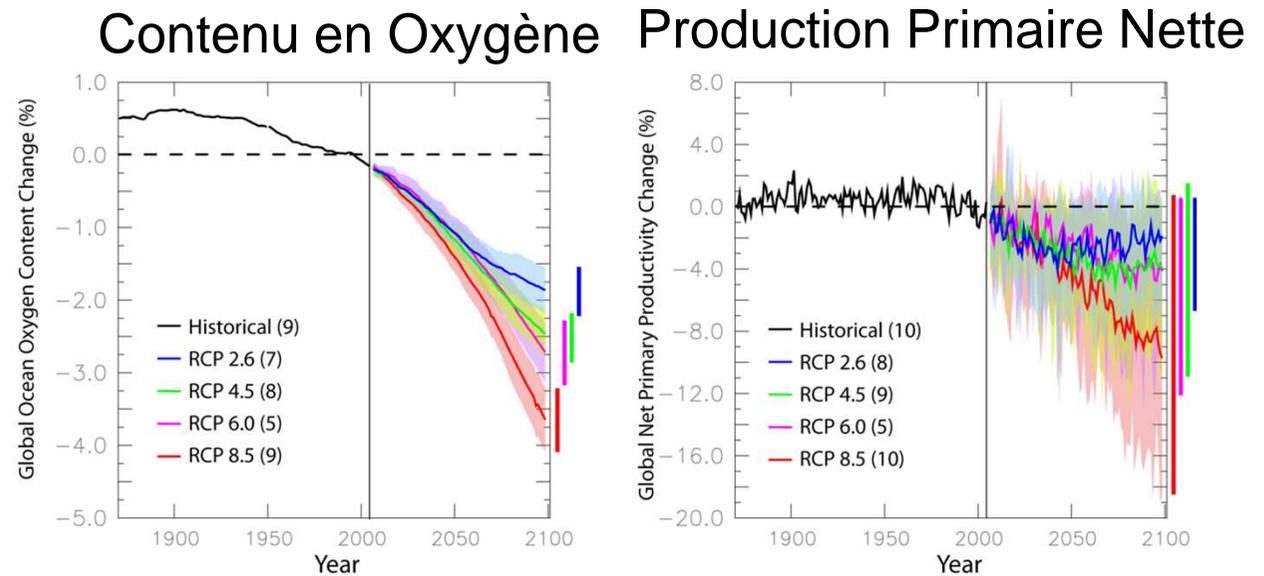


# Impacts du changement climatique sur les écosystèmes marins : Multi-modèle

Des eaux de surface plus chaudes...  
et plus acides



Moins d'oxygène et  
moins de production  
primaire



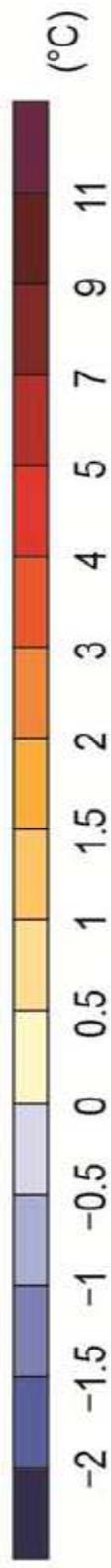
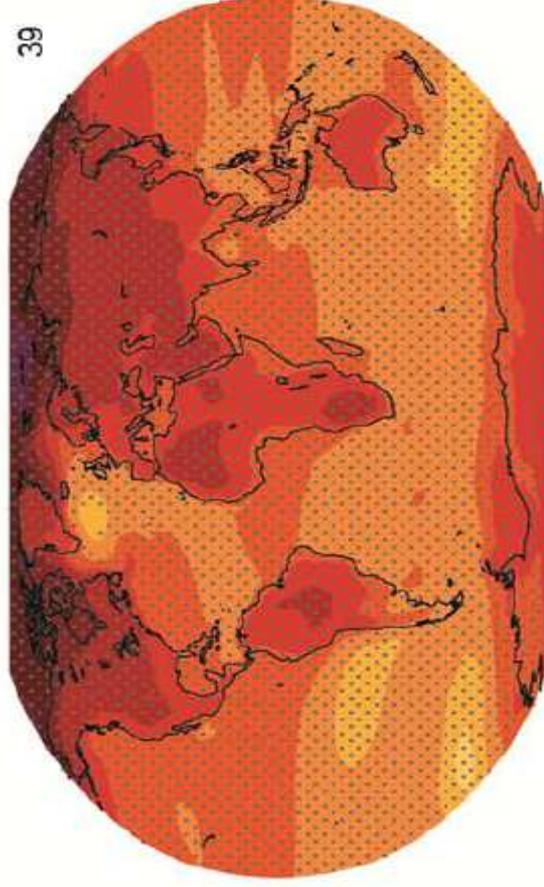
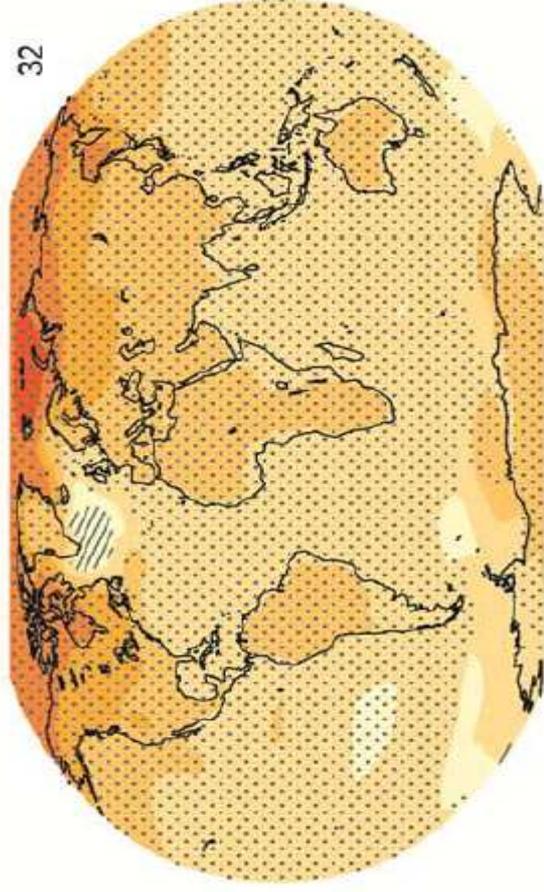


**De nouvelles données: la constellation de l'A-Train**

RCP 2.6

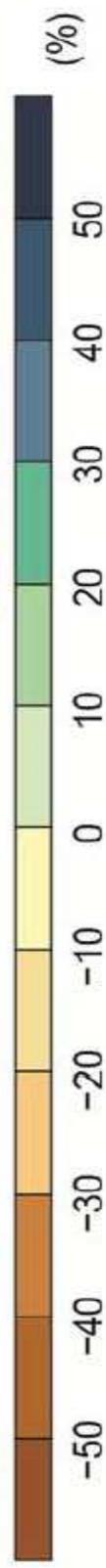
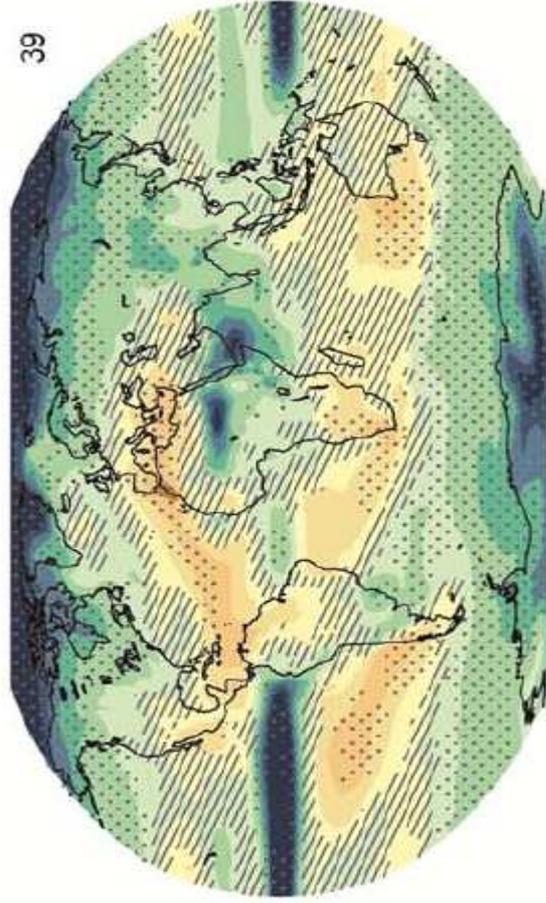
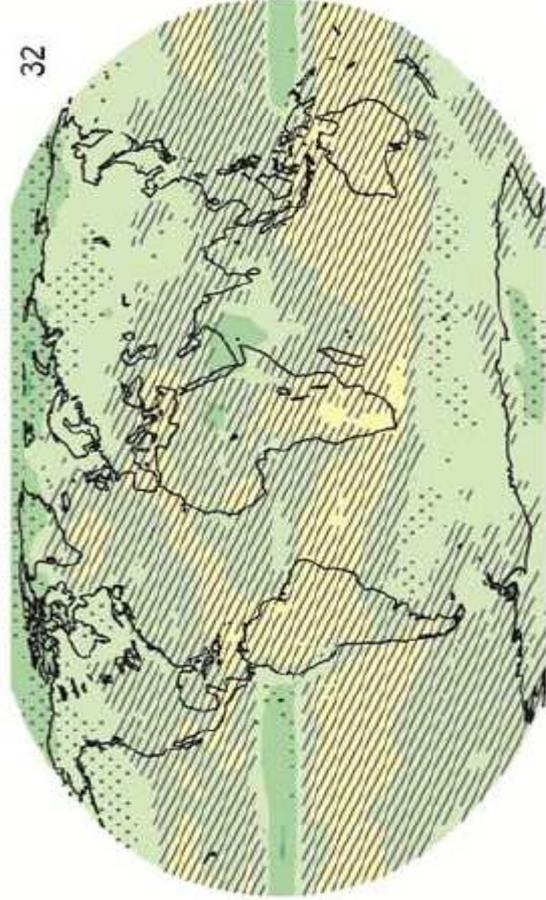
RCP 8.5

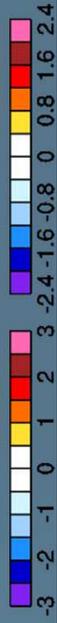
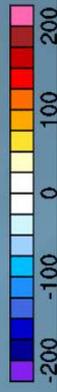
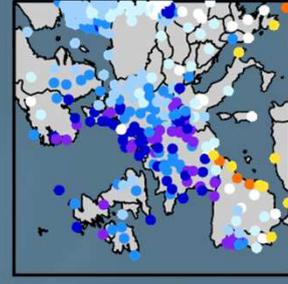
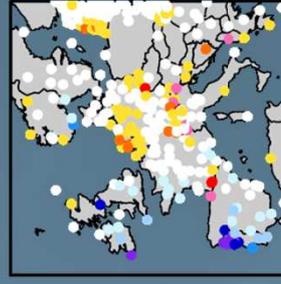
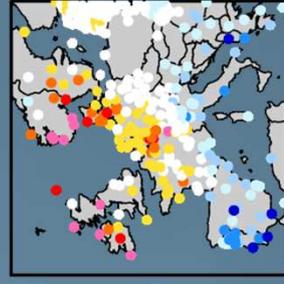
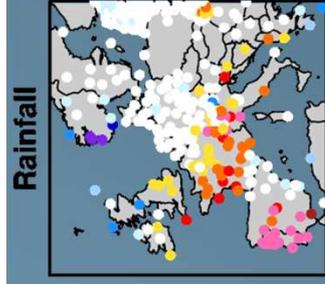
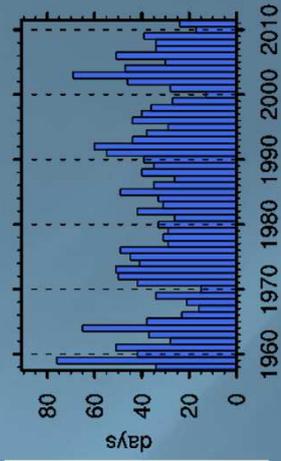
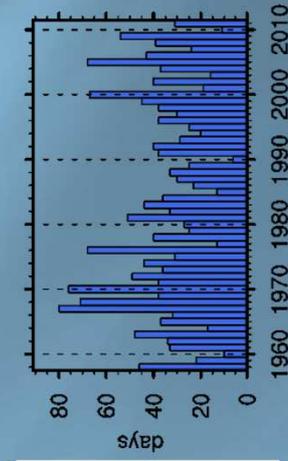
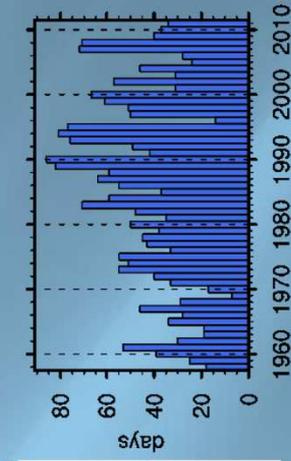
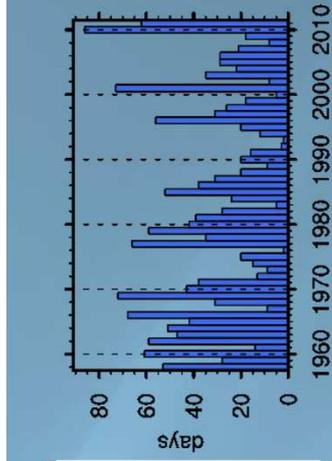
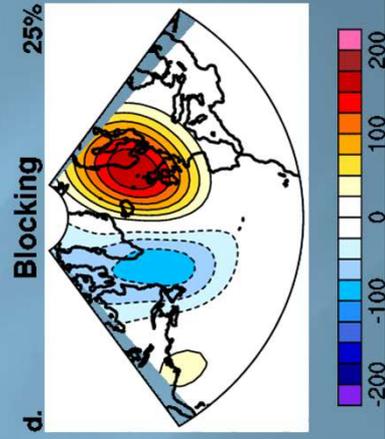
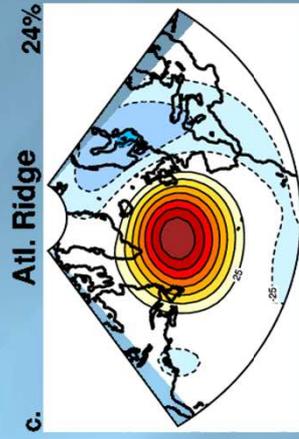
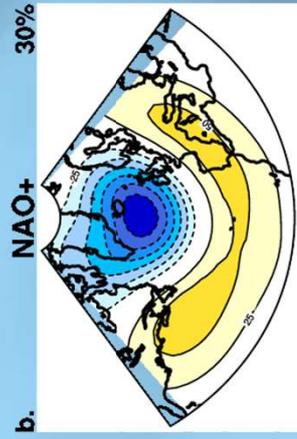
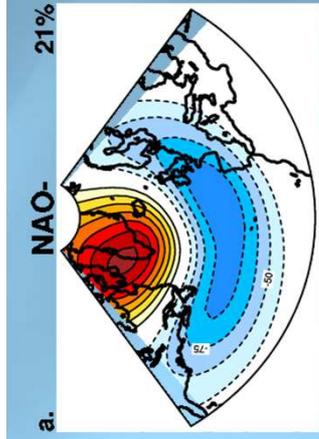
(a) Change in average surface temperature (1986–2005 to 2081–2100)



(b)

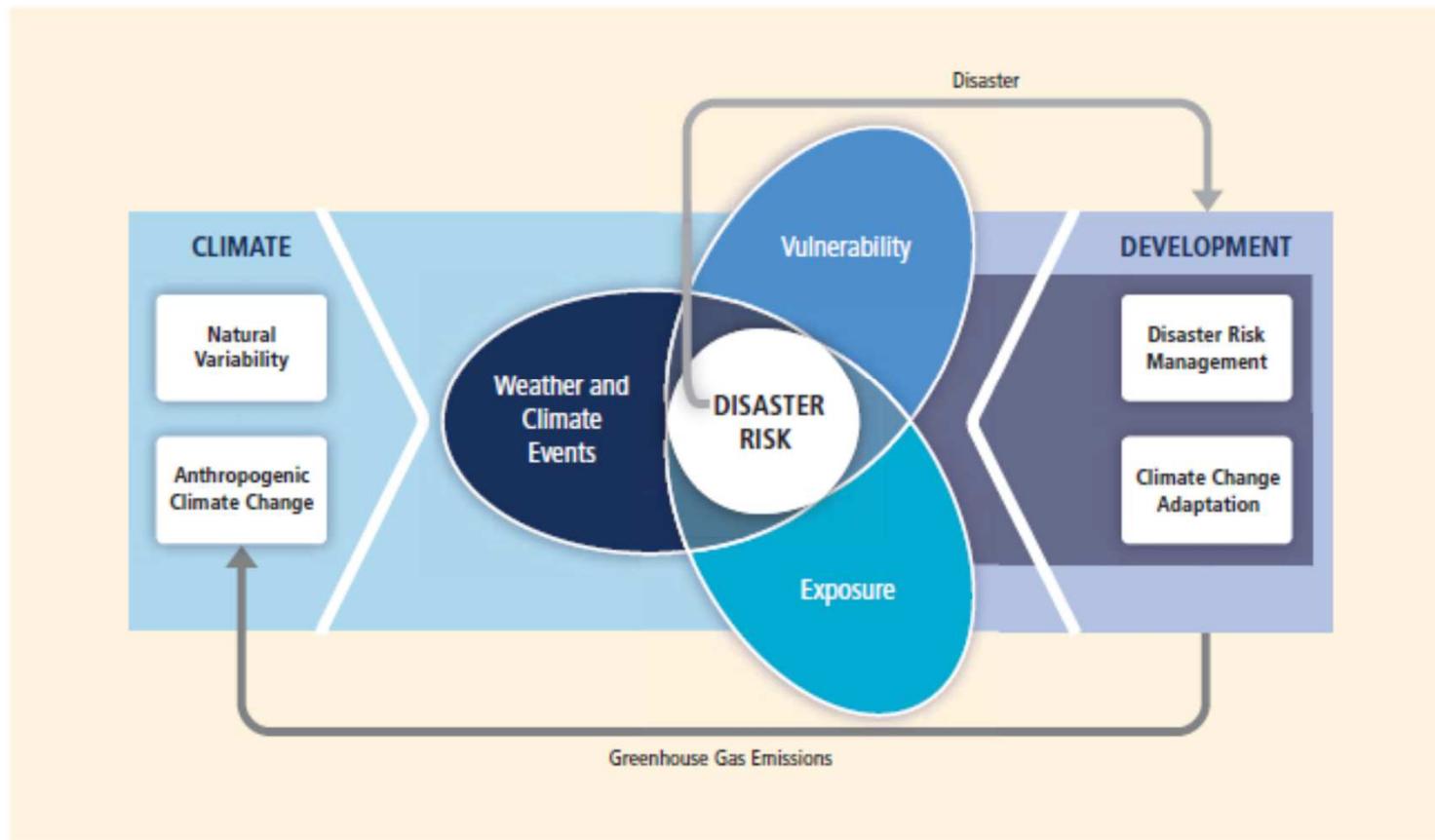
Change in average precipitation (1986–2005 to 2081–2100)





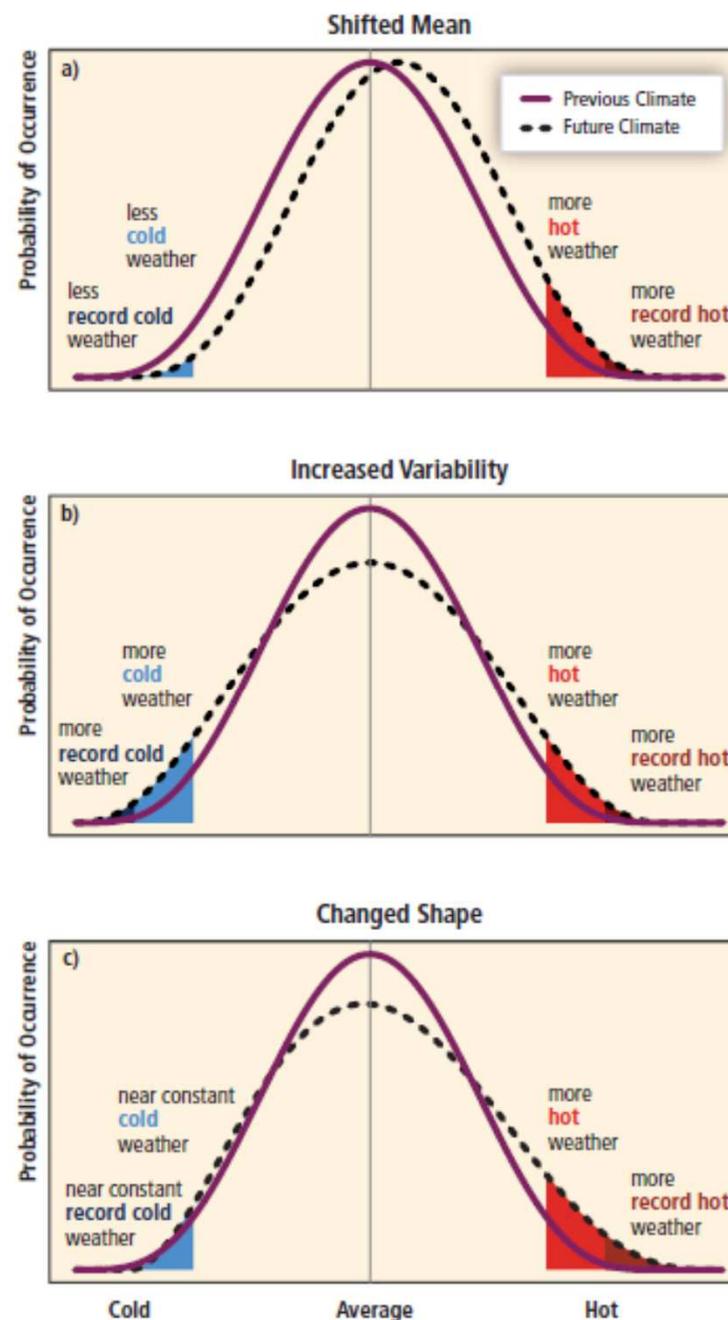
The difference between risk and vulnerability has been emphasized in the recent IPCC/SREX report on extreme events:

SREX SPM Graphics

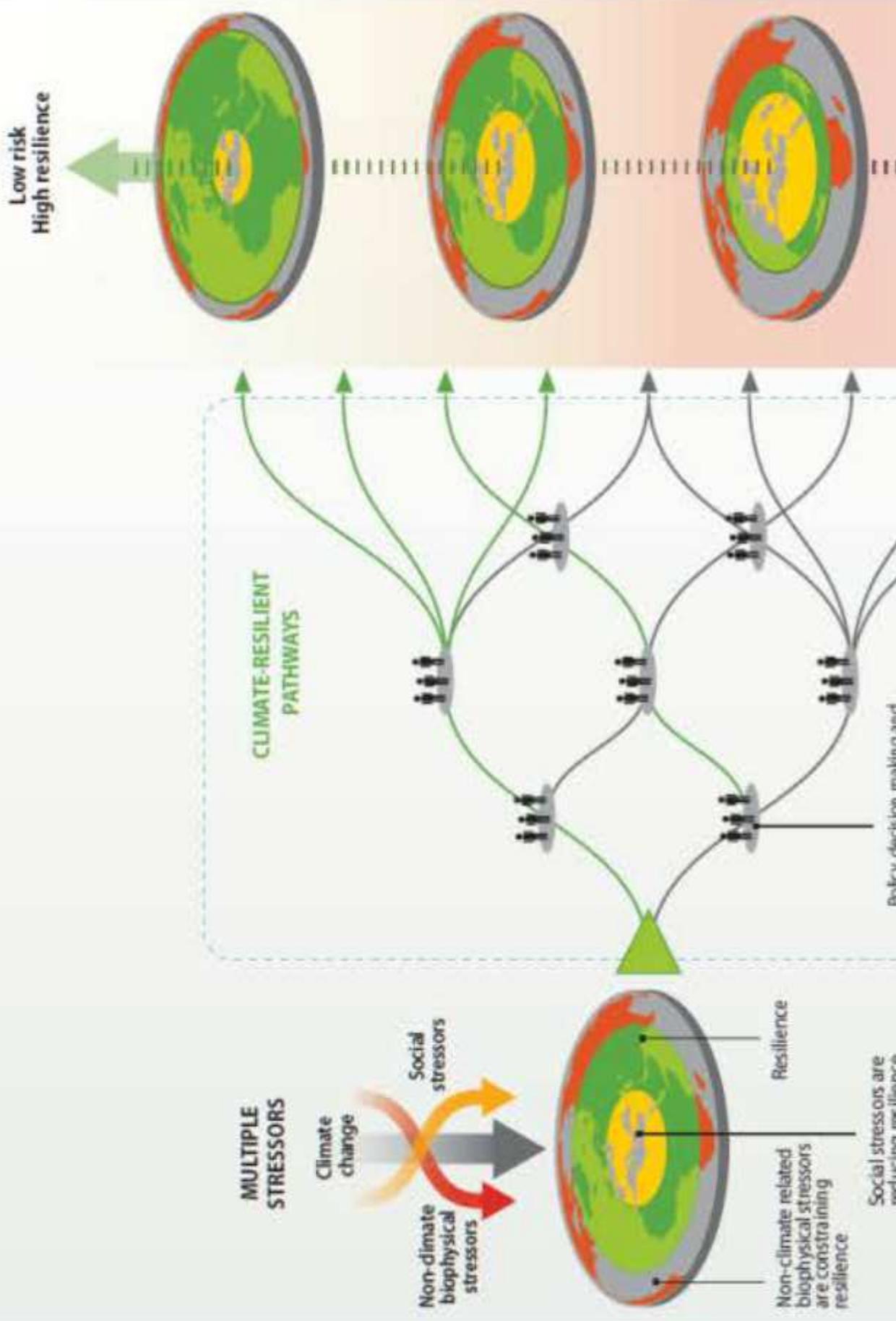


Des dangers plus difficiles  
à étudier et évoquer

Le nombre d'évènements  
rares (extrêmes?) peut  
fluctuer de manière  
importante



# Multiple stressors and Climate-resilient development pathways



## Some issues at stake

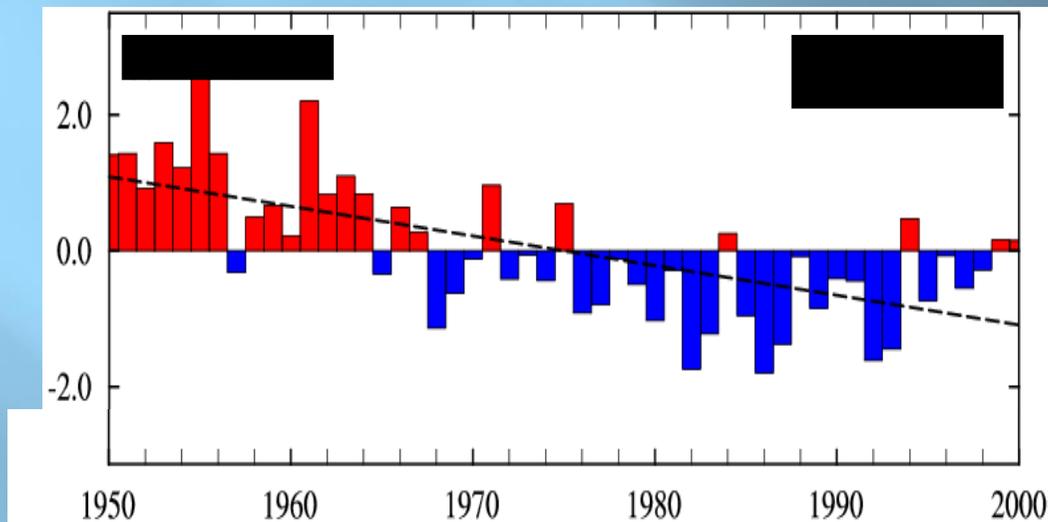
Continent	Besoins alimentaires à l'horizon 2050
Afrique	5.14
Asie	2.34
Europe	0.91
Amérique Latine	1.92
Amérique du Nord	1.31
Océanie	1.61

Besoins alimentaires à l'horizon 2050 (base 1 en 2000) sous l'effet combiné de la croissance de la population, de la modification de sa composition (age, sexe) et du régime alimentaire (Collomb 1999, FAO)

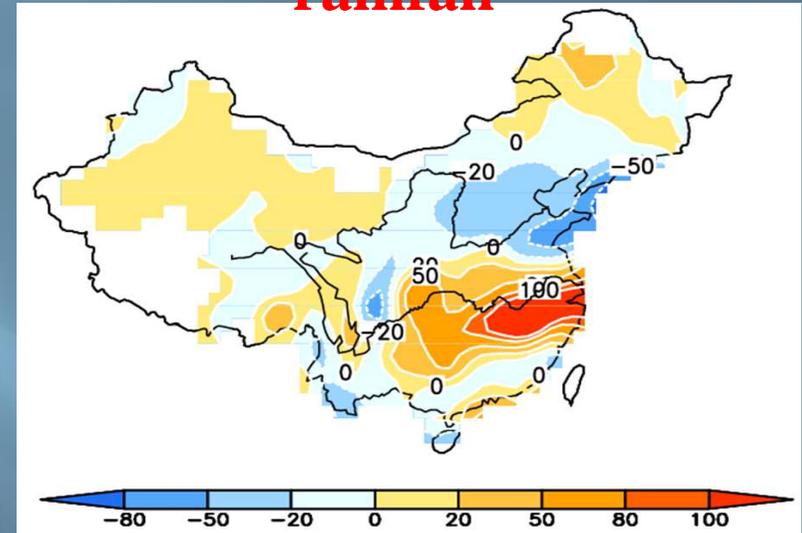


## Variation of the East Asian Summer Monsoon during the second half of the 20th century

### East Asian Summer Monsoon Index



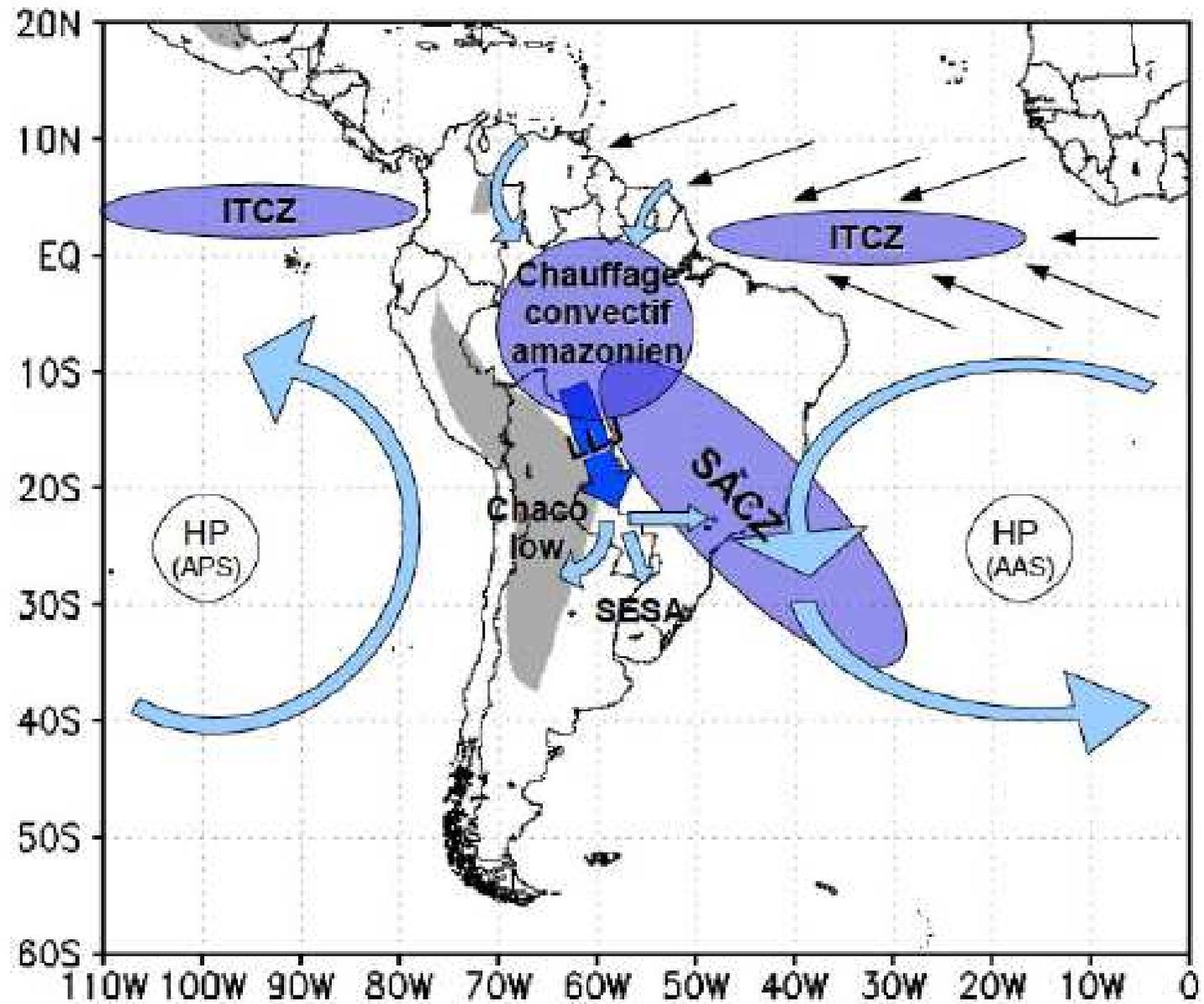
### Decadal variation of rainfall



East Asian Summer Monsoon has strong variabilities at interannual and decadal scales. Since the 1980s, the monsoon diminished in intensity, creating precipitation anomalies (above-normal in the south and below-normal in the north).

Courtesy Dr. T. Zhou

# THE « SESA »



DYNAMIQUES ENVIRONNEMENTALES  
*À la croisée des Sciences*

Sous la direction d'Hervé LE TREUT

# Les impacts du changement climatique en Aquitaine



A collective work:

F. Grousset, A. Kremer, D. Salles, E. Villenave, E. Bourdenx

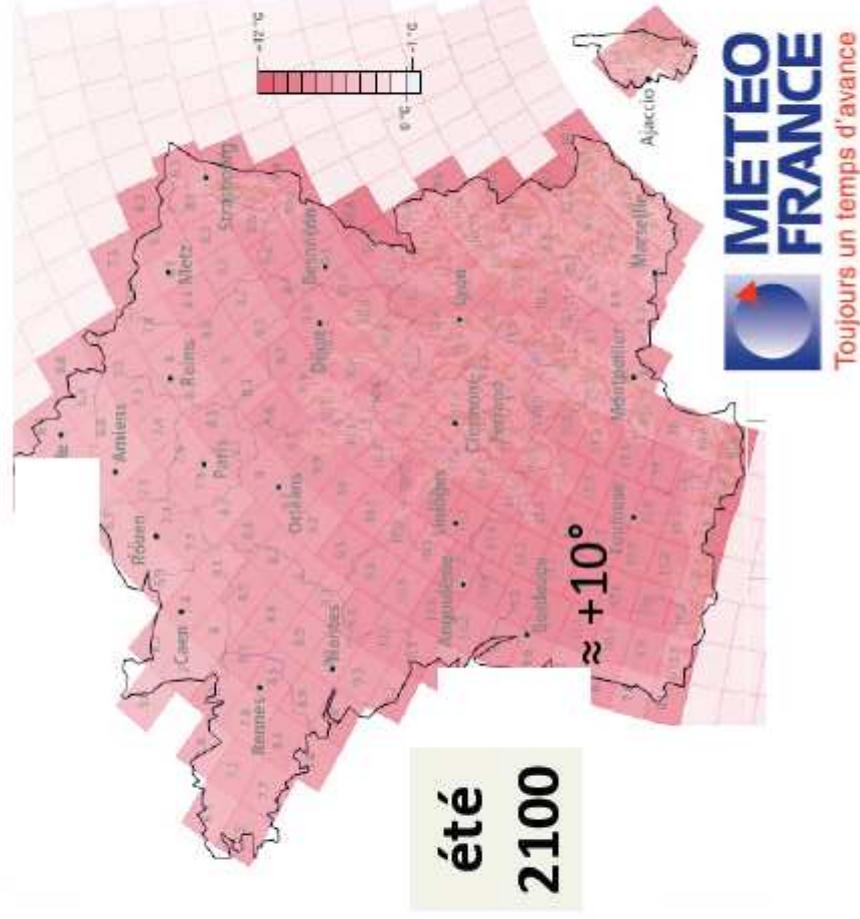
## Les auteurs

(cf. p. 363)

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# I. CONTEXTE ET ENJEUX DU CLIMAT POUR L'AQUITAINE

## Chap. 1 Du climat global au climat régional *Hervé LE TREUT*





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