Climate Change: Challenges ad Opportunities for Software Requirements Engineering

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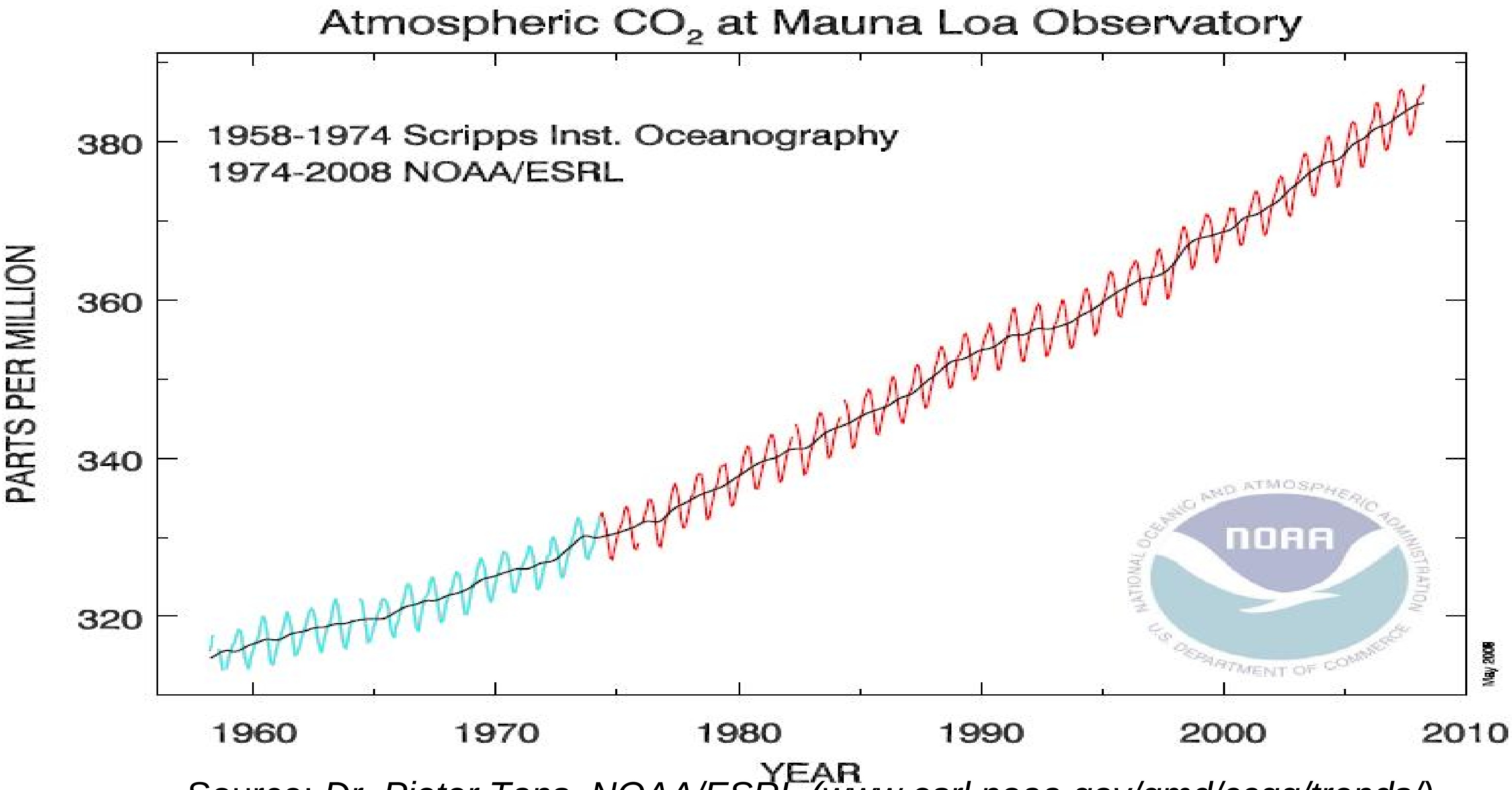
Outline

- Introduction: climate, models, and bath towels
- What does IPCC tell us about the challenge of climate change?
  - How does IPCC work?
  - IPCC Group 1: climatology
  - IPCC Group 2: impacts, vulnerability, & adaptation
  - IPCC Group 3: mitigation
- Opportunities for requirements engineering

Introduction

- Climate & models
- Requirements engineering & bath towels

CO_2 concentration measured at Mauna Loa (3400 m)



Source: *Dr. Pieter Tans, NOAA/ESRL (www.esrl.noaa.gov/gmd/ccgg/trends/)*

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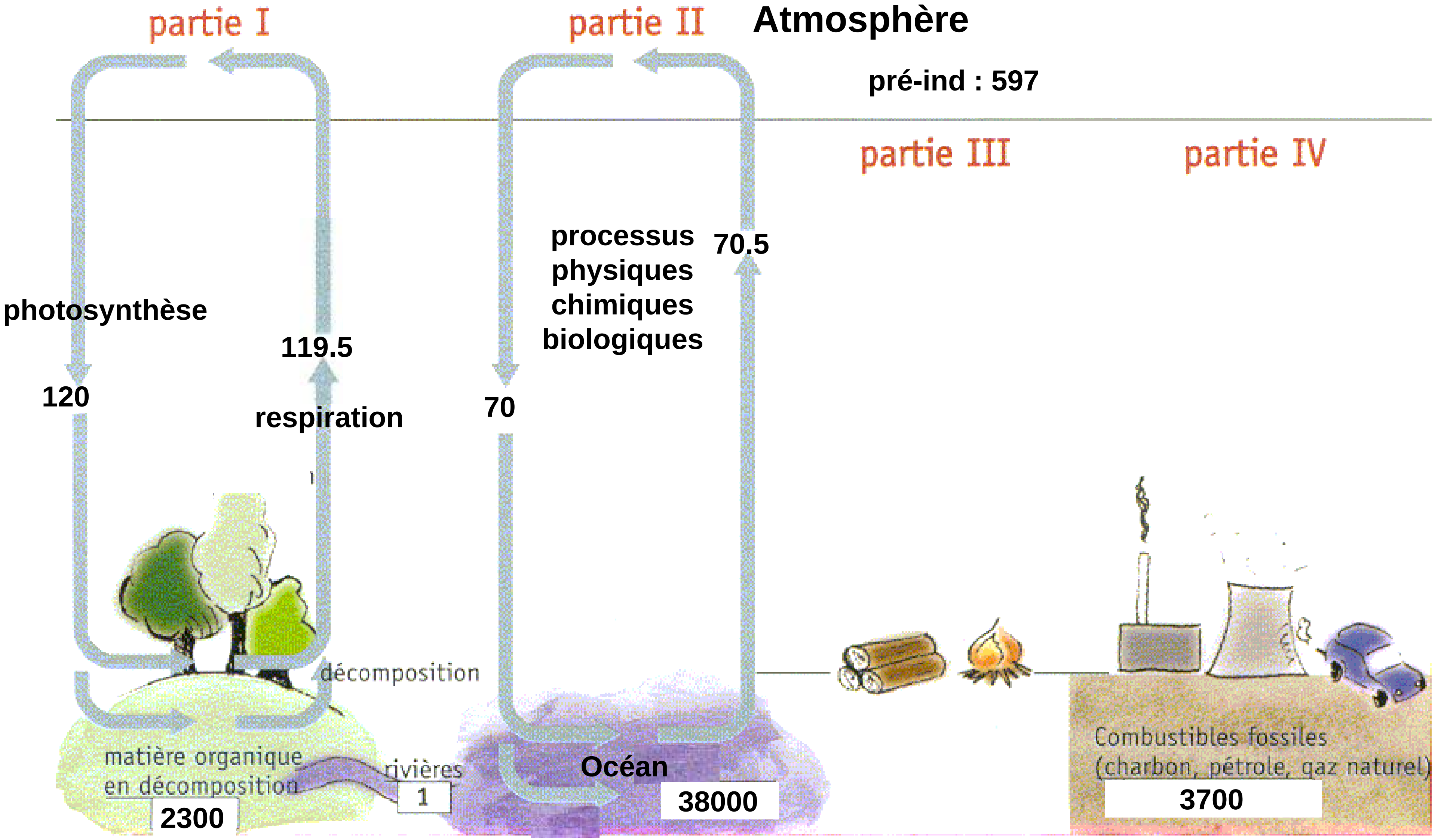
Cycle du carbone



Unités: GtC (milliards de tonnes de carbone) ou GtC/an

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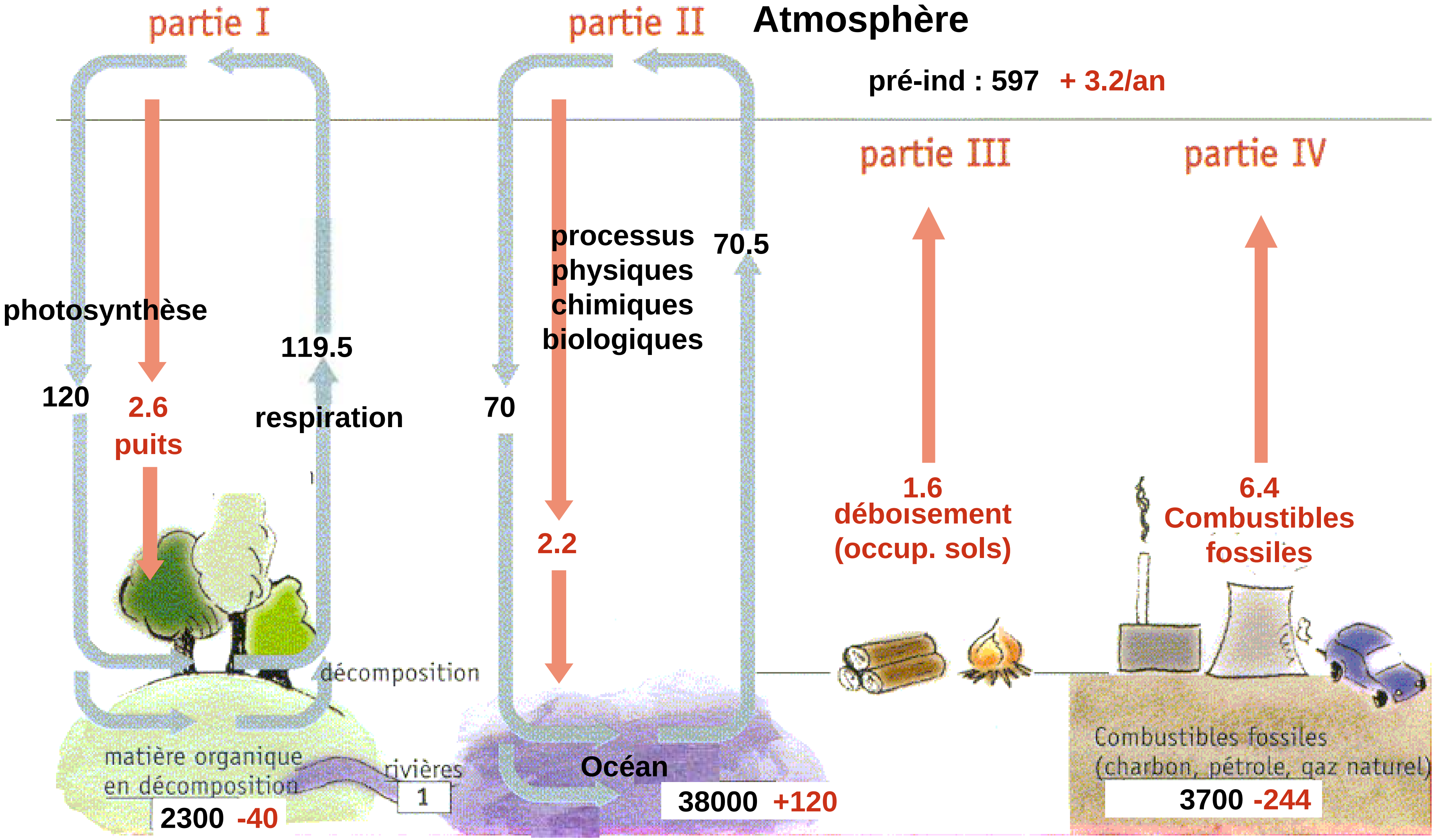
Cycle du carbone



Unités: GtC (milliards de tonnes de carbone) ou GtC/an

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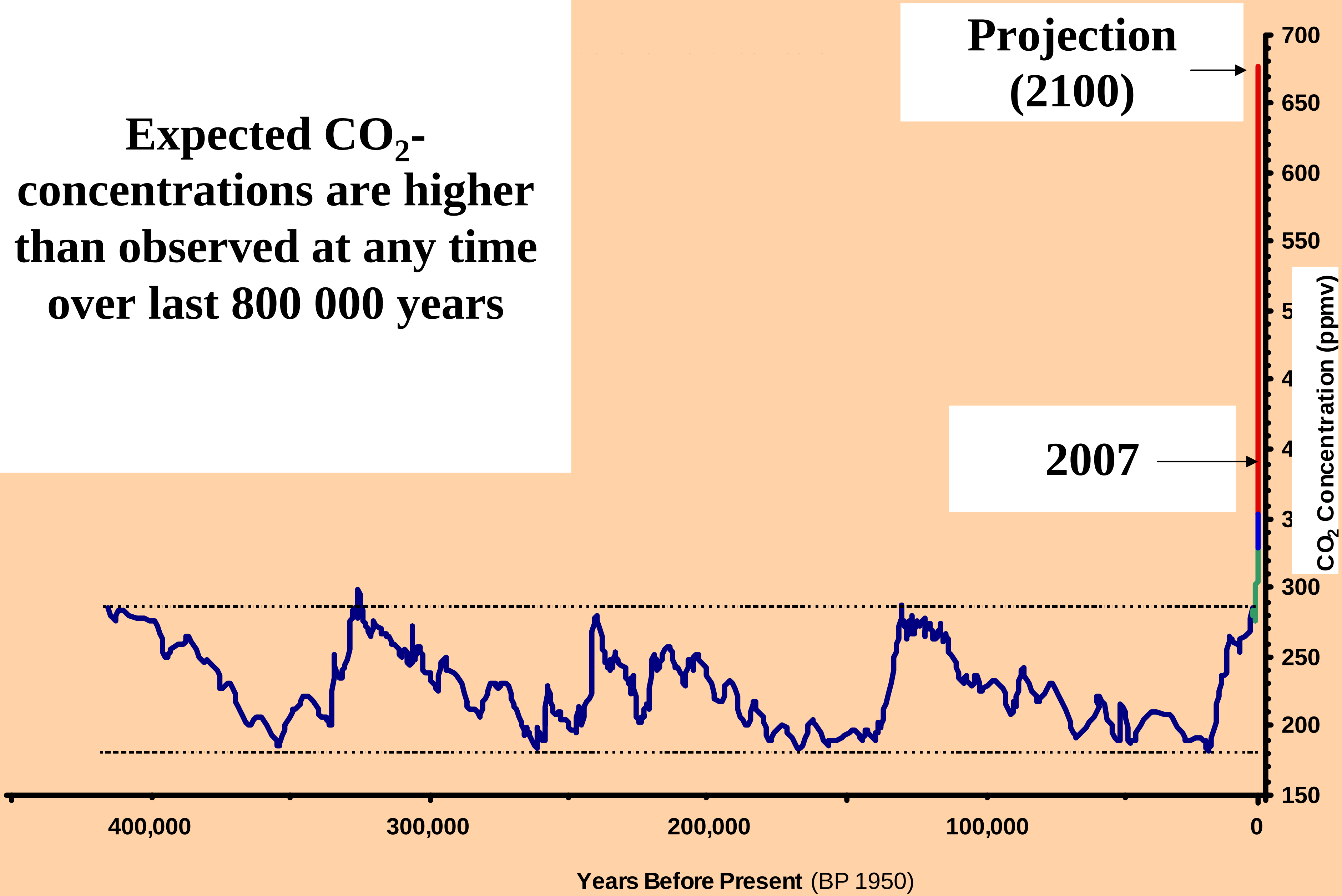
Expected CO_2-concentrations are higher than observed at any time over last 800 000 years

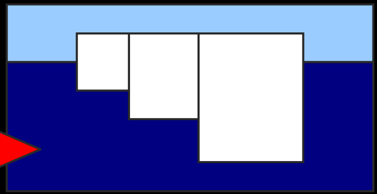


Modèles

Définition

Réalité

Idéalisation



Formulation mathématique

$$\rho c(S,T)\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}[k(S,T)\frac{\partial T}{\partial z}] + \kappa R_0 e^{-\kappa z}$$

Discrétisation Numérique

```
DO ji = kideb , kiut
   ztitemp(ji,layer)    = t_i_b(ji,
   zspeche_i(ji,layer) = cpic + zga
   MAX((t_i_b(ji,layer)-rtt)*(ztio
   zeta_i(ji,layer)     = rdt_ice /
                                  ze
END DO
 DO

layer = 1, nlay_s
DO ji = kideb , kiut
   ztstemp(ji,layer) = t_s_b(ji,lay
   zeta_s(ji,layer)  = rdt_ice / MA
END DO
```

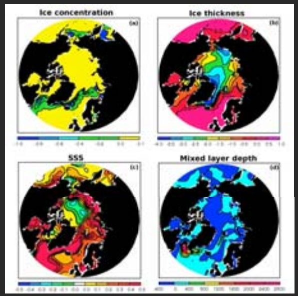
1) Validation
2) Sensibilité

Résolution par ordinateur

Nombres

432586309543950923149328932589
432509534590342950439509432324
3425439530429504329532450932454
4350934253042950324950495049545
345904305943023914364320932193
432586309543950923149328932589
432509534590342950439509432324
3425439530429504329532450932454
4350934253042950324950495049545
345904305943023914364320932193

Analyse



Martin Van Coppenolle (UCL)

A climate model:

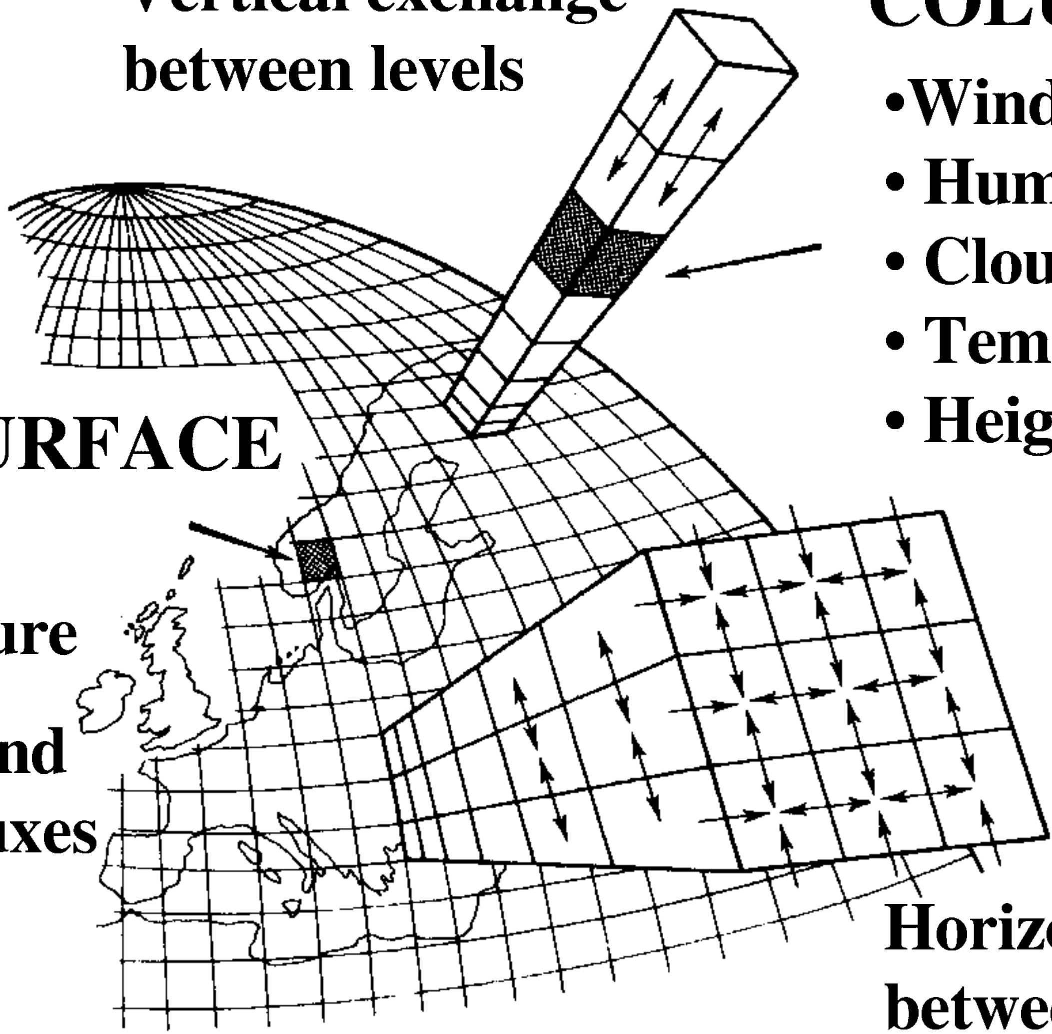
Vertical exchange between levels

IN THE ATMOSPHERIC COLUMN

- **Wind vectors**
- **Humidity**
- **Clouds**
- **Temperature**
- **Height**

AT THE SURFACE

- **Ground temperature**
- **Water and energy fluxes**



Horizontal exchange between columns

Time step ~ 30 minutes

Grid spacing ~ 3°x 3°

Source: McGuffie & Henderson-Sellers (1997)

The Java Climate Model:

⌘www.climate.be/JCM:

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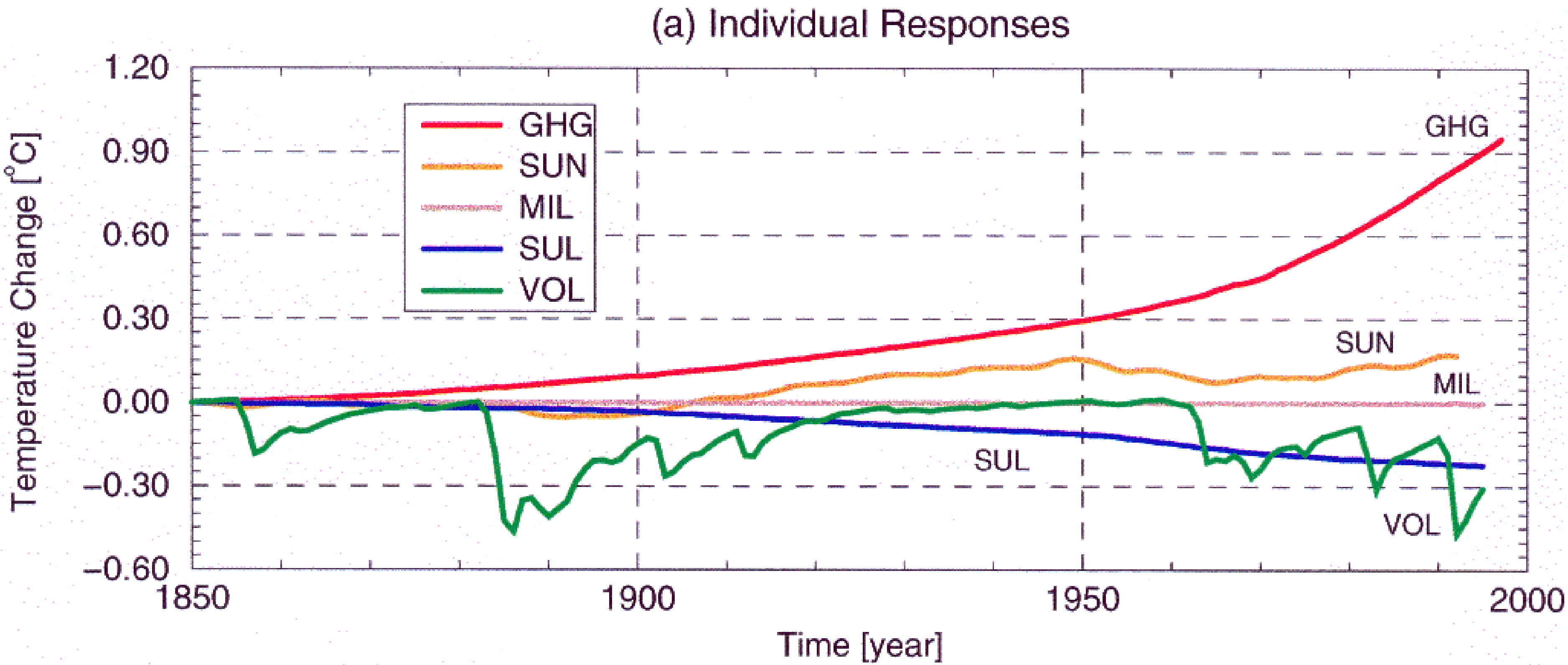
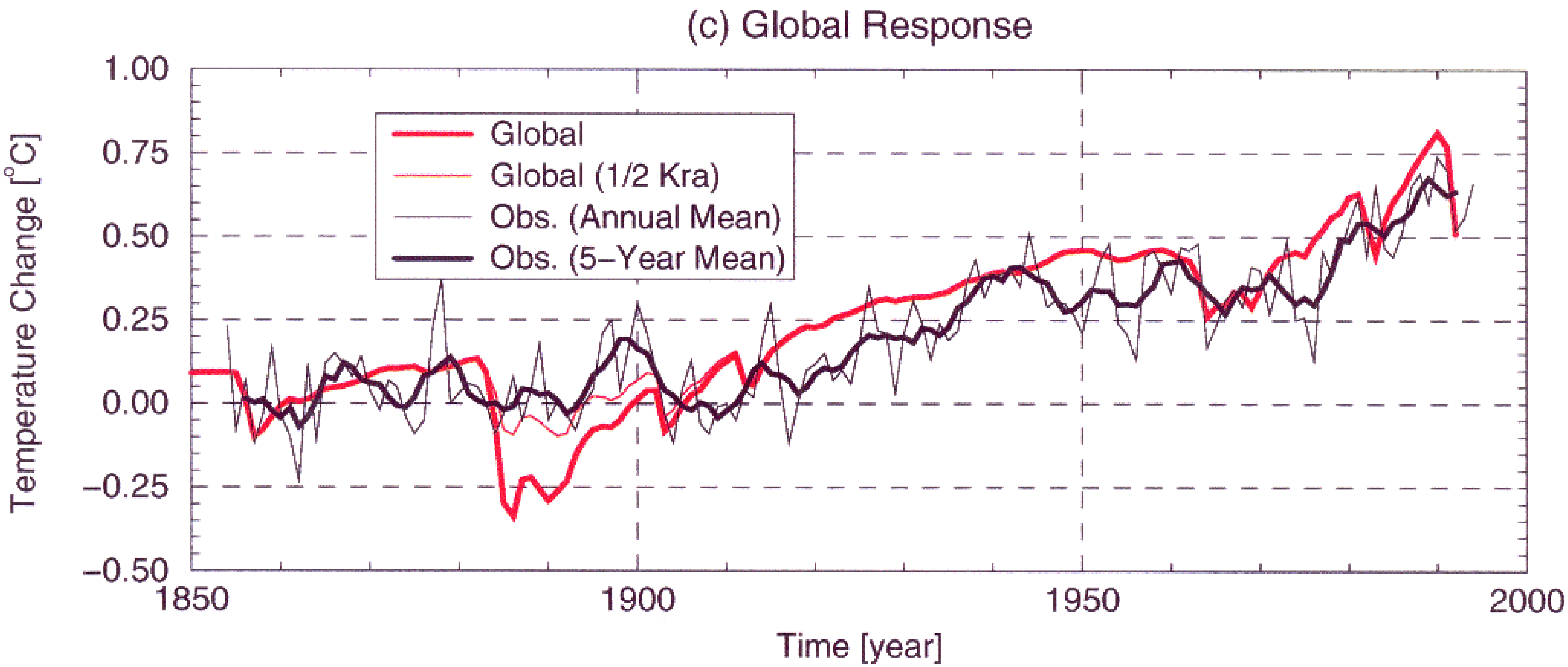
Effet des différents facteurs sur le modèle 2D de LLN



Bertrand et al. 2001

Effet des facteurs combinés sur le modèle 2D de LLN



Bertrand et al. 2001

Bathrooms in this hotel:

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Do you think this will be effective?

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How does IPCC work?

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What is the IPCC (GIEC in French) ?

- **IPCC : Intergovernmental Panel on Climate Change**
- **Created by World Meteorological Organisation (WMO) & United Nations Environment Programme (UNEP) in 1988**
- **Mandate : assess the science of climate change, impacts and adaptation, mitigation options**
- **Publishes consensus reports (1990, 1996, 2001, 2007) (Cambridge University Press)**
  Advises Climate Change Convention
- **Nobel Peace prize (2007)**
- **Web :** http://www.ipcc.ch

IPCC writing cycle (4 years, 2500 scientists)

- Plenary decides table of content of reports
- Bureau appoints world-class scientists as authors, based on publication record
- Authors assess all scientific literature
- *Draft* – Expert review (+ Review editors)
- *Draft 2 (+ Draft 1 Summary for Policy Makers (SPM)* – Combined expert/government review
- *Draft 3 (+ Draft 2 SPM)* – Government review of SPM
- Approval Plenary (interaction authors – governments) – *SPM and full report*

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⌘IPCC Working Group I: climatology

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Key points from the WG1 IPCC AR4 Report

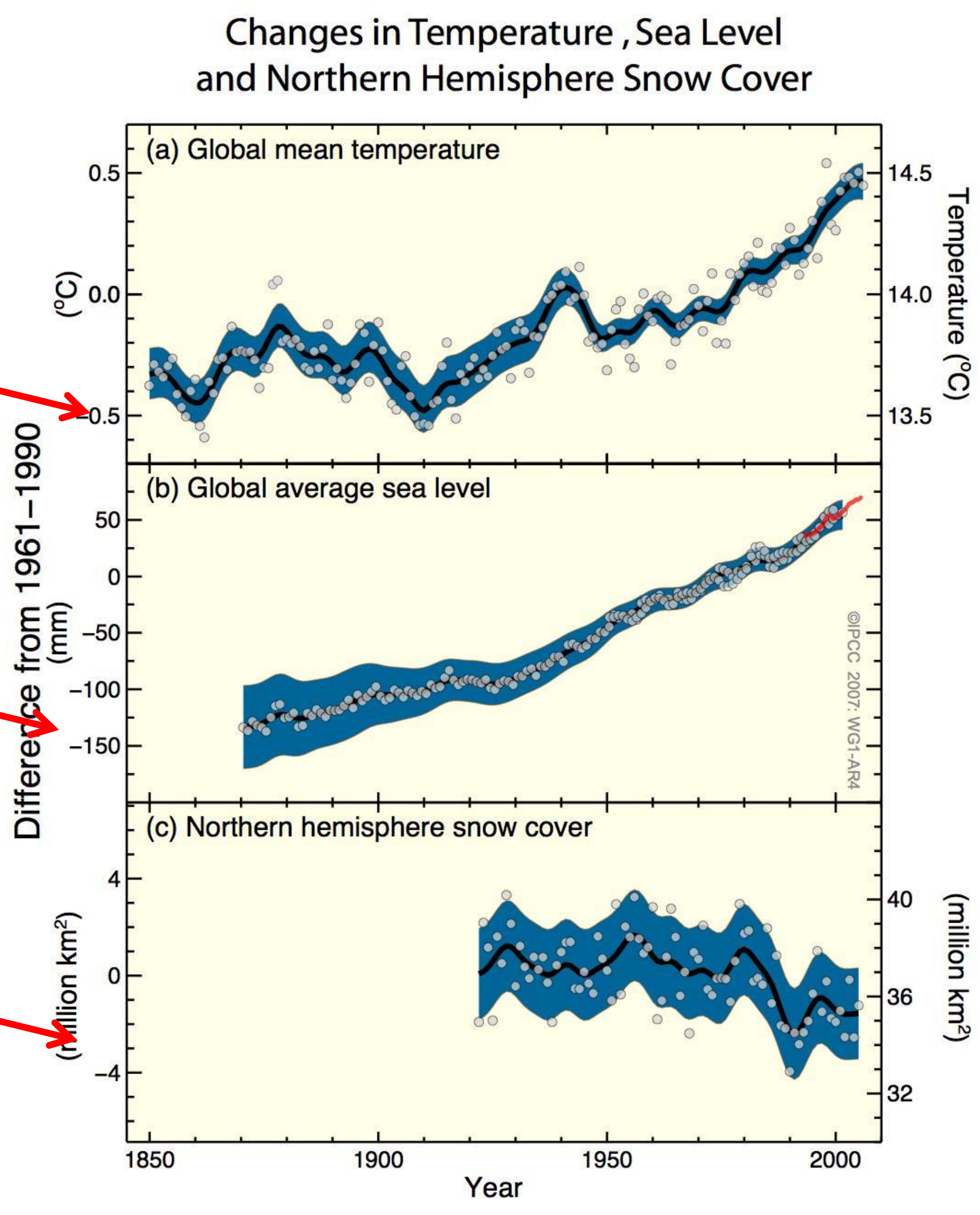
- Warming of the climate system is unequivocal
- Very high confidence that net effect of human activities since 1750 = warming
- Last 50 years likely to be highest temperature in at least last 1300 yrs
- Most of this warming is very likely due to increase in human greenhouse gases
- Without emission reduction policies, global temperature could increase by 1.1 to 6.4°C, or even higher in 2100 compared to 1990
- Sea level could increase by 18 to 59 cm, or more
- Frequency/intensity of several extreme phenomena due to increase (ex: heat waves, droughts, floods, ...)

Warming is Unequivocal

Rising atmospheric temperature

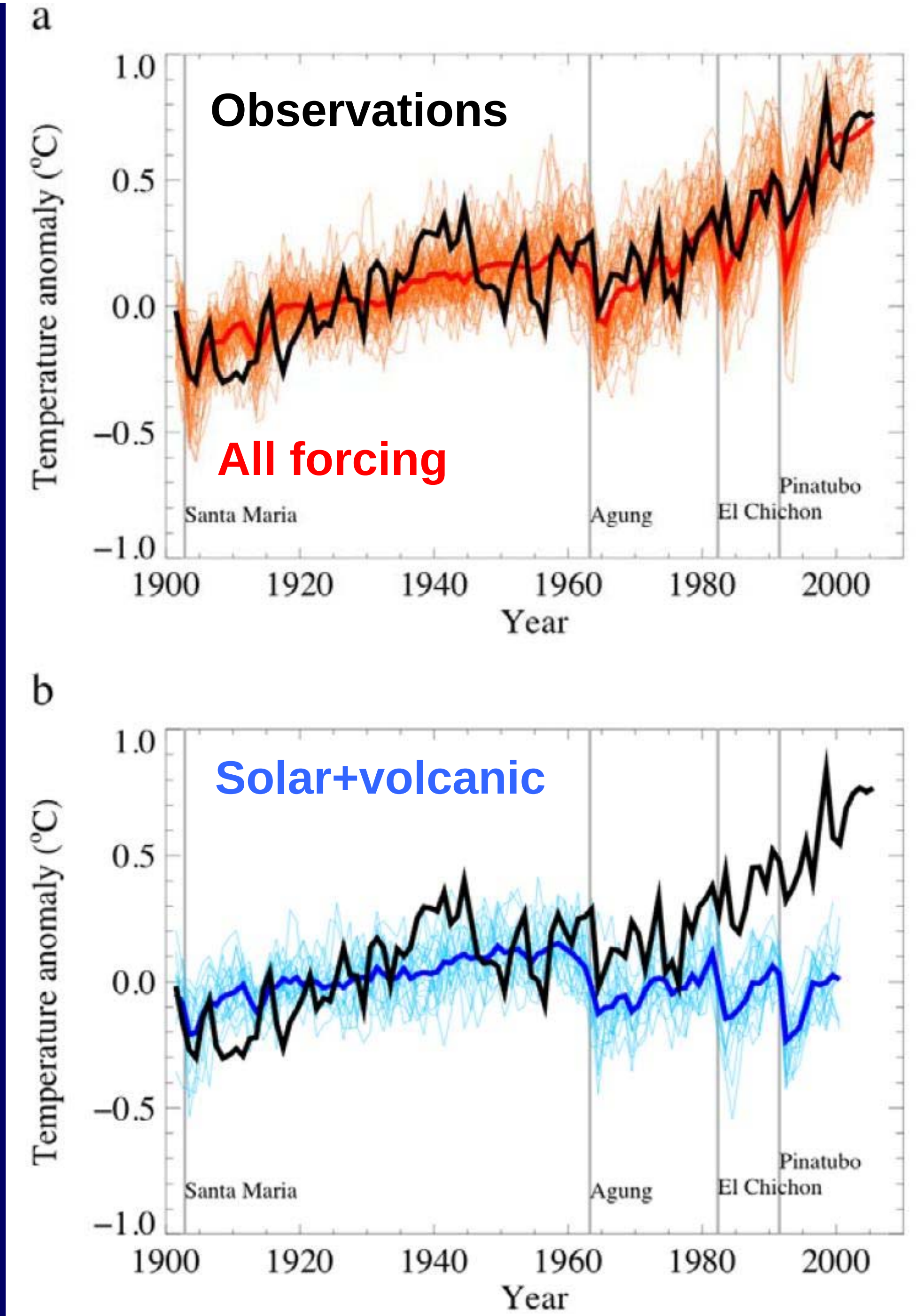
Rising sea level

Reductions in NH snow cover



Attribution

- are observed changes consistent with
- ☑ expected responses to forcings
- ☒ inconsistent with alternative explanations

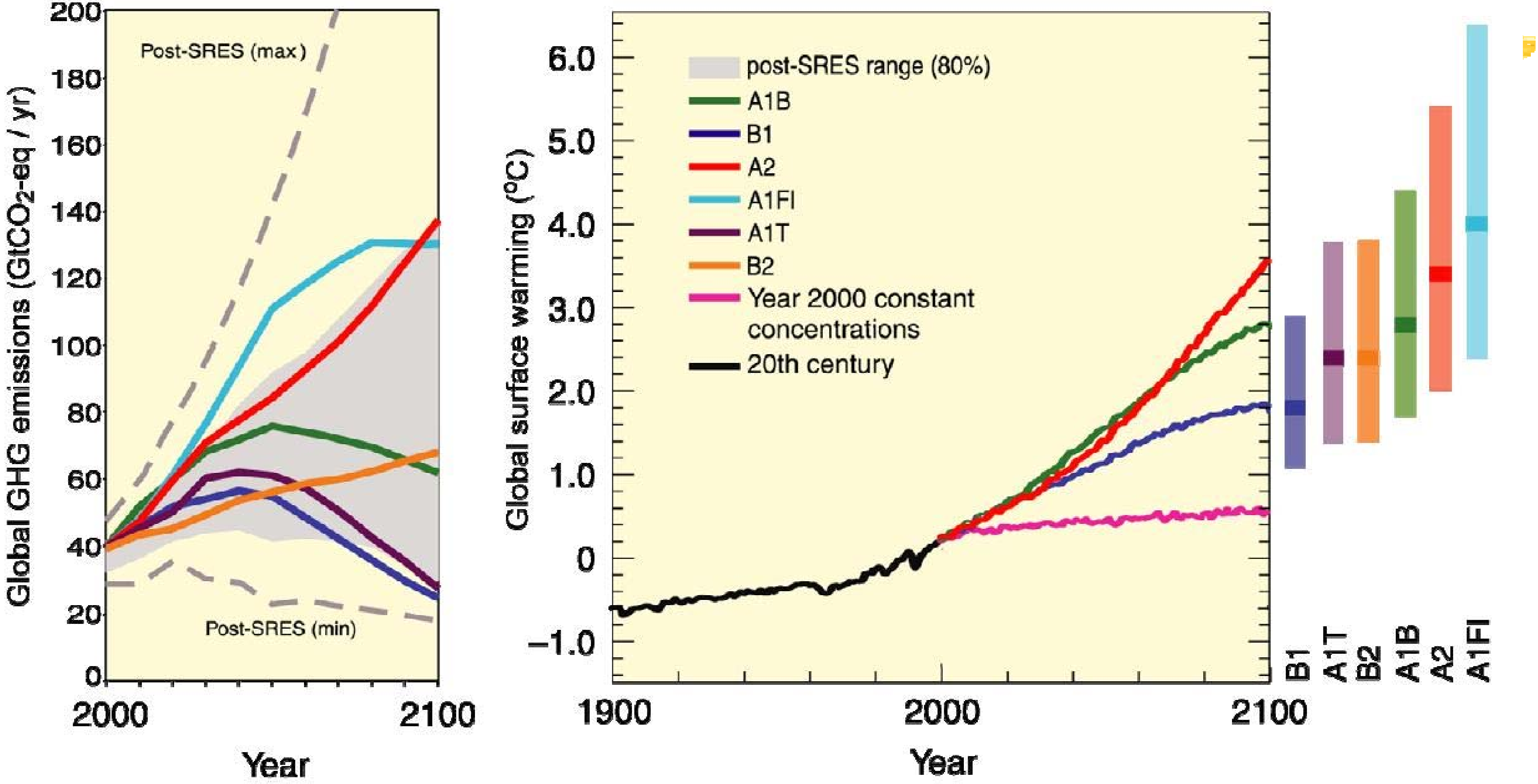


Understanding and Attributing Climate Change

- **Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely (>90%) due to the observed increase in anthropogenic greenhouse gas concentrations.**
- **This is an advance since the TAR's conclusion that "most of the observed warming over the last 50 years is likely (>66%) to have been due to the increase in greenhouse gas concentrations".** .

Source: IPCC, AR4 (2007)

Climate projections without mitigation



NB: écart par rapport à la moyenne 1980-1999

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Projected globally averaged surface warming and sea level rise at the end of the 21st century (IPCC WG1 AR4)

	Temperature Change (°C at 2090-2099 relative to 1980-1999)[a]		Sea Level Rise (m at 2090-2099 relative to 1980-1999)
Case	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations[c]	0.6	0.3 – 0.9	NA
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

NB: add 0.5°C to get pre-industrial reference

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Climate change and extremes
(IPCC AR4 WG1)

Post 1960 **21th century**

Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend [b]	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely* [c]	*Likely* [d]	*Virtually certain* [d]
Warmer and more frequent hot days and nights over most land areas	*Very likely* [e]	*Likely (nights)* [d]	*Virtually certain* [d]
Warm spells / heat waves. Frequency increases over most land areas	*Likely*	*More likely than not* [f]	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not* [f]	*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not* [f]	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis) [g]	*Likely*	*More likely than not* [f, h]	*Likely* [i]

Virtually certain > 99%, very likely > 90%, likely > 66%, more likely than not > 50%

What if the Gulf Stream is affected?

- Based on current model simulations, it is *very likely* that the meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21st century.
  - **longer term changes not assessed with confidence**
- Temperatures in the Atlantic region are projected to increase despite such changes due to the much larger warming associated with projected increases of greenhouse gases.

- **IPCC Working Group II: Impacts, Vulnerability, and adaptation**

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Following addressed by WG II:

- Impacts observed so far

- Future scenarios
- Impacts on sectors:
  - Water
  - Ecosystems
  - Agriculture, forestry, fisheries
  - Coasts
  - Settlements and industry
  - Health

WMO UNEP

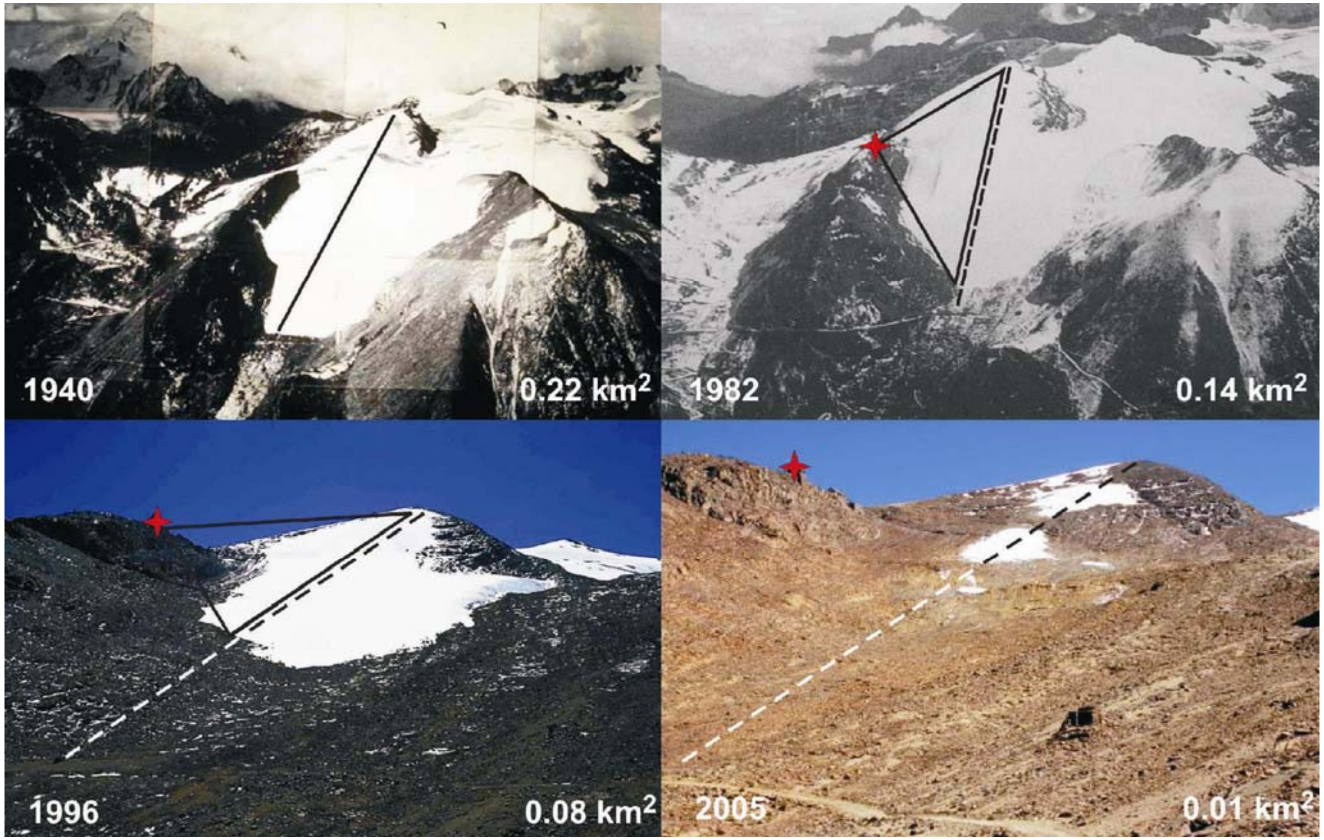
Following addressed (cont.):

- Impacts on regions:
  - Africa, Asia, Australia and New Zealand, Latin America, North America, Polar regions, Small islands, and
  - Europe (including the Alps)

- Adaptation practices
- Adaptation vs. mitigation
- Key vulnerabilities
- Sustainability

The Chacaltaya glacier and ski-lift, Bolivia

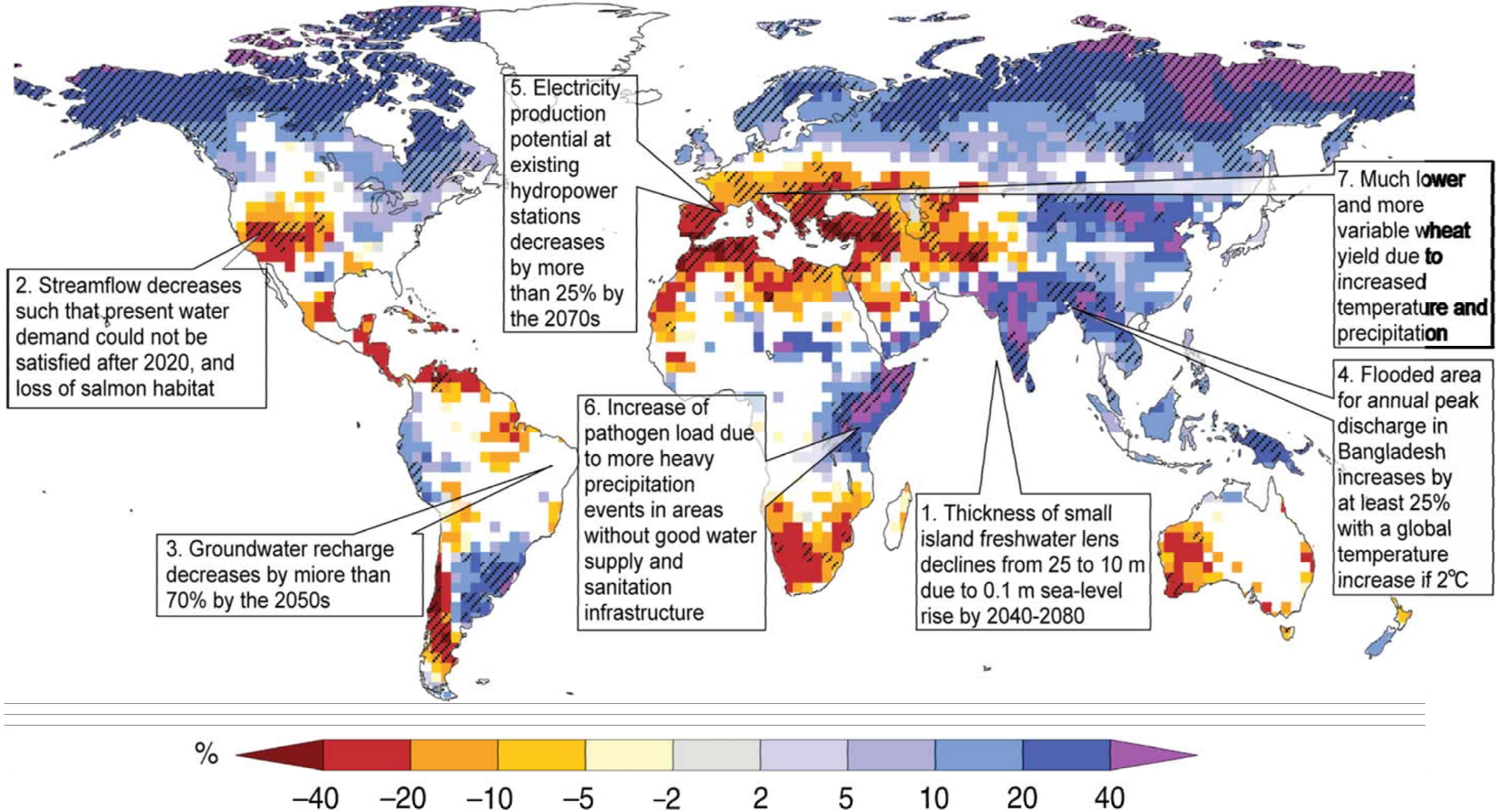
Skiing was no longer possible after 2004



WMO

UNEP

Water at the end of the 21st century for SRES A1B



TP Figure 3.4: Ensemble mean change of annual runoff, in percent, between present (1980-1999) and 2090-2099 for the SRES A1B emissions scenario (based on Milly et al., 2005).

WMO

UNEP

Effects on Nile delta: 10 M people above 1m

(Time 2001)

WMO

UNEP

20% - 30% of plants and animals species likely at increased risk of extinction

if ΔT 1.5°C - 2.5°C (above 1990 temperature)

Regions most affected

- The Arctic
- Sub-Saharan Africa
- Small islands
- Megadeltas

In all regions, there are some areas and communities which are particularly vulnerable

- The poor
- Young children
- The elderly

WMO UNEP

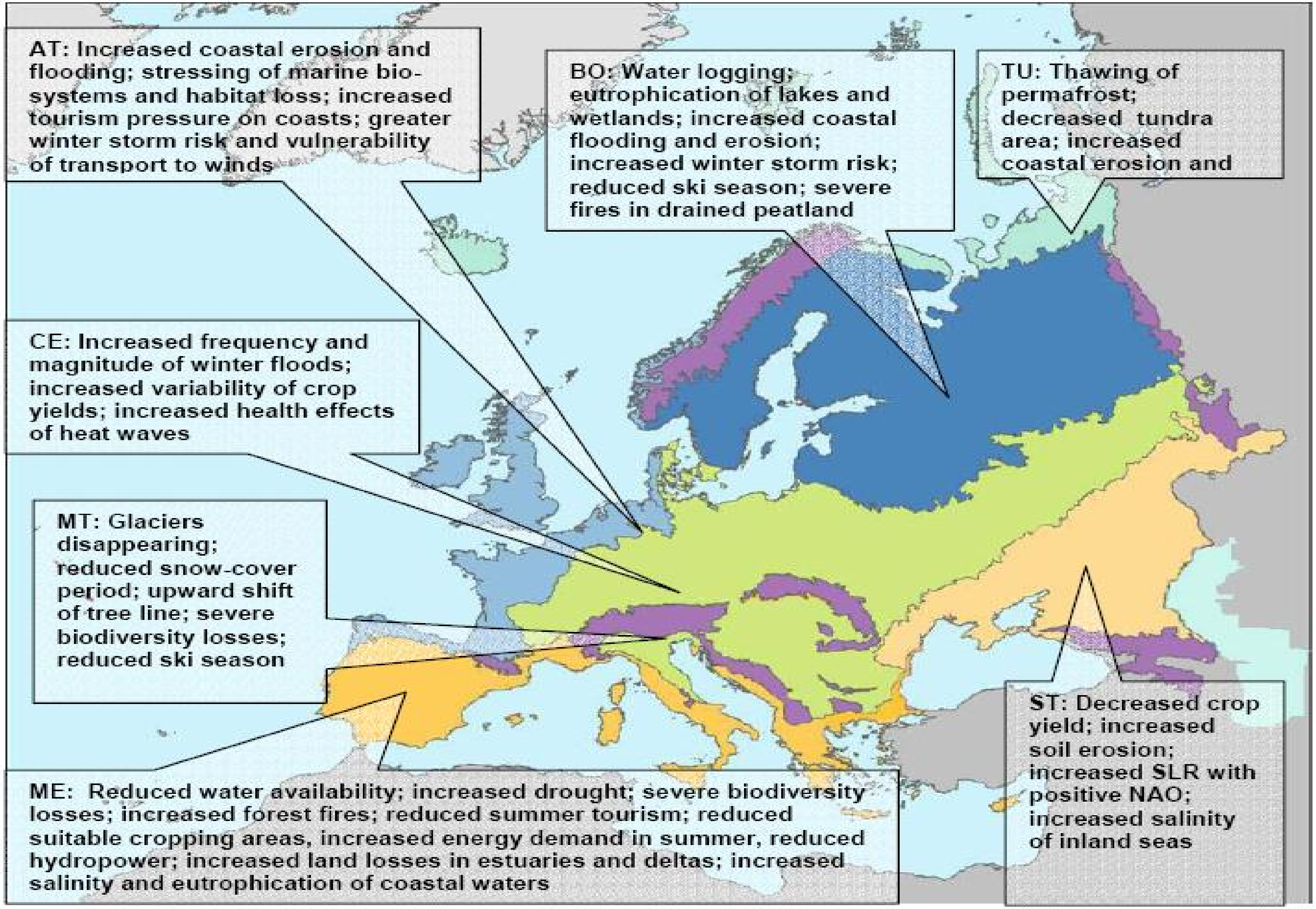
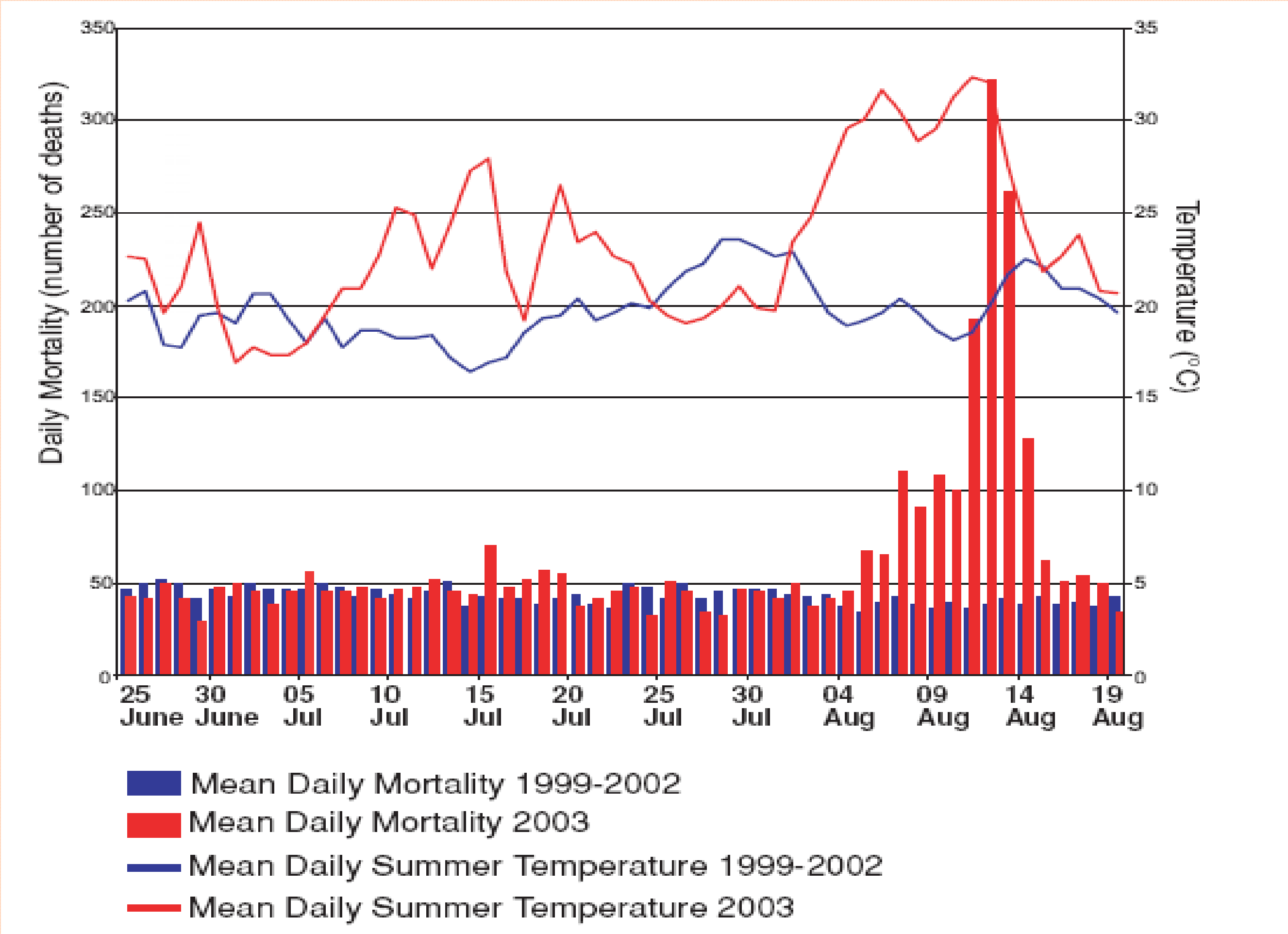


Figure 12.3: *Key vulnerabilities of European systems and sectors to climate change during the 21st century for the main biogeographic regions of Europe (EEA 2004a): TU (Tundra, pale turquoise); BO (Boreal, dark blue); AT (Atlantic, light blue); CE (Central, green [includes the Pannonian Region]); MT (Mountains, purple); ME (Mediterranean, orange [includes the Black Sea region]); ST (Steppe, cream); SLR (sea-level raise); NAO (North Atlantic Oscillation).*

Daily mortality in Paris (summer 2003) (IPCC AR4 Ch 8)



Ice sheet melting

- Melting of the Greenland ice sheet
  - Total melting would cause 7 m SLR contribution
- Melting of the West Antarctic Ice Sheet
  - Total melting would cause 5 m SLR contribution
- Warming of 1 – 4^{o}C over present-day temperatures would lead to partial melting over centuries to millennia

WMO

UNEP

With 1 metre sea-level rise: 63000 ha below sea-level in Belgium (likely in 22nd century, not impossible in 21st century) (NB: flooded area depends on protection)

Source: N. Dendoncker (Dépt de Géographie, UCL), J.P. van Ypersele et P. Marbaix (Dépt de Physique, UCL) (www.climate.be/impact)

With 8 metre sea-level rise: 3700 km^2 below sea-level in Belgium

(very possible in year 3000)

(NB: flooded area depends on protection)

Source: N. Dendoncker (Dépt de Géographie, UCL), J.P. van Ypersele et P. Marbaix (Dépt de Physique, UCL) (www.climate.be/impact)

Adaptation will be necessary to address unavoidable impacts

⌘IPCC Working Group III: Mitigation

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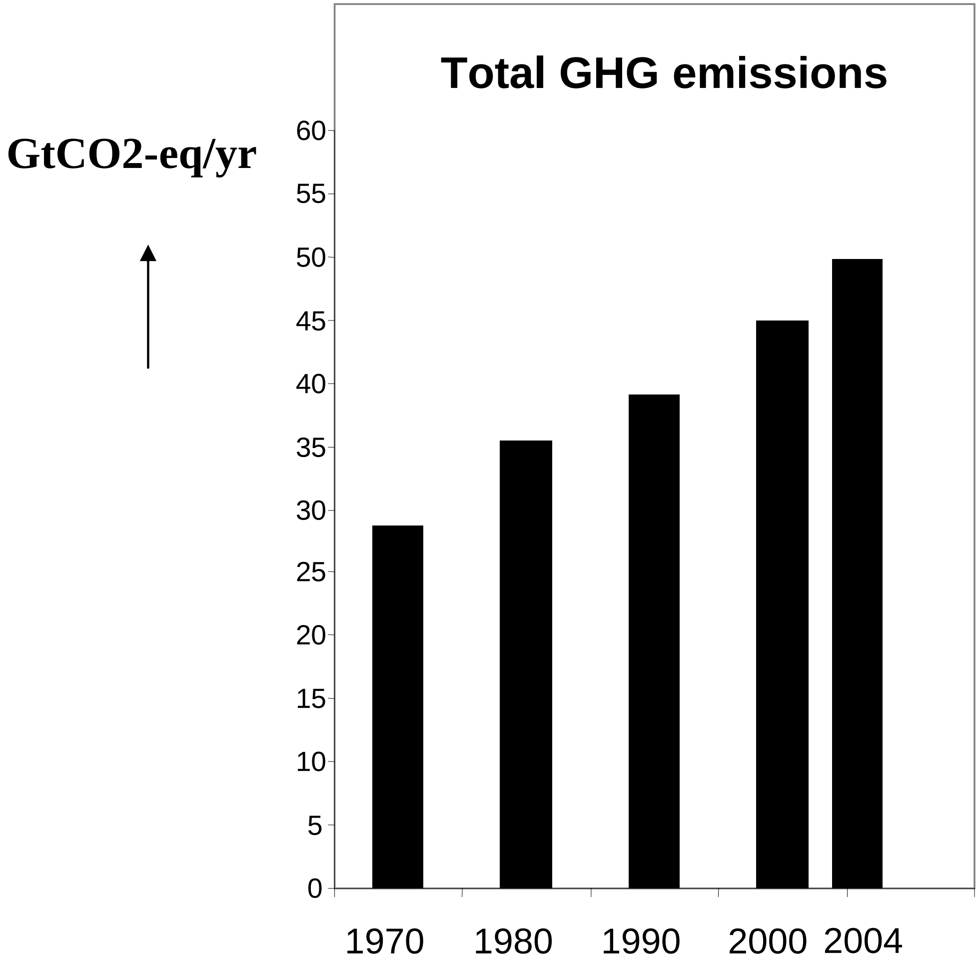
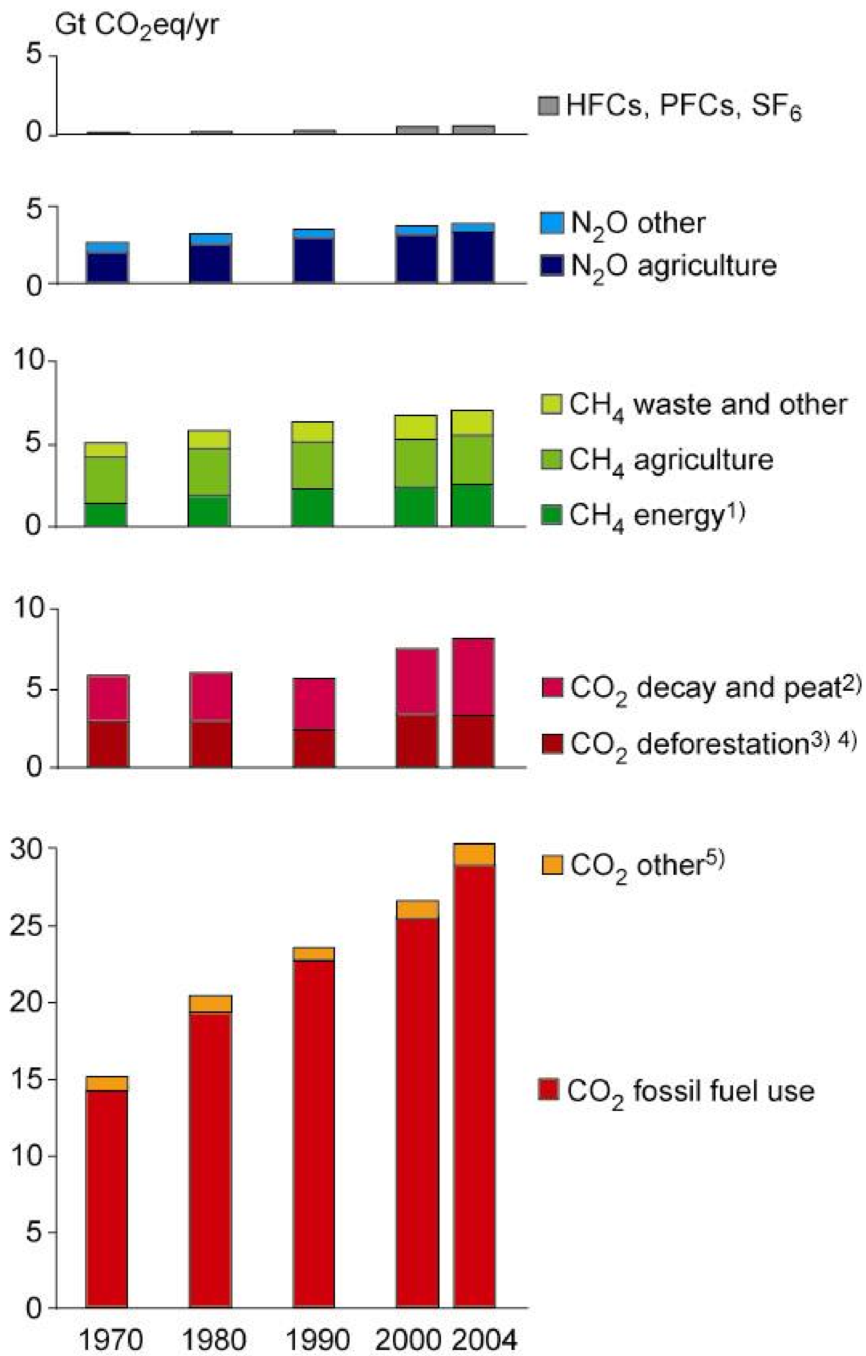
Between 1970 and 2004 global greenhouse gas emissions have increased by 70 %



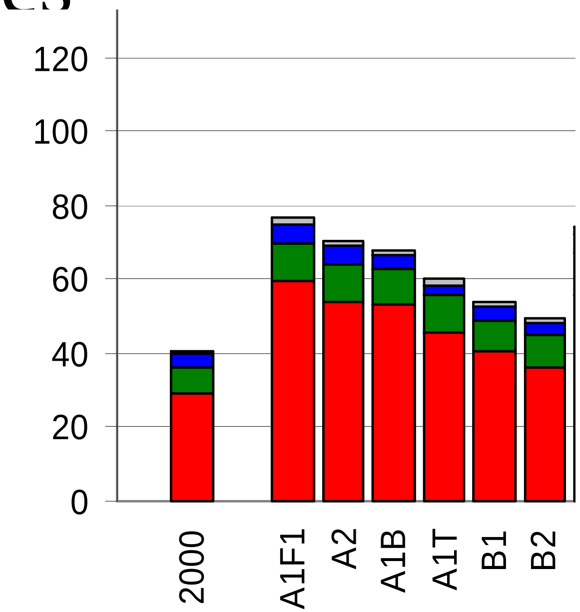
Carbon dioxide is the largest contributor



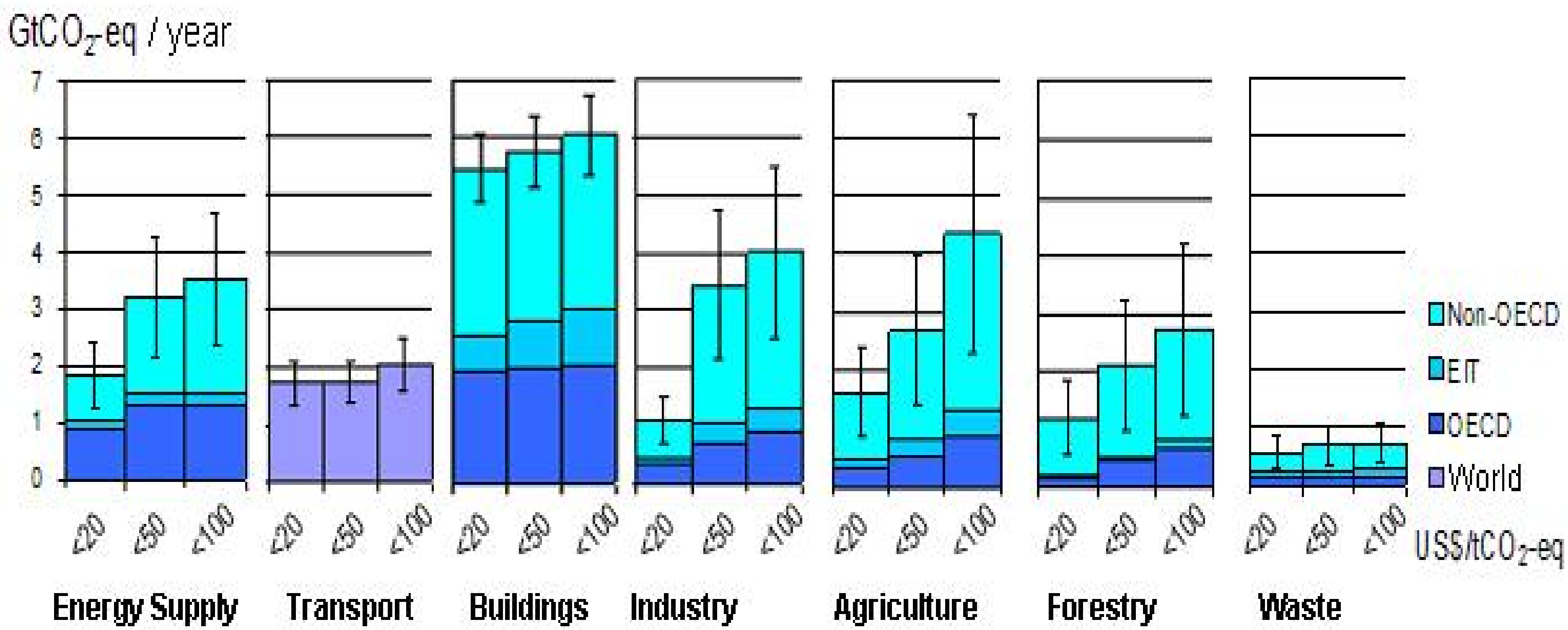
Future emissions will grow further

- With current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades

- IPCC SRES scenarios: 25-90 % increase of GHG emissions in 2030 relative to 2000



All sectors and regions have the potential to contribute



Note: estimates do not include non-technical options, such as lifestyle changes.

How can emissions be reduced?

Sector	**(Selected) Key mitigation technologies and practices currently commercially available.**
Energy Supply	efficiency; fuel switching; nuclear power; renewable (hydropower, solar, wind, geothermal and bioenergy); combined heat and power; early applications of CO2 Capture and Storage
Transport	More fuel efficient vehicles; hybrid vehicles; biofuels; modal shifts from road transport to rail and public transport systems; cycling, walking; land-use planning
Buildings	Efficient lighting; efficient appliances and airco; improved insulation ; solar heating and cooling; alternatives for fluorinated gases in insulation and aplliances

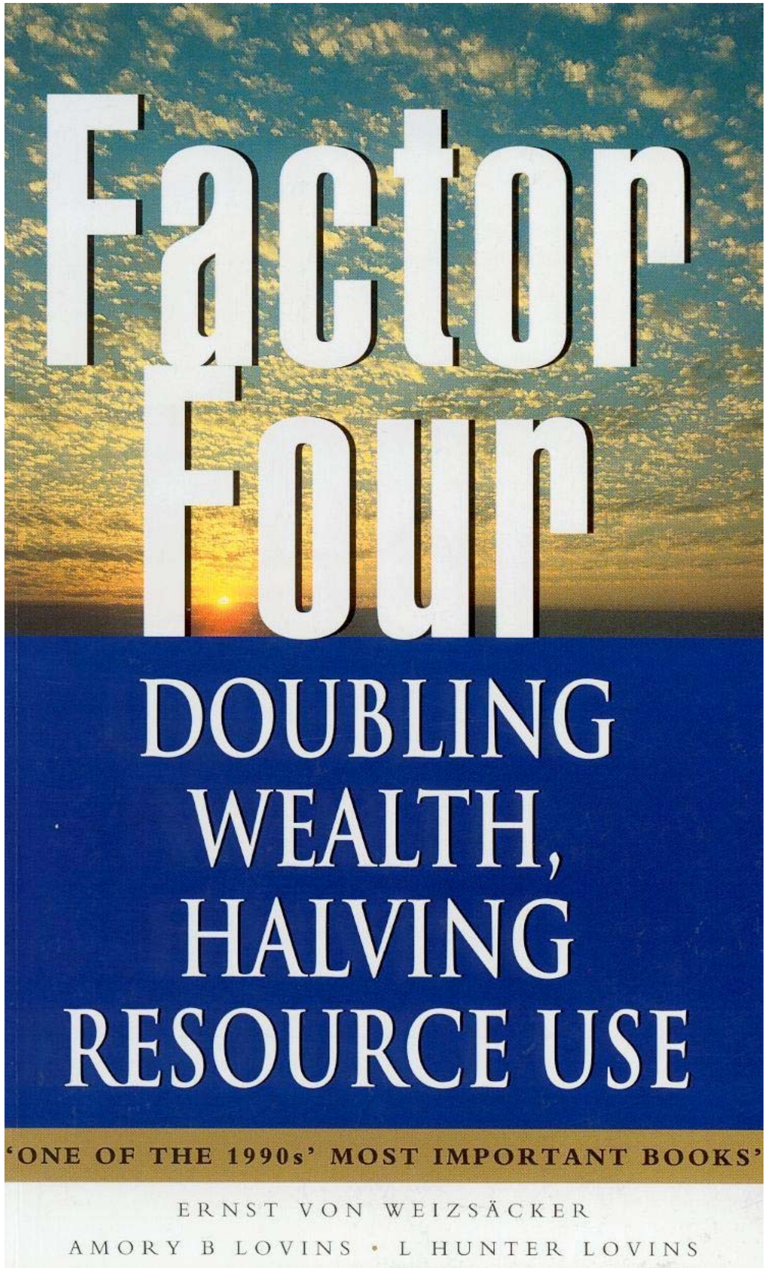
How can emissions be reduced?

Sector	(Selected) Key mitigation technologies and practices currently commercially available.
Industry	More efficient electrical equipment; heat and power recovery; material recycling; control of non-CO_2 gas emissions
Agriculture	Land management to increase soil carbon storage; restoration of degraded lands; improved rice cultivation techniques; improved nitrogen fertilizer application; dedicated energy crops
Forests	Afforestation; reforestation; forest management; reduced deforestation; use of forestry products for bioenergy
Waste	Landfill methane recovery; waste incineration with energy recovery; composting; recycling and waste minimization

E. von Weizsäcker
A.B. Lovins
L.H. Lovins

1998

Earthscan



October 2008 issue

Changes in lifestyle and behaviour patterns can contribute to climate change mitigation

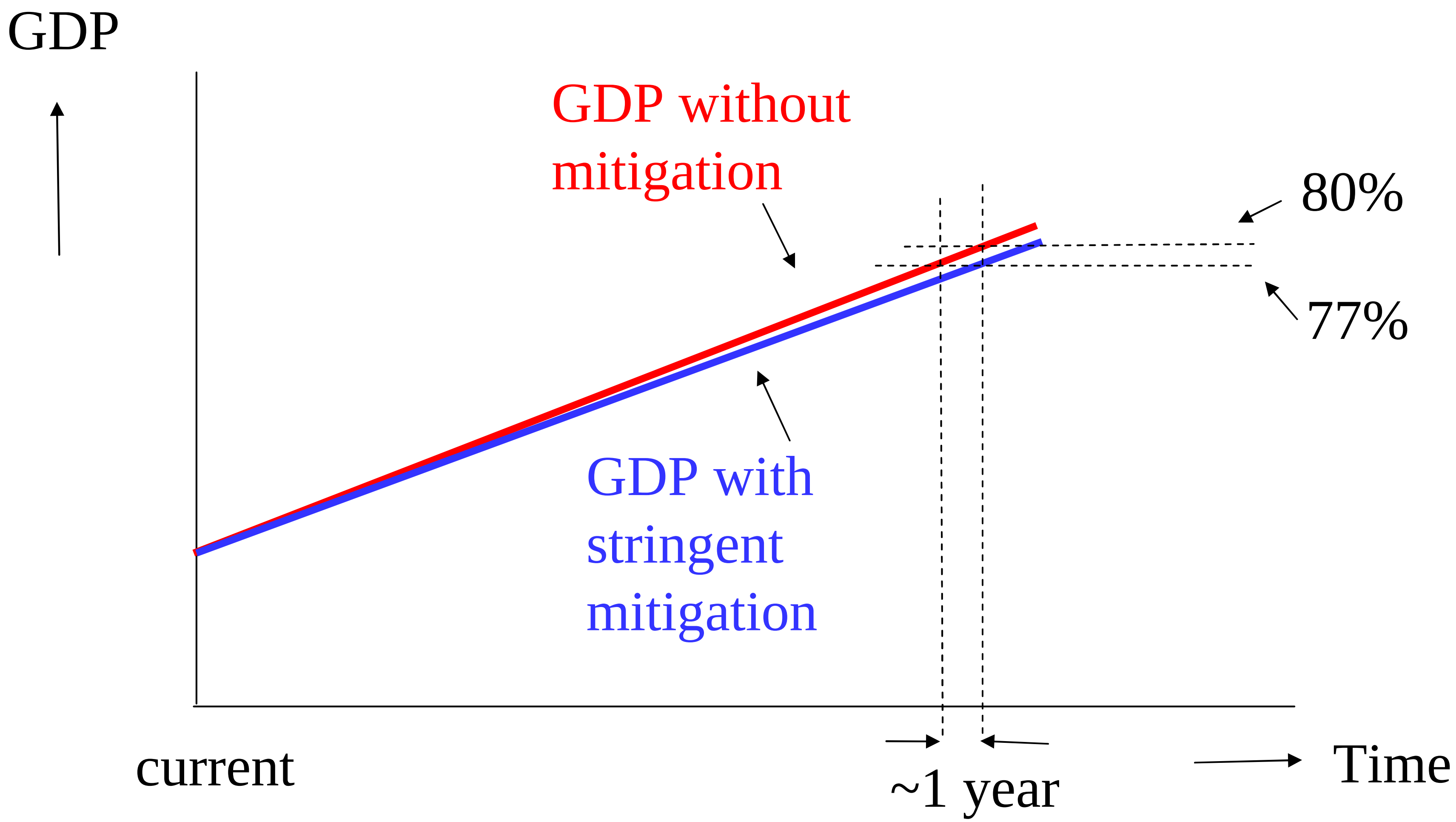
- Changes in occupant behaviour, cultural patterns and consumer choice in buildings.
- Reduction of car usage and efficient driving style, in relation to urban planning and availability of public transport
- Staff training, reward systems, regular feedback and documentation of existing practices in industrial organizations

What are the macro-economic costs in **2030**?

Stabilization levels (ppm CO_2-eq)	Median GDP reduction[1] (%)	Range of GDP reduction [2] (%)	Reduction of average annual GDP growth rates [3] (percentage points)
590-710	0.2	-0.6 – 1.2	< 0.06
535-590	0.6	0.2 – 2.5	<0.1
445-535[4]	Not available	< 3	< 0.12

[1] This is global GDP based market exchange rates.
[2] The median and the 10th and 90th percentile range of the analyzed data are given.
[3] The calculation of the reduction of the annual growth rate is based on the average reduction during the period till 2030 that would result in the indicated GDP decrease in 2030.
[4] The number of studies that report GDP results is relatively small and they generally use low baselines.

Illustration of cost numbers



There are also co-benefits of mitigation

- Near–term health benefits from reduced air pollution may offset a substantial fraction of mitigation costs
- Mitigation can also be positive for: energy security, balance of trade improvement, provision of modern energy services to rural areas and employment

BUT

- Mitigation in one country or group of countries could lead to higher emissions elsewhere (“carbon leakage”) or effects on the economy (“spill-over effects”).

Long term mitigation (after 2030)

•The lower the stabilization level, the more quickly emissions would need to peak and to decline thereafter

•Mitigation efforts over the next two to three decades will have a large impact on opportunities to achieve lower stabilization levels

Stab level (ppm CO2-eq)	Global Mean temp. increase at equilibrium (ºC)	Year CO2 needs to peak	Reduction in 2050 compared to 200
445 – 490	2.0 – 2.4	2000 - 2015	-85 to -50
490 – 535	2.4 – 2.8	2000 - 2020	-60 to -30
535 – 590	2.8 – 3.2	2010 - 2030	-30 to +5
590 – 710	3.2 – 4.0	2020 - 2060	+10 to +60
710 – 855	4.0 – 4.9	2050 - 2080	+25 to +85
855 – 1130	4.9 – 6.1	2060 - 2090	+90 to +140

Stabilisation levels and equilibrium global mean temperatures

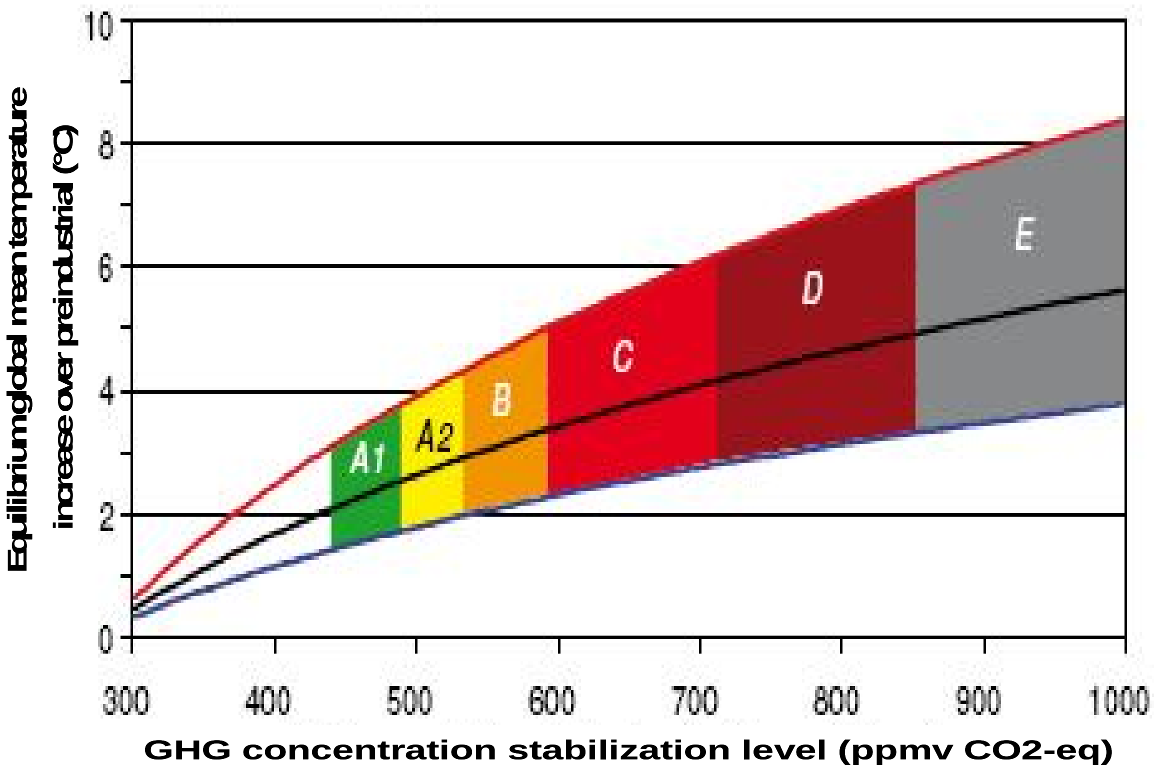


***Figure SPM 8**: Stabilization scenario categories as reported in Figure SPM.7 (coloured bands) and their relationship to equilibrium global mean temperature change above pre-industrial, using (i) "best estimate" climate sensitivity of 3 ℃ (black line in middle of shaded area), (ii) upper bound of likely range of climate sensitivity of 4.5 ℃ (red line at top of shaded area) (iii) lower bound of likely range of climate sensitivity of 2 ℃ (blue line at bottom of shaded area). Coloured shading shows the concentration bands for stabilization of greenhouse gases in the atmosphere corresponding to the stabilization scenario categories. The data are drawn from AR4 WGI, Chapter 10.8.*

Policies are available to to governments to realise mitigation of climate change

- Effectiveness of policies depends on national circumstances, their design, interaction, stringency and implementation
  - Integrating climate policies in broader development policies
  - Regulations and standards
  - Taxes and charges
  - Tradable permits
  - Financial incentives
  - Voluntary agreements
  - Information instruments
  - Research and development

Selected sectoral policies, measures and instruments that have shown to be environmentally effective

Sector	Policies[1], measures and instruments shown to be environmentally effective	Key constraints or opportunities
Energy supply	Reduction of fossil fuel subsidies	Resistance by vested interests may make them difficult to implement
	Taxes or carbon charges on fossil fuels	
	Feed-in tariffs for renewable energy technologies	May be appropriate to create markets for low emissions technologies
	Renewable energy obligations	
	Producer subsidies	

[1] Public RD&D investment in low emission technologies have proven to be effective in all sectors.

Selected sectoral policies, measures and instruments that have shown to be environmentally effective

Sector	Policies[1], measures and instruments shown to be environmentally effective	Key constraints or opportunities
Transport	Mandatory fuel economy, biofuel blending and CO_2 standards for road transport	Partial coverage of vehicle fleet may limit effectiveness
	Taxes on vehicle purchase, registration, use and motor fuels, road and parking pricing	Effectiveness may drop with higher incomes
	Influence mobility needs through land use regulations, and infrastructure planning	Particularly appropriate for countries that are building up their transportation systems
	Investment in attractive public transport facilities and non-motorised forms of transport	

[1] Public RD&D investment in low emission technologies have proven to be effective in all sectors.

The importance of a “price of carbon”

- Policies that provide a real or implicit price of carbon could create incentives for producers and consumers to significantly invest in low-GHG products, technologies and processes.

- Such policies could include economic instruments, government funding and regulation

- For stabilisation at around 550 ppm CO2eq carbon prices should reach 20-80 US$/tCO2eq by 2030 (5-65 if “induced technological change” happens)

- At these carbon prices large shifts of investments into low carbon technologies can be expected

International agreements

- Notable achievements of the UNFCCC/Kyoto Protocol that may provide the foundation for future mitigation efforts:
  - global response to the climate problem,
  - stimulation of an array of national policies,
  - the creation of an international carbon market and
  - new institutional mechanisms
- Future agreements:
  - Greater cooperative efforts to reduce emissions will help to reduce global costs for achieving a given level of mitigation, or will improve environmental effectiveness
  - Improving, and expanding the scope of, market mechanisms (such as emission trading, Joint Implementation and CDM) could reduce overall mitigation costs

I am convinced RE could have imagined a much more effective procedure

Could RE apply its skills to climate protection?

⌘…It would be most welcome

Conclusion

- Climate is changing due to our activities
- ...and fast
- Mitigation is essential to prevent the avoidable
- Adaptation is essential to cope with the unavoidable
- The more integrated mitigation and adaptation are in all policies, the more efficient and cheap they will be
- As for bath towels and water savings, RE can help!

John Holdren, President of the American Association for the Advancement of Science

- ***'We basically have three choices – mitigation, adaptation, and suffering.***
- ***We're going to do some of each. The question is what the mix is going to be.***
- ***The more mitigation we do, the less adaptation will be required, and the less suffering there will be.'***

Useful links:

- www.ipcc.ch : IPCC
- www.unfccc.int : Climate Convention
- www.climate.be/JCM: interactive climate model