Climate Change: The Factor Forty Problem

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Climate Change: a future source of conflict

www.international-alert.org

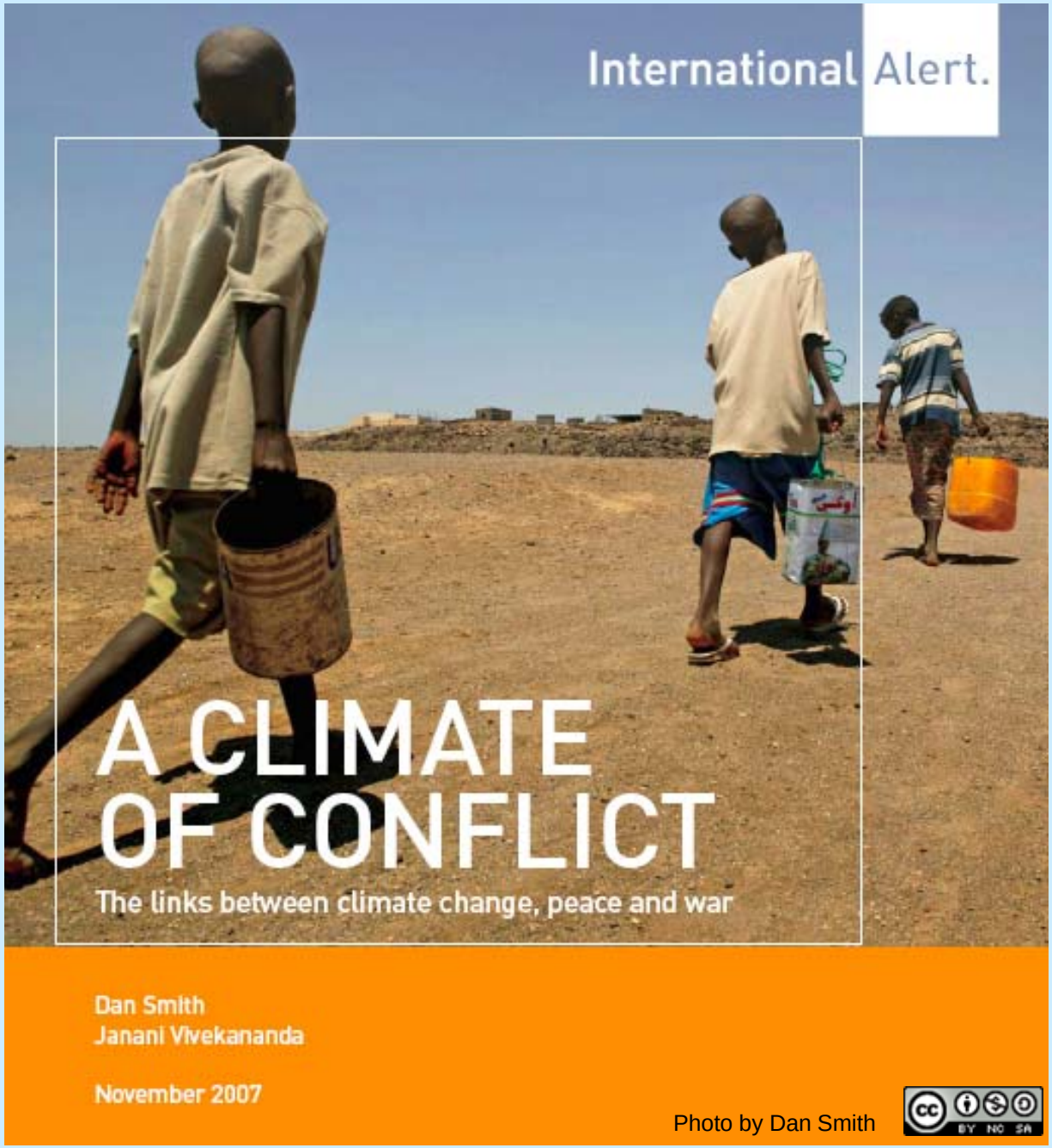
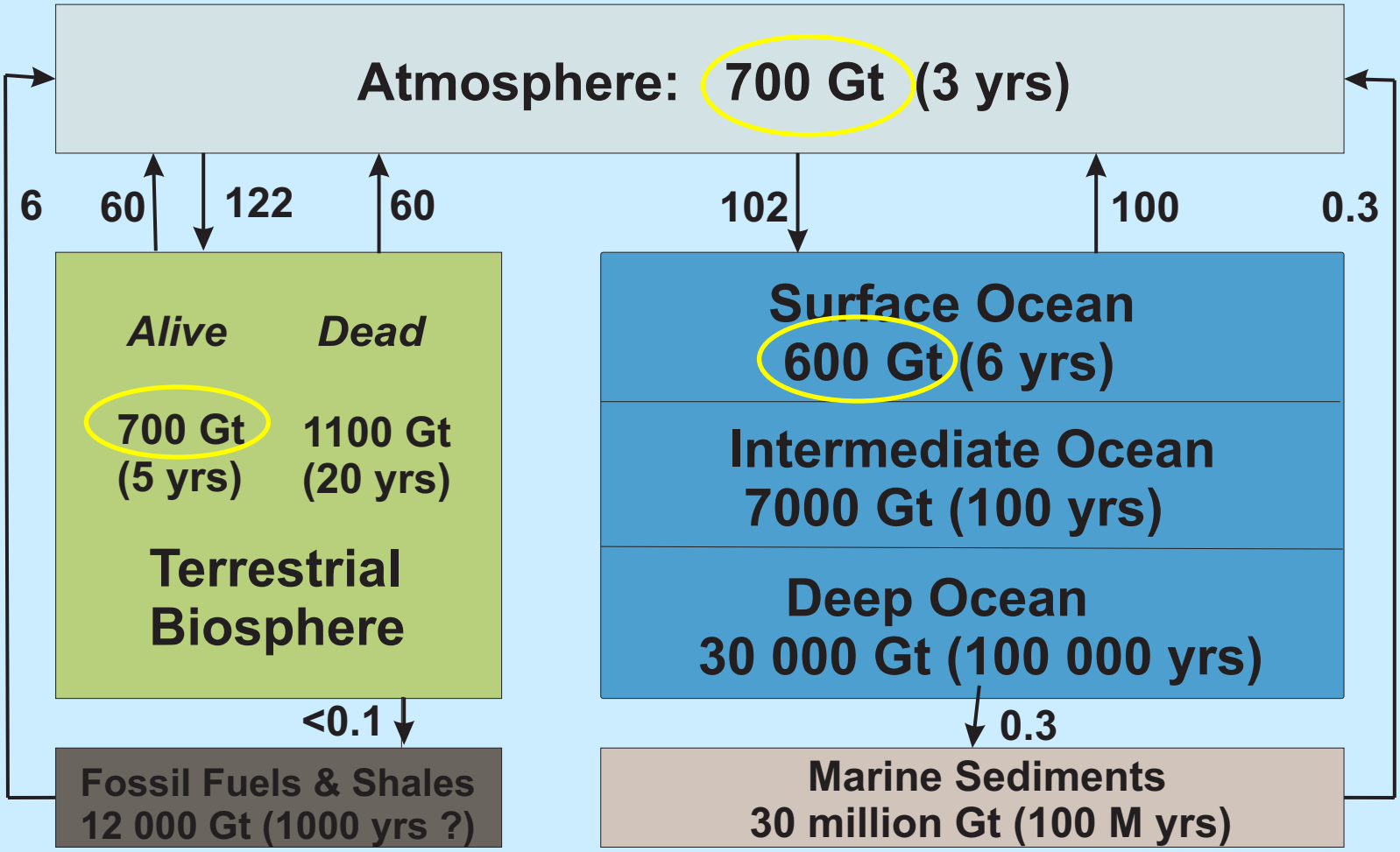


Photo by Dan Smith

Overview

- **Basic Climate Science**
  - Energy Balance and the Greenhouse Effect
- **Natural variability & past rapid climate change**
  - some surprises in store ??
- **Prospects for Climate Change**
  - The IPCC Fourth Assessment: to 2100, and beyond...
  - a global and longer term perspective
  - the next 1000 years
- **Dealing with climate change: what can we do about it ?**
  - the **size** of the problem
  - some possible **responses**...

The Carbon Cycle



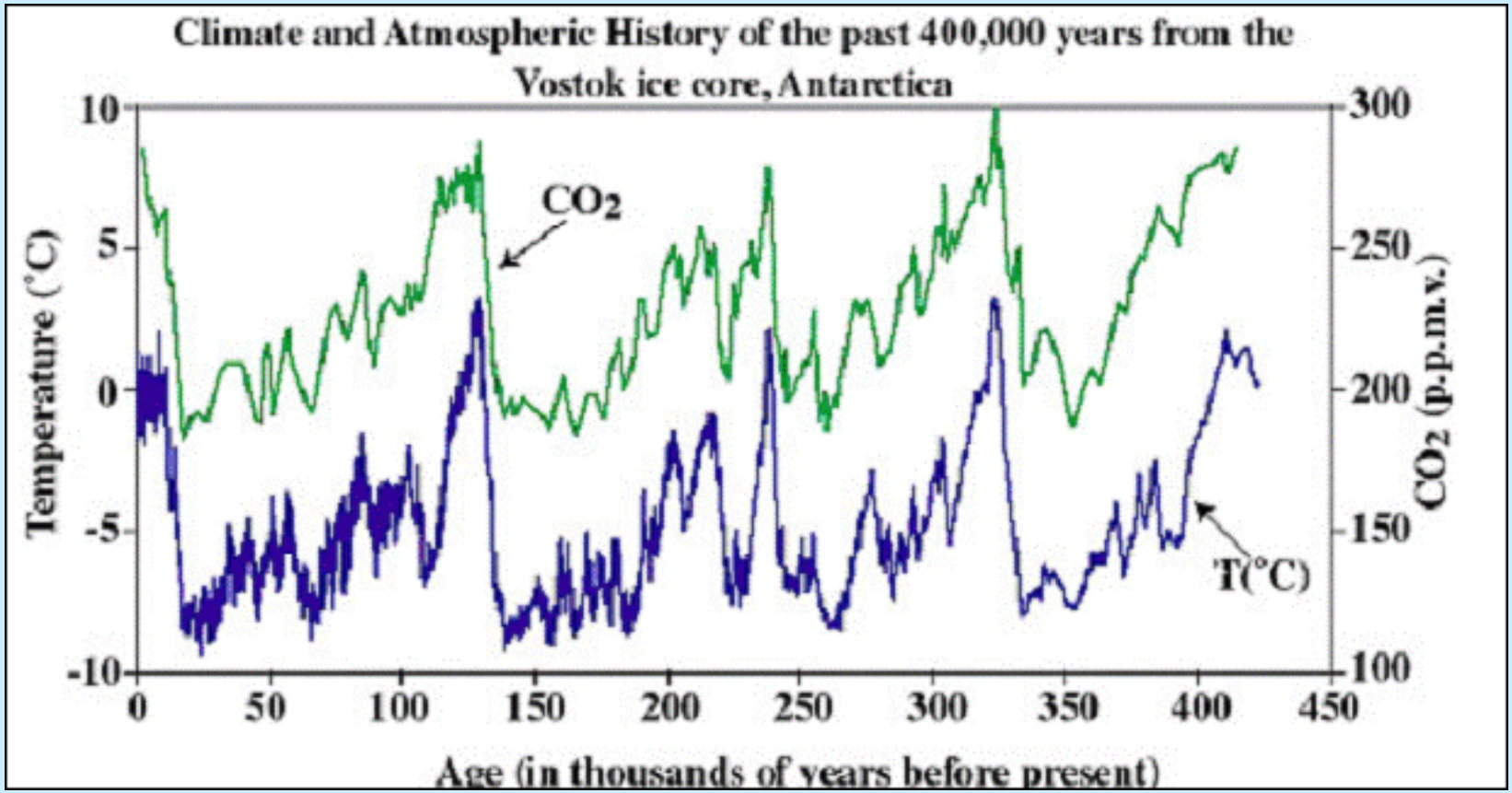
Basic Climate Science (2)

- **The Earth System and the carbon cycle**
  - The atmosphere and the living terrestrial biosphere (land plants) contain comparable amounts of CO_2
  - There is quite a bit more in soils (dead plants)
  - Most of the available CO_2 is in the ocean (as sodium bicarbonate)
  - The ocean is dominant in the long term…
  - and the ocean is the ultimate sink for CO_2

- **Positive feedbacks**
  - Water vapour feedback
  - Ice/albedo feedback
  - These just ***amplify*** responses to changes
    - They ***enhance climate sensitivity***
    - They do not necessarily lead to ***runaway*** responses…

Climate in the past

- ***"Those who are ignorant of the past are condemned to misunderstand the future"***
  - *With apologies to G Santayana*
- Climate been somewhat stable (within limits) for most of the history of the Earth (>4500 Myr)…
  - especially stable since the last ice age
  - i.e. for the past 10 000 years (the Holocene)
- but sometimes also highly (and rapidly) variable
  - e.g. deglaciations (the terminations of ice ages)
- Evidence from the past suggests that climate change is unlikely to be gradual & steady…



http://www.appinsys.com/GlobalWarming/GW_Part5_GreenhouseGas.htm

Natural Variability of Climate

- **A Source of Comfort ?**
  - Climate has changed a lot naturally, so present changes must be natural too (???)
- **A Reason for Complacency ??**
  - Climate has changed a lot naturally, so nothing we can do will make much difference (???)
- **Not so…**
  - The climate system is ***very sensitive***
  - to ***very small*** changes of forcing
  - via mechanisms which as yet ***we do not fully understand***
- **Present day climate models**
  - Are based on our ***current understanding***
  - They may ***not yet be sufficiently sensitive…***
- **Future changes may be *even greater* than we think**

Climate in the Recent Past & the Future

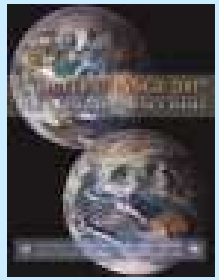
The assessments of the IPCC, and beyond…

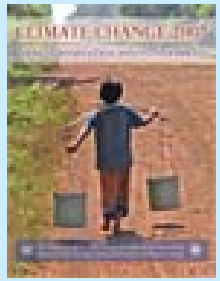
- **The last 100 years**

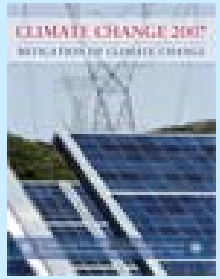
- **The next 100 years**
  - The **Fourth Assessment of the IPCC, 2007**
    - (UN: Intergovernmental Panel on Climate Change)

  - **WG 1 : The Physical Science Basis**
  - **WG 2 : Impacts, Adaptation and Vulnerability**
  - **WG 3 : Mitigation of Climate Change**
  - **The Synthesis Report** (November 2007)
    - All have **Summaries for Policymakers**
    - Downloadable from www.ipcc.ch

- **to 2100 and beyond: the next millennium…**

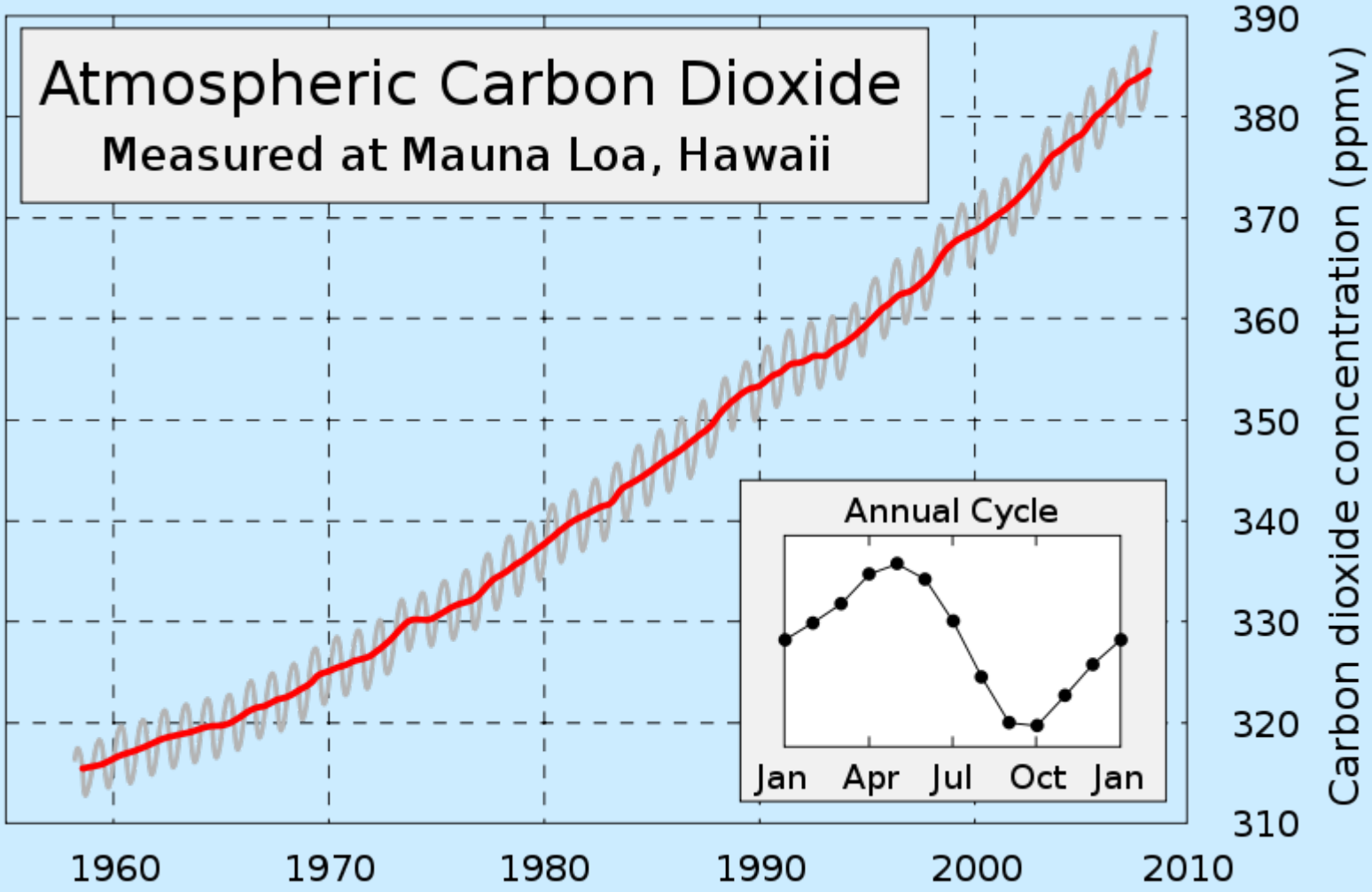






Cover images from IPCC

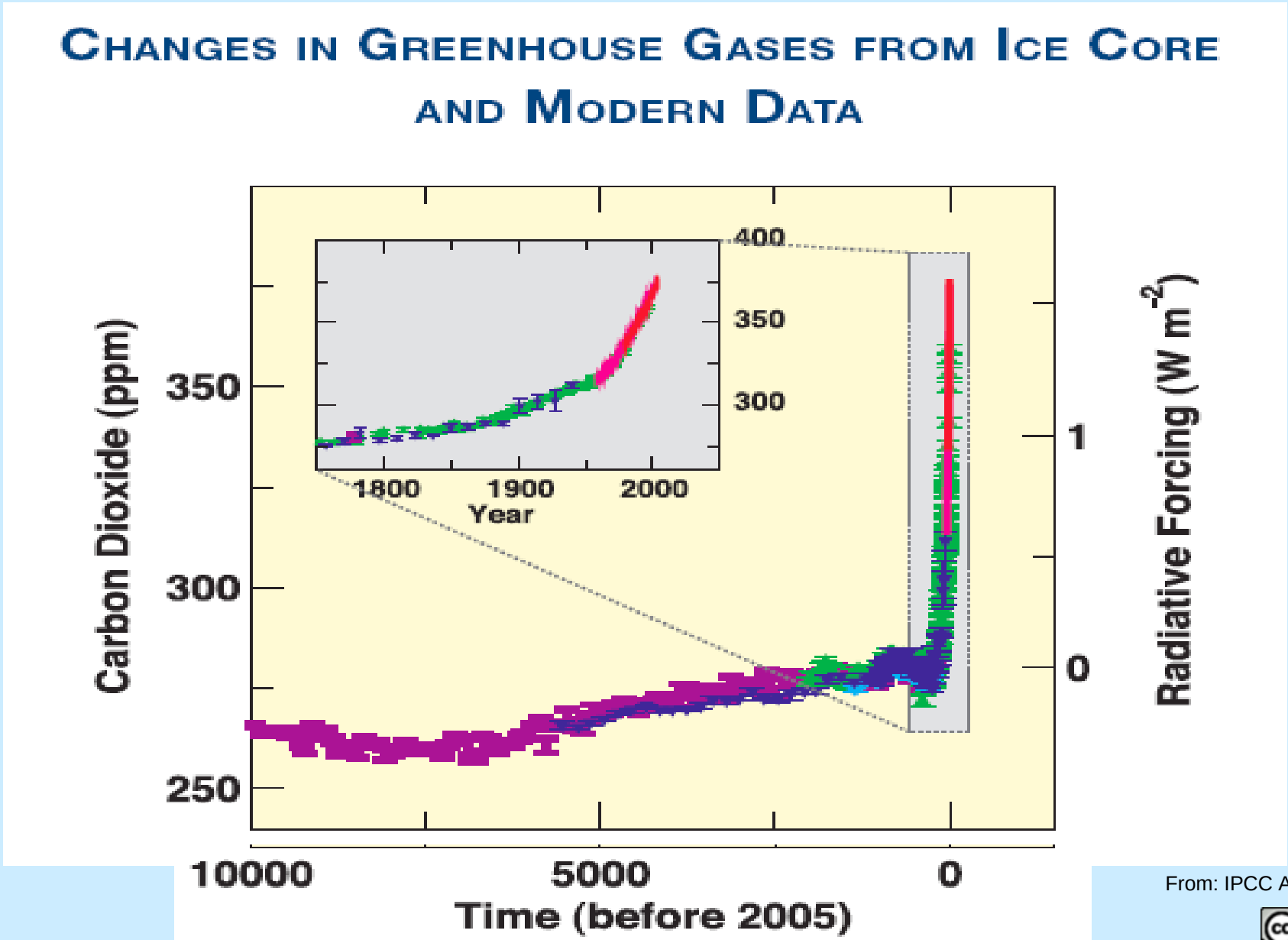
The Keeling Curve



Courtesy: Robert A. Rohde from NOAA published data

Past Changes of Atmospheric CO_2

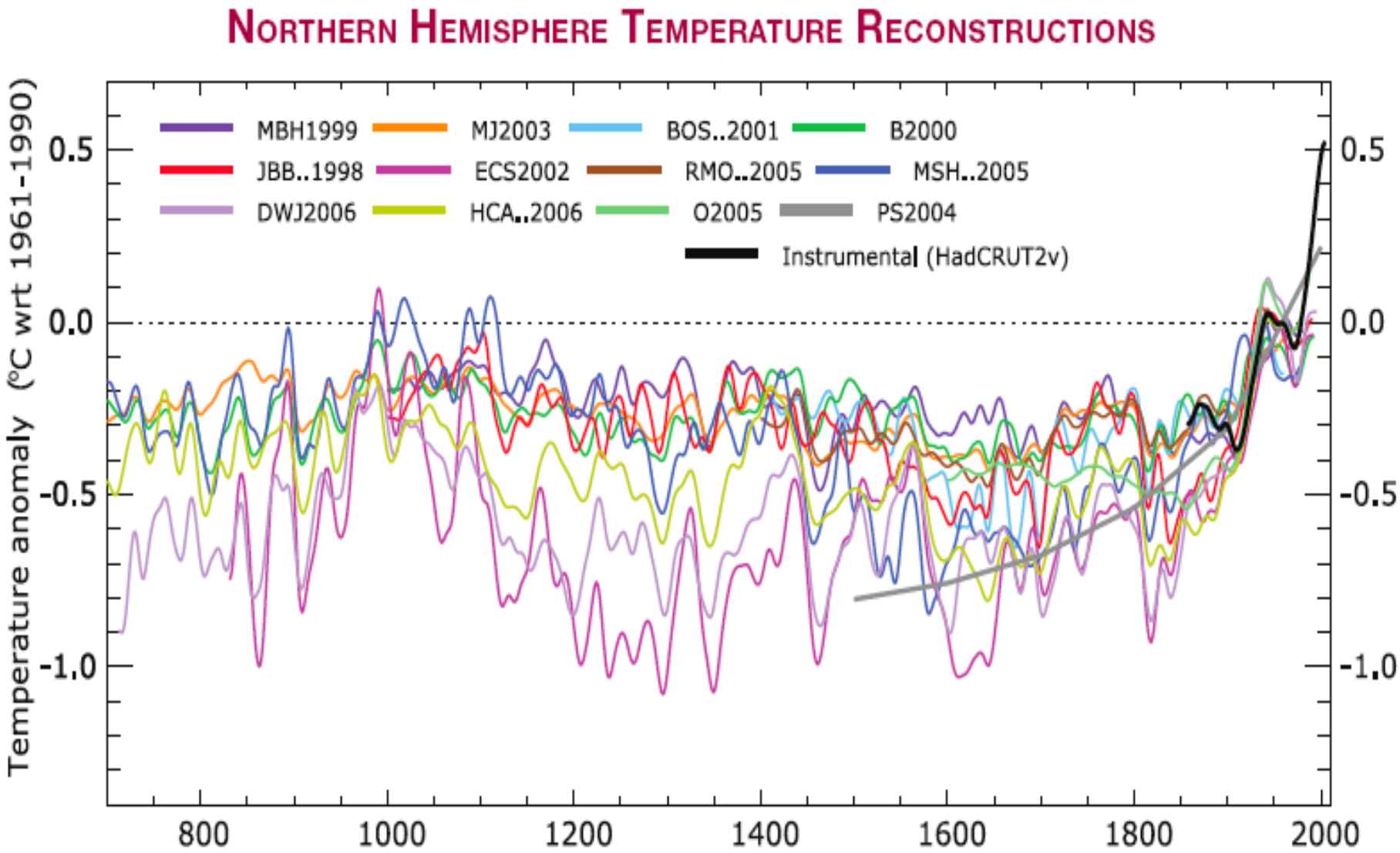
(IPCC AR4 WG1)



From: IPCC AR4 WG1

Past Changes of NH Mean Temperature

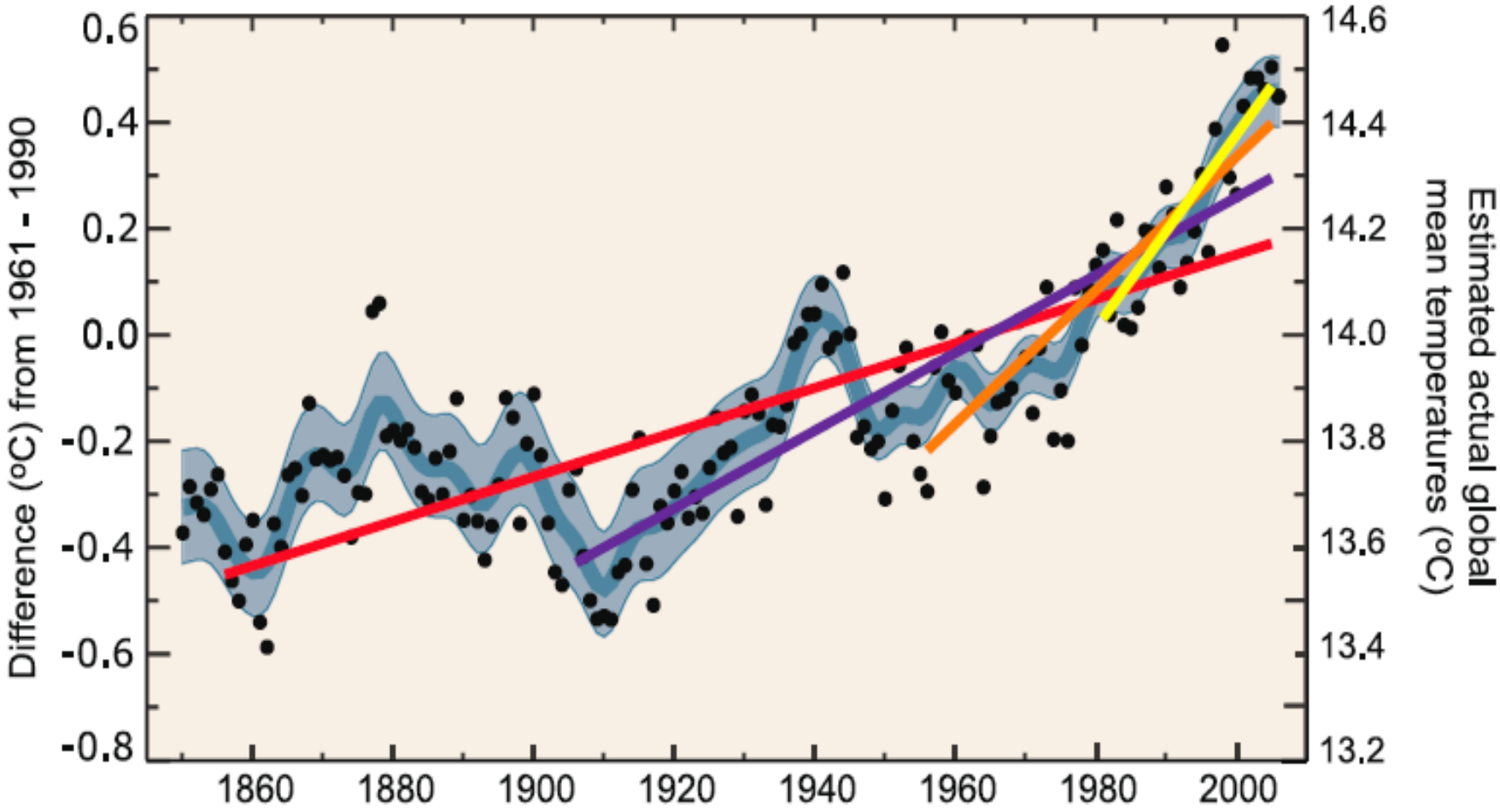
(IPCC AR4 WG1)



From: IPCC AR4 WG1

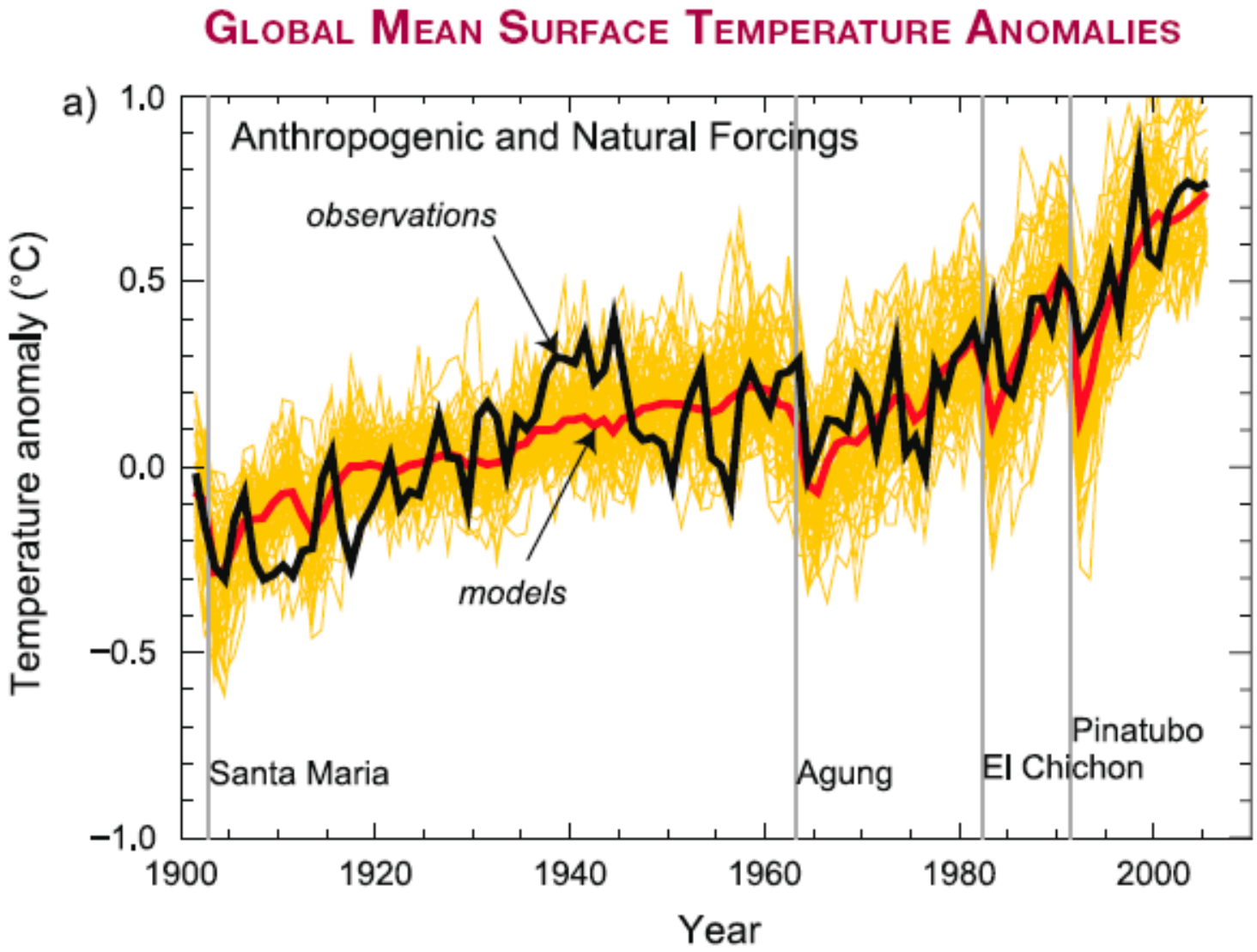
Recent Changes of Global Mean Temperature

(IPCC AR4 WG1)



From: IPCC AR4 WG1

How good are the models ?



From: IPCC AR4 WG1

Climate Facts

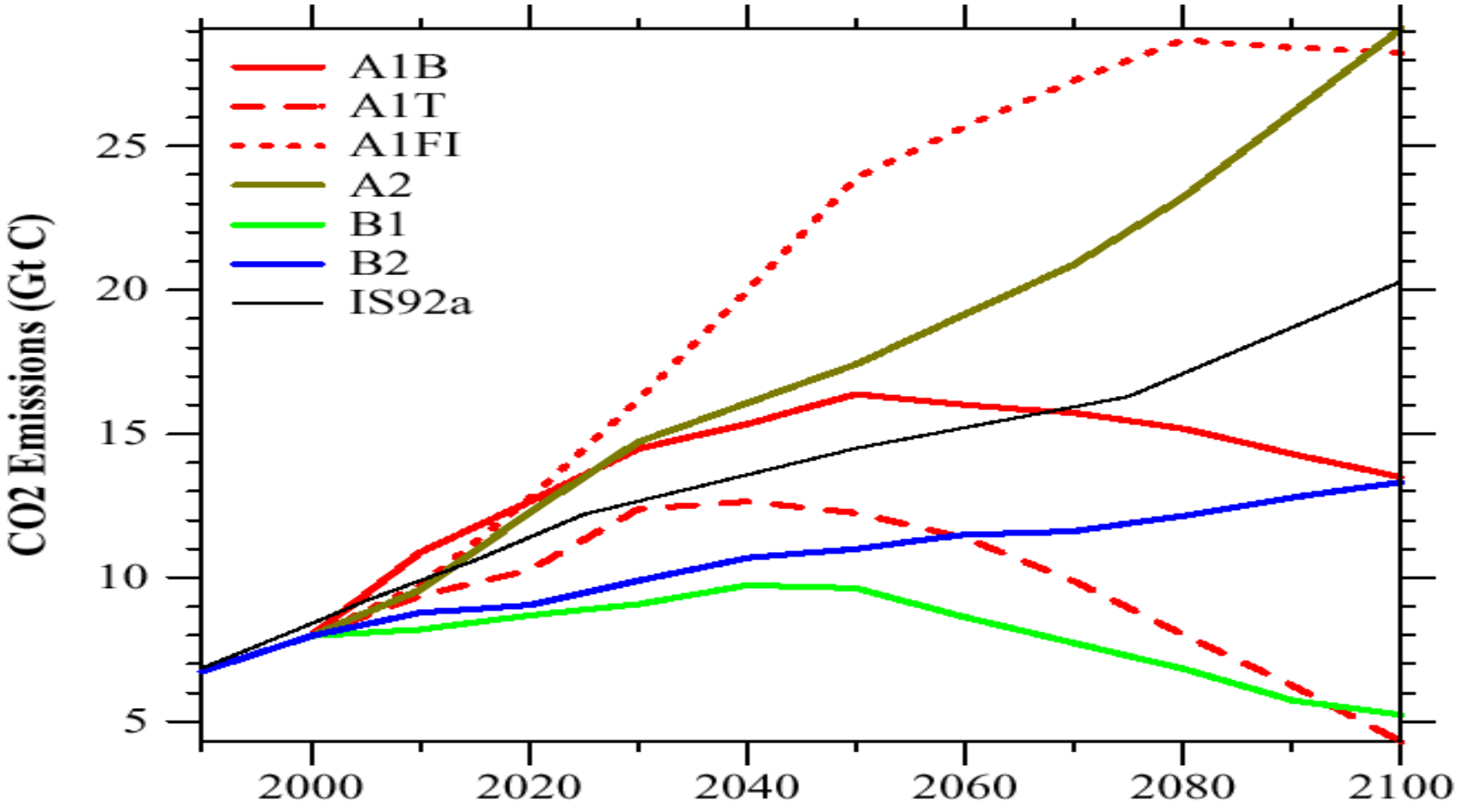
- It is ***effectively certain*** (i.e. beyond reasonable doubt) that…
- the ***combustion of fossil fuels*** is the largest single cause of emissions of carbon dioxide (CO_2).
- ***atmospheric CO_2 concentrations are increasing***, and have done so since the beginning of the industrial revolution.
- ***anthropogenic CO_2 emissions (and deforestation) are sufficient*** to account for the observed change in atmospheric CO_2.
- ***CO_2 is a radiatively active gas*** that absorbs infra-red radiation.
- ***increases in absorption*** of infra-red in the atmosphere ***contribute to global warming*** (i.e. increase the greenhouse effect).
- ***global warming is occurring*** at rates that are unprecedented in human history (and beyond…).
- the ***rate of warming*** observed is ***quantitatively consistent*** with the ***observed changes in greenhouse gas concentrations*** (and well founded estimates of the greenhouse effect).
- ***What more could one reasonably ask for ?***

Real **Climate Controversies**

are mostly about ***uncertainties*** concerning…

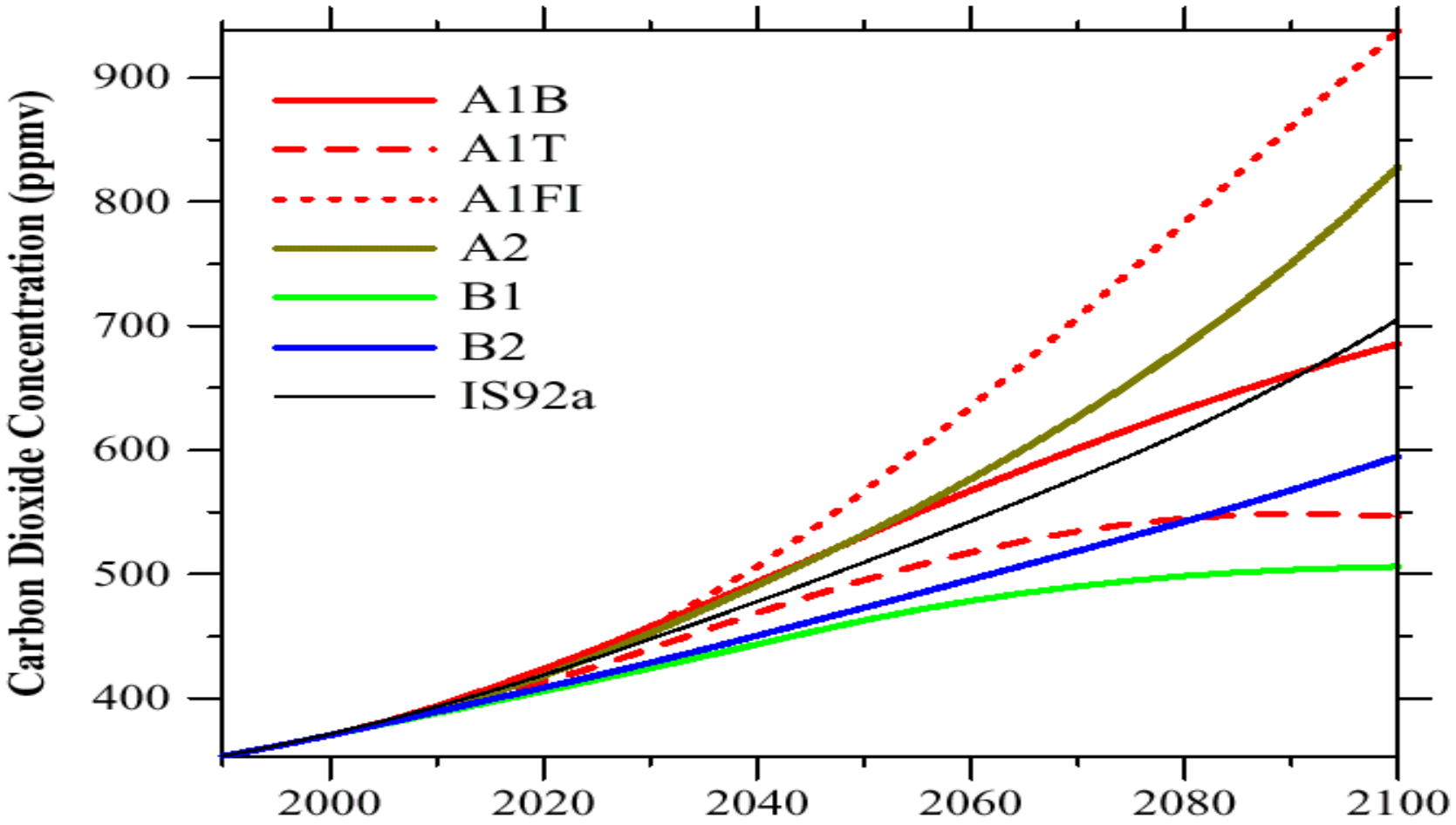
- the ***mechanisms and magnitudes of feedbacks*** between greenhouse gas concentrations and radiative forcing
  - for example, through changes in ***cloud formation***
  - and ***carbon cycle feedbacks*** (marine & terrestrial)
- the precise magnitude of natural effects
  - (for example, ***solar variations***)
- the ***precise extent*** to which observed climate change is natural or anthropogenic
- the possible/probable ***rates of melting of ice sheets***
  - and the consequent ***rates of sea-level rise***
- However, the ***existence and primary causes*** of anthropogenic climate change are not seriously questioned
  - except by a very small but extremely vocal minority
- ***For reliable information***: go to www.realclimate.org

CO_2 emissions under various scenarios



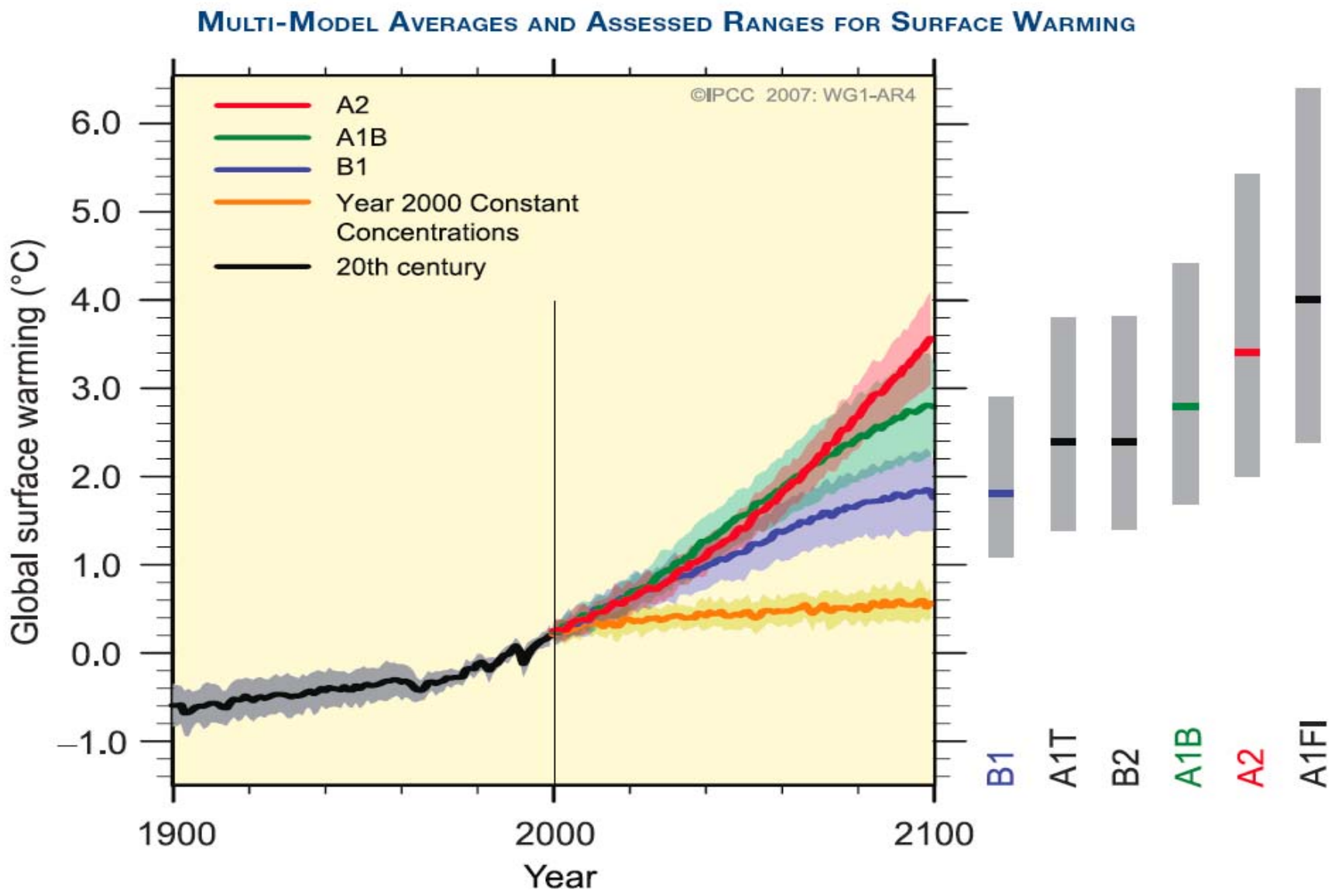
From: IPCC AR4 WG1

CO_2 concentrations under various scenarios



From: IPCC AR4 WG1

IPCC AR4 Temperature Projections



From: IPCC AR4 WG1

Comparison of IPCC 2001 projections with recent data

Are they alarmist?

No: if anything they are too **conservative**

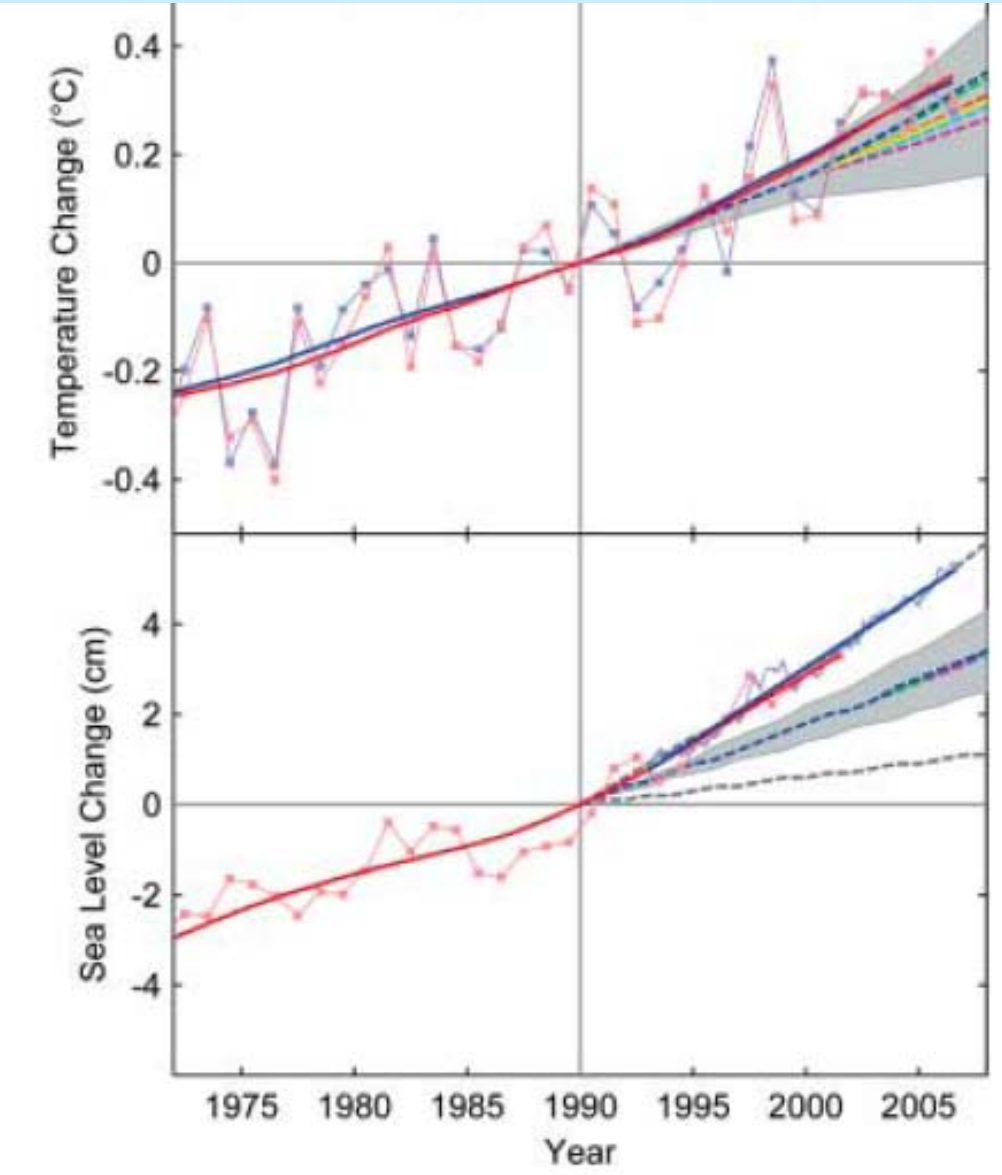
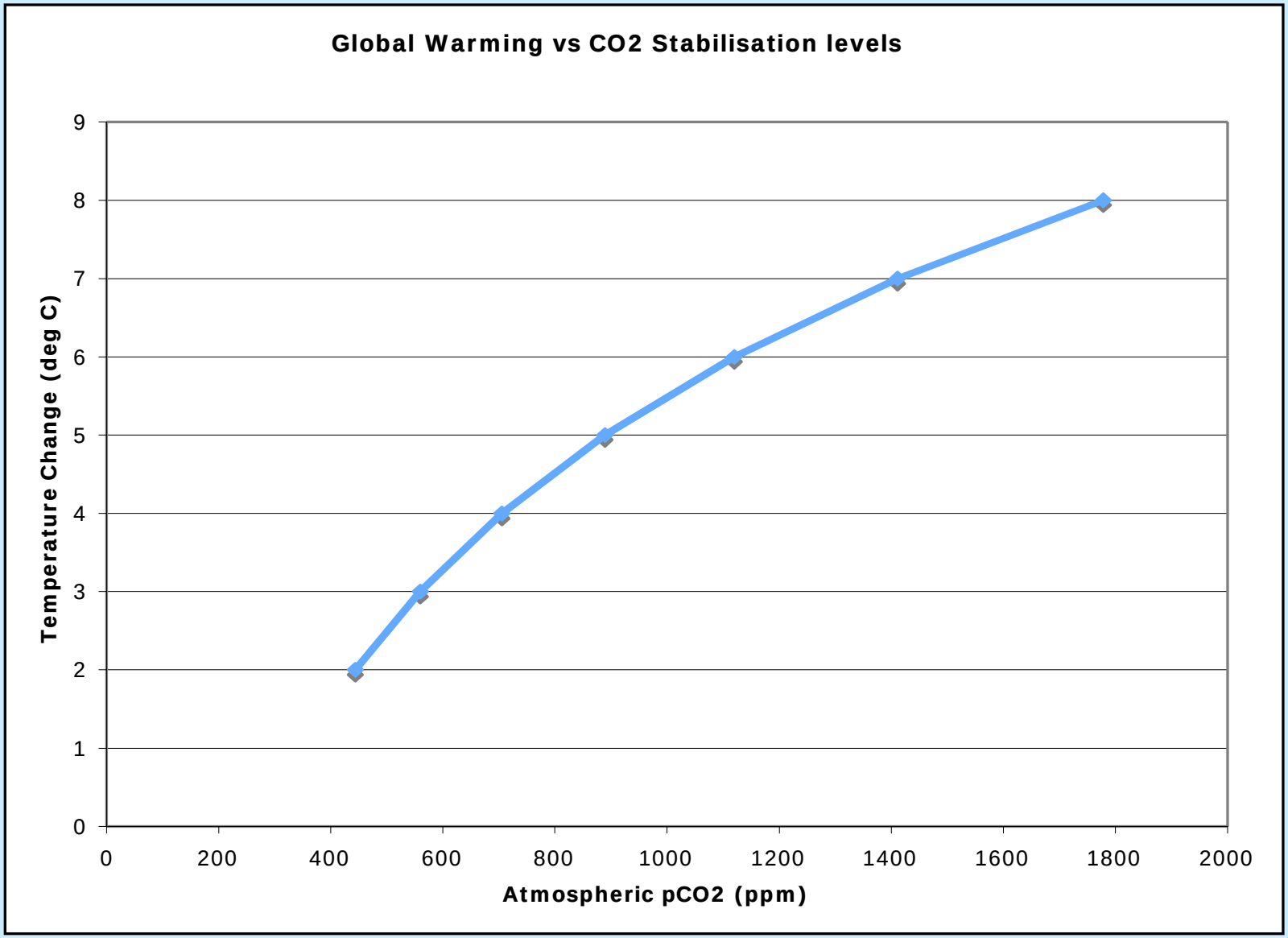
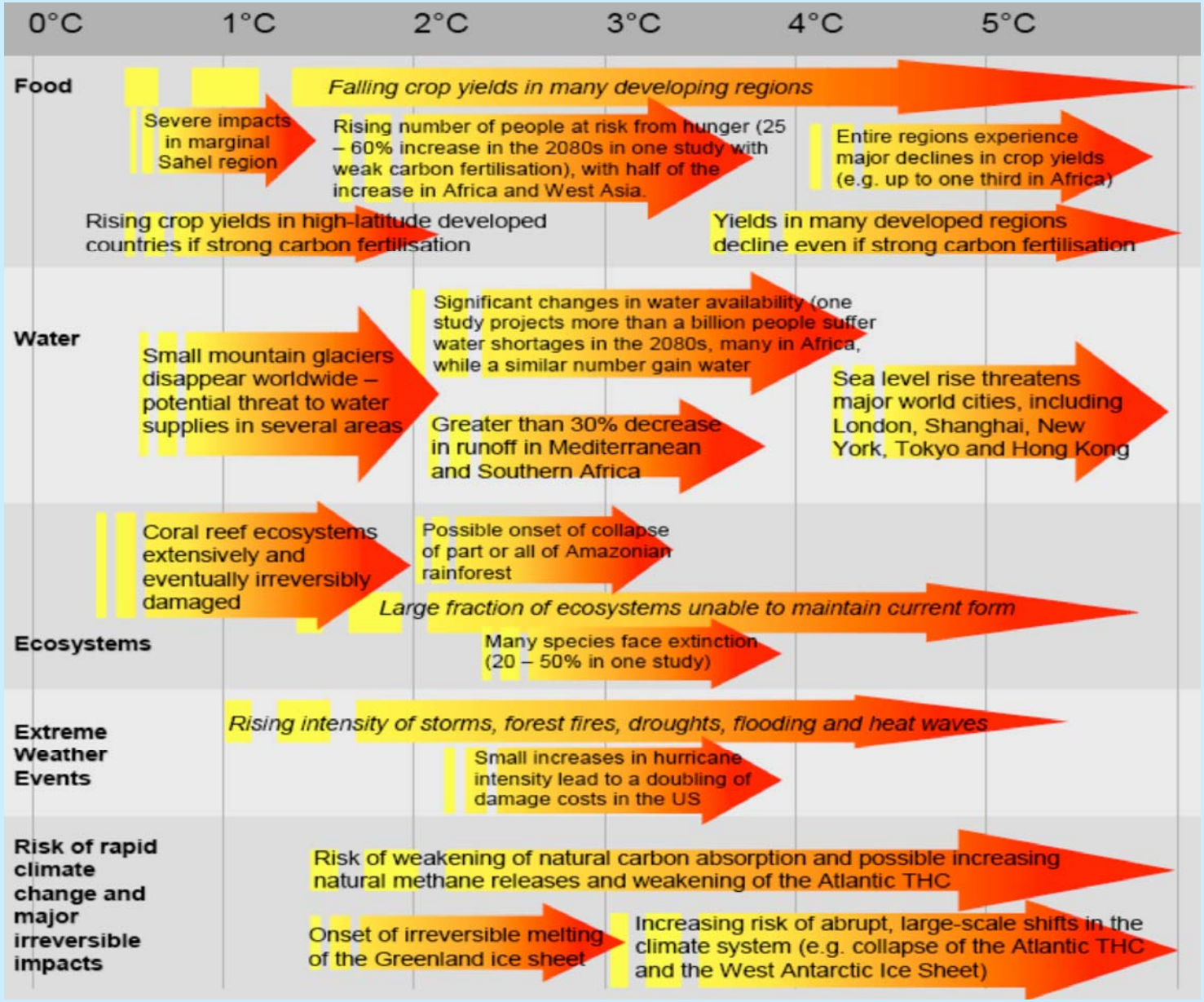


Fig. 1. Changes in key global climate parameters since 1973, compared with the scenarios of the IPCC (shown as dashed lines and gray ranges). (**Top**)

Temperature Change for Various Stabilisation Levels

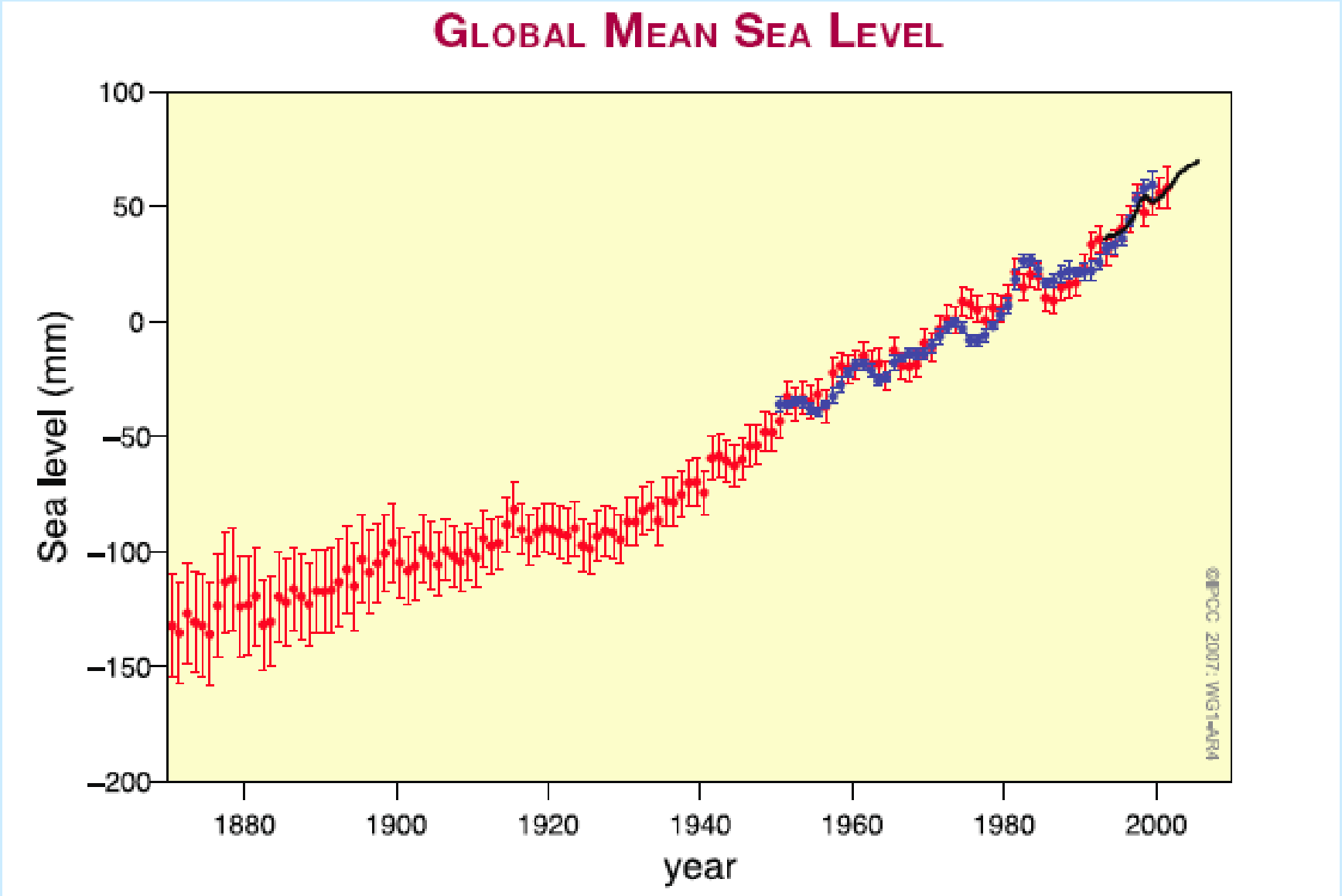


Impacts of Global Warming (Stern Review fig 13.4)



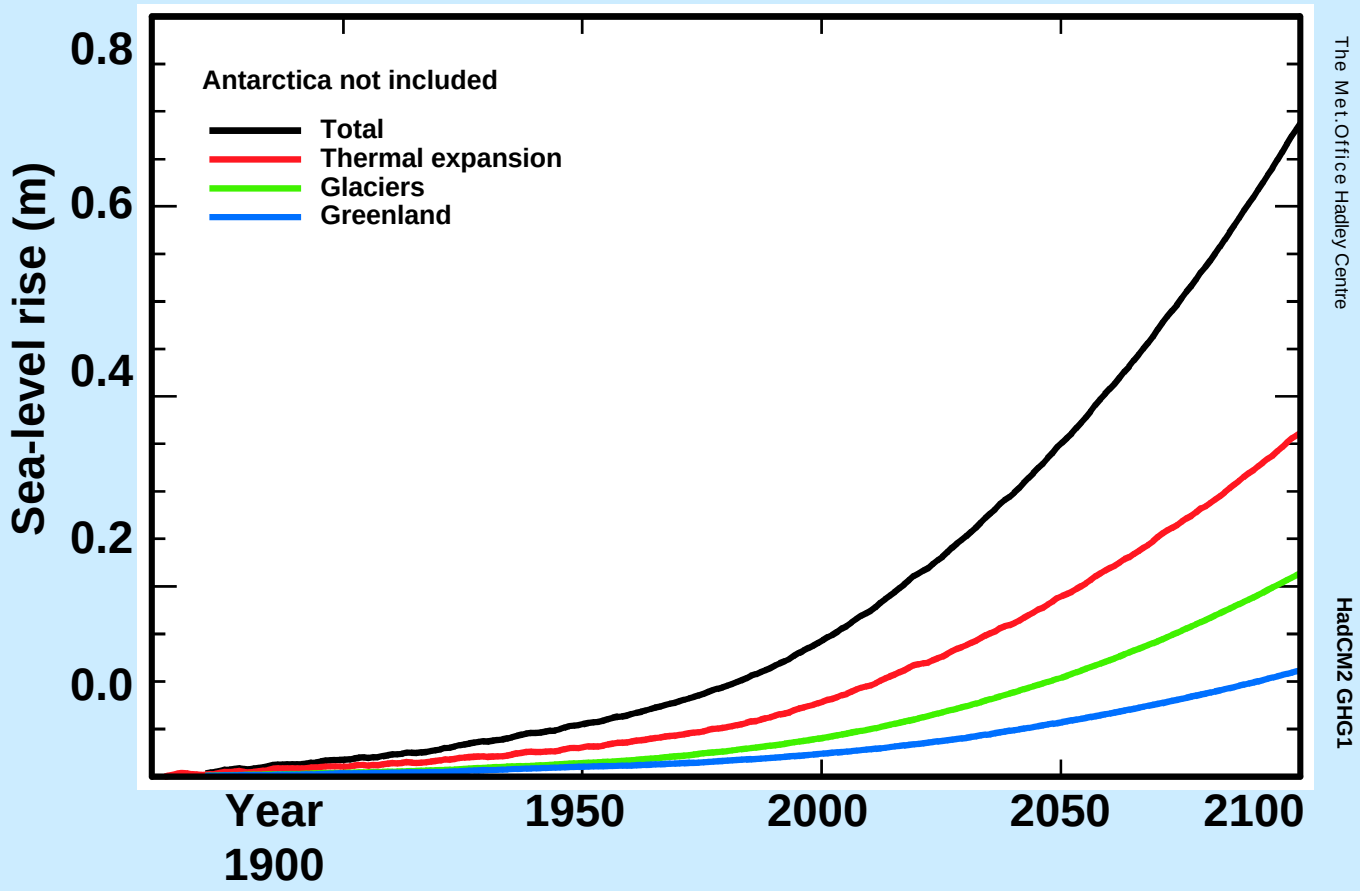
Recent Changes of Sea Level

(IPCC AR4 WG1)



From: IPCC AR4 WG1

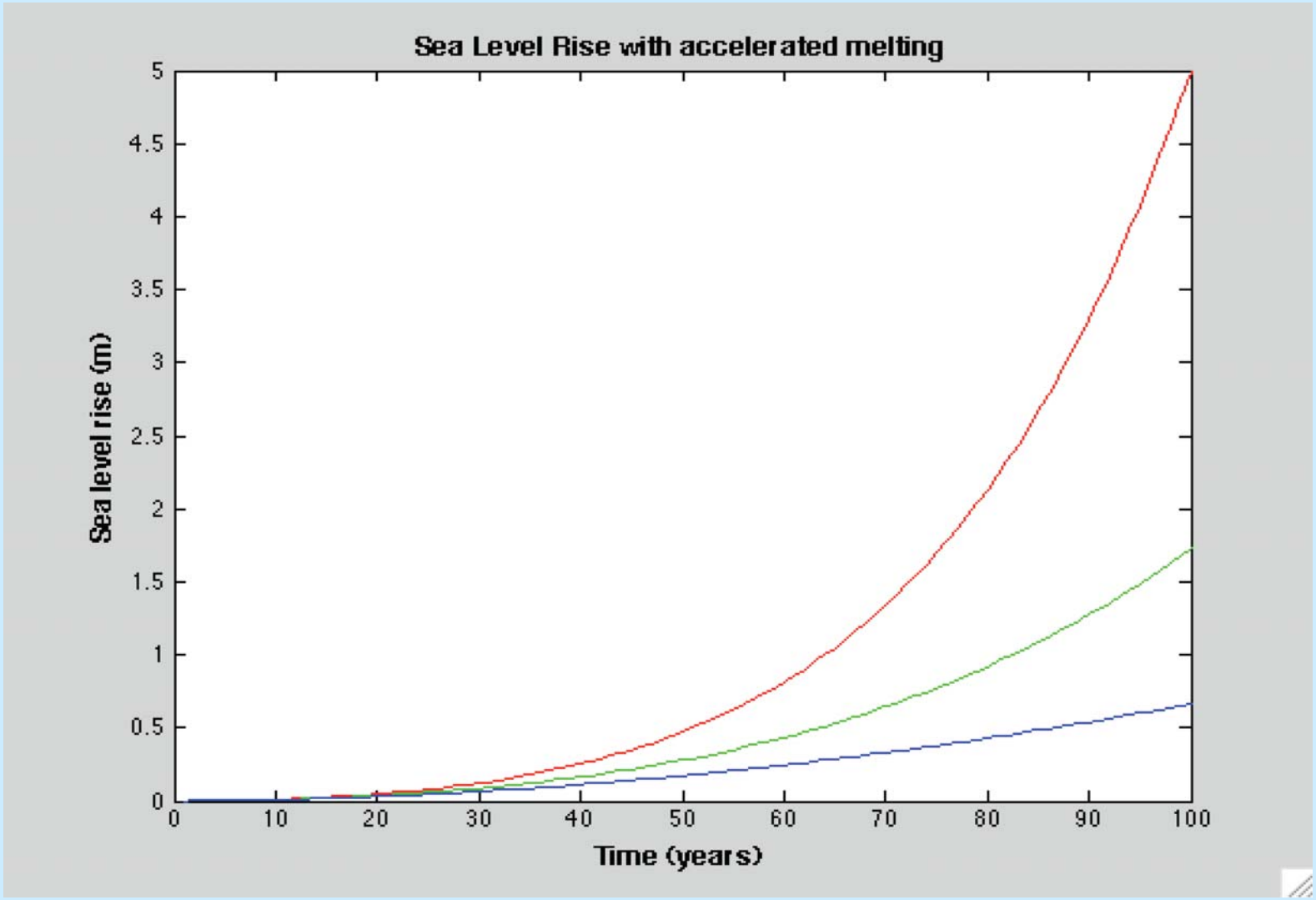
SEA LEVEL RISE and its components
(from the IPCC *Third* Assessment Report)



From: IPCC 3rd Assessment

Sea-level rise: how much by 2100 ?

Several meters may not be impossible…
(i.e. Jim Hansen may be right)



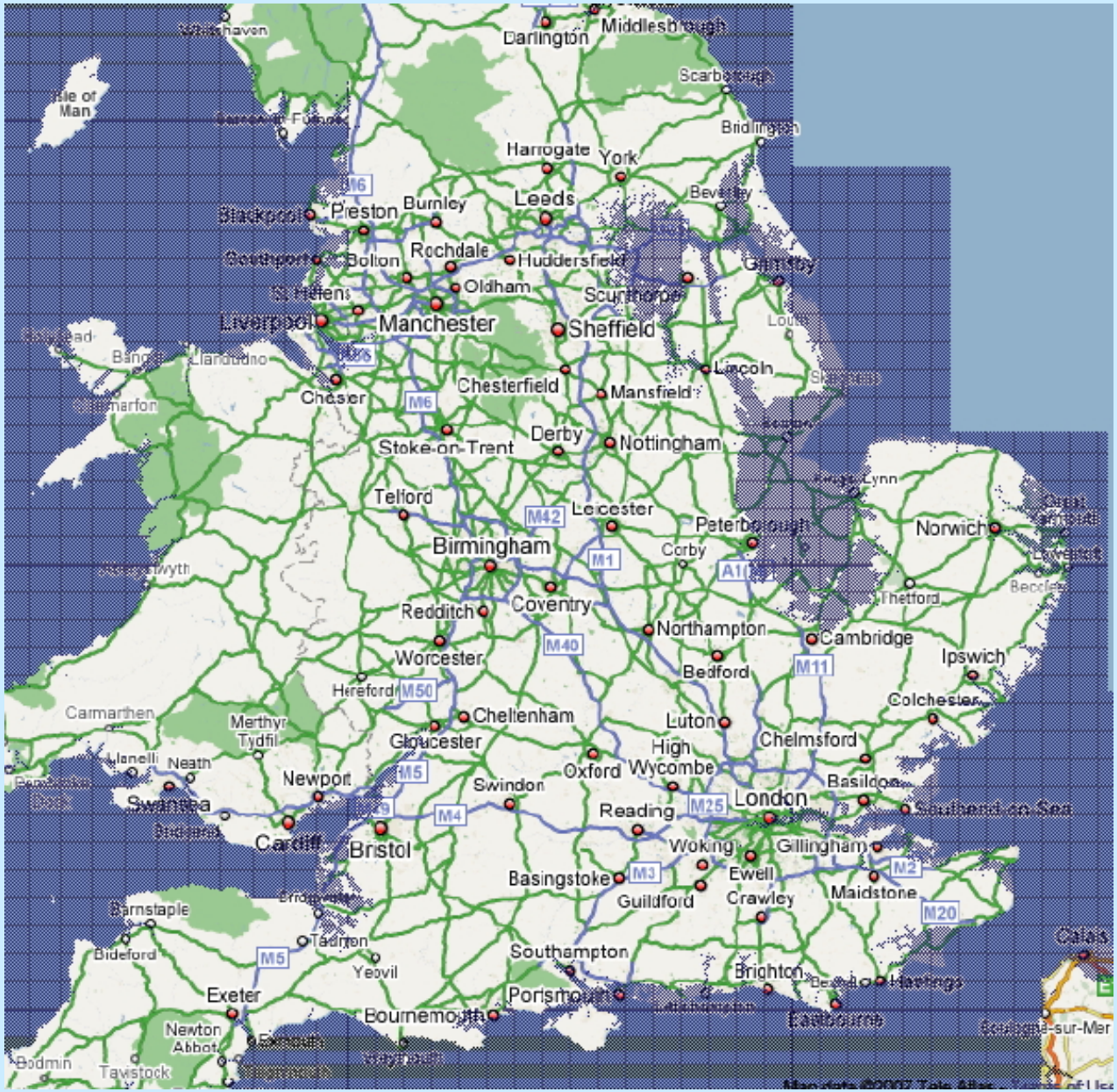
What happened the last time the world was warmer than today ?

- **The last interglacial: the Eemian**
  - Around 110 000 years ago
- The world was about 2 °C warmer than today
- Greenland was 3 to 5 °C warmer
  - With **much** less ice in the ice-sheet
- Sea level was **4 to 6 m above present**
- Up to half of this was due to Greenland melt
  - (but Antarctica may also be involved…)
- Rate of rise above present was **1 to 2 cm y^{-1}**
  - i.e., 2 to 3 times the max IPCC rate….

Modelled ‘best estimate’ Eemian Greenland ice sheet extent

Redrawn based on the model by: Marshall, S.J, Cuffet, K.M., (2000) Paregінations of the greenland ice sheet divide in the last glacial cycle: Implications for central Greenland ice cores. Marshall, S.J, Cuffet, K.M., ESPL, v.179, no. 1, p. 73-90.

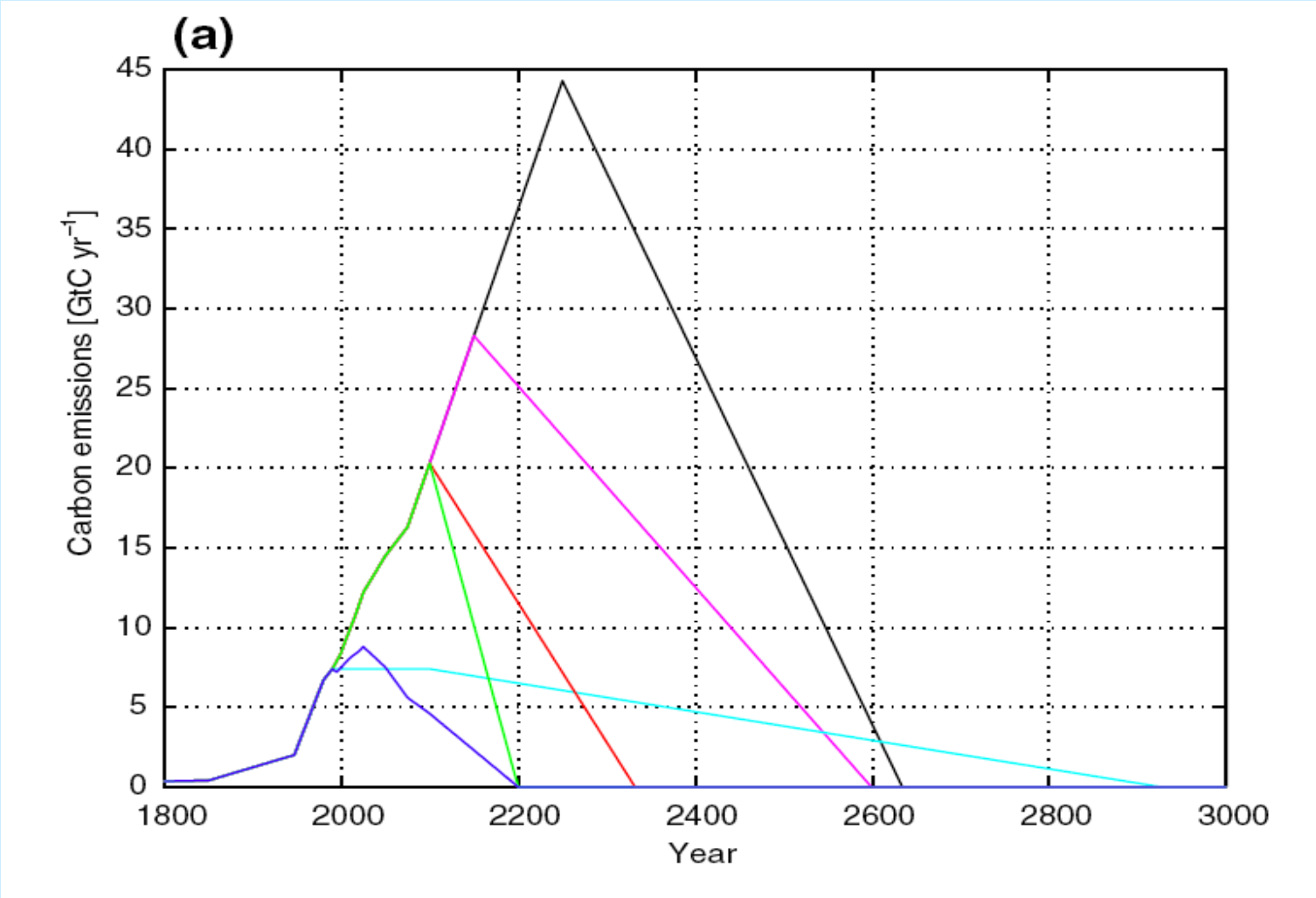
U.K: Sea level rise of 7m (from flood.firetree.net)



Global Warming : the IPCC & beyond

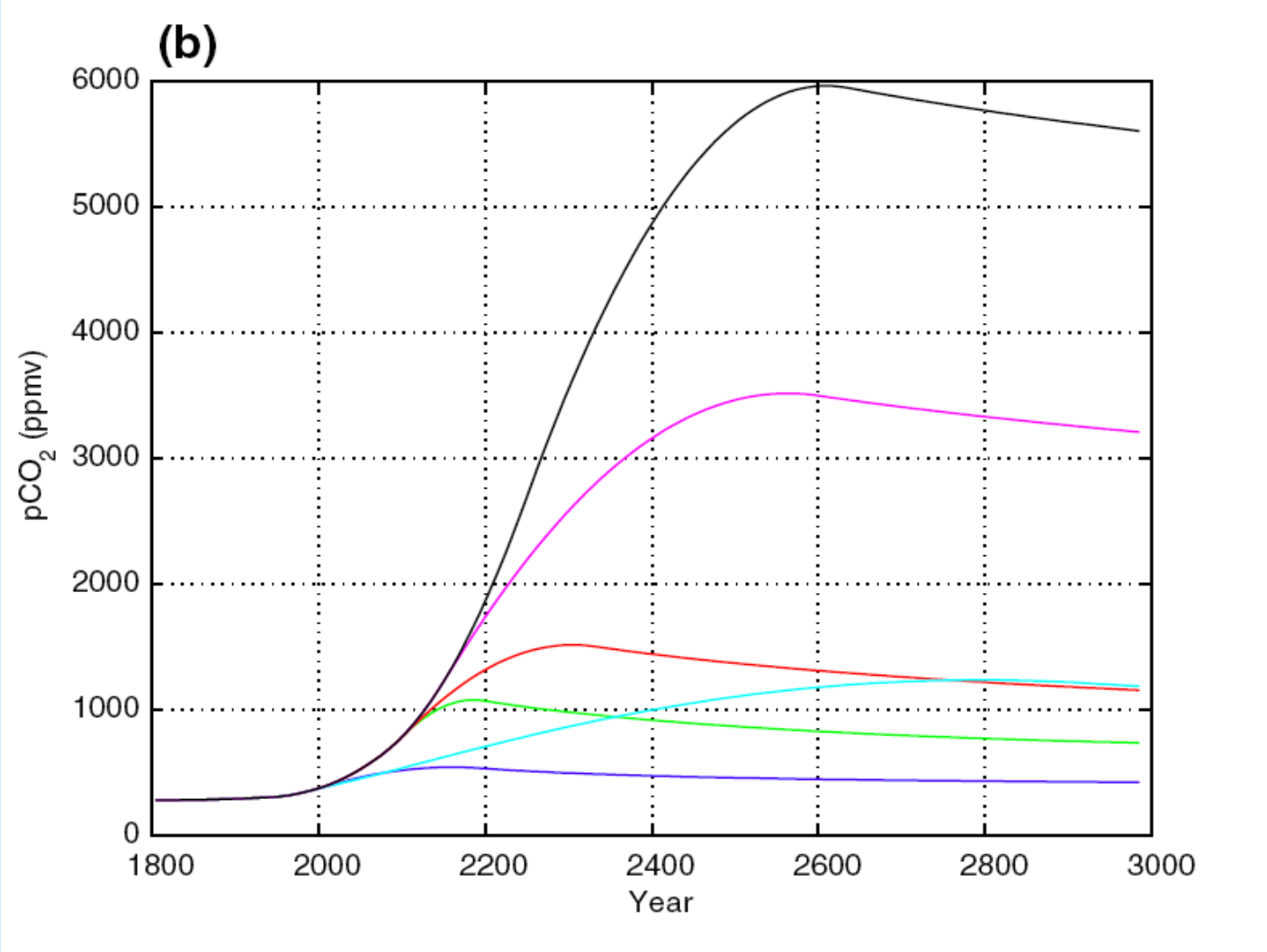
- **The IPCC fourth assessment report (AR4) states that**
  - **“Warming of the climate system is unequivocal”**
  - “The total temperature increase from 1850–1899 to 2001–2005 is **0.76°C**…”
  - There is now “very high confidence that the global average net **effect of human activities since 1750 has been one of warming**, with a radiative forcing of +1.6 [+0.6 to +2.4] W m–2”
  - **“Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.”**
  - **Under the A1FI scenario**, **global mean temperatures are likely to rise by about 4 °C** [2.4 to 6.4 °C] by 2100...
- but **temperatures will continue to rise for a long time after 2100…**
  - so we need **multi-millennial projections** of climate change
  - need to use an Intermediate Complexity climate model
  - Results from **Genie** project (Lenton et al., Climate Dynamics 2006)

Carbon Emissions



From preprints of: Millennial timescale carbon cycle and climate change in an efficient Earth system model
T. M. Lenton, M. S. Williamson, N. R. Edwards, R. Marsh, A. R. Price, A. J. Ridgwell, J. G. Shepherd, S. J. Cox and The GENIE team

Atmospheric CO_2



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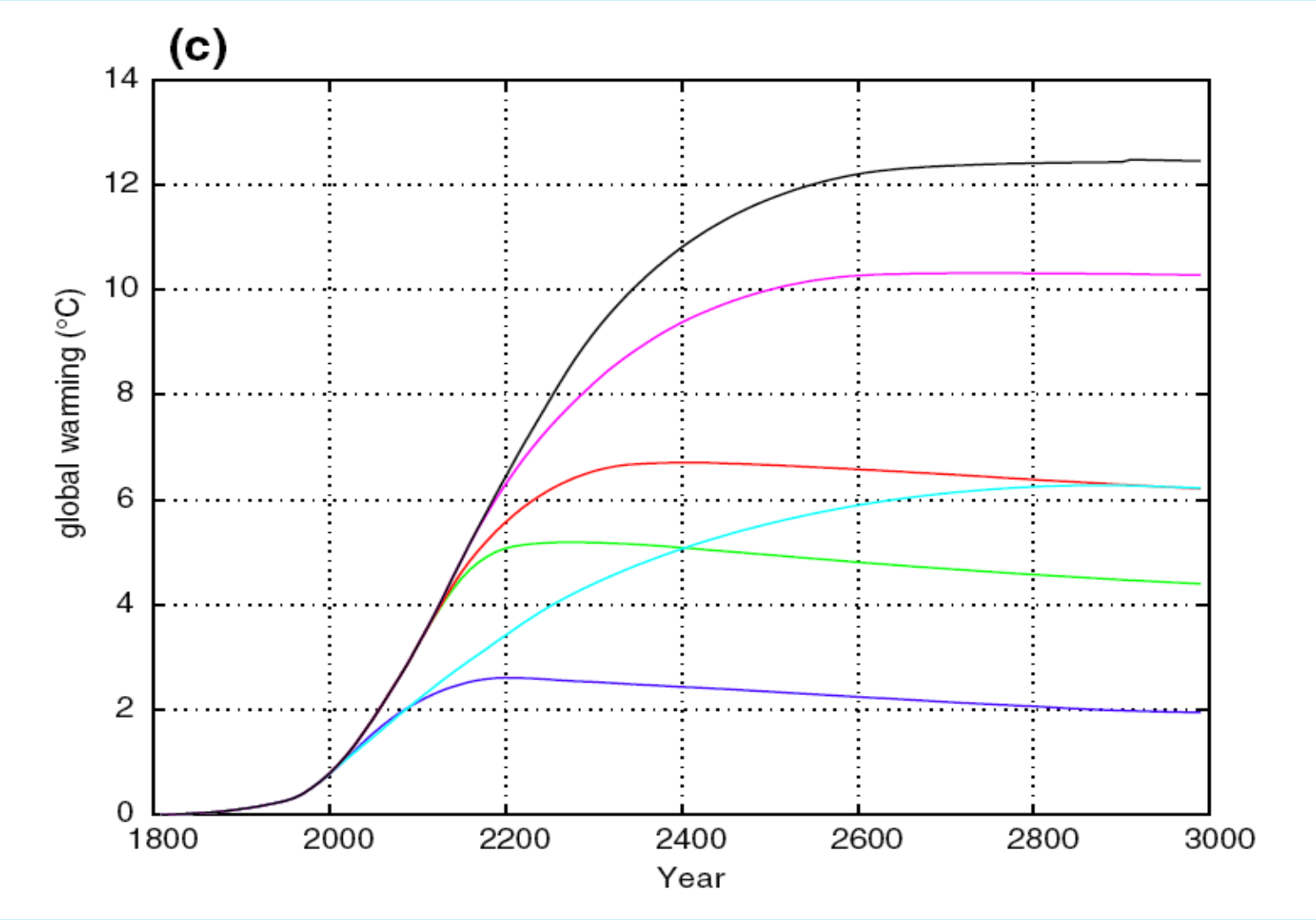
Global Mean Surface Temperature Change



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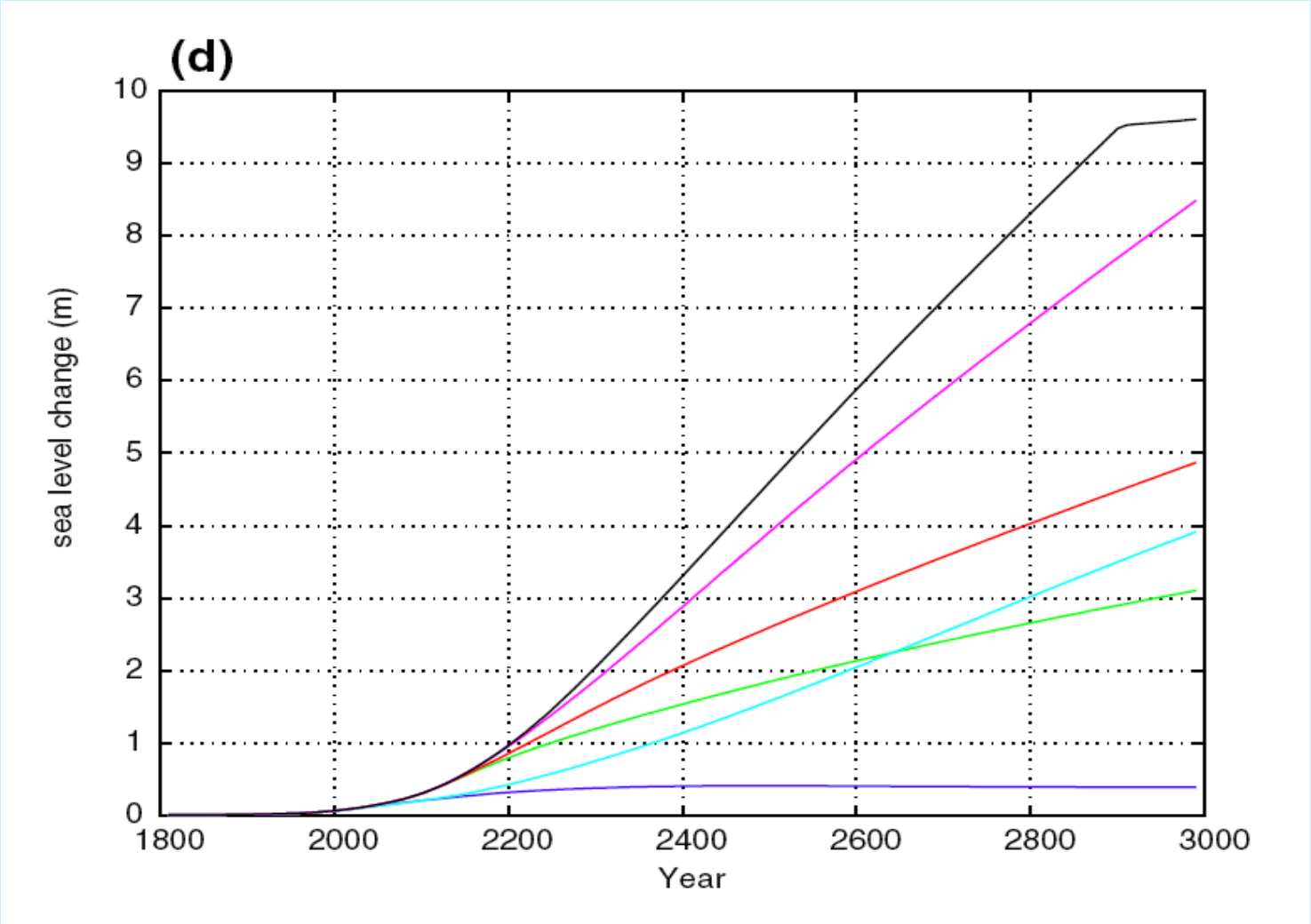
Sea-level Rise



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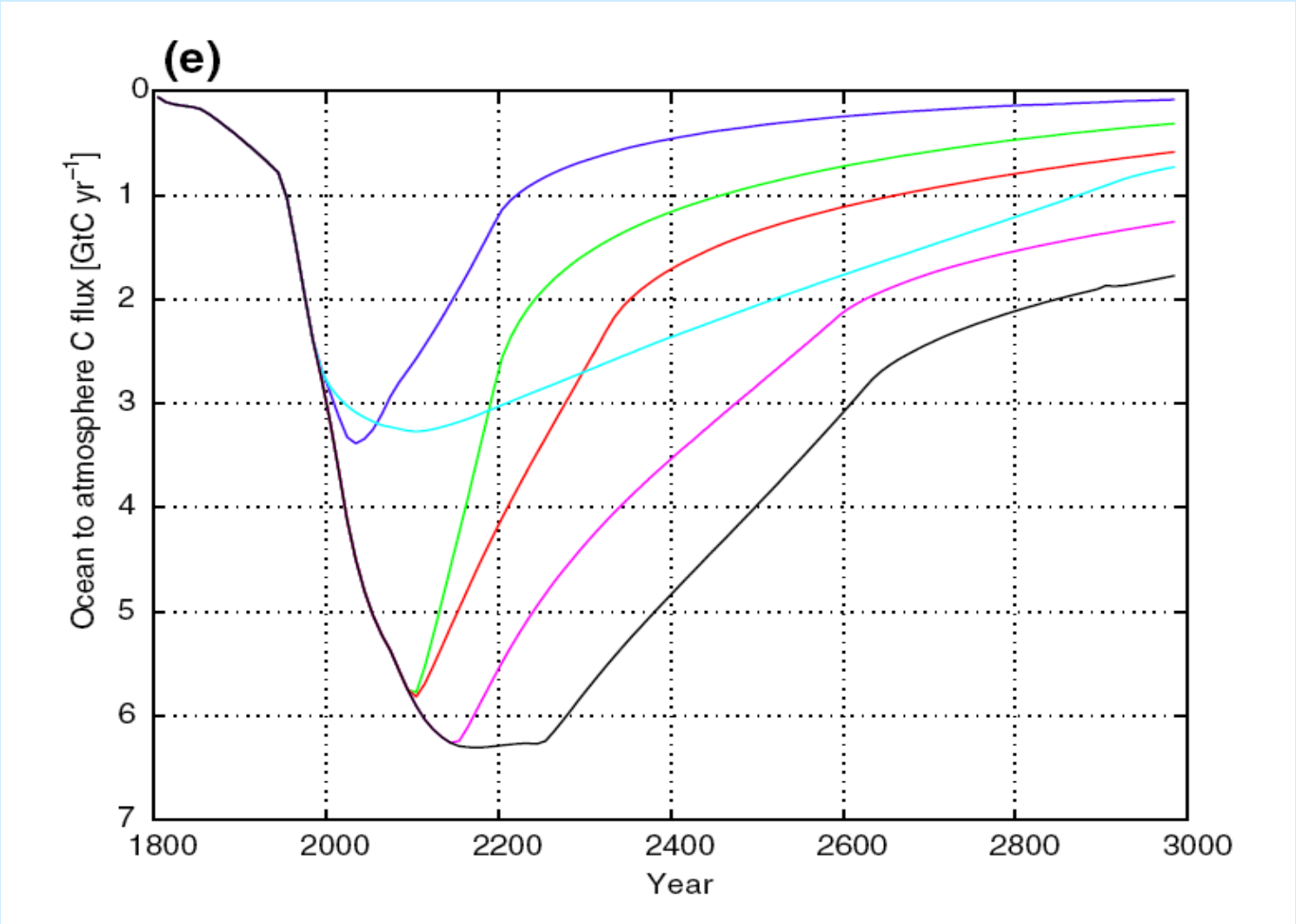
The Ocean Carbon Sink



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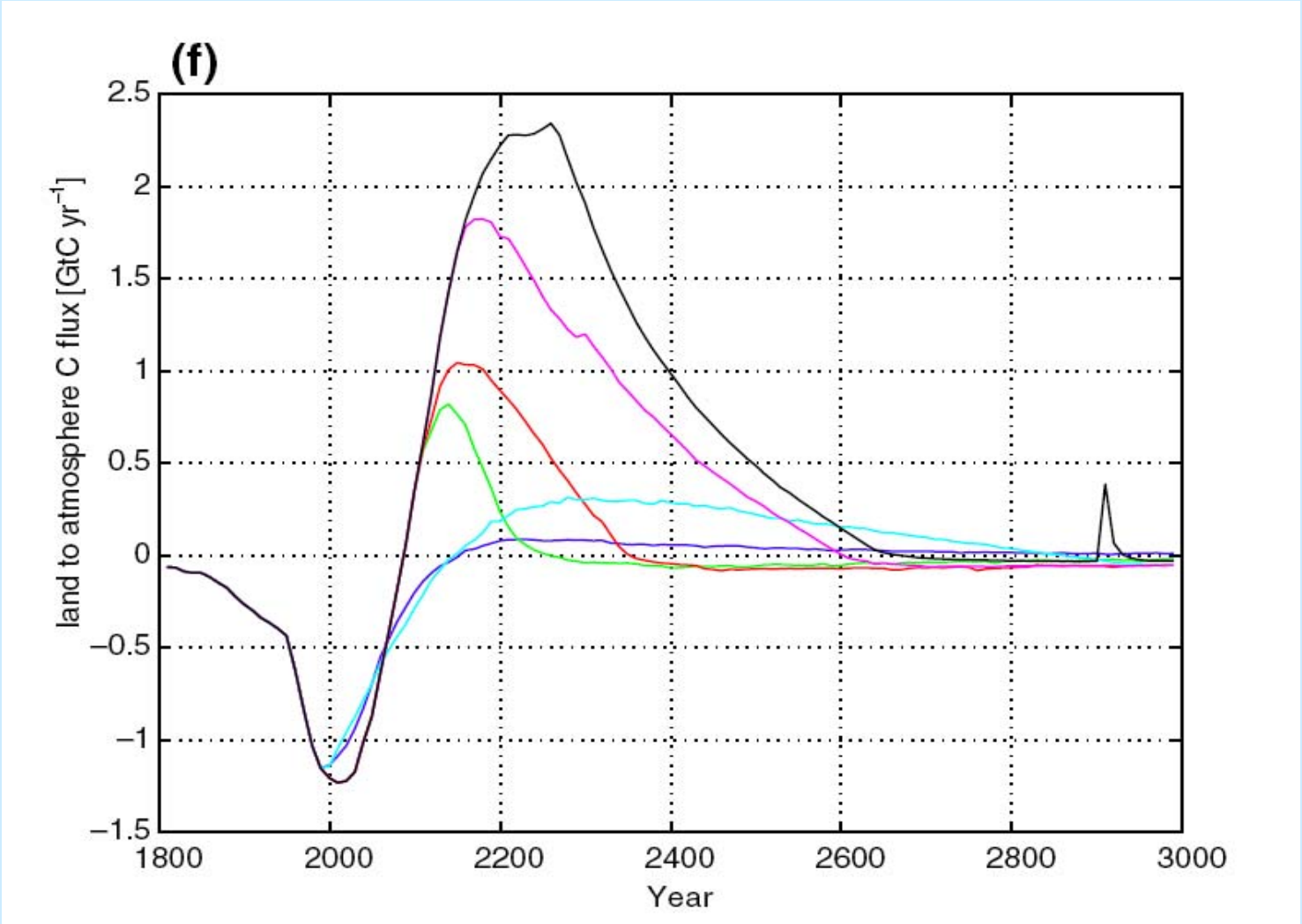
The Terrestrial Carbon Sink/Source



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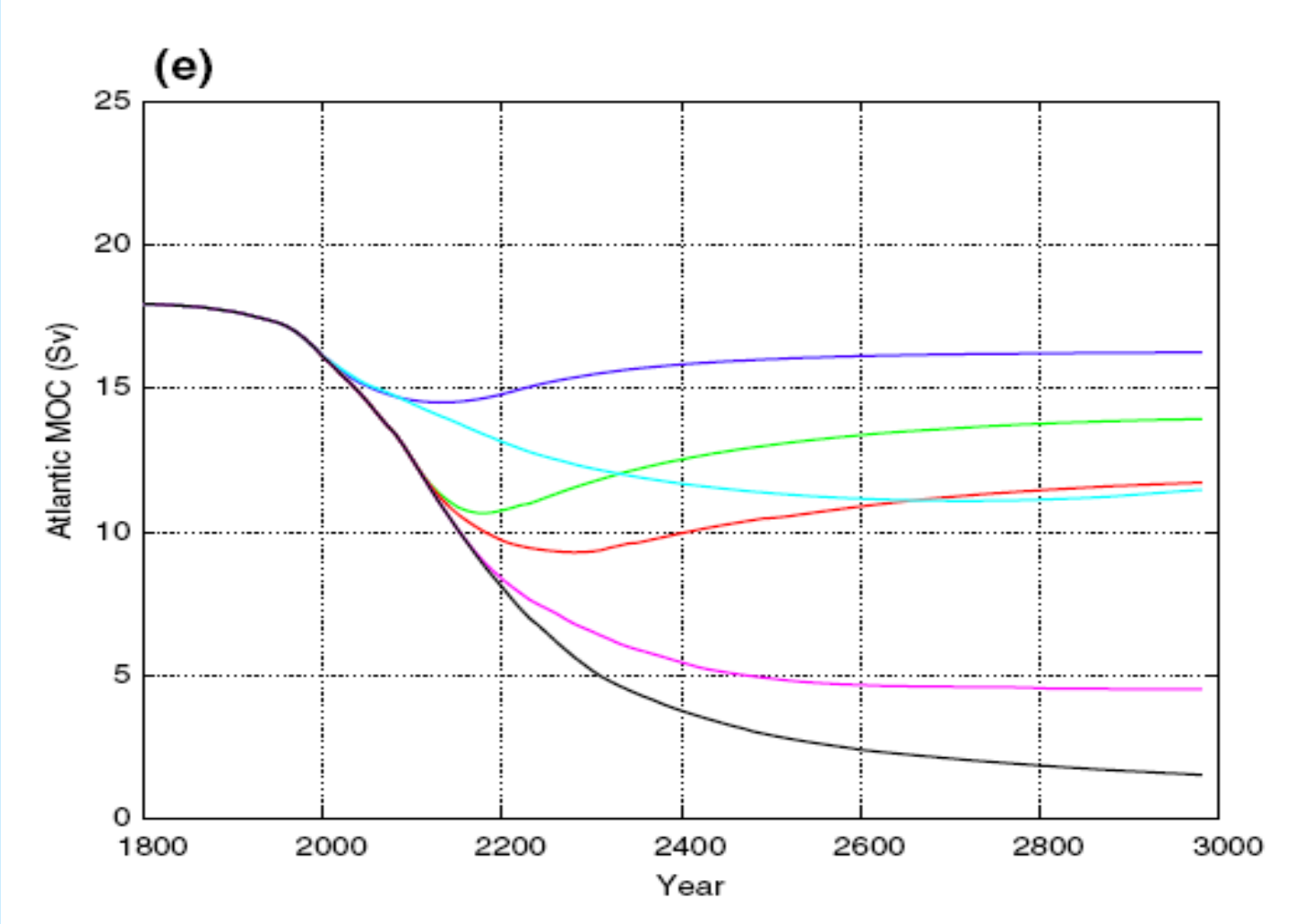
Atlantic Meridional Overturning Circulation



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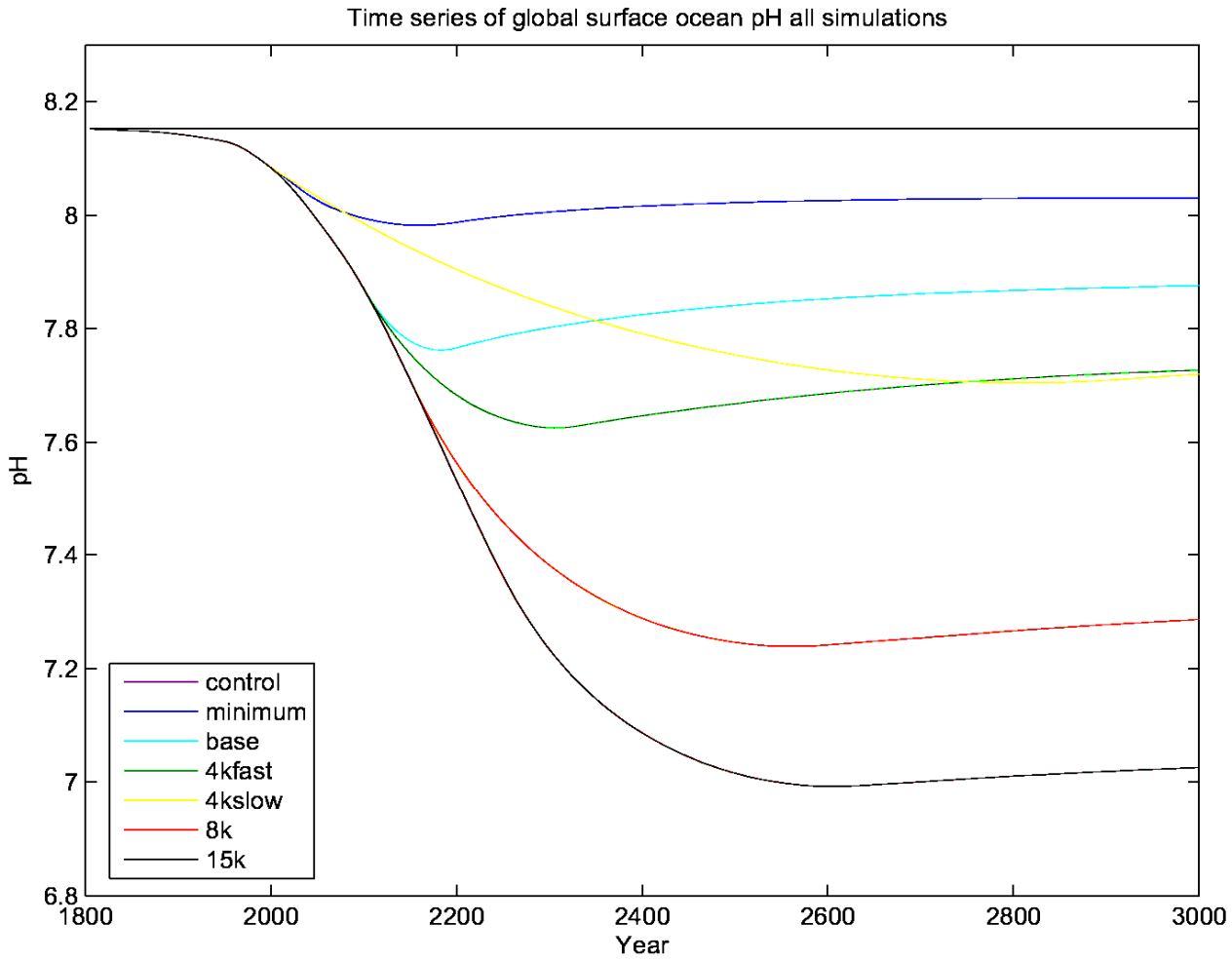
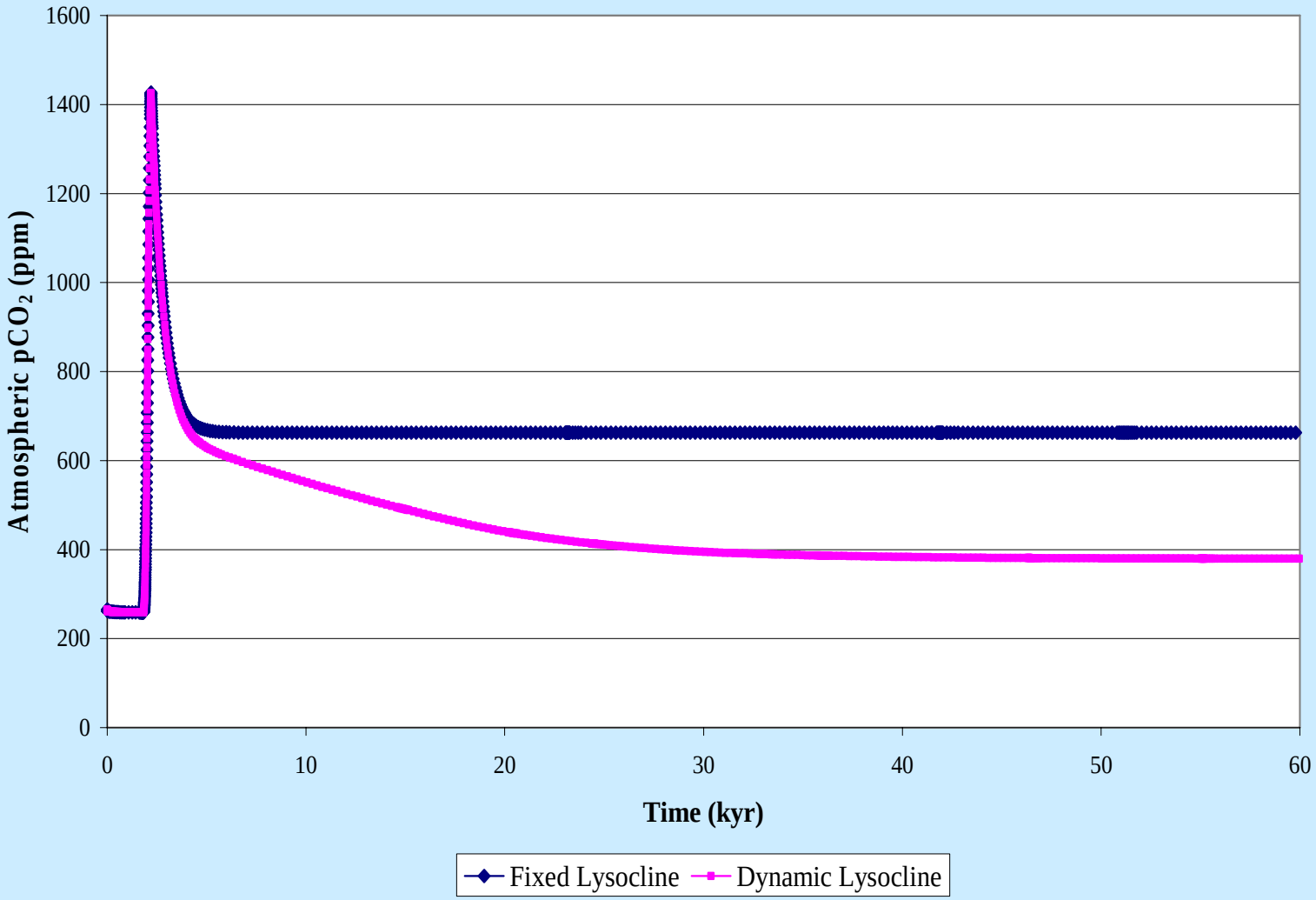
Ocean Acidification (mean surface pH)



Courtesy: Hembury, D. (MOcean disser., unpublished)

Very long-term variation of atmospheric *p*CO2 as a result of burning 3000 Gt(C) of fossil fuels



Courtesy: Castle, S., Undergraduate Disser.

Climate Change: the Role of the Oceans

- Absorbing **most** of the heat & **moderating climate change**
  - Only half of the committed change has yet occurred…
- **Maintaining global climate patterns** (warm N Atlantic !)
  - The "Ocean Conveyor Circulation" (AMOC)
    - 1PW of heat transport…
- Absorbing **much** of the Carbon Dioxide
  - About half of all the extra, so far…
  - Will absorb 80 to 90 % eventually
- **Sea-level rise**: only a few mm per year at present
  - But up to **7 to 14m eventually**…
  - if the Greenland and W Antarctic ice sheets disintegrate
  - Rate uncertain: maybe several meters in the next 100 years (??)
- **Ocean Acidification**
  - Due to CO_2 itself, not global warming

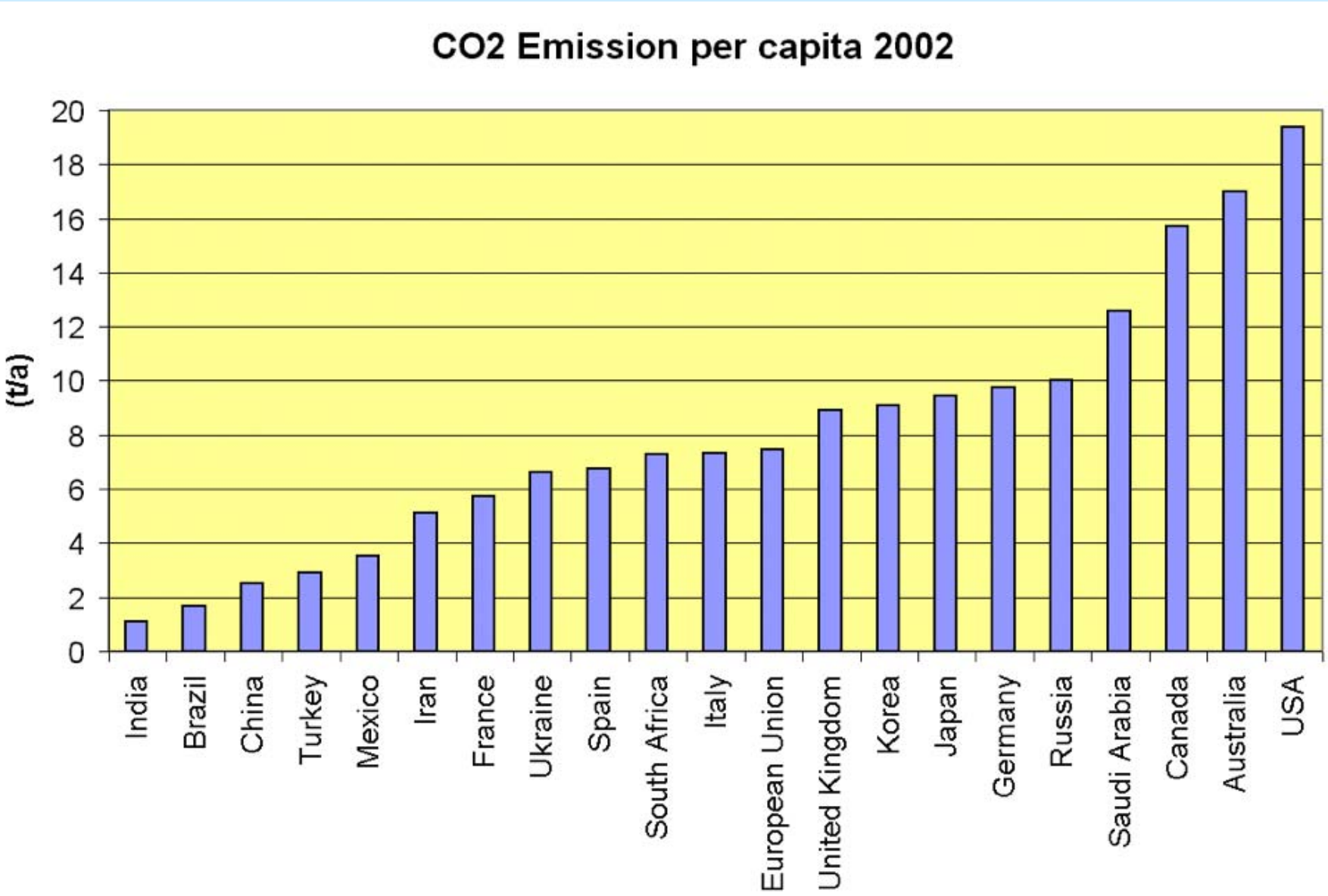
Climate in the future

- to restrict global warming to no more than **a few °C** over the next few centuries
  - e.g. **to stabilise temperature** anywhere near the EU adopted maximum level of **2 °C**
- **Global CO_2 emissions** will need to be reduced to a level around that of the Ocean Sink
  - i.e. about 2 Gt(C) per year (at present)
- **i.e. to less than 25%** of their current global level
- to achieve this is a ***massive*** challenge…
- In fact it is a **Big, Hard, Long-term Problem**
- i.e. it is very difficult for politicians (!)

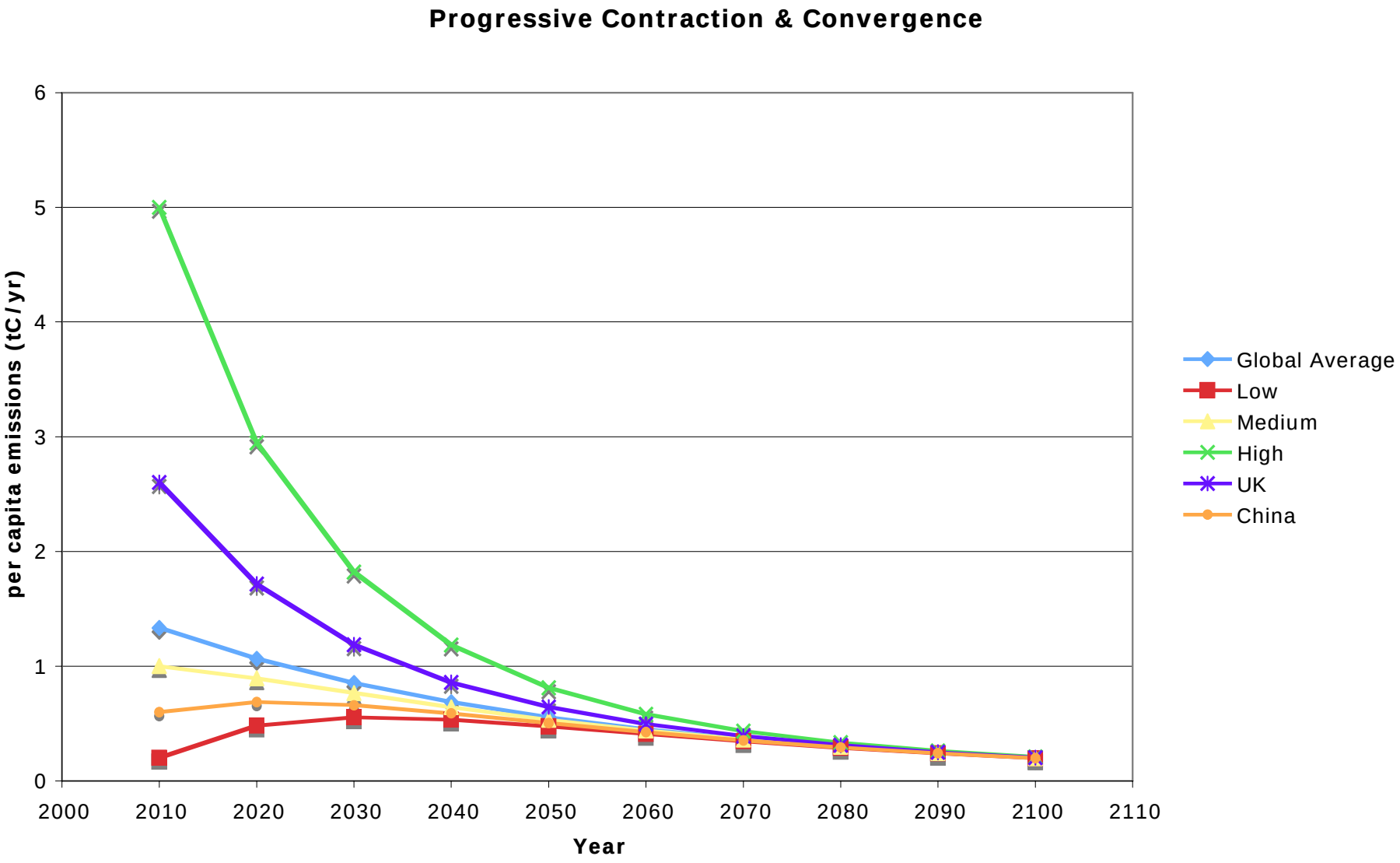
Mitigating Global Warming : The Big Picture

- Reducing global emissions ***by*** 75% : **a factor of 4**
- with population growth (global) : **another factor of 2**
- and increased energy use (per capita) in the developing world (to EU level only) : **a further factor of 5**…
- Altogether we need a **factor of 40** of decarbonisation
  - (of economic activity, globally)
- Need energy efficiency, renewables (etc) : maybe we can achieve a **Factor 4** (Weizsacker, Lovins & Lovins, 1994)
- There is ***still*** a mismatch by **a factor of 10**
- Is there any hope of closing the gap ???
- Maybe…

Unequal distribution of CO2 emissions globally



Contraction & Convergence: of ***per capita*** emissions



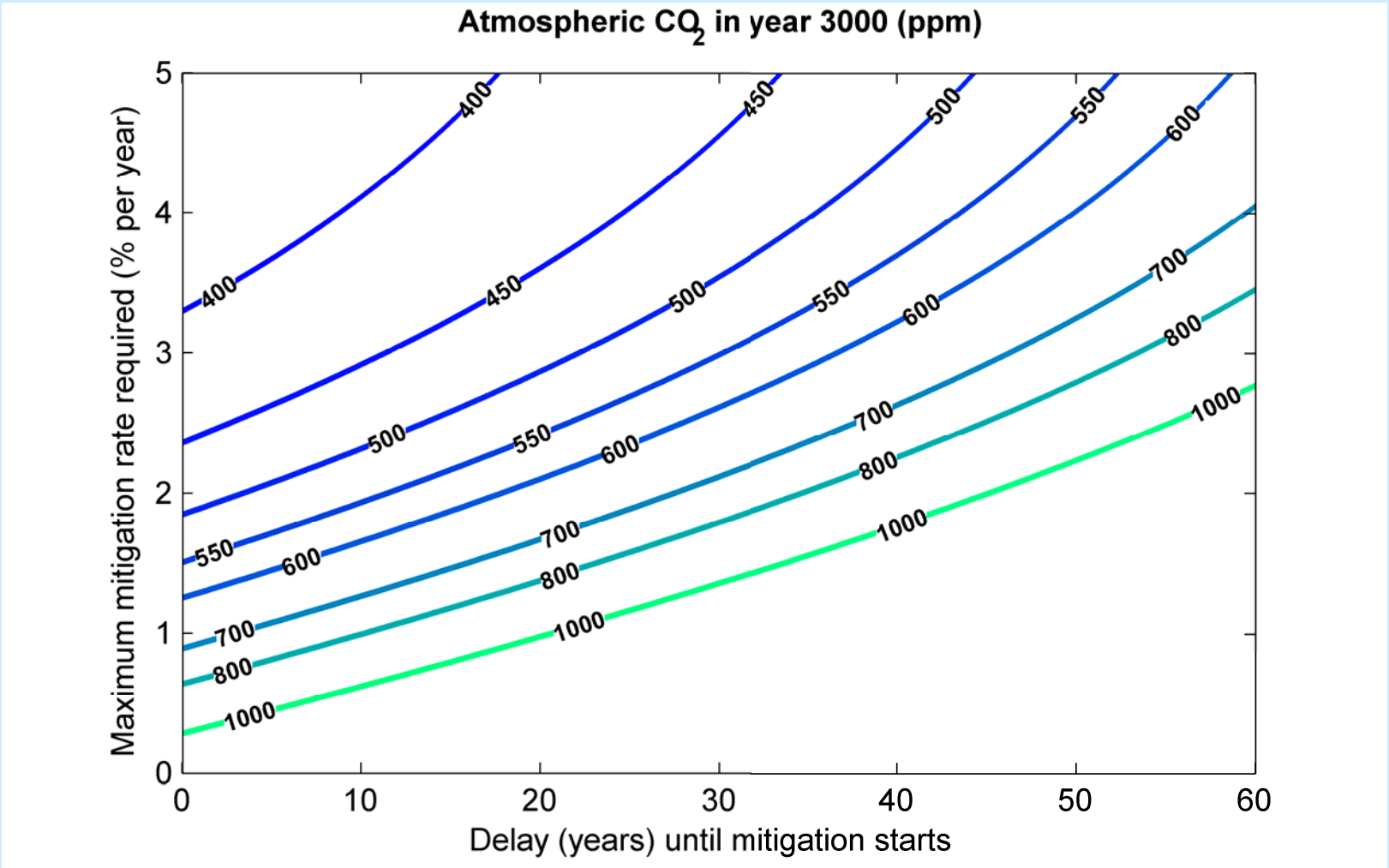
Courtesy of John Shepherd

What we need to achieve

- **50% reduction in global total emissions by 2050**
- **This means ~ 2% per year reductions, globally**
- **Each year, every year**, for the foreseeable future
  - (say the next 100 years)
- Compared with ~ 3% per year ***increases*** right now
- **More** (80%, at ~ **-**4% per year) for the UK & Europe
- **Even more** (90%, at ~ **-**5% per year) for the USA
- And ***even more still, if we delay*** taking action…
    - 20 years delay makes it **twice as hard**

Delay makes stabilisation much harder

The emissions mitigation rate (% per year decline) required to stablilise CO_2 at various levels increases considerably if we delay getting started…



Courtesy of John Shepherd

Ways and Means

We need **energy conservation & efficiency, and renewables**

- Offshore wind, solar thermal, marine…
- Decarbonisation of the electricity supply & transport…

- **Hydrogen** is only a carrier
  - it still needs a primary energy source
  - (e.g. **solar** or **nuclear** power…)
- **Nuclear fission** is available now
- **Nuclear fusion** will probably work eventually
  - good for electricity (and hydrogen ?)…
  - But not much good for road transport & aviation !
- Meanwhile, we need **Carbon Capture & Storage**
  - i.e. physical/chemical sequestration of CO_2
- And maybe also **geo-engineering** schemes, such as
  - **albedo modification** (“sunshade” methods)
  - engineered **capture of CO_2** from the atmosphere
  - artificially **accelerated geochemical weathering**

Carbon Dioxide Sequestration a.k.a. Carbon Capture & Storage (CCS)

- Must be **physical/chemical**
  - biological sinks (trees) are **too small** (~ 100 Gt(C) in total)
  - and **too uncertain** (too easily remobilised)
- Serious options include
  - **geological** (liquid CO_2, into gas/oil fields or deep saline aquifers)
    - e.g. Sleipner Project (1 Mt/yr)
  - **oceanic** (liquid CO_2, pumped to water depths > 3000m) ?
    - residence time ~ 500 years, ~ 80% permanent
    - good enough (?), favoured by Japan
  - **chemical** (CO_2 + serpentine [$MgSiO_4$] $\rightarrow$ magnesite [$MgCO_3$]) ??
    - Klaus Lackner, LDEO, Columbia University, NY
    - To produce a solid, most of which can replace rock mined
    - Could also use some to neutralise acidified surface ocean water ?
- **Cost** is non-trivial, but maybe ~ \$50/t(CO_2) and falling

CO_2 capture & storage (CCS)

- See recent IPCC special report (2005)…
- **CO_2 capture & storage methods** are well adapted for implementation
  - at **large fixed installations**
  - but ***not*** for diffuse sources
    - (i.e not much use for **transport**)
  - **Transport is a really serious and difficult problem**
  - for which bio-fuels may be the best solution ??
- **in 50 years time…**
- ***"No Combustion without Sequestration"***

CO_2 capture from the air

may be possible…

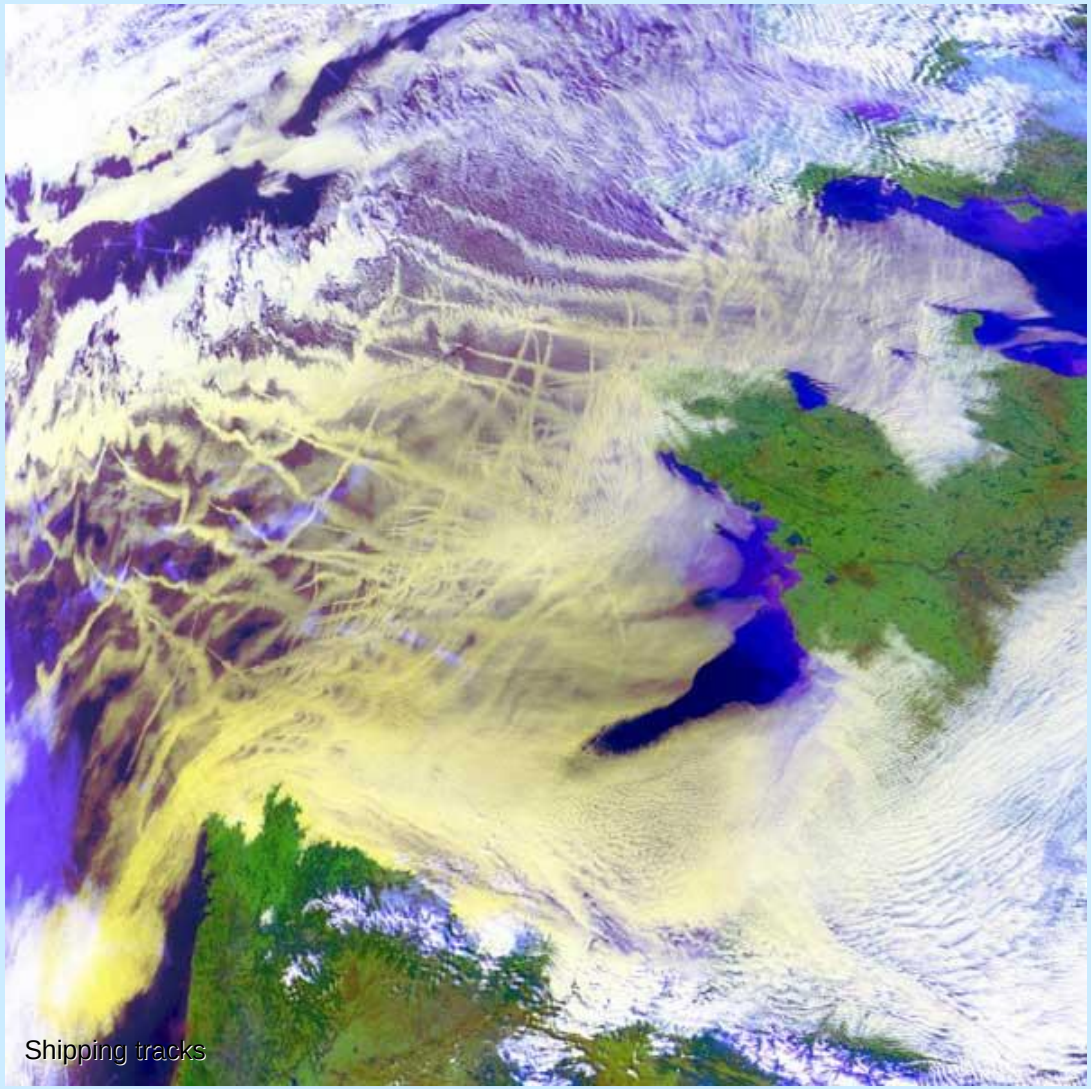
(Klaus Lackner, LDEO, Columbia University, NY)

- This could be done **anywhere in the world** (and also unilaterally…)
- It would allow CO_2 levels to be **reduced** again (!)
- and with a carbon-free source of hydrogen…
  - (can we engineer one ? Nuclear ? Solar ?)…
- one could also produce **CO_2 neutral carbon-based liquid fuels**
- Ideal for transport applications !!

Albedo Modification

- An increase of albedo by 1.8% roughly balances $2\times CO_2$
  - ***Maybe this could be safely engineered ?***
- "**Macro-engineering Options For Climate Change Management & Mitigation"**
  - (Tyndall Centre & Cambridge-MIT Institute Symposium Cambridge, England, Jan 2004)
    - See article by Fred Pearce in "New Scientist" (27 March 2004)
    - Website at www.tyndall.ac.uk/events/past_events/cmi.shtml
- Several possible schemes…
  - Low-level marine stratus cloud enhancement (John Latham)
    - Using spray-generated sea-salt cloud condensation nuclei
  - Stratospheric reflecting aerosols (Lowell Wood *et al*)
  - Mirror in space (at the L1 point) (Lowell Wood *et al*)
- See also Paul Crutzen (Climatic Change, 2006)
  - (Using SO_2 to create stratospheric aerosol)

Marine Cloud Enhancement
(John Latham, UMIST & NCAR)



- Enhance brightness & longevity of low-level marine stratus clouds
- By generating additional sea-salt cloud condensation nuclei
- Generated by wind powered spray turbines (Stephen Salter) ??

Image courtesy of: Mathias Schreier

For shipping, low-carbon technologies already exist!

For aviation, they do not, yet…

A way forward ?

- We should rapidly ***develop & implement*** large-scale
  - **Use of bio-fuels for transport**
  - **CO_2 sequestration (CCS) technology**
  - it will take a long time..., so **we should start real soon**
  - the energy industry could and should take a lead…
- We should also ***actively research***
  - **Solar (and/or nuclear) generation of hydrogen**
  - **Extraction of CO_2 from ambient air**
  - **Albedo modification techniques**
    - Especially as a back-stop in case we ever need a quick fix
- Need ***economic incentives*** and ***regulation*** to make things happen
- We also need to shift public & political opinion : by ***education*** ?

Economic incentives

- A **carbon tax** of 50 $ or Eu per T(C) would probably be enough to make **sequestration** (and other options e.g. **renewable energy**) much more attractive…
- This corresponds to :
  - Only about 100 Eu per person per year (for UK/Europe)
  - Only about 3p/litre increase in the price of fuel (UK)
    - i.e. about 30 cents/gallon in the USA
- To make this **revenue neutral**…
  - We would only need to reduce VAT from 17.5% to 15%
- This is ***not such a big deal***…
  - But it would distort international trading relationships
  - So ideally it should be done by international agreement.
- Europe (or the USA !) could take a lead : unilaterally ??
- Ultimately: ***replace VAT by a carbon tax***, entirely ?

Al Gore's list from "An Inconvenient Truth"

1. Change a light (to a low-energy type)
2. Drive less
3. Recycle more
4. Check your tyres
5. Use less hot water
6. Avoid products with a lot of packaging
7. Reset your thermostats
8. Plant a tree
9. Turn off electronic devices
10. Be a part of the solution

Al Gore's list from "An Inconvenient Truth" : Revised

1. **Fly less** (less far, and less often)
2. **Scrap the SUV** & buy a smaller car, and then Drive less
3. Use Public Transport (if any) or walk or cycle
4. Insulate your home better
5. Avoid over-heating and over-cooling (get better controls)
6. Turn off some lights (& change to a low-energy type)
7. Recycle more
8. Check your tyres
9. Use less hot water
10. Avoid products with a lot of packaging
11. Reset your thermostats
12. Plant a tree
13. Turn off electronic devices
14. (Be a part of the solution)

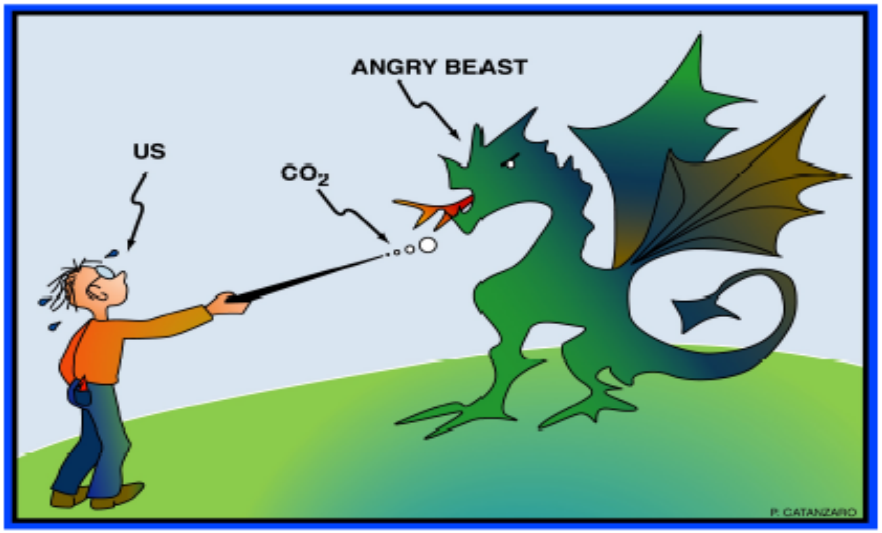
The Day after Tomorrow…

- **Is it already too late ?**
  - **No**. A few °C of global warming is now inevitable…
  - But we can probably still avoid +5°C or more…
- **Can local action help ?**
  - **Yes. It is essential.**
  - Only if we put our own house in order can we hope to persuade China, India, Africa & South America
- **What is the best solution ?**
  - **There is no single "magic bullet"**
  - We need "horses for courses" (especially for transport !)
  - Forget "Is nuclear better than wind ?"…
  - **We need all possible contributions, as much and as soon as we can engineer them**

Meanwhile…

- **Increased energy efficiency** and **use of renewables** are vital
- **Reducing CO_2 emissions** is the crucial task
  - CCS is essential for continued use of fossil fuels
- Remember: ***"No combustion without sequestration"***
- **Transport** (especially **aviation**) is the **most intractable** problem
  - Reserve bio-fuels and allowable fossil fuels for this ?
- **Carbon offsets** are a step in the right direction
  - But not a complete solution
- **Delay** (e.g. by a decade or two) makes the problem ***much harder***: so we should get started real soon…
- **Uncertainty** is **not** a valid reason for ***inaction***
  - Rather, it **is** a reason for **precautionary** action
- Be prepared for a bumpy ride… !

FOSSIL FUEL CO_2 AND THE ANGRY CLIMATE BEAST



W.S. BROECKER

ELDIGIO PRESS
2003

Recommended Reading

A proto-book by

Wally Broecker

- Available as pdf only from

  Patty Catanzaro at the Lamont-Doherty Earth Observatory

  <pcat@ldeo.columbia.edu>

Children of today may still be alive in 2100

They will suffer the impacts of what ***we*** do now.

Should we discount future environmental damage at all ??

Courtesy of John Shepherd

“Man has lost the capacity to foresee and to forestall. He will end by destroying the Earth”

Albert Schweitzer, quoted by Rachel Carson, in her dedication of “Silent Spring”, (1962)

Climate Change:
The Factor Forty Problem

Can we fix it ??

Maybe…

… but we need to try much harder…

John Shepherd

National Oceanography Centre
University of Southampton
&
Tyndall Centre for Climate Change Research

Key Issues (for future research)

- We need ***both*** Mitigation ***and*** Adaptation
- Need to go beyond "Dangerous Climate Change"
  - Consider Costs of Impacts, Losses, ***and*** Adaptation
  - For +2°C, +4°C and even +6°C….
  - c.f. the Costs (and environmental impacts) of Mitigation
- Adaptation is "painful" (Neil Adger)
  - "Lumpy, costly and patchy"
  - ***Not*** a soft option…
- +2°C is now probably inevitable…
  - These losses and costs become the baseline
- How much should we spend to avoid going on to 4°C and 6°C ?
- Better data and models for rapid melting of ice sheets are vital
- Don't forget about clouds and the carbon cycle (+ve feedbacks)

Additional Resources: for general information

- The Royal Society
  - some more general and less technical material at
    - http://www.royalsoc.ac.uk/landing.asp?id=1278
  - including an attempt to address some of the controversial issues at
    - http://www.royalsoc.ac.uk/page.asp?id=6229.
- The New Scientist magazine
  - special report "Climate change: A guide for the perplexed"
    - http://environment.newscientist.com/channel/earth/dn11462
- Al Gore's Climate Leadership Programme
  - run in the UK by the Cambridge Programme for Industry.
    - http://www3.cpi.cam.ac.uk/index.php?option=com_content&task=view&id=412&Itemid=179.
  - material specific to Al Gore's involvement in the UK
    - http://www.cpi.cam.ac.uk/gore/.

Additional Resources: for detailed information

- the Met Office (Hadley Centre)
  - who run the best big, detailed climate models in the UK
    - http://www.metoffice.gov.uk/research/hadleycentre/index.html
- the IPCC (Intergovernmental Panel on Climate Change)
    - http://www.ipcc.ch/.
  - the Summary for Policymakers (SPM) of Working Group 1 (on the Physical Science Basis of Climate Change)
    - http://ipcc-wg1.ucar.edu/wg1/wg1-report.html.
  - The whole report is also downloadable at
    - http://www.ipcc.ch/
  - (but only as individual chapters), as are the SPMs for WG 2 (Impacts) and WG 3 (Mitigation)...

Additional Resources: re Controversies

- For much more detailed and really well-informed discussion of climate change controversies, I strongly recommend the Realclimate web-log site at
  - http://www.realclimate.org/
- Most of the main postings here are by really good & knowledgeable people
  - you need patience to wade through all the comments though !
- Check the index at
  - http://www.realclimate.org/index.php/archives/2004/12/index/
- to see the tremendous range of subjects covered here…

Additional Resources: what you can do…

- Energy efficiency & conservation
  - http://www.energysavingtrust.org.uk/
  - http://www.carbontrust.co.uk/energy
- Top Tips
  - http://www.carbonneutral.com/pages/toptips.asp
  - http://www.cred-uk.org/CentralContent.aspx?intCID=4
- Carbon Emissions Offsetting
  - http://www.climatecare.org/
  - http://www.carbonneutral.com/
- For information on *research* about what to do about CC try the Tyndall Centre for Climate Change Research
  - http://www.tyndall.ac.uk
    - (declaration of interest: I am one of its deputy directors)

Channel 4 TV “The Great Global Warming Swindle”

- On the specific issue of this truly atrocious TV programme, you can now find a number of critical reviews of this, for example...
- from the CPI Climate Leadership Programme
  - http://www.cpi.cam.ac.uk/gore/resources/channel_4_response.aspx
- from RealClimate at
  - http://www.realclimate.org/index.php/archives/2007/03/swindled/
- From the National Oceanography Centre
  - http://www.noc.soton.ac.uk/nocs/news.php?action=display_news&idx=350
- including my own personal contribution at
  - http://www.noc.soton.ac.uk/nocs/news.php?action=display_news&idx=351

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