

# Climate Change: The Factor Forty Problem

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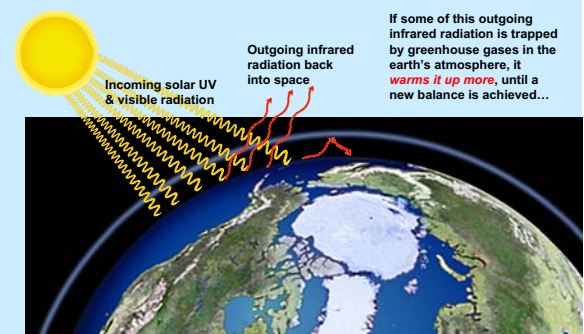
[www.noc.soton.ac.uk](http://www.noc.soton.ac.uk) Tyndall Centre for Climate Change Research National Oceanography Centre, Southampton

## 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...

## Energy Balance and the Greenhouse Effect (2)

(slide amended from an original provided by courtesy of Al Gore)



Incoming solar UV & visible radiation

Outgoing infrared radiation back into space

If some of this outgoing infrared radiation is trapped by greenhouse gases in the earth's atmosphere, it **warms it up more**, until a new balance is achieved...

## Basic Climate Science (1)

- **Energy Balance and the Greenhouse Effect**
  - Incoming (Ultraviolet & Visible) radiation must (eventually) be **balanced** by outgoing (Thermal Infra-red) radiation
  - Outgoing (thermal) radiation: more if the surface is warmer
  - If some outgoing radiation is blocked, the surface will get warmer until it has compensated for this
  - This is the Greenhouse effect
- **Natural greenhouse gases**
  - Water vapour
  - Carbon dioxide

## Climate in the past

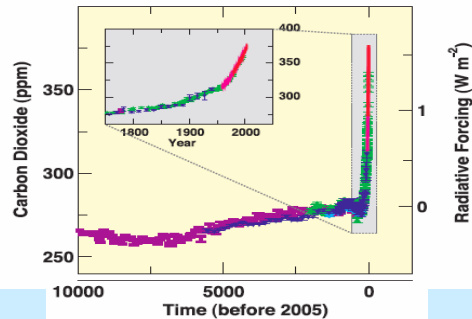
- **“Those who are ignorant of the past are condemned to misunderstand the future”**
  - *With apologies to G Santayana*
- Climate been somewhat stable (within limits) for most of the history of the Earth (>4500 Myr)...
  - especially stable since the last ice age
  - i.e. for the past 10 000 years (the 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...

## Natural Variability of Climate

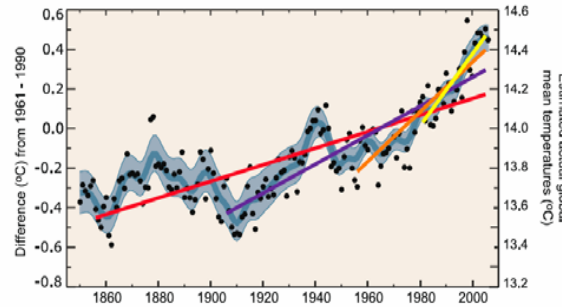
- **A Source of Comfort ?**
  - Climate has changed a lot naturally, so present changes must be natural too (???)
- **A Reason for Complacency ??**
  - Climate has changed a lot naturally, so nothing we can do will make much difference (???)
- **Not so...**
  - The climate system is **very sensitive**
  - 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**

### Past Changes of Atmospheric CO<sub>2</sub> (IPCC AR4 WG1)

CHANGES IN GREENHOUSE GASES FROM ICE CORE  
 AND MODERN DATA



### Recent Changes of Global Mean Temperature (IPCC AR4 WG1)



### Climate Facts

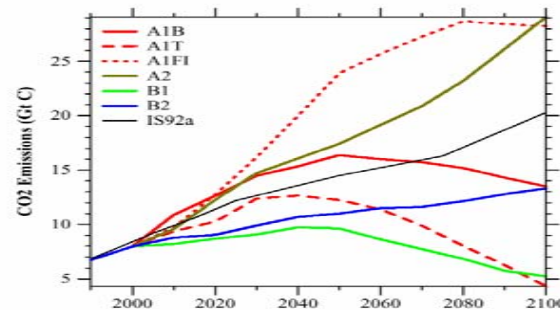
- It is *effectively certain* (i.e. beyond reasonable doubt) that...
- the *combustion of fossil fuels* is the largest single cause of emissions of carbon dioxide (CO<sub>2</sub>).
- *atmospheric CO<sub>2</sub> concentrations are increasing*, and have done so since the beginning of the industrial revolution.
- *anthropogenic CO<sub>2</sub> emissions (and deforestation) are sufficient* to account for the observed change in atmospheric CO<sub>2</sub>.
- *CO<sub>2</sub> 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

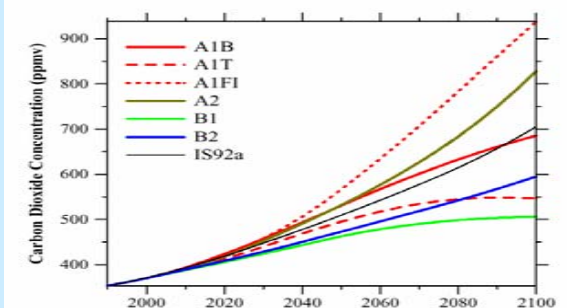
are mostly about *uncertainties* concerning...

- 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](http://www.realclimate.org)

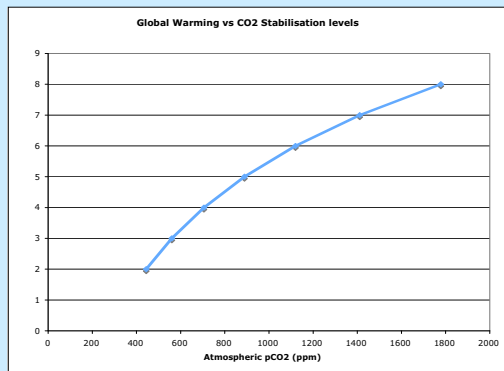
### CO<sub>2</sub> emissions under various scenarios



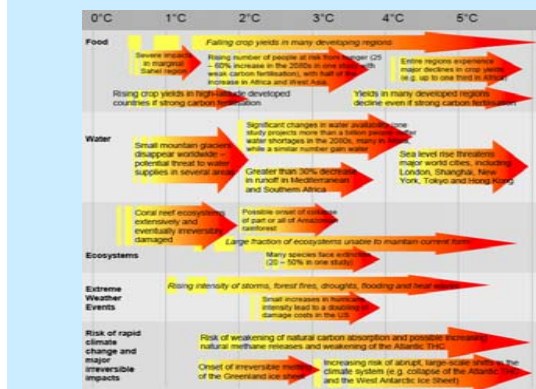
### CO<sub>2</sub> concentrations under various scenarios



Temperature Change for Various Stabilisation Levels

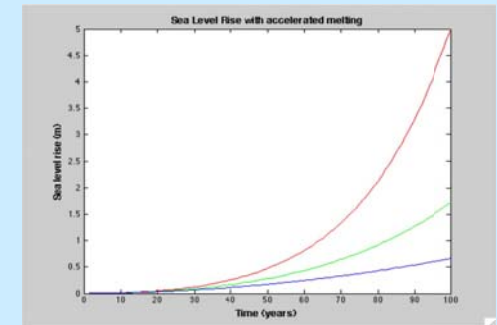


Impacts of Global Warming (Stern Review fig 13.4)

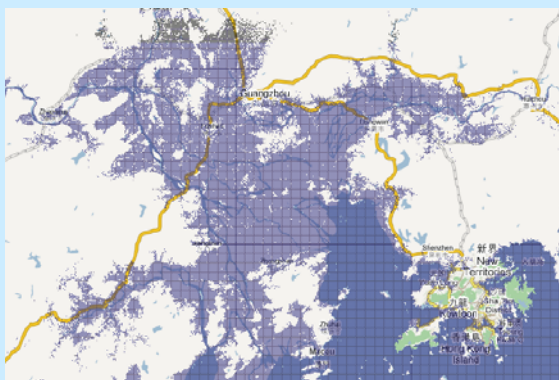


Sea-level rise: how much by 2100 ?

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



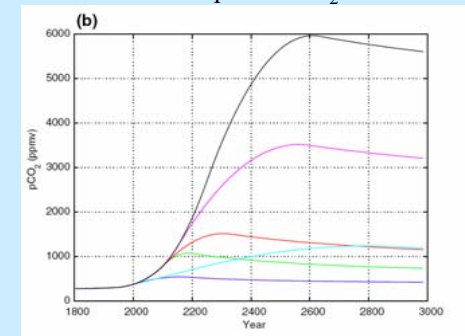
Hong Kong: Sea level rise of 7m (from flood.firetree.net)



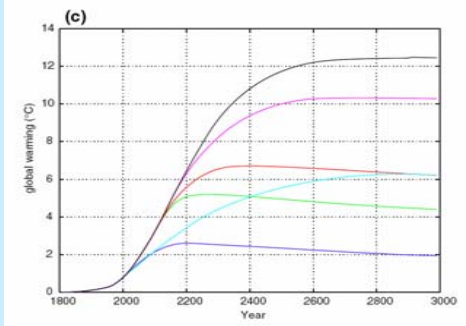
Global Warming : the IPCC & beyond

- 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<sup>-2</sup>”
  - “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)

Atmospheric CO<sub>2</sub>



### Global Mean Surface Temperature Change



### 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<sub>2</sub> 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 (!)

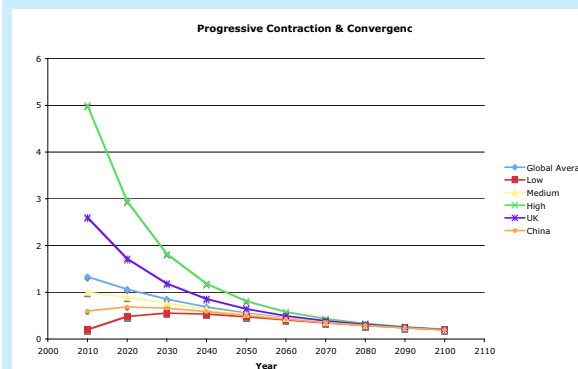
### Mitigating Global Warming : The Big Picture

- 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...

### Ways and Means

- **We need to achieve ~2% per year reductions in emissions**
  - Every year, continuing for the foreseeable future (say 100 years)
  - Compared with ~2% per year *increases* right now
  - More (4 to 5 % per year) for Europe, the USA, etc
    - “Contraction & Convergence”
  - And *even more, if we delay* taking action...
- **Hydrogen** is only a carrier
  - it still needs a primary energy source
  - (e.g. **solar** or **nuclear** power...)
- **Nuclear** is otherwise good for electricity...
  - But not much good for road transport & aviation !
- We shall probably need to deploy **Macro-engineering solutions**
- Such as **Carbon Capture & Storage**
  - i.e. **physical sequestration of CO<sub>2</sub>**
  - “*No Combustion without Sequestration*”
- and maybe even **geo-engineering** (e.g. **albedo modification**)...

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



For shipping,  
low-carbon  
technologies  
already exist!

For aviation,  
they do not,  
yet...

### 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

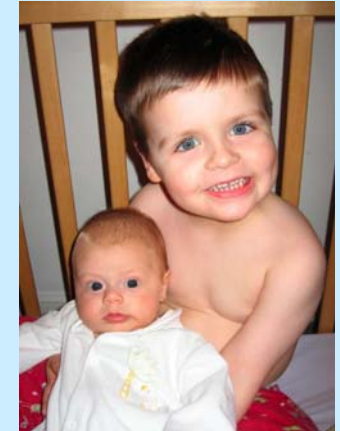
### Meanwhile...

- **Increased energy efficiency and use of renewables** are vital
- **Reducing CO<sub>2</sub> 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... !

### 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 ??



## Climate Change: The Factor Forty Problem Can we fix it ?? Perhaps we can !

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### 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](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)