THE ImpEE PROJECT

IMPROVING ENGINEERING EDUCATION

Climate Change and Sustainability

The Cambridge-MIT Institute

UNIVERSITY OF CAMBRIDGE

Notes

• Information relating to the science of climate change helps engineers make informed decisions based on facts. Climate change lends itself to the teaching of fundamental thermodynamics/fluid mechanics and some of the data can be incorporated into other lecture courses such as those addressing renewable energy sources.

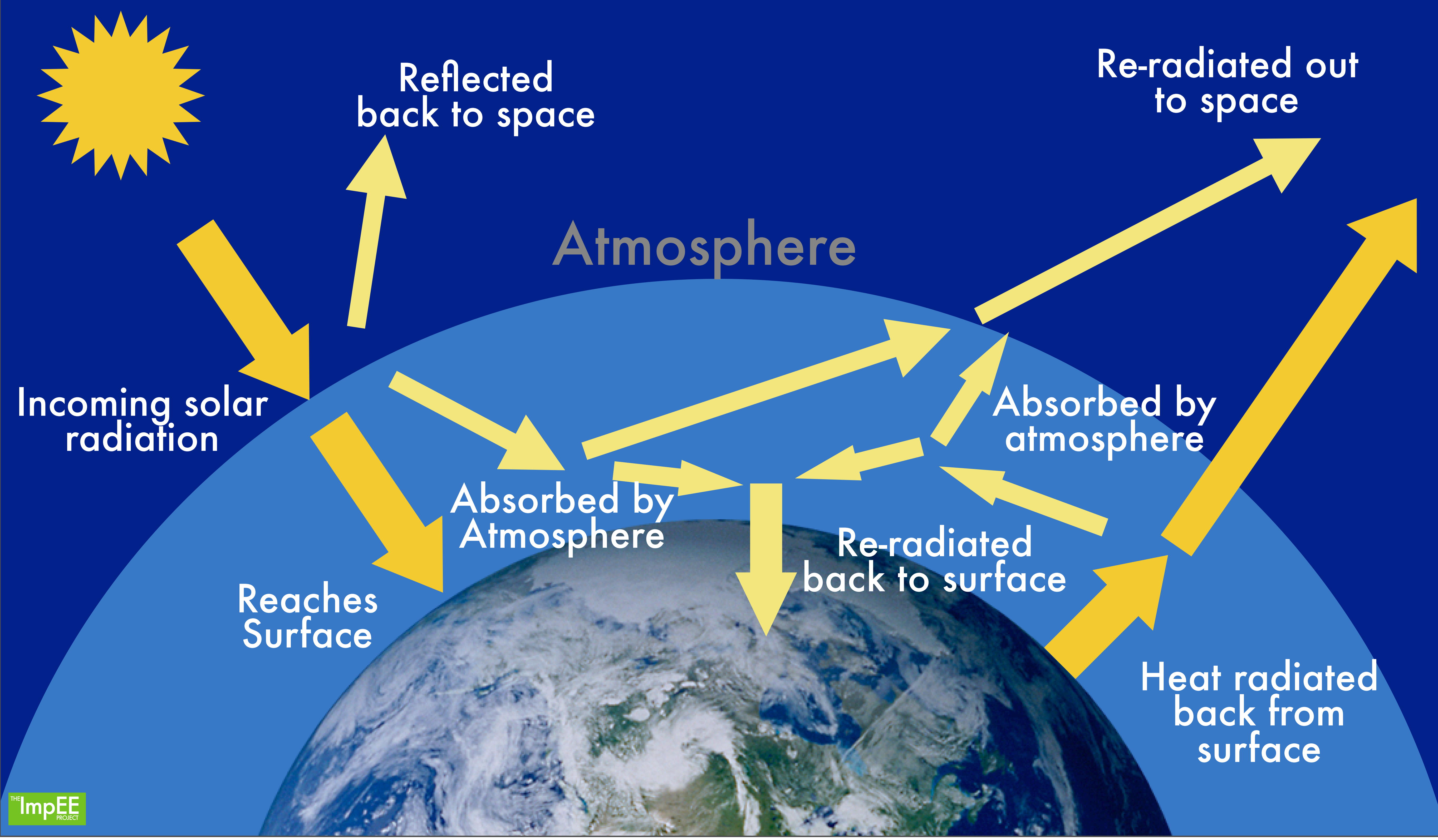
• Based on a slide presentation from the Hadley Centre for Climate Prediction and Research and further material from Prof. Roderick Jones, Department of Chemistry, Cambridge University. Produced for ImpEE by Drs. Sue Jackson and Tamás Bertényi, ImpEE Project, Department of Engineering, University of Cambridge

• version 4

• September 2006

• Climate Change and the Greenhouse Effect, a briefing from the Hadley Centre

The Greenhouse Effect



Notes

- The average energy reaching the surface of the earth from the sun is around 343 Watts per square meter. As this passes through the atmosphere, around 6% is scattered back to space and about 10% is reflected from land and ocean surfaces. The remaining 84% (288 Watts per square meter) remains to heat the surface of the earth.
- To balance this, the Earth must radiate on average the same amount of energy back to space. However, the so called Greenhouse gases such as water vapour, carbon dioxide and other minor gases absorb some of the radiation leaving the surface and re-radiate it back to the surface causing the earth to be warmer than it would otherwise be.
- The warming effect of greenhouse gases in the atmosphere was first recognised in 1827 By Jean Baptiste Fourier (of mathematics fame) .

Extracts from 'Global Warming The complete briefing' 3rd Edition. John Houghton CUP 2004

Greenhouse Gases

The most talked about factors contributing to Global warming are Greenhouse Gases (GHG)

Gas	CO_2 Equivalent	Amount	Residence Time
H_2O	N/A	~1%	Days
CO_2	1	350 ppm	~50 years
CH_4	21	1800 ppb	12 years
N_2O	310	320 ppb	114 years
CFCs	6,500	~1 ppb	100 years
SF_6	23,900	5 ppt	3,200 years

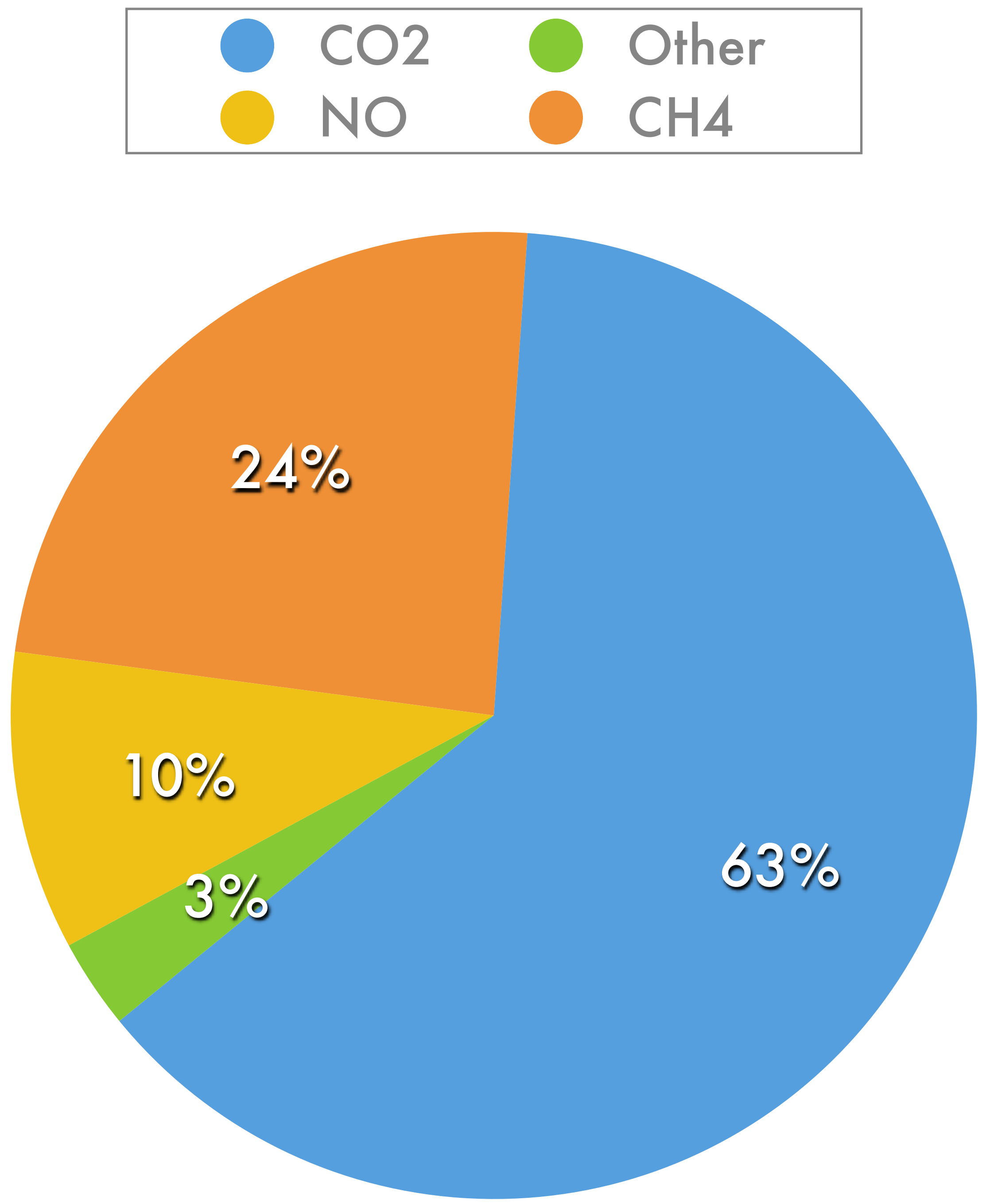
Notes

- These are the principal GHGs, and the table shows their effectiveness in relation to carbon dioxide and their residence times in the atmosphere.
- The ratio of the enhanced greenhouse effect of a molecule of a gas compared to a molecule of CO_2 is known as its global warming potential (GWP). Although, for example, SF_6 is 23,900 times more potent as a greenhouse gas, it is present in such low concentrations that it doesn't matter.
- CO_2 is the dominant contributor, followed by methane, CH_4

CO_2 is not the *only* greenhouse gas

- Taking into account the affectivity, residence, and concentration of the different gases:

The relative warming of different greenhouse gases based on current emissions, effect quantified over the next 100 years



Notes

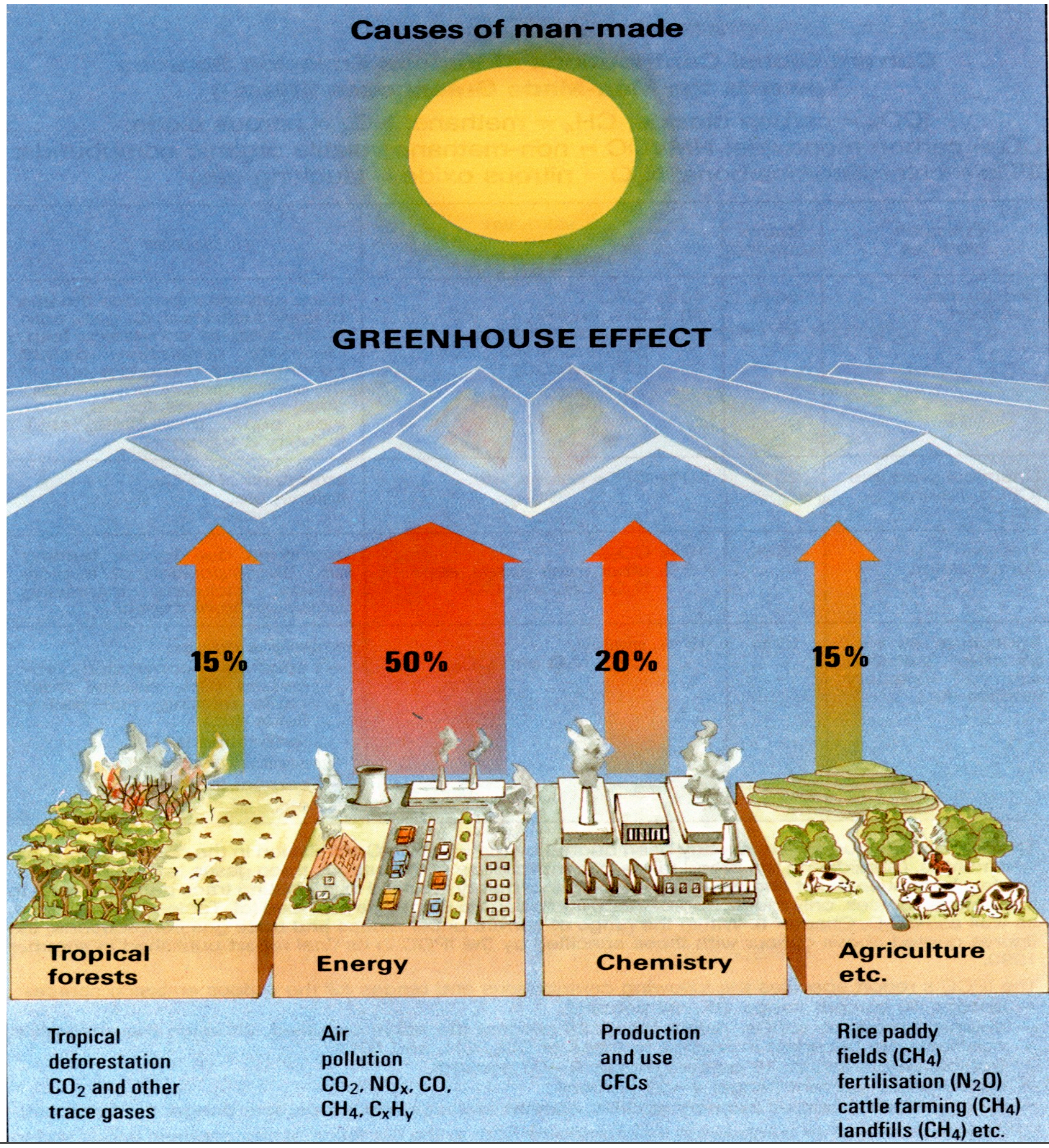
- CO_2 is the major contributor to global warming, the warming effect over the next 100 years of current emissions of greenhouse gases will depend upon the amount of each gas being delivered globally and its global warming potential, GWP. The GWP is the warming effect of an extra 1kg of a greenhouse gas emitted today, relative to 1kg of CO_2.
- The results of the calculation are shown in this slide. CO_2 will be responsible for about two thirds of the expected future warming.

Source: Hadley Centre for Climate Prediction and Change.

Sources and Lifetimes of Greenhouse Gases

- Carbon Dioxide (CO_2): 100 years
- Methane: 10 years
- Nitrous Oxide: 150 years
- Chlorofluorocarbons: 100 years

(*Source*: Hadley Centre for Climate Prediction and Research)



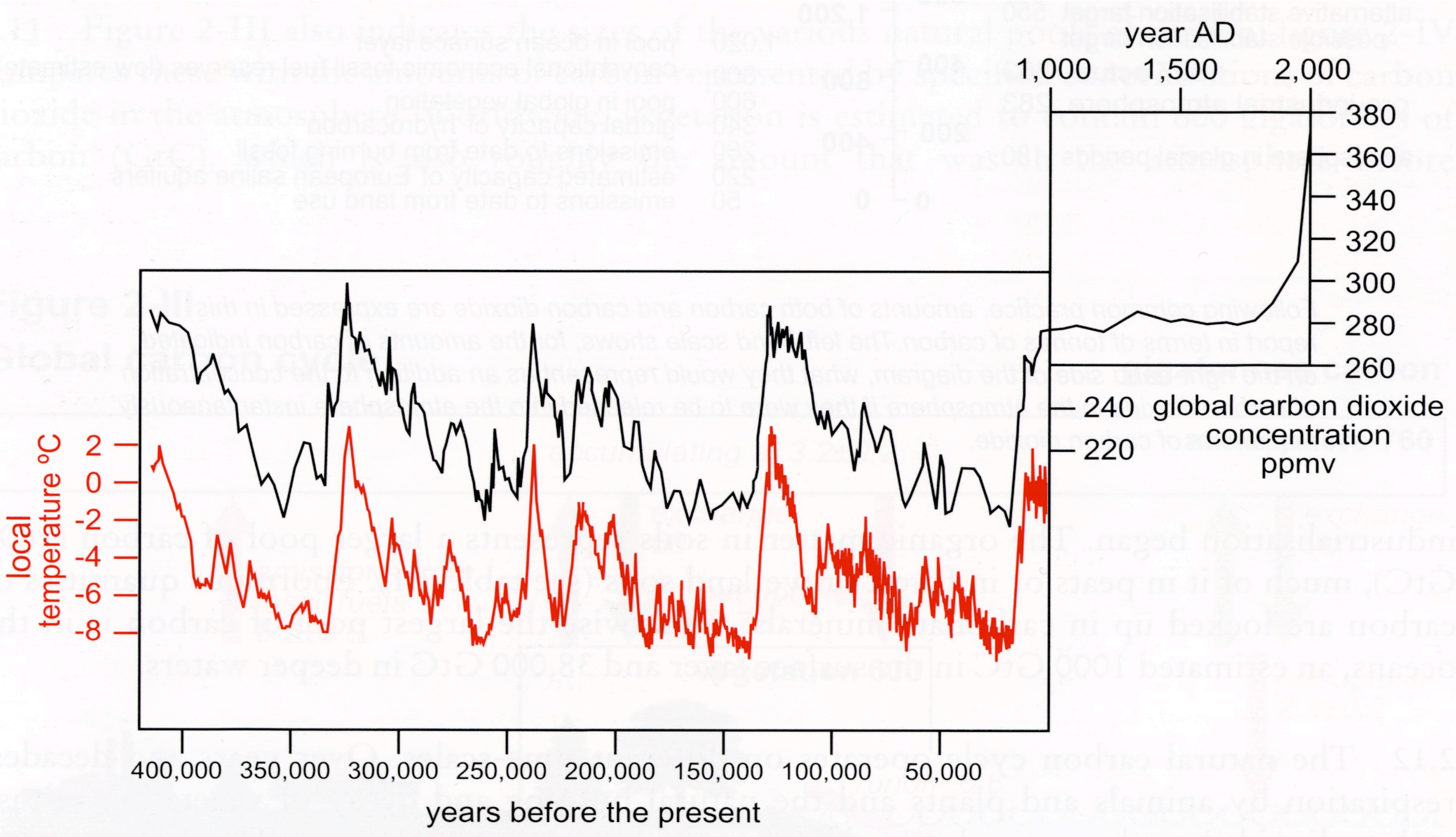
Notes

- If all emissions into the atmosphere from human activities were suddenly halted, no sudden change would occur in atmospheric concentration. It would decline very slowly taking a few hundred years to reach pre-industrial values.
- The majority of emissions (50%) come from fossil-fuel burning and cement manufacture. Land use change accounts for a further 15%. The 15% from agriculture is predominantly methane from cattle (belching), rice paddy fields and decay of rubbish in landfill sites.
- The chemical industry, biomass burning and increases in fertiliser use are human contributions to emissions of nitrous oxide, which is very long lived.
- Although the manufacture of CFCs has been gradually phased out since the 1990s when it was discovered to be depleting the ozone layer, the molecules still have a significant greenhouse effect because of their longevity in the atmosphere and relatively huge global warming potential (see previous slide).

Source: Hadley Centre for Climate Prediction and Change.

Evidence for the Impact of CO_2

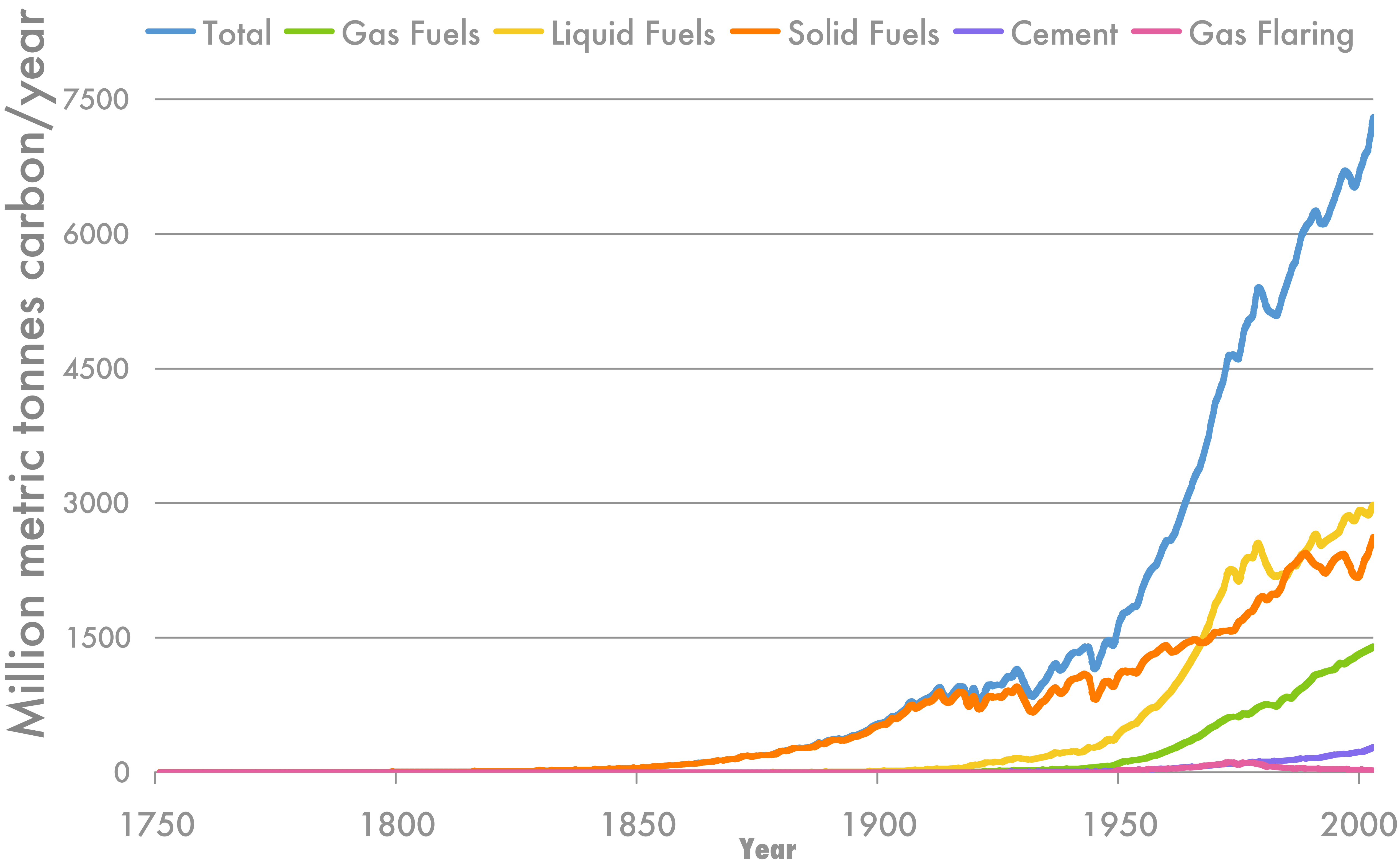
Vostok Ice-Core and Temperature graph



Notes

- Ice cores have been drilled from Vostok, a region of Antarctica, deep enough so that ice laid down 420 000 years ago has been analysed.
- Air bubbles within the ice have been analysed to yield climatic data stretching back over this time period. The temperature is deduced from the ratio of different isotopes of oxygen (18O and 16O) present in molecules in the ancient air. Higher temperatures lead to a more energetic atmosphere, allowing a larger proportion of the heavier isotope to remain in the air.
- The oscillations in temperature are predominantly caused by variations in the solar input of radiation (the Milankovitch cycles) affecting how much heat the Earth receives from the Sun as a function of time.
- Note the strong observed correlation between temperature and CO_2 concentration. CO_2 levels have now risen to 380 ppmv and are climbing. Growth of atmospheric CO_2 in the twenty-first century is heading towards levels that are unlikely to have been exceeded during the last twenty million years. The start of the 'spike' in CO_2 production observed in the last hundred years coincides with the industrial revolution and the rapid industrialisation of the western world.
- Source: Vostok Ice Cores, National Ocean & Atmosphere Administration

Anthropogenic CO_2 Forcings

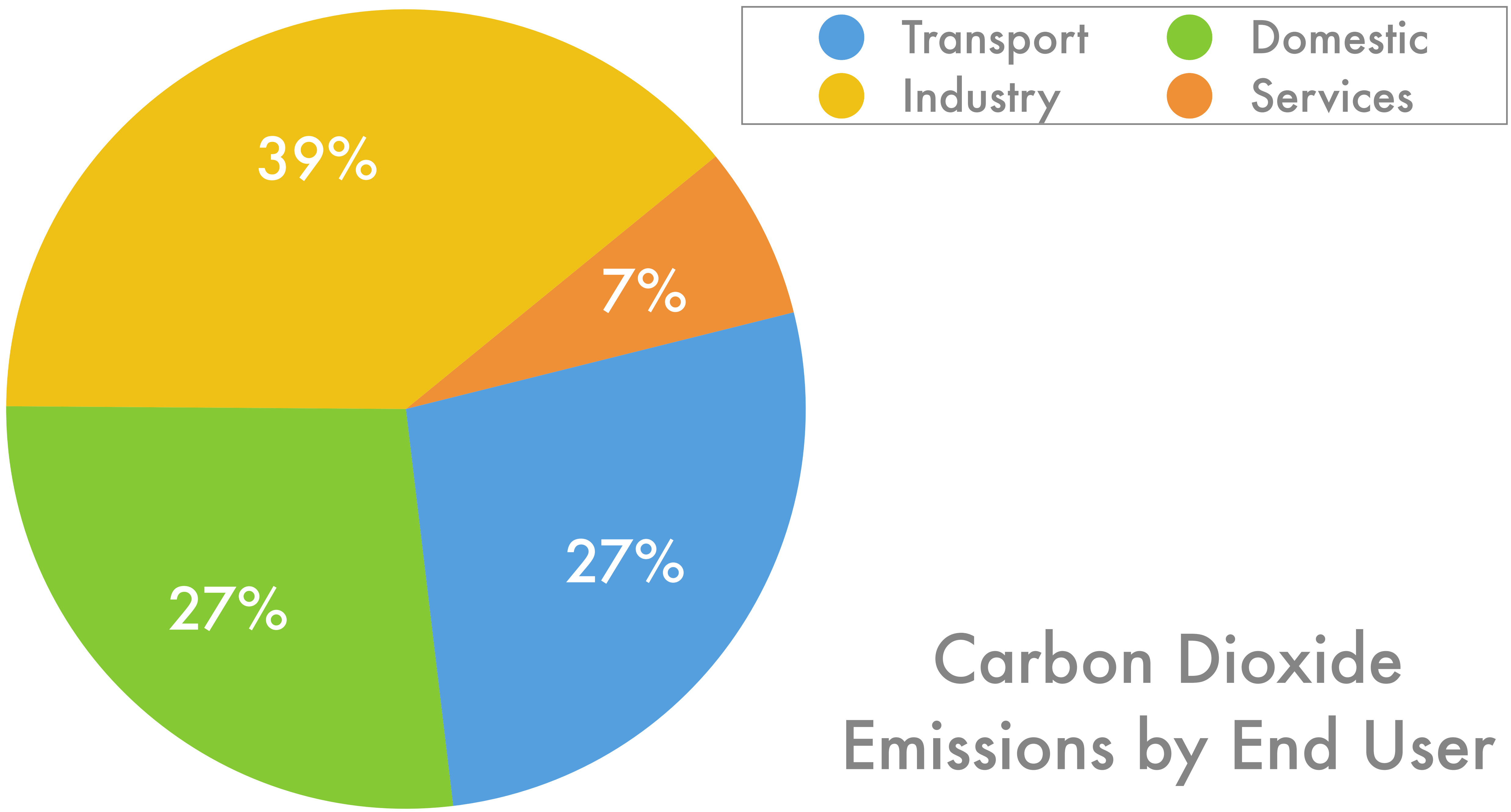


Notes

- Emissions of carbon dioxide into the atmosphere from human activities have increased since the Industrial Revolution, particularly since about 1950.The chief culprits are the burning of fossil fuels and cement manufacture.
- These are areas in which engineers are involved, and can now start to make a difference.
- Since the beginning of the Industrial Revolution in about 1700, approximately 600Gt of carbon have been emitted from fossil fuel burning.
- Units are in gigatons of carbon per year: to calculate the amount of CO_2, multiply this by 3.7.

Source data :Marland, G., T.A. Boden, and R. J. Andres. 2006. Global, Regional, and National CO2 Emissions. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

Carbon Dioxide Emissions

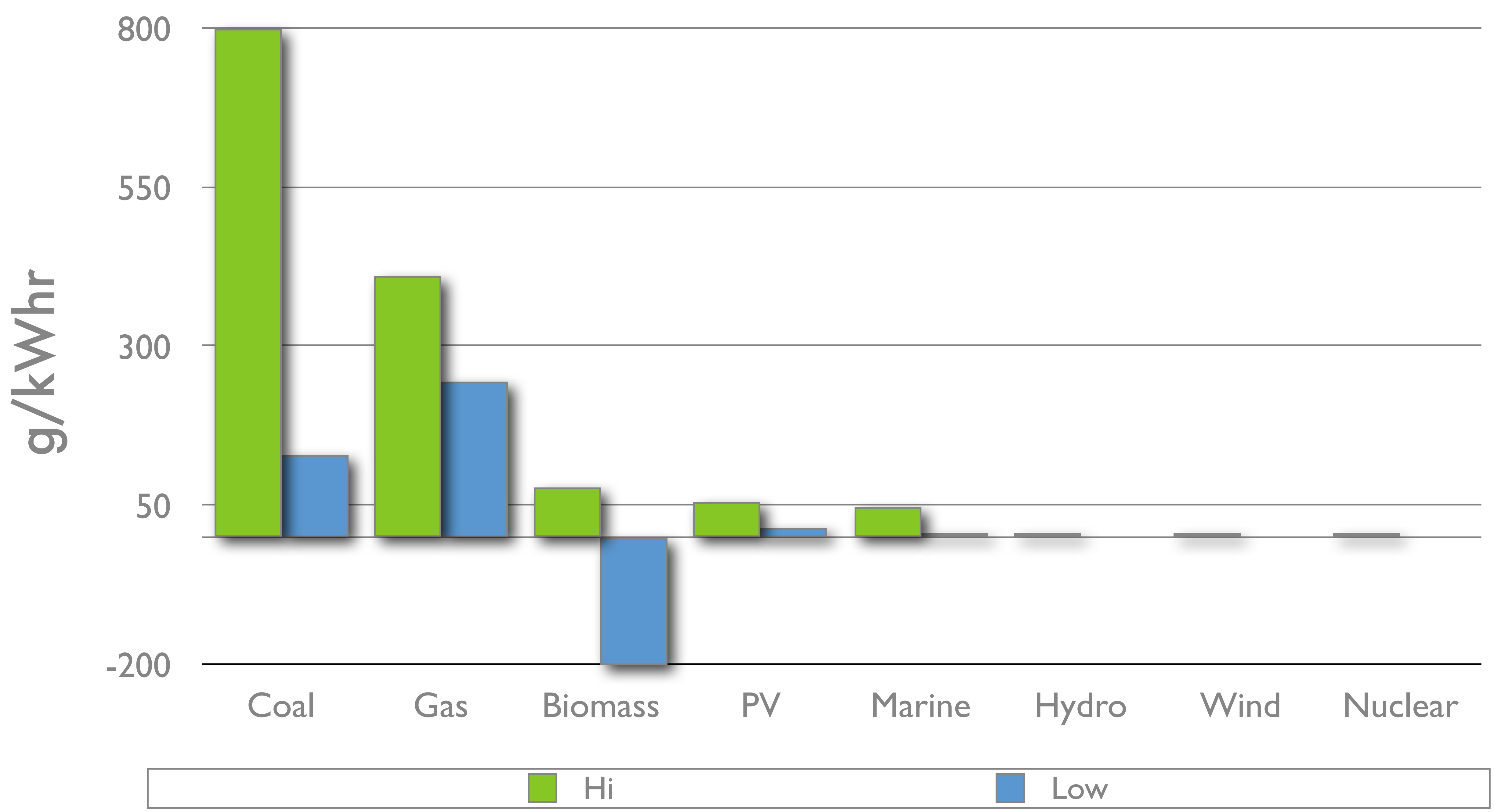


Notes

- The chart shows the major causes of carbon dioxide emissions by sector.
- The 'Services' category includes commerce and agriculture, the latter being a major source of methane, another greenhouse gas.
- 'Industry' includes power generation, a particularly large source of carbon emissions, and construction, where cement production is responsible for 7% of total emissions.**As engineers we can influence these.**

Source: DEFRA, NAEI

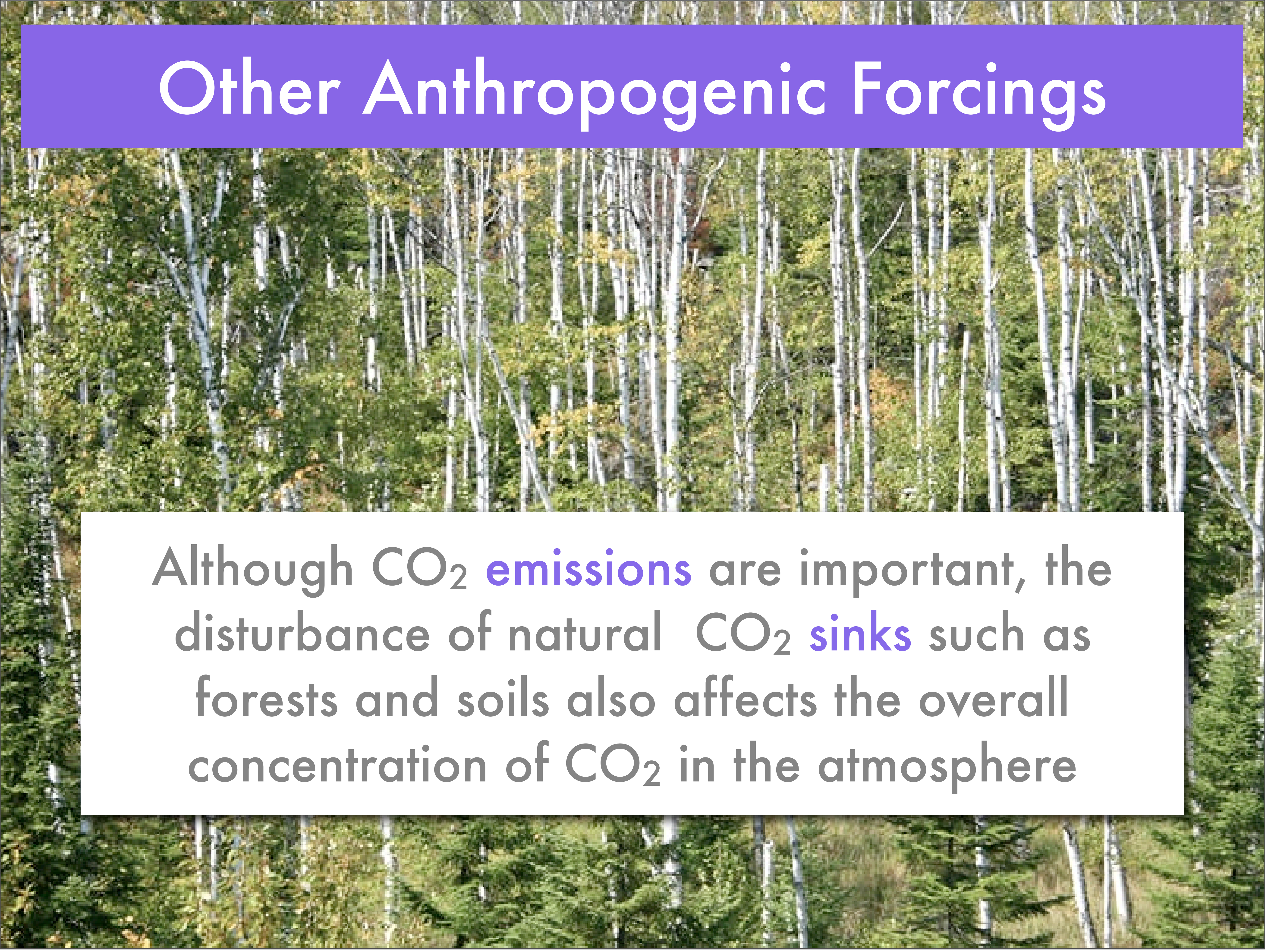
CO_2 Emissions from Fossil Fuels



Comparison of high and low lifetime carbon emissions for all technologies (grams of carbon dioxide per kilowatt hour)

Notes

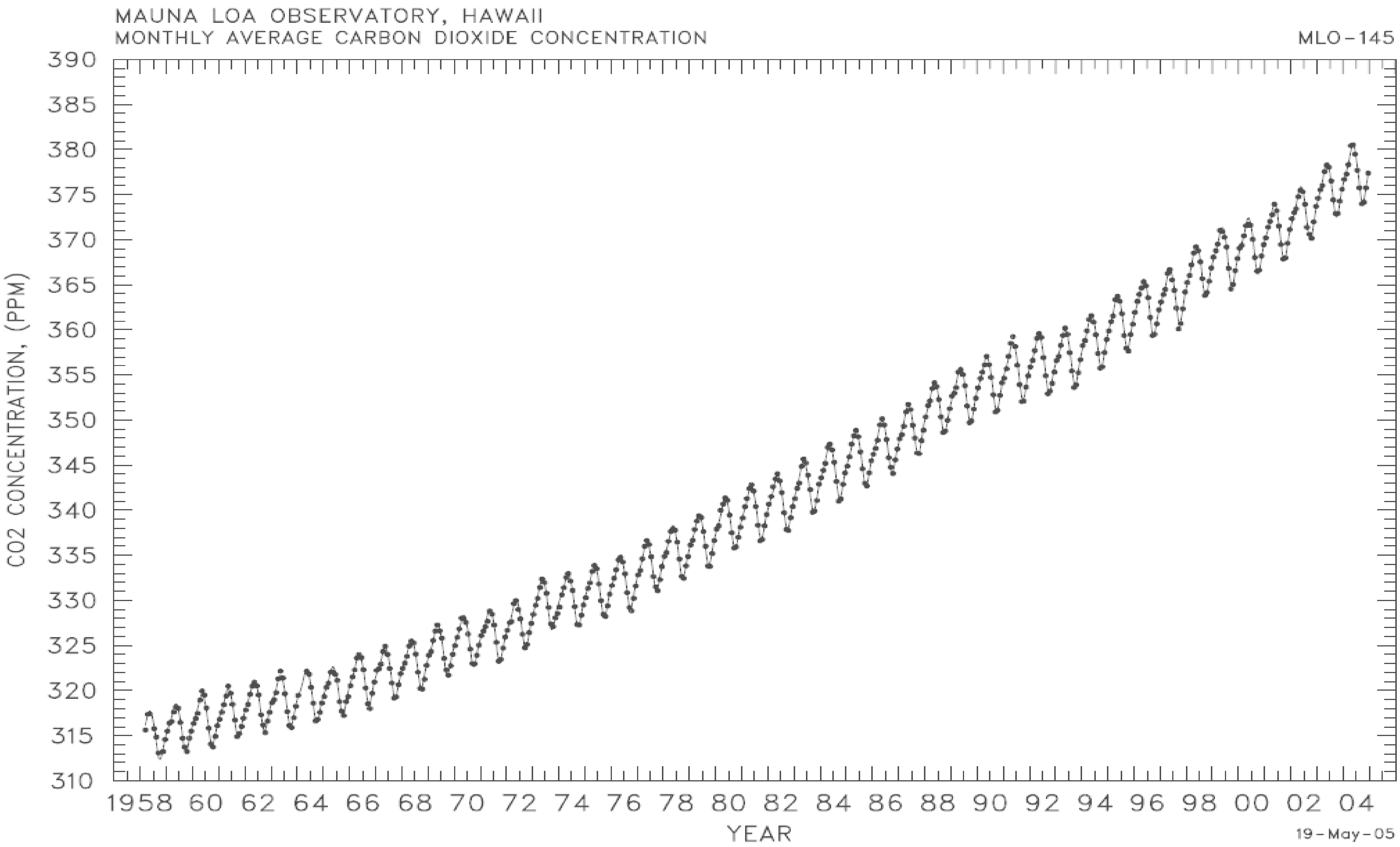
- This slide is referenced from the PostNote on Carbon Footprint of Electricity Generation http://www.parliament.uk/documents/upload/postpn268.pdf
- All electricity generating systems have a 'carbon footprint' i.e. at some points during their construction and operation carbon dioxide is emitted. The chart shown above indicates the relative carbon dioxide emissions associated with the various technologies. The units are given as grams of carbon dioxide per kilowatt hour.
- It is considered that technology improvements could increase the energy efficiency, as shown, and thus reduce CO_2 emissions from power generation considerably. This information was prepared as a briefing note for the UK Parliamentary



Notes

- The dynamics of terrestrial ecosystems depend on interactions between a variety of bio-geo-chemical cycles, particularly the carbon cycle, the nutrient cycles, and the circulation of water; all of which may be modified indirectly by climate changes and by direct human actions (e.g., land-use/cover change).
- During the period 1850-1998, net cumulative global CO_2 emissions from land-use change are estimated to have been 136 ± 55 Gt C , while that emitted from fossil fuel burning and cement production in the same period was 270 ± 30 Gt C These estimates are controversial, however.
- Re-forestation of temperate regions could help to provide an overall sink for carbon dioxide.
- Source:IPCC Special Report on Land Use, Land-Use Change And Forestry http://www.grida.no/climate/ipcc/land_use/index.htm

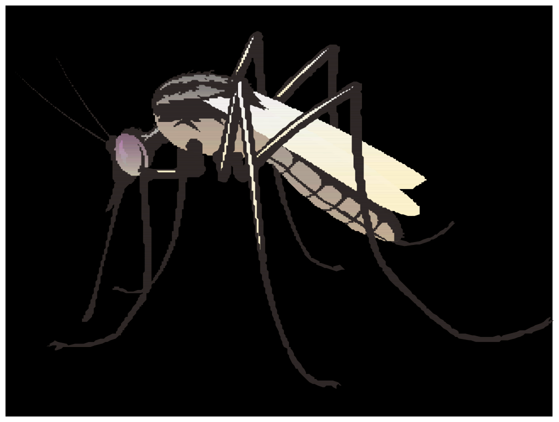
CO_2 Concentrations in the Atmosphere *(measured at Mauna Loa, Hawaii)*



Notes

- Because of the favorable site location, continuous monitoring, and careful selection and scrutiny of the data, the Mauna Loa record is considered to be a precise record and a reliable indicator of the regional trend in the concentrations of atmospheric CO_2 in the middle layers of the troposphere.
- The Mauna Loa record shows a 19.4% increase in the mean annual concentration, from 315.98 parts per million by volume (ppmv) of dry air in 1959 to 377.38 ppmv in 2004.
- Source: Atmospheric carbon dioxide record from Mauna Loa. *Keeling, C.D. and T.P. Whorf. 2005. Atmospheric CO_2 records from sites in the SIO air sampling network. In Trends: A Compendium of Data on Global Change.* Carbon Dioxide Information Analysis Center, *Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.*

Impacts of Climate Change



- Health risks

- Decreased agricultural productivity

- Increased storminess

Notes

- Data from the London School of Hygiene and Tropical medicine indicate that by 2080, malaria transmission will be common in the northern hemisphere as far North as Britain, Norway and North America.(see later slide)
- Decreases in agricultural productivity are likely to hit the poorest parts of the world first, those with populations least able to deal with the effects (India, parts of Africa and Mexico).
- Increased storminess is already being observed around the globe, with devastating effects.

Slide courtesy of Professor Roderick Jones, Department of Chemistry, University of Cambridge

Impacts of Climate Change

- Coastal flooding from rising sea levels

- River flooding from more heavy rainfall events

- Water supply problems from droughts

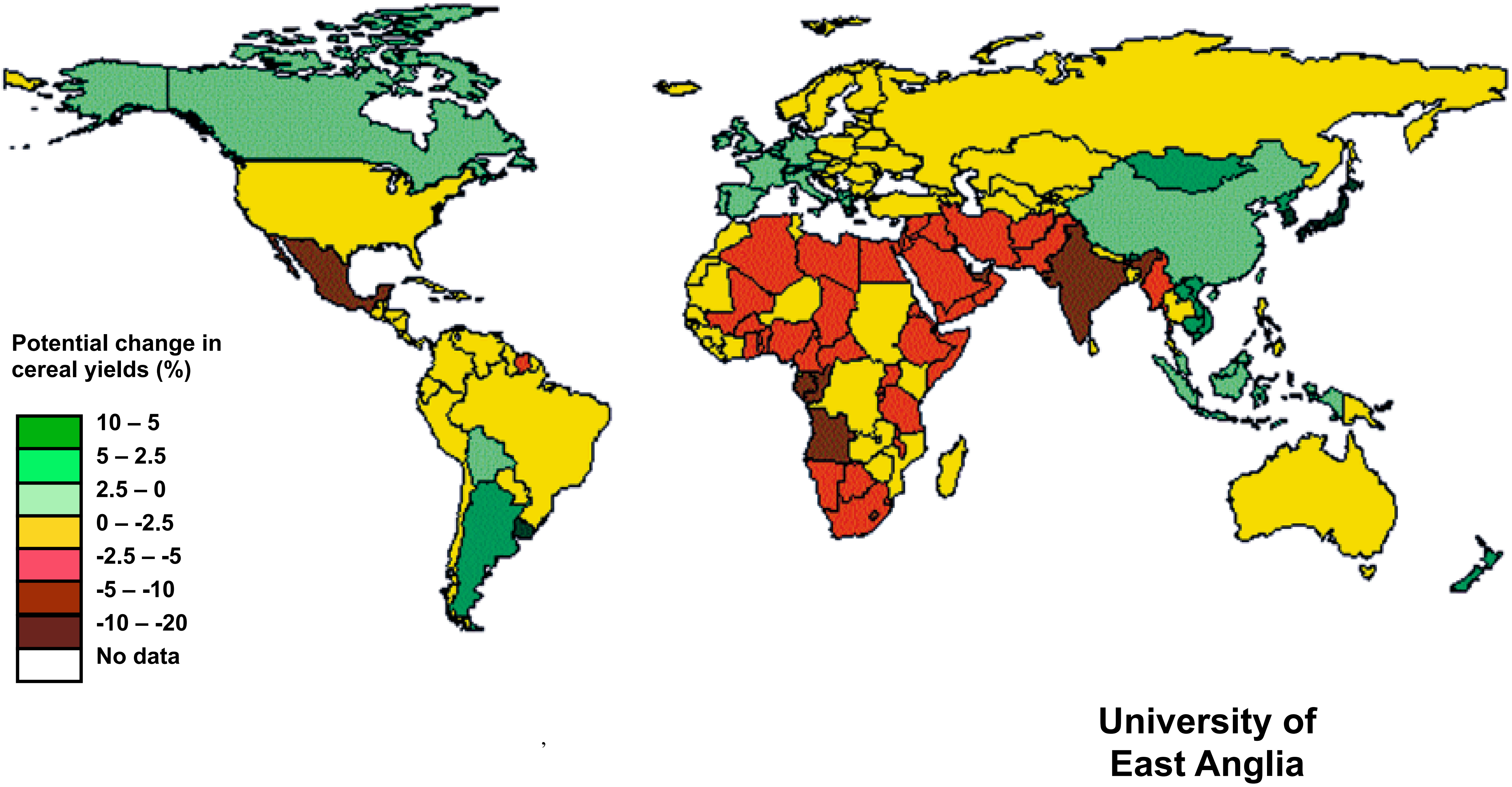
Notes

- These impacts of Climate Change are already being observed globally

Slide courtesy of Professor Roderick Jones, Department of Chemistry, Cambridge Universit

Changes in Crop Yield

from the present day to 2080s

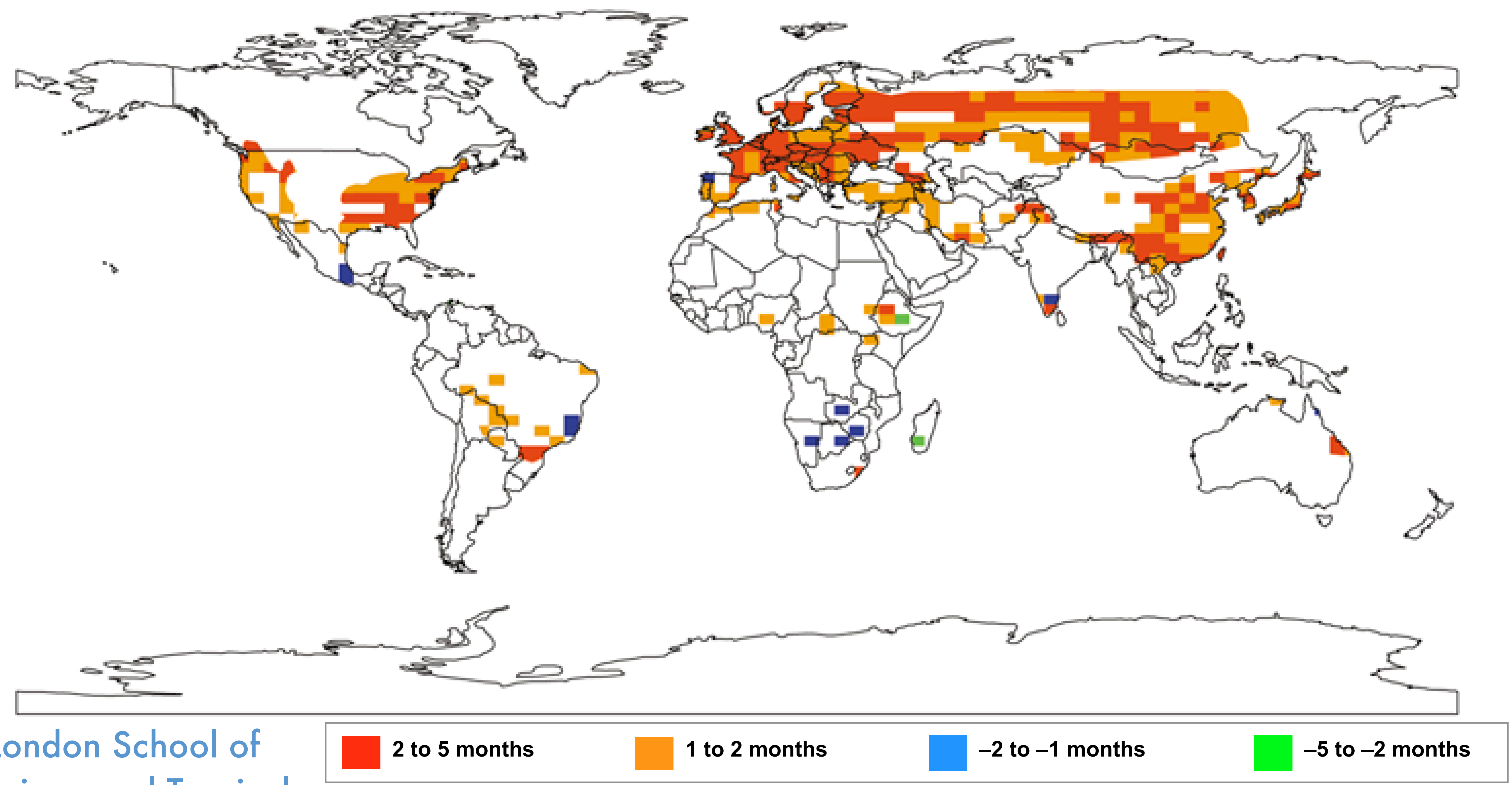


Notes

- The places in the world most likely to suffer crop failure because of climate change are coloured in red and brown
- Note that these tend to be the most populous (and poorest)countries: India, parts of Africa and Mexico.

Malaria Transmission Season

change in duration by the 2080s



London School of Hygiene and Tropical Medicine

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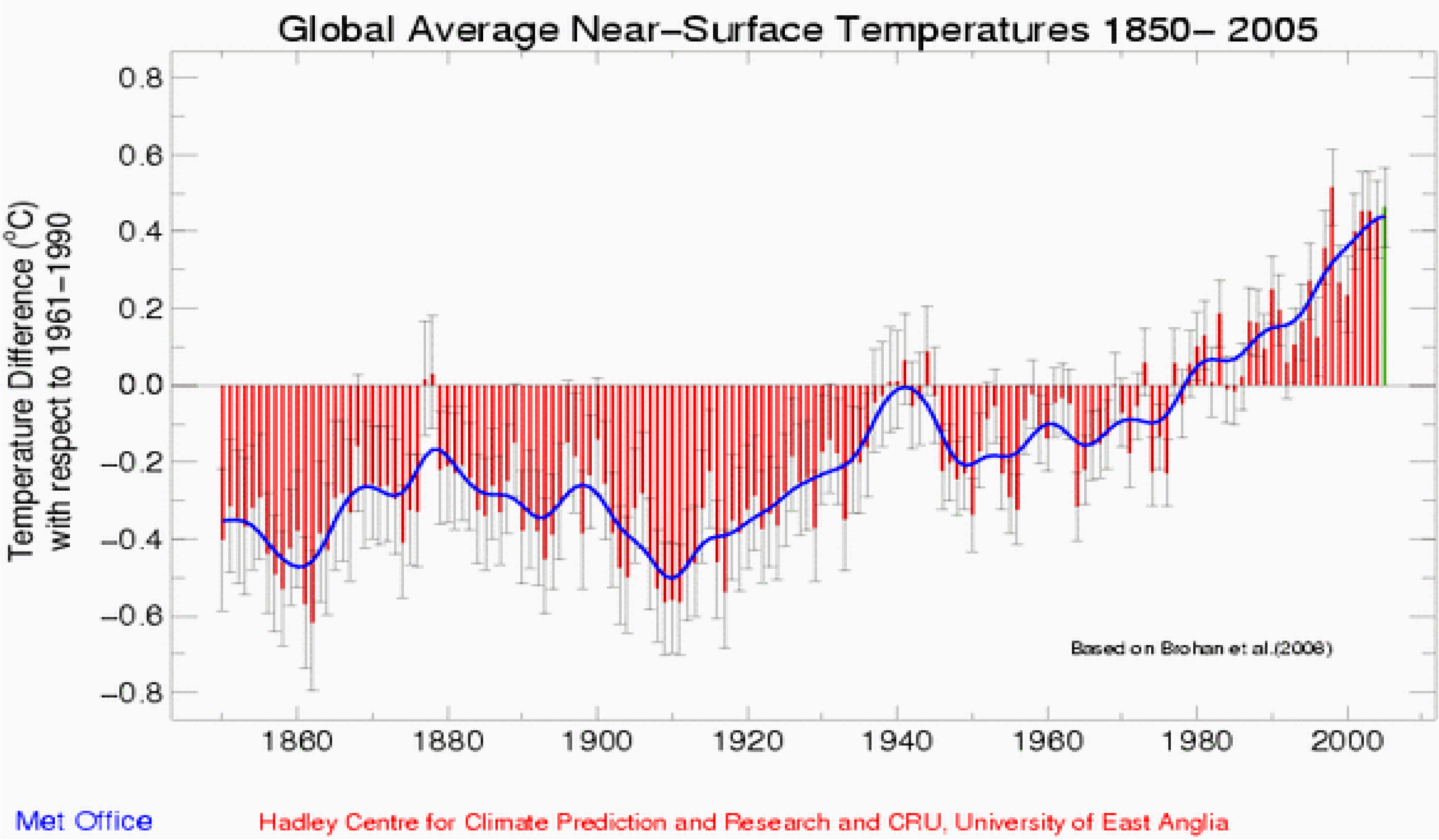
Notes

- People in many parts of the Northern hemisphere, including Europe, the USA and China will be exposed to Malaria infection from mosquitoes, a disease which in recent times has been prevalent only in tropical countries.

What Has Happened...

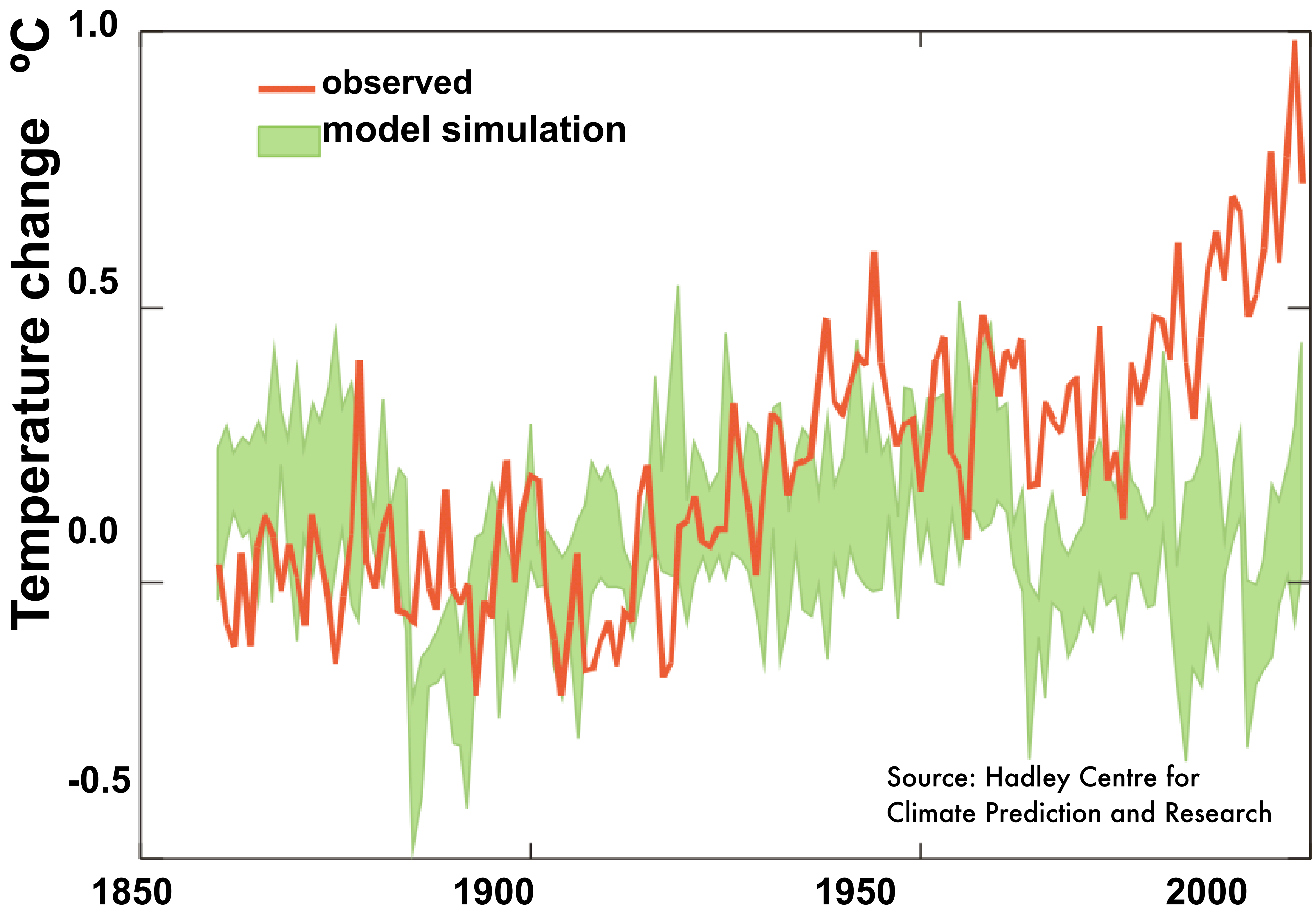


Notes

- This graph shows changes in global average surface temperature from 1861 (when sufficient observations were made to form a meaningful global average) to 2004,consisting of annual differences from 1961-1990 normals.
- The individual red lines show annual averages and the blue line shows a smoothed trend.
- Updates to this graph can be seen at the Met Office Hadley Centre website.

Observed and Simulated Change

Natural Factors Only

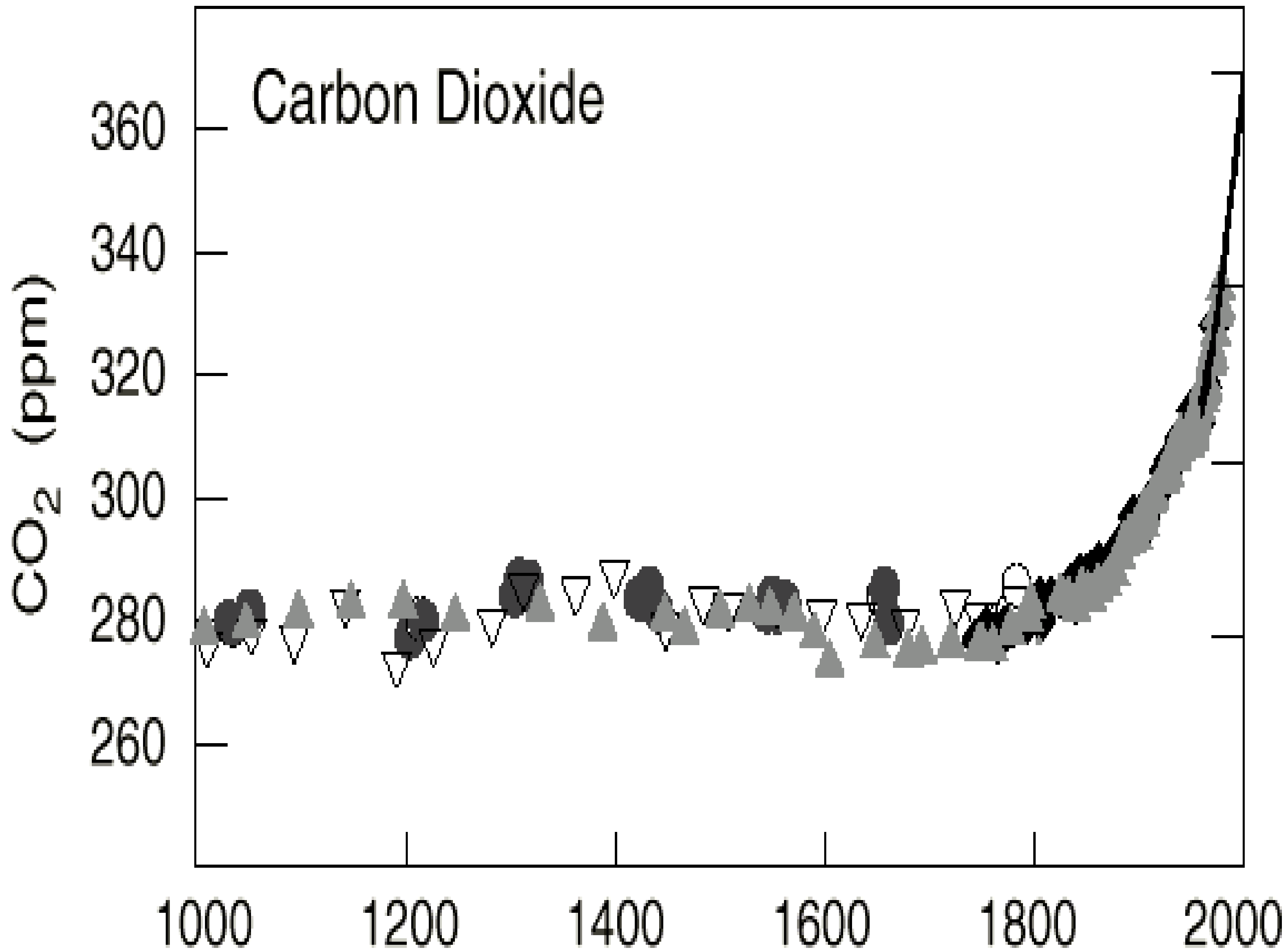


Notes

- Slide 1 of a sequence of 3 about climate modelling, aiming to answer the question: what are the causes of changes in global mean temperature observed since the early 1900s (shown in red on this slide)?
- The output from the Hadley Centre climate model, using 'natural' changes such as changes in the output of the sun and the results of volcanic emissions is shown by the green band in the slide above.
- This clearly does not agree with observations (shown in red on this slide) , particularly since 1970.

Source: Climate Change and the Greenhouse Effect: a briefing from the Hadley Centre.

Carbon Dioxide in the Atmosphere



Source: Hadley Centre for
Climate Prediction and Research

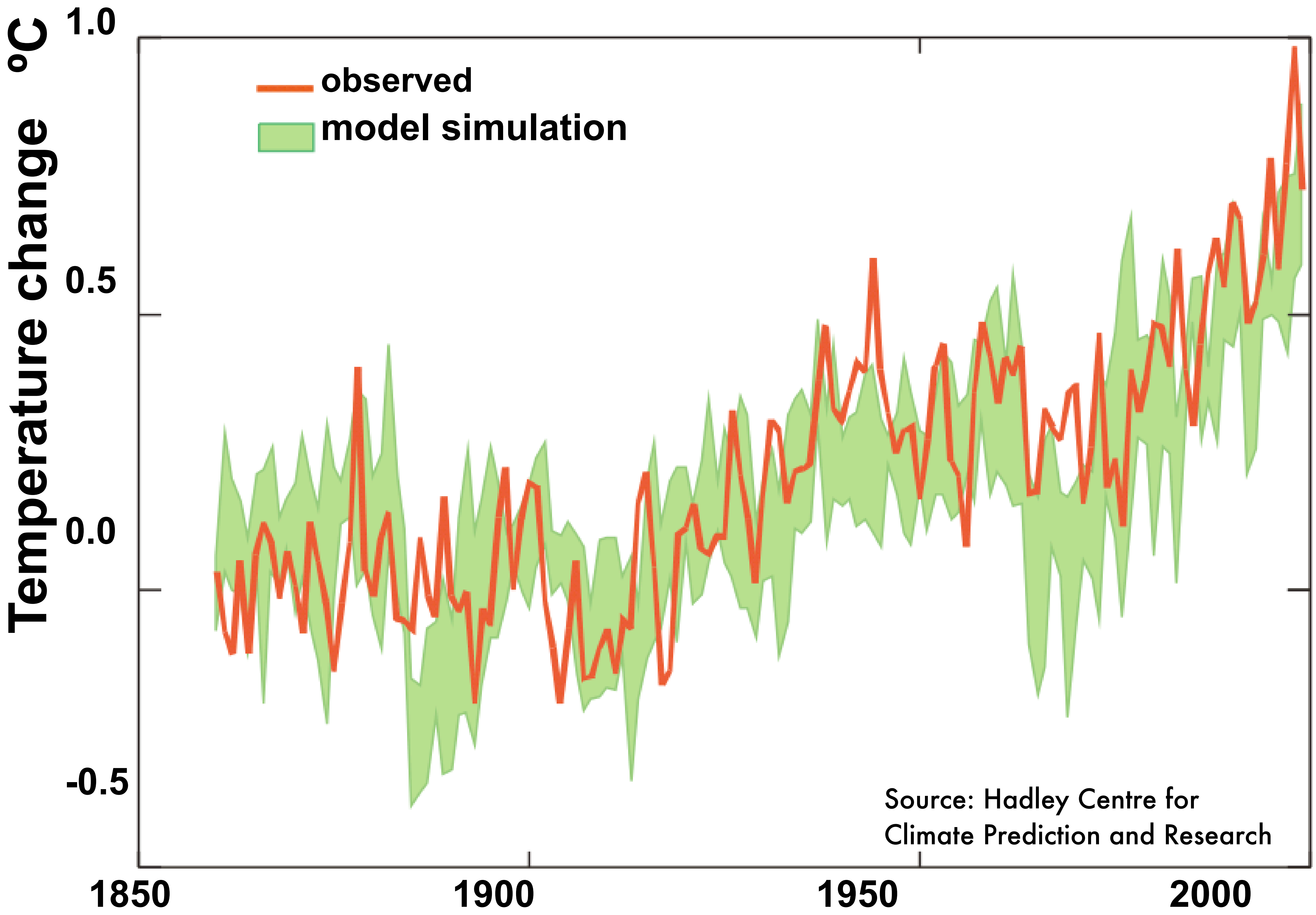
Notes

- Slide 2 of a sequence of 3 about climate modelling.
- This a reminder of the increased CO_2 emissions in the last 1000 years, with one of the causes. The concentration of CO_2 was roughly constant at about 280ppm for 800 years (and probably longer) before the start of the Industrial Revolution.
- When this increase in CO_2 , up to 360ppm, is fed into the climate model seen in the previous slide, the result is a much better match as shown in the next slide.

Data from : IPCC 2001 Third Assessment Report, Chapter 3.

Observed and Simulated Change

Natural AND Man-Made *Factors*



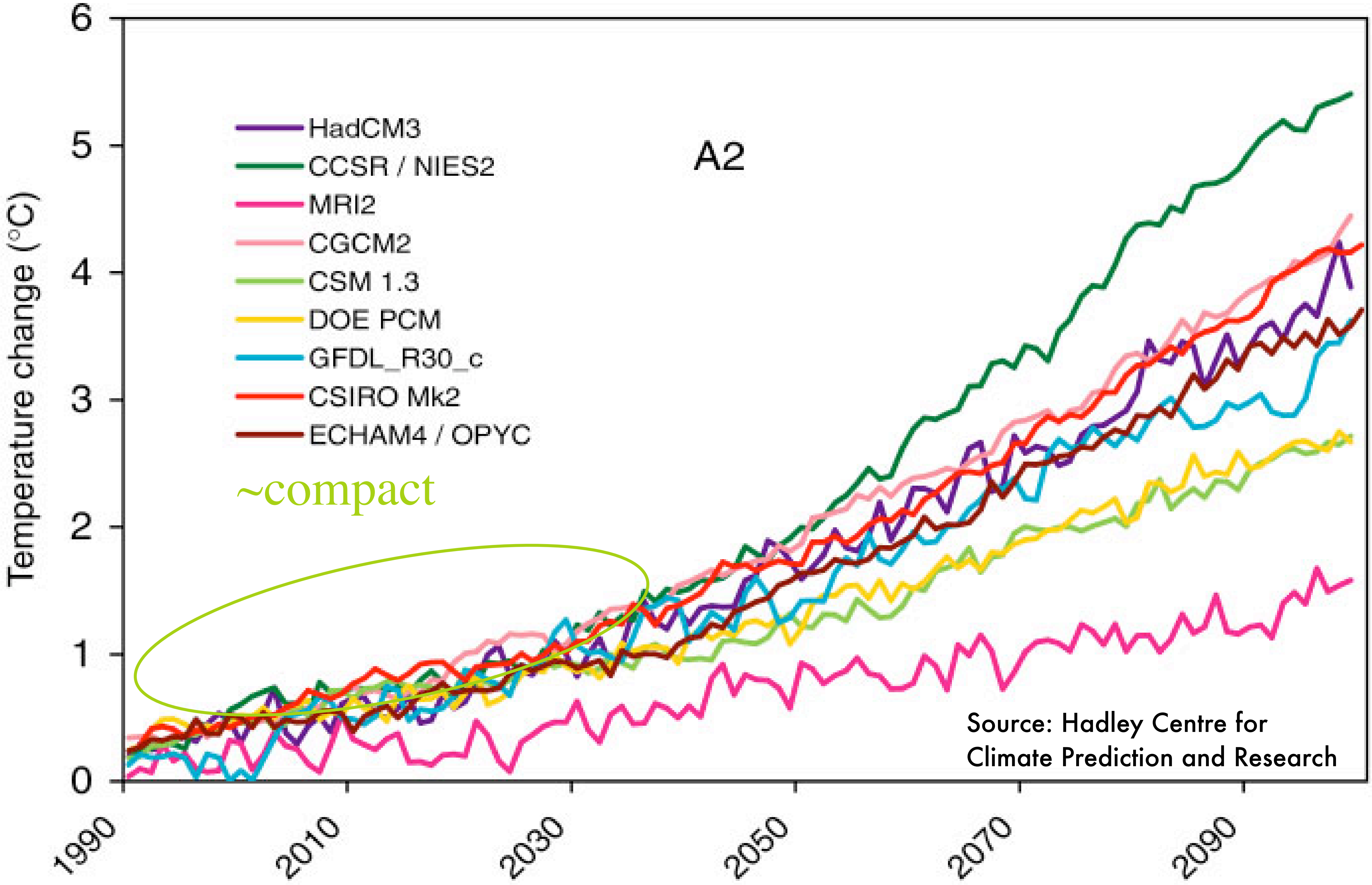
Notes

- Slide 3 of a sequence of 3 about climate modelling.
- If the Hadley Centre climate model is now driven by changes in human made factors (changes in GHG concentrations and sulphate particles) in addition to natural factors, the model (green band) and observations (red) are in much better agreement).
- This provides a powerful argument for the influence of humans on climate. Since this original modelling experiment, other modelling centres have been able to reproduce the same broad conclusion.

Source: Hadley Centre for Climate Prediction and Research.

Cautionary note: Global Temperature Rise

for the same emission scenario, predicted by 9 climate models

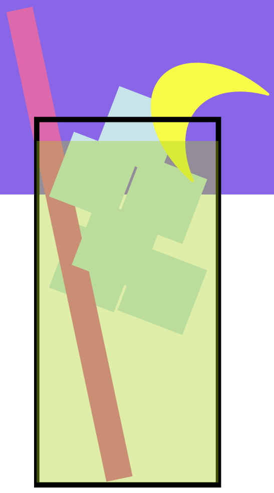


Notes

- Climate models are complex, and there is a great deal of variability. This slide shows the results of nine global climate models run using an emissions scenario labelled A2, which assumes medium to high emissions.
- The predicted warmings vary from 1.5 to 6 degrees Celsius by the end of the century. However there is pretty close agreement between the models up to 2050 (within the lifetime of the majority of current undergraduates)indicating that global warming of the order of 1 or 2 degrees will occur.

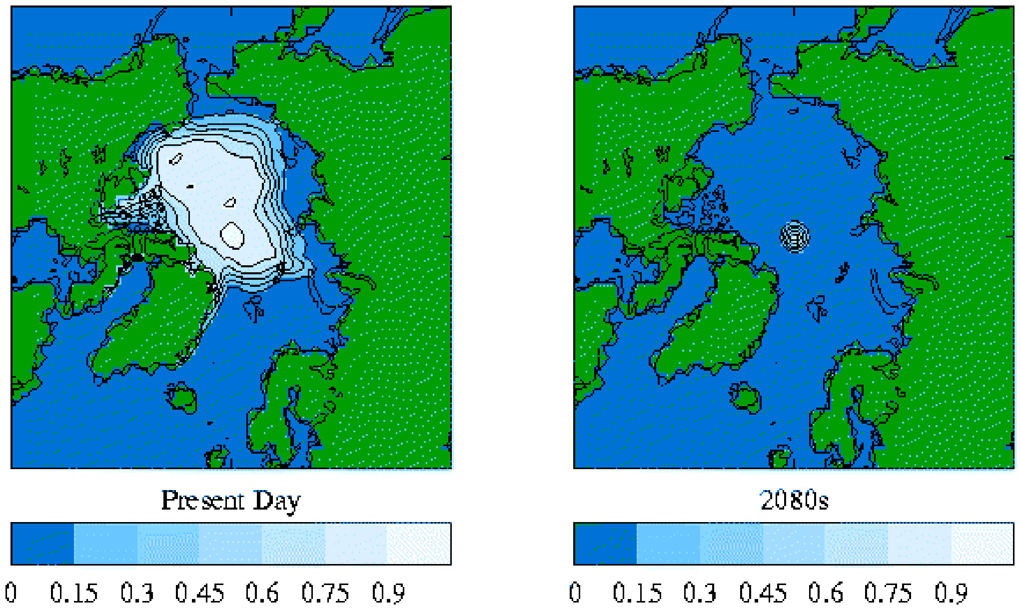
Source: Hadley Centre for Climate Prediction and Research.

Sea level changes



Decline in floating sea ice has little impact on sea level….

Arctic summer sea ice



Source: Hadley Centre for Climate Prediction and Research

1900

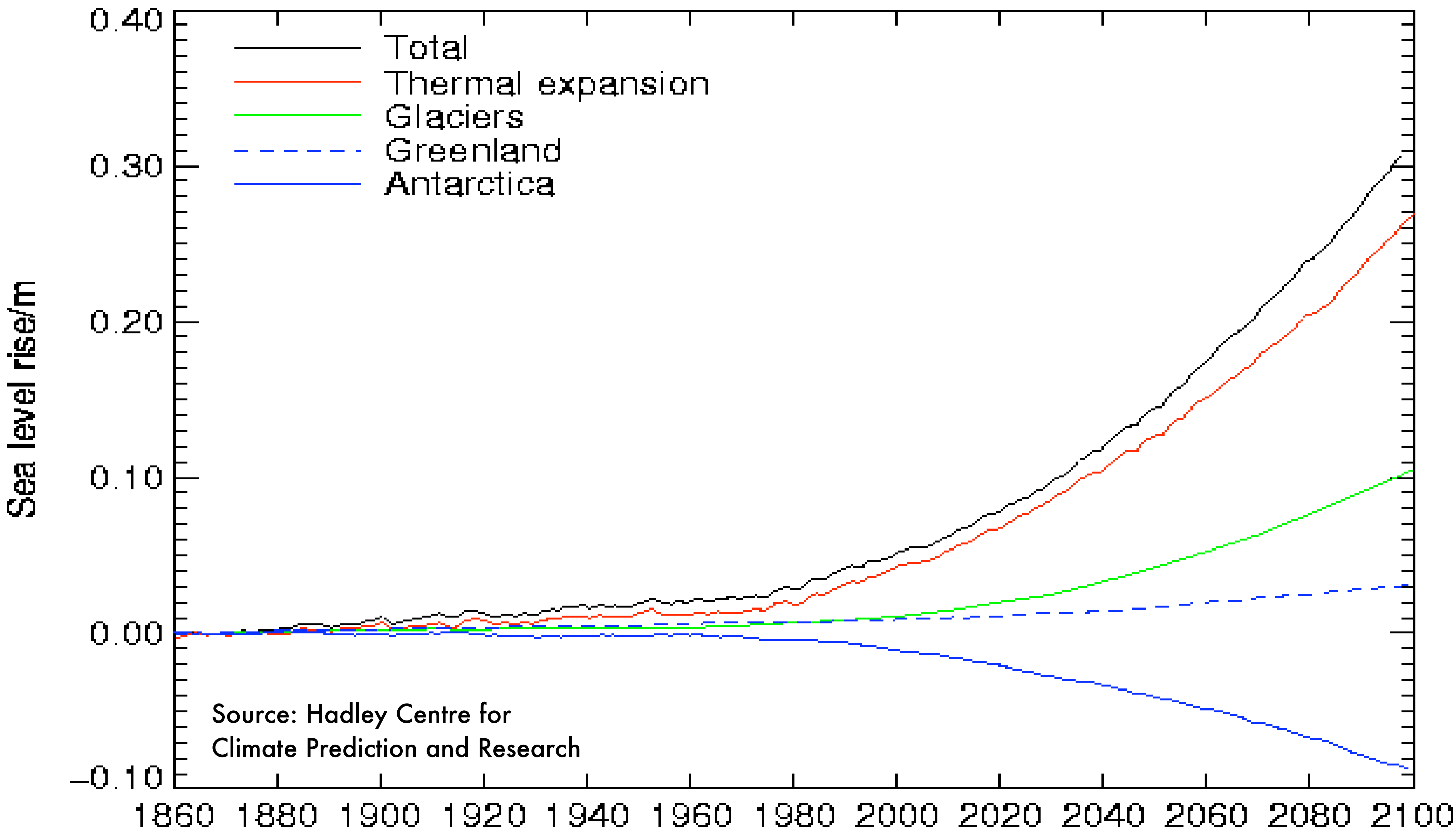
2000

Melting glaciers do…

Notes

- Using a high emissions scenario, it is predicted by the Hadley Centre model that Arctic Sea Ice will have almost completely disappeared by the 2080s.
- Of course the melting of floating ice does not cause the sea level to rise, just as when the ice melts in your drink, the glass does not overflow.
- However the melting of glaciers will cause sea level rise, as then water is being added to the sea. This effect is shown in the next slide.

Why Does the Sea Level Change?



Notes

- Above is a plot of changes in sea level predicted by the Hadley Centre model from the years 1860 to 2100, under a medium to high emissions scenario.
- The dotted blue line shows expected changes due to melting of the Greenland ice sheet;
- The green line predicts changes due to melting of glaciers and snow on land;
- The red line is the major component of sea level rise which is thermal expansion of ocean waters.
- Changes in the Antarctic ice sheet are difficult to estimate and are shown by the blue line.
- Adding these together gives an estimated sea level rise of about 0.4 metres from the middle of the last century to 2100, 0.1m of which should already have occurred, leaving around 0.3m over the next 100 years.

Source: Hadley centre for Climate Prediction and Research

Commitments

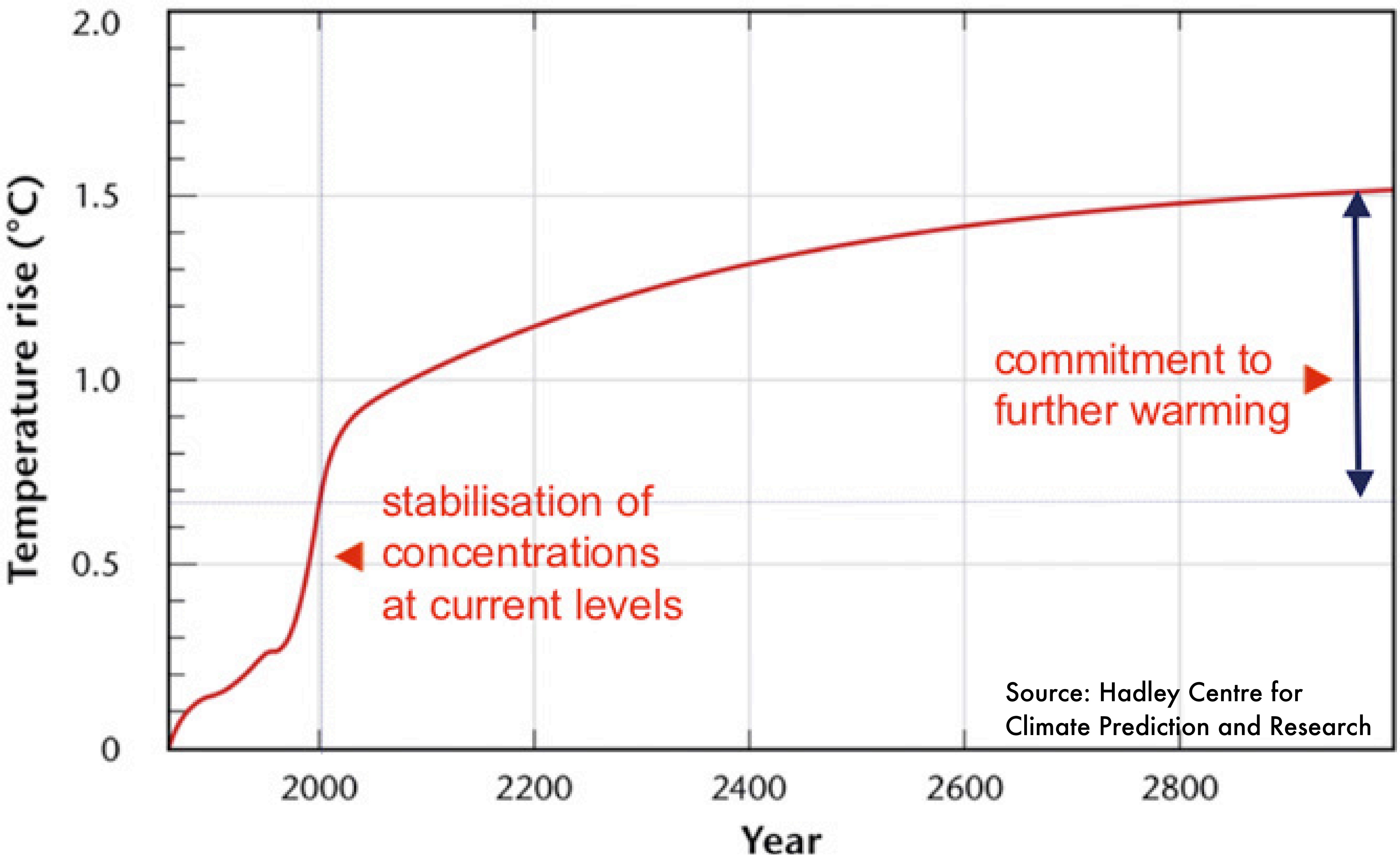
What if we could stabilise CO_2?

- Temperature rise......
- Sea level rise......

Notes

- Even if we could stop all CO2 emissions today, we are still committed to temperature and sea level rises because of the long term consequences of the gases we have put in to the atmosphere in the last 100 years. See next two slides.

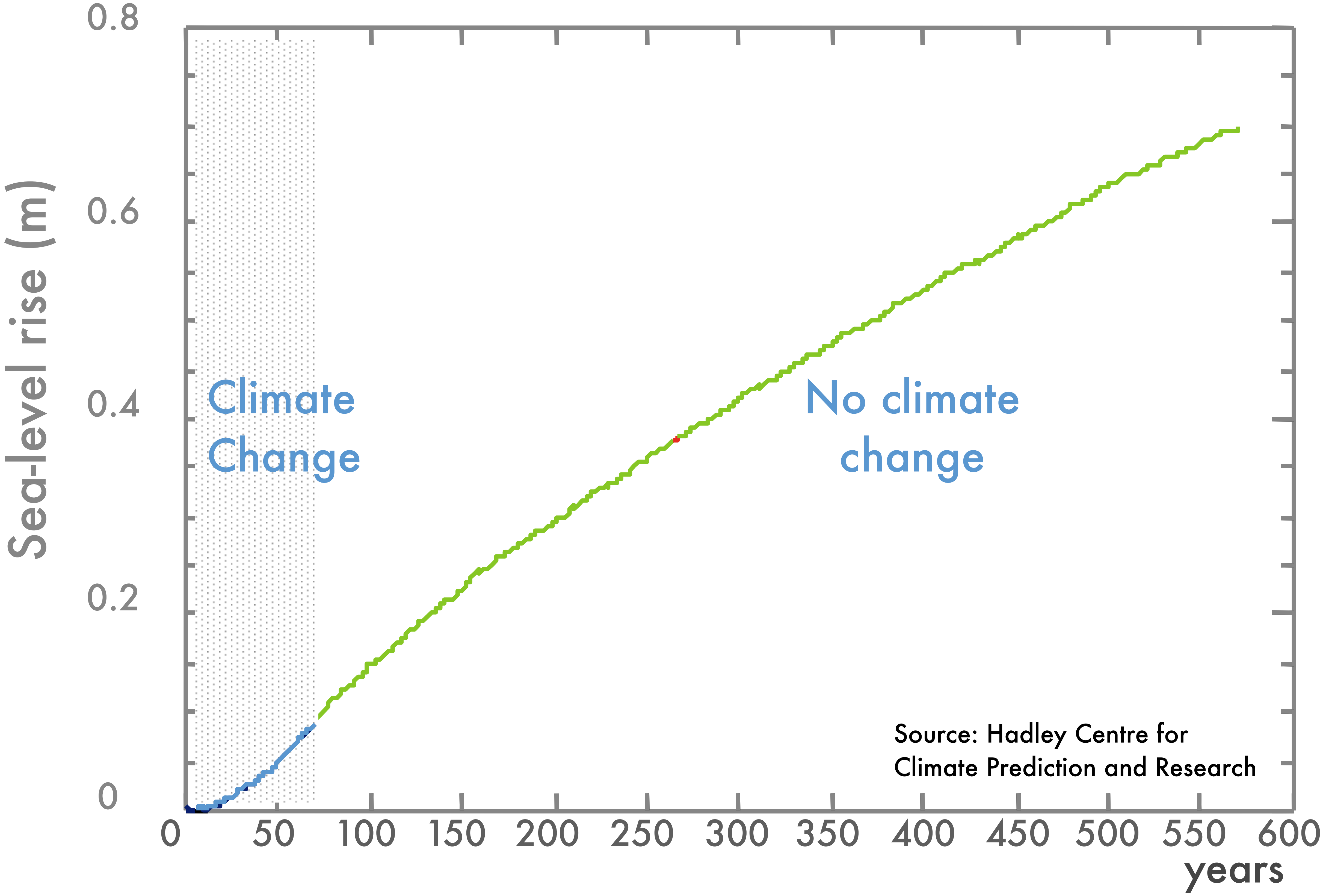
Temperature Rise Commitment



Notes

- If Greenhouse Gas concentrations were stabilised today which (in the case of carbon dioxide) would require a 70% reduction in emissions, it is predicted that the global average temperature would keep rising and eventually warm a further 1 degree celsius above today's temperature .
- This is because of the inertia of the climate system, particularly the ocean which has a large thermal capacity.
- Climate models predict that if we stabilised CO_2emissions at their current level we are still committed to a further warming of around 1degree in the next century.
- The related topic of ' Stabilisation Wedges' indicates some ways in which a reduction in CO_2 emissions can be achieved in the next 50 years.

Sea Level Rise Commitment



Notes

- The ocean takes thousands of years to reach equilibrium with a warmed atmosphere. Once, and if, CO_2 levels stabilise,the oceans will continue to warm and expand because of the gradual penetration of heat downwards.
- This figure shows the thermal expansion component of sea level rise, in a climate model experiment where CO_2 was increased by 1% per year for 70 years, until the amount of CO_2 in the atmosphere had doubled, and then was halted.
- The blue part of the curve at the beginning is the rise during the climate change part of the experiment. But, despite the fact that CO_2 did not change after year 70 (which is obviously impractical as it would require an overnight reduction of about 70% in global CO_2 emissions), the sea level carried on rising for hundreds of years.
- So at any point the sea level rise caused by the greenhouse effect carries with it a commitment to an additional, inescapable, rise.

Source: Hadley Centre for Climate Prediction and Research

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ImpEE is based at the Department of Engineering at the University of Cambridge and is funded by the CMI Institute.

Notes

- Many of these slides were copied from an excellent briefing document produced by the Hadley centre for Climate Prediction and Research, specifically for the purpose of self briefing, or briefing others on the subject of Climate change and the greenhouse effect. Their further dissemination is encouraged, with proper acknowledgement of the source material.
- The full set of slides can be downloaded from http://www.met-office.gov.uk/research/hadleycentre/pubs/brochures/