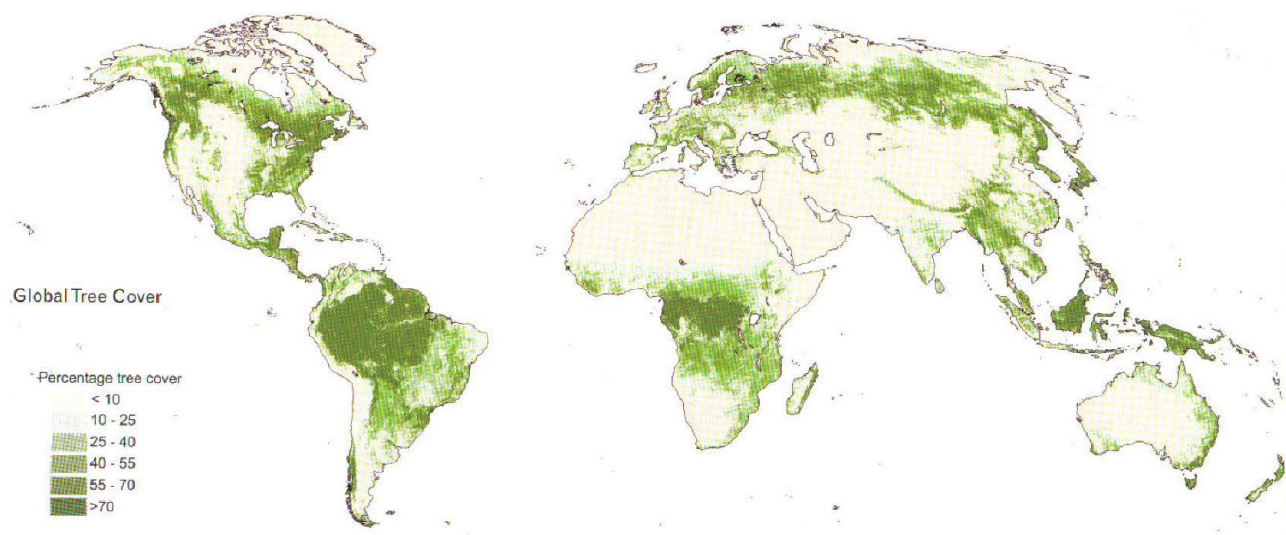


# THE CUTTING EDGE: CLIMATE SCIENCE TO APRIL 2005

## Global and UK emissions reductions Targets for 2030



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## ABSTRACT

In March 05, The EU Heads of State at the EU Council agreed that the temperature rise due to climate change should not exceed 2°C above pre-industrial levels.

This report explores, using work from the Potsdam Institute, by Hare and Meinshausen, 2004, how this temperature limit leads to a requirement to stabilise atmospheric concentrations of greenhouse gases at less than 440 ppm (parts per million) CO<sub>2</sub> equivalent.

Following work by Chris Jones et al., 2003, at the Hadley Centre we find that using a climate model which incorporates feedback from natural carbon cycles, a 2°C rise would be likely around 2030 under a business as usual scenario.

Furthermore, we find that the current natural sinks for anthropogenic emissions, around 4 gigatonnes of carbon per year (or 4 GtC a<sup>-1</sup>) will be reduced to around 2.7 GtC a<sup>-1</sup> in 2030. 2.7 GtC a<sup>-1</sup> therefore, is the amount of greenhouse gases we will be able to emit in 2030, without increasing atmospheric concentrations.

When this global emission limit is shared out between the projected world population of 8.2 billion people, we get a per capita emission limit of 0.33 tonnes of carbon per year.

In the UK we currently emit around 3 tonnes of carbon equivalent per person per year, so we will require to reduce our greenhouse gas emissions by 90%, compared with current levels, by 2030.

Further research by the Hadley Centre may have identified a major climate trigger point related to dieback of vegetation in Amazonia, which if confirmed, would require a further tightening of these emission reduction targets. The time lag between a drop in atmospheric concentrations of greenhouse gases, and a corresponding fall in mean surface temperature, means that emissions stabilisation at 440 ppm may have to be achieved sooner than 2030.

At this point, we have reached the edge of current scientific understanding, however imperfect it may be. Defra has commissioned the Hadley Centre to research the "time lag" question, and results are expected in May/June 05.

## LINKING A TEMPERATURE RISE OF UNDER 2°C TO ATMOSPHERIC CO<sub>2</sub> LIMITS

### THE EU COUNCIL STATEMENT<sup>1</sup>

" 43. The European Council acknowledges that climate change is likely to have major negative global environmental, economic and social implications. It confirms that, with a view to achieving the ultimate objective of the UN Framework Convention on Climate Change, the global annual mean surface temperature increase should not exceed 2°C above pre-industrial levels."

There is widespread support for this ceiling within the scientific and environmental communities, and recent research by Hare and Meinshausen, 2004<sup>2</sup> indicates that stabilisation of atmospheric CO<sub>2</sub>, including other greenhouse gases, at 440 ppm CO<sub>2</sub> eq. or under will be required. As illustrated in figure 1 below, only mitigation scenarios which stabilise at 350 or 400 ppm CO<sub>2</sub> (including other greenhouse gases, 380 and 440 ppm CO<sub>2</sub> eq. respectively) limit the temperature rise to less than 2°C.

For our purposes we do not require need to know the details of the various scenarios illustrated below. The point to take on board is that stabilising emissions at 450 ppm CO<sub>2</sub> (around 500 ppm, including other greenhouse gases) results in a temperature rise of around 2.3°C, whereas stabilising at 400 ppm CO<sub>2</sub> (around 440 ppm, including other greenhouse gases) limits the temperature rise to just under 2°C.

It should be noted that the B1 400-WBGU scenario leads to a temperature rise of just over 2°C for several decades around 2100, due to higher initial emissions in the next few decades.

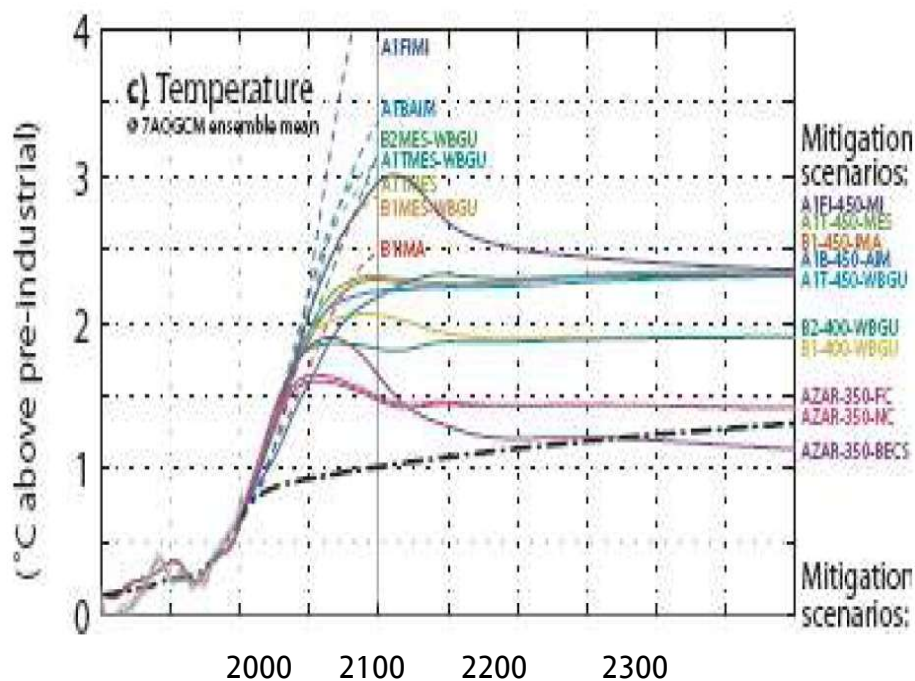


Figure 1 Temperature rise for stabilisation scenarios 350 to 450 ppm CO<sub>2</sub> only.

## ATMOSPHERIC CONCENTRATIONS OF CO<sub>2</sub>, AEROSOLS AND OTHER GREENHOUSE GASES

The current concentration of CO<sub>2</sub> in the atmosphere is 379 ppm. Adding in other greenhouse gases gives a CO<sub>2</sub> equivalent concentration of around 450 ppm CO<sub>2</sub>. The cooling effect of aerosols (SO<sub>2</sub> and NO<sub>2</sub>) reduces the warming down to around 382 ppm CO<sub>2</sub> eq.

In the graph below, from Jones et al, 2003<sup>3</sup>, the black line is the recorded global mean surface temperature to 2000, the green line is the modelled temperature under a "business as usual" emissions scenario, SRES A2, including the cooling effect of aerosols, and the red line is without.

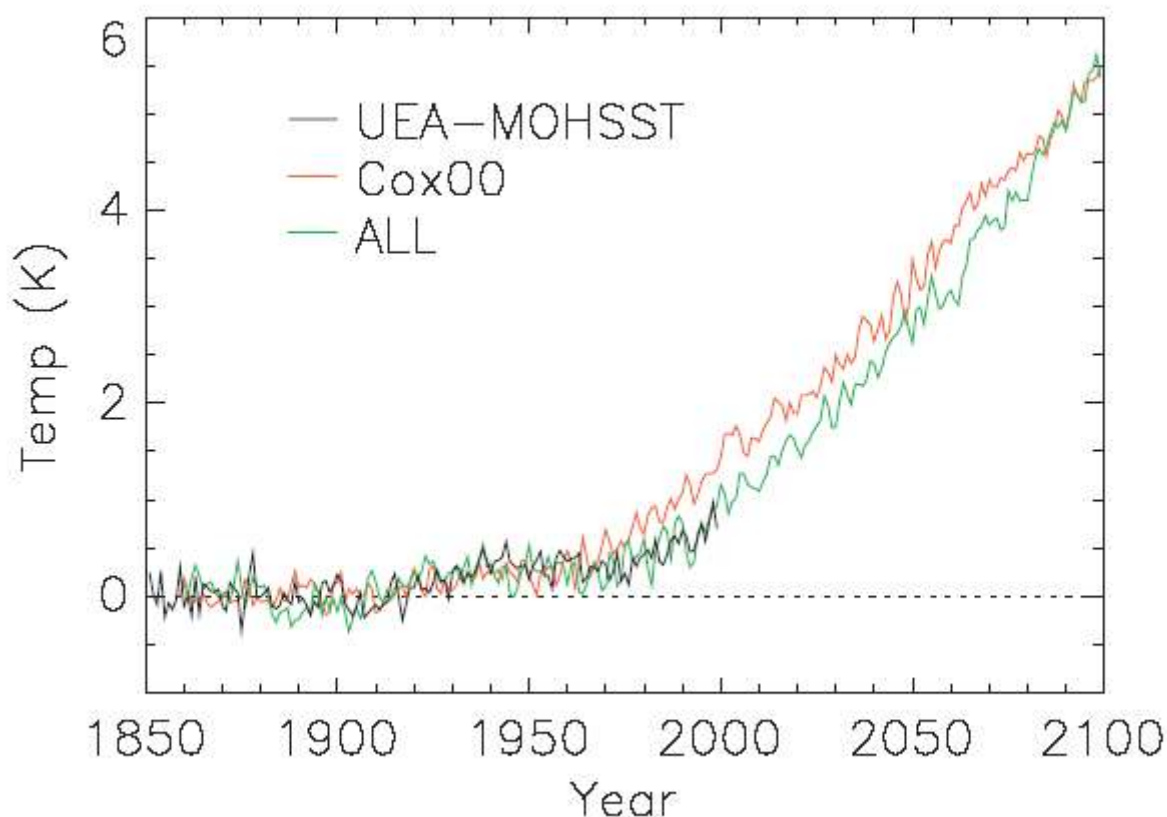


Figure 2: Projected temperature rise with and without aerosol cooling effect.

### FUTURE CHANGES IN AEROSOL CONCENTRATIONS

As an environmentalist, it is my opinion that we will need to use carbon capture and storage technology (CCS) to remove CO<sub>2</sub> from coal, gas, and biomass fired power stations, on a global scale, within the next decades, to stand a chance of avoiding a runaway climate effect. As these power stations are a major source of aerosols, which are causing widespread health, environmental, and economic impacts when they are washed out of the atmosphere by rain (acid rain), it is likely that the technology to remove CO<sub>2</sub> will also include flue gas scrubbing

to take out SO<sub>2</sub> and NO<sub>2</sub>.

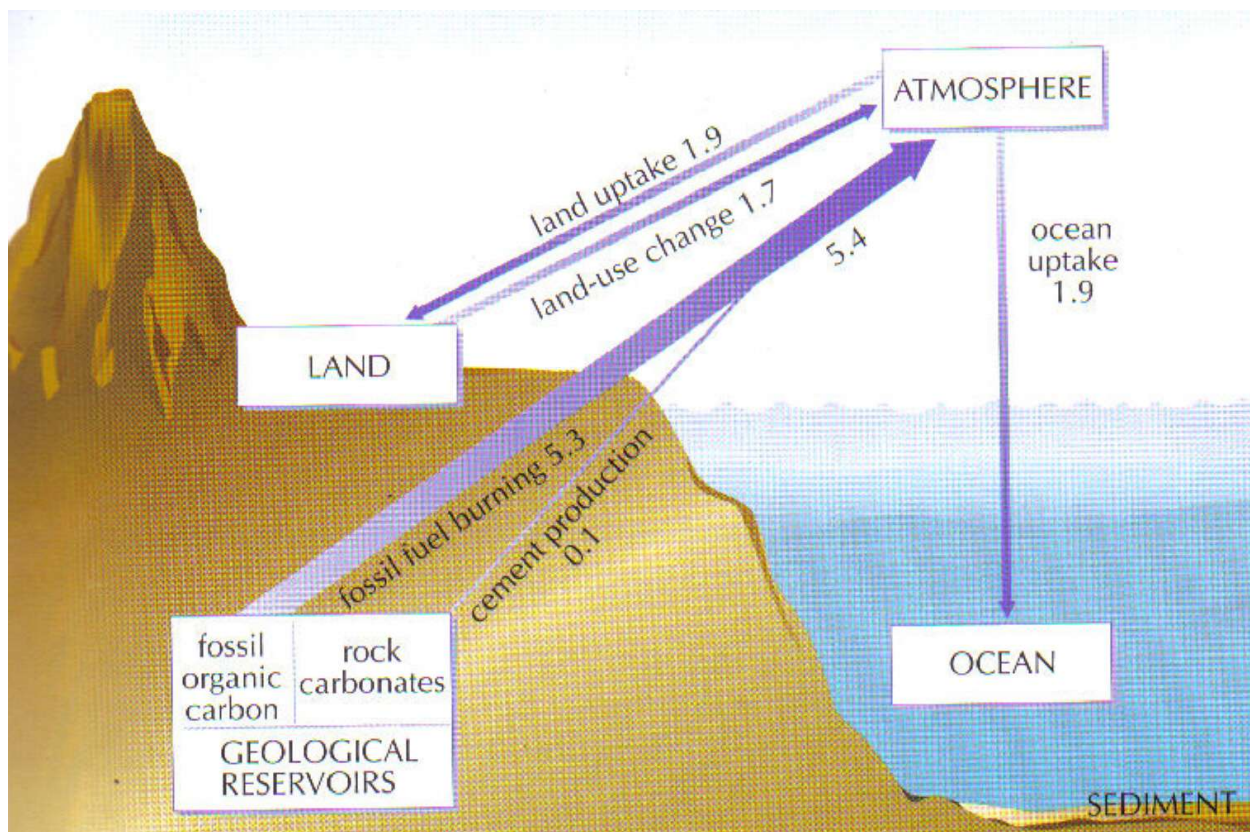
Transport fuels are another source of aerosols, and whether we manage to reduce transport emissions voluntarily or are forced to by dwindling supplies of oil after 2010 - 2015<sup>4</sup>, any decent global effort to stop climate change within the next couple of decades, will involve losing most of the cooling effect of these aerosols.

So, while there would appear to be some headroom between the suggested maximum stabilisation limit of 440 ppm CO<sub>2</sub> eq., and the current net radiative forcing of 382 ppm CO<sub>2</sub> eq., we will lose that margin when we lose the cooling effect of aerosols, giving us an effective warming effect of around 450 ppm CO<sub>2</sub> eq.<sup>7</sup>

When we discount the aerosol effect, which we are going to lose over the next decades, the stabilisation level needed to avoid dangerous climate change (under 440 ppm CO<sub>2</sub> eq.) is basically the same as the current level (450 ppm CO<sub>2</sub> eq.).

Given the large uncertainties involved in estimating and modelling global systems, it would be unwise to quibble about 10 ppm either way. Basically, we are talking about stabilising greenhouse gas concentrations in the atmosphere at current levels, or, if they increase in the short term, reducing them to under 440 ppm CO<sub>2</sub> eq. as soon as possible.

Figure 3 CARBON SINKS AND SOURCES<sup>9</sup>



## SINKS, STORES AND SOURCES OF CARBON

If we want to stabilise atmospheric greenhouse gases at current levels, we will have to limit our emissions to the amount which can be absorbed by the planet's ecosystems and oceans.

About 2 GtC per year is absorbed by plants (mostly trees), and by dead plant matter adding to the carbon stored in soils. In figure 4, below, darker areas store more carbon. There is a major belt of tropical rainforest along the equator (Amazonia, the African Congo and SE Asia) where more of the carbon is stored in living vegetation. The other major stores of carbon are contained in the high northern latitudes in the boreal forests and peatlands and tundra where more of the carbon is stored in organic matter in soils (Scandinavia, Scotland, arctic Russia, Canada and northern USA)

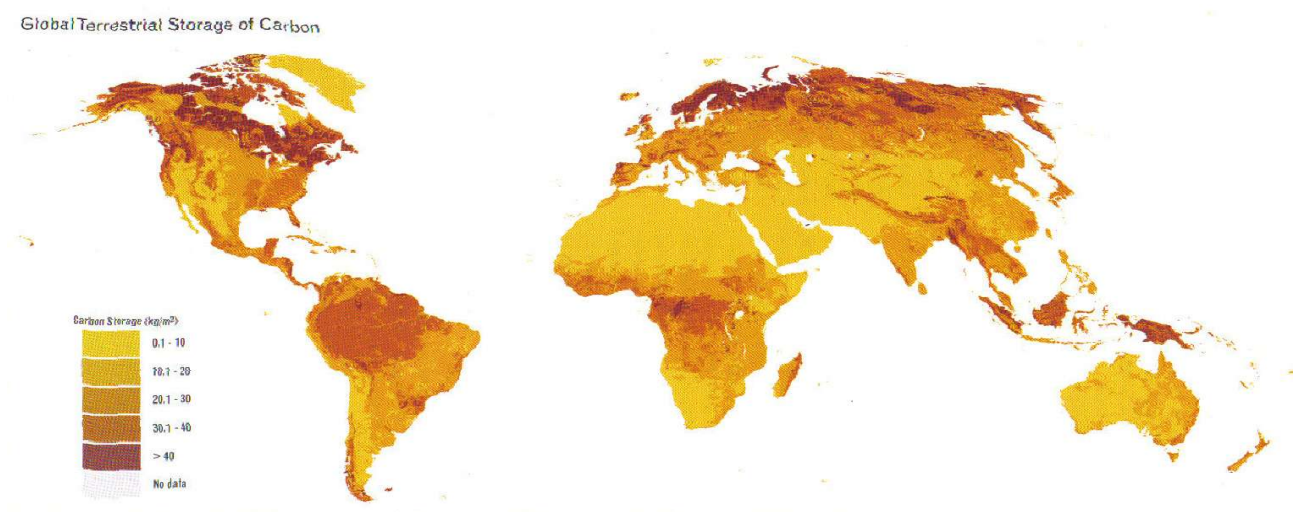
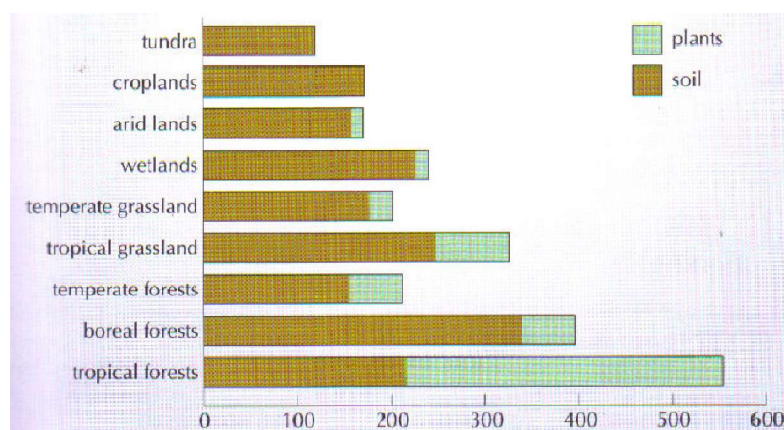


Figure 4 Global terrestrial storage of carbon<sup>10</sup>

Figure 5 carbon stored globally in major climate zones<sup>11</sup>



We now look at the work of Chris Jones et al. (2003) who included carbon cycle feedback from terrestrial sources in the HAD CM3 climate model<sup>3</sup>, driven by anthropogenic emissions from a "business as usual" emissions scenario, IS92a.

Figure 6, below, shows cumulative changes in carbon stores from an arbitrary zero point in 1850. If the curves are rising, CO<sub>2</sub> is being taken out of the atmosphere and if the curves are falling CO<sub>2</sub> is being emitted.

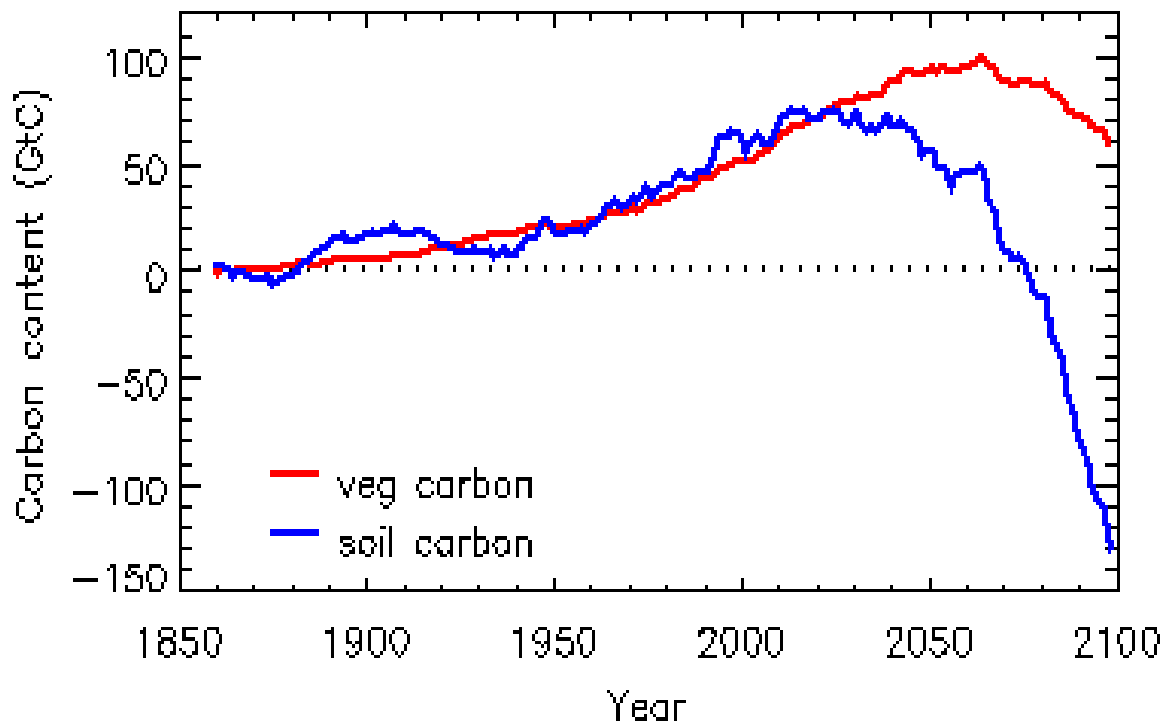


Figure 6 modelled changes in global soil and vegetation carbon, Jones et al. 2003

In figure 6 above, we can see that carbon is projected to accumulate in vegetation at a steady rate until 2060, but no more carbon is stored in soils after 2010. Between 2010 and 2040, global vegetation absorbs about 28 GtC, while soils emit about 5 GtC, giving an overall sink of 23 GtC, which averages 0.8 GtC per year over the period.

Modelling of CO<sub>2</sub> fluxes between the atmosphere and the oceans is less developed, but it is likely that the oceans will continue to absorb the same amount of CO<sub>2</sub> (2 GtC per year) between 2010 and 2050.

Between 2010 and 2040 we can estimate that only 2.8 GtC per year will be absorbed by natural processes on land and in the oceans, and this is the upper limit to the amount of anthropogenic emissions we can allow without increasing atmospheric concentrations of greenhouse gases to rise above current levels.

### EMISSIONS REDUCTIONS TARGETS

Anthropogenic emissions are currently around 7 GtC per year, (5.5 GtC from fossil fuel combustion and 1.5 GtC from deforestation and land degradation, see figure 3 on page 5) so this implies a reduction of 60% on current global emissions.

Table 1, below shows the per capita allowable emissions, if the global emissions budget of 2.8 GtC per year is shared out globally under the principle of contraction and convergence. The per capita allowance varies from 0.3 to 0.4 tonnes of carbon per year, depending on the size of the global population.

(	Year	population <sup>4</sup> (billions)	per capita emissions (tonnes of carbon per year)
	2010	6.8	0.4
	2020	7.5	0.36
	2030	8.2	0.33
	2040	8.7	0.31

Table 1 Global population, permissible per capita emissions, temperature, to 2040

This will be a particularly hard target for energy intensive developed countries to meet. In the UK, for example, we currently emit about 3 tonnes of carbon per year, per person, so we will need cuts of 90% (or if we use the base year for Kyoto Protocol targets, 1990, when we used around 3.5 tonnes of carbon per year, per person, the reductions required would be 94%).

## TIMESCALE FOR REDUCTIONS

Figure 2 on page 4 shows global temperature rise exceeding 2°C around 2030, even taking the current aerosol cooling into account (the green line). As there is a time lag in the climate system between reducing emissions and a corresponding fall in temperature, we will need to reach stabilisation at 440 ppm or less before this point.

## COMMITTED WARMING

Even after we stabilise emissions, temperatures will continue to rise, at a gradually reducing rate, for hundreds of years. If we stabilised emissions at current levels now, in 2005, we would be committed to a further rise of 0.2°C by 2050 and a further rise of 0.2°C by 2400<sup>8</sup>. To prevent a 2°C rise, we will need to stabilise emissions before the mean surface temperature reaches 1.8°C, or reduce emissions below 440 ppm CO<sub>2</sub> eq. between 2030 and 2050 (or possibly both).

## UNCERTAINTY ABOUT THE "CLIMATE SENSITIVITY" OF COMPUTER MODELLING

A further cause for worry is the scientific uncertainty over the "climate sensitivity" of the model which runs the emissions scenario. The climate sensitivity is a measure of the temperature rise in a modelling system for a doubling of atmospheric CO<sub>2</sub>, once the climate has reached equilibrium, i.e. in hundreds of years. It takes no account of non-linear or catastrophic climate changes which could be triggered at certain temperature or precipitation thresholds, but gives a useful measure to compare models over the narrow range of CO<sub>2</sub> concentrations and temperature rises which we are concerned with in avoiding dangerous climate change.

The "real" climate sensitivity is thought by the IPCC to be between 1.5 and 4.5 °C (for a doubling of atmospheric CO<sub>2</sub> concentrations), which is one of the reasons for the large ranges and uncertainties in IPCC reports. The current scientific consensus is that the real climate sensitivity is probably about 2.8°C, around the midpoint of the IPCC, and which is the average of the 7 models selected to run the emissions scenarios in Hare, 2004, and the HAD CM3 model used by Jones et al., 2003, above.

In other words, all the computer modelling projections in this report are based on an assumed climate sensitivity of 2.8°C, which seems to be an unofficial consensus "best guess".

Figure 7, below, shows a range of possible global temperatures for a 440 ppm CO<sub>2</sub> eq. stabilisation scenario, depending on the "climate sensitivity" which ranges from 1.5 to 4.5 °C. The solid black line represents the median and coloured bands show the probability gradients. The 440 ppm CO<sub>2</sub> eq. stabilisation scenario illustrated has a 33% chance of exceeding the 2°C ceiling.

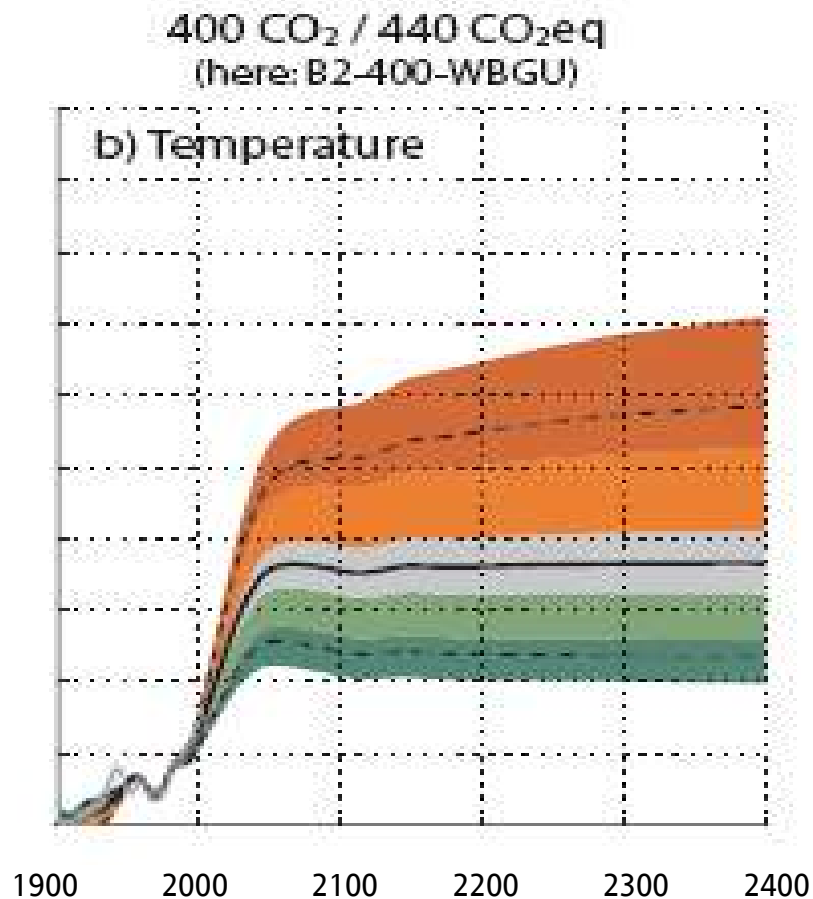


Figure 7 Temperature rise for 440 ppm CO<sub>2</sub> eq. Stabilisation scenario, under the current IPCC range of climate sensitivity.

If the climate sensitivity is higher than current estimates (for example because of large positive feedbacks from the terrestrial carbon cycle ) then stabilisation at 440 ppm CO<sub>2</sub> eq. would be less likely to prevent a temperature rise of over 2°C.

## DIEBACK IN AMAZONIA

Another reason for opting for a precautionary approach relates to the non-linear response of ecosystems to temperature and precipitation change. We now look at some further work by Chris Jones and colleagues at the Hadley Centre, who have possibly identified one of the first and most important trigger points regarding climate change feedback. Their report has not been published yet, but the graph below was taken from the Hadley brochure "Stabilising Climate to Avoid Dangerous Climate Change" Feb 05.

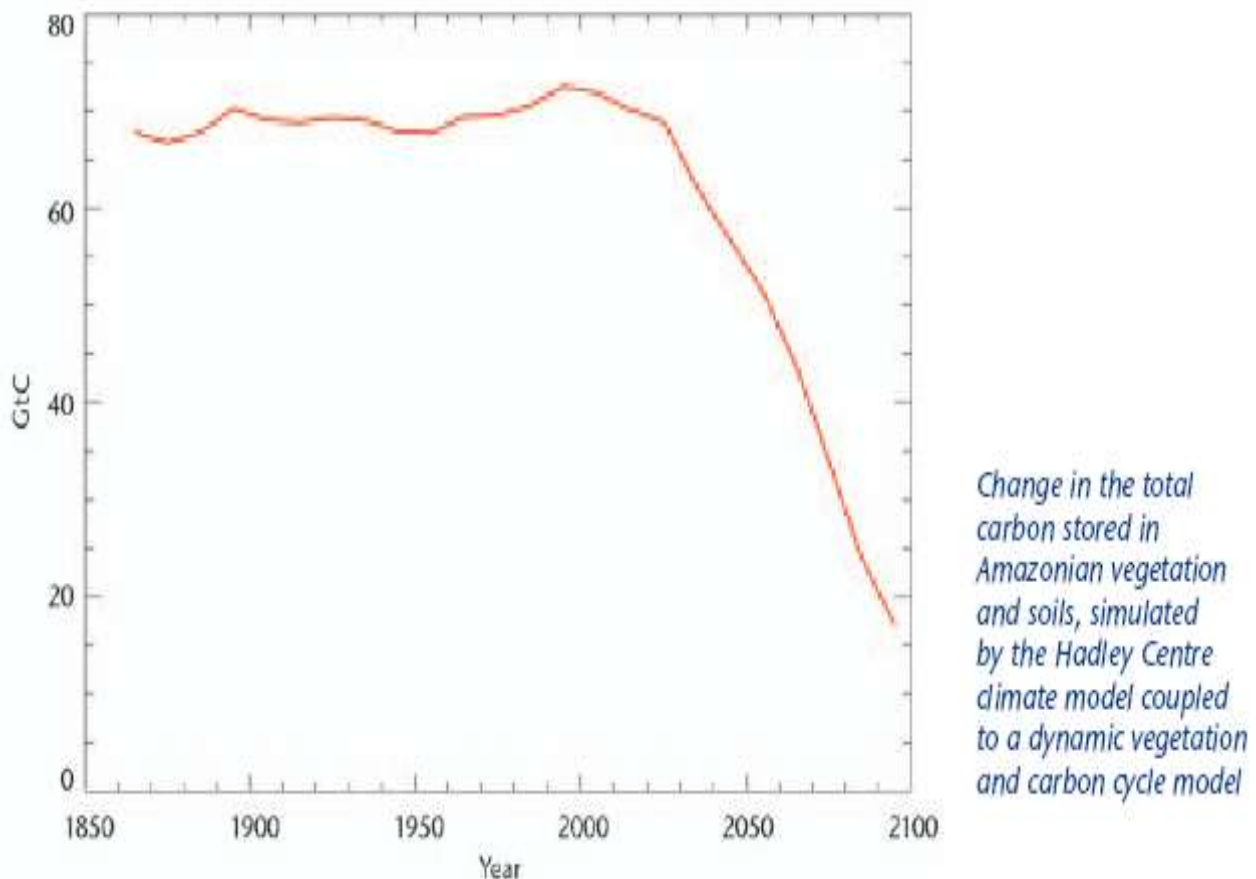


Figure 8 Changes in total carbon stocks in Amazonia, 1850 – 2100

Figure 8, above shows that the Amazonian ecosystem is fairly stable until 2025, releasing 5 GtC over 25 years, averaging 0.2 GtC emissions per year.

At 2025, the region becomes a major source of CO<sub>2</sub>, emitting 55 GtC over the next 75 years. This is an average of 0.73 GtC per year, which, to put things in perspective, is equivalent to the current US emissions from burning oil, or about 10% of all man-made emissions.

The dieback in Amazonia will be caused by reduced precipitation as well as increased temperature, but as the temperature at that trigger point in 2025 is likely to be less than 2°C above pre-industrial (from Jones et al. 2003) it would suggest a lower temperature ceiling might be needed, implying an atmospheric CO<sub>2</sub> stabilisation level between 400 and 350 ppm CO<sub>2</sub> eq.

Whether other climate models with carbon cycle feedbacks also find the same result remains to be seen, but in the interim, we can safely say that we will at least need to reduce global emissions by 60% by 2030, to have a reasonable chance of avoiding dangerous and possibly runaway climate change.

## CONCLUSIONS

To limit global mean surface temperature rise to under 2°C will require stabilising atmospheric concentrations of greenhouse gases at under 440 ppm CO<sub>2</sub> eq.

This target will have to be reached before 2030, to stand a reasonable chance of avoiding dangerous and possibly runaway climate change.

This task is made more difficult due to a decrease in the capacity of terrestrial ecosystems to absorb atmospheric CO<sub>2</sub> of 1.2 GtC per year. The capacity of the combined vegetation, soil and ocean sinks over the period from 2010 to 2030 will be about 2.8 GtC.

2.8 GtC per year will therefore be the upper limit for anthropogenic emissions if we are to keep atmospheric concentrations at current levels. As current anthropogenic emissions are around 7 GtC per year, this implies a reduction in global greenhouse gas emissions of 60%.

Assuming a world population of 8.2 billion in 2030, this gives an allowable per capita emission of 0.33 tonnes of carbon per year.

The emissions reductions required for energy-intensive developed countries, such as the UK, will be around 90% on current levels, and will need to be achieved by 2030.

These targets appear challenging, but give an indication of the timescale and scale of reductions required. Ongoing research on climate sensitivity and positive feedbacks in the carbon cycle may indicate that a lower ceiling on temperature rise may be necessary to stop irreversible damage to global ecosystems, implying a lower target concentration of atmospheric CO<sub>2</sub>, and on a shorter timescale.

Colin Forrest 6/04/05, revised 14/04/05

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Bill Hare, Visiting Scientist, Potsdam Institute for Climate Impact Research, P.O. Box 60 12 03, D-14412 Potsdam, Germany, Phone: +49-331-288-2412, Mobile: +49-0170-9057015  
E-mail: [hare@pik-potsdam.de](mailto:hare@pik-potsdam.de) WWW: <http://www.pik-potsdam.de>

Malte Meinshausen, Swiss Federal Institute of Technology (ETH Zurich)  
Environmental Physics, Department of Environmental Sciences  
Rämistrasse 101, CH-8092 Zurich, Switzerland, Phone: +41-632-0894  
E-mail: [malte.meinshausen@env.ethz.ch](mailto:malte.meinshausen@env.ethz.ch) WWW: <http://www.ethz.ch>

3 Strong carbon cycle feedbacks in a climate model with interactive CO<sub>2</sub> and sulphate aerosols

Chris D. Jones, Peter M. Cox, Richard L. H. Essery, David L. Roberts, and Margaret J. Woodage, (2003)

Hadley Centre, Met Office, Bracknell,

GEOPHYSICAL RESEARCH LETTERS, VOL. 30, NO. 9, 1479, doi:10.1029/2003GL016867, 2003

4 David Crabbe, 2003, Energy Systems and Sustainability, Chapter 7, P 283-290, Open University, Milton Keynes, UK

4b US Census, Sept. 2004

5 UK population was approximately 60 million in 2000, and IPCC common format greenhouse gas emissions in 2000 were 181 MtC eq. (excluding international air travel)

6 Avoiding Dangerous Climate Change, 2005, page 7

Met Office Hadley Centre FitzRoy Road Exeter EX1 3PB United Kingdom

Tel: +44 (0)1392 885680 Fax: +44 (0)1392 885681

E-mail: [enquiries@metoffice.gov.uk](mailto:enquiries@metoffice.gov.uk) [www.metoffice.gov.uk](http://www.metoffice.gov.uk)

7 Hare and Meinshausen, 2004 Note that there is significant uncertainty in regard to the aerosols' cooling effect. This greenhouse gas only CO<sub>2</sub> equivalence level has been derived from the 2005 radiative forcing when running the SRES A1B emission scenario with zeroed SO<sub>2</sub> emissions under the '7 AOGCM ensemble mean' procedure.

8 Hare and Meinshausen, 2004, Table 2, line 1

9 Silvertown, J. (ed) 2003, Biodiversity and Ecosystems (U 316), p 25, Open University, Milton Keynes, UK

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## THANKS, NOTES

I would like to thank all the scientists whose work I have used.

This report has been prepared as an internal briefing, but may be used freely. The diagrams and maps have been used without the publishers' permission.

I would hope to prepare another climate science update in the future and would welcome comments and further information.

A report, Reducing Climate Emissions in Scotland, is also available

Colin Forrest [cdforrest@tiscali.co.uk](mailto:cdforrest@tiscali.co.uk) 01382 509844