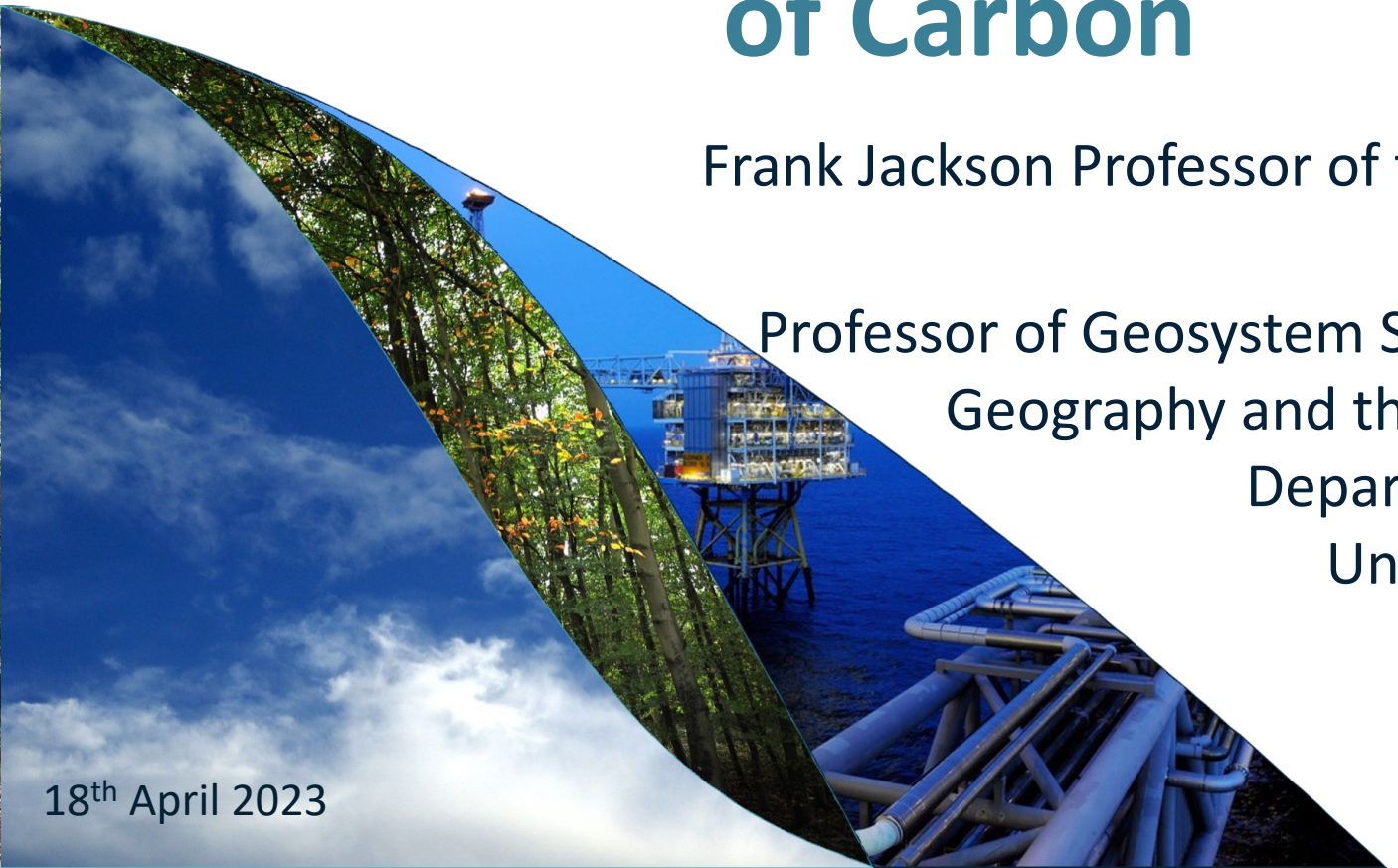
The Trillionth Tonne of Carbon



Myles Allen

Frank Jackson Professor of the Environment, Gresham College

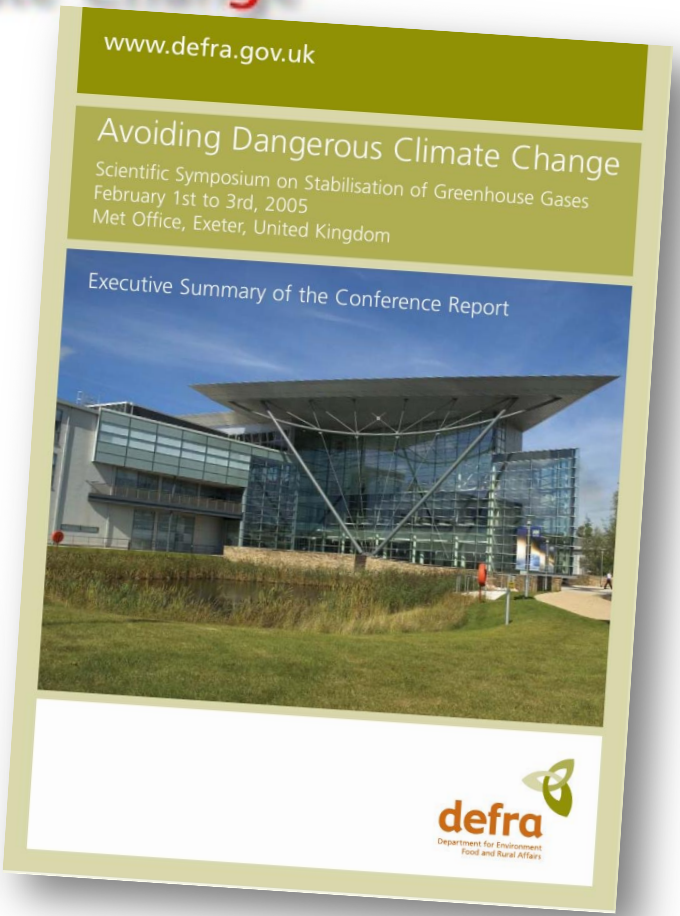
Professor of Geosystem Science, School of Geography and the Environment & Department of Physics, University of Oxford

18th April 2023

The 2005 Conference

Avoiding Dangerous Climate Change

- For different levels of climate change what are the key impacts?
- What would such levels imply in terms of greenhouse gas stabilisation concentrations and emission pathways required to achieve such levels?



The 2005 Conference

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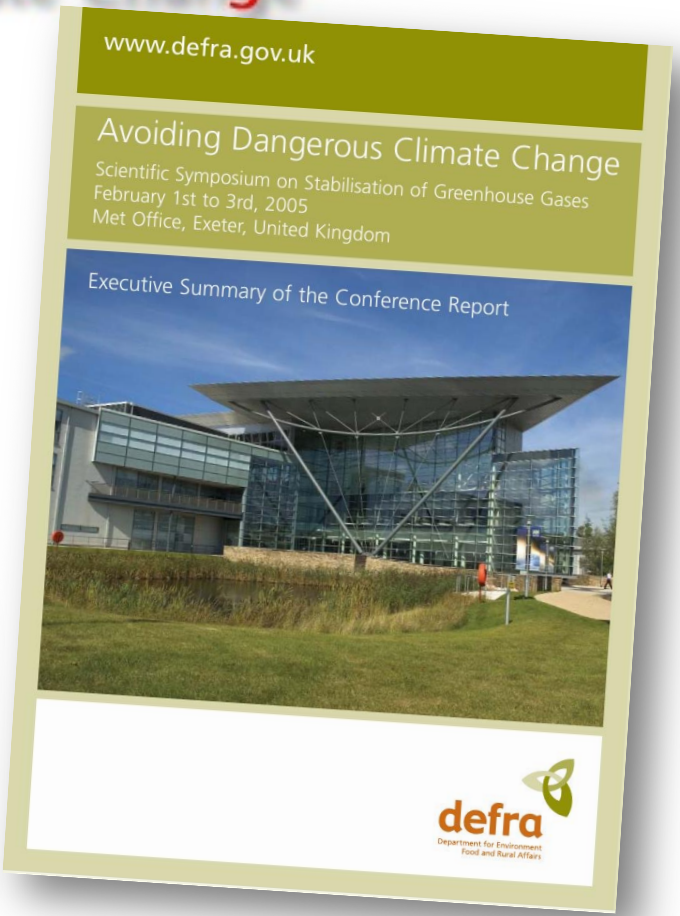
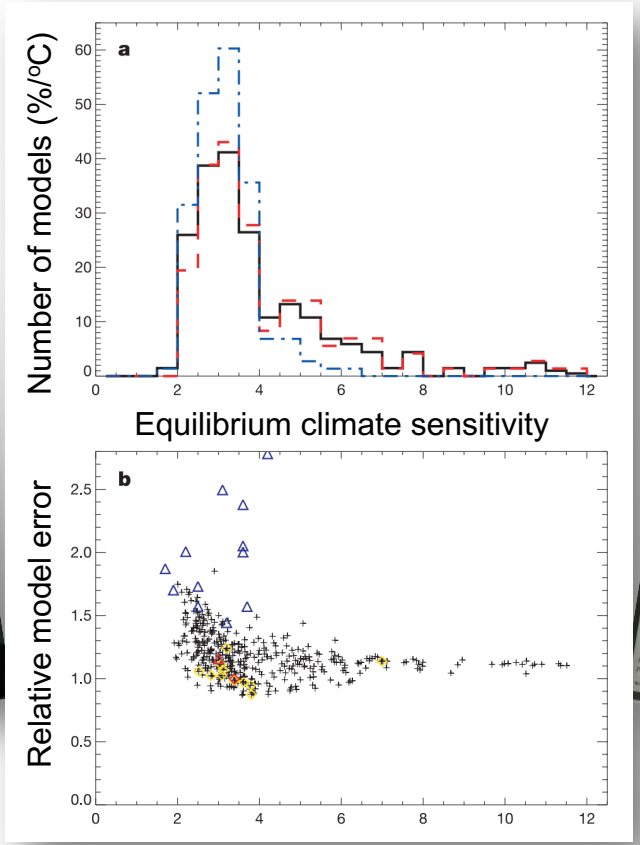


Just published: equilibrium climate sensitivities from the climate*prediction*.net experiment



Stainforth et al, 2005

From our presentation at the 2005 conference

So what should our Tony have asked?

- Not: “What level of greenhouse gases in the atmosphere is self-evidently ‘too much’?”
- But: “What injection of greenhouse gases into the atmosphere is self-evidently ‘too much’?”
- A question we can answer, *objectively*: “If we want to stay below X degrees, (with 95% confidence) how much carbon can we afford to burn?”
- Apparently we don’t like to talk about this because the answer makes people uncomfortable…
- Why focus on unanswerable questions just because the word “stabilisation” appears in the UNFCCC?

climate*prediction*.net

Oxford University

And another talk later that year

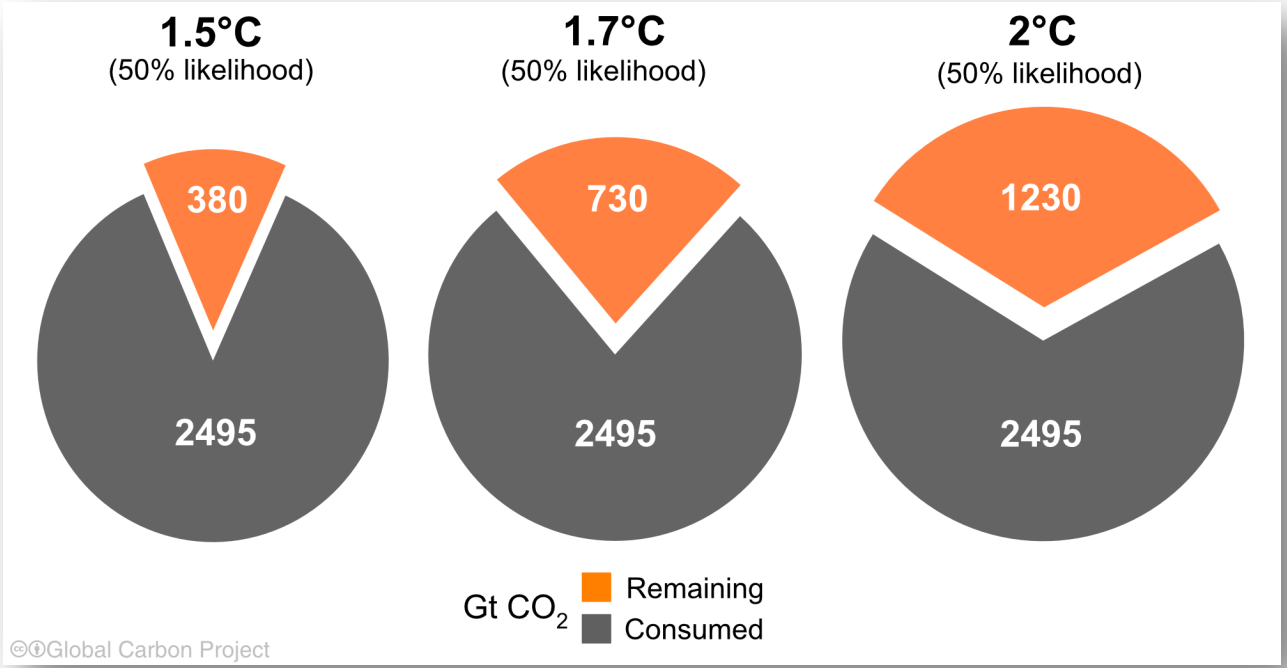
Conclusions

- The notion of a “sustainable per capita emission rate” is indefensible: we can’t observe the things we need to know to say what is sustainable.
- Maximum forecast warming is constrained by things we can observe if we sign up to a “containment scenario”, limiting total CO_2 emissions.
- With ~500GtC released already, we can release 600-700 more GtC before the risk of CO_2-induced warming >2°C exceeds 20%: extrapolating past land-use/fossil mix, this means a total fossil emissions of...
- One Trillion Tonnes.

climate*prediction*.net

Oxford University

18 years on



Global Carbon Project, 2022

1230+2495 = 3725 billion tonnes of CO_2

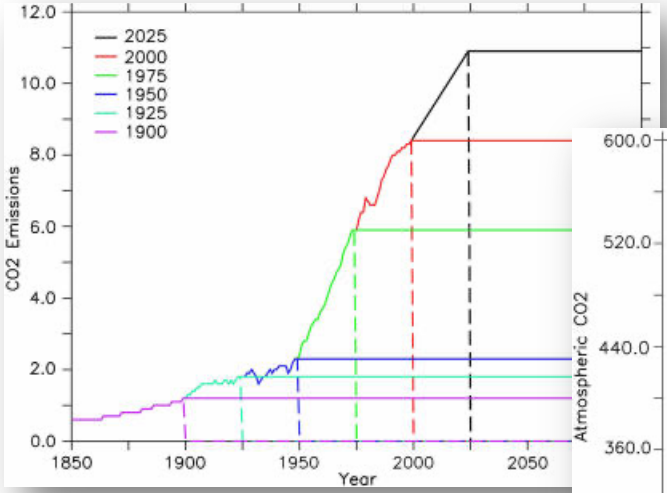
= 3725x12/44 billion tonnes of carbon

= 1.02 trillion tonnes of carbon

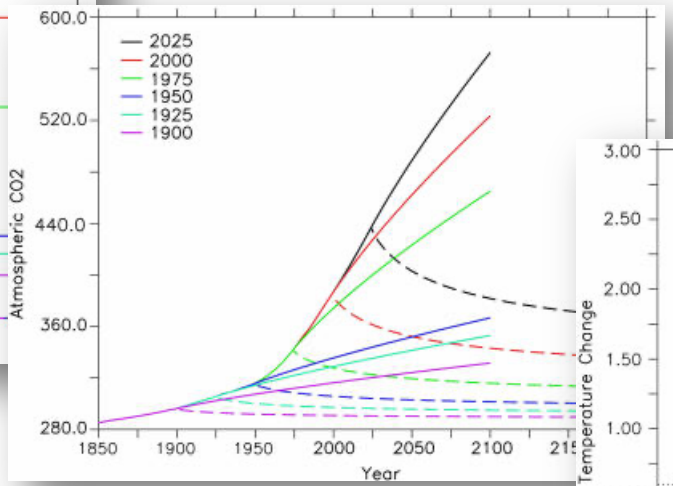
So Dave Frame and I got the principles right, but didn't do that well on the numbers…

- We claimed an 80% chance of staying below 2°C even after burning 1.1-1.2 trillion tonnes of carbon.
- Modern estimates give a 50% chance of staying below 2°C after burning 1 trillion tonnes of carbon.
- The problem was that Dave and I had an over-optimistic carbon cycle (Bill Nordhaus' model from the early DICE).
- And neither of us knew anything about the carbon cycle…

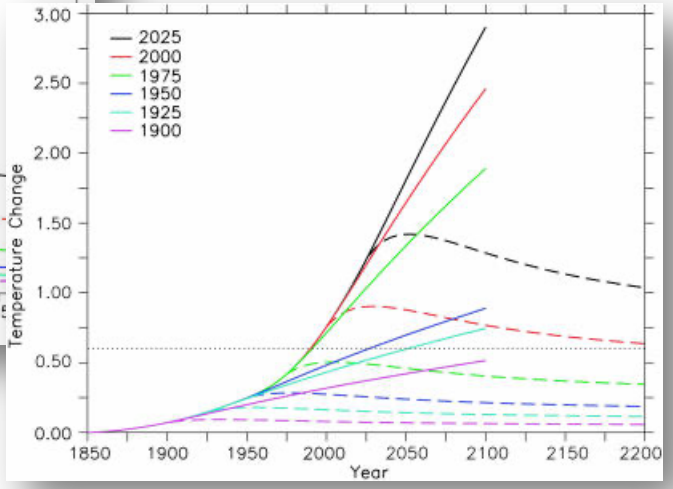
That very same year, Pierre Friedlingstein and Susan Solomon almost hit on the same result…



Zero emissions every 25 years (dashed lines)



Realistic carbon cycle response



Unrealistic temperature response (model too simple)

Then everyone got distracted…

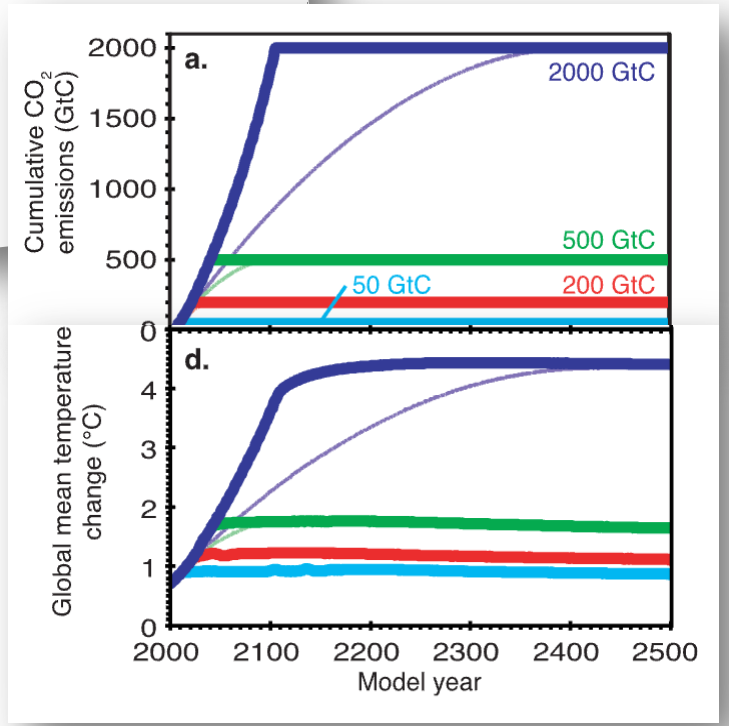
…although relevant papers continued to appear…

GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L04705, doi:10.1029/2007GL032388, 2008

Stabilizing climate requires near-zero emissions

H. Damon Matthews[1] and Ken Caldeira[2]

Received 17 October 2007; revised 11 December 2007; accepted 11 January 2008; published 27 February 2008.



…and suddenly got busy again in 2009

PNAS

Irreversible climate change due to carbon dioxide emissions

Susan Solomon[a,1], Gian-Kasper Plattner[b], Reto Knutti[c], and Pierre Friedlingstein[d]

[a]Chemical Sciences Division, Earth System Research Laboratory, National Oceanic and Atmospheric Administration, Boulder, CO; [b]Biogeochemistry and Pollutant Dynamics and [c]Institute for Atmospheric and Climate Science, ETH CH-8092, Zurich, Switzerland; and [d]Laplace/Laboratoire des Sciences du Climat et de l'Environnement, Unité Mixte de Recherche 1572 Commissariat à l'Energie Atomique-Centre National de la Recherche Scientifique–Université Versailles Saint-Quentin, Commissariat a l'Energie Atomique-Saclay, l'Orme des Merisiers, 91

Contributed by Susan Solomon, December 16, 2008 (sent for review November 12, 2008)

nature Vol 458|30 April 2009|doi:10.1038/nature08017

LETTERS

Greenhouse-gas emission targets for limiting global warming to 2 °C

Malte Meinshausen[1], Nicolai Meinshausen[2], William Hare[1,3], Sarah C. B. Raper[4], Katja Frieler[1], Reto Knutti[5], David J. Frame[6,7] & Myles R. Allen[7]

Vol 458|30 April 2009|doi:10.1038/nature08019 nature

LETTERS

Warming caused by cumulative carbon emissions towards the trillionth tonne

Myles R. Allen[1], David J. Frame[1,2], Chris Huntingford[3], Chris D. Jones[4], Jason A. Lowe[5], Malte Meinshausen[6] & Nicolai Meinshausen[7]

Quantifying Carbon Cycle Feedbacks

J. M. Gregory

Walker Institute for Climate System Research, University of Reading, Reading, and Met Office Hadley Centre, Exeter, United Kingdom

C. D. Jones

Met Office Hadley Centre, Exeter, United Kingdom

P. Cadule

CNRS/IPSL, Paris, and IPSL/LSCE, Gif-sur-Yvette, France

P. Friedlingstein

IPSL/LSCE, Gif-sur-Yvette, France, and QUEST, University of Bristol, Bristol, United Kingdom

PNAS

Setting cumulative emissions targets to reduce the risk of dangerous climate change

Kirsten Zickfeld[a,1,2], Michael Eby[a], H. Damon Matthews[b], and Andrew J. Weaver[a]

[a]School of Earth and Ocean Sciences, University of Victoria, Victoria, BC, Canada V8W 3V6; and [b]Department of Geography, Planning, and Environment, Concordia University, Montréal, QC, Canada H3G 1M8

Edited by Hans Joachim Schellnhuber, Potsdam Institute for Climate Impact Research, Potsdam, Germany, and approved July 20, 2009 (received for review June 16, 2008)

Avoiding "dangerous anthropogenic interference with the climate approach, whereby we work backwards from a specified tem-

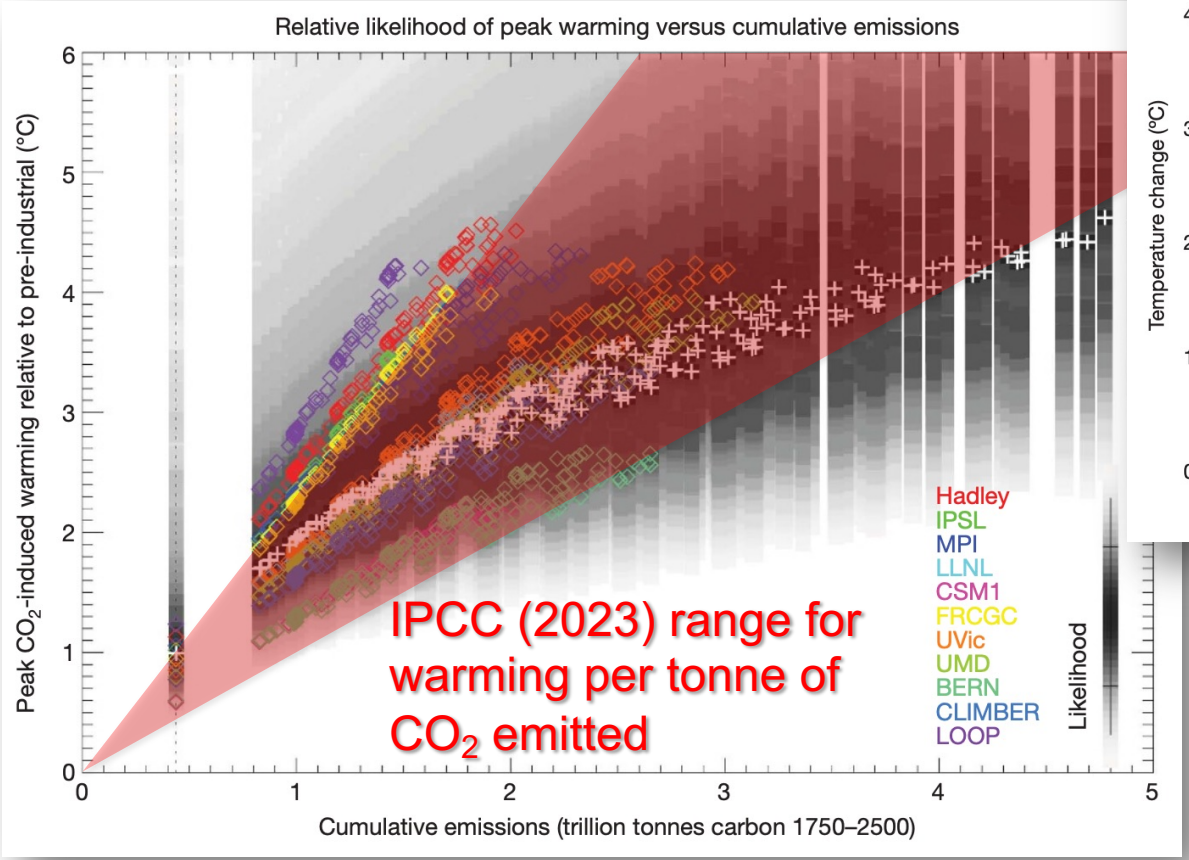
Vol 459|11 June 2009|doi:10.1038/nature08047 nature

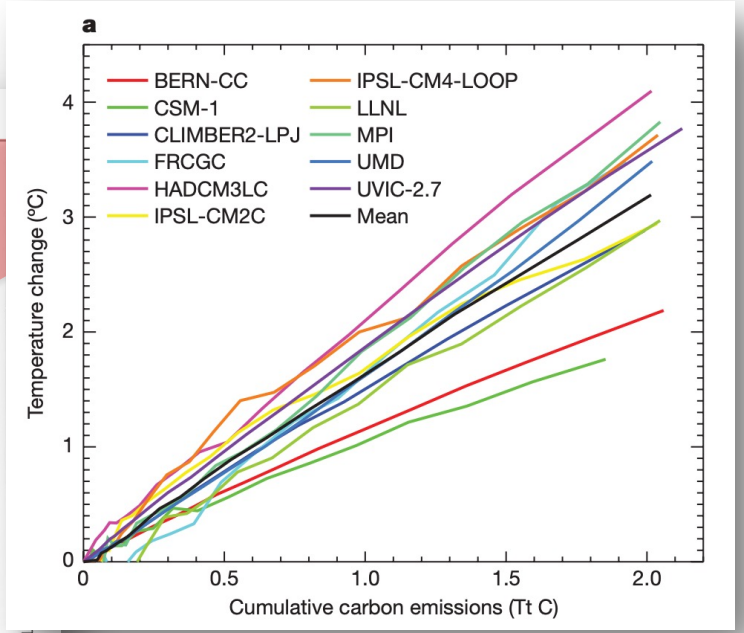
LETTERS

The proportionality of global warming to cumulative carbon emissions

H. Damon Matthews[1], Nathan P. Gillett[2], Peter A. Stott[3] & Kirsten Zickfeld[2]

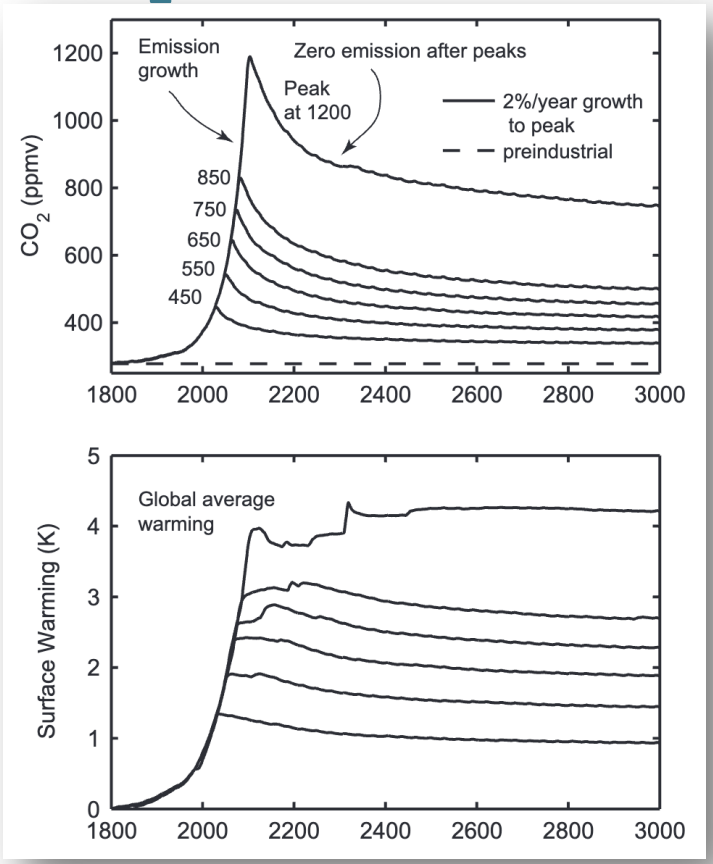
Warming is proportional to cumulative CO_2 emissions



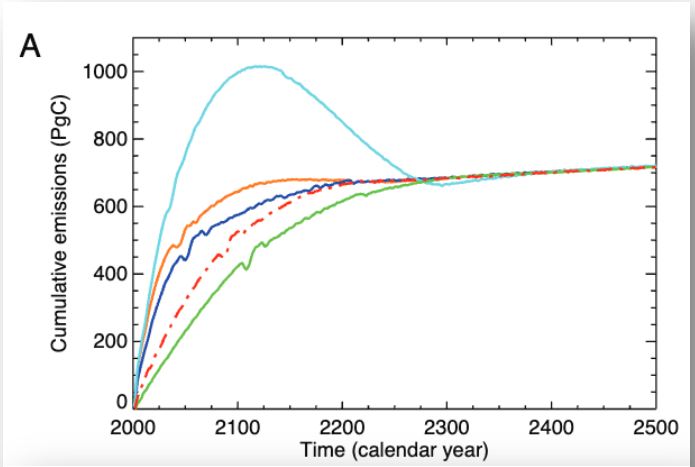


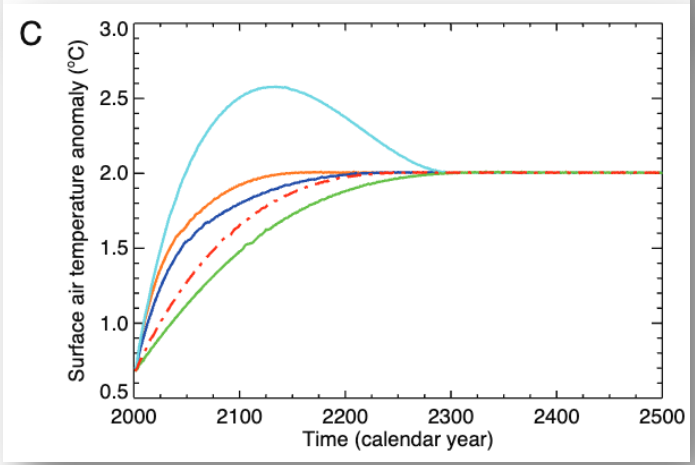
Allen et al (2009) and Matthews et al (2009)

And little further warming or cooling occurs after CO_2 emissions reach net zero

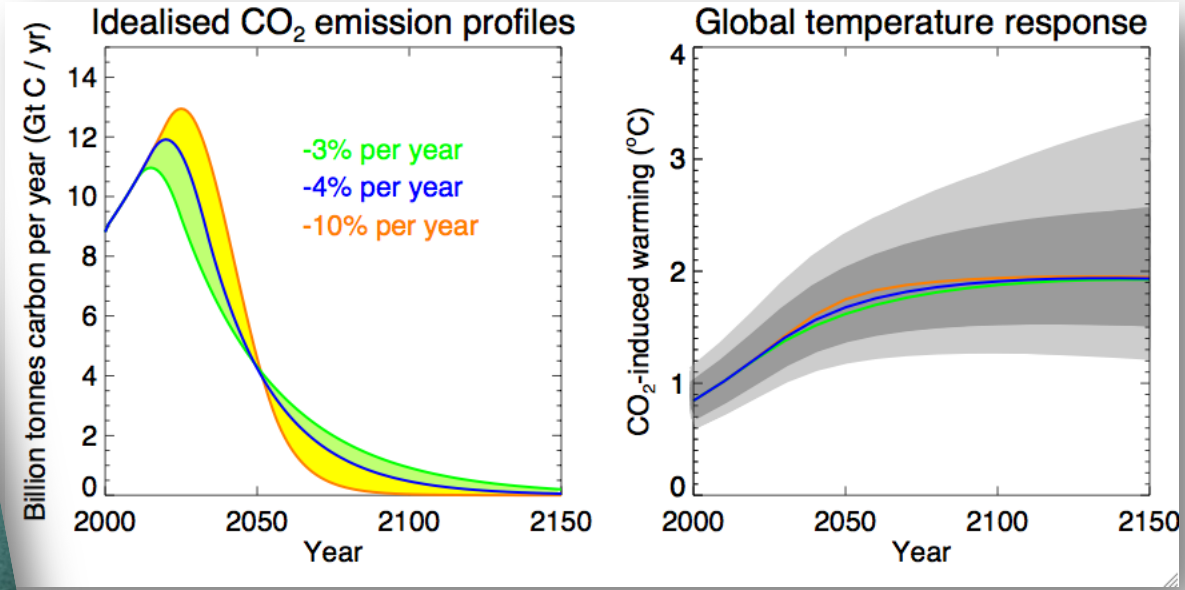


Solomon et al (2009) and Zickfeld et al (2009)





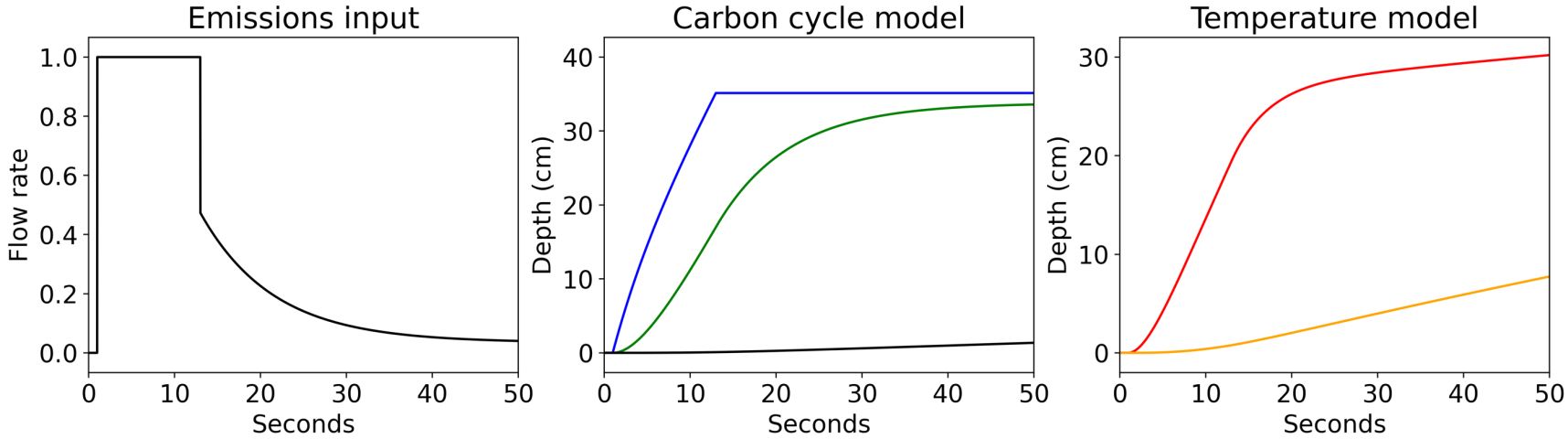
In a single figure: cumulative carbon dioxide emissions determine peak warming…



…so warming continues until CO_2 emissions reach net zero

Understanding why with our coupled Gresham climate-carbon-cycle model

Stabilizing atmospheric CO_2 concentrations



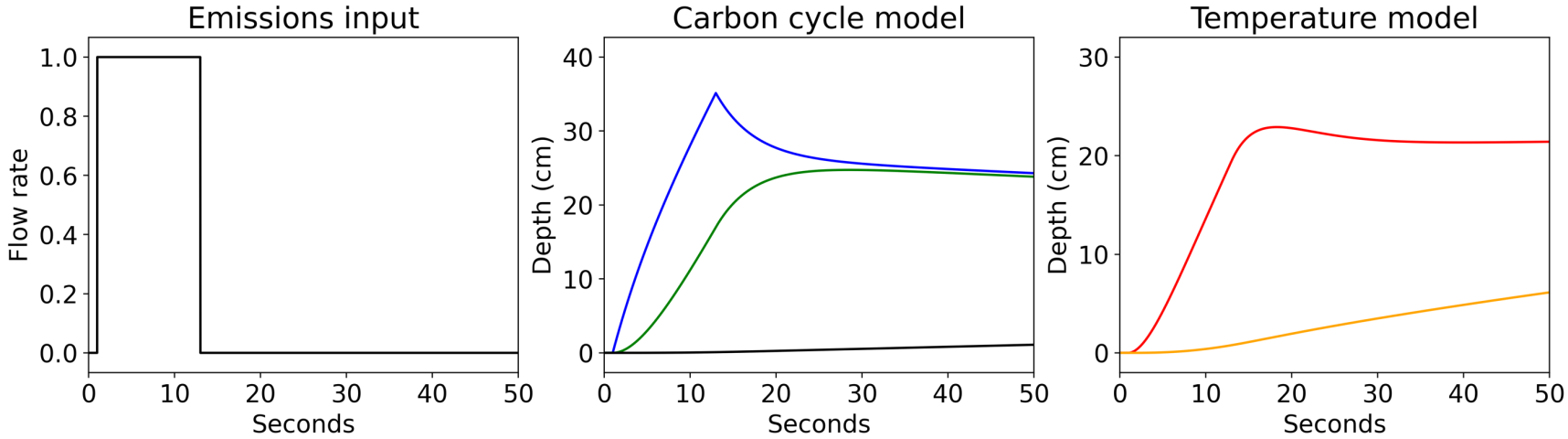
Allows emissions to continue

But temperatures keep rising

Understanding why with our coupled Gresham climate-carbon-cycle model

And net zero CO_2 emissions

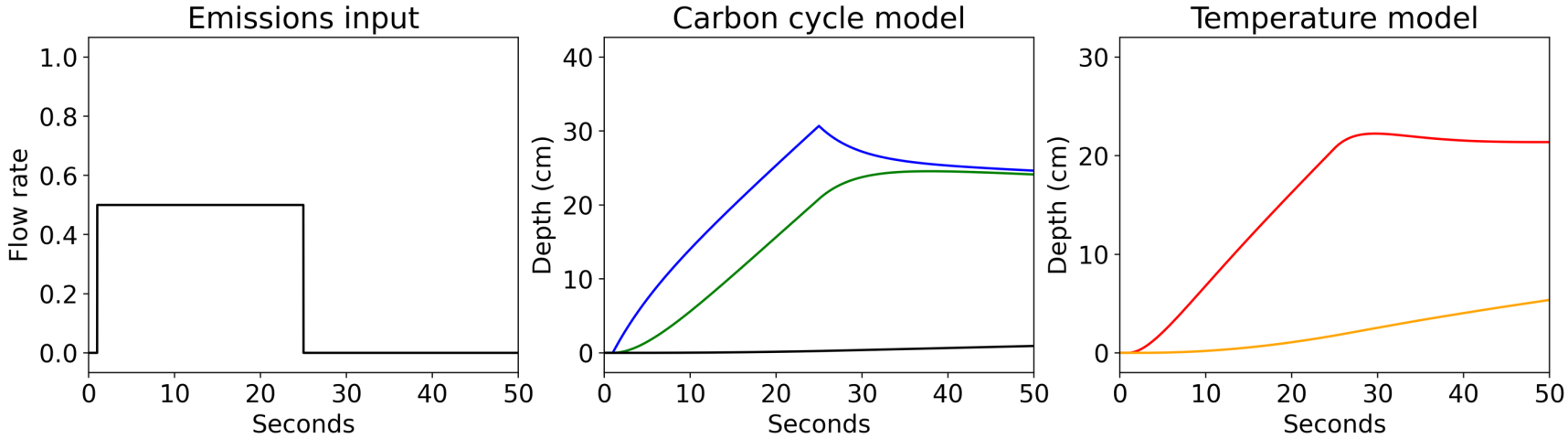
Stabilising temperatures



Requires declining atmospheric CO_2 concentrations

Understanding why with our coupled Gresham climate-carbon-cycle model

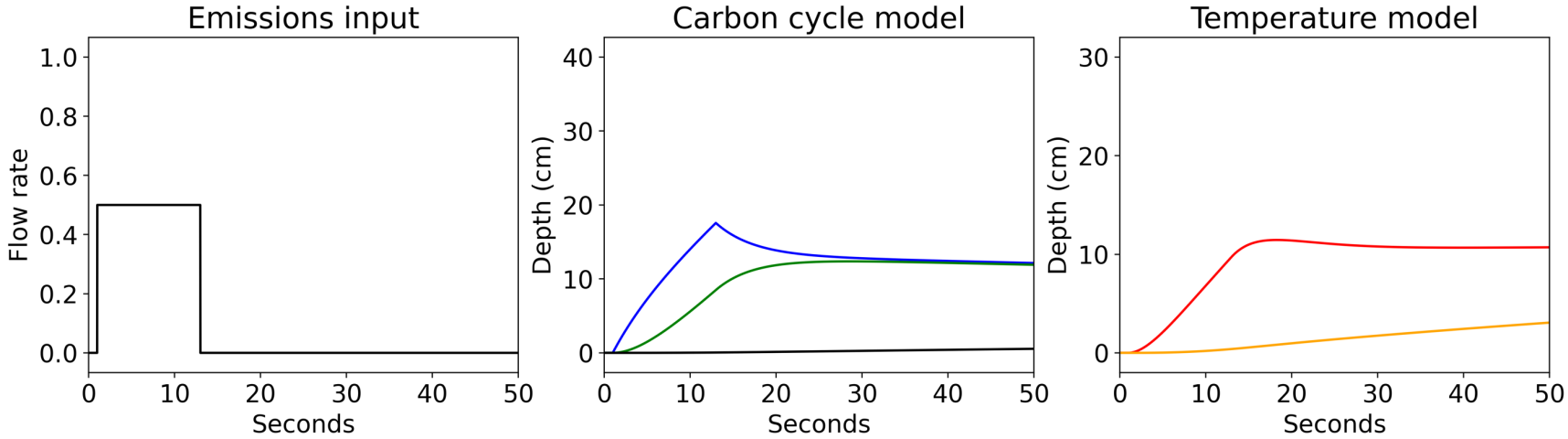
For the same cumulative amount of CO_2 And we get the same temperature



Even though peak CO_2 concentrations are different

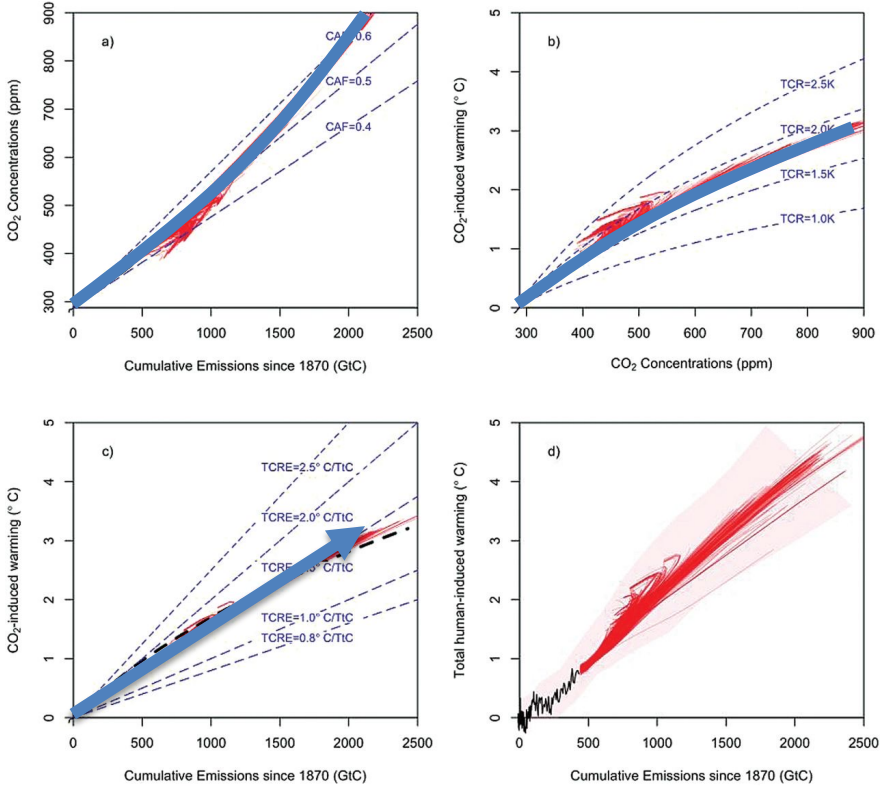
Understanding why with our coupled Gresham climate-carbon-cycle model

For half the cumulative amount of CO_2 We get half the warming



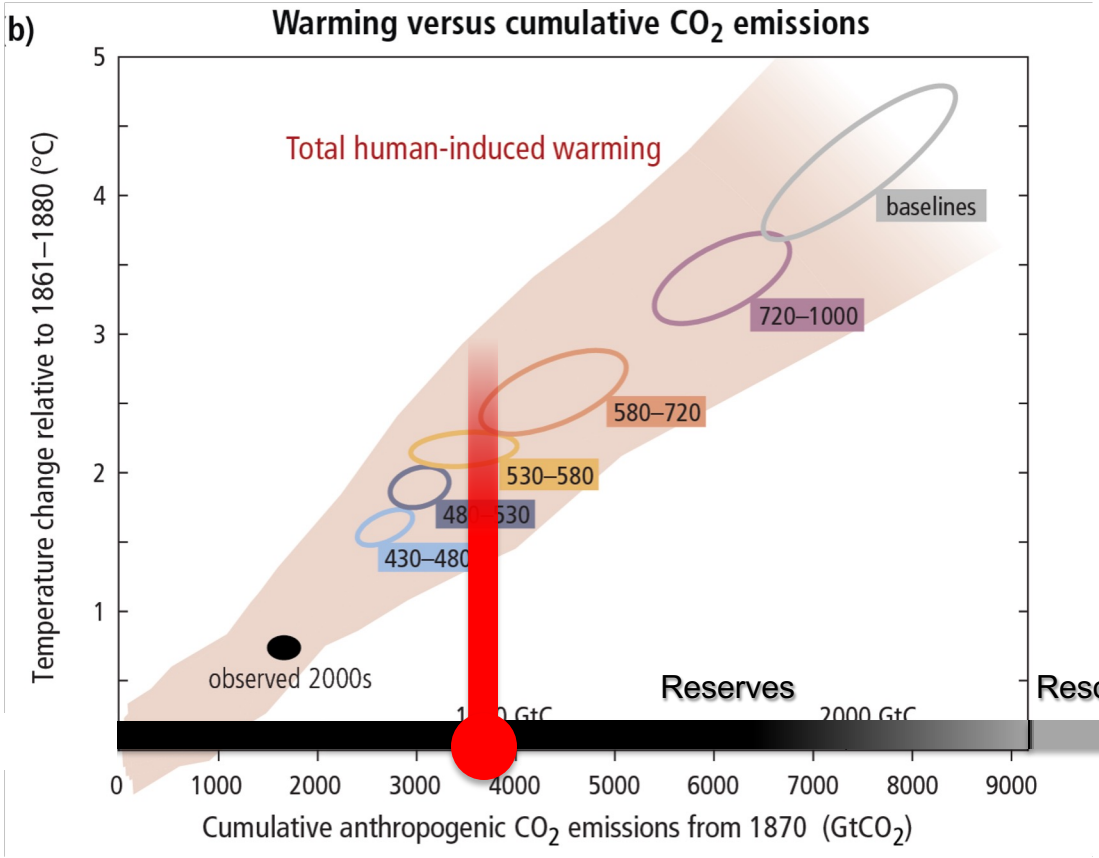
Two complications we can't represent in our Gresham models – but they cancel out!

- Increasing airborne fraction balances Arrhennius' curve to give…
- 0.45±0.18°C warming per trillion tonnes of CO_2 emitted.

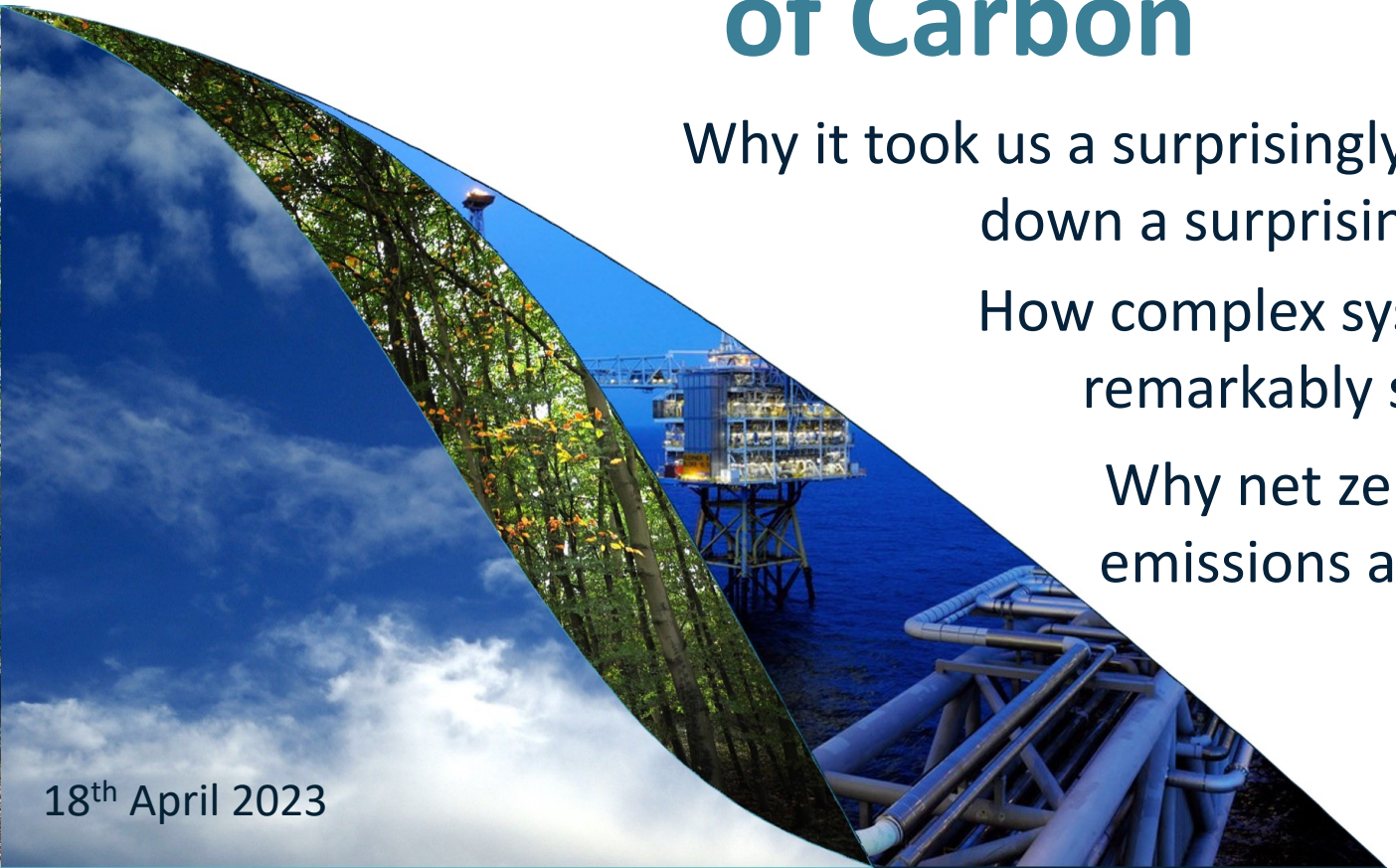


Richard Millar et al. Oxf Rev Econ Policy 2016;32:323-342

The reason all this matters: fossil fuel reserves



The Trillionth Tonne of Carbon



Why it took us a surprisingly long time to nail down a surprisingly simple result.

How complex systems can display remarkably simple behaviour.

Why net zero carbon dioxide emissions are needed to halt global warming.

18th April 2023

EST. 1597

GRESHAM COLLEGE