Fossil fuels constraints on global warming

by
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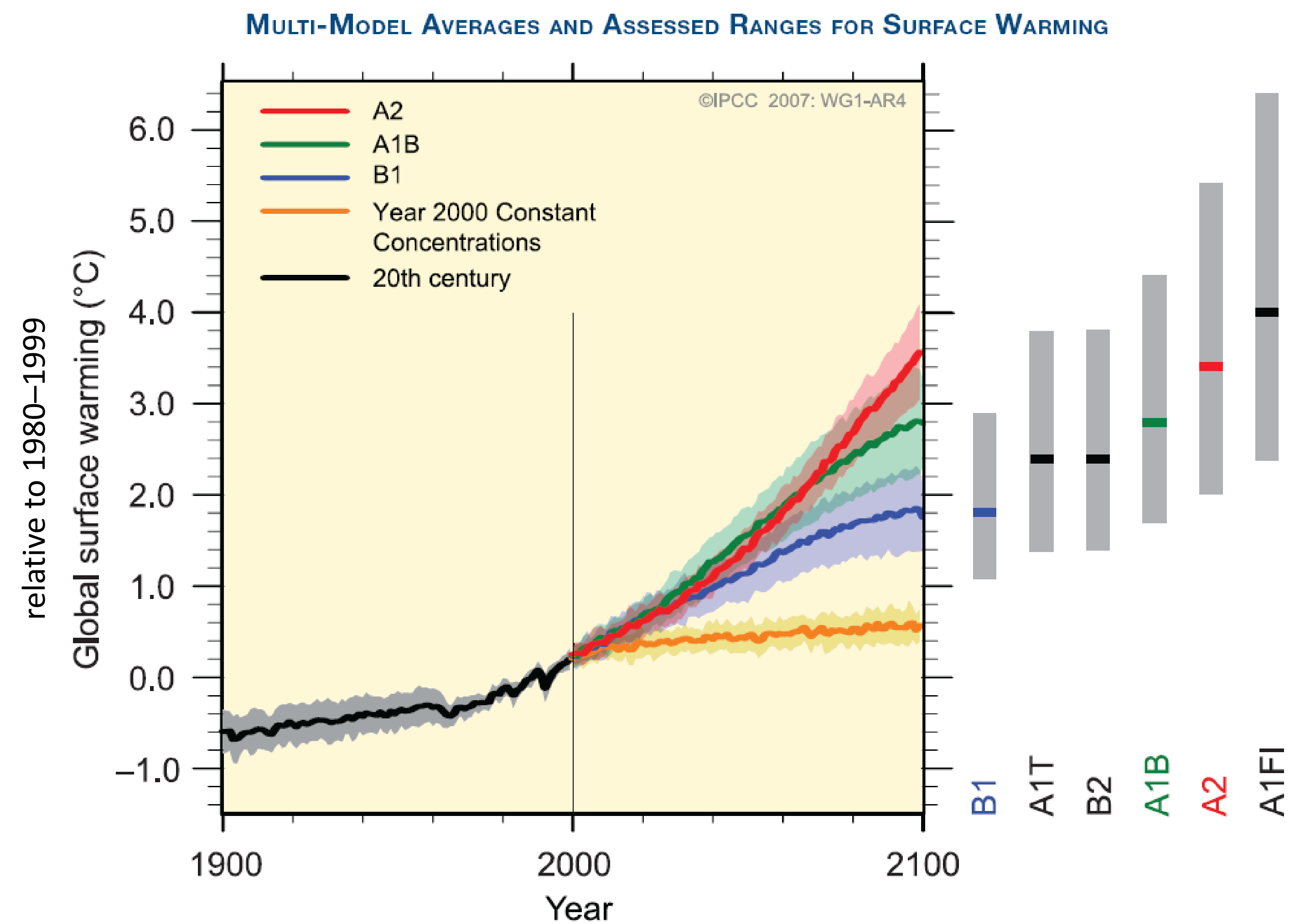
Outline

Implications of “peak oil” for atmospheric CO_2 and climate

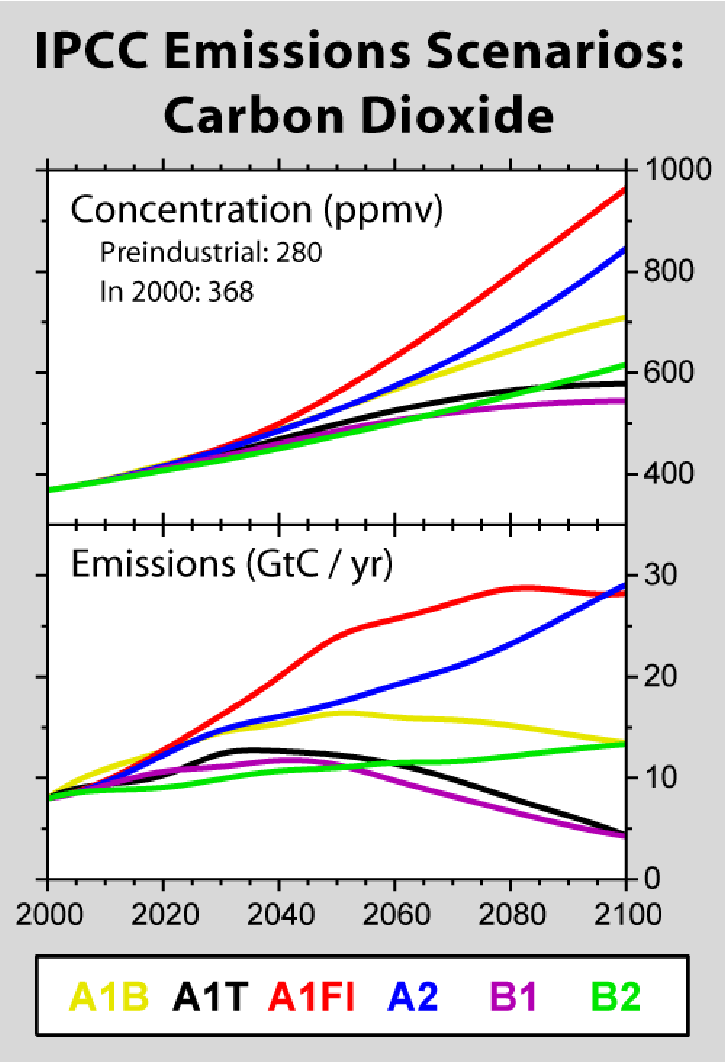
- Until a few years ago, projections of climate change have been performed without taking into account the future depletion of fossil fuels. Also IPCC simulations have always been run without reckoning on fossil fuel exhaustion.
- Physics (geology) places a limit to anthropogenic CO_2 emissions and, therefore, on future global warming.
- “Peak oil” is supposed to occur (or to have happened) some time between 2000 and 2010, therefore accounting for it in climate change simulations is becoming of key importance.

IPCC 2007 global temperature projections



IPCC 2007, Summary for Policymakers, pag. 14. http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf

IPCC SRES emissions scenarios



http://www.globalwarmingart.com/wiki/Image:Carbon_Dioxide_Emissions_Scenarios_png

- IPCC emissions scenarios are based on detailed energy system models in which demographics, technology and economics are used to generate projections of future world energy consumption, and therefore, of GHG emissions.
- 40 scenarios, distributed in 6 groups, as described in the SRES, are used to generate inputs to climate models, which in turn deliver projections for global average temperature or sea-level change.

R. Brecha, Emission scenarios in the face of fossil-fuel peaking, *Energy Policy* **36**, 3492 (2008).

Beyond IPCC SRES emissions scenarios

- The factors for future fossil-fuel production are primarily population, policy, and GDP, and limitations in fossil-fuel supplies are not considered critically.
- A key point is that the scenarios assume a large value for the fossil-fuel Ultimate Recoverable Reserves (URR), and do not consider fundamental limits to establishing a rate of production that is sufficient to support the economic development, population growth, and technological change assumed as inputs to each scenario.
- Energy costs are an integral part of the feedback loop between "social system" scenarios and GHG emissions in that increasing demand of a finite resource may lead to prices high enough to limit consumption, and therefore emissions.

R. Brecha, Emission scenarios in the face of fossil-fuel peaking, *Energy Policy* **36**, 3492 (2008).

Peak oil and climate projections: a review of the studies

Early papers

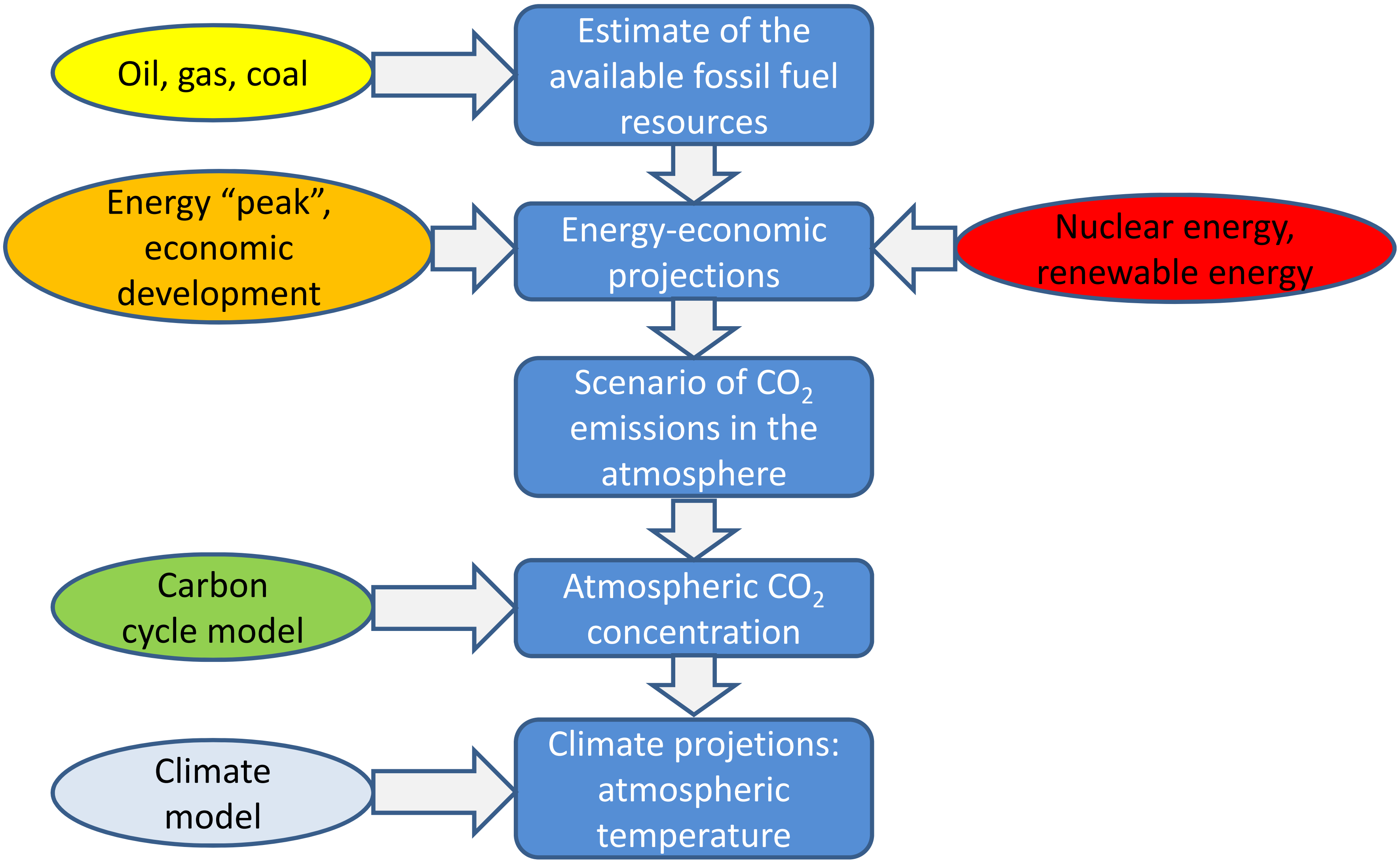
- J. H. Laherrère, Estimates of Oil Reserves, IIASA International Energy Workshop, Laxenburg, June 19-21 (2001). http://www.iiasa.ac.at/Research/ECS/IEW2001/pdffiles/Papers/Laherrere-long.pdf
- K. Aleklett, A. Sivertsson, C. Campbell, Not enough oil for climate change, *The New Scientist*, 2 August (2003). http://www.newscientist.com/article/dn4216

Later papers

- P. Kharecha and J. Hansen, Implications of "peak oil" for atmospheric CO_2 and climate, *Global Biogeochemical Cycles* **22**, GB3012 (2008).
- D. Rutledge, The coal question and climate change, *The Oil Drum* (2007). http://www.theoildrum.com/node/2697
- R. J. Brecha, Emission scenarios in the face of fossil-fuel peaking, *Energy Policy* **36**, 3492 (2008).
- L. de Sousa and E. Mearns, Fossil fuel ultimates and CO_2 emission scenarios, *The Oil Drum: Europe* (2008). http://europe.theoildrum.com/node/4807
- W. P. Nel and C. J. Cooper, Implications of fossil fuel constraints on economic growth and global warming, *Energy Policy* **37**, 166 (2009).

U. Bardi, Fire or Ice? The role of peak fossil fuels in climate change scenarios, *The Oil Drum: Europe* (March 9, 2009), http://europe.theoildrum.com/node/5084

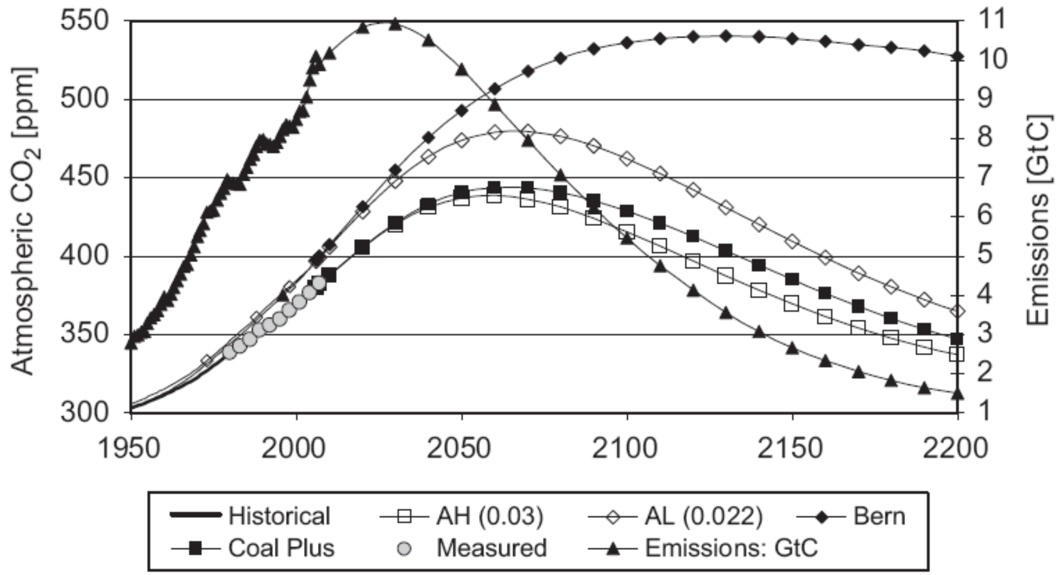
Peak oil and climate projections: working approach

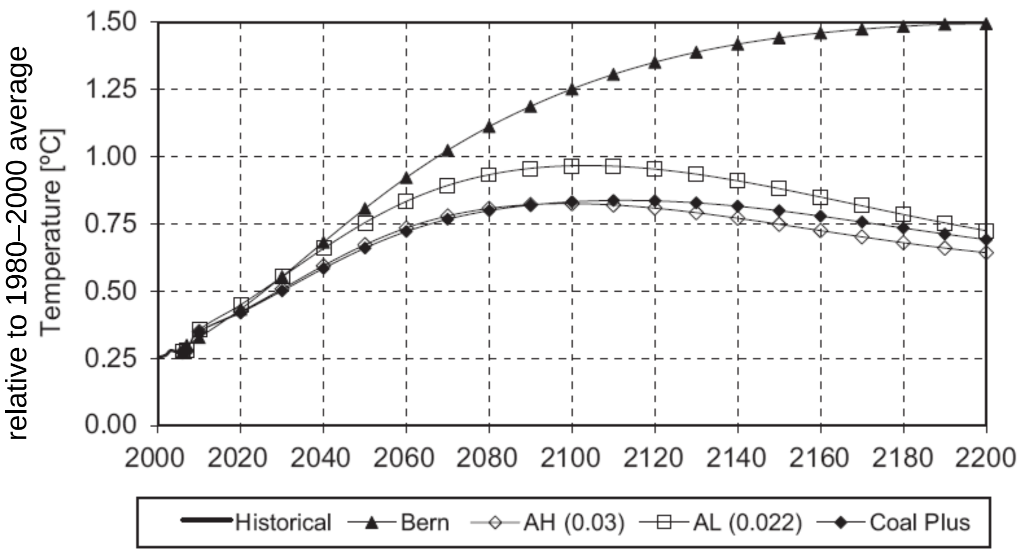


Peak oil and climate projections: results

Reference	Scenario	Peak CO_2 emissions	CO_2 concentration (ppm)		Temperature (°C) relative to 2000	
			Peak	2100	Peak	2100
Kharecha & Hansen (2008)	BAU	2080	>570 (>2100)	570		
	Coal phase out	2015	450 (2040)	430		
	Fast oil use	2025	460 (2040)	440		
	Less oil reserves	2010	440 (2040)	420		
	Peak oil plateau	2025	460 (2050)	440		
Rutledge (2007)	Producer limited	2020	460 (2070)	450	1.8 (2140)	1.7
	Super-Kyoto	2030	440 (2100)	440	1.8 (2200)	1.5
Brecha (2008)	low	2050	500 (2100)	500	>2 (>2100)	2
	high	2035	560 (2080)	550	>2.3 (>2100)	2.3
de Sousa & Mearns (2008)		2020	470 (2080)	460	1.5 (2100)	1.5
Nel & Cooper (2009)	AH (0.03)	2025	440 (2060)	420	0.6 (2100)	0.6
	AL (0.022)		480 (2070)	460	0.8 (2100)	0.8

Nel and Cooper (2009)





CO_2 concentration

- CO_2 emissions are expected to peak with primary energy, that is around 2025.
- The maximum CO_2 concentrations don't exceed 500 ppm, except for the most pessimistic scenario, in which 550 ppm are reached.

Temperature

- The temperature increase prior to 2100 should not exceed 1 °C.
- Such temperature increase is not dangerous. Therefore reaching these CO_2 levels is preferable than facing the economic and social consequences of not fully exploiting the remaining fossil fuels.

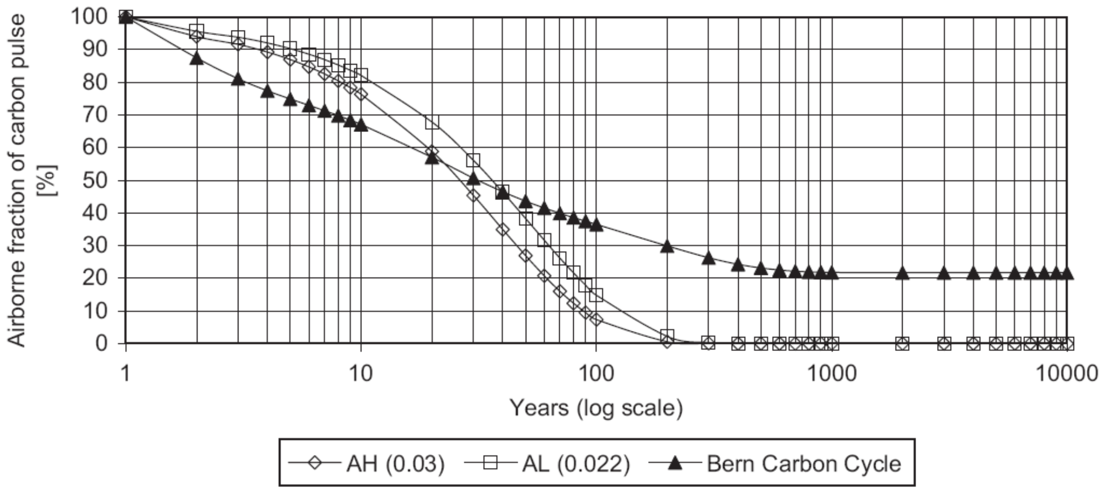
Challenging Nel and Cooper (2009)…

- Main wrong assumptions and mistakes about climate physics contained in the paper by Nel and Cooper (2009):
    1) Carbon cycle model: ~ 0% of CO_2 airborne fraction of a carbon pulse after only 200 years;
    2) Equilibrium climate sensitivity: 0.4 °C/(W/m^2) instead of 0.8 °C/(W/m^2) (best estimate by IPCC 2007);
    3) Thermal inertia of the climate system: ignored.
- Even if topics 1 and 2 are fairly well understood today, nevertheless they remain two weak points in the present knowledge of the climate system.
- These uncertainties influence our predictive capacity on the future greenhouse warming.

A. Zecca & L. Chiari, Fossil fuel constraints on global warming, *Energy Policy*, in press (2009).

Carbon cycle models

- CO_2 added to the atmosphere will be gradually captured by natural sinks:
  - continental and marine biology;
  - continental vegetation;
  - the oceanic mixing layer;
  - the deep ocean;
  - ...



from Nel and Cooper (2009)

- Each sink has its own typical time constant spanning from the seasonal action of the vegetation to the century-to-millennia scale of the deep ocean.

Models of the carbon cycle

- First order approximation: single exponential decay → AH (0.03) model by Nel and Cooper (2009) : $\tau \sim 30$ years
- Bern model (used by most IPCC 2007 models):

$$CF = 0.217 + 0.259e^{-t/172.9} + 0.338e^{-t/18.51} + 0.186e^{-t/1.186}$$

IPCC, Fourth Assessment Report (AR4), Working Group I, UNEP, Cambridge University Press, New York, pp. 213, 790 (2007).
F. Joos et al., Global warming feedbacks on terrestrial carbon uptake under the Intergovernmental Panel on Climate Change (IPCC) emission scenarios, *Global Biochemical Cycles* **15**, 891 (2001) .

Equilibrium climate sensitivity

- Equilibrium climate sensitivity λ is defined as the equilibrium change in the annual mean global temperature following a change in the total net radiative forcing:

$$\Delta T = \lambda \Delta F$$

- Alternatively it is also defined as the global annual mean temperature change experienced by the climate system after it has attained a new equilibrium in response to a doubling of atmospheric CO_2 concentration.
- The value of λ lies in the range from 0.3 to 1.3 °C/(W/m^2). The lowest value can be achieved in a climate system with no feedbacks, as a planet with an inert atmosphere, while the highest one can be achieved in a system with very strong feedbacks. In the present climate state of the Earth, λ is believed to have a value close to 0.8 °C/(W/m^2).
- Nel and Cooper (2009) estimate λ in an incorrect way, by using the definition and by collecting from IPCC 2007 report the 1850 to 2000 global temperature increase ΔT = 0.76 °C and the corresponding radiative forcing $\Delta F \sim$ 1.84 W/m^2. This way they obtain a very low value $\lambda \sim$ 0.413 °C/(W/m^2).

IPCC, Fourth Assessment Report (AR4), Working Group I, UNEP, Cambridge University Press, New York, pp. 798-799 (2007).

Thermal inertia of the climate system

- The problem is that *it is fruitless to try to obtain an accurate climate sensitivity from observed global temperature change in the last century* (Hansen et al., 2007), since the climate system has not reached a thermal equilibrium condition yet.
- This way Nel and Cooper (2009) completely ignore the large response time of the Earth's climate system to a radiative forcing, which is not instantaneous but it is delayed as an effect of its considerable thermal inertia.
- The lag in the climate response to a forcing is a sensitive function of λ and it depends on the rate of heat exchange between the ocean's surface mixed layer and the deeper ocean. If λ = 0.75 °C/(W/m^2), about 25 to 50 years are needed for Earth's surface temperature to reach 60 % of its equilibrium response.
- The 2005 total forcing relative to that in 1880 is $\sim$1.8 W/m^2. The observed 1880 to 2007 global warming is 0.76 °C, which is the full response to $\sim$1 W/m^2 of forcing, if assuming λ = 0.75 °C/(W/m^2). Of the 1.8 W/m^2 forcing, 0.8 W/m^2 remains; it means that additional global warming of 0.8 W/m^2 · 0.75 °C/(W/m^2) = 0.6 °C is missing to date and will occur in the future even if atmospheric composition and other climate forcings remain fixed at today's values.

J. Hansen *et al.*, Dangerous human-made interference with climate: a GISS modelE study, *Atmospheric Chemistry and Physics* **7**, 2287 (2007).
J. Hansen *et al*., Climate Response Times: Dependence on Climate Sensitivity and Ocean Mixing, *Science* **229**, 857 (1985).
J. Hansen *et al*., Earth's Energy Imbalance: Confirmation and Implications, *Science* **308**, 1431 (2005).

MAGICC

Model for the Assessment of Greenhouse-gas Induced Climate Change

- MAGICC is a coupled gas-cycle/climate model.
- MAGICC has been one of the primary models used by IPCC since 1990 to produce projections of future global-mean temperature and sea level rise.
- The climate model in MAGICC is an upwelling-diffusion, energy-balance model that produces global- and hemispheric-mean temperature output together with results for oceanic thermal expansion.
- The MAGICC climate model is coupled interactively with a range of gas-cycle models that give projections for the concentrations of the key greenhouse gases. Climate feedbacks on the carbon cycle are therefore accounted for.
- Parameters in the carbon cycle model have been set to give concentration projections consistent with the results from the C^4MIP Coupled Climate–Carbon Cycle Model Intercomparison Project.

T. M. L. Wigley, MAGICC/SCENGEN 5.3: user manual (version 2, September 2008).
P. Friedlingstein *et al.*, Climate-carbon cycle feedback analysis: results from the C^4MIP model intercomparison, *Journal of Climate* **19**, 3337 (2006).

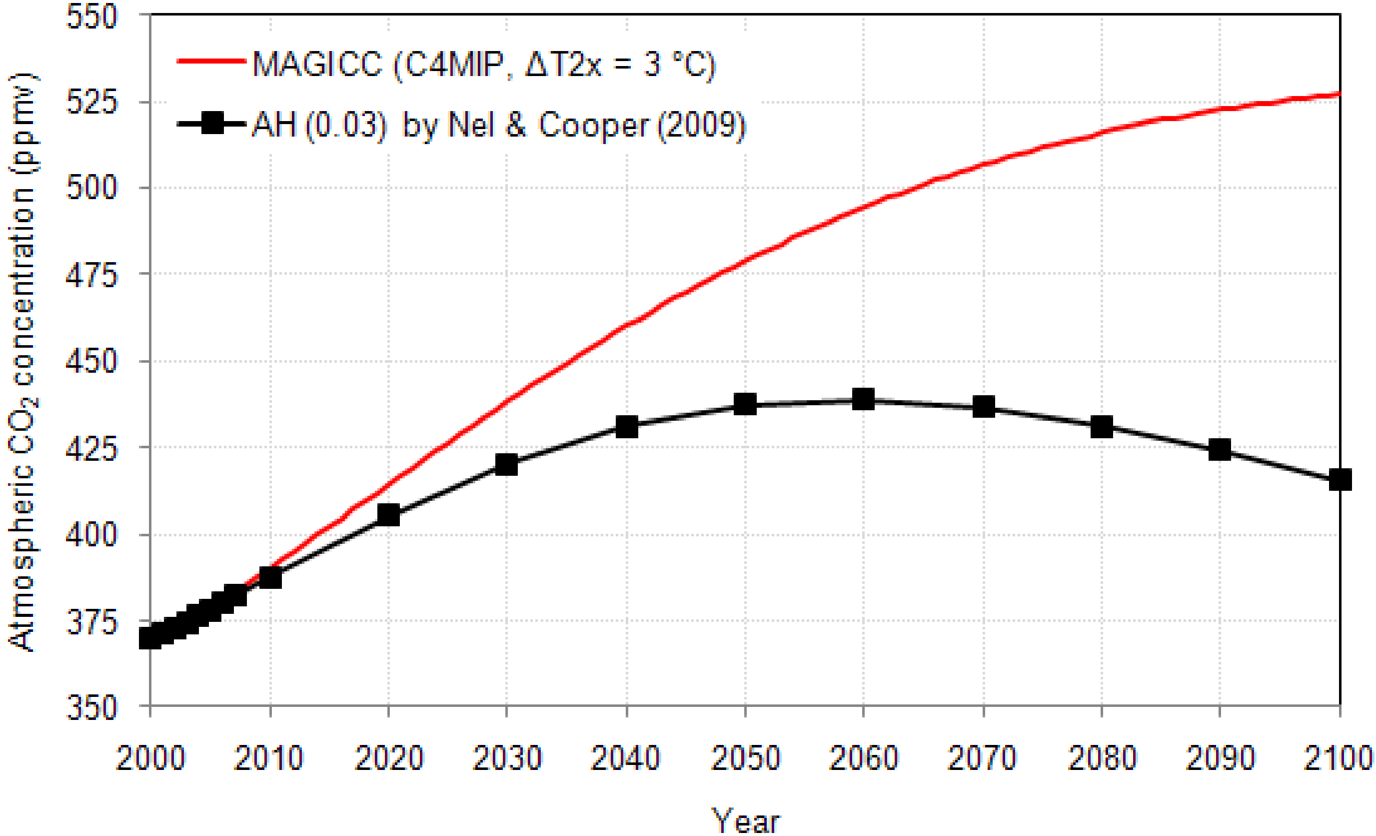
Emissions scenario for MAGICC

	2000 level	2000 – 2100 projection
Fossil fuel CO_2	7.5 GtC/yr	According to scenario by Nel & Cooper (2009)
Land use CO_2	1 GtC/yr	Fixed at 1 GtC/yr
CH_4	582 Tg/yr	Natural emissions fixed at 232 Tg/yr + anthropogenic emissions proportional to fossil fuel CO_2 emissions (350 Tg/yr in 2005)
N_2O	18 TgN/yr	Natural emissions fixed at 11 TgN/yr + anthropogenic emissions proportional to fossil fuel CO_2 emissions (7 TgN/yr in 2000)
NO_x	44 TgN/yr	Natural emissions fixed at 11 TgN/yr + anthropogenic emissions proportional to fossil fuel CO_2 emissions (33 TgN/yr in 2000)
VOCs	850 Tg/yr	Fixed at 850 Tg/yr
CO	877 Mt/yr	Fixed at 877 Mt/yr
SO_2	83 TgS/yr	Natural emissions fixed at 29 TgS/yr + anthropogenic emissions proportional to fossil fuel CO_2 emissions (54 TgS/yr in 2000)
CF_4	13 kton/yr	Proportional to fossil fuel CO_2 emissions (13 kton/yr in 2000)
C_2F_6	3 kton/yr	Proportional to fossil fuel CO_2 emissions (3 kton/yr in 2010)
HFC-125	8 kton/yr	Proportional to fossil fuel CO_2 emissions (16 kton/yr in 2010)
HFC-134a	56 kton/yr	Proportional to fossil fuel CO_2 emissions (77 kton/yr in 2010)
SF_6	6 kton/yr	Proportional to fossil fuel CO_2 emissions (6 kton/yr in 2000)

A. Zecca and L. Chiari, manuscript in preparation (2009).

Final results: atmospheric CO_2 concentration

Effects of the correction for the carbon cycle model to Nel and Cooper (2009) projections by performing simulations with MAGICC

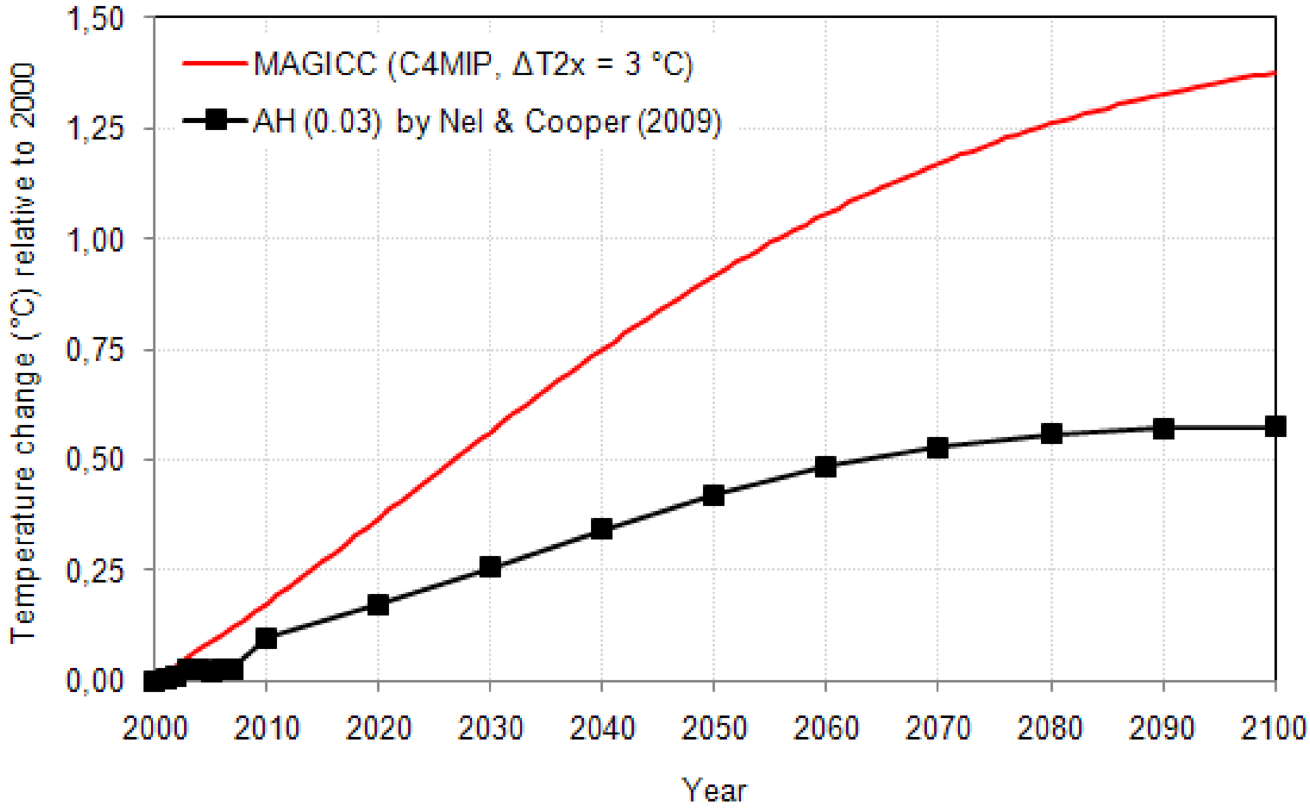


- Atmospheric CO_2 concentrations will exceed 525 ppm, thus going over the upper threshold of 450 ppm estimated by Nel and Cooper (2009).

A. Zecca and L. Chiari, manuscript in preparation (2009).

Final results: global temperature

Effects of the correction for the carbon cycle model, climate sensitivity and thermal inertia of the climate system to Nel and Cooper (2009) projections, by performing simulations with MAGICC



- The most probable warming in 2100 relative to 2000 level will be slightly less than 1.4 °C, thus much larger than the ~0.6 °C estimated by Nel and Cooper (2009).

A. Zecca and L. Chiari, manuscript in preparation (2009).

Conclusions

- Even without policy interventions, atmospheric CO_2 concentration will reach levels between 450 and 550 ppm in 2100. These values are far below the IPCC projections of a possible concentration of ~1000 ppm by the end of this century (BAU scenario).
- Even if fossil fuels depletion clamps down future atmospheric CO_2 concentrations, global temperature will increase anyway due to past GHG emissions and may also reach dangerous levels.
- Moreover there are several positive feedbacks that today's climate models have not accounted for yet:
  - water vapour feedback;
  - cloud feedback;
  - ice-albedo feedback;
  - arctic methane release;
  - saturation of CO_2 sinks.

  These feedbacks could make global warming much more serious than currently believed.
- We just don't know enough to be able to say whether fossil fuel depletion will "save" us from global warming, but very likely it will not.

ASPO

Thank you !

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