Estimating carbon equivalent emissions and quantifying climate benefits

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Thanks to: Jan Fuglestvedt, Terje Berntsen (CICERO, Oslo)
Jolene Cook, Nicola Stuber (Reading)

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PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A

Phil. Trans. R. Soc. A (2007) **365**, 1903–1914
doi:10.1098/rsta.2007.2050
Published online 18 May 2007

Comparing the climate effect of emissions of short- and long-lived climate agents

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European Union Assessment of Transport Impacts on Climate Change and Ozone Depletion (ATTICA)

www.pa.op.dlr.de/attica/

ATTICA

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Starting point: 1

BC emitting sources also emit a whole range of species that contribute to climate change.

We might like to put these on some kind of common scale so we can compare them:

(a) To find out the *net* effect of these emissions (e.g. in a legislative framework, or in "carbon" trading) and/or

(b) to consider the *net* effect of technical or operational changes etc. ("trade-offs") and/or

(c) to compare climate and non-climate emissions (e.g. noise, air quality and climate)

Here we use the word *metric* to denote a technique to place the effects of emissions on a common scale

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Starting point: 2

If we don’t develop such metrics:

We may take actions which we believe are beneficial (e.g. reduce climate change), but actually exacerbate the problem.

If we do develop such metrics:

We may take actions which we believe are beneficial (e.g. reduce climate change), but actually exacerbate the problem (!)

But we must try and be fully aware of the difficulties

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The problems

Two fundamental problems:

1. We have an incomplete understanding of how BC emissions (and *many* other emissions) influence climate change – a *scientific* problem

2. The design of metrics for such comparisons is a subject in its *infancy* – and one that cannot be solved by natural science alone – requires many value-laden judgements – a *structural* problem

Metric design: 1

- The metric provides an "exchange rate" to allow the *climate effect* of emissions of gas x to be compared with emissions of gas y (normally CO_2)
- We can then put emissions of all gases on a common scale ("equivalent CO_2")
- Ideally, the same equivalent CO_2 emissions produce the same climate effect regardless of their *composition*

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Metric design 2

- We *assume* that the metrics should be simple and transparent enough for use without further science input
- They must be flexible to incorporate new knowledge
- Ideally they should provide the user with a measure of uncertainty

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UN Framework Convention on Climate Change, 1992

- UNFCCC requires that we stabilise atmospheric concentrations "at a level that would prevent *dangerous* anthropogenic interference with the climate system"
- Comprehensive approach: "measures should cover *all relevant sources*, sinks and reservoirs" and be "*cost effective*"

http://unfccc.int

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Kyoto Protocol to UNFCCC, 1997

- In the Kyoto Protocol, "all relevant sources" are emissions of CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 .. the "Kyoto gases"; all are generally long lived (greater than 10 years)
- Multi-gas agreements require a metric to intercompare the impact of different emissions. In Kyoto, the climate effect of these is put on a common scale using *100-year* time-horizon *Global Warming Potentials*
- *Widely* and *deeply* accepted as an appropriate measure by the user community

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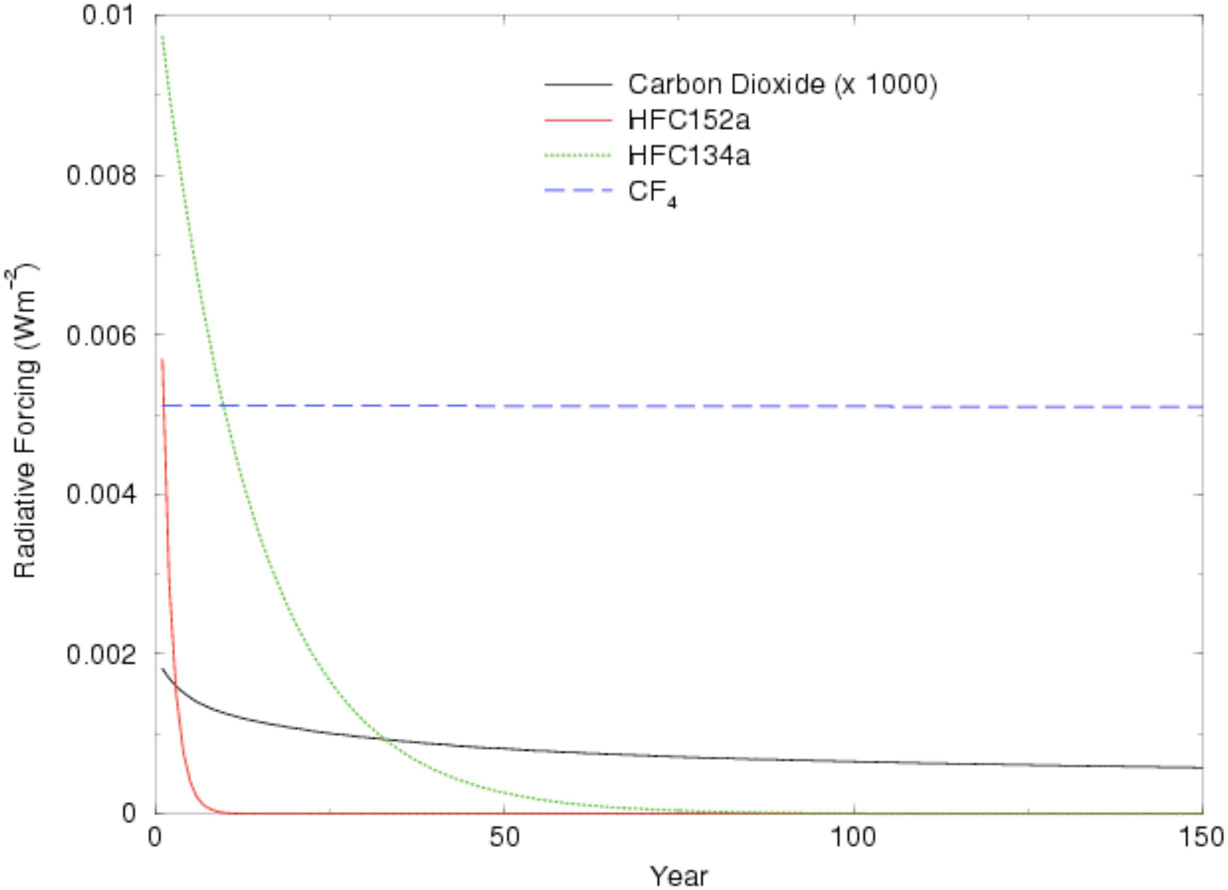
Global Warming Potential



Pulse emission at time t=0: Absolute Global Warming Potential (GWP) is the area under this curve to some given time.

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Example values of GWPs (relative to CO_2) for different time horizons

	GWP(20)	**GWP(100)**	GWP(500)
CH_4 (12 years)	62	**22**	7
N_2O (114 years)	270	**290**	150
HFC152a (1.4 years)	400	**120**	37

Shine et al. Climatic Change, 2005

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Kyoto – some questions

- Why a subset of emissions? (This is especially important for emissions by the transport sector as almost none of the non-CO_2 climate emissions are Kyoto gases)
- Why GWP (i.e. time-integrated radiative forcing)?
- Why a pulse emission?
- Why 100 years?
- etc

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What kind of "equivalence" does the GWP give?

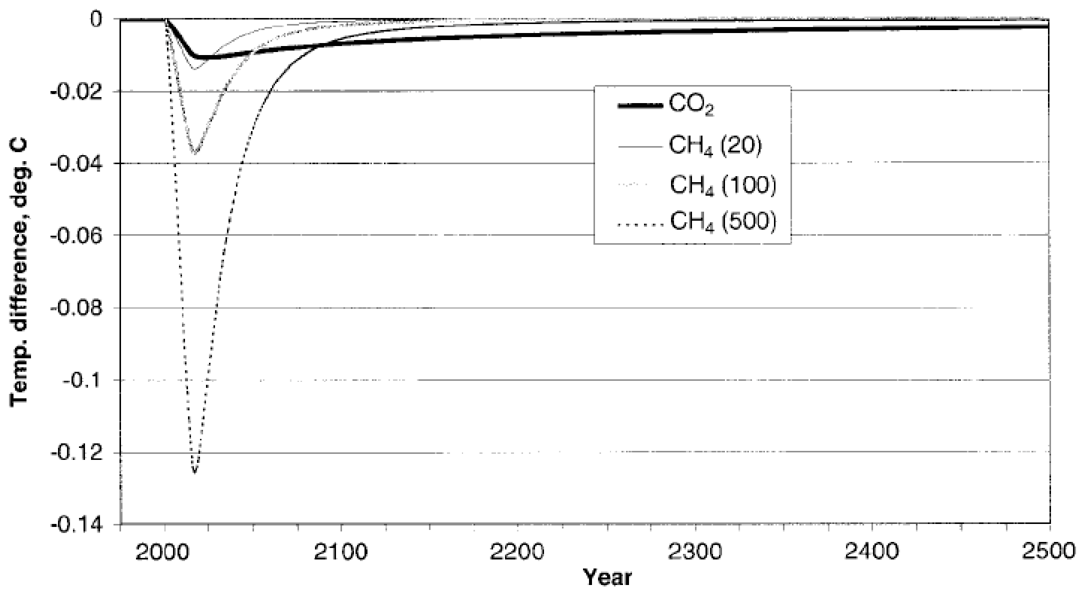

Figure 4. Temperature responses to sustained changes in emissions of CO_2 and CH_4 in terms of 'CO_2-equivalents' for various time horizons. The reductions are assumed to last for 15 years.

- Equivalence of emission reductions in GWP terms does not (necessarily) lead to equivalence in temperature change
- GWP is just one possible metric; it may not be the best – but what does "best" mean?

Fuglestvedt et al. 2003 *Climatic Change* 58:267-331

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Choices for metrics

•What parameter? e.g. radiative forcing, temperature change, sea-level rise, economic impacts, or the rate of change of these?

• What emission? Pulse, sustained,…?

• What time horizon?

• Value at a given time or integrated over a given "time horizon"?

• "discounted" so that changes in near-future are more important than changes in far-future ($\propto e^{-rt}$)?

The above choices affect decisions as to whether to it is best to cut short-lived or long-lived gases

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Examples of differing policies …

In 2005, the European Union stated that:

"the global annual mean surface temperature increase should not exceed 2 deg C above pre-industrial levels"

Differs from Kyoto approach … specified cuts in CO_2-equivalent emissions over some time period, with no specific climate target

Different policies may require different metrics

Are GWPs suitable if we have a target-based climate policy?

An alternative approach to establishing trade-offs among greenhouse gases

Alan S. Manne* & Richard G. Richels†

** Stanford University, Stanford, California 94305, USA*
†Electric Power Research Institute (EPRI), PO Box 10412, Palo Alto, California 94303, USA

NO!

Nature, 410, 675-677, 2001

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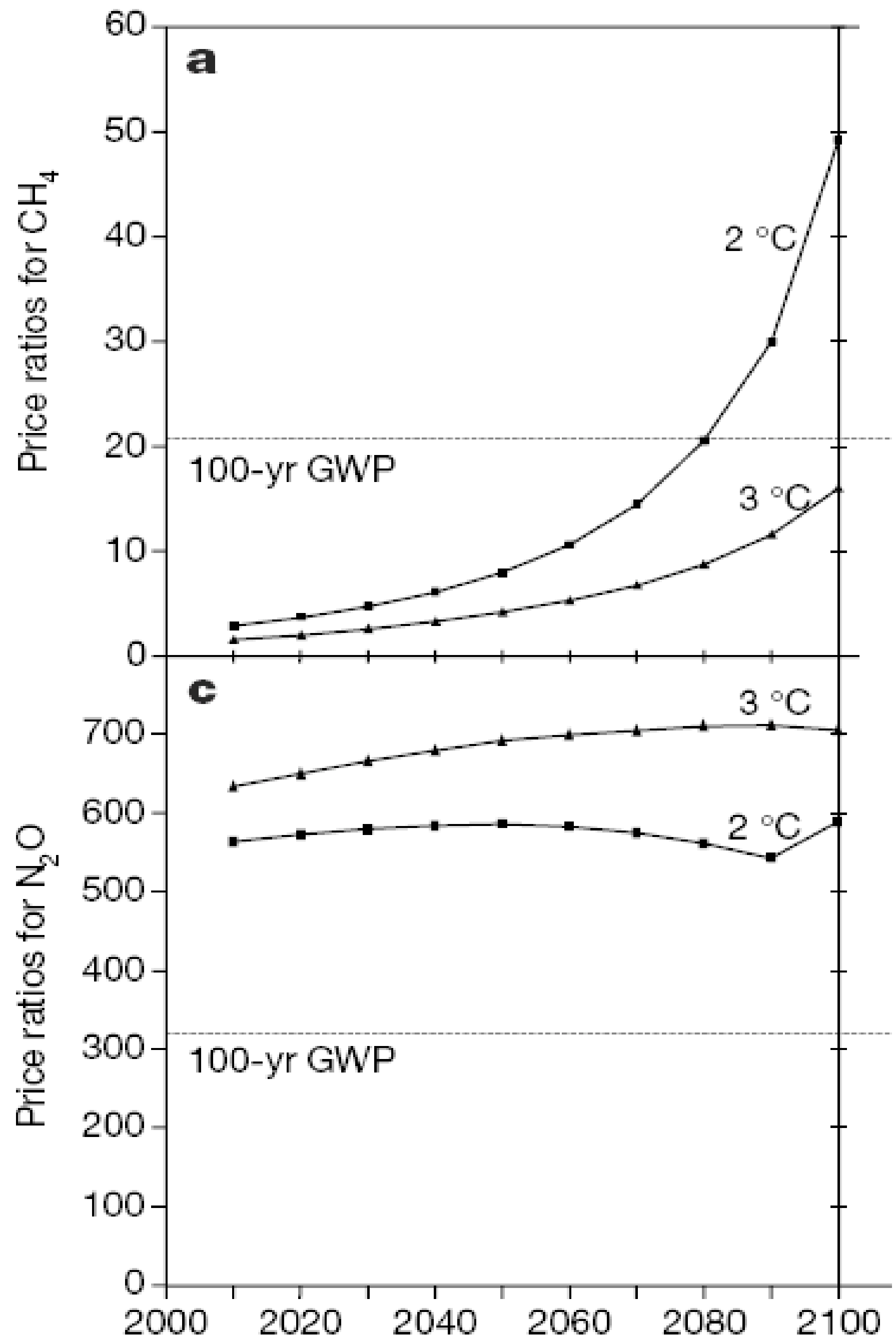

Manne and Richels, Nature, 2001

MERGE model

"... Integrates sub-models ... (with) ... reduced-form description of energy sector, economy, emissions, concentrations and temperature change, disaggregated over space and time"

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Manne and Richels' problems with GWPs

1. Failure to incorporate damage and abatement costs
2. Arbitrary choice of time horizon
3. Assumption that the metric values remain constant over time
4. Independent of the ultimate goal

"illogical" … "doesn't make economic sense"

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Different emission reduction strategies depending on technique

Restrain radiative forcing below 4.5 Wm^{-2} by 2100 (or about 3 deg C)

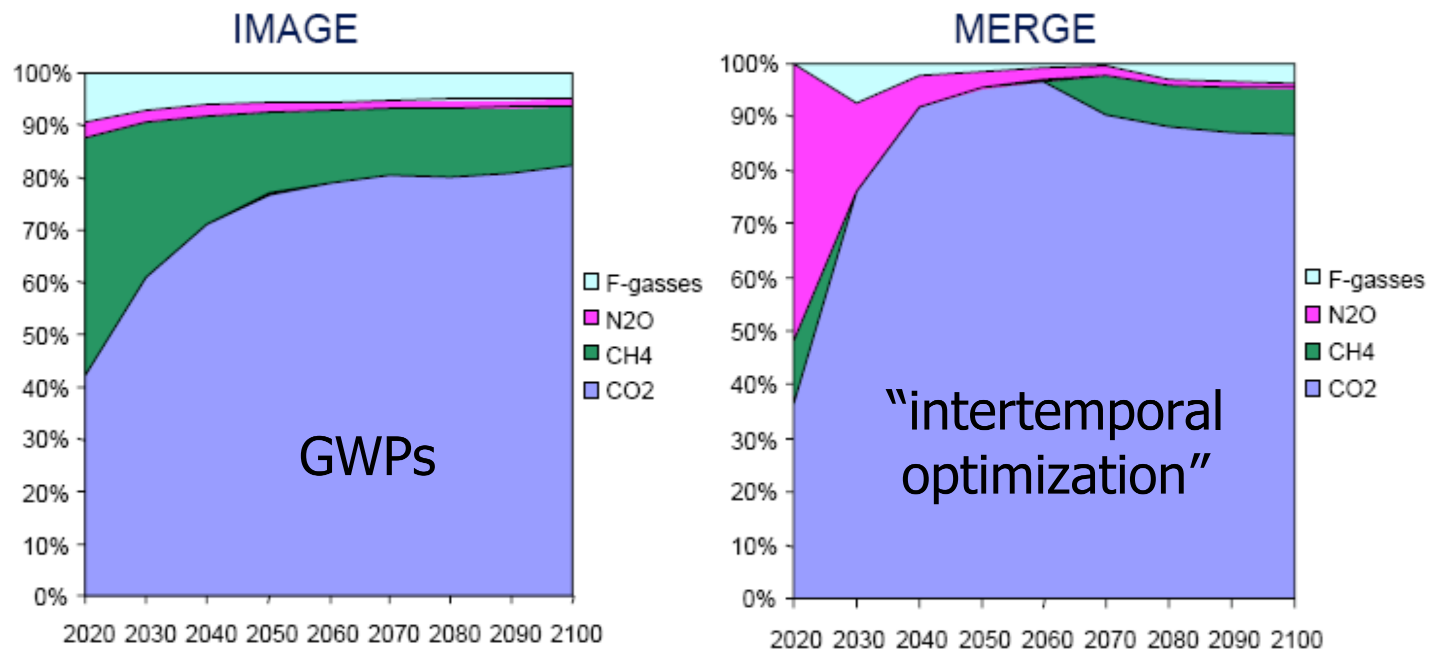

Fig. 9. Contribution of different gases in overall reductions. Comparison of a model using GWPs as the basis of substitution (IMAGE) to a model using inter-temporal optimization (MERGE).

Compares 21 different Energy Modelling Forum models

Van Vuuren et al., Energy Economics, 28, 102-120, 2006

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Can a purely physical metric do a useful job?

- Important to understand behaviour of climate parts of "integrated" models
- Physical metrics *may* be more acceptable to policymaking community – fewer assumptions, more transparency

What is the simplest possible metric that can do this?

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Simplest global-mean climate model

$$C\frac{d\quad T(t)}{dt} = \quad F(t) \qquad \frac{\quad T(t)}{\quad}$$

ΔT is global-mean surface temperature change

ΔF is the global-mean radiative forcing

C is the heat capacity of the system

λ is a (highly uncertain) climate sensitivity parameter $(K(Wm^{-2})^{-1})$

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Analytical solution for a pulse emission – the Global Temperature Change Potential GTP_P

$$AGTP_P^x(t) = \frac{A_x}{C(\quad^{1} \qquad {}_x{}^{1})}(\exp(\quad \frac{t}{\quad_x}) \quad \exp(\quad \frac{t}{\;}))$$

$$(\quad \pi \quad {}_x)$$

Shine et al. Climatic Change, 2005

Can be modified to include deep ocean memory e.g. by adding other terms – see Boucher and Reddy (Energy Policy, 2007)

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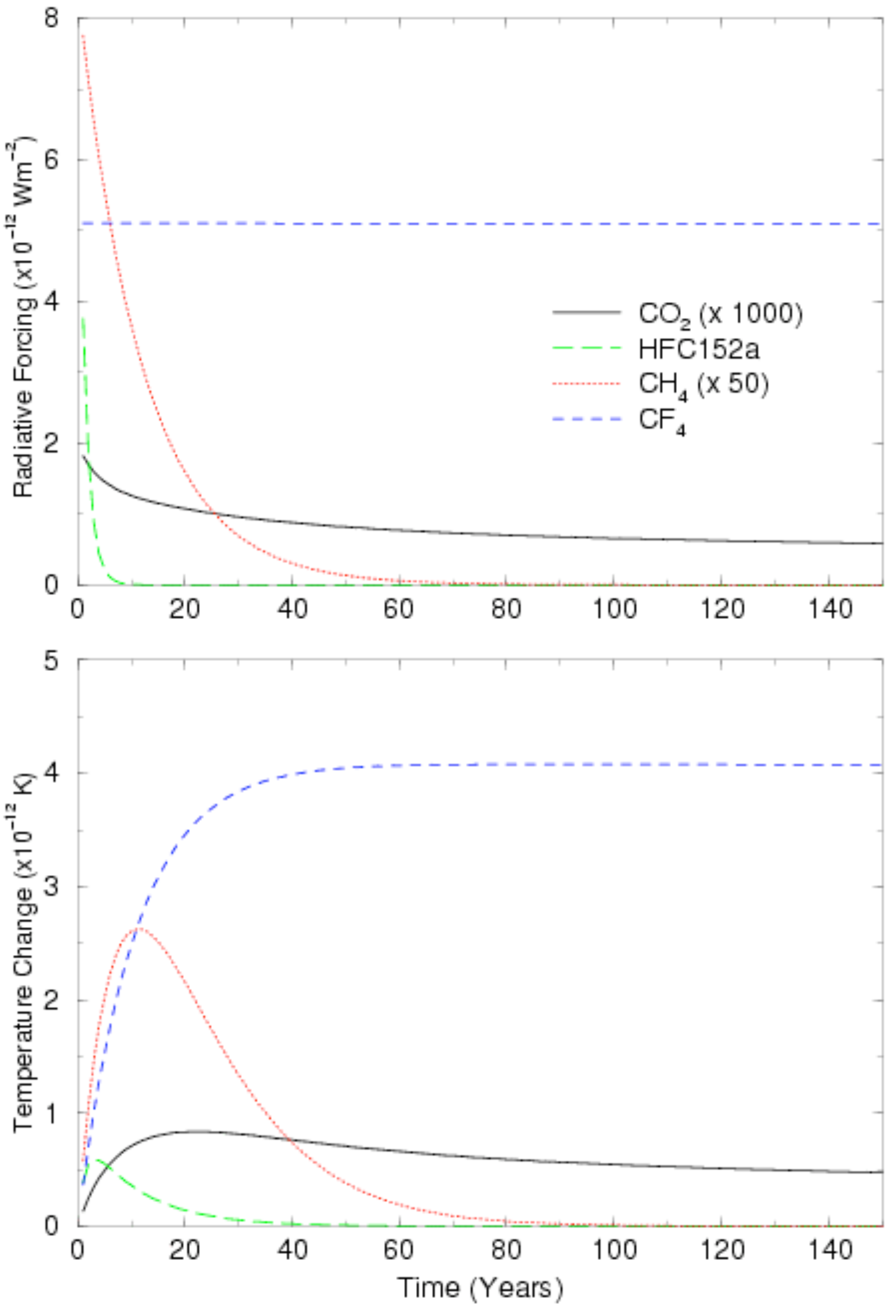

Radiative forcing due to a pulse emission

Temperature response due to a pulse emission

Shine et al. Climatic Change, 2005

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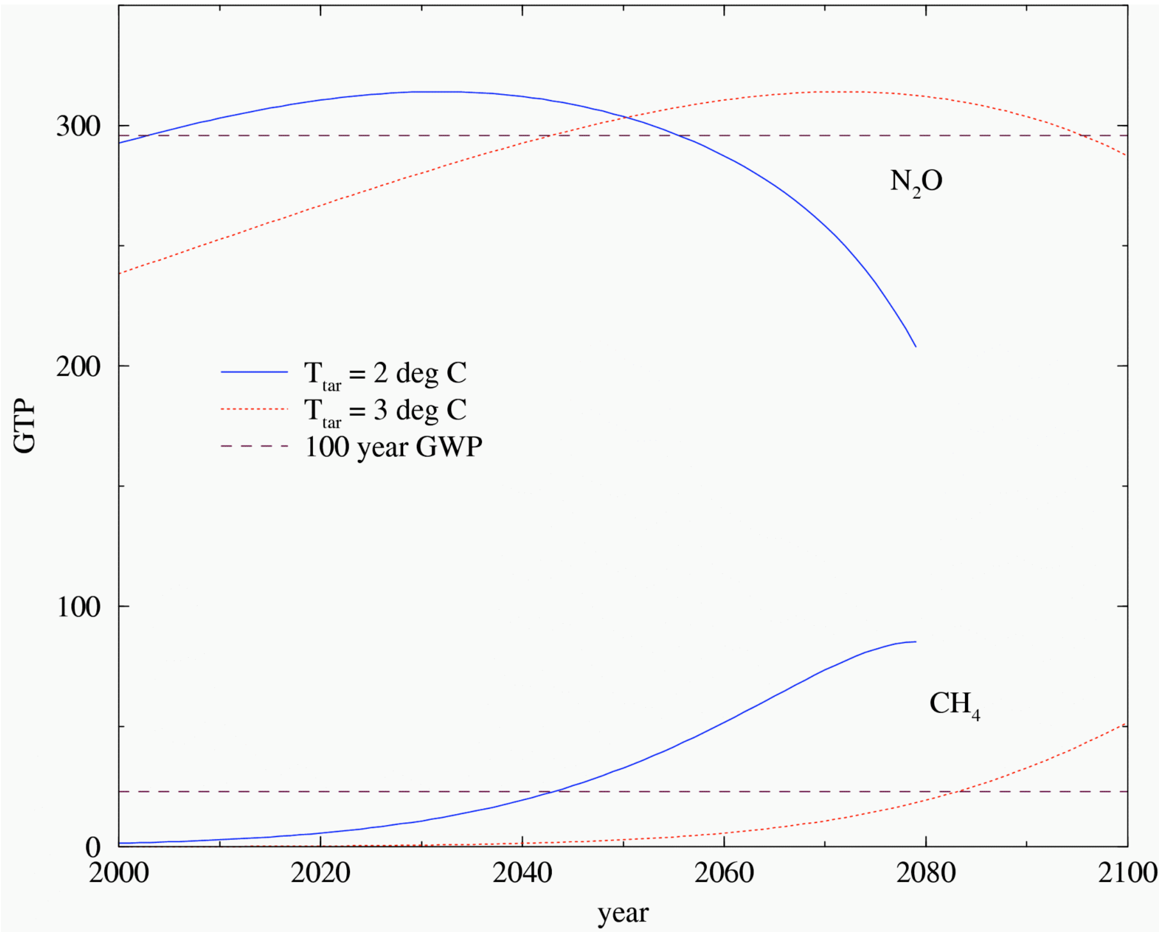
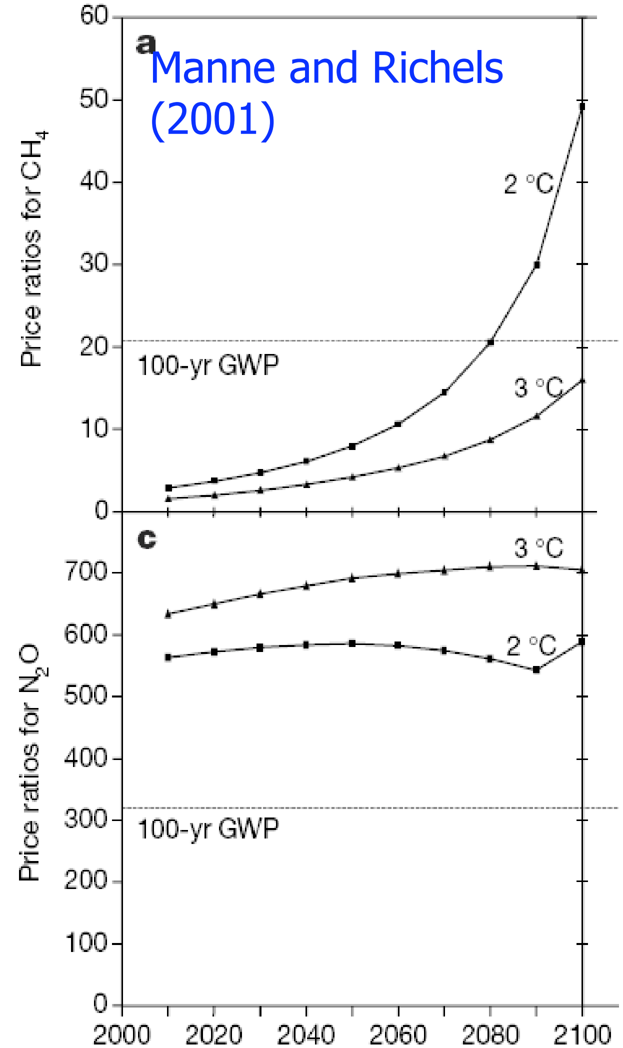
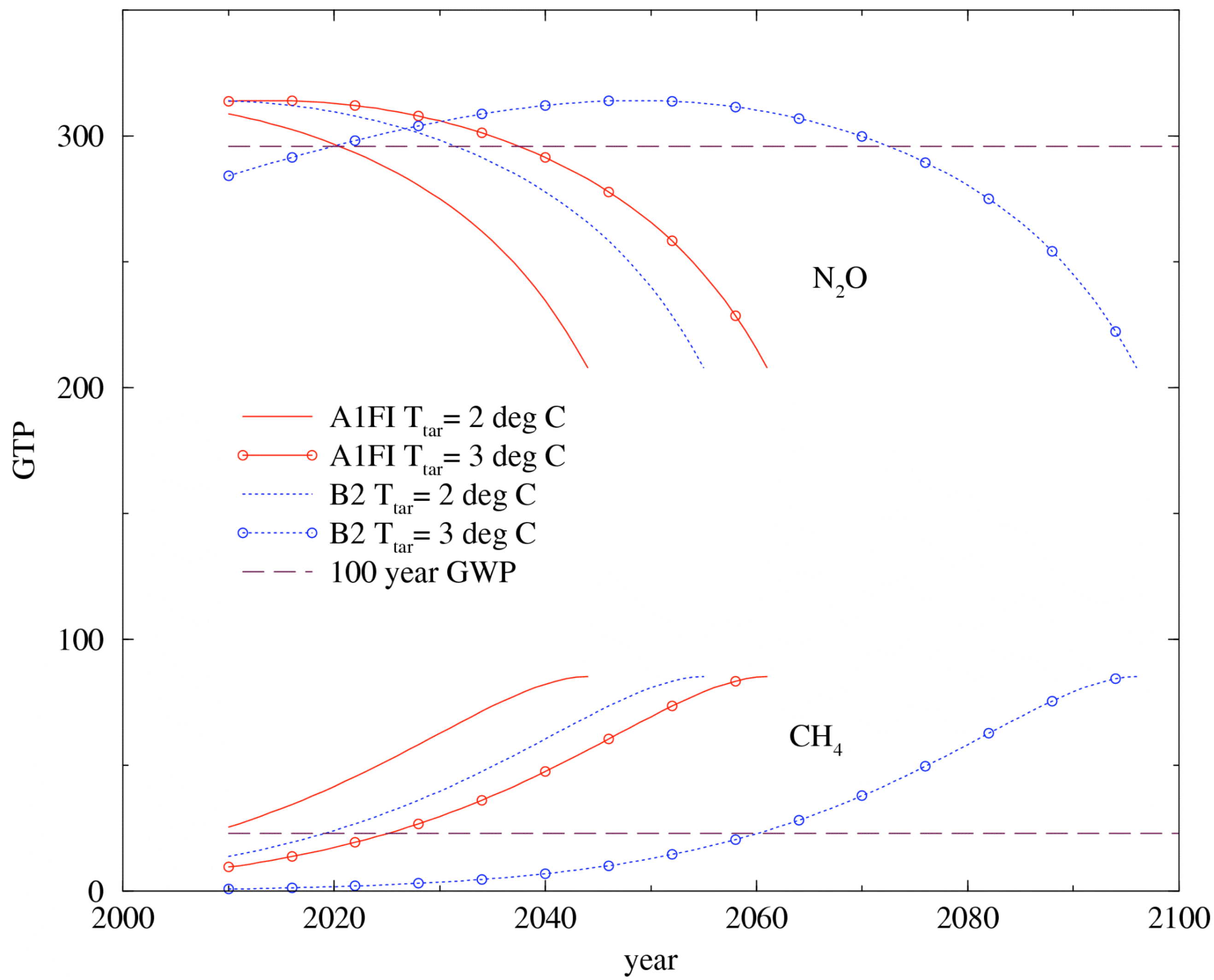
Using the $GTP_P(t)$ to "mimic" Manne and Richels





$\lambda = 0.8\ K(Wm^{-2})^{-1}$

Dependency on target and scenario



Choice of target and assumption of future climate "trajectory" have strong impact on $GTP_P(t)$

$\lambda = 0.8\ K(Wm^{-2})^{-1}$

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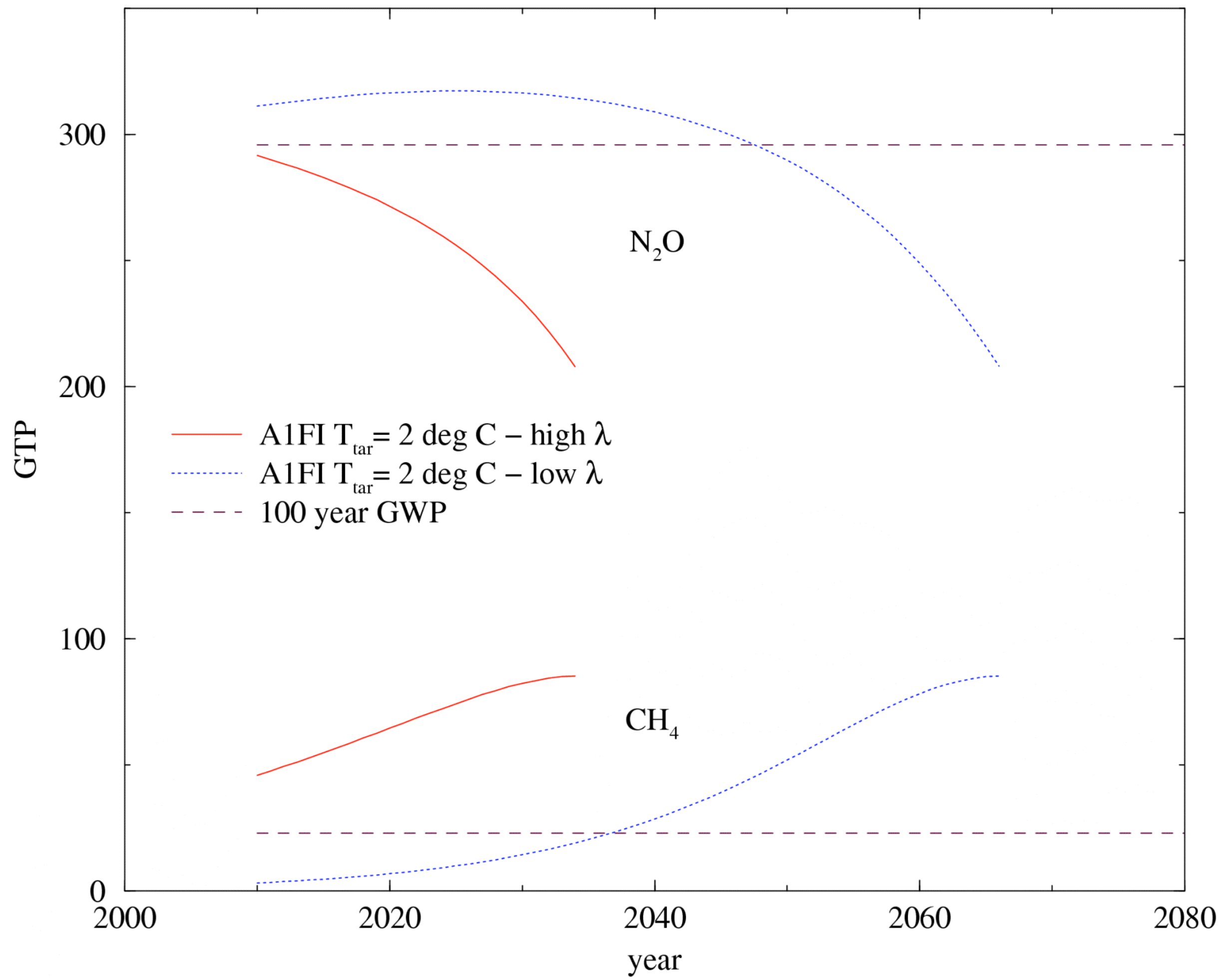
Dependence on climate sensitivity



Uncertainty in climate sensitivity has dramatic effect on the $GTP_P(t)$

$\lambda = 0.4$ and $1.2\ K(Wm^{-2})^{-1}$

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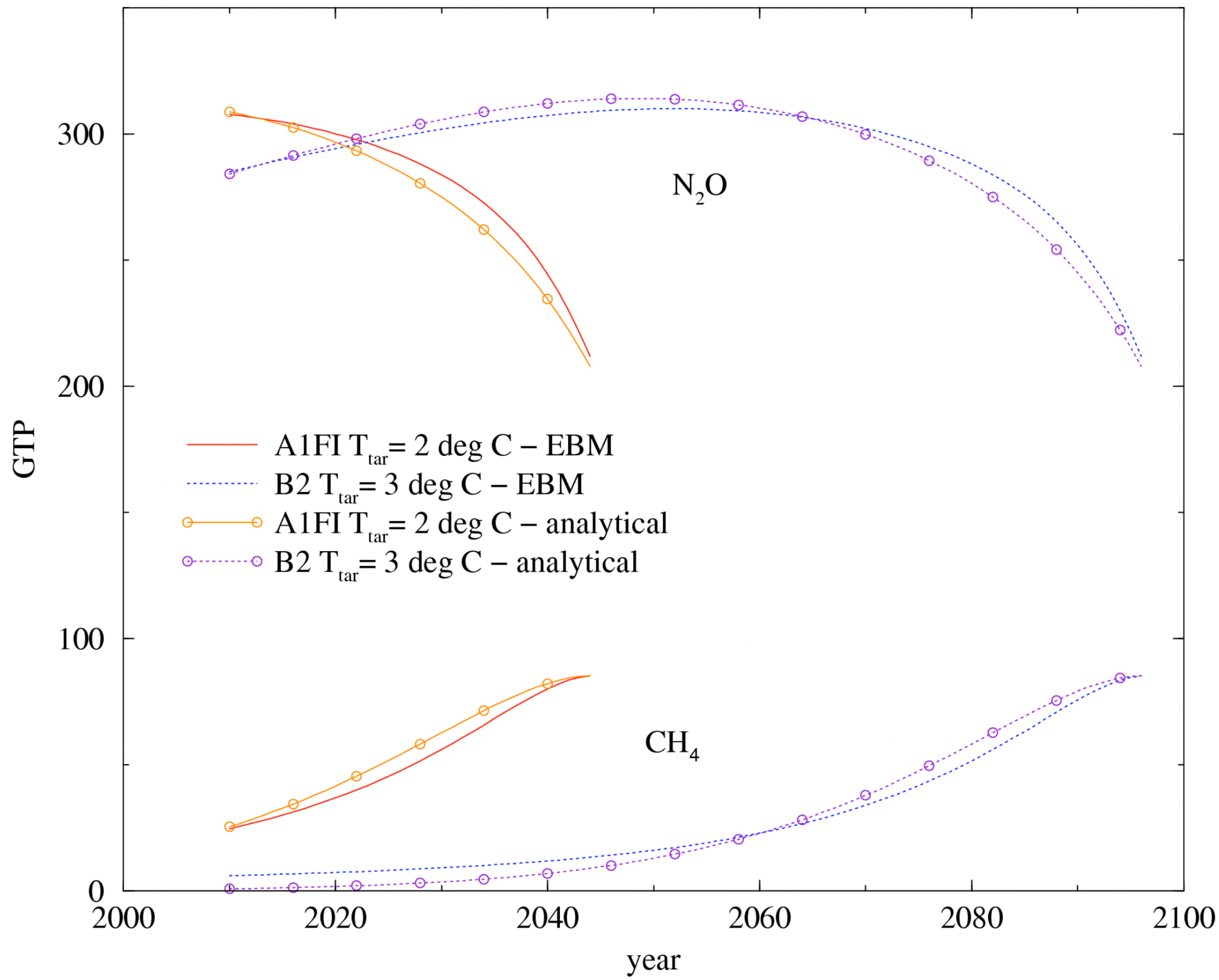
Dependency on climate model used



Dependence is quite modest compared to other uncertainties

$\lambda = 0.8\ K(Wm^{-2})^{-1}$

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Sample values

	GWP(100)	$GTP_P(100)$ - simple	$GTP_P(100)$ - "deep"
CH_4	25	0	3
N_2O	300	240	240
HFC152a	120	0	16
Black carbon	650	0.6	80
Wild (!) Aviation NO_x	70	-3	7

All values cited here are provisional and subject to change

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GTP versus GWP

- Both GWP and GTP values depend on the chosen time horizon, especially for short-lived gases
- The GTP of short-lived gases is *significantly* lower, at long time horizons, than the GWP
- Hence, our perception of the importance of whether it is better to cut short-lived or long-lived gases depends on (a) our choice of metric (e.g. GWP vs GTP) and (b) choices within that metric (e.g. time horizon)

How does the new metric meet some of the criticisms of GWPs?

1. Failure to incorporate damage and abatement costs ☒ ☺
2. Arbitrary choice of time horizon ☑
3. Assumption that the metric values remain constant over time ☑
4. Independent of the ultimate goal ☑

BC difficulties

- BC direct effect is only a part of the story
- Surface albedo, semi-direct effect …
- Challenges the definition of radiative forcing
- Model dependence
- Regional dependence
- At least it is easier than NO_x ☺

Efficacy

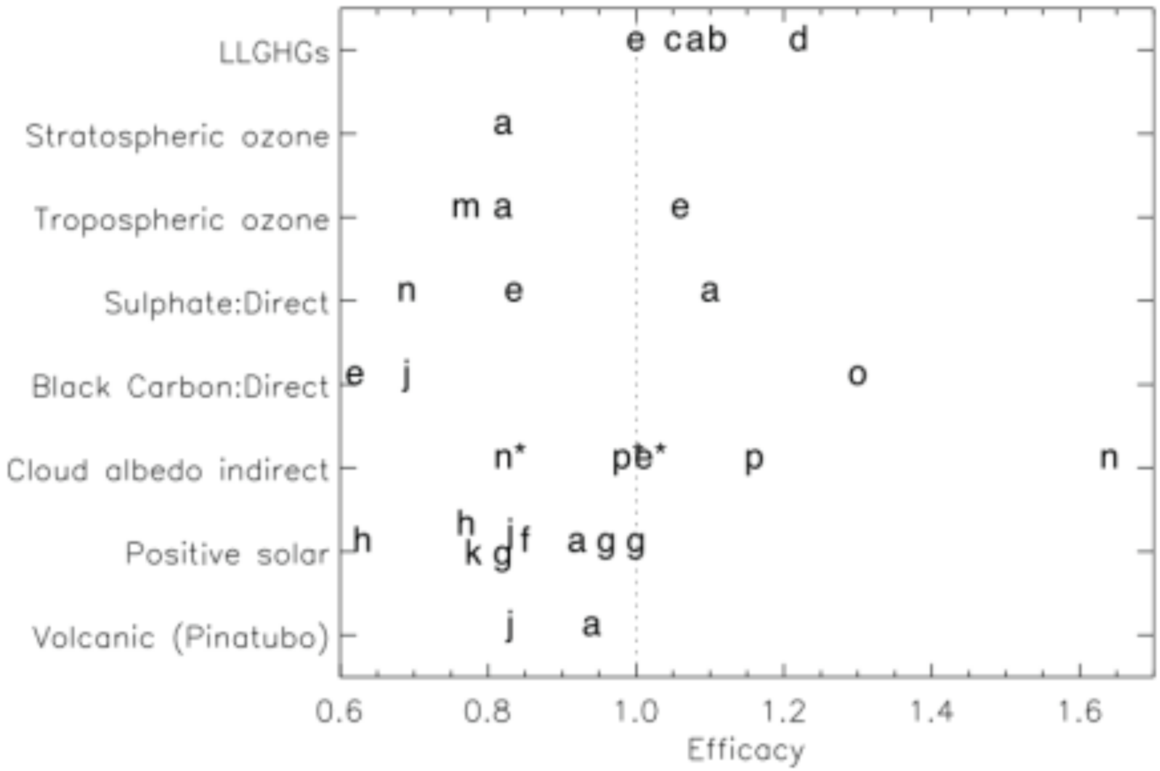

Figure 2: Summary of GCM calculations of efficacy of different climate forcings from the IPCC Fourth Assessment Report (Forster et al. 2007). The individual letters refer to different studies, which are specified in the caption of Figure 2.19 of Forster et al. (2007).

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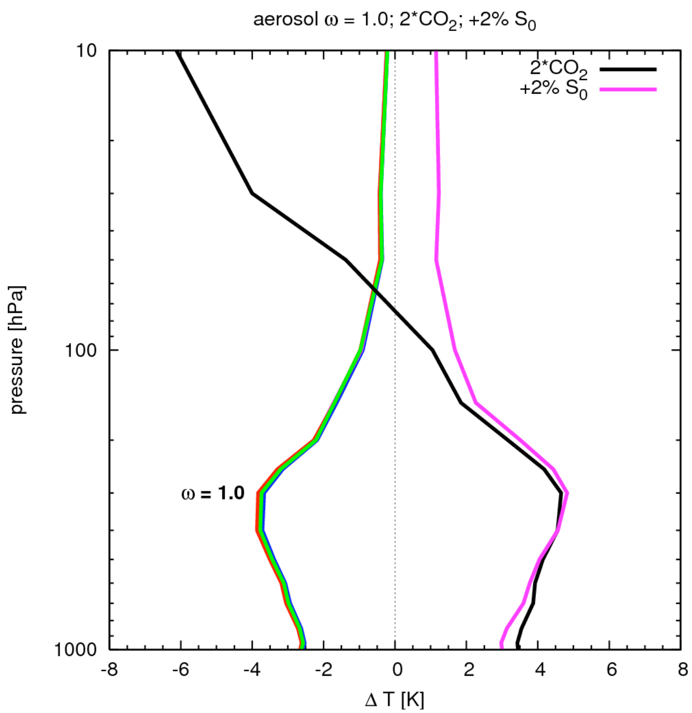

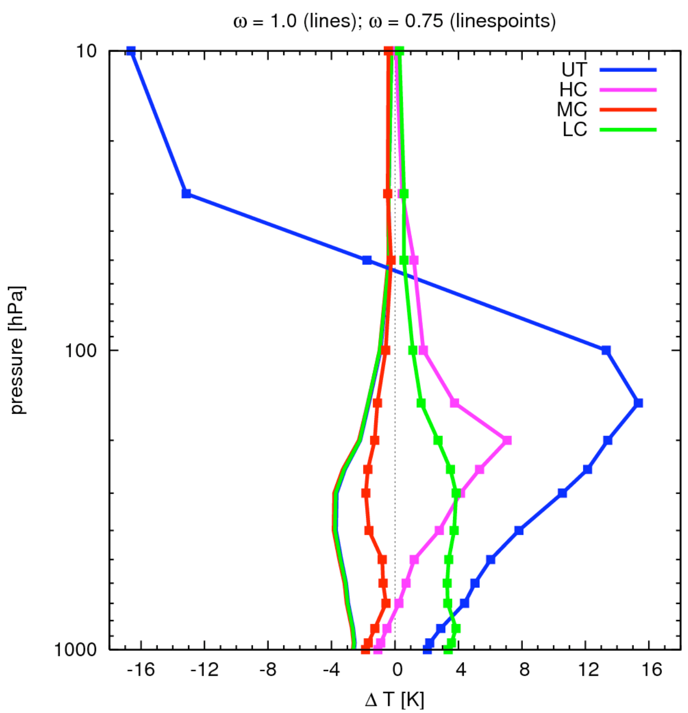

BC experiments in GCMs

Transport sectors are a major source of atmospheric aerosols – we compare how to climate models respond to idealised changes in aerosols.

They are insensitive to where *scattering* aerosols are placed … but highly sensitive (cannot even predict *sign* of response) to where *absorbing* aerosols are placed.

(Stuber et al. Climate Dynamics, submitted)

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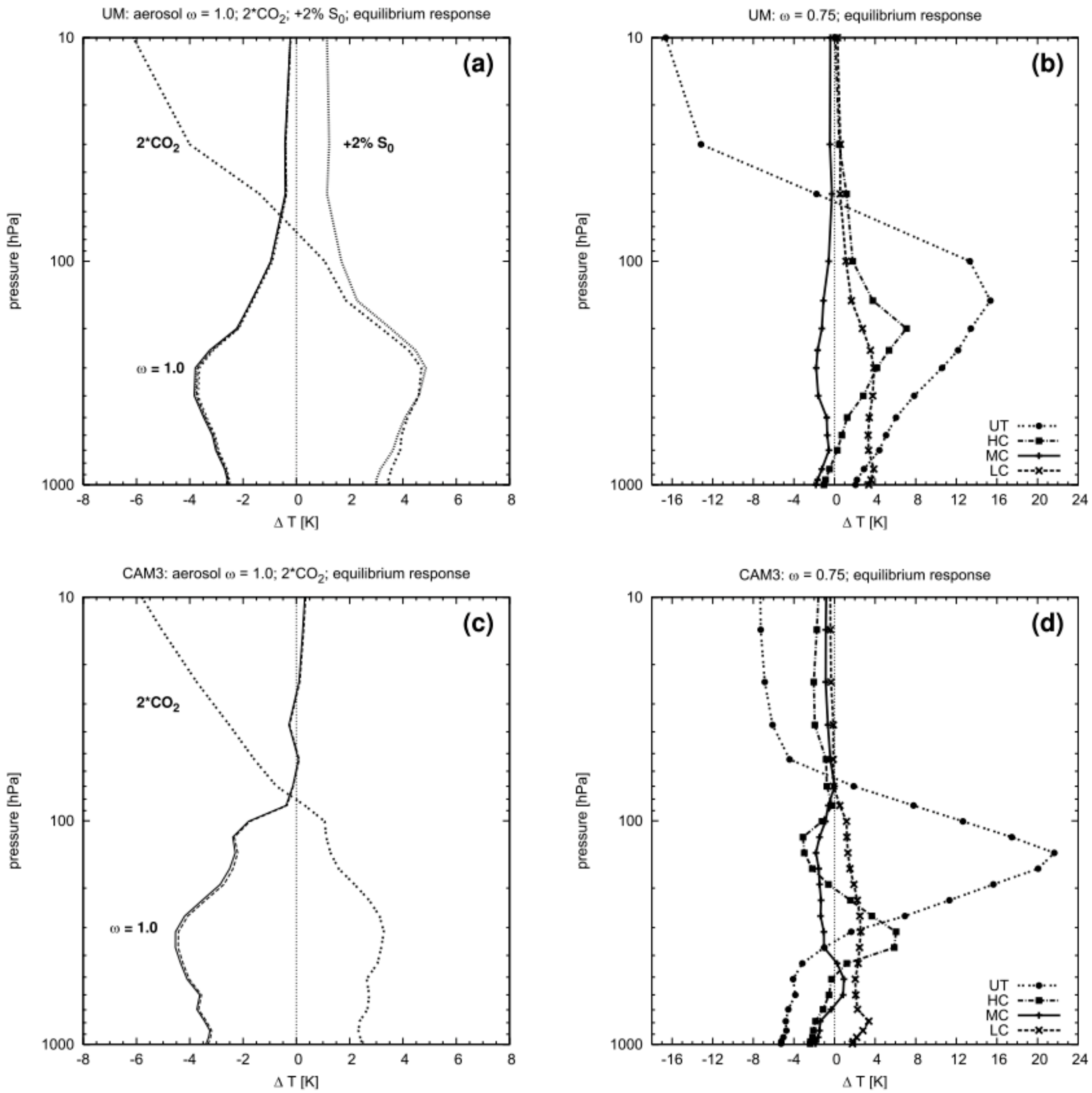
Comparison of 2 GCMs



Reading (top), CICERO (bottom).

NCAR (CICERO) model response is more local than Met Office (UREADMY) calculations

(Stuber et al. Climate Dynamics, submitted)

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The case of black carbon …

- An *illustration* for a very short-lived substance … many caveats
- But several suggestions we should target black carbon for both climate and health reasons
- Use Bond and Sun (Environ.Sci.Technol, 2005) parameters …

$$A_{bc}=3.5\text{x}10^{-9}\ \text{Wm}^{-2}\text{kg}^{-1}\ (!)$$

$$\alpha_{bc}=0.015\ \text{years}$$

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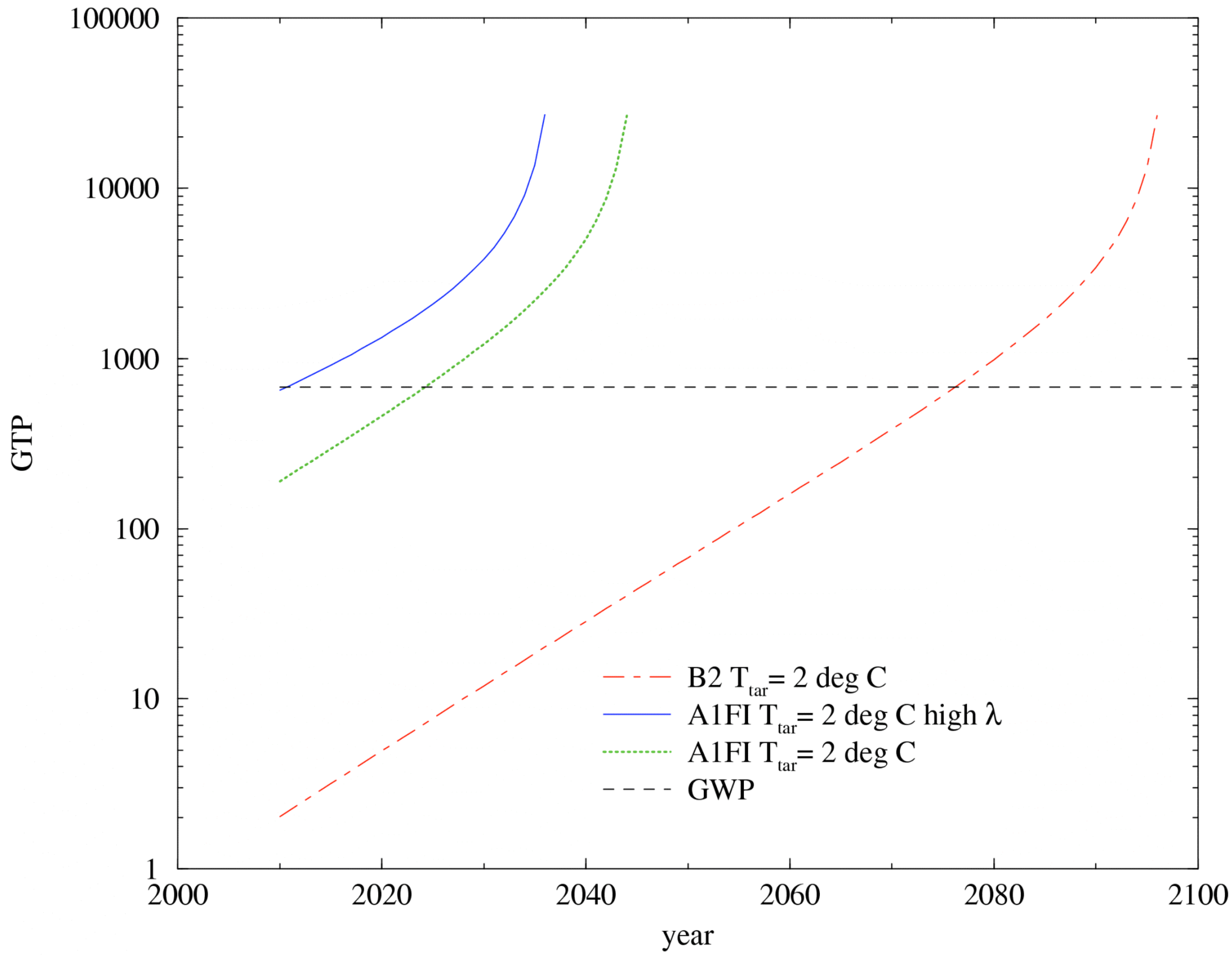
Black carbon GTP



$GTP_P(t)$ increases sharply as T_{tar} is approached, but can still be significant at earlier times

Regional Dependences

- Various studies have provided forcing and lifetime results for emissions from different regions – e.g. Berntsen et al. (Cli Cha 2006), Koch et al. (JGR 2007), Naik et al (GRL, 2007) and Reddy and Boucher (GRL, 2007)
- They do not include efficacy, surface albedo or cloud effects
- And we compare apples and oranges

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Inter-regional dependence

- Take GWP (100) as an example:

Study	Min	Max
Koch et al	350 (Africa)	940 (S.Asia)
Naik et al	590 (FSU)	1500 (India)
Reddy and Boucher	390 (Europe)	760 (mid-East)
Berntsen et al	350 (China)	660 (S.Asia)

All values cited here are provisional and subject to change

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Inter-model dependence

- Take GWP (100) as an example:

Region	Koch	Naik	Reddy
Africa	350 (least important)	1300	730 (2nd most important)
India	940	1600	600

All values cited here are provisional and subject to change

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Concluding comments

- Frameworks exist for producing carbon-equivalent emissions of BC, but there are many value-laden and policy dependent decisions in the metric choice
- Formidable problems in quantifying the climate effects of BC emissions (and their regional dependence). Values provided today would have large uncertainties and likely prove volatile in the face of improved understanding – but this does *not* mean they should not be used