Climate and Clean Air Coalition Scientific Advisory Panel Expert Workshop "Metrics for Evaluating and Reporting on Black Carbon and Methane Interventions"
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Metrics for evaluating the climate impacts of methane and black carbon interventions

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Acknowledgements

- General thanks to Jan Fuglestvedt for ≈1.8 decades of discussions on climate metrics (and for some slides!)
- Particular thanks to Myles Allen for stimulating and leading a new perspective (and for some more slides!)
- Both sorry not to be here!
- Misunderstandings are mine …

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- Background and how we got to where we are
- Beyond the GWP?
- A new metric which uses GWP in a new context for SLCPs (GWP*)

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Metric design 1

- The “absolute” metric provides a short-cut between an emission and its climate effect
- The “relative” metric provides an “exchange rate”. It allows (or at least *purports* to allow) the climate effect of emissions of gas x to be compared with emissions of gas y (normally CO_2)
- Emissions of all gases can then be placed on a common scale (“equivalent CO_2”)
- *Ideally*, the same equivalent CO_2 emissions would produce the same climate effect regardless of which gases contribute to that equivalence.

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Metric design 2

- Metrics should be simple to apply without further science input
- They must be flexible enough to incorporate new knowledge
- Ideally they should provide the user with a measure of uncertainty

Choices for metrics

- What parameter? e.g. radiative forcing, temperature change, precipitation 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, and/or discounted?

The above choices can affect whether it is (perceived to be) best to cut short-lived or long-lived gases – ***and the choice of metric depends on the policy that it aims to fulfil***

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Kyoto Protocol and the Global Warming Potential (GWP)

- The first Kyoto commitment period used the *100-year* GWP as given in SAR. (I)NDC's use a "rich variety" of values from different assessments
- *Generally* accepted as an appropriate measure by the user community
- At the time of Kyoto, the GWP was the only metric that IPCC had assessed
- AR5 assessed the Global Temperature-change Potential (GTP) as well as the GWP, but recommended *neither* (AR4 *did* recommend GWP)

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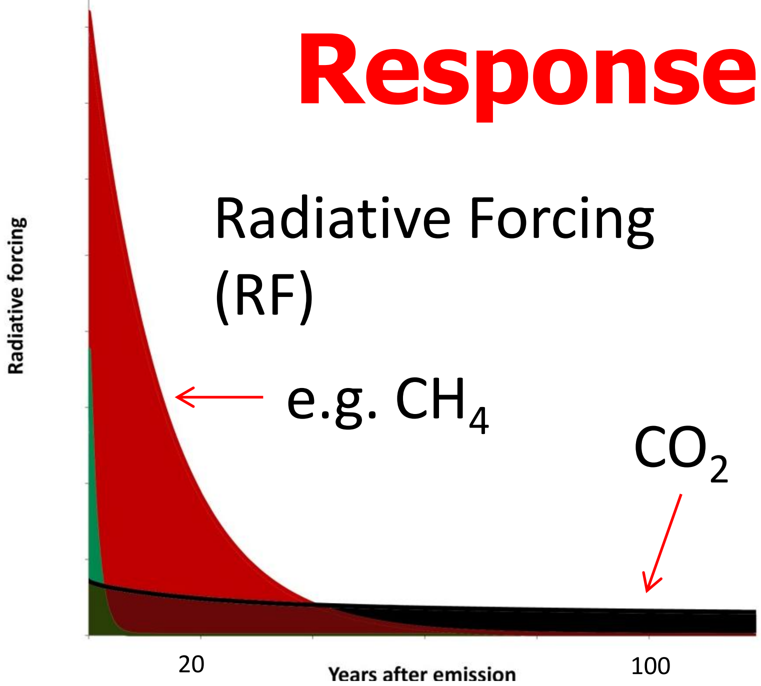
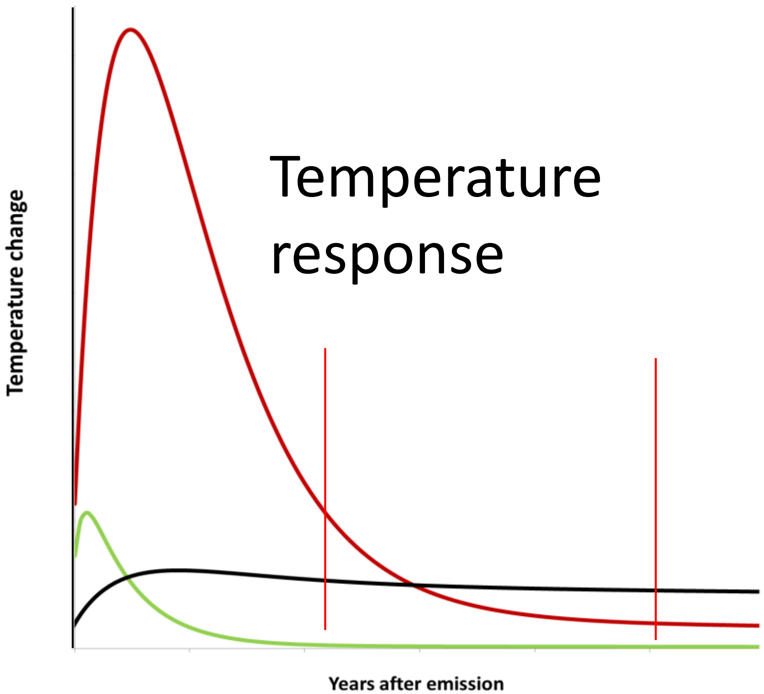
Response to a pulse emission



$$GWP_i(H) = \frac{\int_0^H RF_i(t)dt}{\int_0^H RF_{CO_2}(t)dt} = \frac{AGWP_i(H)}{AGWP_{CO_2}(H)}$$

➔ strong memory even when pulse has disappeared completely



$$GTP_i(t) = \frac{AGTP(t)_i}{AGTP(t)_{CO_2}} = \frac{\Delta T(t)_i}{\Delta T(t)_{CO_2}}$$

Large differences between GTP and GWP for short-lived components e.g.

BC: GWP(100) =**320**; GTP(100)=**130**

CH_4: GWP(100) =**28**; GTP(100)=**4**

But no reason to compare 100 years!

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Some personal conclusions

- There is nothing uniquely good about GWP (100) – arguably it is an "accident of birth" that we use it
- But it has enabled multi-gas climate policy and has generally been viewed as allowing a cost-effective approach to mitigation
- And there would be "costs" associated with moving away from using the GWP(100) to another metric (as there are in using updated GWP(100) values)
- Two cheers for the GWP!

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Evolution of GWP(100) for methane in IPCC reports

	GWP (100)	Indirect multiplier	Radiative Efficiency (W m^{-2} $ppbv^{-1}$)	Adjustment time (years)	AGWP of CO_2 relative to AR5
FAR	21	x2.3?	?	10	1.35
RF Rep	24.5	x2.3?	?	14.5	1.08
SAR	**21**	**x1.3**	**?**	**12.2**	**1.12**
TAR	23	x1.3	3.7E-4	12.0	0.98
AR4	25	x1.4	3.7E-4	12	0.95
AR5	28	x1.65	3.63E-4	12.4	1

AR5 stated uncertainty is ±40% for CH_4 which is dominated by indirect effects and the AGWP for CO_2. Even higher uncertainty for shorter-lived species.

Some post-AR5 developments

- Climate-carbon feedbacks: AR5 tentatively indicated CH_4 GWP(100) increases from 28 to 34. More recent work indicates increase to 31 (Gasser et al. 2016) or 33-35 (Sterner and Johansson 2017)
- Radiative efficiency: New calculations (Etminan et al. 2016) of radiative efficiency of CH_4 (especially inclusion of shortwave absorption bands) increase GWP(100) from 28 to 32
- AR6? If AR6 assesses both to be reliable then, in absence of other changes, it would increase CH_4 GWP(100) to at least 35

Gasser et al: 10.5194/esd-2016-55; Etminan et al: 10.1002/2016GL071930
Sterner and Johansson 10.1088/1748-9326/aa61dc

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Some criticisms of GWPs (a la Manne and Richels 2001)

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

See also Pierrehumbert (2016, 10.1146/annurev-earth-060313-054843) specifically in SLCP context

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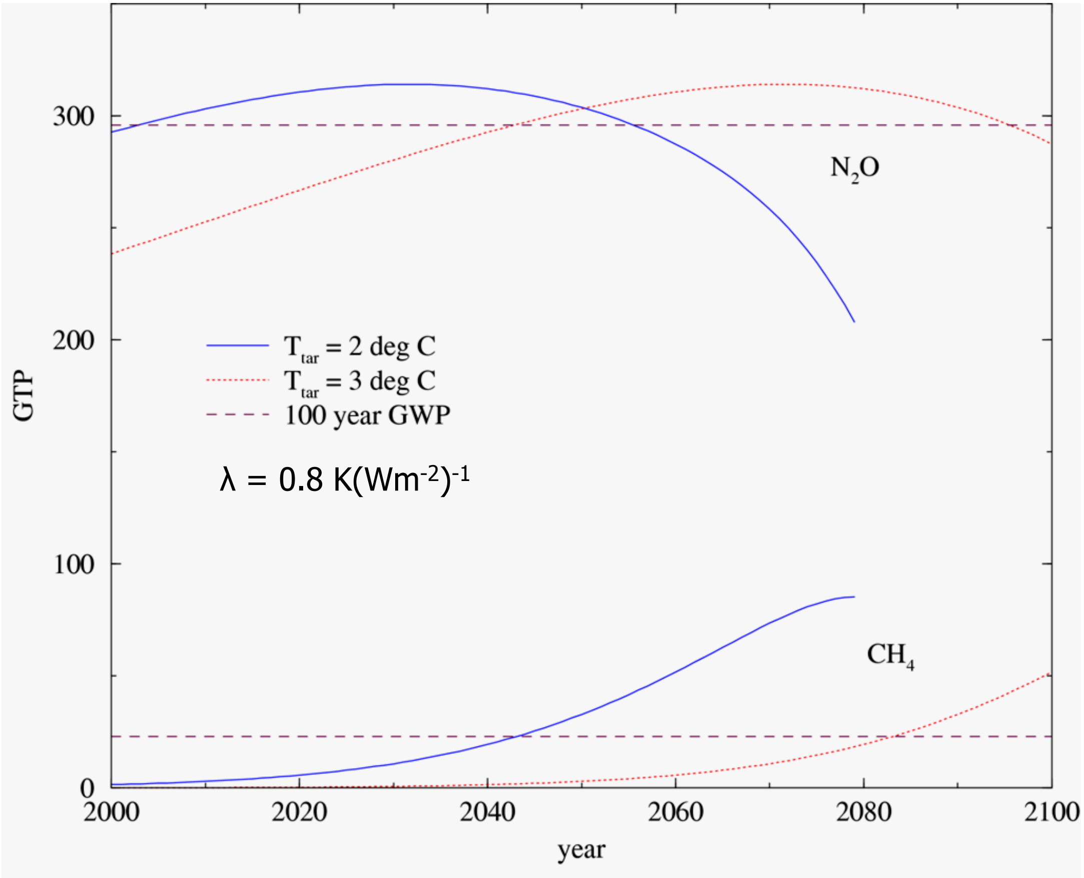
Time-dependent and target orientated metrics



e.g. Time dependent GTP

See also Manne and Richels (Nature 2001), Johansson (Cli Cha 2011) etc.

Shine et al. Phil Trans Roy Soc, 2007

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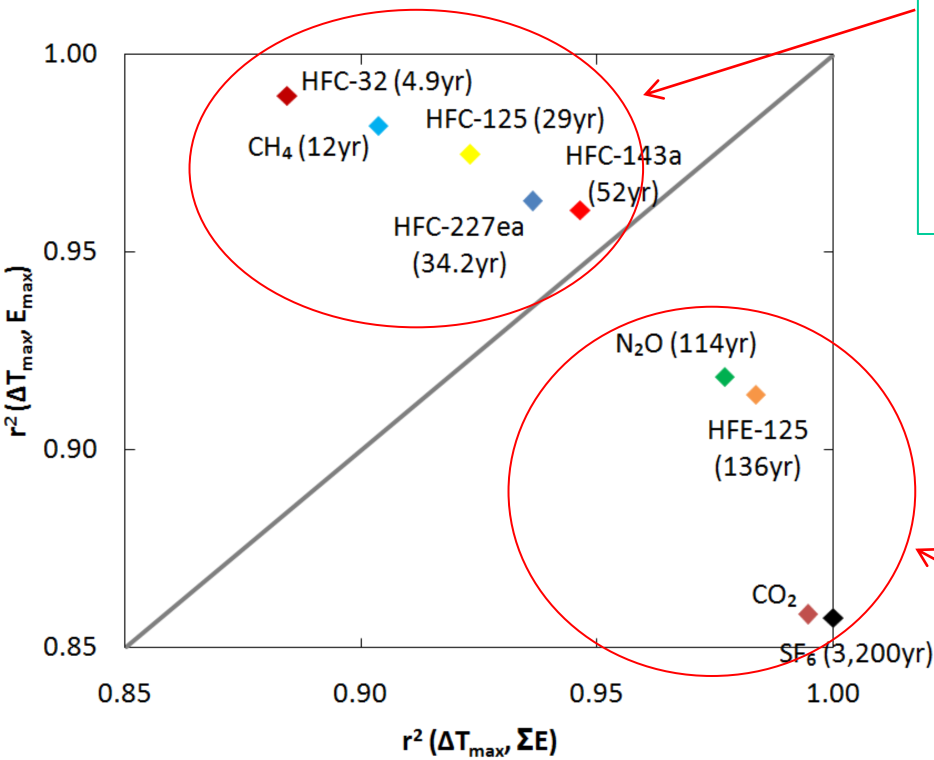
Could separate into two baskets with different reference gases



Smith et al. Nature Cli Change, 2012

See also Cherubini and Tanaka, Env. Sici Tech 2016

Shorter-lived gases: peak temperature change more related to *sustained emission rate.* CH_4 as a reference?

Longer-lived gases: peak temperature change more related to *cumulative* emissions. CO_2 as a reference?

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Reconciling short-lived versus long-lived in the context of 1.5/2 deg target

nature climate change

LETTERS

PUBLISHED ONLINE: 2 MAY 2016 | DOI: 10.1038/NCLIMATE2998

New use of global warming potentials to compare cumulative and short-lived climate pollutants

Myles R. Allen[1,2]*, Jan S. Fuglestvedt[3], Keith P. Shine[4], Andy Reisinger[5], Raymond T. Pierrehumbert[2] and Piers M. Forster[6]

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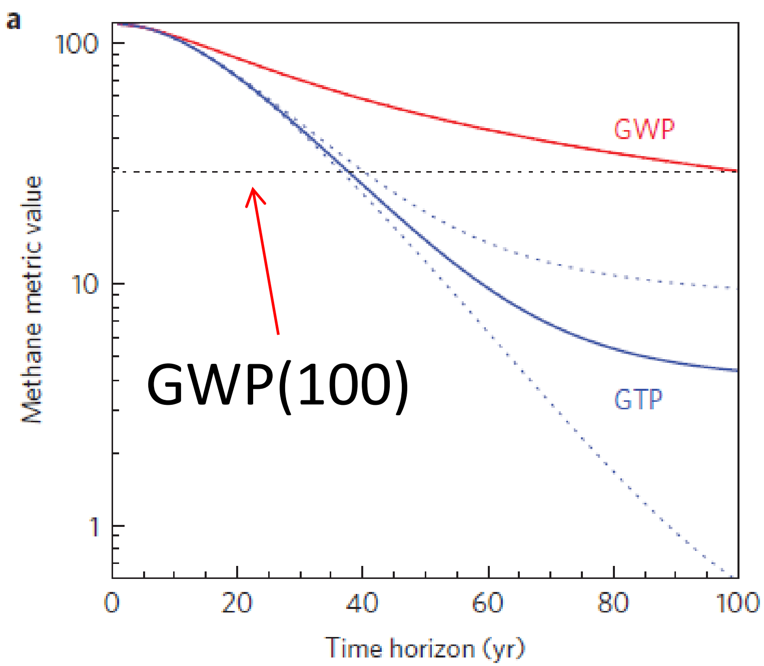
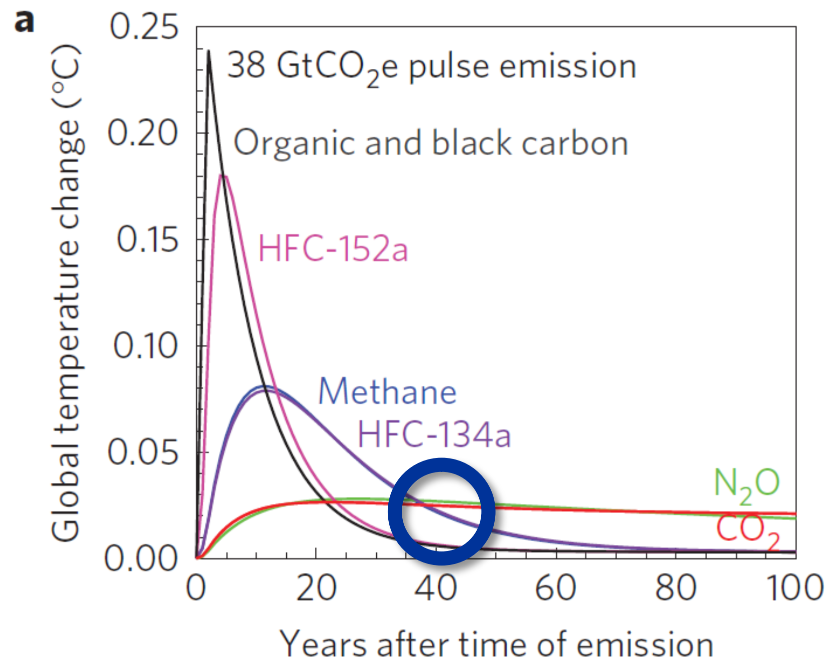
GWP(100) gives SLCP GTP 20-40 years after a pulse emission





But no amount of (linear) scaling would make the CO_2 ΔT look like the CH_4 ΔT, for all times, despite emissions being equivalent in GWP(100) terms

Allen et al (2016)

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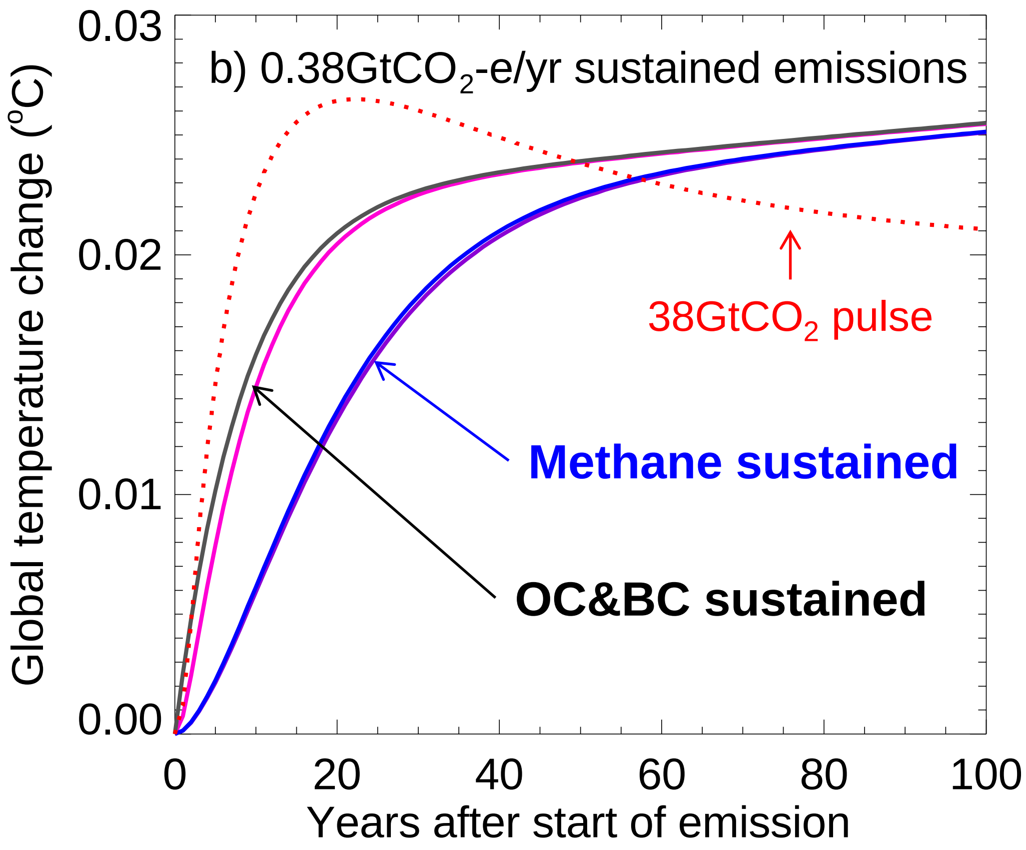
Possible short-term solution

- $GWP_{100} \approx GTP_{40}$ for methane, so GWP_{100} happens to indicate impact on temperature in about 40 years.
- To stabilize at 1.5° C, temperatures must be approaching stabilization in about 40 years, so…
  - *if* we meet the goal of limiting warming to 1.5° C, without overshoot (this means reducing CO_2 and N_2O emissions to net zero in about 40 years) then GWP_{100} just happens to be an adequate metric right now.
- But…
  - As we approach temperature stabilization, GWP_{100} will begin to undervalue methane emissions.
  - If we fail to stabilize at 1.5° C, or overshoot, GWP_{100} still overvalues methane.
- So, can we do better?

Approximate equivalence between *one-off* CO_2 emissions and *permanent* changes in methane emission rates



Allen et al (2016)

Comparing impact of a pulse emission of CO_2 with equivalent (GWP_{100}) sustained SLCP emissions spread out over 100-year time horizon.

Why?

- Following the "trillionth tonne" argument for CO_2, the temperature change depends on how much is emitted rather than when it is emitted
- e.g. 20 units emitted in year 1, has roughly same effect as 1 unit emitted in each year for 20 years

- (This allows to approximate the absolute pulse GTP in terms of the sustained pulse GTP)

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Why??

- But the pulse GWP also measures the relative equilibrium temperature change due to *sustained* emissions – what we now call the sustained GTP. Long-established result "rediscovered" by Shine et al. (2005)

- (Hence, we can approximate GWP in terms of sustained GTPs and, from previous slide, write the sustained GTP of CO_2 in terms of its pulse GTP – see methods of Allen et al. 2016)

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GWP*

- Allen et al. (2016 and in prep) propose a new metric: GWP* = HxGWP(H) applied to a permanently sustained increase in SLCP emissions
- *i.e: A permanent increase of 1 tonne yr^{-1} of SLCP ≡ a one-off CO_2 emission of GWP* tonnes*
- e.g. a 1 tonne pulse of CO_2 = 1/(28x100) tonnes yr^{-1} ≡ 0.36 kg yr^{-1} change in CH_4 emissions sustained indefinitely
- GWP* depends little on H if H > SLCP lifetime and < characteristic CO_2 residence time

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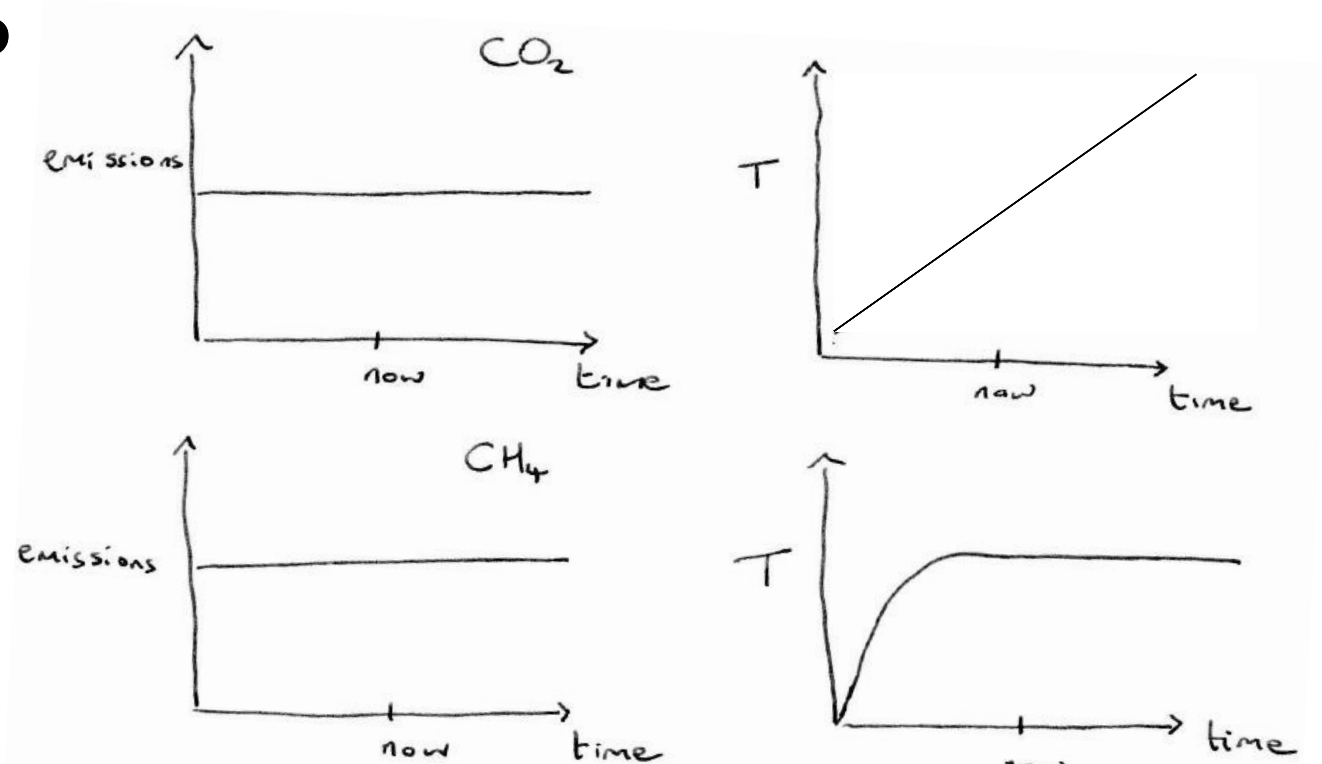
Constant SLCP emissions have no CO_2-equivalence …

Constant SLCP emissions have zero CO_2 equivalence under GWP*: they cause no *further* ΔT (unlike actual constant CO_2 emissions)



But CH_4 emissions continue to elevate temperatures so they possess mitigation potential

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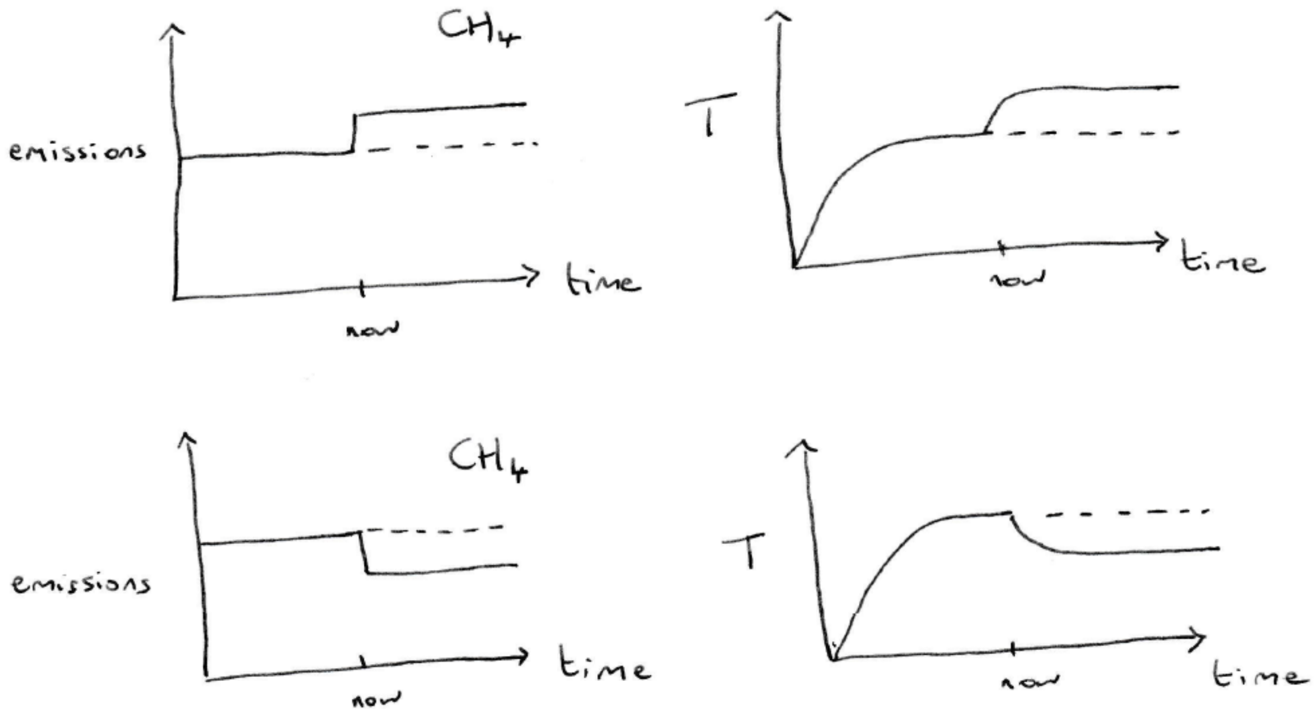
But changing SLCP emissions do

A *change* in SLCP emissions leads to a change in ΔT and so they do have CO_2-equivalence



Falling SLCP emissions are equivalent to *negative* CO_2 emissions using GWP*

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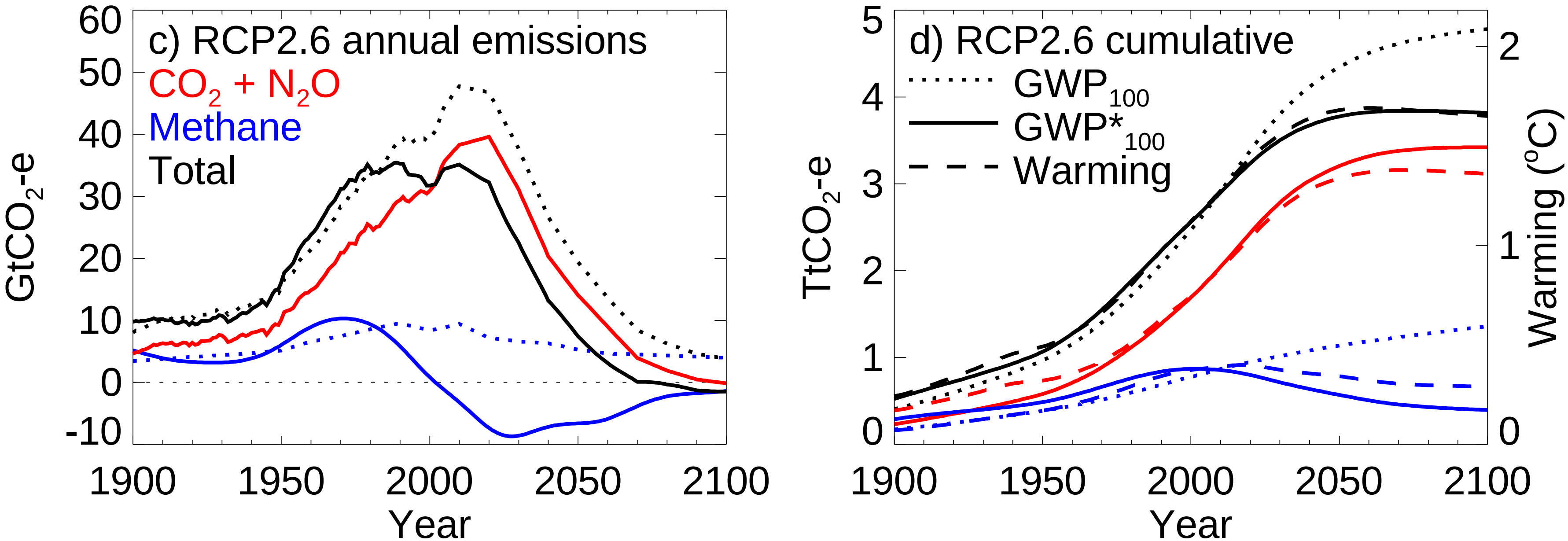
Under GWP* cumulative emissions indicate future warming. Under GWP they do not.



Under GWP*, it is the *change* in CH_4 emissions that holds the CO_2 equivalence. Using this CO_2-equivalence approximately captures the temperature effect of falling CH_4 emissions under RCP2.6.

Under GWP, *all* CH_4 emissions would be regarded as having positive CO_2 equivalence, and would then be (wrongly) deemed to cause continued warming

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Concluding comments

- The GWP* better captures the temperature impact of CO_2 and SLCP emissions on timescales relevant to current targets
- SLCP reductions can be "worth" much short-term CO_2 provided (i) this doesn't lead to higher future CO_2 emissions and (ii) provided the SLCP reductions are not reversed
- There is a limit to how much CO_2 equivalence can be "bought" by SLCP reductions without the SCLP emissions having to go negative

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