Science-based, not scenario-based

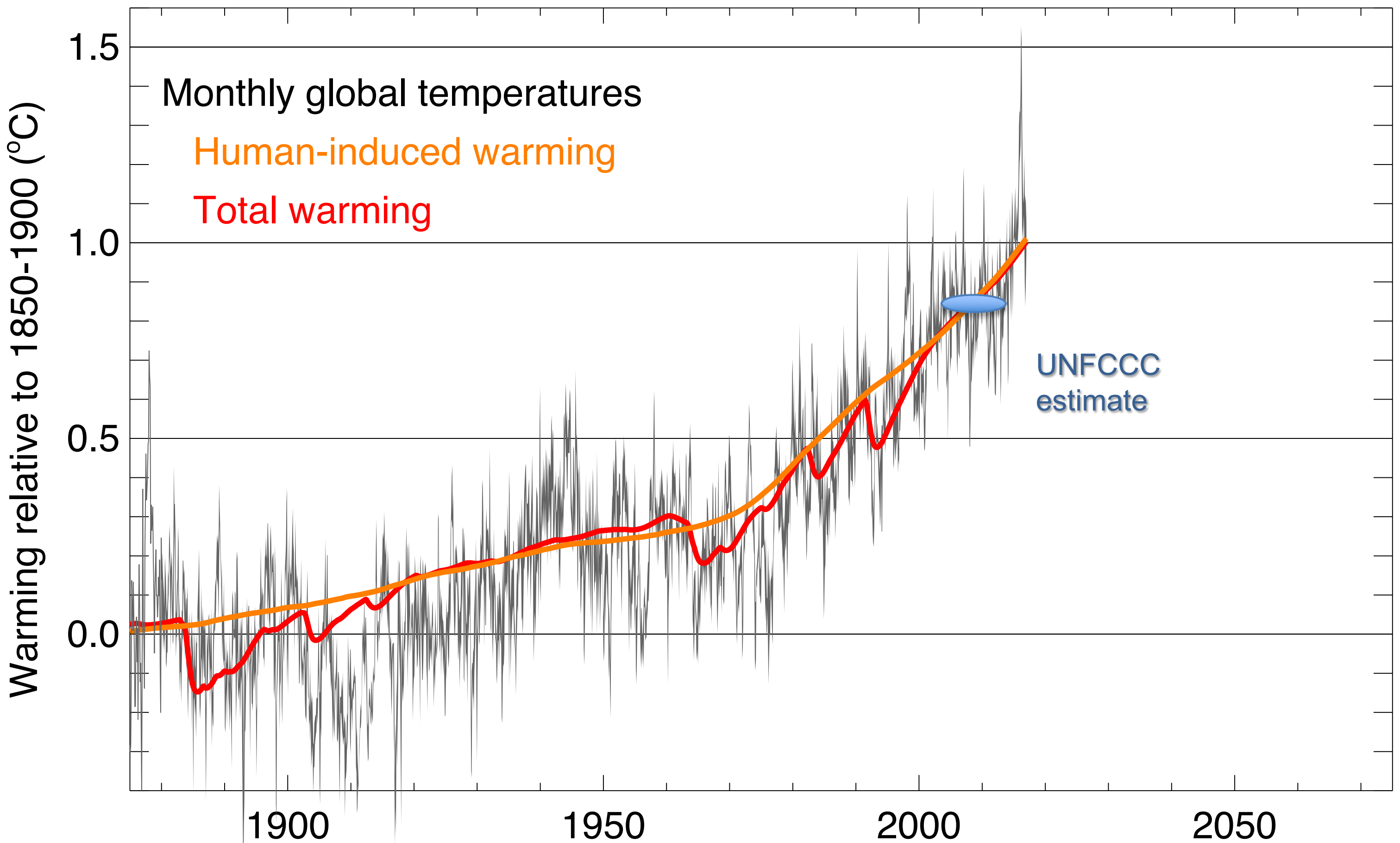
Measuring progress to a long-term temperature goal

MYLES ALLEN

School of Geography & the Environment & Dept. of Physics, University of Oxford

myles.allen@ouce.ox.ac.uk

Warming currently at 1° C, rising at 0.2° C per decade



"At the **current level of warming of 0.85° C** above pre-industrial levels…"

UNFCCC Report on the Structured Expert Dialogue on the 2013-2015 review

A simple way of computing outstanding carbon budgets for science-based targets

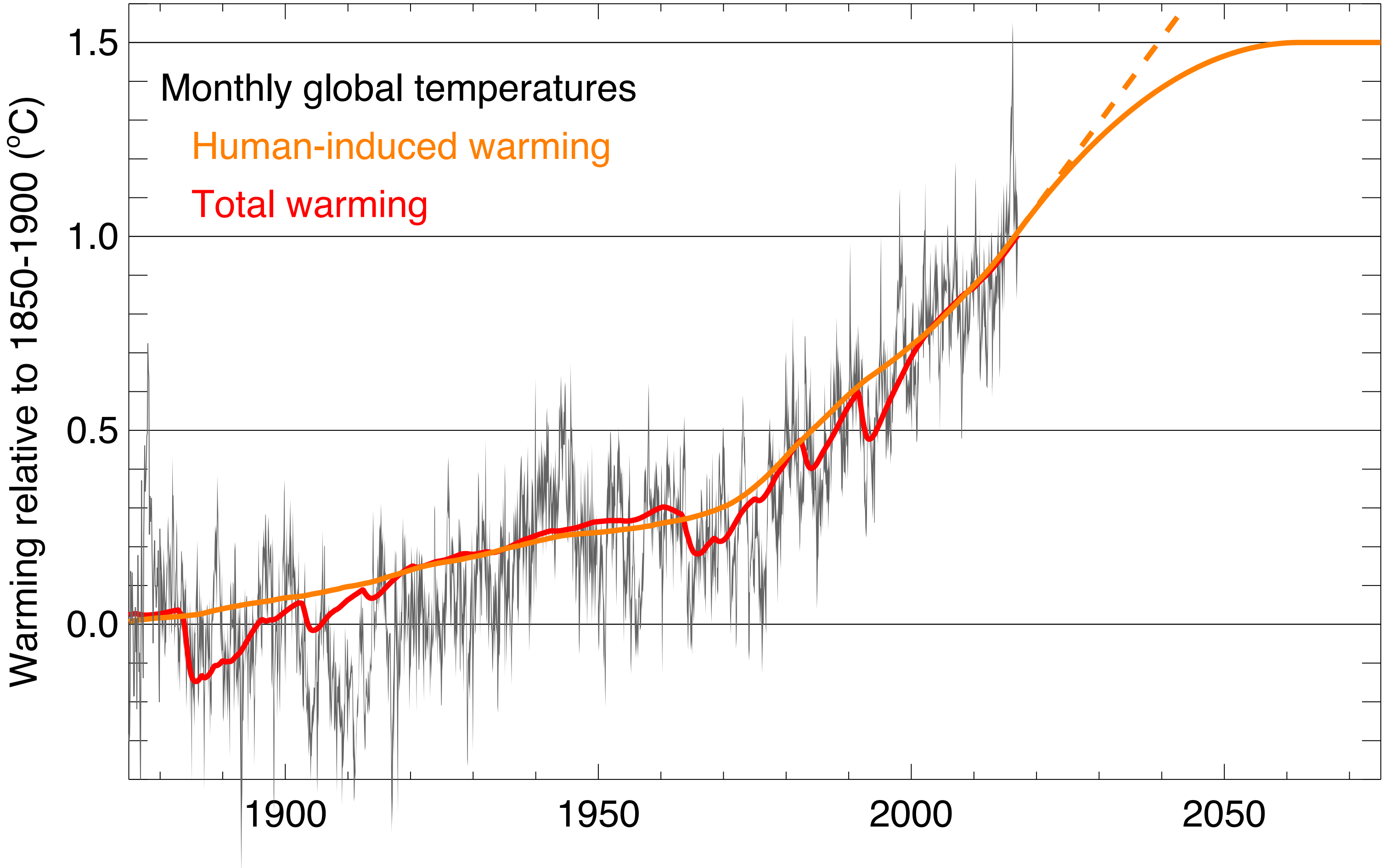
- Start with a truism: if warming continues at the current rate, then time to exceed $T_{\max}$ is

$$t_{\text{exceed}} = \frac{\left(T_{\max} - T_{\text{now}}\right)}{\left.\frac{dT}{dt}\right|_{\text{now}}}$$

- But how to estimate T_{now} and $\left.\frac{dT}{dt}\right|_{\text{now}}$?

- Need *human-induced*, not total, warming.

24 years to 1.5° C at the current rate

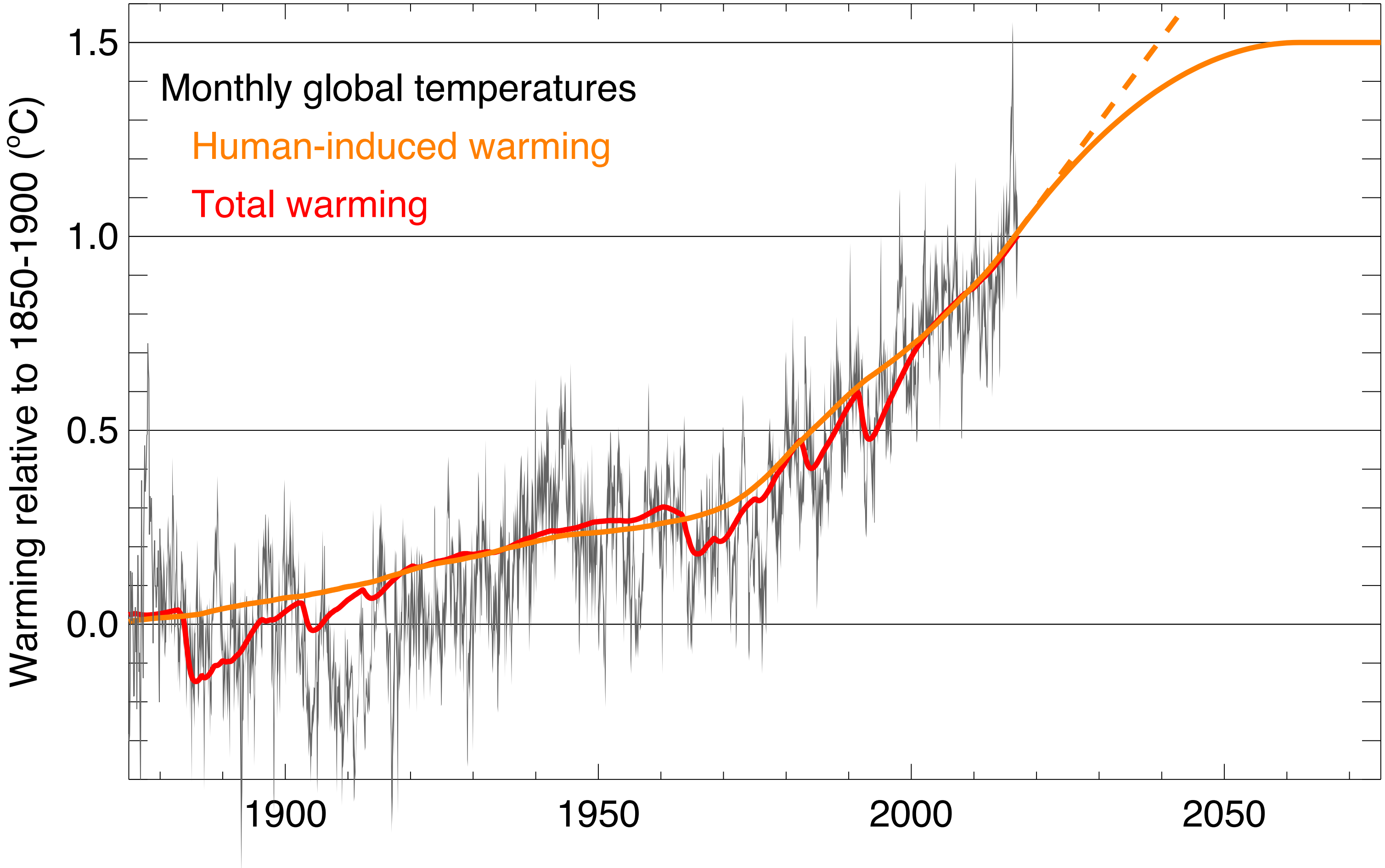


Another truism:

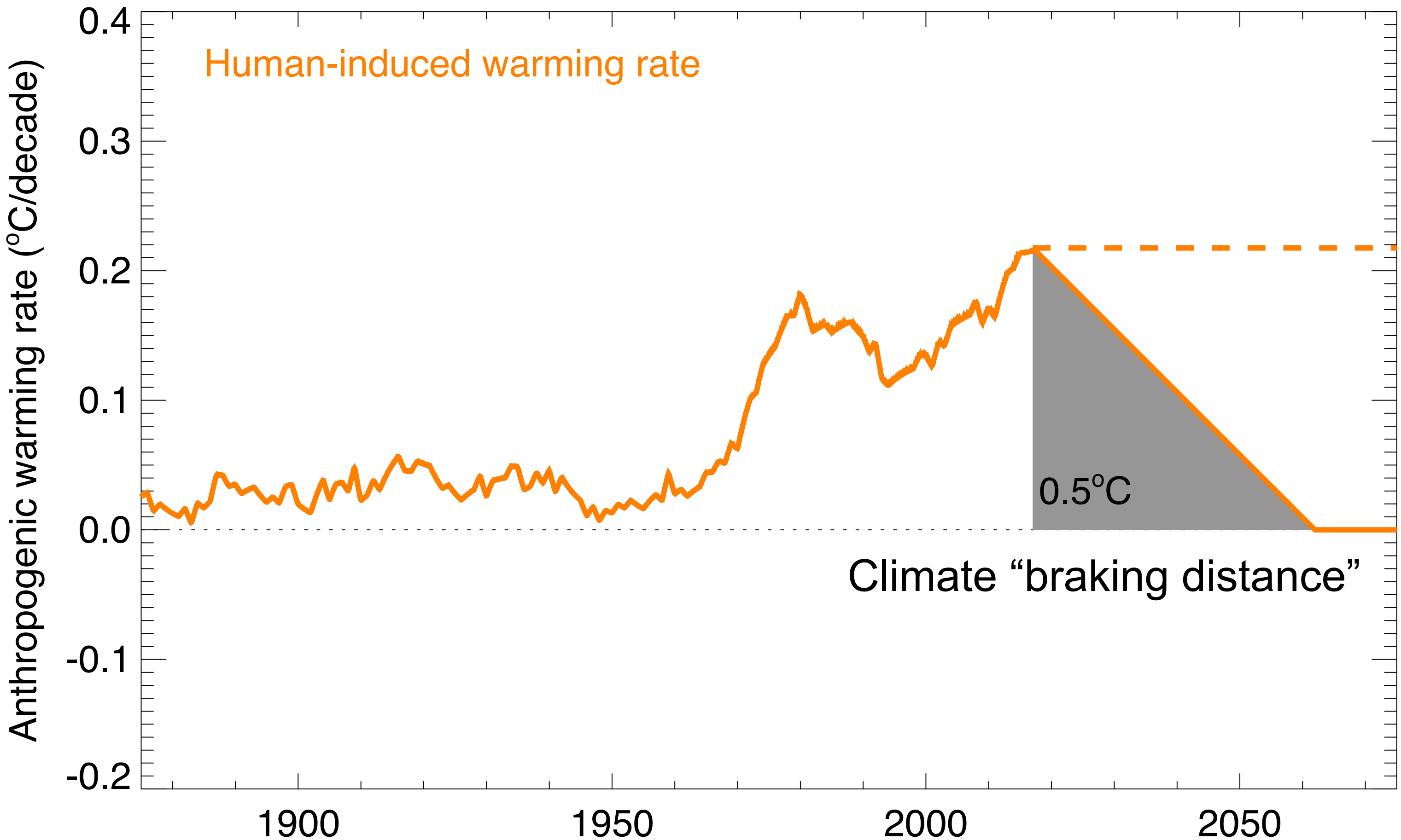
- If warming rates fall at a constant rate from now on, then time to stabilize at $T_{\max}$ is

$$t_{\text{stabilize}} = \frac{2\left(T_{\max} - T_{\text{now}}\right)}{\left.\frac{dT}{dt}\right|_{\text{now}}}$$

So we have almost 50 years to reduce warming rate to zero, starting now



Current rate of warming determines future warming under constant deceleration



So how does this relate to carbon budgets? First, what will it take to fail?

- If CO_2 emissions and warming both continue at their current rate, then temperature will exceed $T_{\max}$ after we have emitted a further

$$\int_{\text{now}}^{\text{exceed}} E\,dt = \frac{E_{\text{now}}\left(T_{\max} - T_{\text{now}}\right)}{\left.\frac{dT}{dt}\right|_{\text{now}}}$$

- Or about 24 years x 40 $GtCO_2$/yr ≈ 960 $GtCO_2$

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Next, what will it take to succeed?

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- If CO_2 emission rates fall at least as fast as the rate of human-induced warming, then to stabilize temperatures at $T_{\max}$:

$$\int_{\text{now}}^{\text{peak}} E\,dt \leq \frac{E_{\text{now}}\left(T_{\max} - T_{\text{now}}\right)}{\left.\dfrac{dT}{dt}\right|_{\text{now}}}$$

- Inequality because non-CO_2 forcing contributes a scenario-dependent (but positive) future warming in addition to CO_2.

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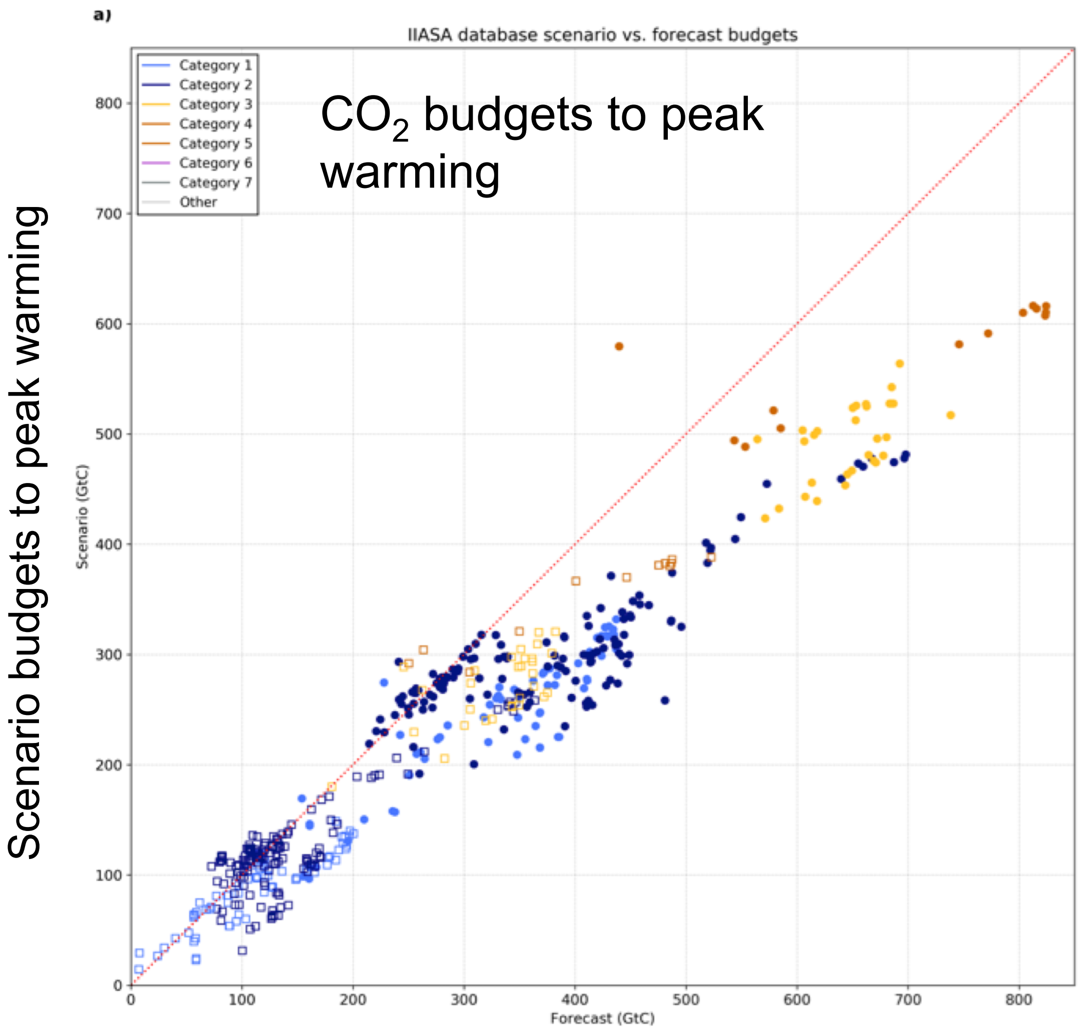
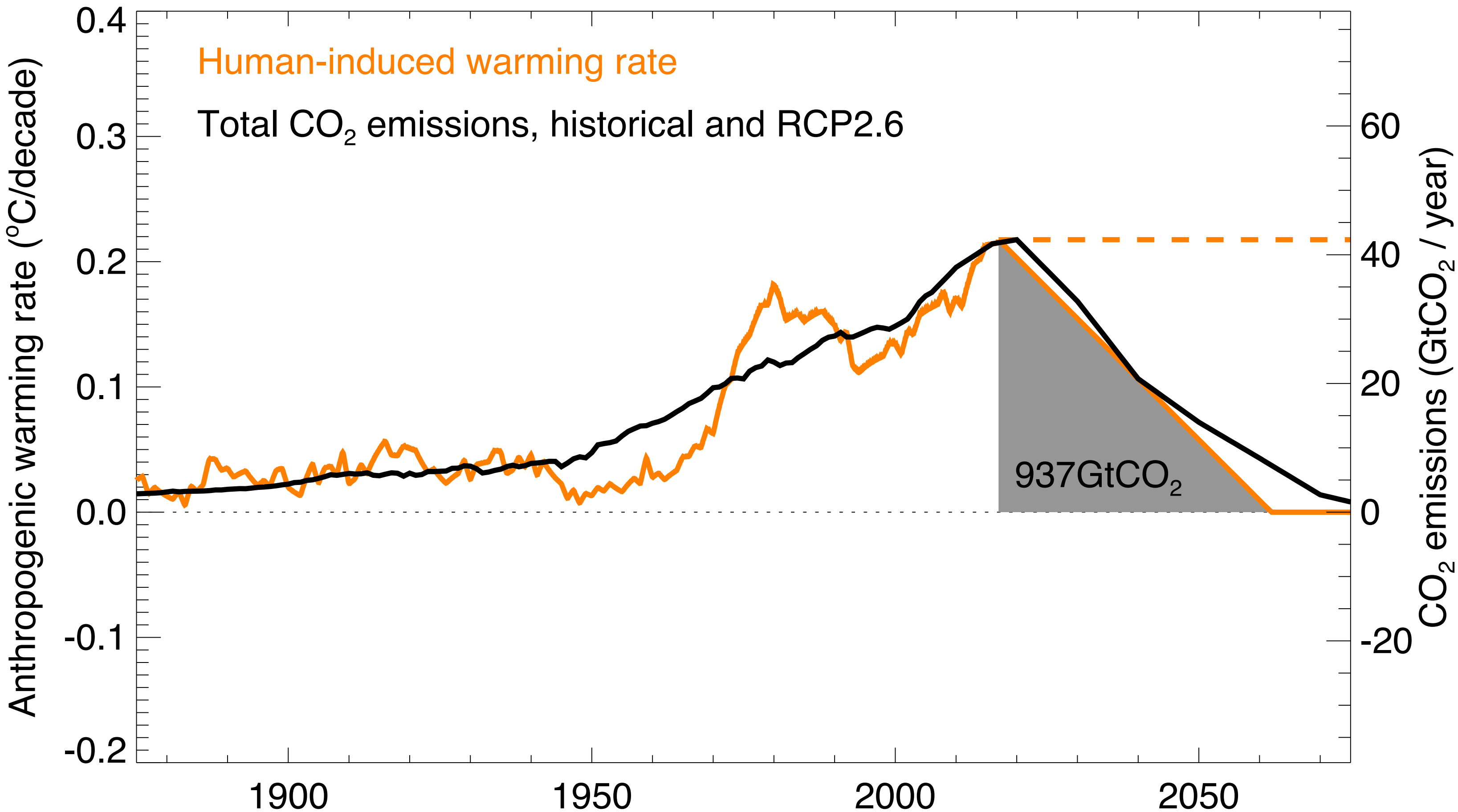
Inequality works for AR5 WG3 mitigation scenarios



Forecast budgets to peak warming based on warming and warming rate in 2020 & 2035

And predicts c. 0.6° C future warming under RCP2.6 (low net non-CO_2 warming in this scenario)



How to include non-CO_2 forcing?

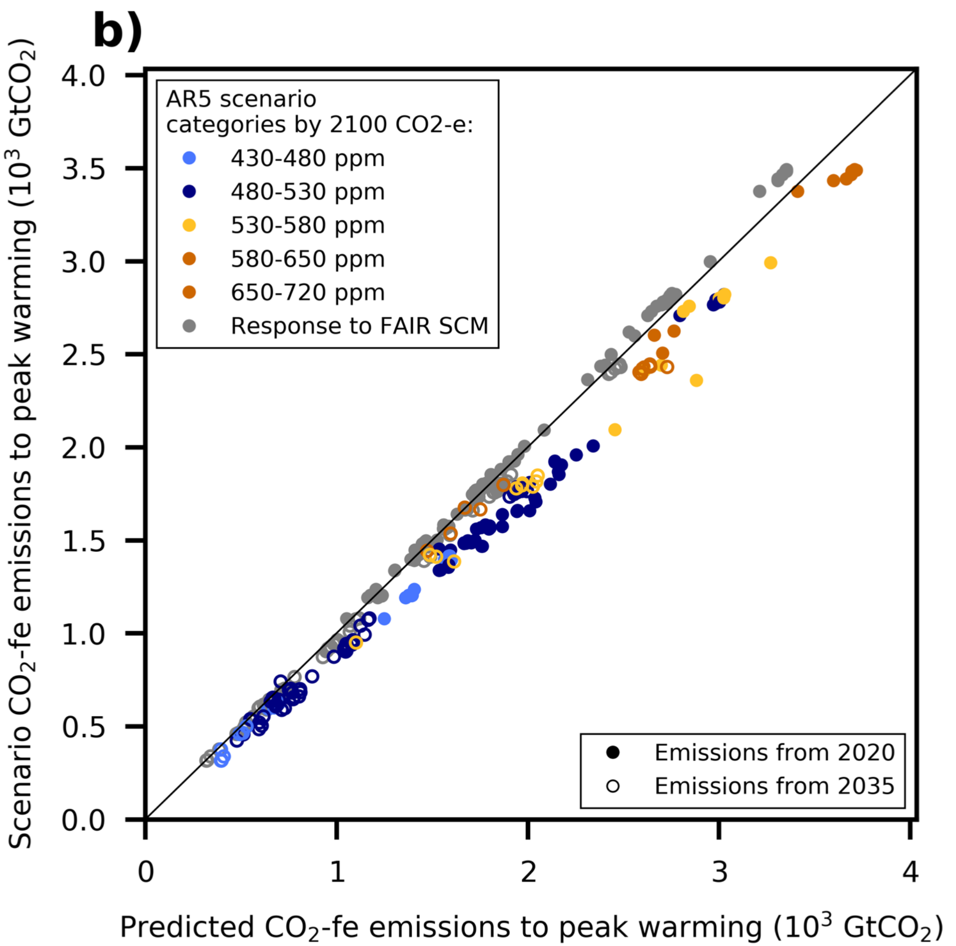
- Express it as CO_2-forcing-equivalent emissions
  - *not* GWP-based CO_2-eq
- Convert forcing to CO_2-equivalent concentrations and diagnose required CO_2 emissions by inverting a carbon cycle model (Wigley, 1998)

  or

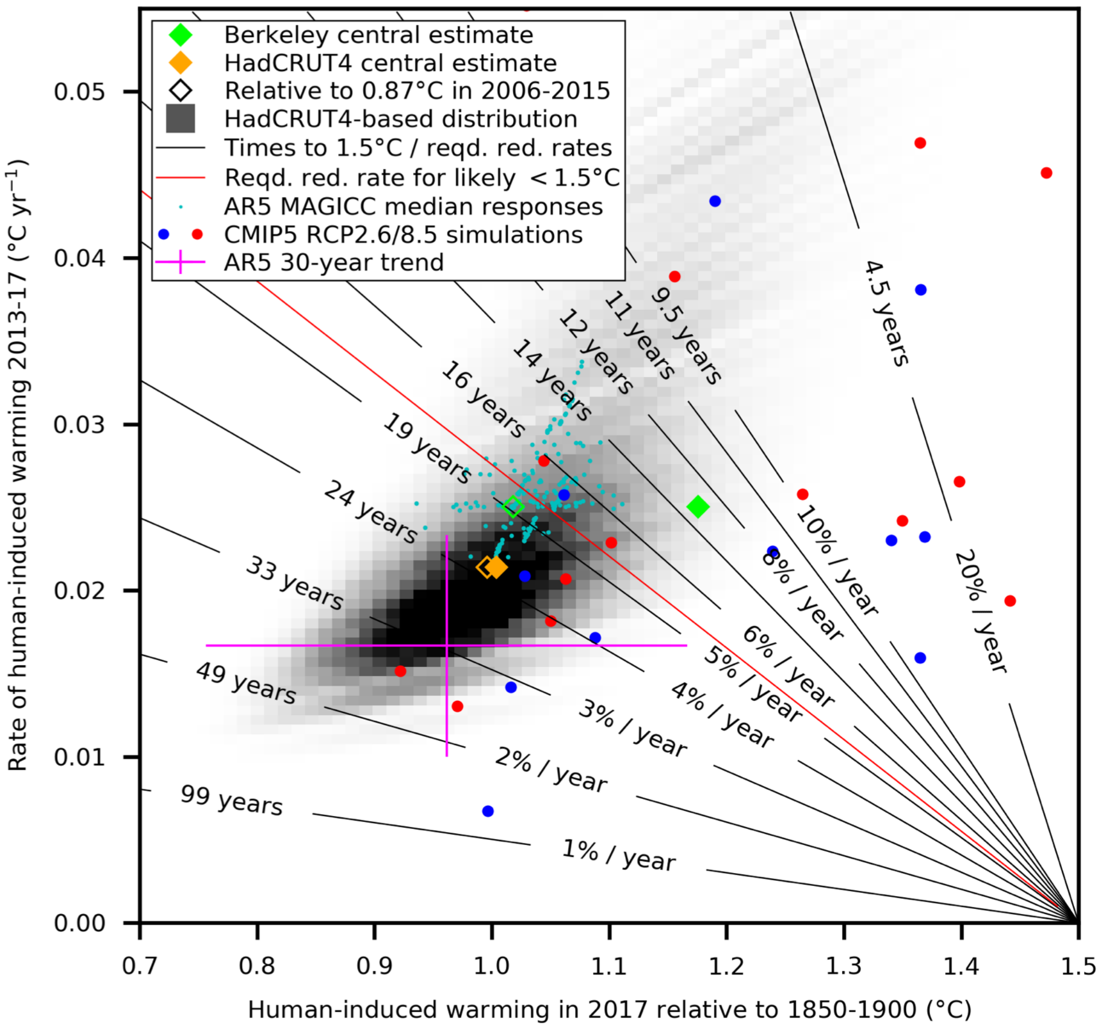
- Use the handy approximation (Allen et al, 2018):

$$\int E_{\text{CO2-fe}} \approx \frac{H \times \Delta F}{\text{AGWP}_H(\text{CO}_2)} \approx \left[1250\,\text{GtCO}_2 \big/ \left(\text{Wm}^{-2}\right)\right] \times \Delta F$$

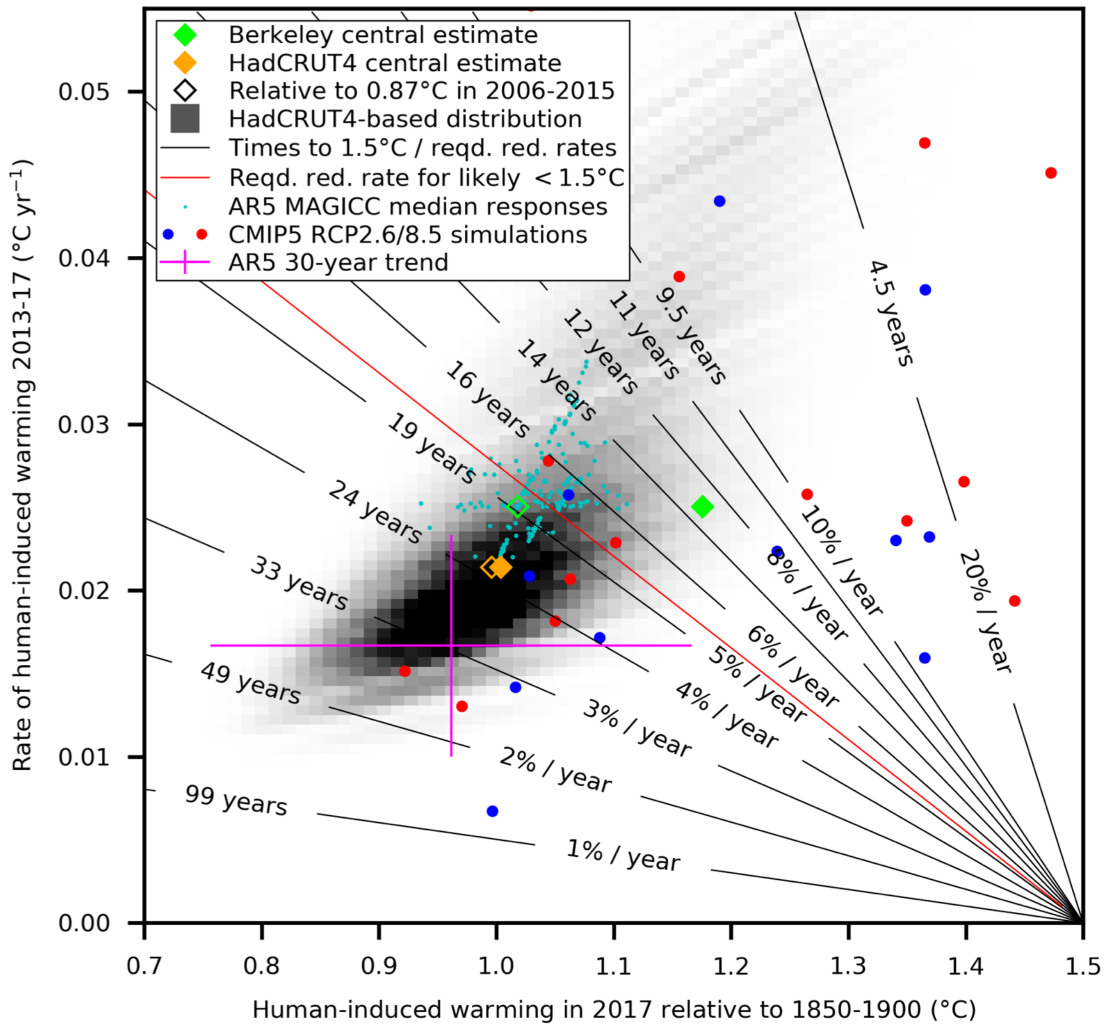
Current level and rate of human-induced warming determines outstanding CO_2-fe emissions budgets



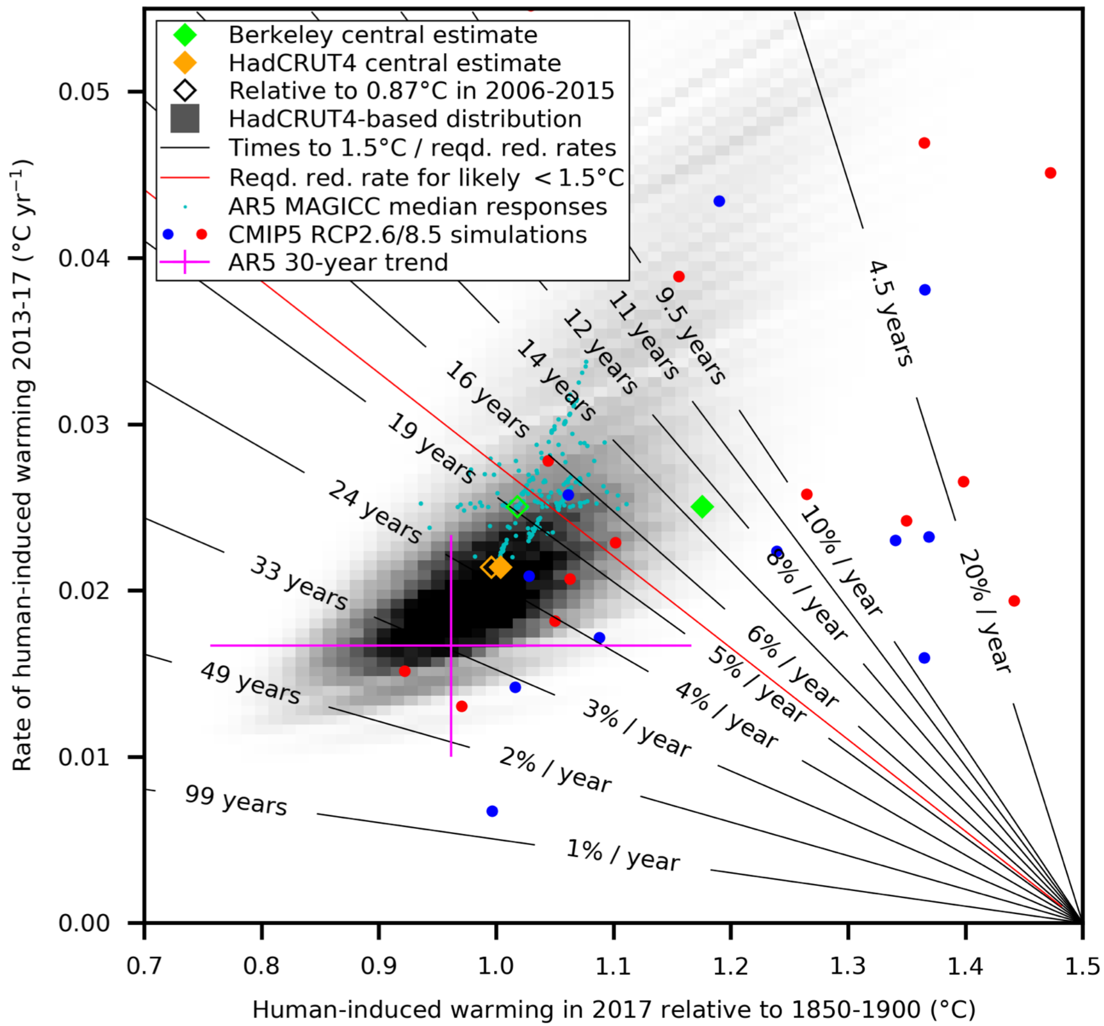
Current level and rate of human-induced warming determines time to 1.5° C at current rate



Current level and rate of human-induced warming determines required warming reduction rate



Current level and rate of human-induced warming determines maximum future CO_2 emission budget



24 years' emissions at current rate ≈ 960GtCO_2

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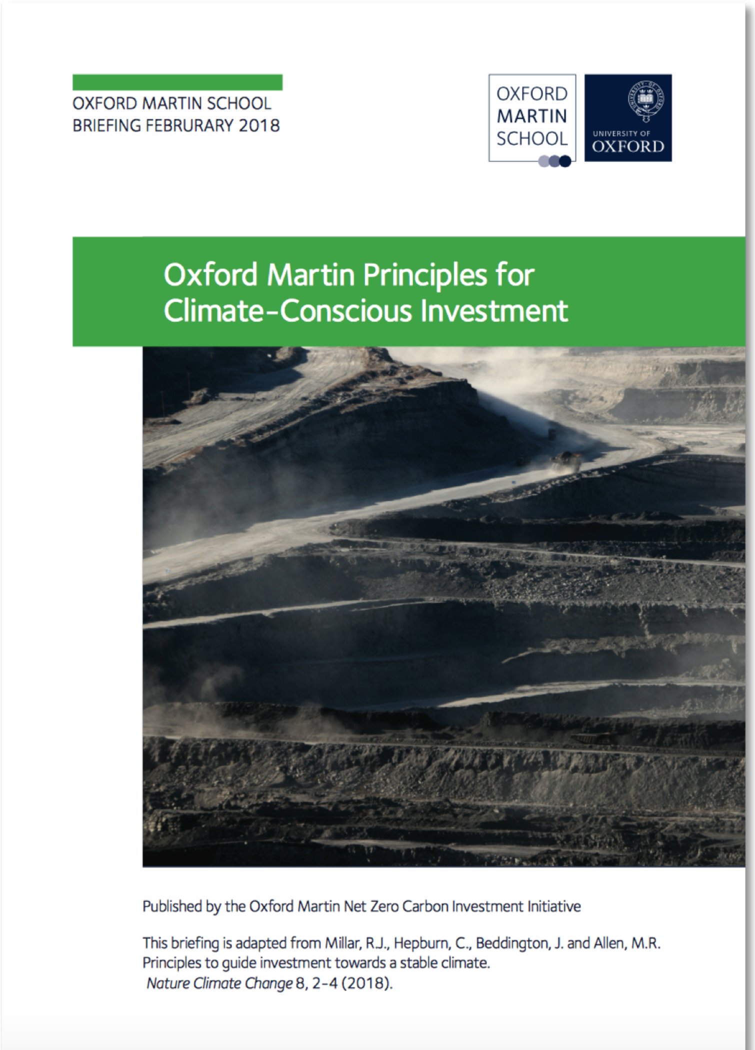
Direct estimates of the carbon budget for 1.5°C

- Using the definitions of GMST and pre-industrial adopted by the UNFCCC, 1.5°C is ~24 years away at the current warming rate (likely range 12-34 years).
- Which means we have almost 50 years to get CO_2 emissions to zero if reductions start immediately and we reduce the rate of non-CO_2 warming at the same rate as we reduce CO_2 emissions.
- Implying a future 1.5°C carbon budget of 24x current annual emissions, or ~960GtCO_2 (likely range 500-1,400 GtCO_2).

So much for global targets, but what of company-level targets?



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BRIEFING FEBRURARY 2018

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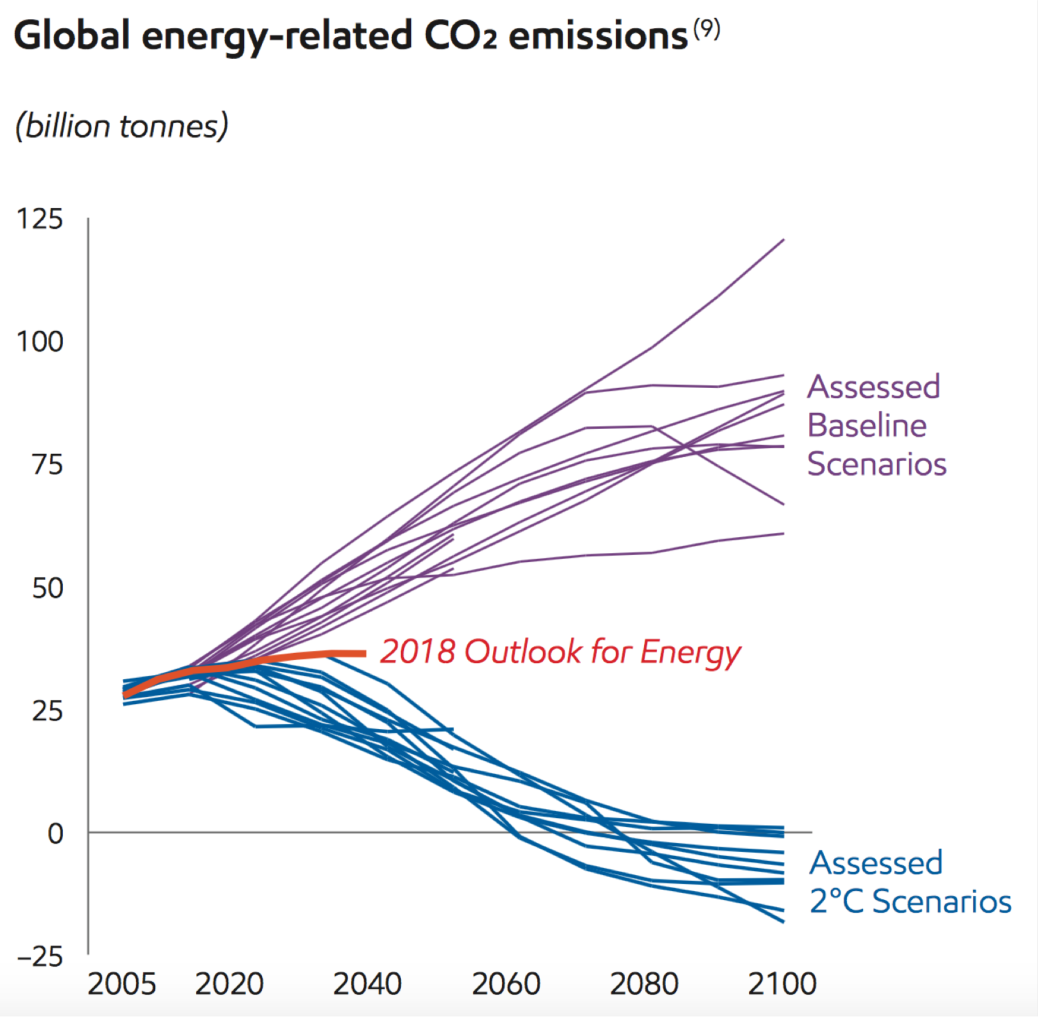
Oxford Martin Principles for Climate-Conscious Investment

Published by the Oxford Martin Net Zero Carbon Investment Initiative

This briefing is adapted from Millar, R.J., Hepburn, C., Beddington, J. and Allen, M.R. Principles to guide investment towards a stable climate. *Nature Climate Change* 8, 2-4 (2018).

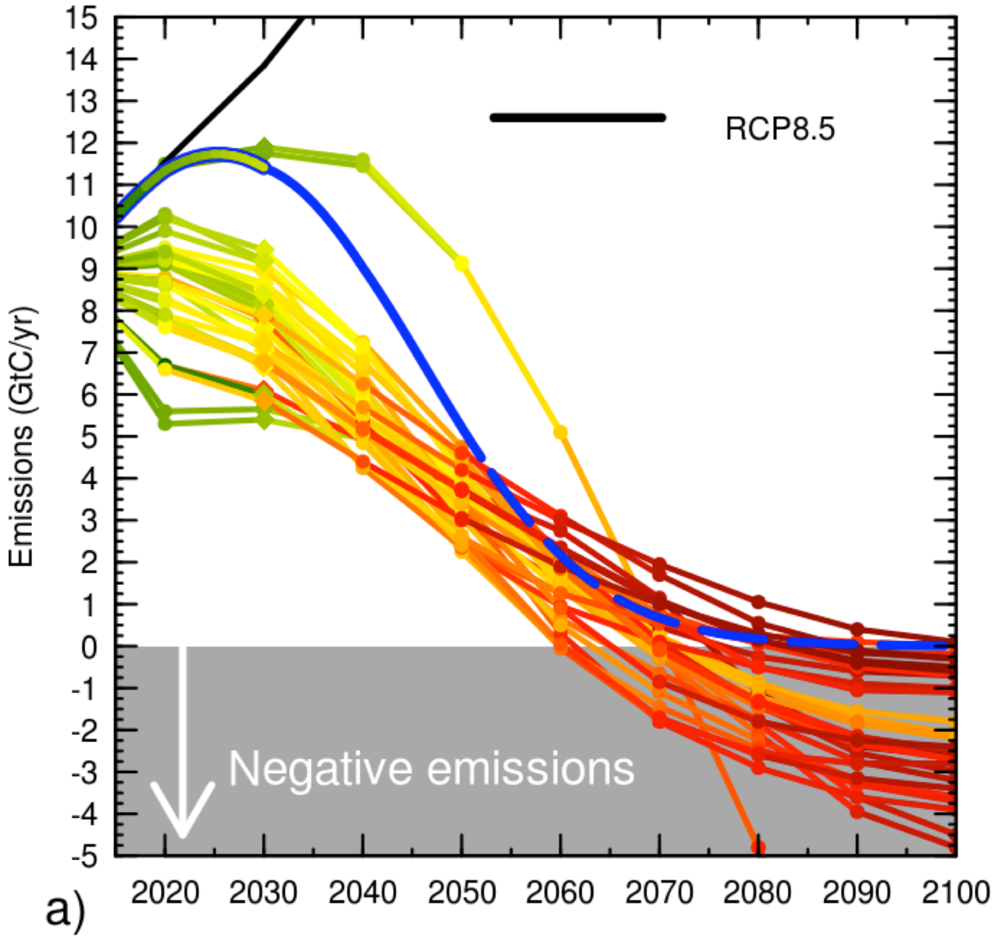
- At what global temperature will your activities, and the products you sell, be consistent with net zero carbon dioxide emissions?
- What is your strategy for achieving net zero, and who will pay for it?
- How do you propose to monitor progress to net zero as the world warms?

An example: excerpt from ExxonMobil "Energy and Carbon Summary", 2018



Characteristics of "cost-effective" <2° C scenarios

Total emissions in scenarios in IPCC WGIII "430-480ppm" (lowest) scenario category



Colours show total policy cost in $US\$_{2005}$

Figures courtesy of Richard Millar based on IIASA database

Another way of plotting <2° C scenarios

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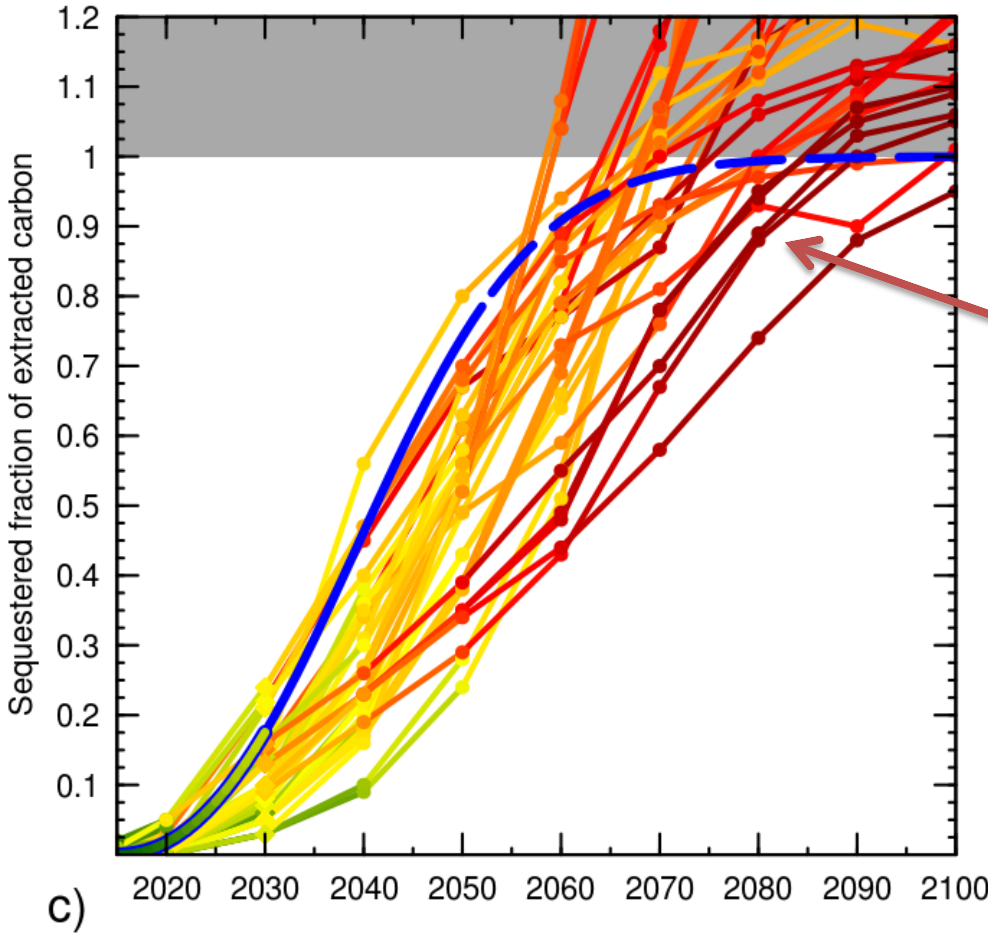
Net fraction of extracted carbon that is re-injected through CCS, Bioenergy with CCS (BECCS) or Direct Air Capture (DAC)



Delayed deployment of CO_2 disposal is associated with mitigation costs >$60 T$_{2005}$/year

Figures courtesy of Richard Millar based on IIASA database

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When “we’re in with the scenarios” is not enough: A metric of progress for the fossil fuel industry

- To reach net zero by 2° C, the fraction of carbon extracted that is permanently sequestered must increase, on average, by 10% per 0.1° C warming from now on.
- Linear increase implies 20% sequestration by 2030…
- Quadratic increase implies 4% sequestration by 2030.

When "we're in with the scenarios" is not enough: A metric of progress for the fossil fuel industry

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- To reach net zero by 1.5° C, the fraction of carbon extracted that is permanently sequestered must increase, on average, by 20% per 0.1° C warming from now on.
- Linear increase implies 40% sequestration by 2030…
- Quadratic increase implies 16% sequestration by 2030.
- Even if entirely passed on to the consumer, 16% sequestration would be far, far less economically disruptive than a 2030 carbon price of >$100/t$CO_2$ required in conventional mitigation scenarios.

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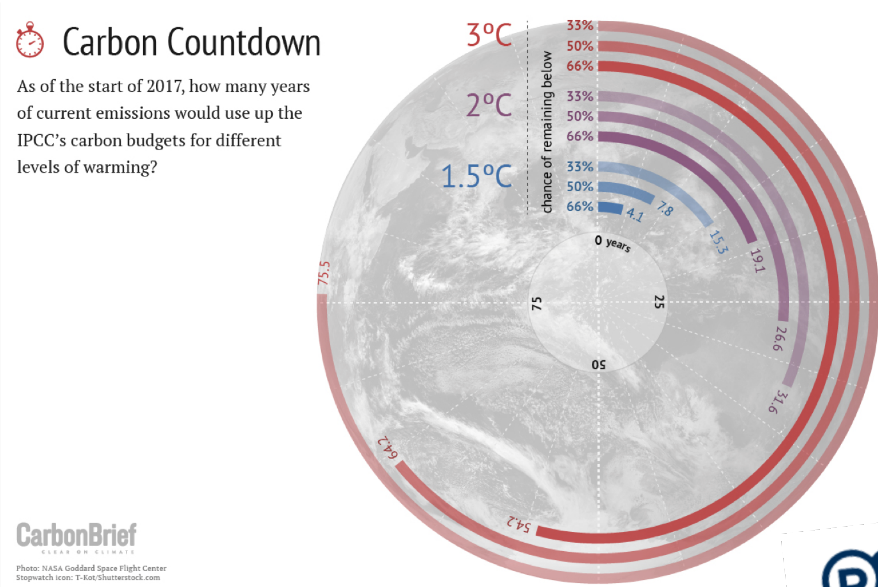
Unhelpful indicators



GLOBAL EMISSIONS | April 5, 2017, 8:00

Analysis: Just four years left of the 1.5C carbon budget

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OPINION

Opinion: Goodbye to an unrealistic climate goal

The Intergovernmental Panel on Climate Change (IPCC) seems to think restricting global warming to below 1.5 degrees is not realistic anymore. What sounds like defeat could be an opportunity, writes Jens Thurau.

Where did these figures come from: the origins of the AR5 SPM "likely below 1.5°C" budget figure

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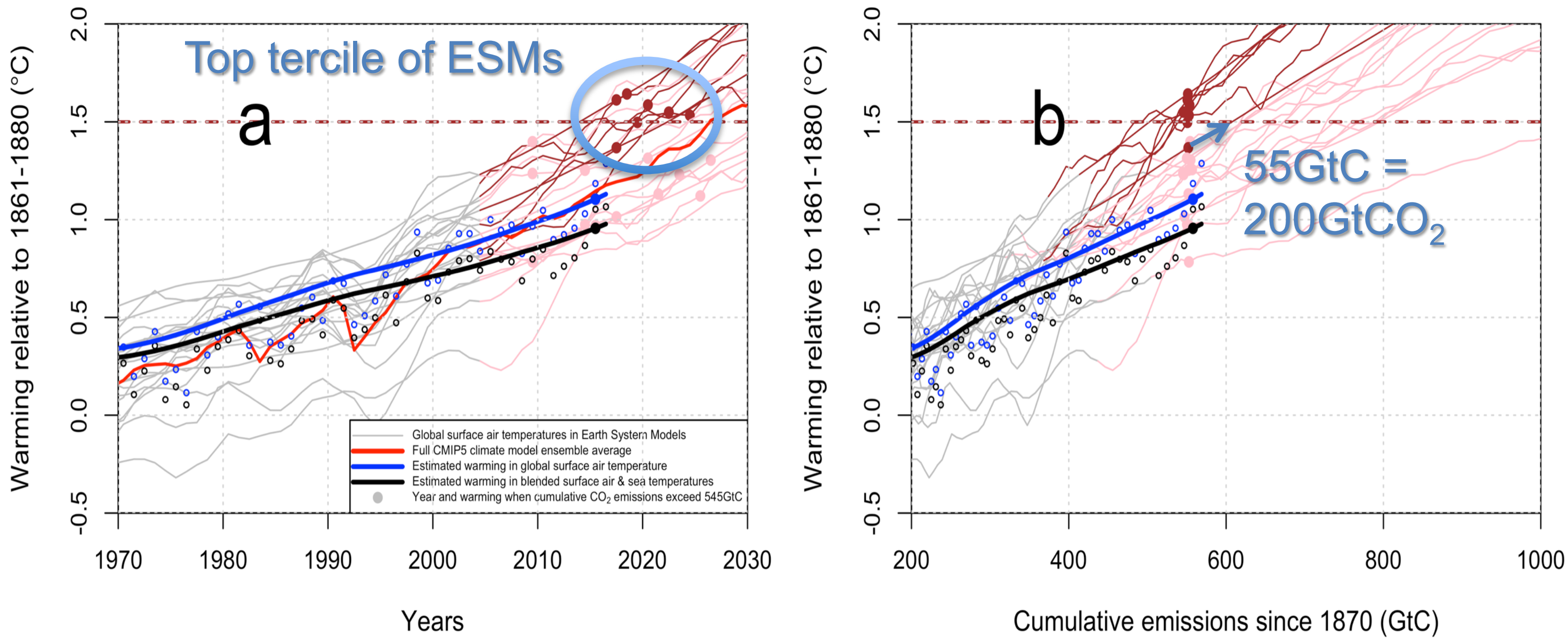

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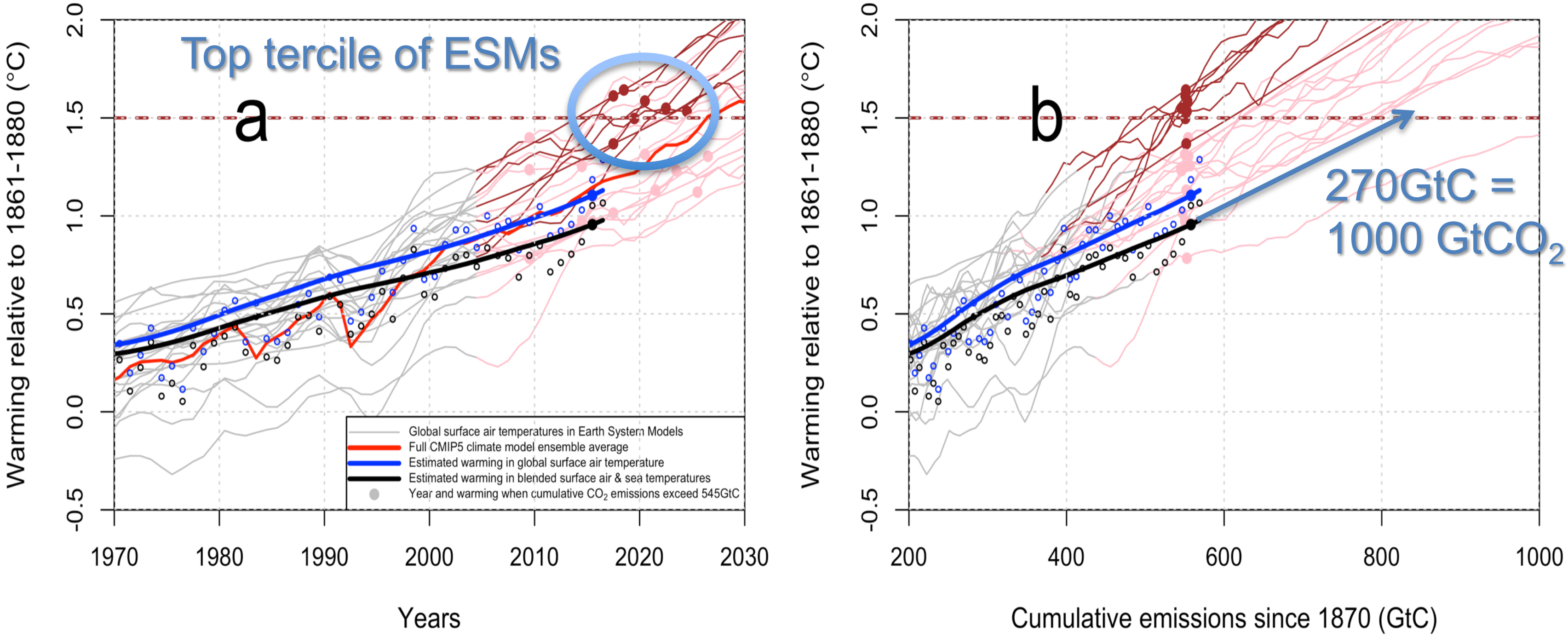

Where did these figures come from: the origins of the AR5 SPM "likely below 1.5° C" budget figure