

Much of the zero emissions commitment occurs before reaching net zero emissions

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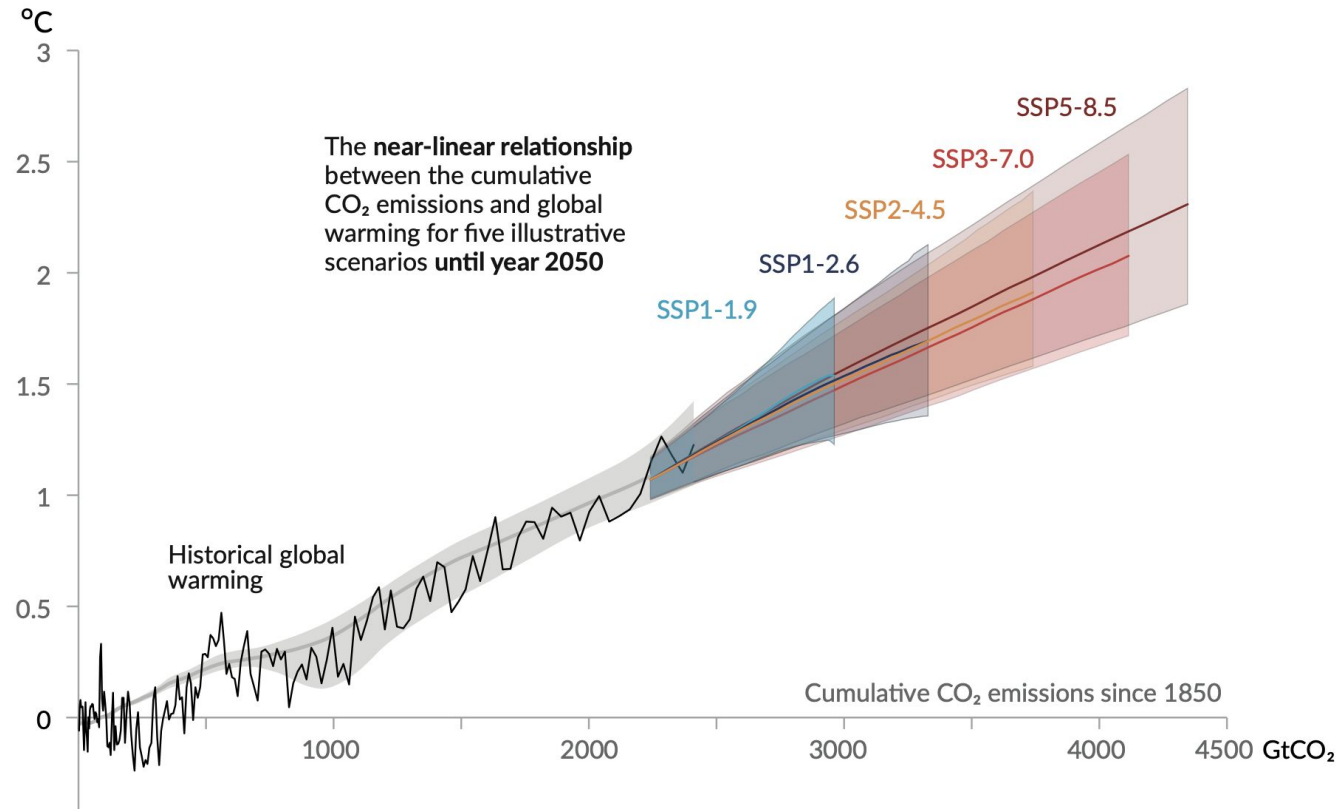
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Every tonne of CO₂ emissions adds to global warming

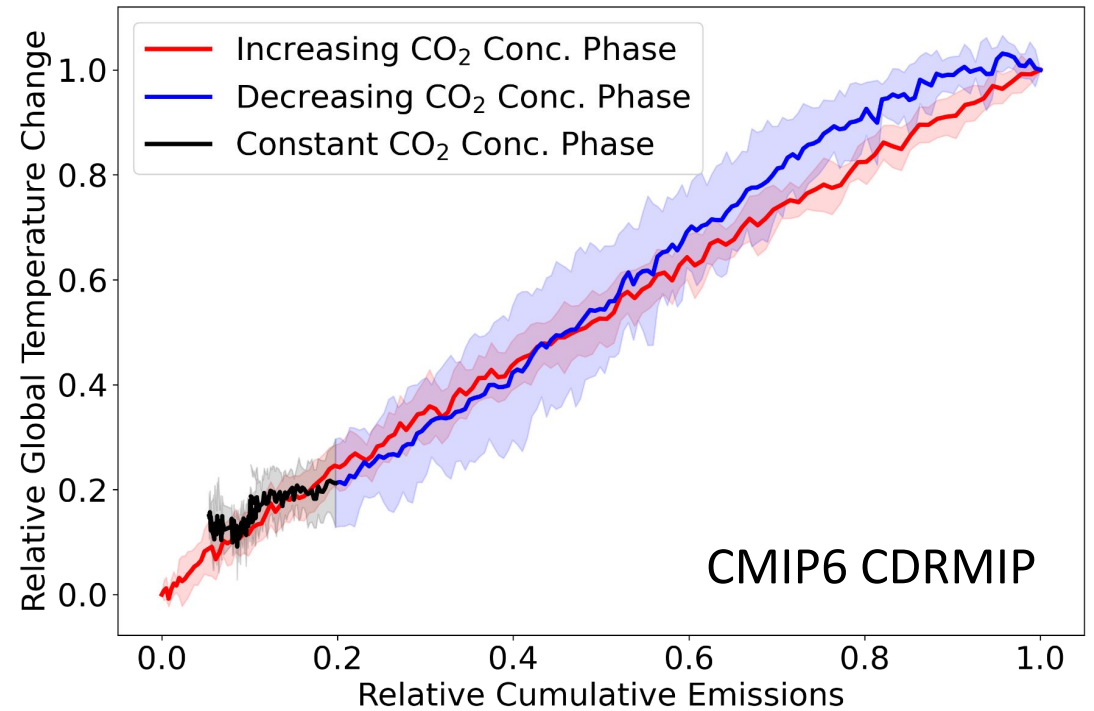
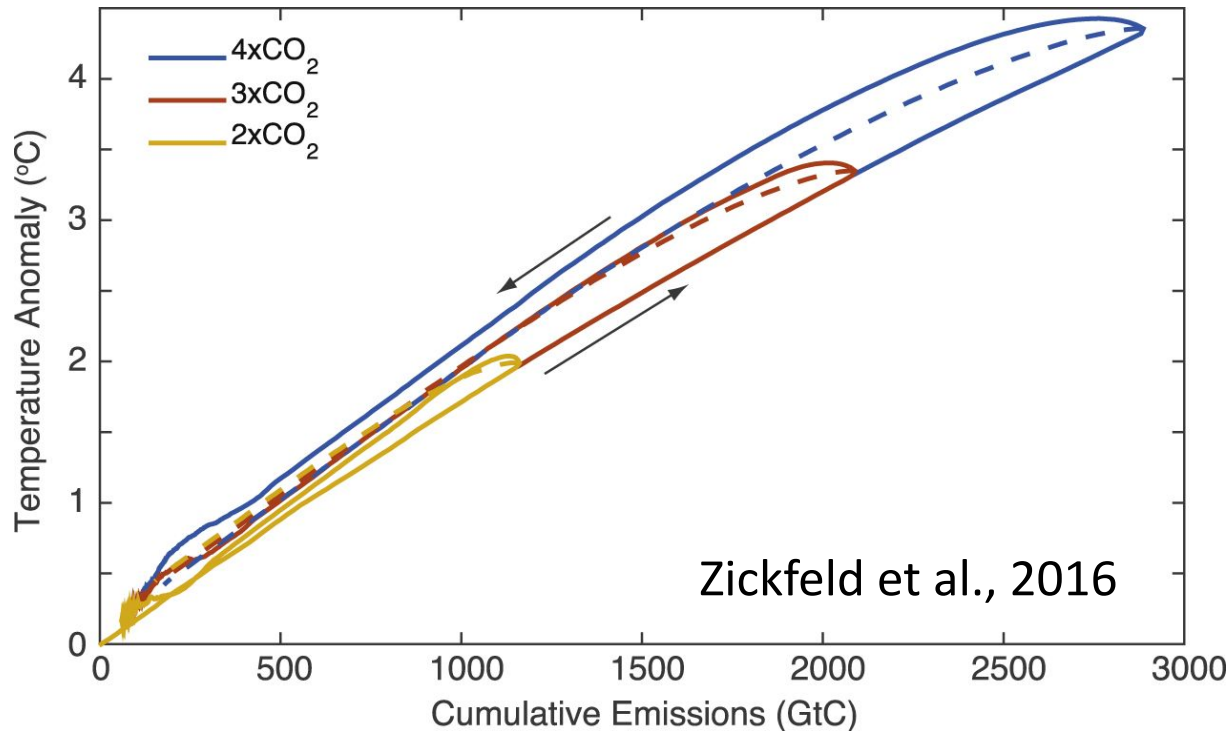
Global surface temperature increase since 1850–1900 (°C) as a function of cumulative CO₂ emissions (GtCO₂)



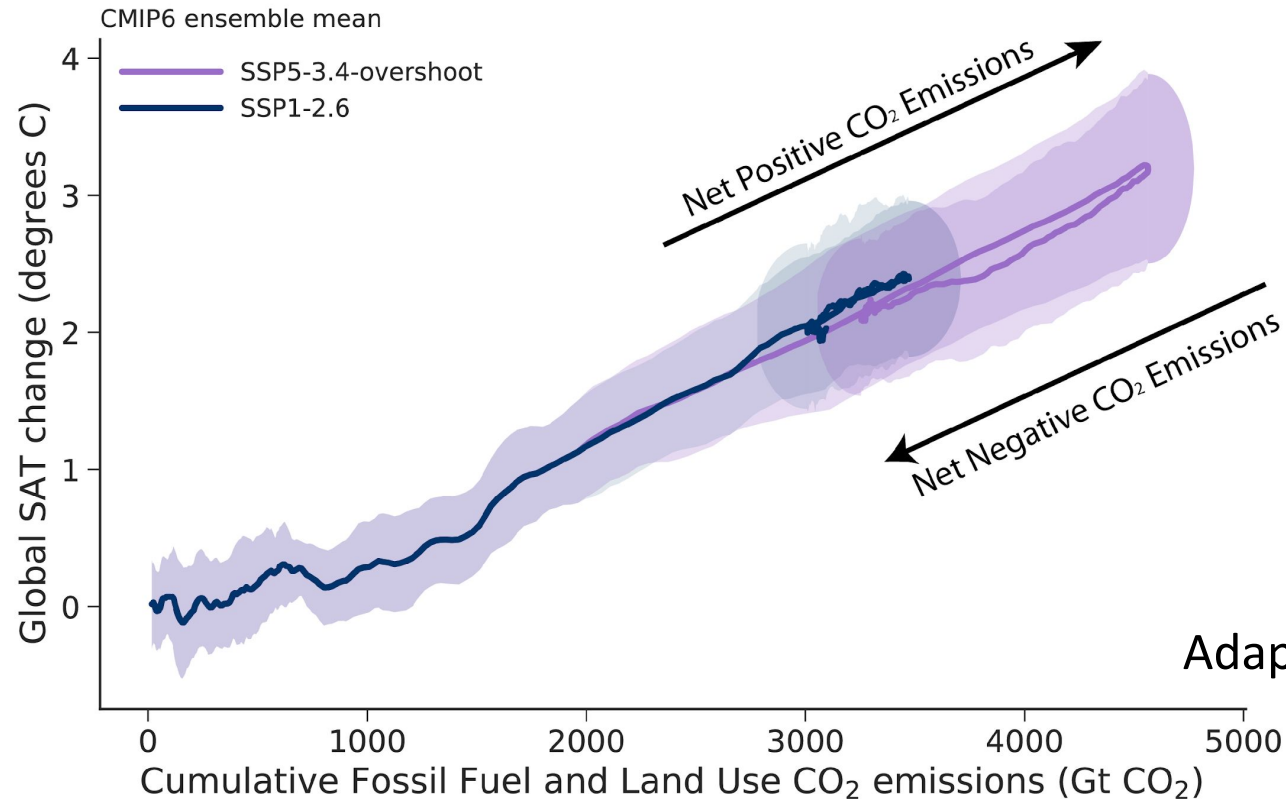
“The relationship is illustrated over the domain of cumulative CO₂ emissions for which there is *high confidence* that the transient climate response to cumulative CO₂ emissions (TCRE) remains constant, and for the time period from 1850 to 2050 over which global CO₂ emissions remain net positive under all illustrative scenarios as **there is *limited evidence* supporting the quantitative application of TCRE to estimate temperature evolution under net negative CO₂ emissions.**”

Does the TCRE relationship hold under net-negative CO₂ emissions?

Idealized 1% CO₂ abrupt concentration reversal experiments say that no, there is a consistent positive asymmetry...



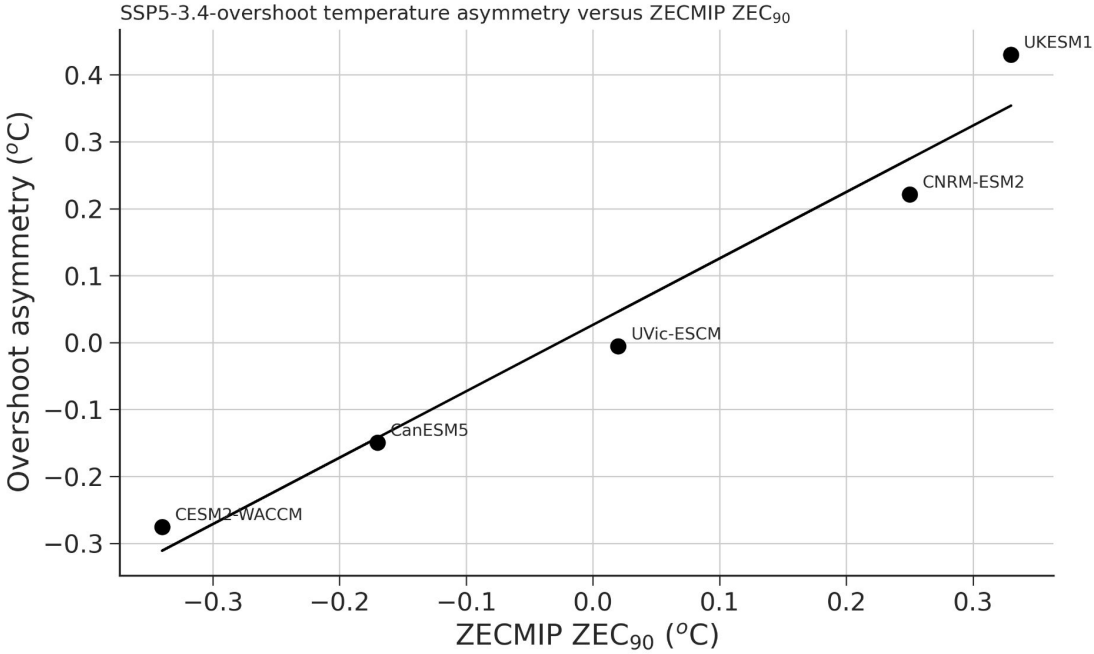
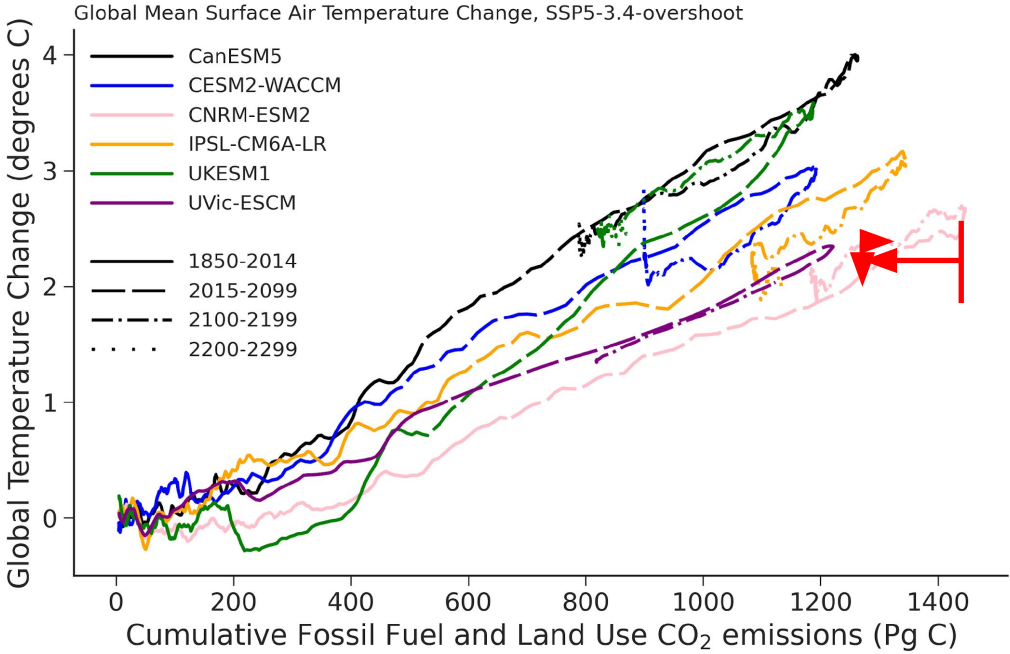
... Whereas non-idealized scenario experiments say that yes, the proportionality* actually does still hold...



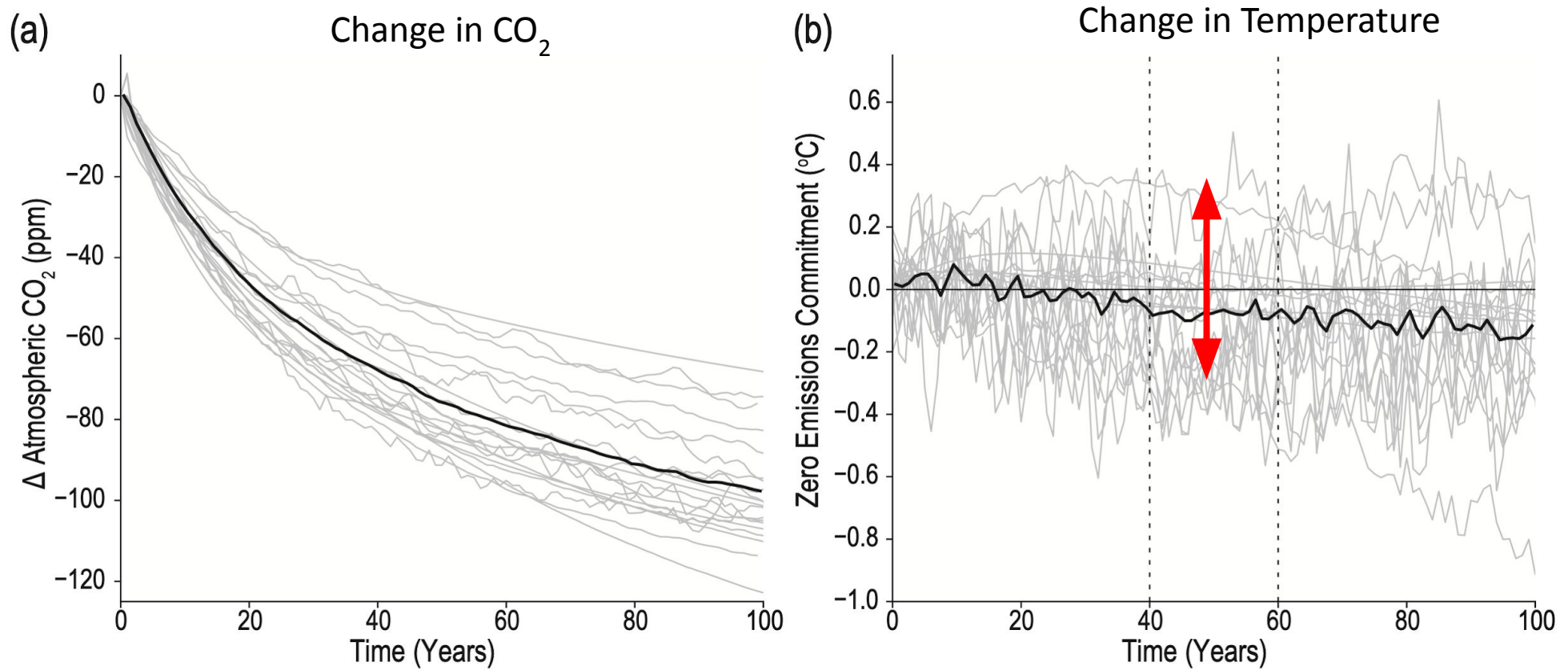
Adapted from Koven et al., 2022

* Not the TCRE proportionality though, because non-CO₂ GHGs are present, thus an Effective TCRE

... and any deviation from proportionality is well explained by the Zero Emissions Commitment (ZEC) ...



... where ZEC is a measure of how much warming would occur if CO₂ emissions were to abruptly stop.

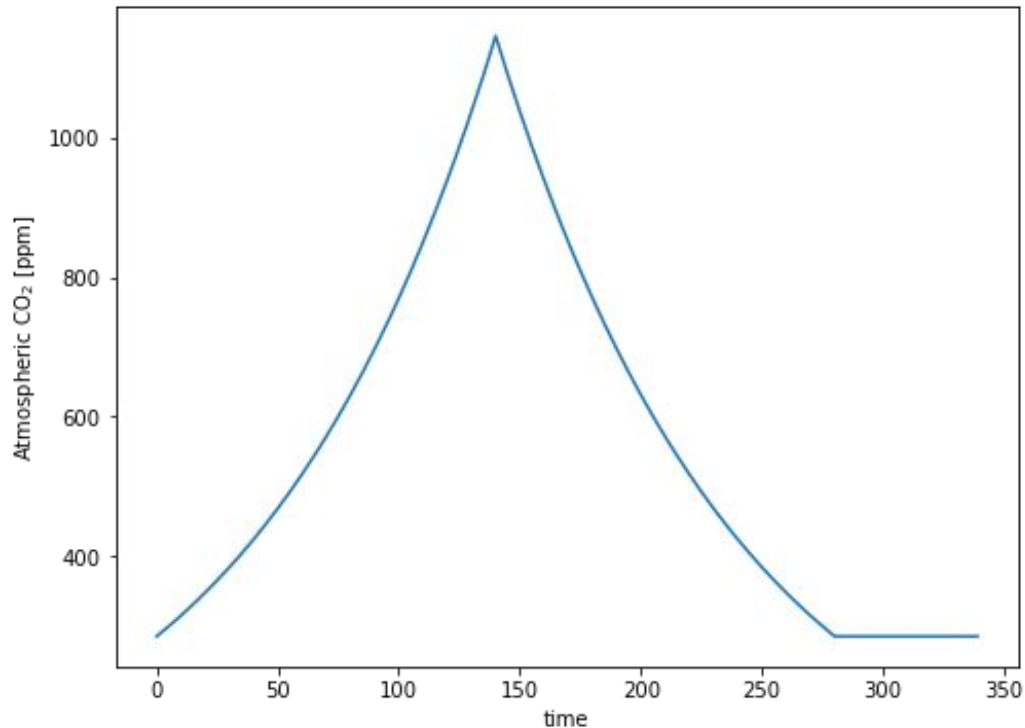


IPCC AR6 WG1 fig. 4.39

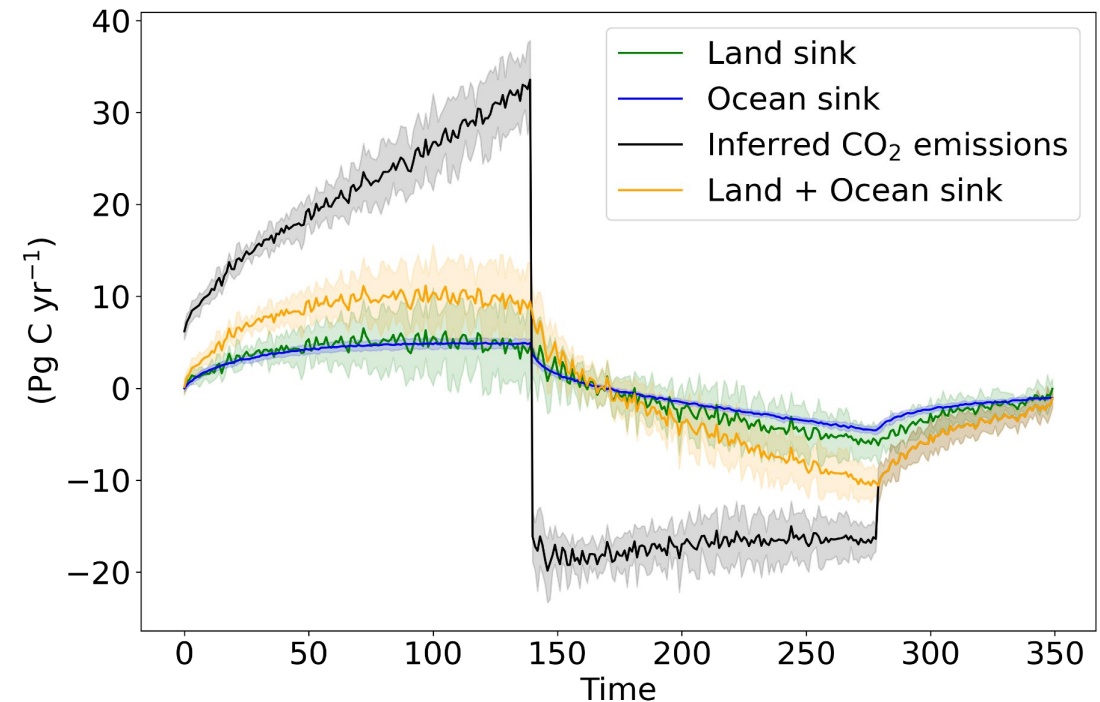
Note: TCRE and ZEC are the two carbon-climate sensitivity metrics used in calculating the IPCC remaining carbon budget for climate stabilization

A hypothesis for what causes the asymmetry in 1% concentration reversal experiments:
~50 Pg C / yr abrupt change in emissions.
Is that too much to ask of path-independence?

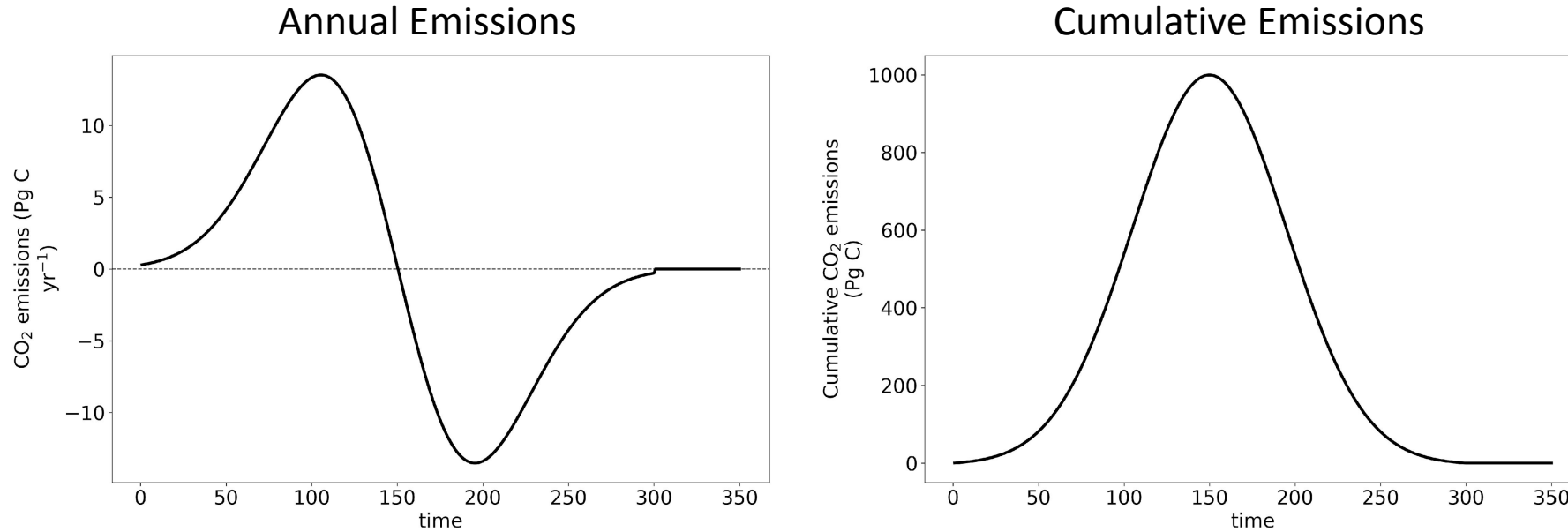
CDRMIP 1%/yr CO₂ concentrations



CMIP6 CDRMIP implied fluxes and emissions



An idealized climate restoration experiment: continuous, symmetric transition from positive to negative CO₂ emissions. Allows asking whether TCRE proportionality holds under idealized non-abrupt transition to net-negative emissions, and if so, whether there are limits to the proportionality.

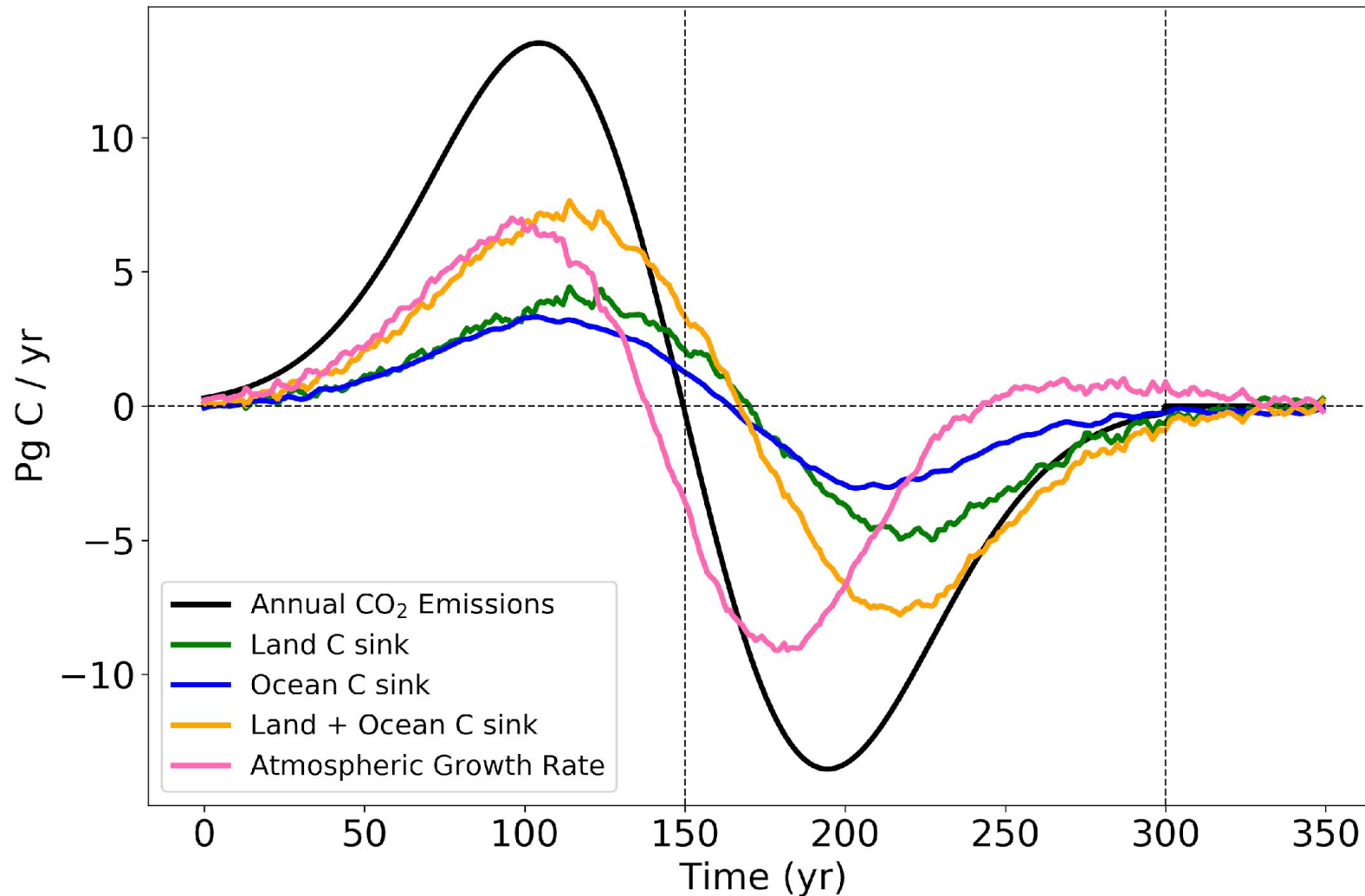


Run through emissions-driven ESM. **Hypothesis is that warming follows TCRE proportionality during the positive emissions phase, and follows the TCRE proportionality + ZEC during the negative emissions phase.**

CESM2 is ideal for this because it has a very negative ZEC (-0.3 °C).

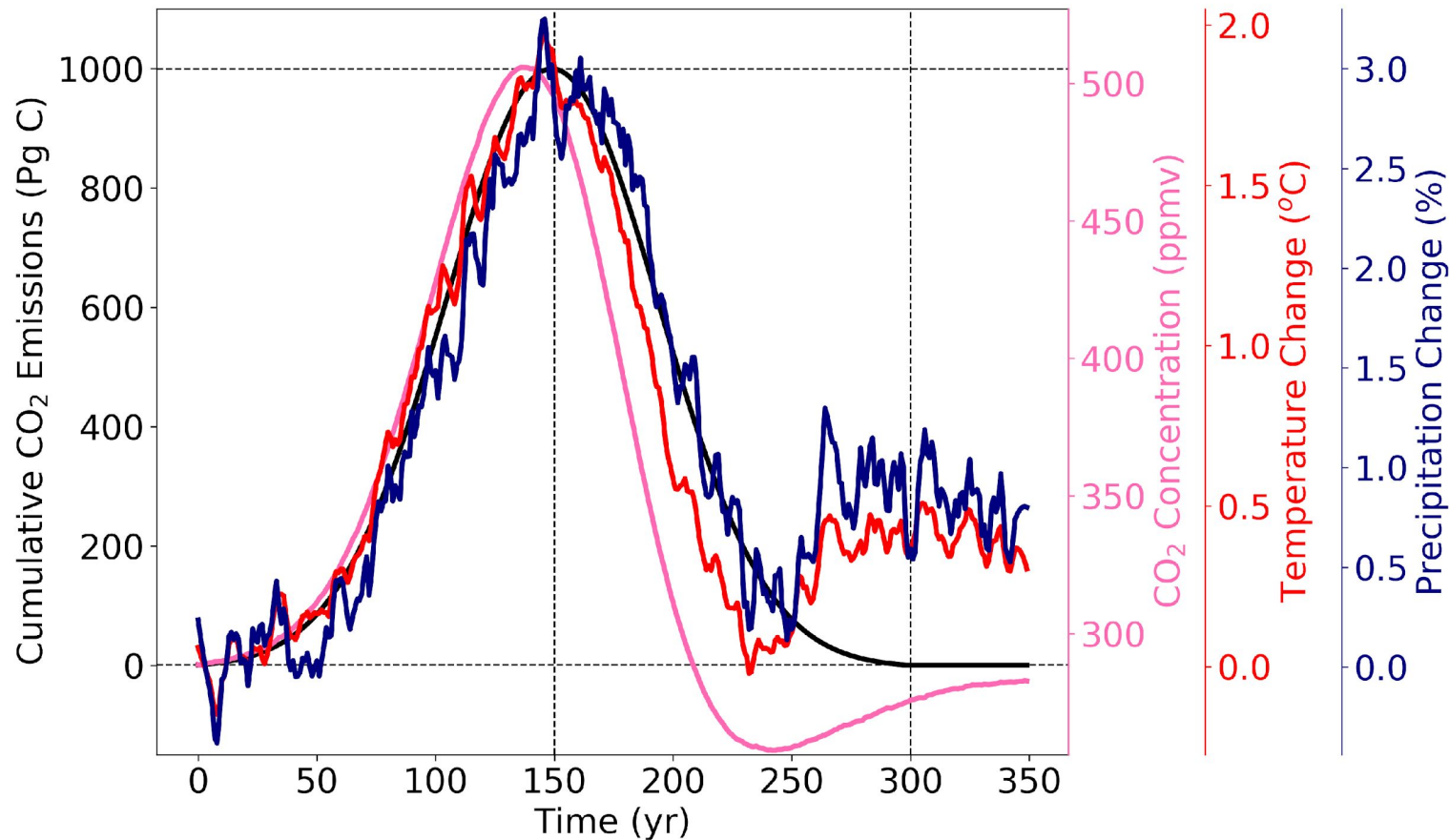
CESM2 CO₂ Flux responses to emissions reversal

Sinks follow emissions, with a lag. Atmospheric growth rate leads emissions *because* sinks lag emissions.



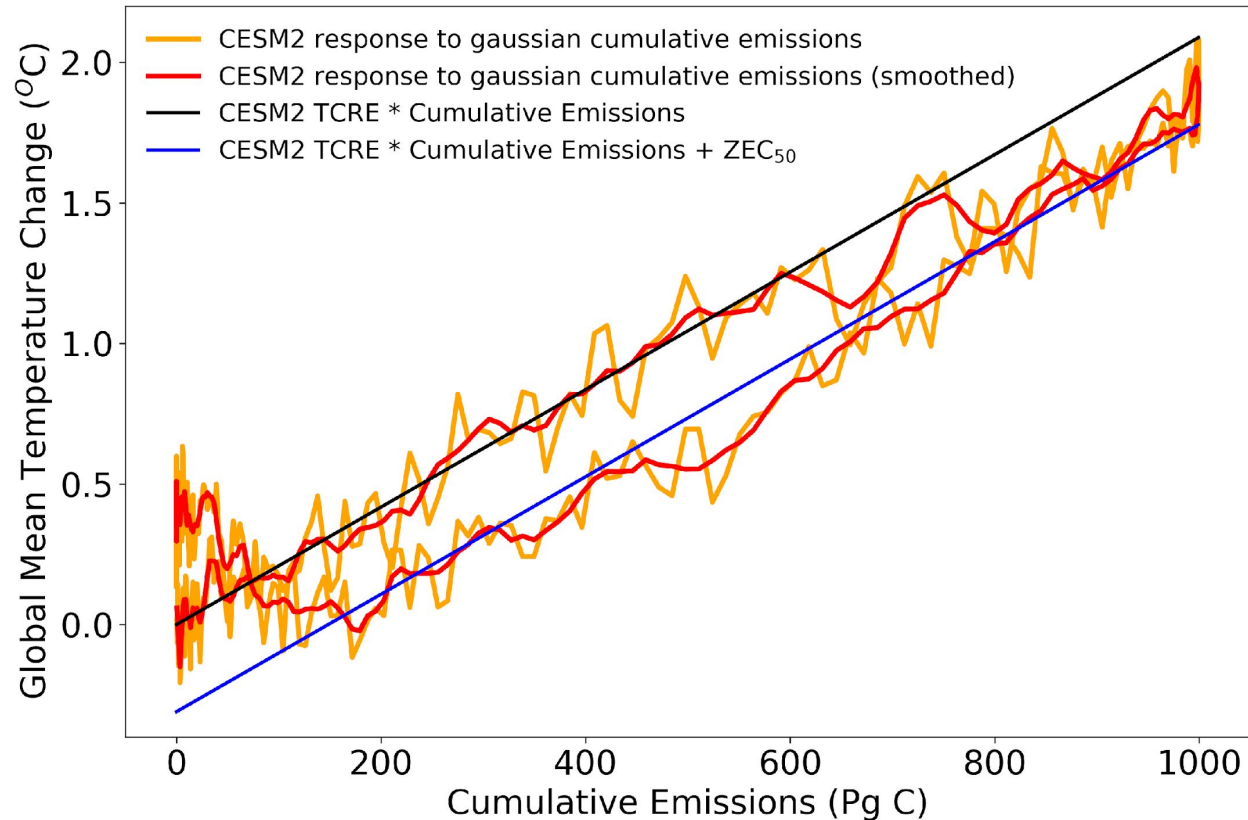
CESM2 Climate responses to CO₂ emissions reversal

- CO₂ concentration leads cumulative emissions, and drops below PI at end.
- Temperature *also leads* cumulative emissions for most of scenario (and then warms again at end).

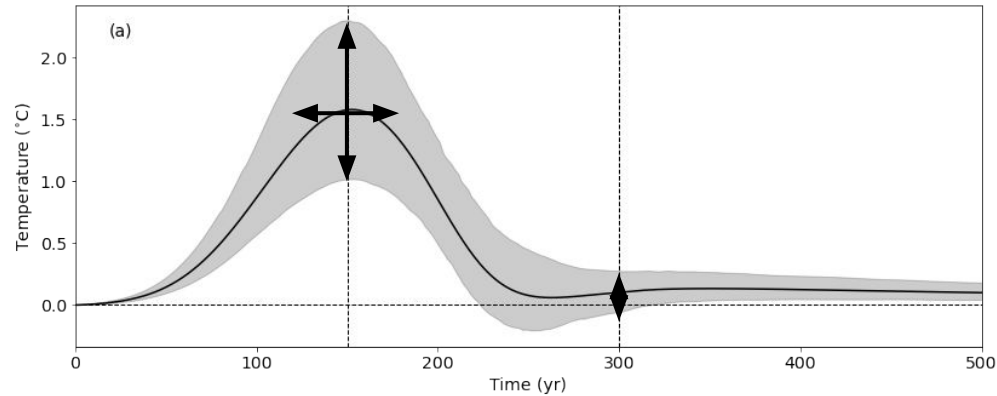


The hypothesis mostly holds.

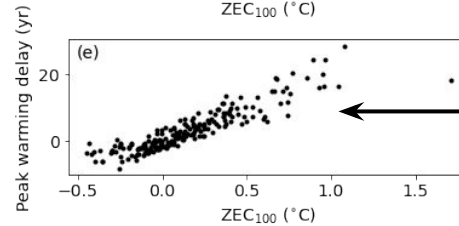
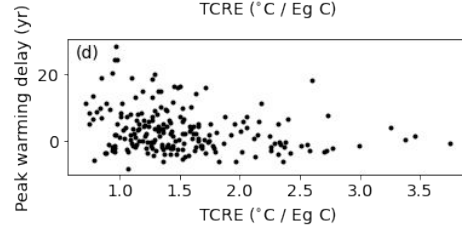
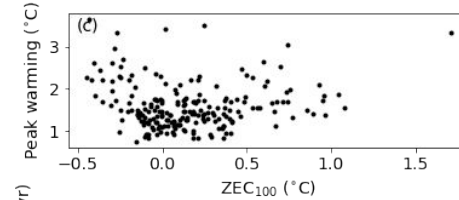
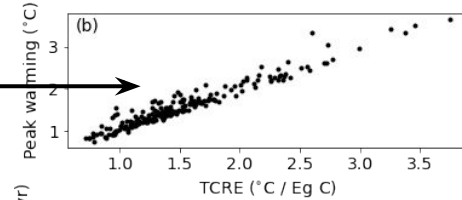
CESM2 **warming** roughly follows the TCRE proportionality on the upslope and the **TCRE proportionality plus ZEC** on the downslope. But it switches lines before peak cumulative emissions. Thus the ZEC appears *before net zero*.



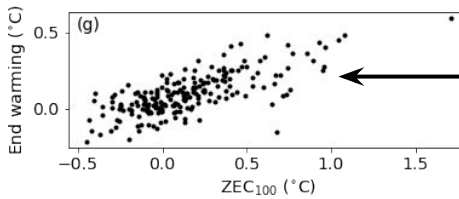
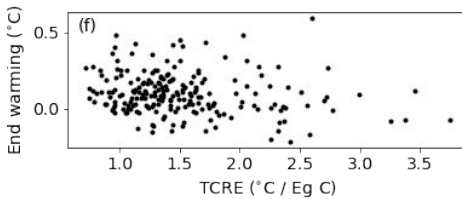
But that is just one ESM, what would a wider ensemble look like?
 We use a FaIR simple climate model PPE to look at responses as a function of TCRE and ZEC.



Peak warming mainly governed by TCRE
 (but $TCRE + 0.5 * ZEC$ correlates even better)



Timing of peak warming governed by ZEC



End warming also governed by ZEC

TCRE

ZEC

Conclusions

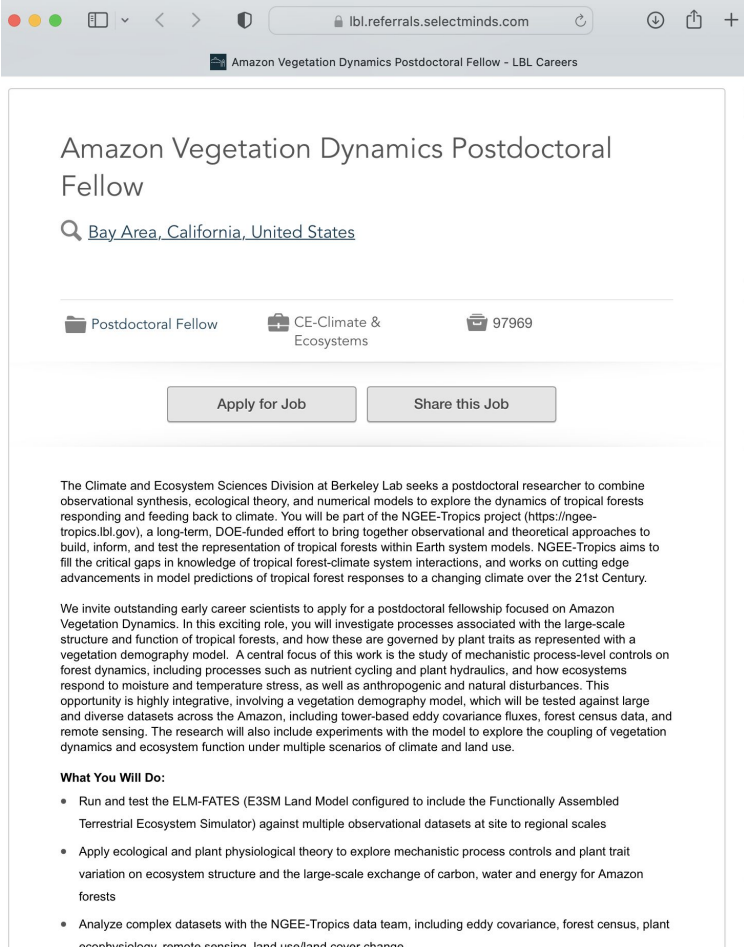
- CO₂ sinks follow emissions, and reverse sign to become sources after emission reverse, with a decade-timescale lag.
- The lag between CO₂ fluxes and emissions causes atmospheric CO₂ concentrations to lead emissions.
- The TCRE proportionality holds under net-negative CO₂ emissions, subject to an asymmetry that is well quantified by ZEC.
- Much of the ZEC appears *before reaching net zero*, and thus ZEC also governs the timing of peak warming relative to net zero.
- Thus the ZEC actually works more robustly as a measure of the long-term path-dependence and deviation from the TCRE relationship under strong emissions, than it does as a measure of warming subsequent to reaching net zero.



Some possible next

- Why does ~~steps~~ have such a negative ZEC?
- If CESM2 ZEC runs are extended longer, do they warm suddenly alongside AMOC restrengthening, as in SSP5-3.4-overshoot and this experiment?
- How does land use change fit into the TCRE/ZEC framework?
- What aspects of these dynamics are sensitive to parameter and structural differences, and how?
- Would this be a useful & practical CMIP7 experiment?
- **How else can we use emissions-driven CESM to explore climate mitigation scenarios?**

... and also a plug for a postdoc position at LBL:
<https://lbl.referrals.selectminds.com/jobs/amazon-vegetation-dynamics-postdoctoral-fellow-5550>



The screenshot shows a web browser window with the URL lbl.referrals.selectminds.com. The page title is "Amazon Vegetation Dynamics Postdoctoral Fellow". Below the title, there is a search bar with the text "Bay Area, California, United States". There are two buttons: "Apply for Job" and "Share this Job". The main content area contains a detailed description of the position, including the following text:

The Climate and Ecosystem Sciences Division at Berkeley Lab seeks a postdoctoral researcher to combine observational synthesis, ecological theory, and numerical models to explore the dynamics of tropical forests responding and feeding back to climate. You will be part of the NGEE-Tropics project (<https://ngee-tropics.lbl.gov>), a long-term, DOE-funded effort to bring together observational and theoretical approaches to build, inform, and test the representation of tropical forests within Earth system models. NGEE-Tropics aims to fill the critical gaps in knowledge of tropical forest-climate system interactions, and works on cutting edge advancements in model predictions of tropical forest responses to a changing climate over the 21st Century.

We invite outstanding early career scientists to apply for a postdoctoral fellowship focused on Amazon Vegetation Dynamics. In this exciting role, you will investigate processes associated with the large-scale structure and function of tropical forests, and how these are governed by plant traits as represented with a vegetation demography model. A central focus of this work is the study of mechanistic process-level controls on forest dynamics, including processes such as nutrient cycling and plant hydraulics, and how ecosystems respond to moisture and temperature stress, as well as anthropogenic and natural disturbances. This opportunity is highly integrative, involving a vegetation demography model, which will be tested against large and diverse datasets across the Amazon, including tower-based eddy covariance fluxes, forest census data, and remote sensing. The research will also include experiments with the model to explore the coupling of vegetation dynamics and ecosystem function under multiple scenarios of climate and land use.

What You Will Do:

- Run and test the ELM-FATES (E3SM Land Model configured to include the Functionally Assembled Terrestrial Ecosystem Simulator) against multiple observational datasets at site to regional scales
- Apply ecological and plant physiological theory to explore mechanistic process controls and plant trait variation on ecosystem structure and the large-scale exchange of carbon, water and energy for Amazon forests
- Analyze complex datasets with the NGEE-Tropics data team, including eddy covariance, forest census, plant ecophysiology, remote sensing, land use/land cover change