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Inherent Uncertainty Disguises Attribution of Reduced Atmospheric CO_2 Growth to Emission Reductions for up to a Decade

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This talk will also be delivered by videoconferencing Friday May 8th 17:45 via zoom.
You can find the agenda here and you can sign up here.

Max-Planck-Institut für Meteorologie
International Max Planck Research School on Earth System Modelling
Climate-Carbon Interactions in the Current Century
Universität Hamburg
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The global carbon cycle is sensitive towards climate-driven internal variability, which might obscure the identification of changes in anthropogenic emissions.

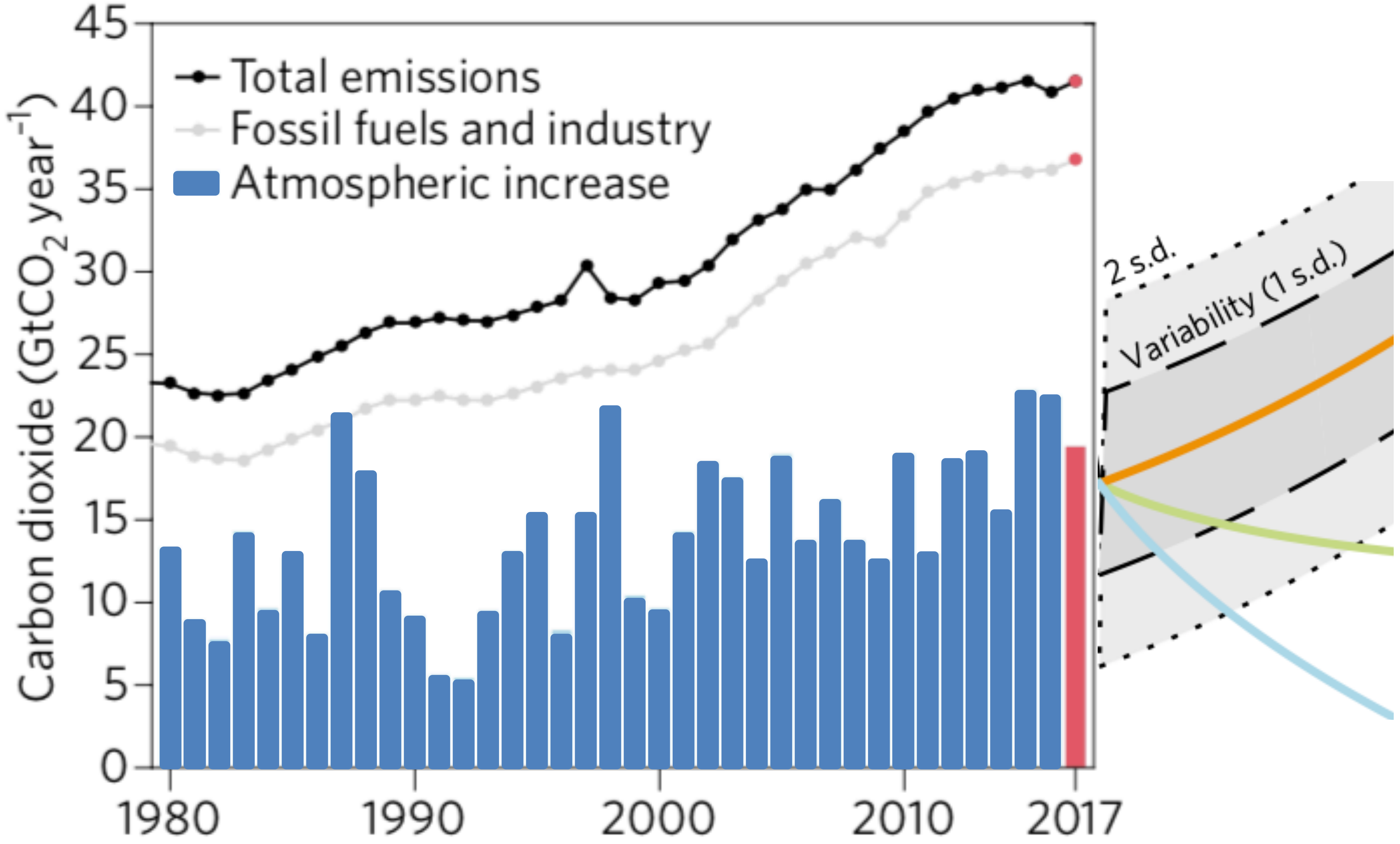
- Long-term dominance of the forced signal undisputed

- When are emission reductions detectable in atmospheric CO_2 measurements?

➡COVID19 signal not yet detectable at Mauna Loa [@PFriedling]

➡Policy-relevant when emission reduction efficacy is assessed by global stocktake.

- On which time-scales does internal variability in atmospheric CO_2 dominate over changes in the forced signal?



[Peters et al. 2017 Figs. 1&2]

Research questions: Inherent uncertainty in atmospheric CO_2 projections and attribution of emission reductions

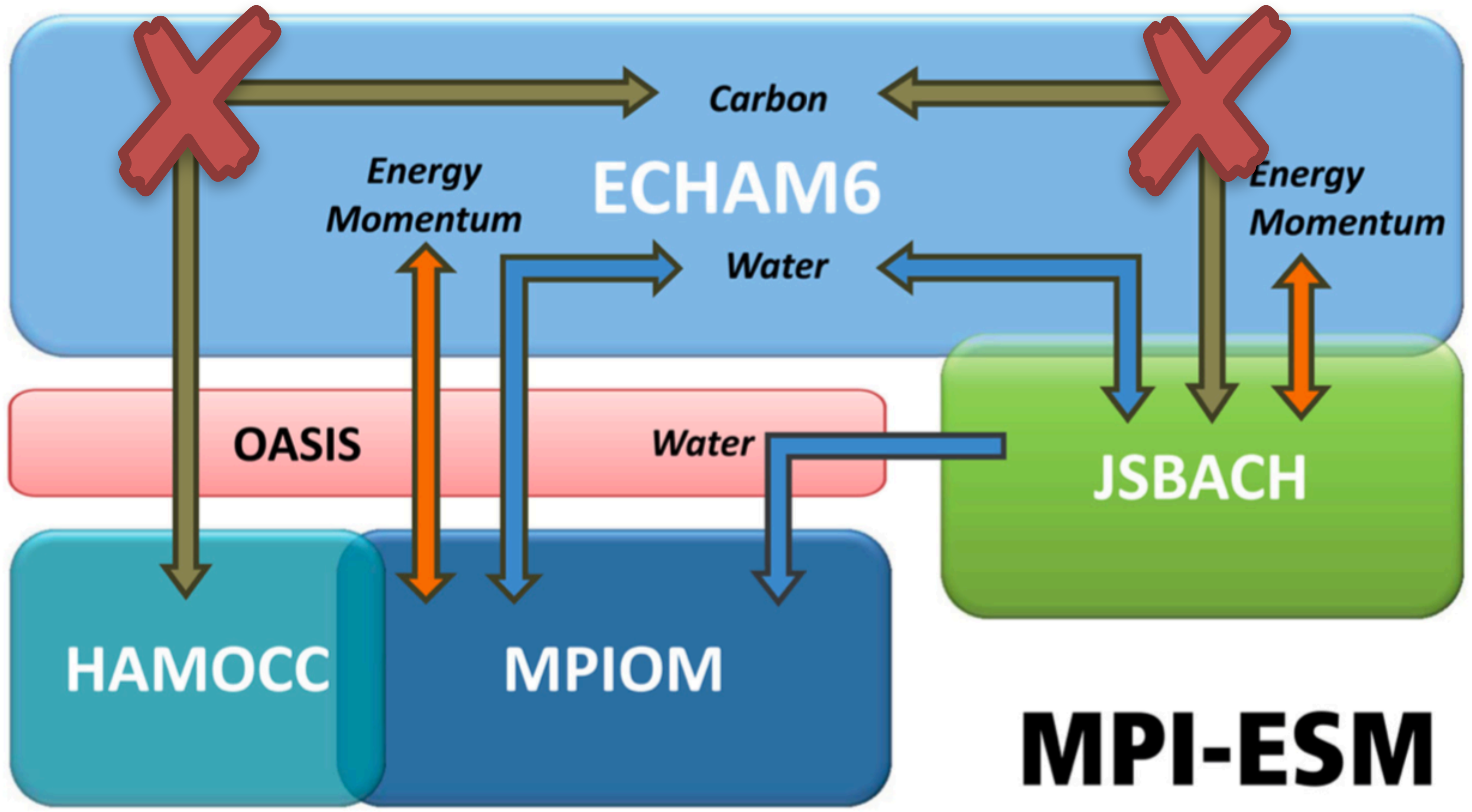
- On what time-scales are trend reductions in atmospheric CO_2 attributable to emission reduction?

  – What is the probability that even if emissions are reduced, the trend in atmospheric CO_2 keeps rising even stronger?

  – How many years after reduced emissions can we be certain that these reduced emissions caused a reduction in atm. CO_2 trend?

MPI-ESM Grand Ensemble provides a 1% resolution in climate event attribution [Marotzke, 2019].

- Uninitialised ensemble to separate internal variability from forced signal [Maher et al., 2019]:
  - – 100 ensemble members from piControl
  - – 3 scenarios
- Causal Theory [Pearl 2020, Hannart et al. 2016]
  - Factual world
  - Counter-factual world
  - Necessary and sufficient causality



Giorgetta et al. 2013

- MPI-ESM1.1-LR historical + RCPs
  - – Atmosphere & Land: T63 (1.8°)
  - – Ocean: GR15 (1.5°)
  - – prescribed atmospheric CO_2 forcing

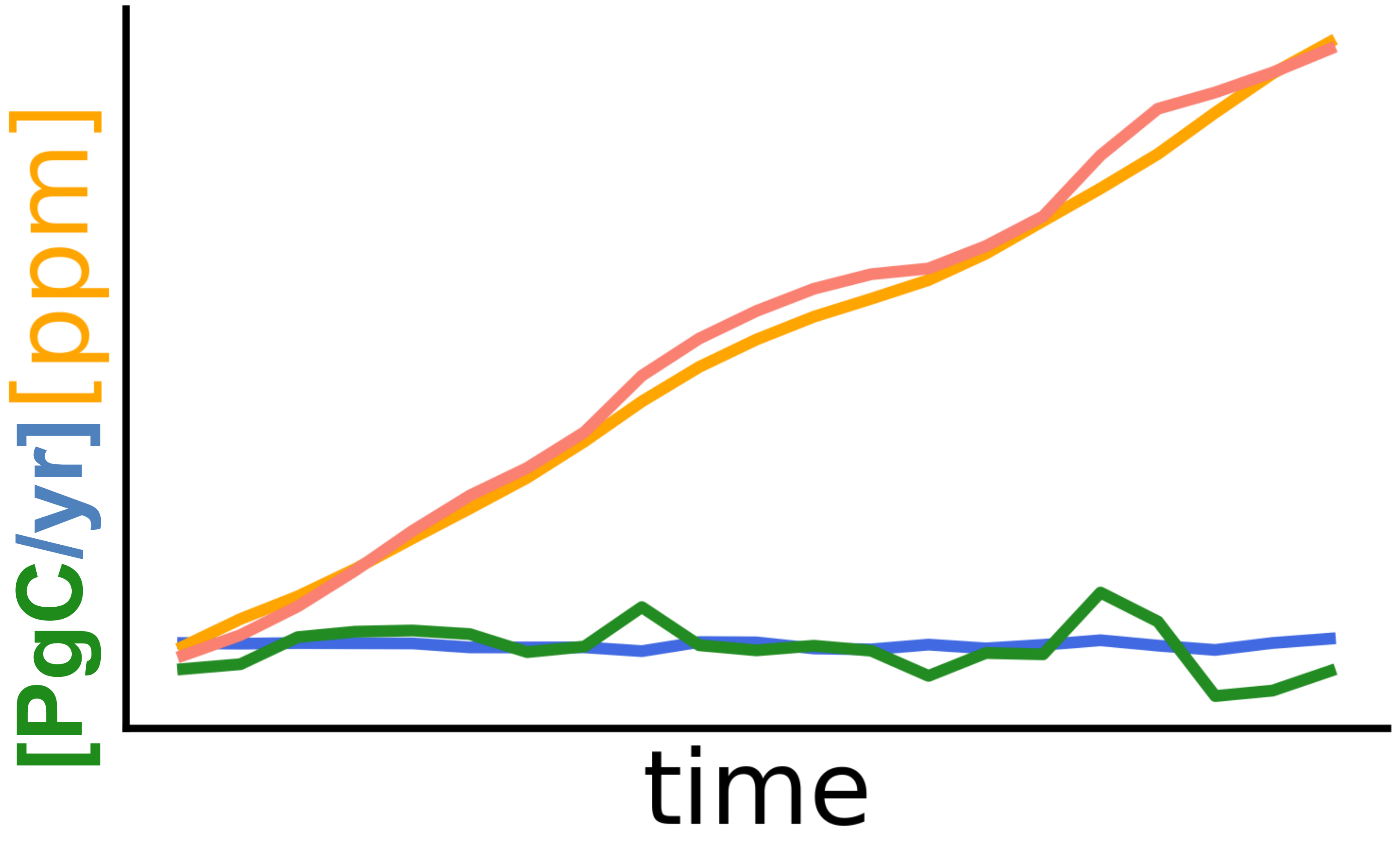
Diagnosing global atmospheric CO_2 variations from the prescribed CO_2 signal and the global carbon sinks ensemble mean residuals.

$$XCO_2(t) = \sum_{t'=t_{start}}^{t} (CO_2flux'(t')) \frac{ppm}{2.12\ PgC} + forcing(t)$$

-= time mean control

-= member mean

= $CO_{2,atm}$ forcing (IAM)



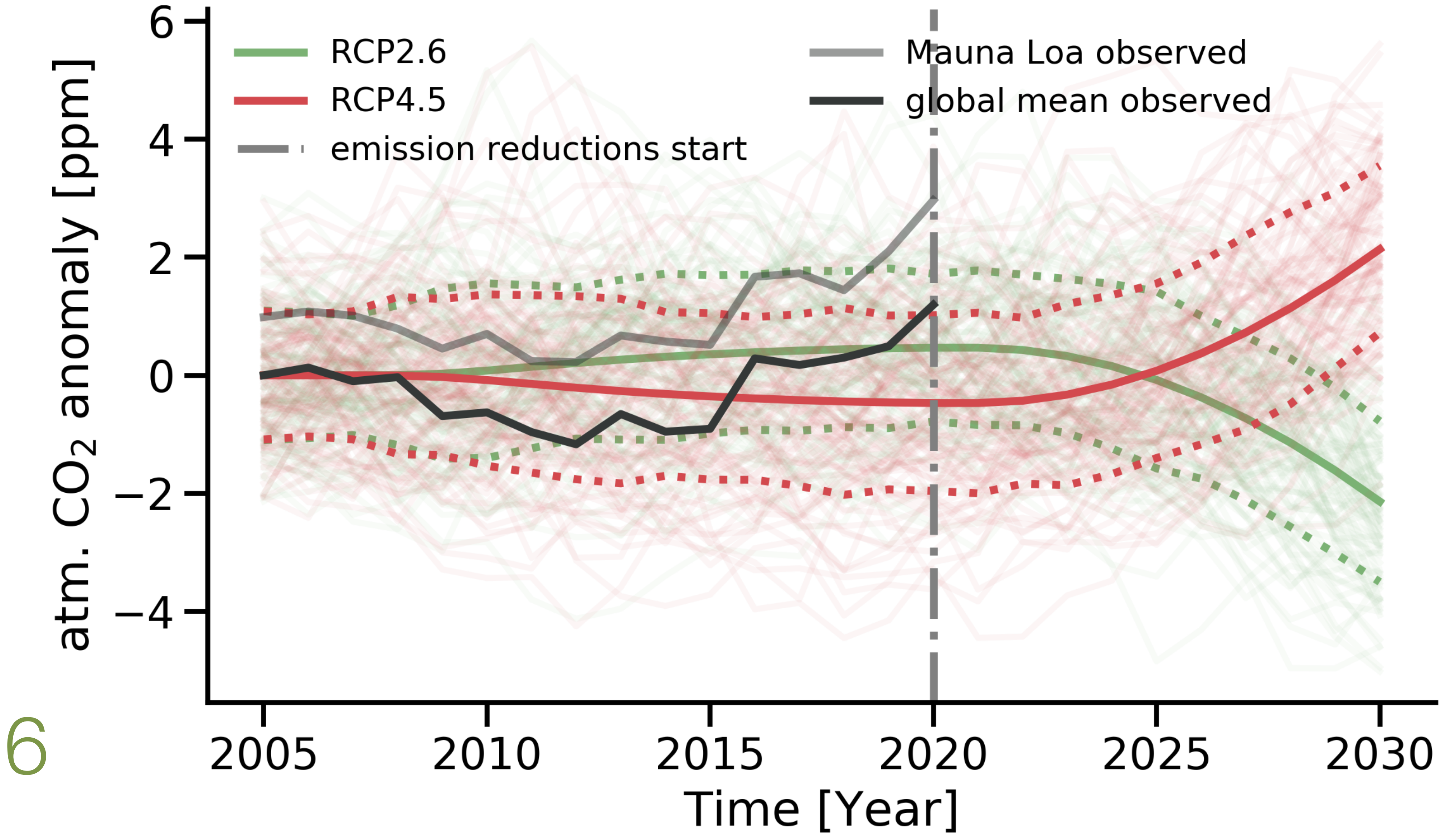
- Assumptions:
  - Instantaneous global atmospheric mixing [Ballantyne et al. 2012]
  - Internal variability of carbon cycle driven by climate variability
  - Disregards short-term influence of atm. CO_2 variability on carbon cycle

Where are we?

[Hausfather and Peters, 2020]

The MPI-ESM Grand Ensemble provides a **Paris targets (RCP2.6)** and **current pledges pathway (RCP4.5)** scenario with diverging CO_2 forcing after 2020.

- Expected climate response to emission cuts: decrease in atm. CO_2 trend
- Uninitialised large ensemble simulations:
  - 100 ensemble members
  - 2 scenarios:
    - **RCP2.6: emission reduction to reach Paris goals**
    - **RCP4.5: current, no emis. reductions before 2040**
    - Emission cuts as policy change from RCP4.5 to RCP2.6

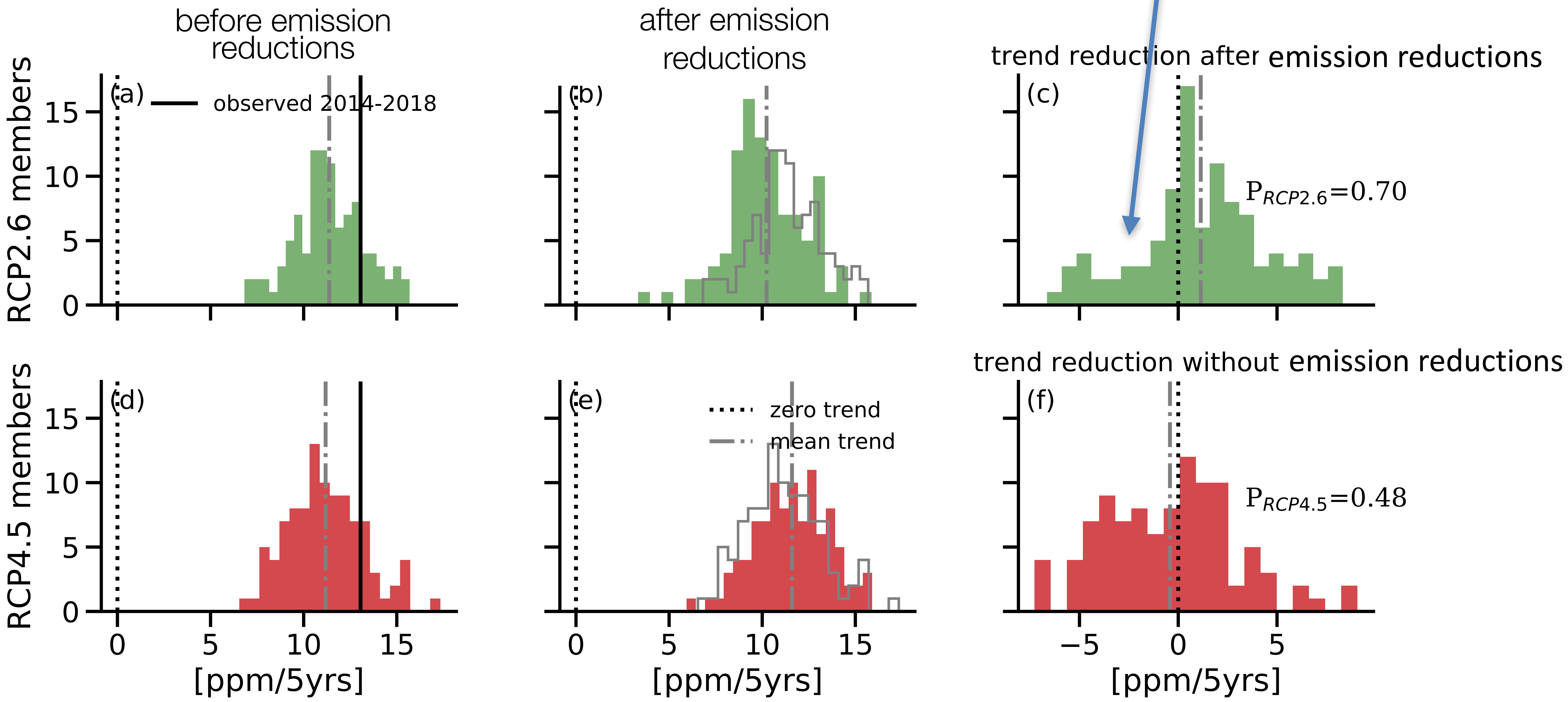


- Probabilities of reduction in 5-year trends

$$P_{RCPx} = \sum_{ens=1}^{100} (trend_{ens}^{2016-2020} > trend_{ens}^{2021-2025})\ \%$$

[adopted from Marotzke, 2019]

Atmospheric CO_2 5-year trends might even increase despite of implemented emission reductions policy due to internal variability.



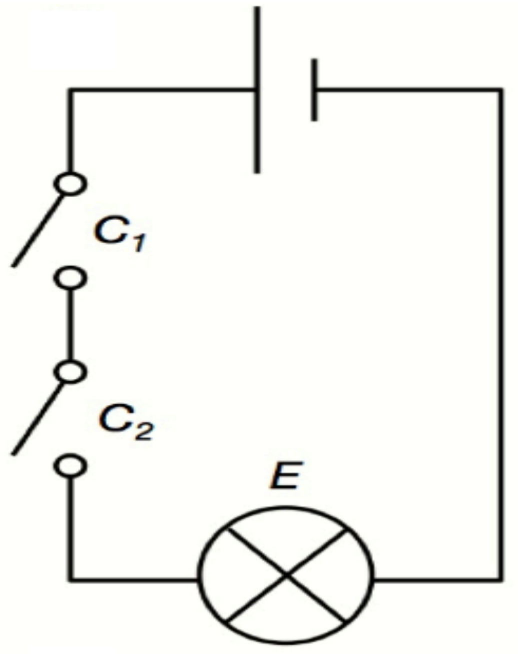
Three facets of causation

Does policy change cause reduced atm. CO_2 trends?

Switch C_1 = policy change from RCP4.5 to RCP2.6
Switch C_2 = internal variability (no strong natural C outgassing)
Light bulb E = reduced atm. CO_2 trends

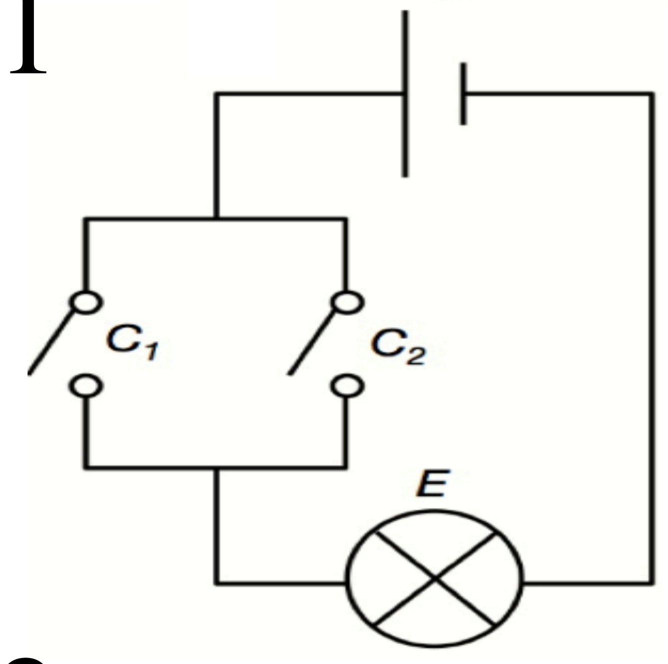
[Pearl 2020, Hannart et al. 2018]

- **necessary causation**
  - Without switch C_1, bulb E is off. Yet C_1 not always turns on E, as C_2 is also required
  - ask retrospectively whether policy change was **necessary**



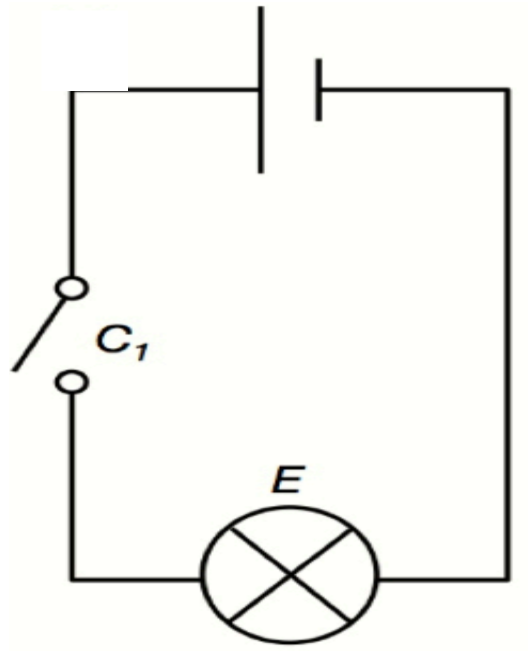
$$P_N = 1 - \frac{P_{RCP4.5}}{P_{RCP2.6}} = 0.31$$

- **sufficient causation**
  - Bulb E is lit every time C_1 is turned on. Yet if C_1 is off, E might still be lit by C_2
  - ask in advance whether a policy change would be **sufficient** to cause a trend reduction



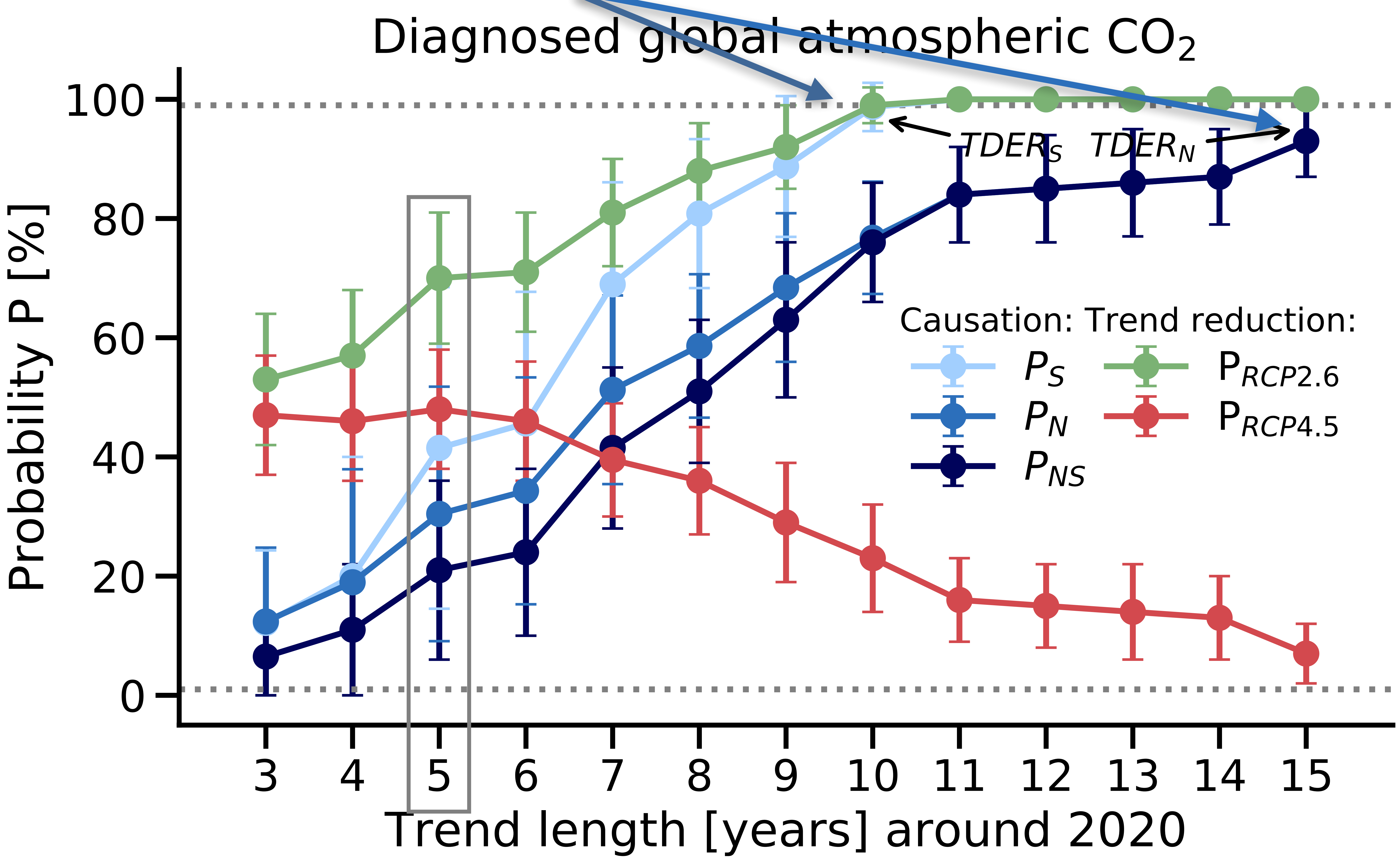
$$P_S = \frac{P_{RCP2.6} - P_{RCP4.5}}{1 - P_{RCP4.5}} = 0.42$$

- **necessary and sufficient causation**
  - Turning on C_1 always lights E, and E may not be lighted unless C_1 is on.
  - policy change is both **necessary and sufficient** $P_{NS} = P_{RCP2.6} - P_{RCP4.5} = 0.22$



Reduced emissions are certain to cause reduced trends in atmospheric CO_2 in a sufficient causation sense when considering 10-year trends.

time of detection of emission reduction [similar Tebaldi and Friedlingstein, 2013]



- Ask in advance whether a policy change would be **sufficient** to cause a trend reduction:

[Hannart et al. 2016] $$P_S = \frac{P_{RCP2.6} - P_{RCP4.5}}{1 - P_{RCP4.5}}$$

- Ask retrospectively whether policy change was **necessary**:

$$P_N = 1 - \frac{P_{RCP4.5}}{P_{RCP2.6}}$$

- Policy change from RCP4.5 to RCP2.6 is both **necessary and sufficient**:

$$P_{NS} = P_{RCP2.6} - P_{RCP4.5}$$

Take home messages: Inherent uncertainty in atmospheric CO_2 projections might disguise emission reduction effects up to a decade.

- Policy change from RCP4.5 to RCP2.6 is ***sufficient*** to cause 5-year CO_2 trend reduction with P=42% and ***necessary*** with P=31% and ***necessary and sufficient*** with P=22%.
- These probabilities, when covering the time-scales of the Global Stocktake, are **far from certain**.
- Certainty is reached after 10 (***sufficient*** causation) and 15 (***necessary***) years.
- Results are based on one model. All models have internal variability.
- Policy-makers should be informed by initialized predictions about near-term internal variability in atmospheric CO_2 evolution [Spring and Ilyina, 2020].
- This influence of internal variability in atm. CO_2 on sub-decadal time-scales in emission reduction attribution is challenging to communicate to the public.

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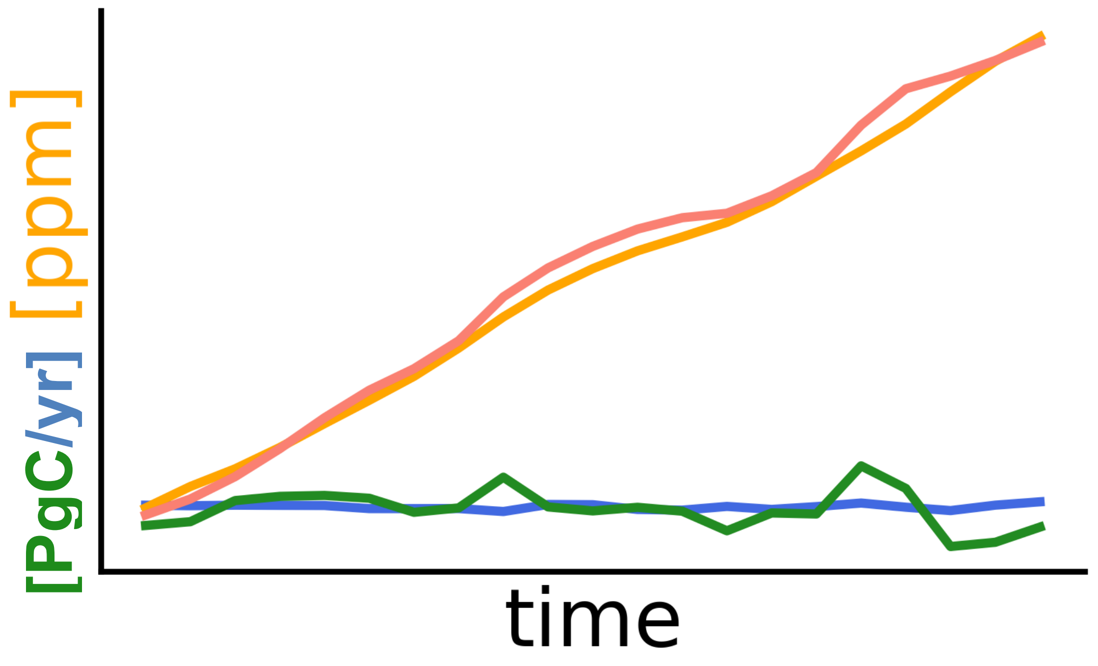
Assumptions about diagnosed atmospheric CO_2

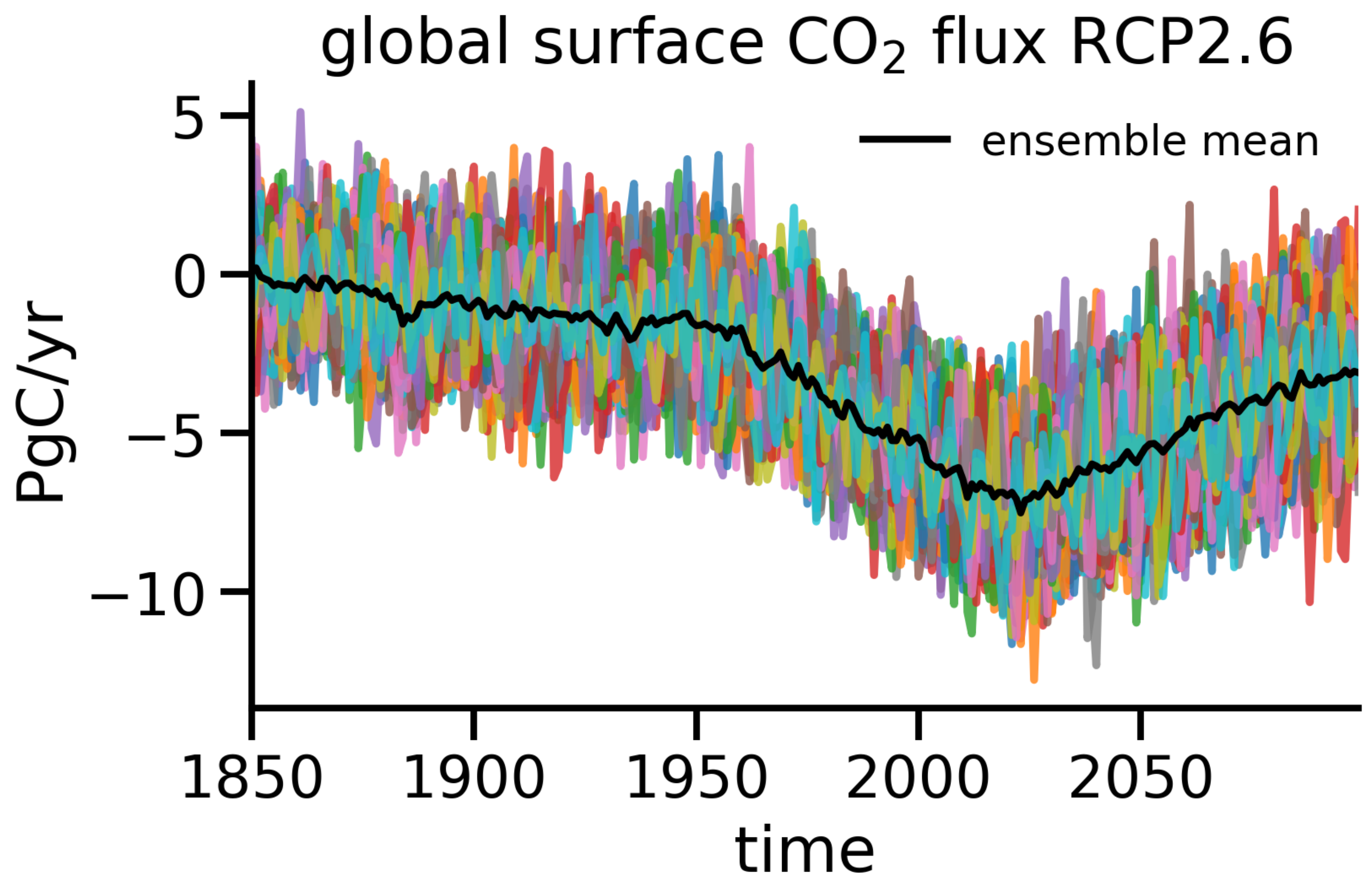
$$XCO_{2,atm}(t) = \sum_{t'=t_{start}}^{t} \underbrace{(CO_2flux'(t'))}_{} \frac{\text{ppm}}{2.12\ \text{PgC}} + \underbrace{forcing(t)}_{}$$

-= time mean control = Historical: $CO_{2,atm}$ forcing (IAM)

-= member mean esmHistorical: member mean CO_2



- Assumptions:
  - Instantaneous global atmospheric mixing: conversion factor 2.12 PgC to 1 ppm [Ballantyne et al. 2012]
  - Internal variability driven by climate-induced variability (temperature effect on biogeochemistry, circulation changes, …)
  - ignores short-term terrestrial CO_2 fertilisation effect and oceanic sensitivity to variability in CO_2 (as all concentration-driven experiments)
  - Same approach as diagnosing compatible emissions from concentration-driven simulations [Jones, 2013] but "backwards"

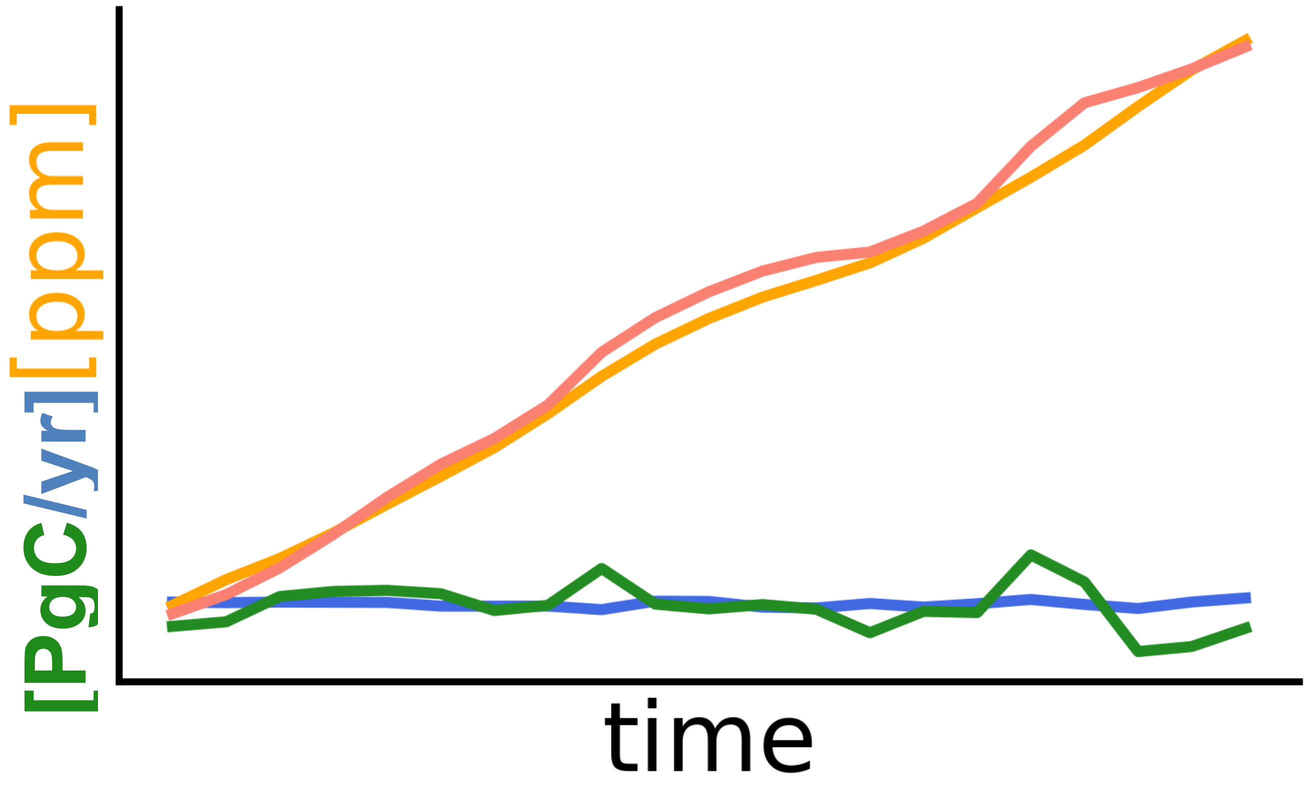


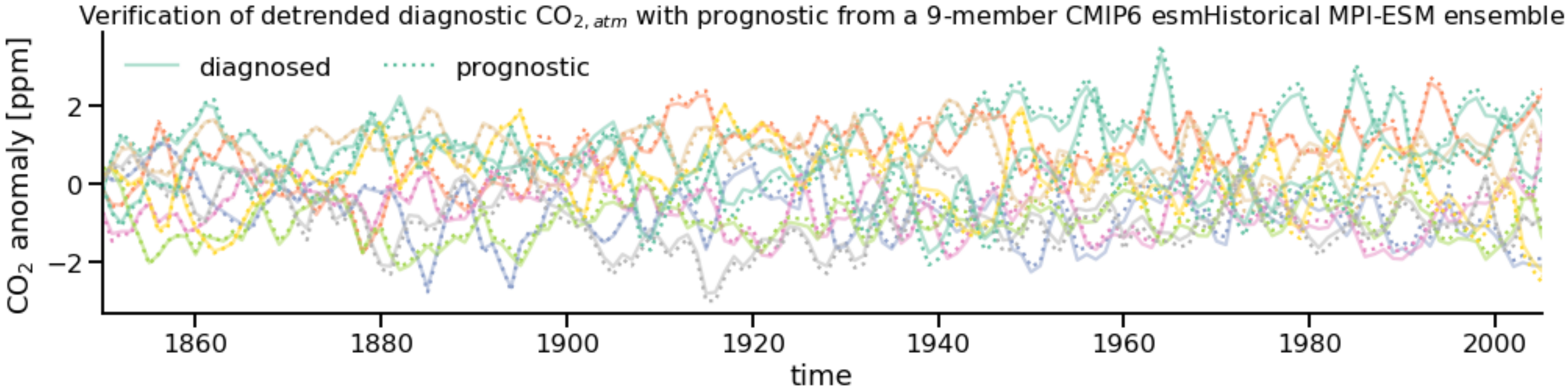
Verification: Diagnosing global atmospheric CO_2 variations tracks actual global atm. CO_2 concentrations in emission-driven simulations.

$$XCO_{2,atm}(t) = \sum_{t'=t_{start}}^{t} \underbrace{(CO_2flux'}(t'))\frac{ppm}{2.12\ PgC} + \underbrace{forcing(t)}$$

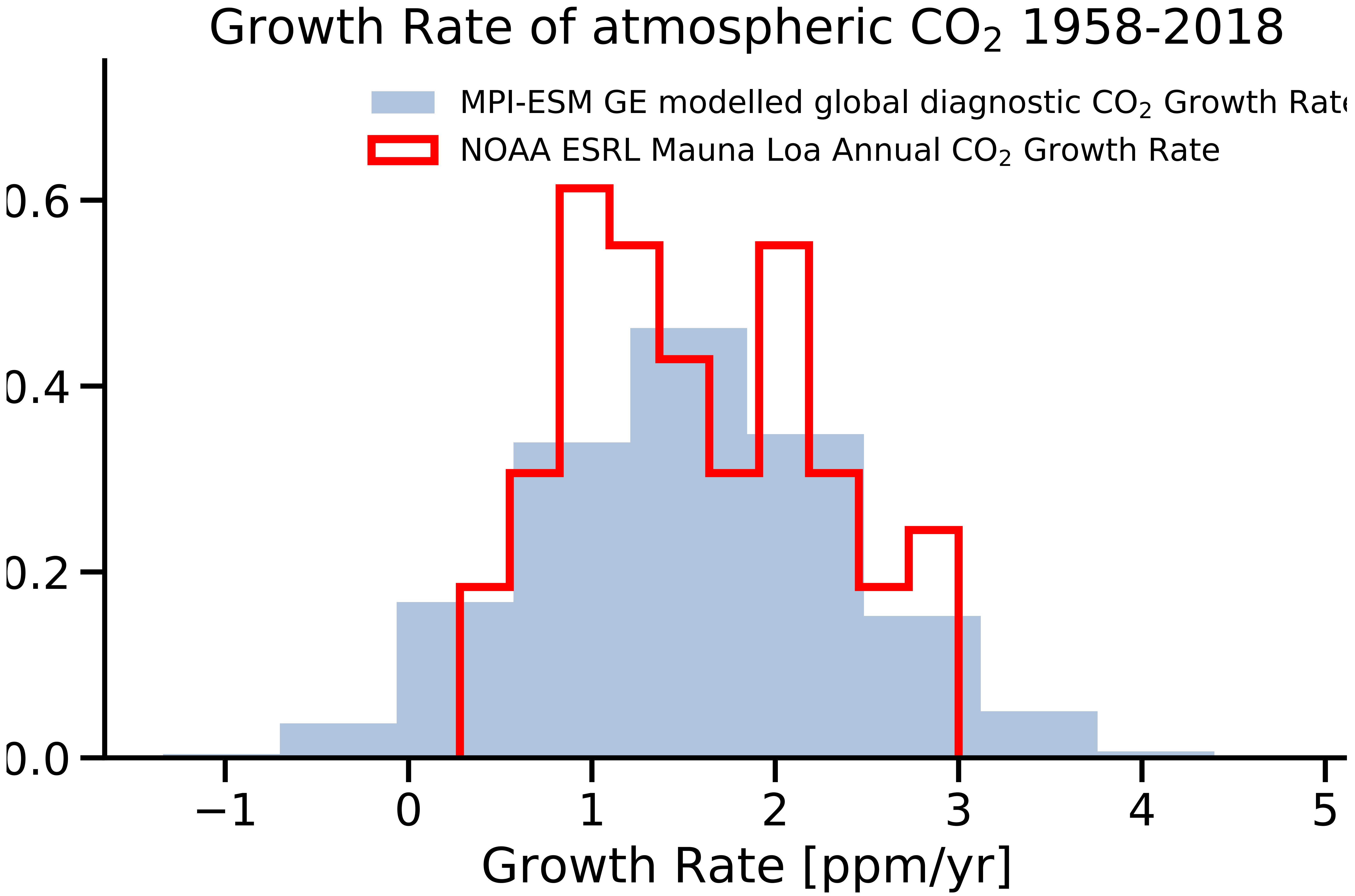
-= time mean control = Historical: $CO_{2,atm}$ forcing (IAM)

-= member mean esmHistorical: member mean $CO_{2,atm}$

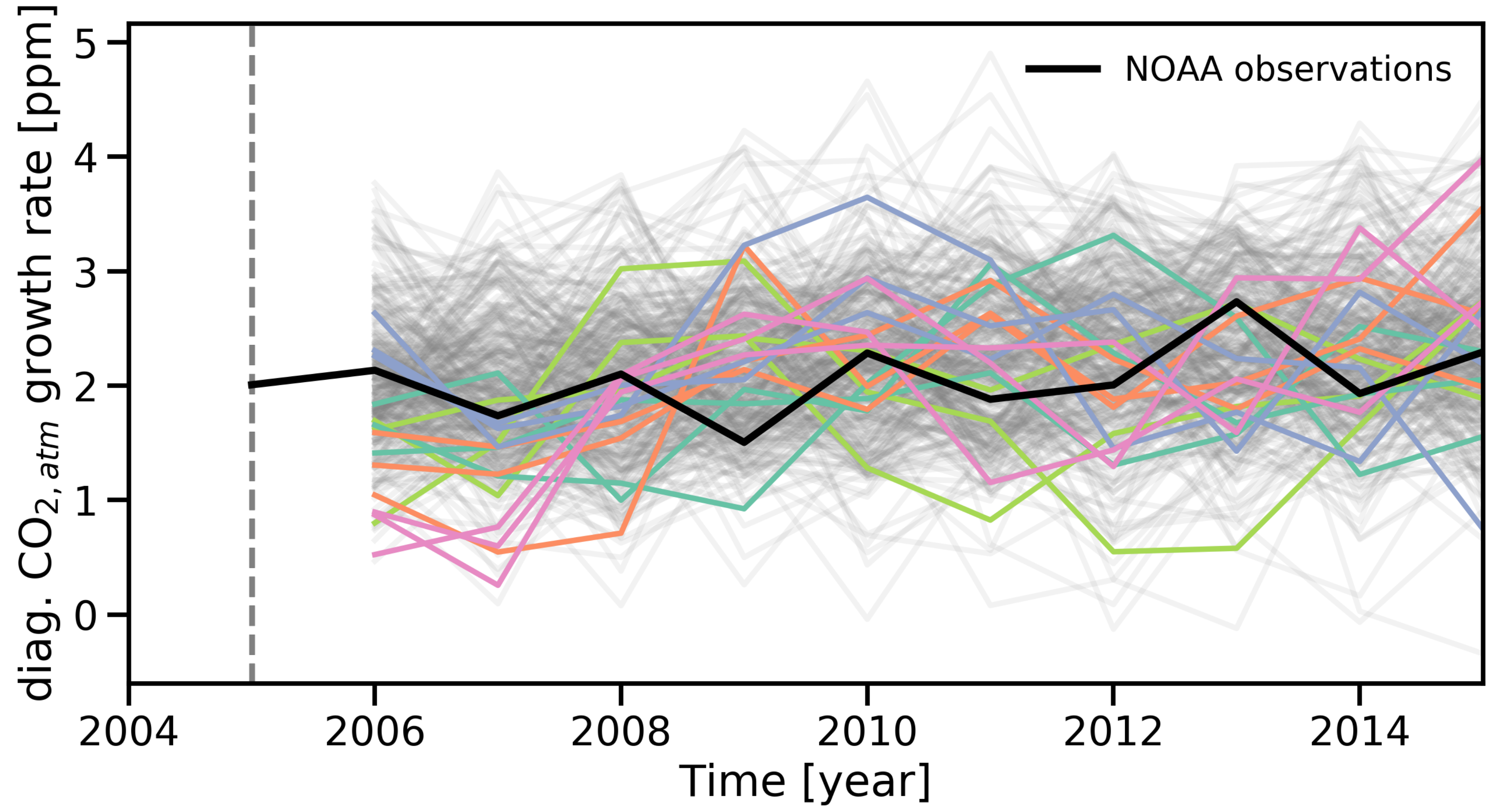




MPIESM Grand Ensemble simulates a realistic range of the atmospheric CO_2 annual growth rate.



	modelled	observed
count	6000.00	60.00
mean	1.54	1.58
std	0.85	0.67
min	-1.34	0.28
25%	0.95	1.04
50%	1.54	1.52
75%	2.12	2.04
max	4.50	3.01



emissions over time in RCP scenarios