

Land carbon cycle response to zero and negative emissions across ESMs

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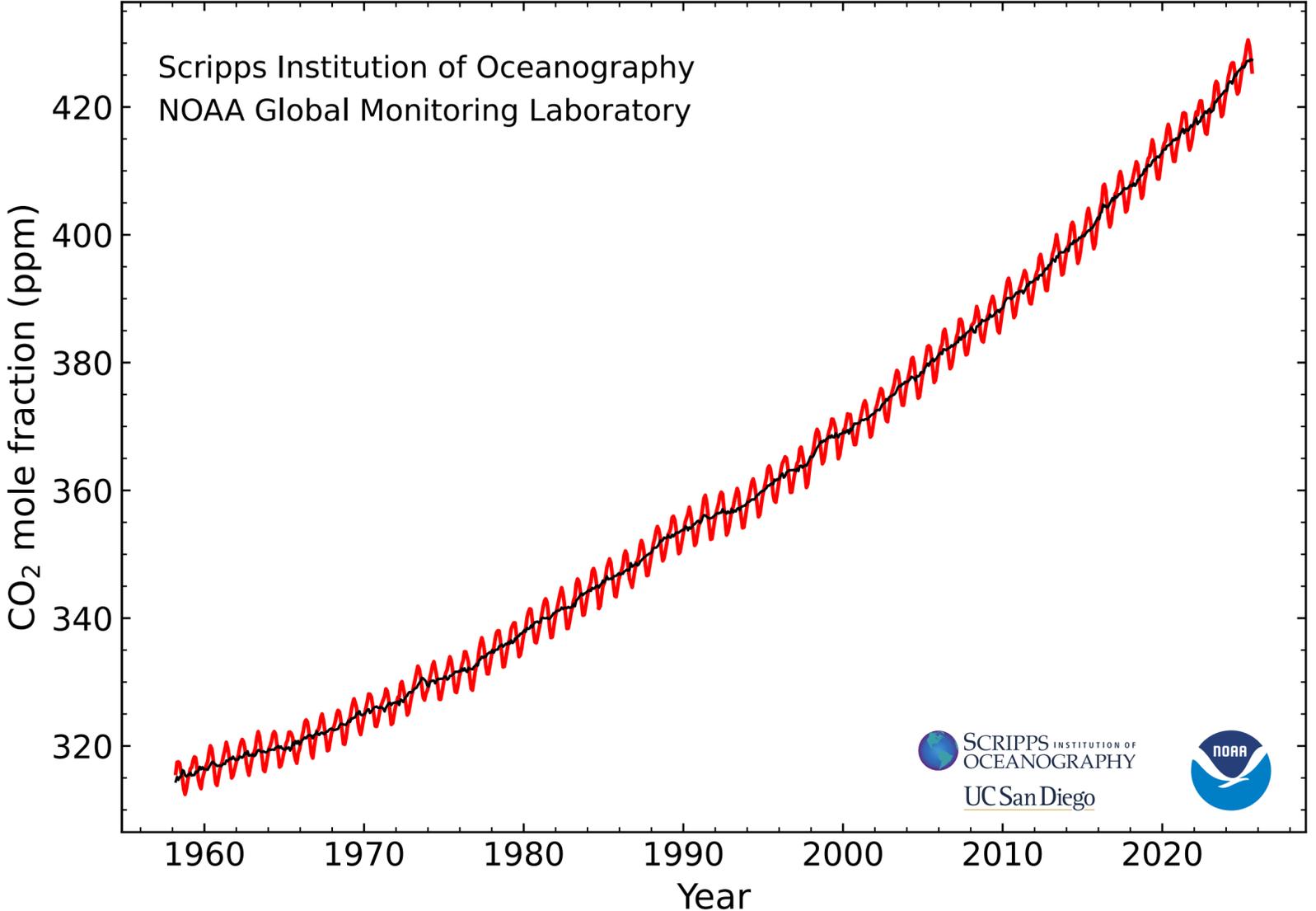
Department of Biology
University of Washington

Charlie Koven, Cristi Proistosescu, Rosie Fisher, Ben Sanderson, Victor Brovkin, Tomohiro Hajima, Chris D. Jones, Nancy Y. Kiang, David M. Lawrence, Spencer Liddicoat, Hannah Liddy, Anastasia Romanou, Roland Sèfèrian, Lori T. Sentman, Norman J. Steinert, Jerry Tjiputra, Tilo Ziehn

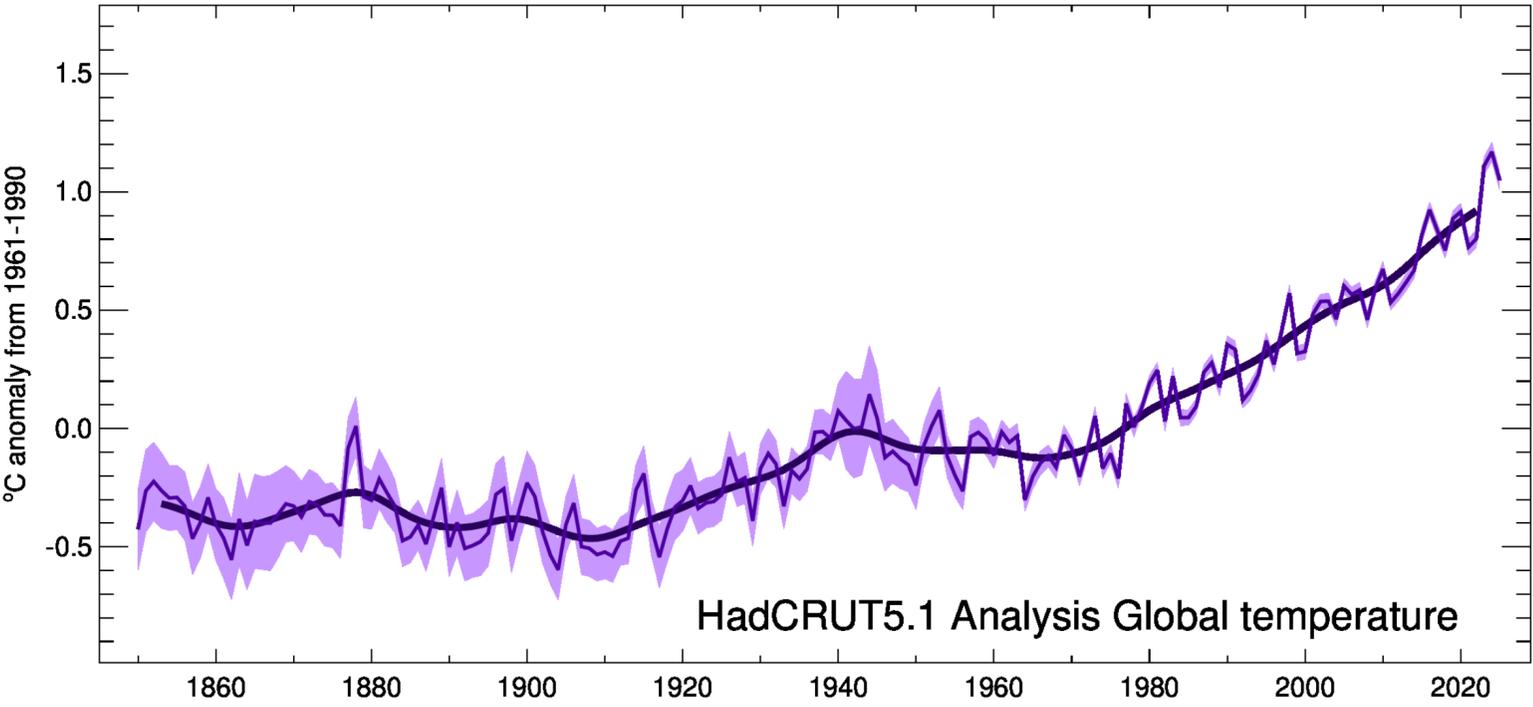
Funding from NSF, DOE

CO₂ in the Atmosphere is rising

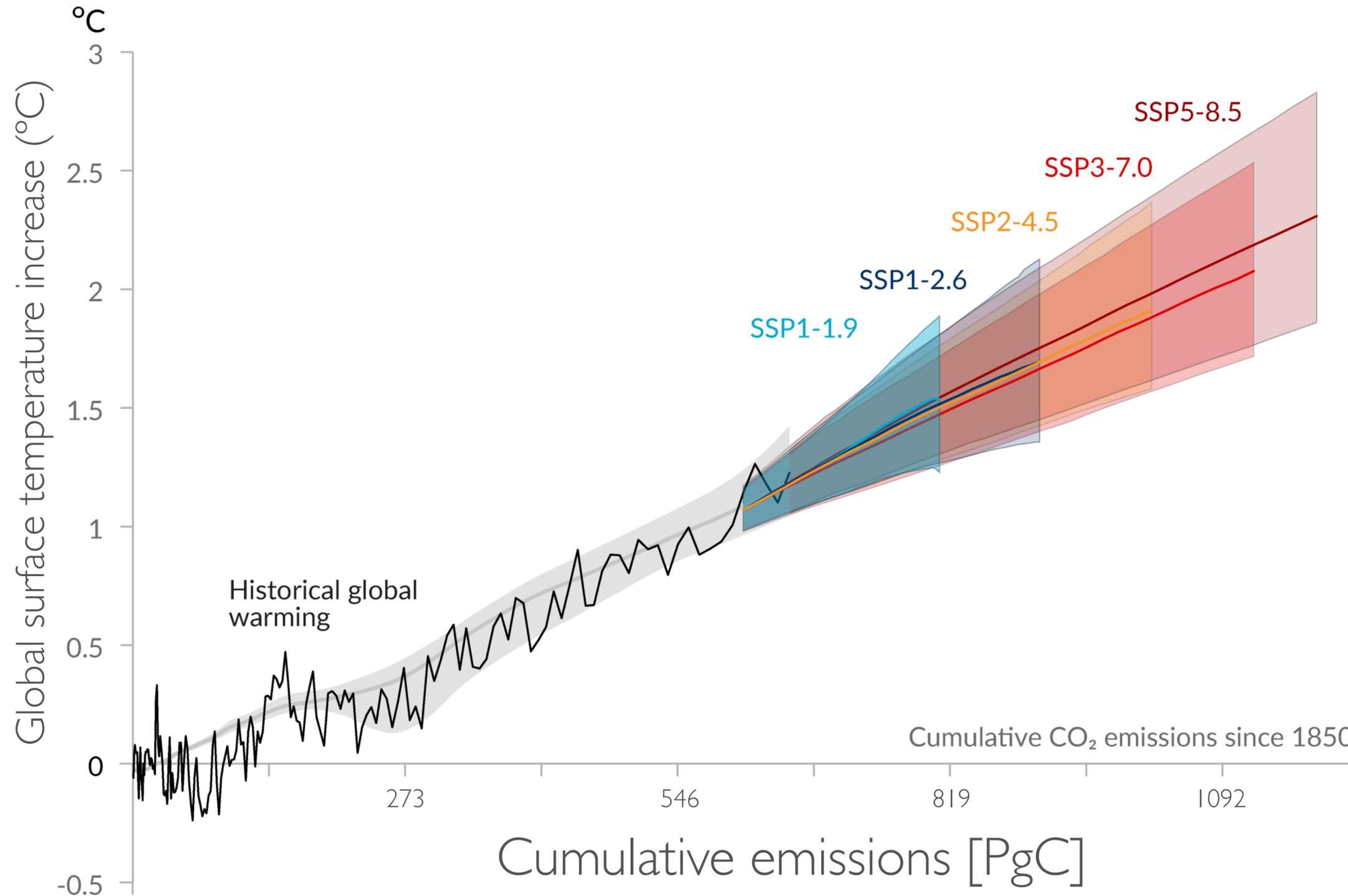
Atmospheric CO₂ at Mauna Loa Observatory



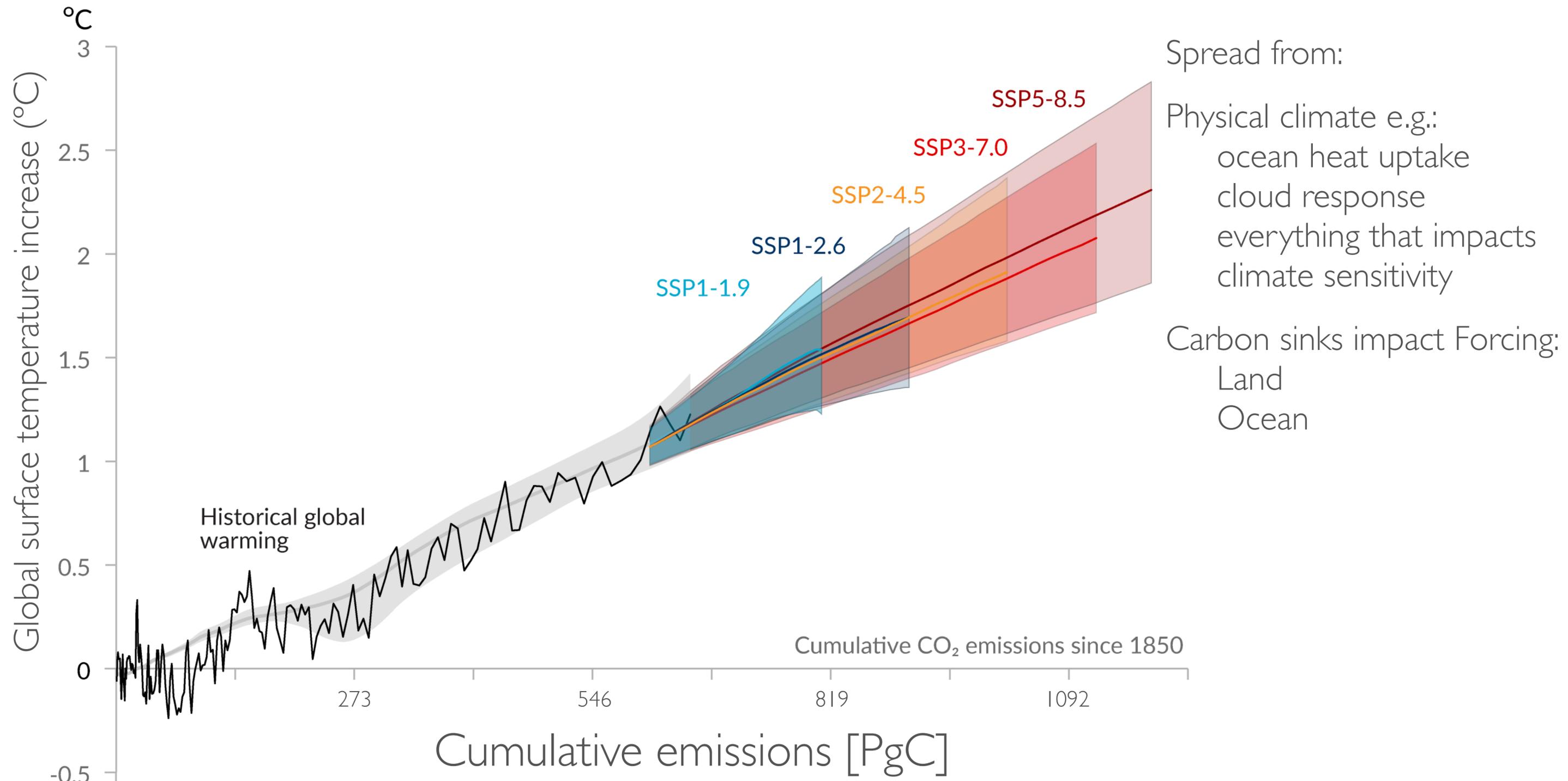
Warming has occurred



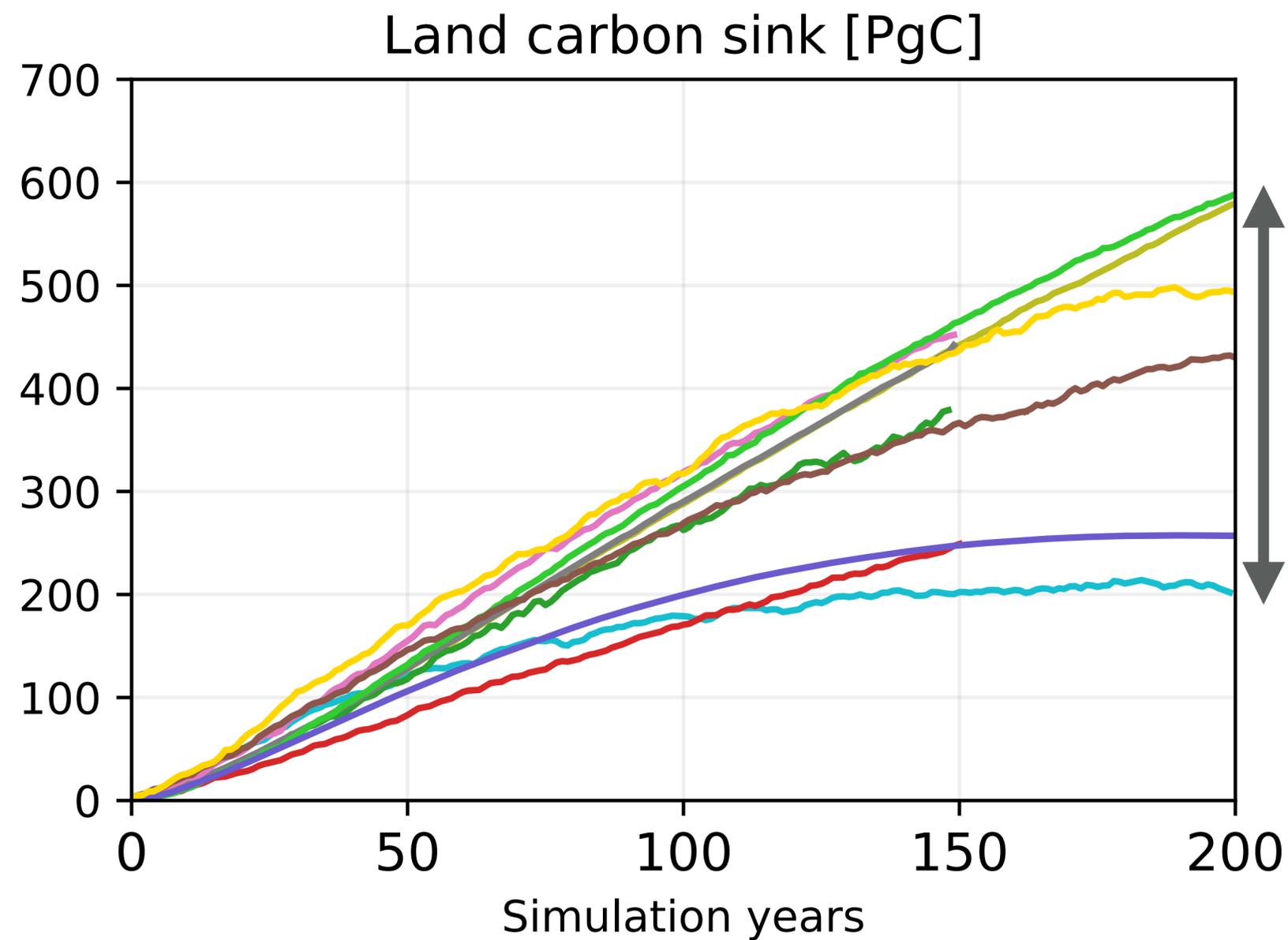
Warming scales with *cumulative* emissions



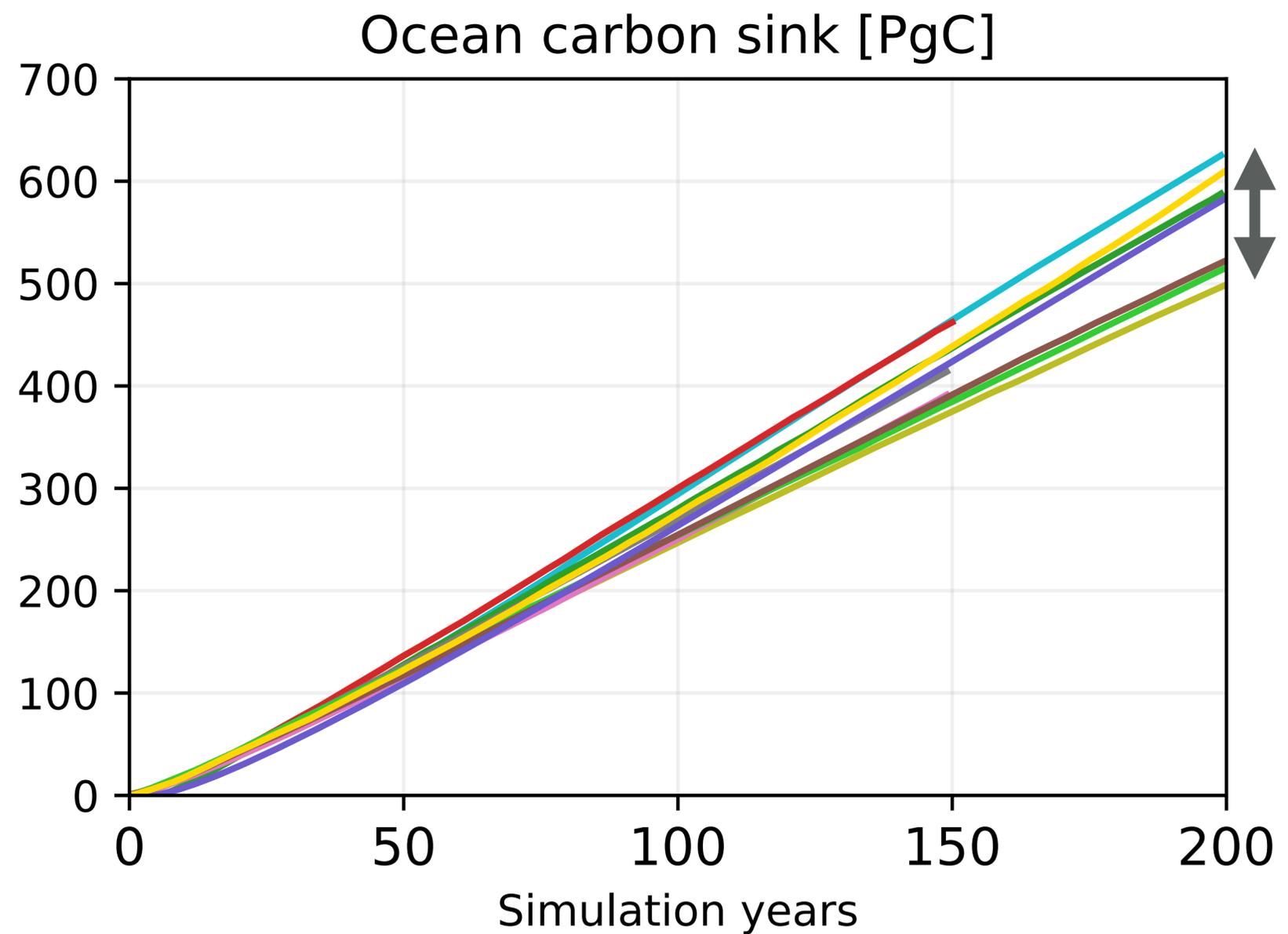
Warming scales with *cumulative* emissions



Across model spread in future CO₂ is due (largely) to differences in **land** fluxes of C

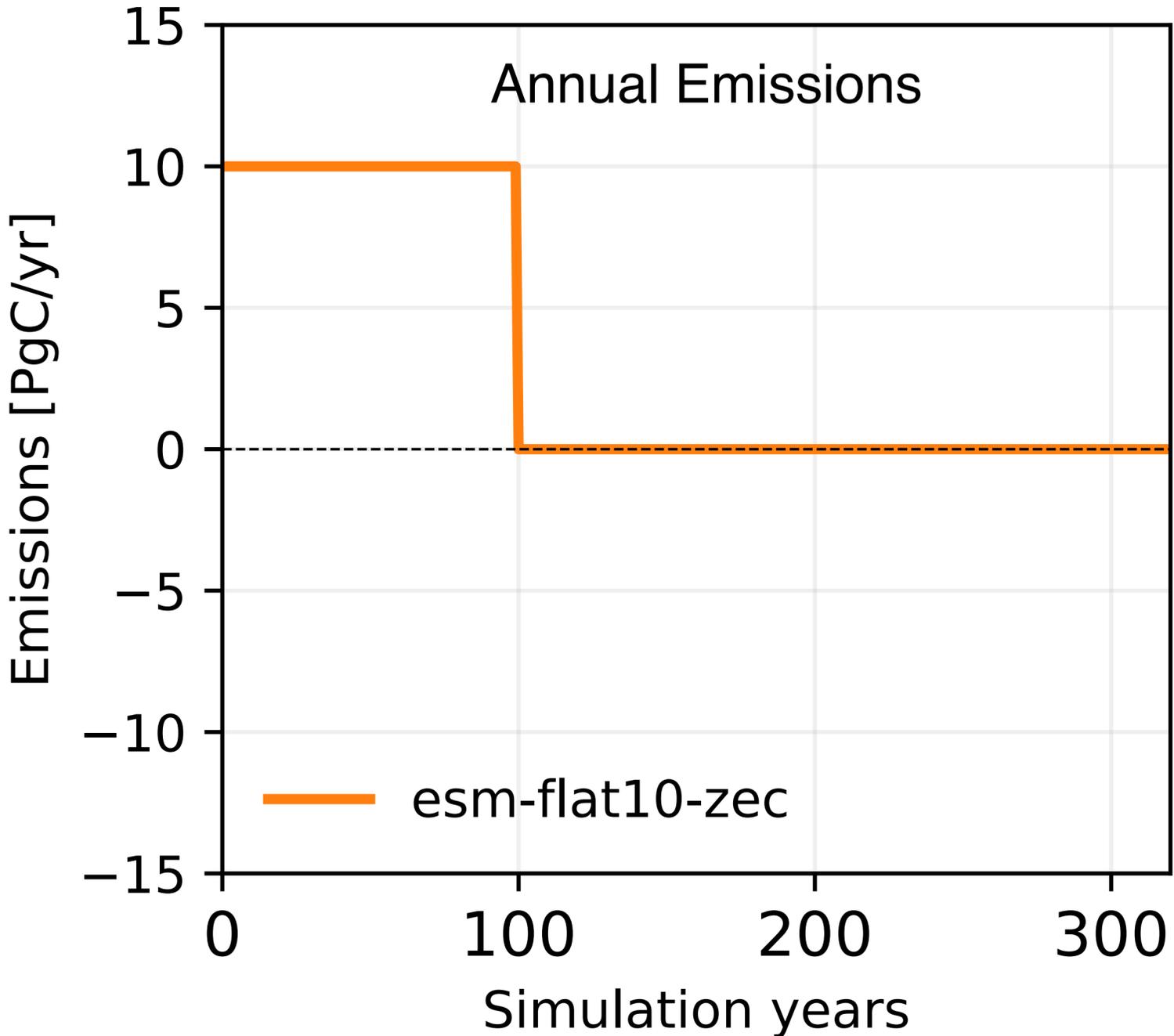


Land uptake of C depends on Biological processes



Ocean uptake of C controlled mostly by physics and chemistry

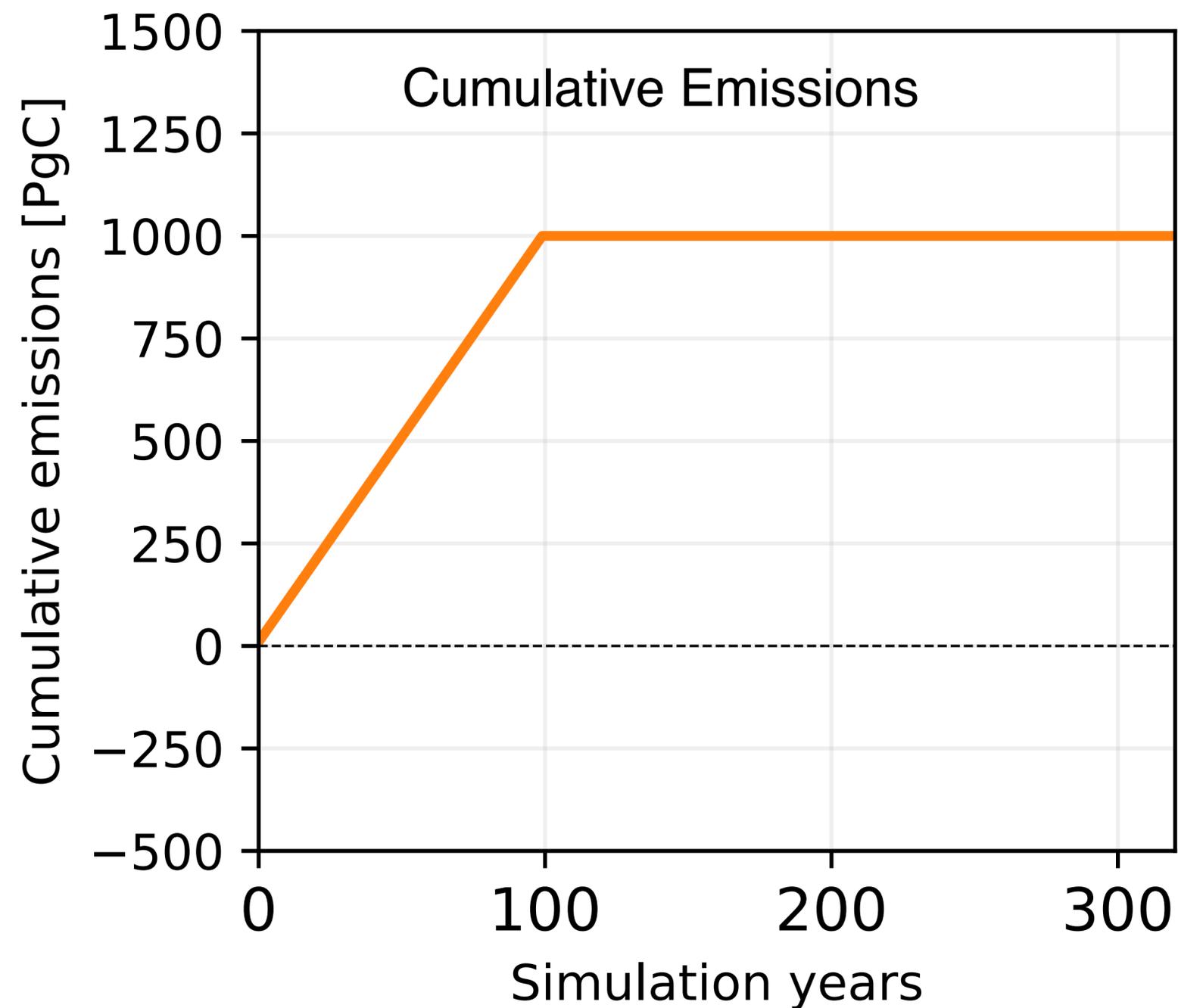
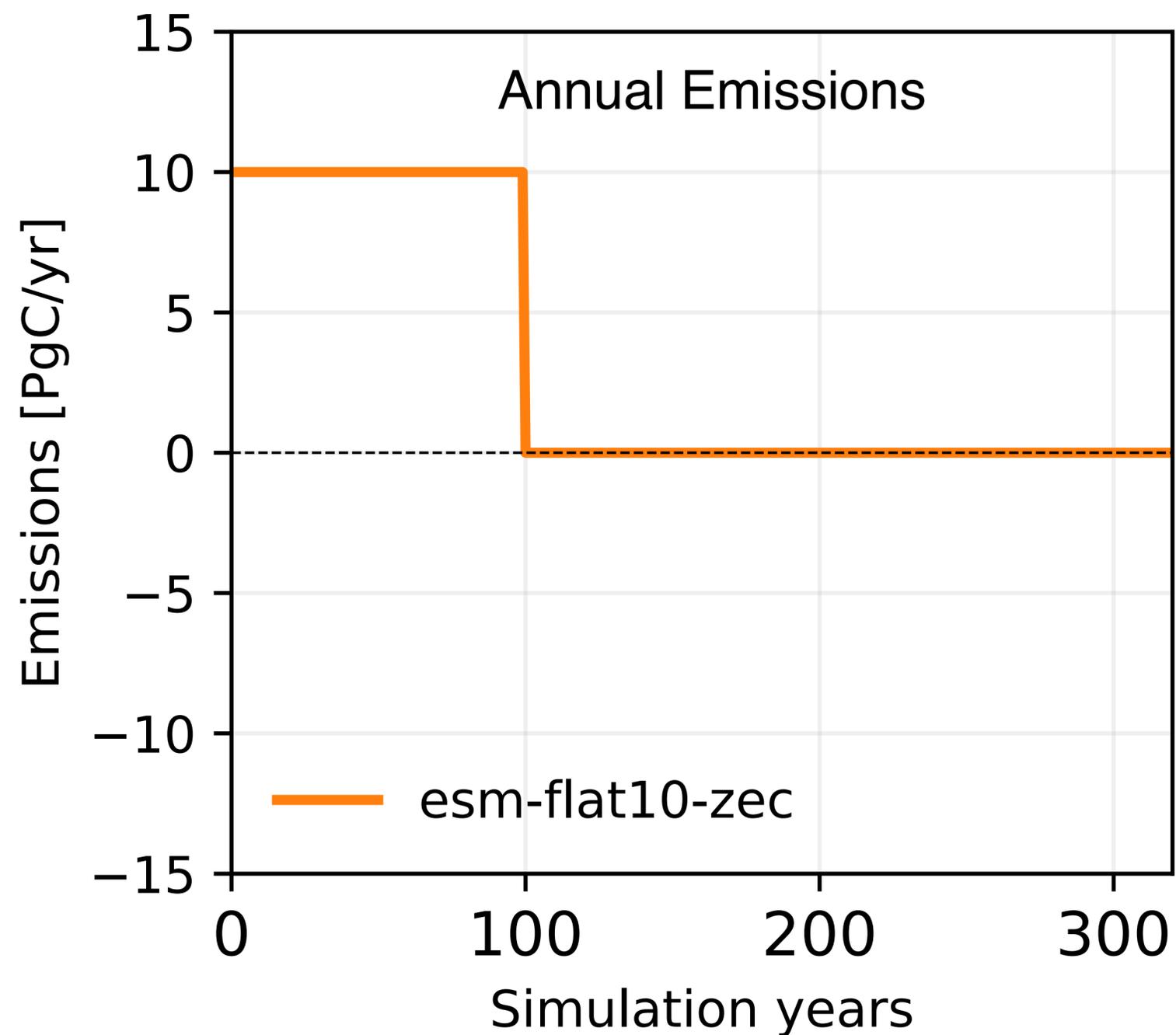
Flat 10 set of experiments \Leftarrow part of Fast Track for CMIP7



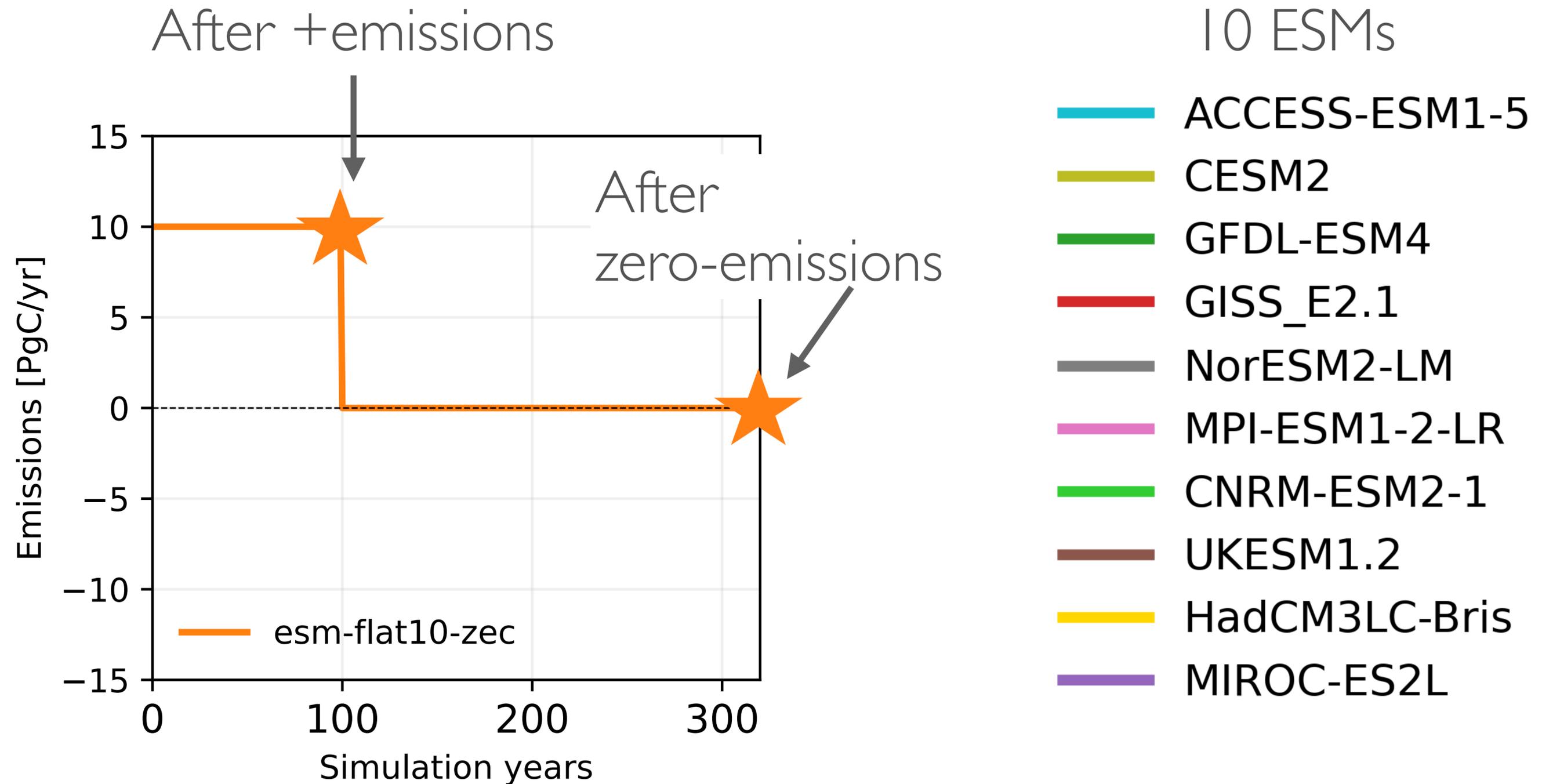
Emit 10PgC/yr for 100 years

Emissions = zero at year 100

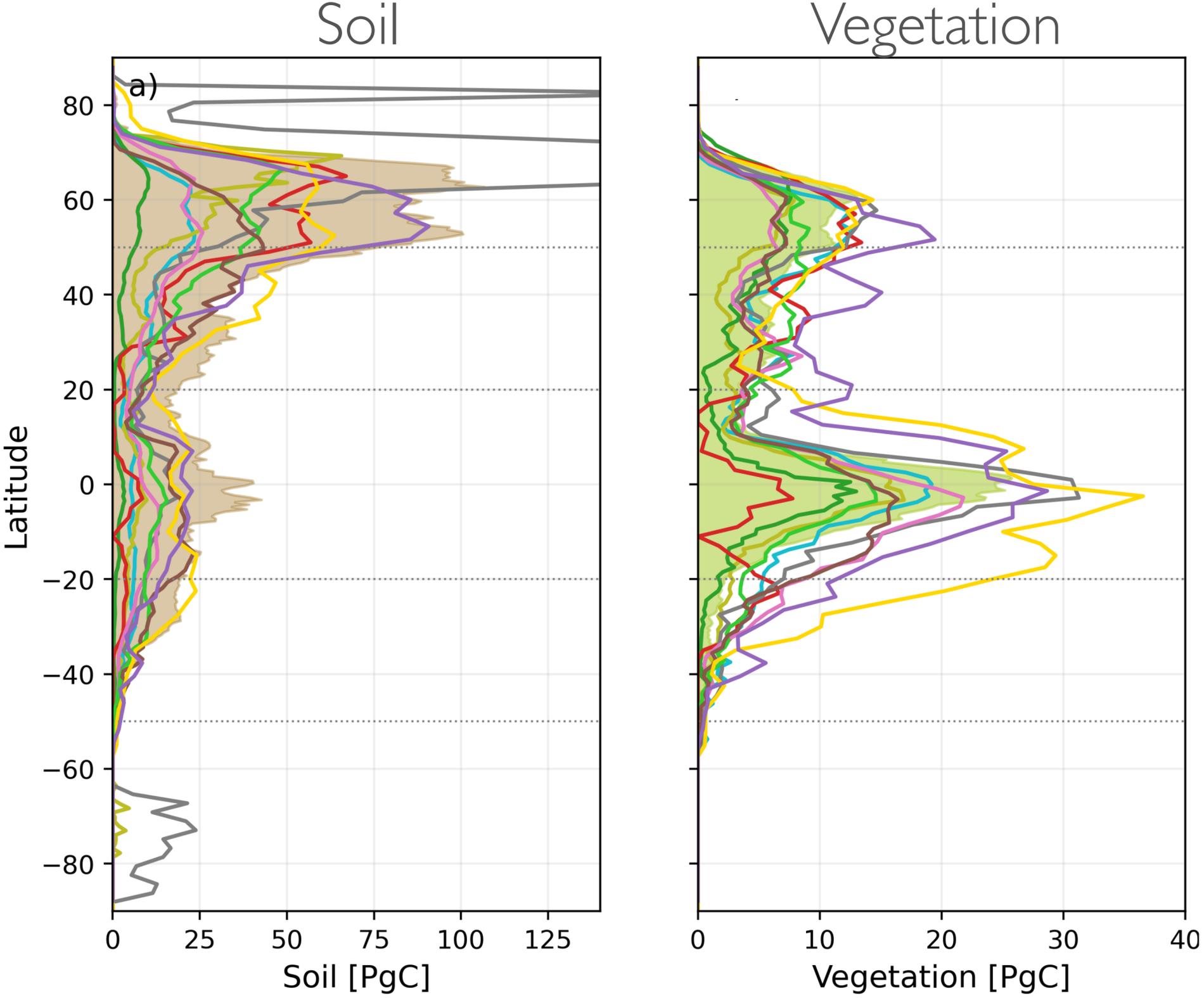
We expect temperature to look like cumulative emissions



How do land carbon pools respond to zero emissions?

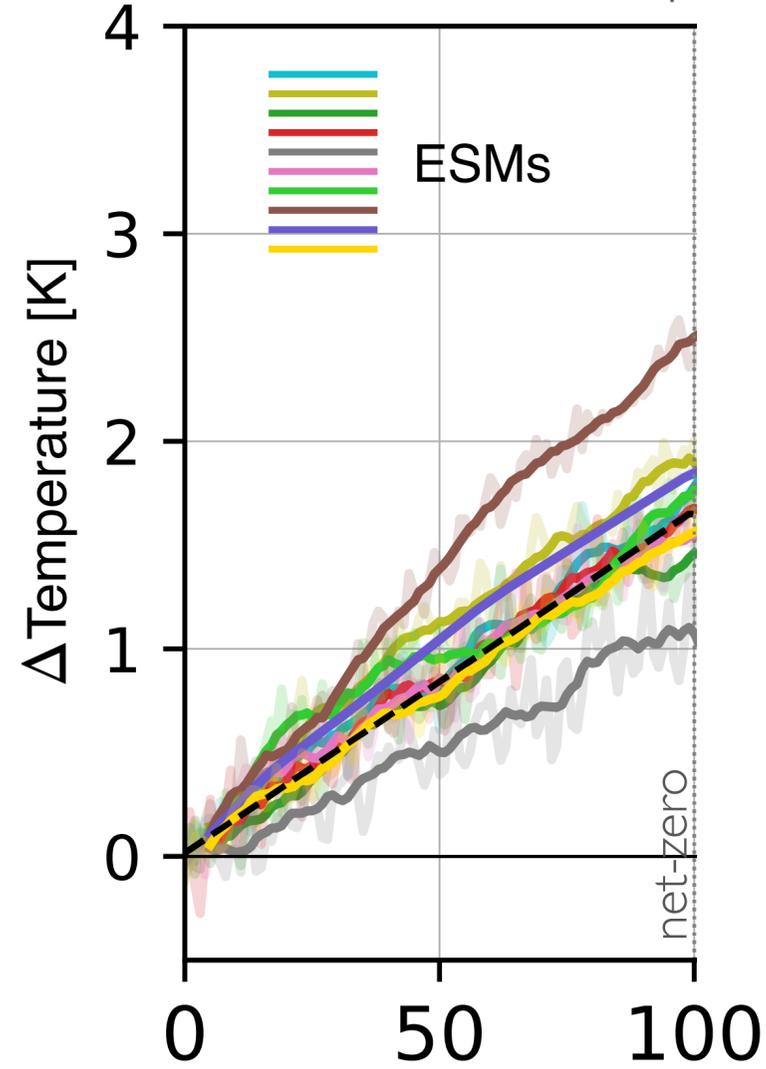


But first: Pre-Industrial carbon stocks vary a lot across models

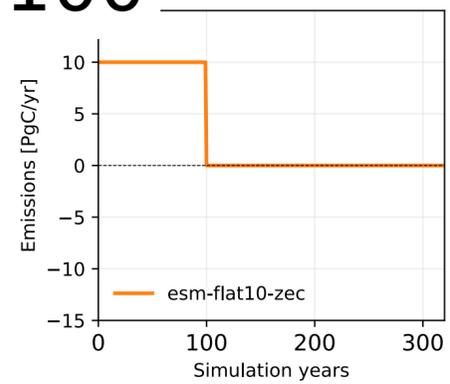
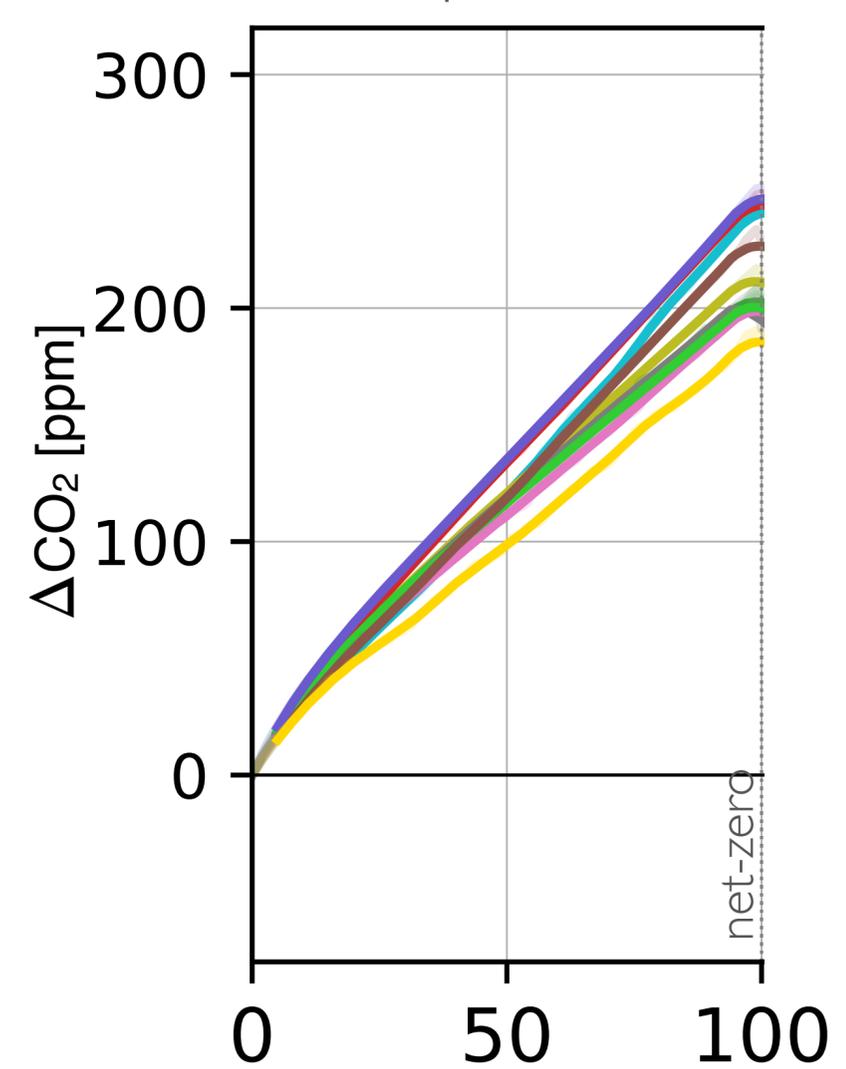


Temp \uparrow , CO₂ \uparrow \Rightarrow Land sink?

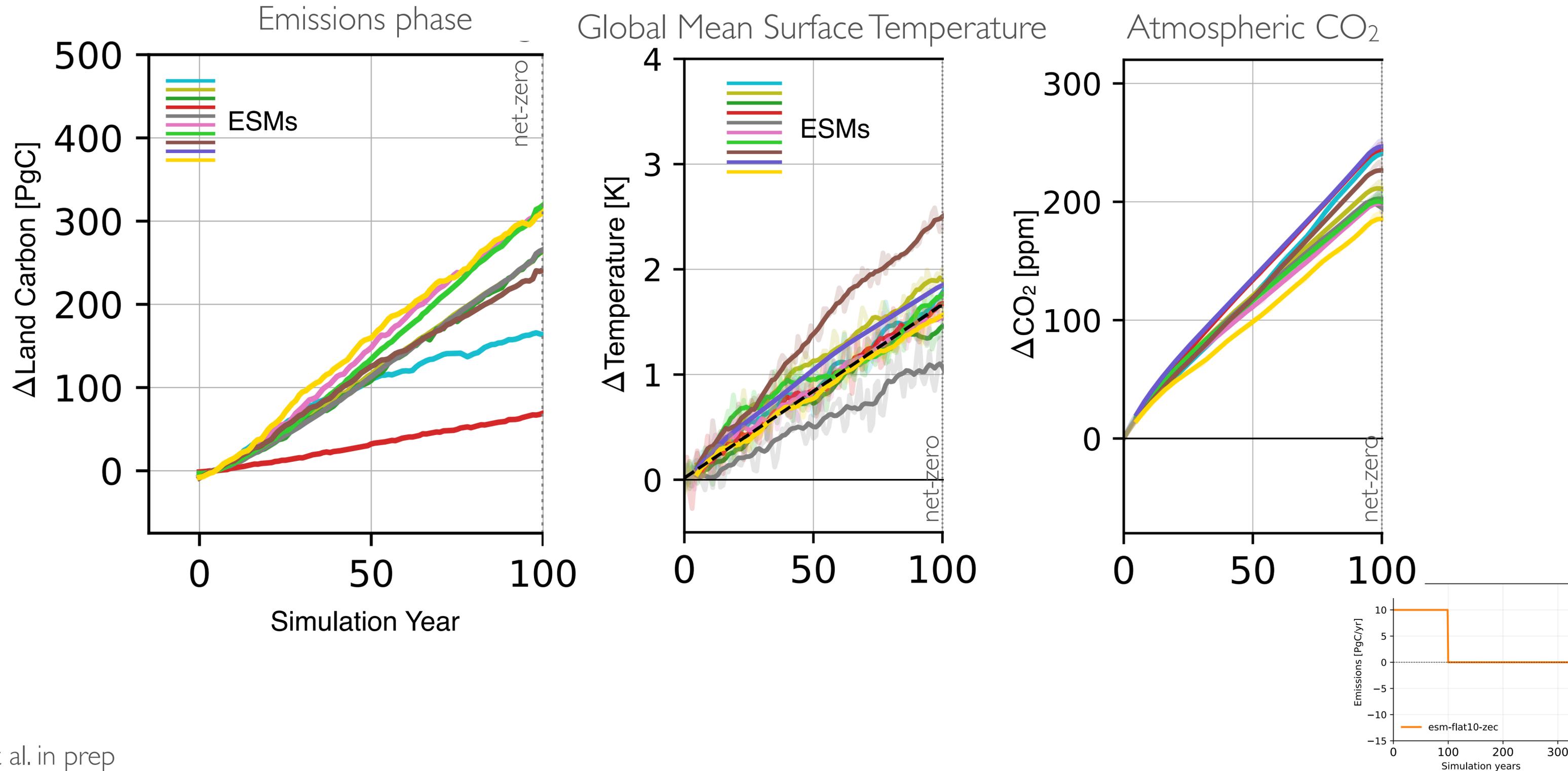
Global Mean Surface Temperature



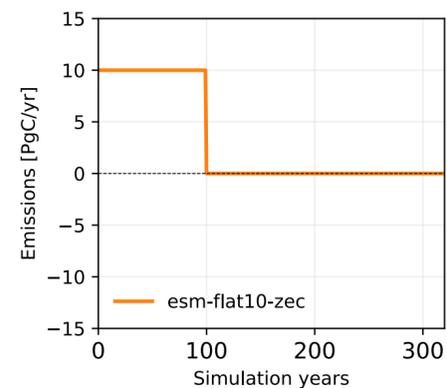
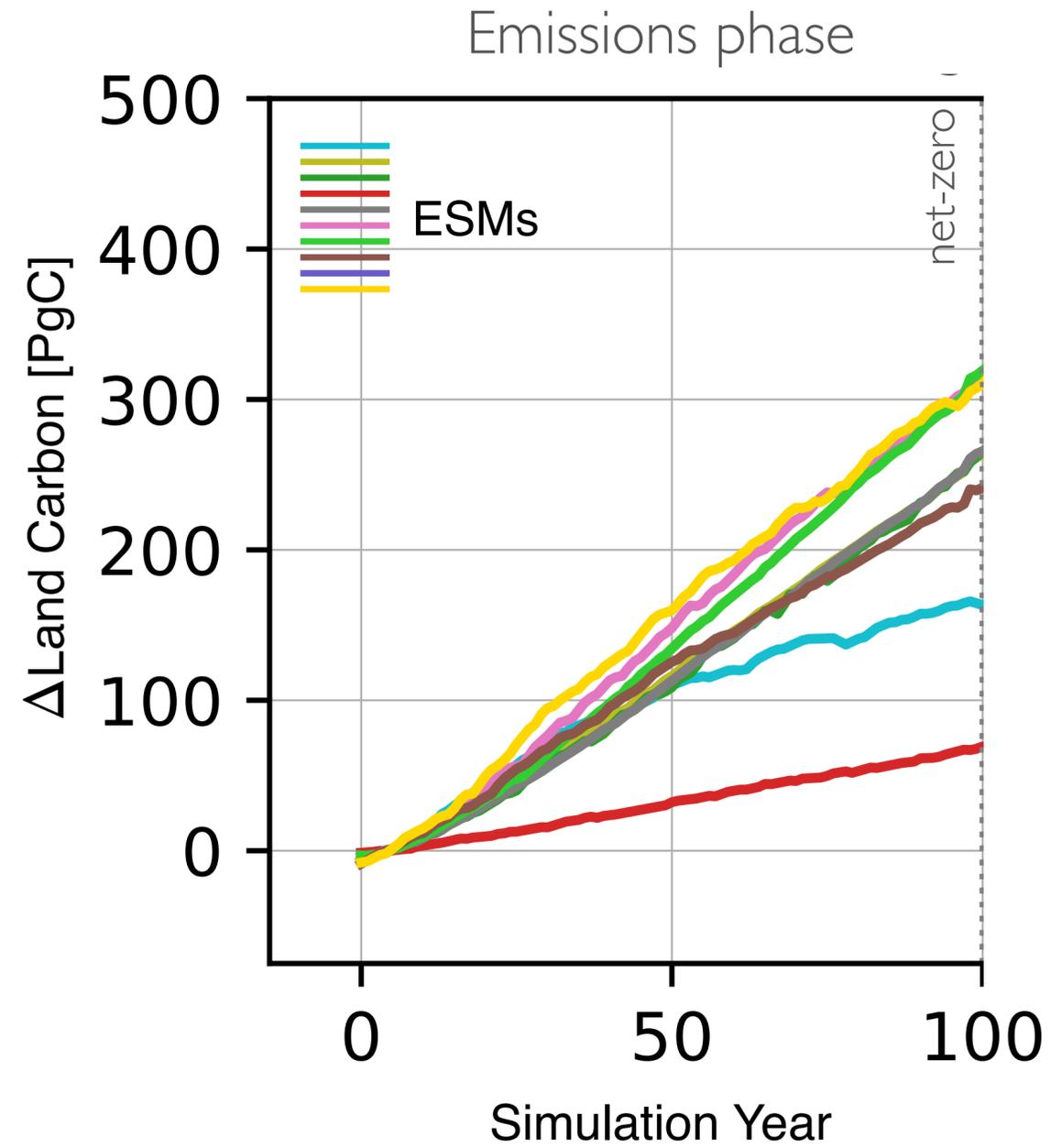
Atmospheric CO₂



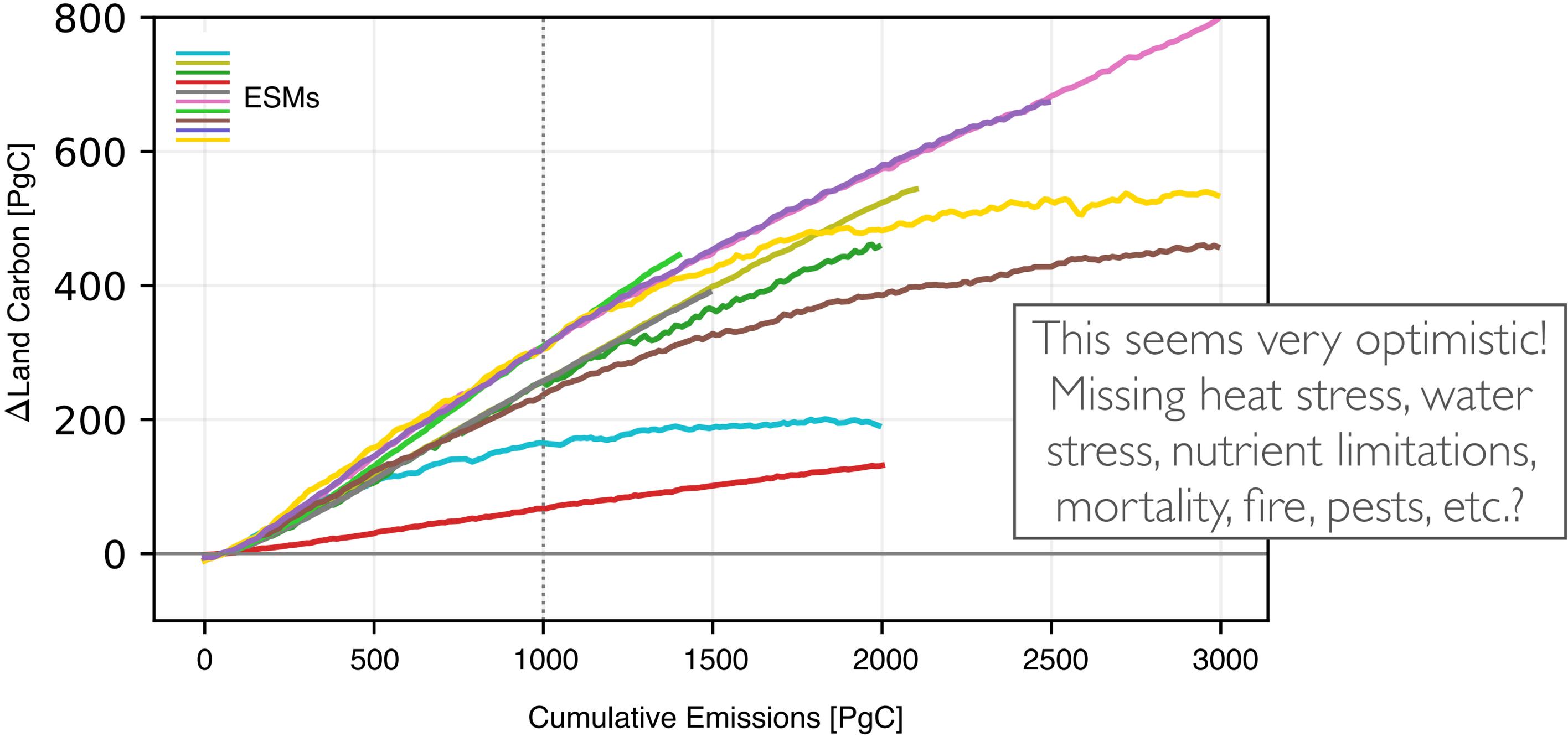
Temp \uparrow , CO₂ \uparrow \Rightarrow Land sink?



Land takes up carbon during the emissions phase



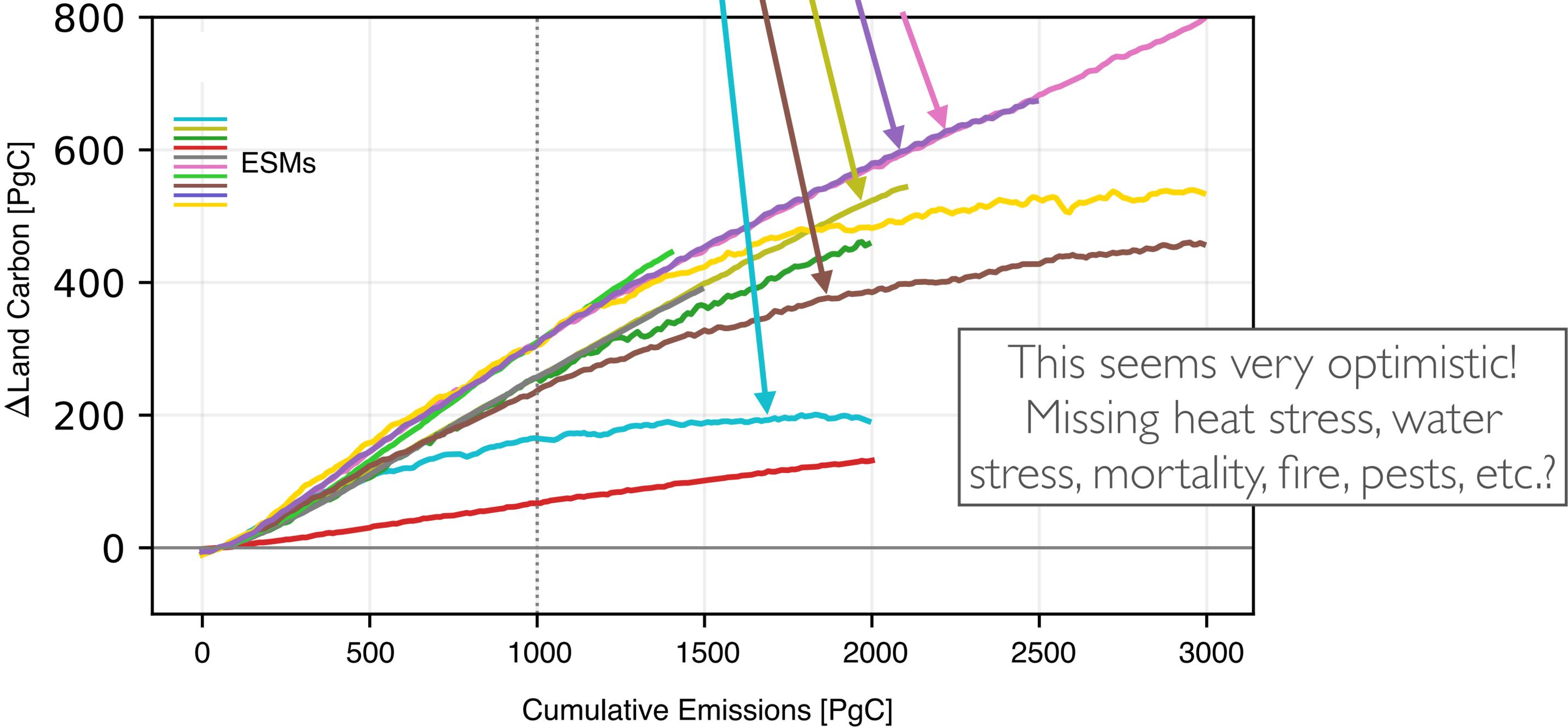
Some models start to decelerate carbon uptake with continued emissions



This seems very optimistic!
Missing heat stress, water stress, nutrient limitations, mortality, fire, pests, etc.?

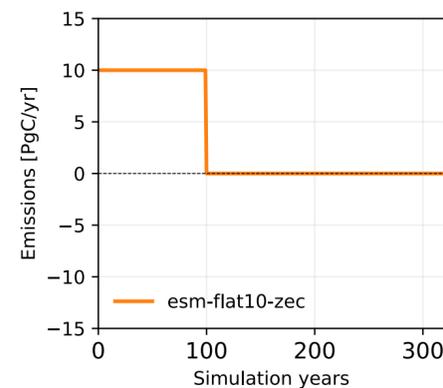
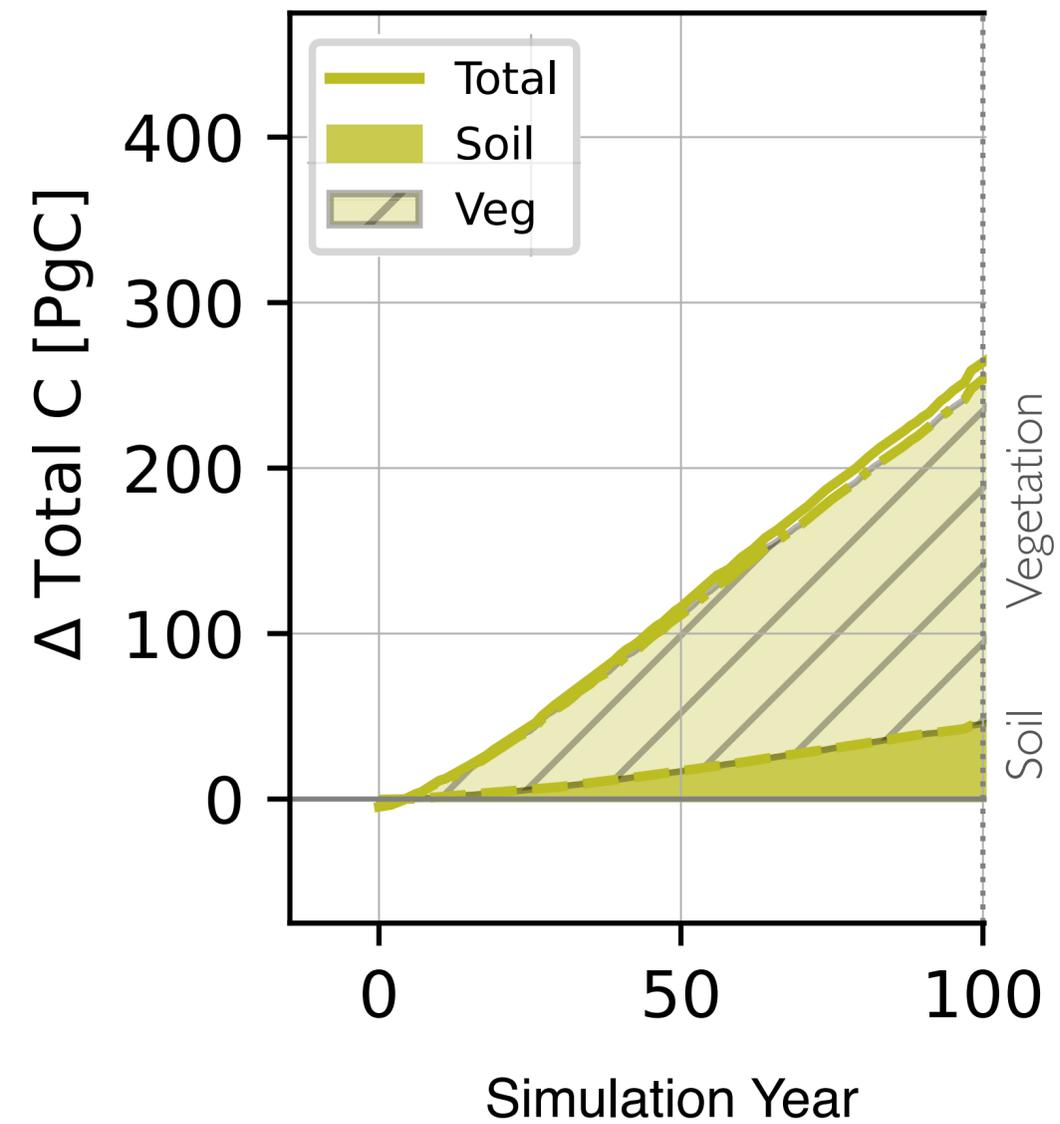
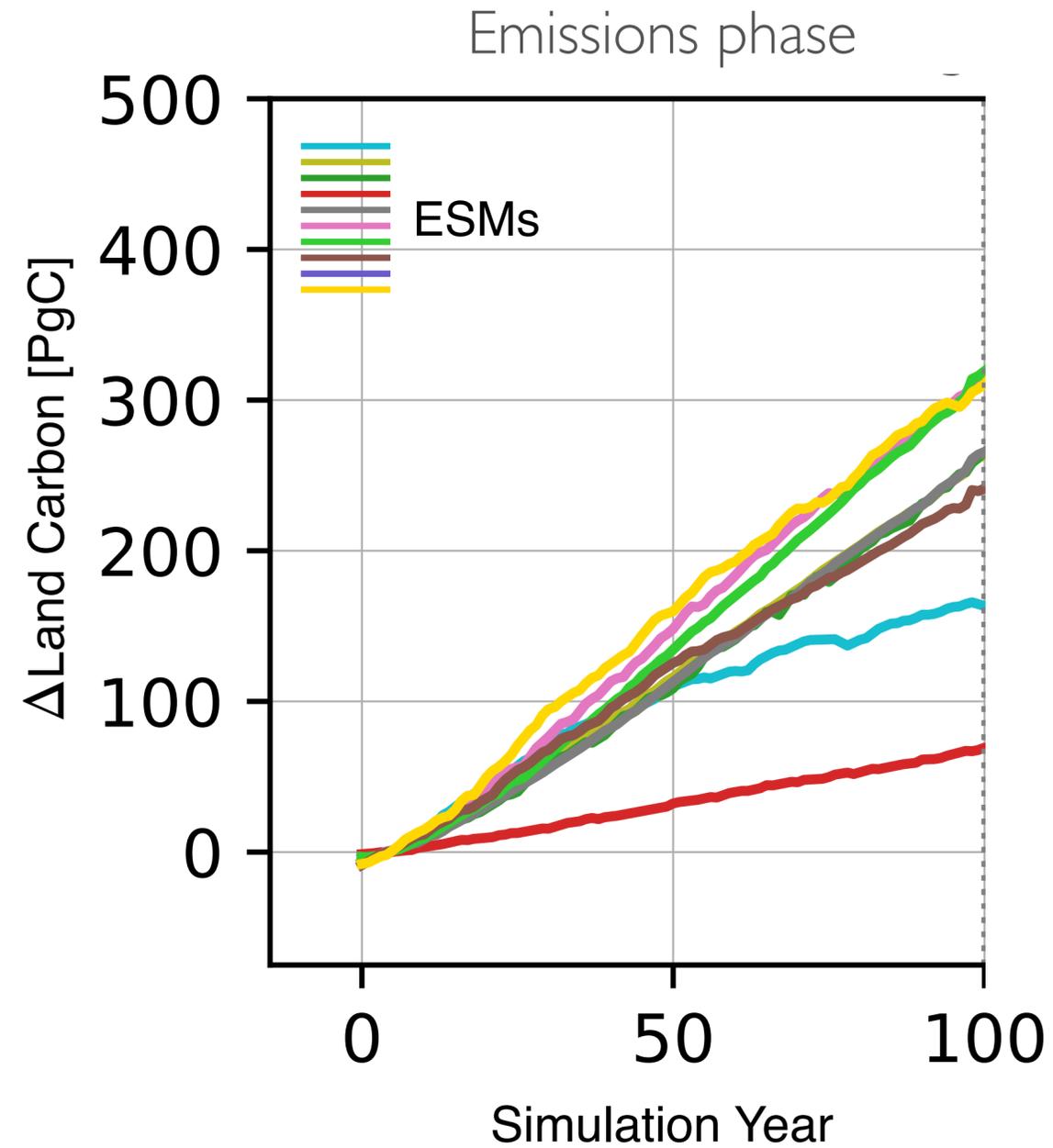
Some models start to decelerate carbon uptake with continued emissions

These models all have dynamic nutrient limitation



Land takes up carbon during the emissions phase

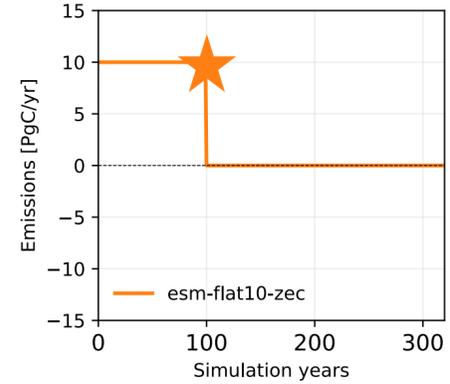
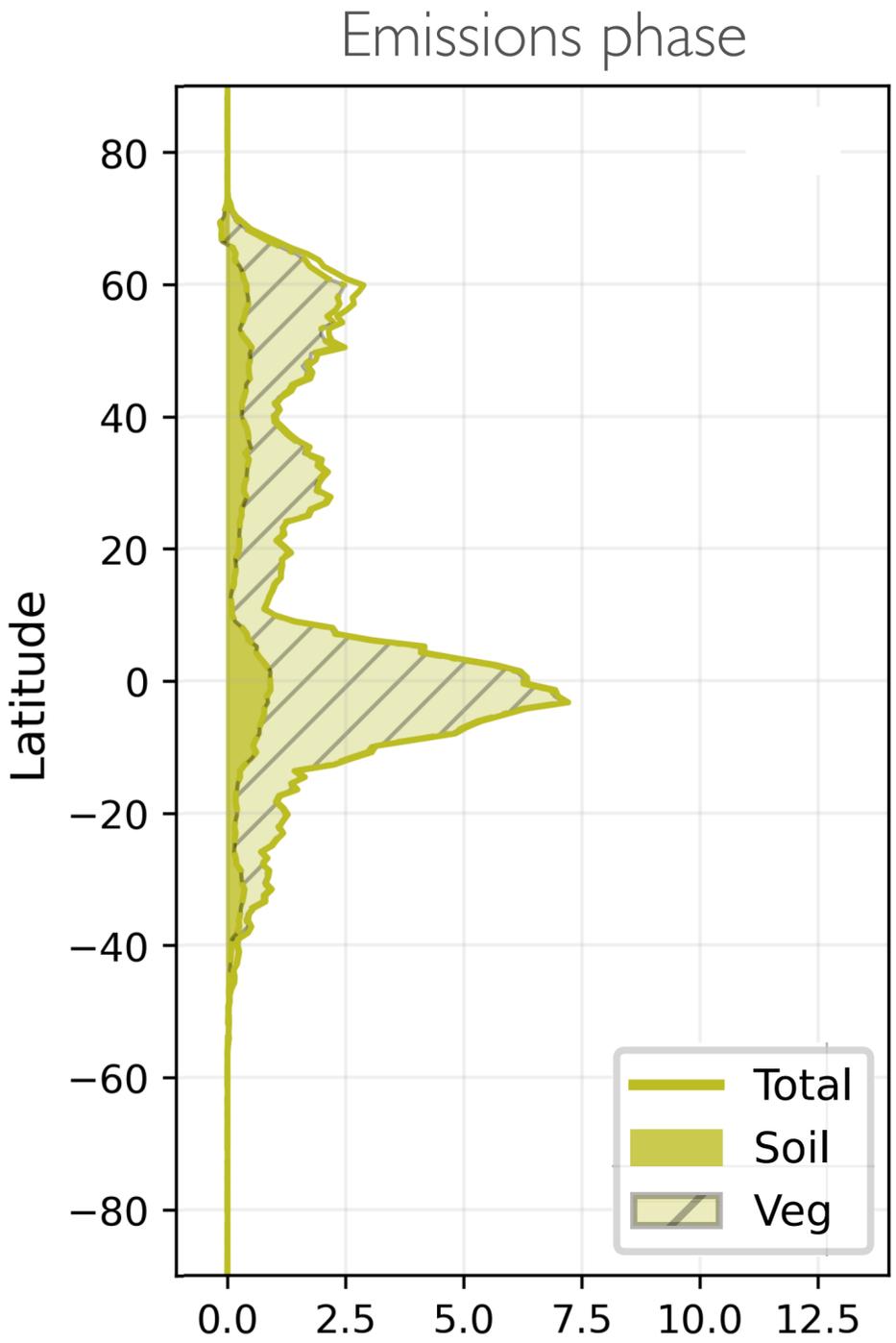
Mostly in vegetation



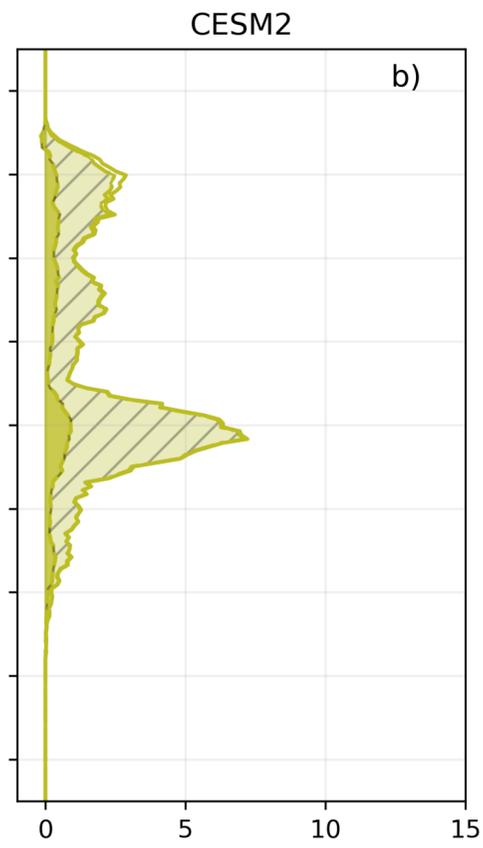
Land sink increases when temperature and CO₂ are rising

Carbon gained in mid+high latitudes

Tropical carbon gain all in vegetation

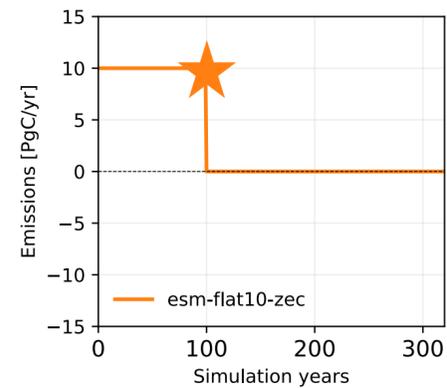


Emissions phase



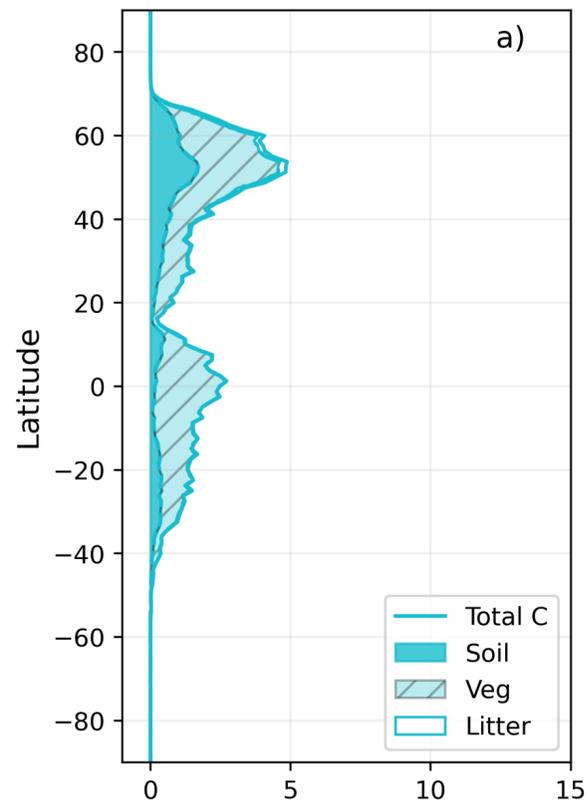
Carbon
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Tropical
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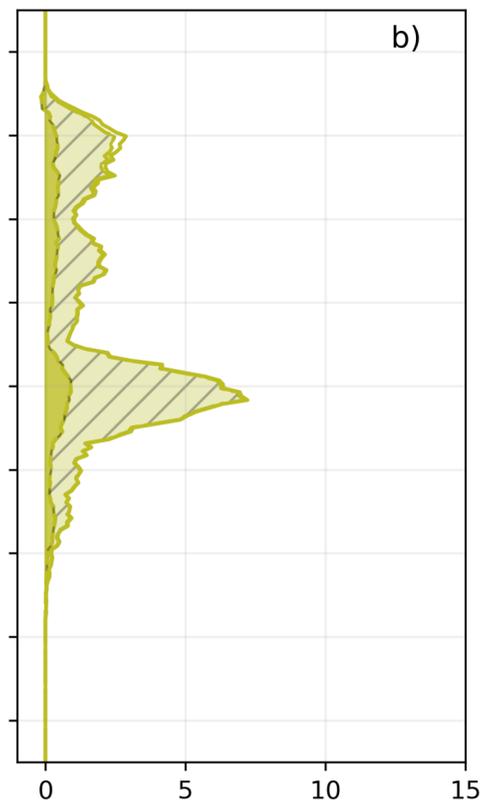


Emissions phase

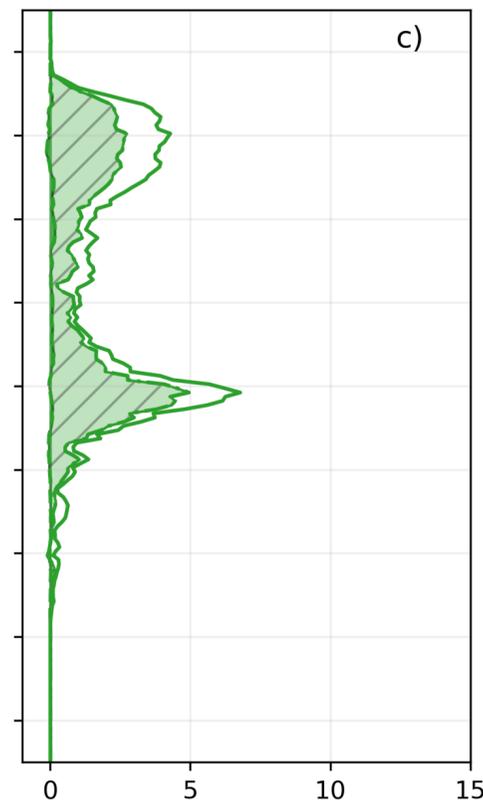
ACCESS-ESM1-5



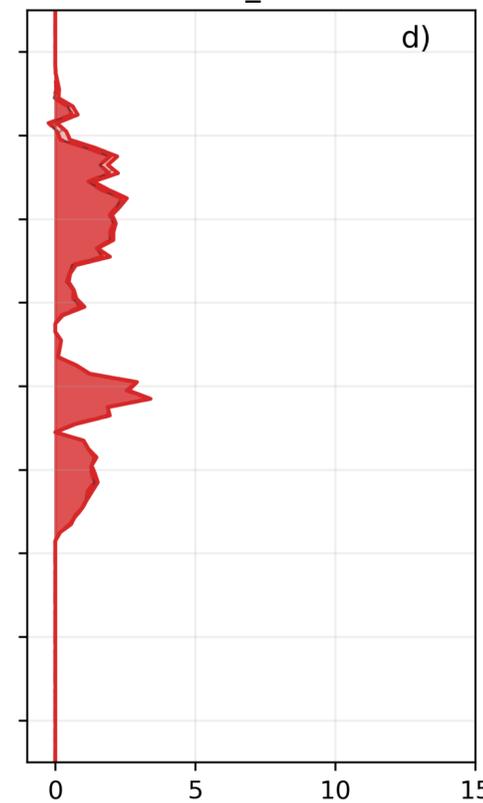
CESM2



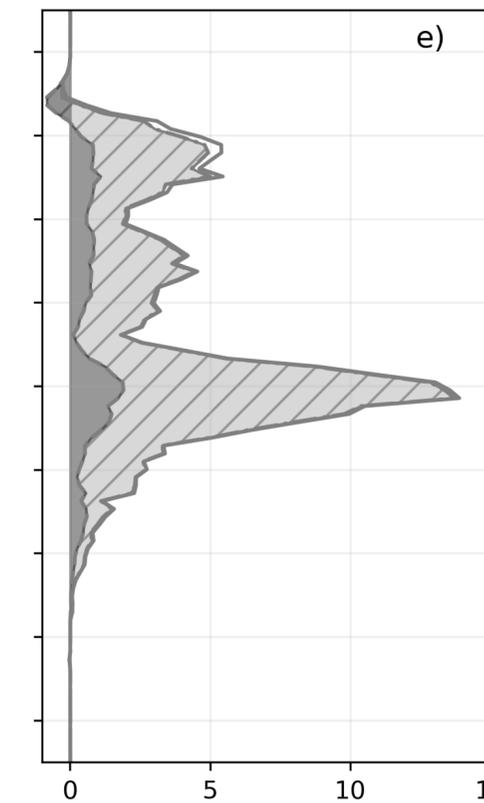
GFDL-ESM4



GISS_E2.1

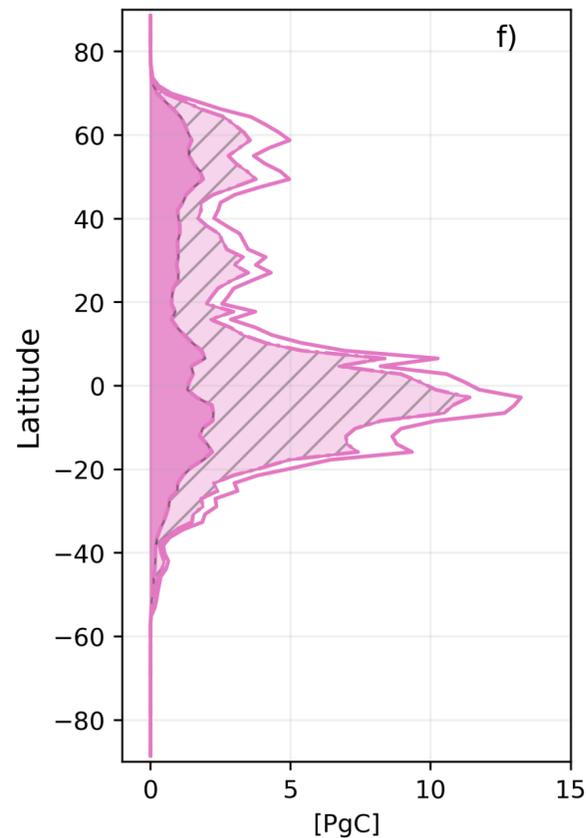


NorESM2-LM

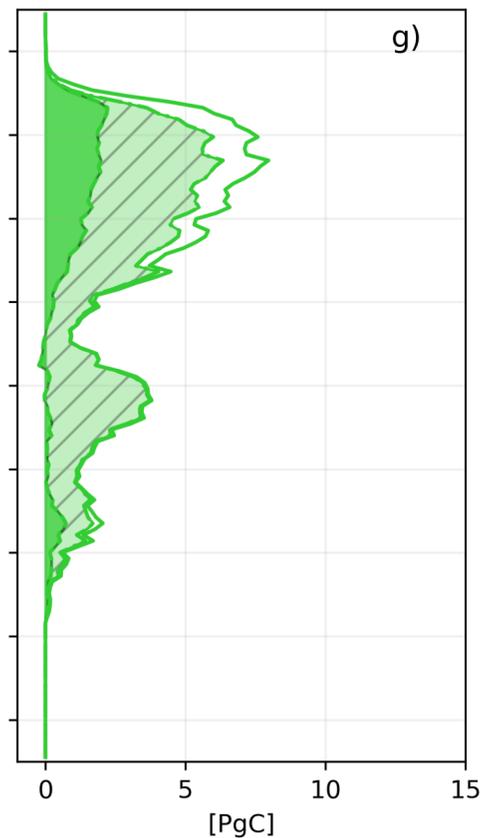


Carbon gained in mid+high latitudes

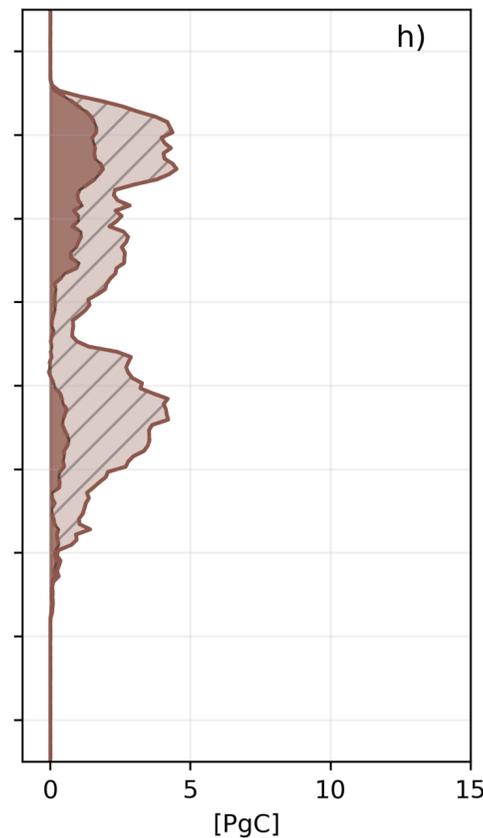
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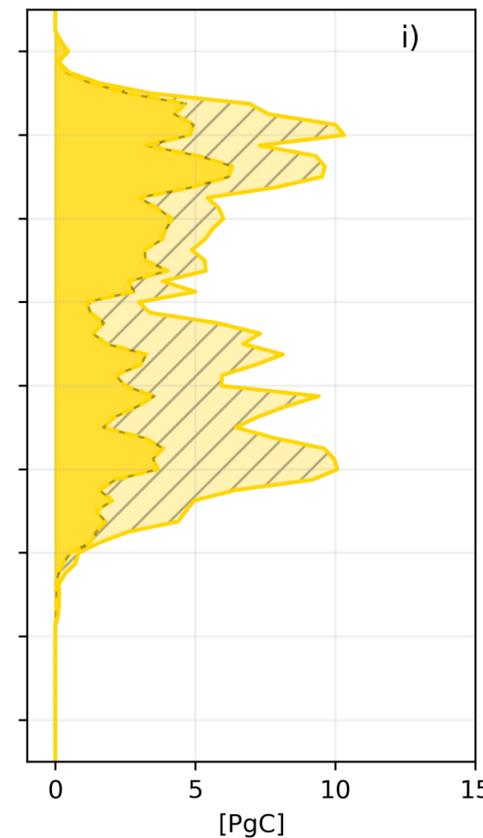
CNRM-ESM2-1



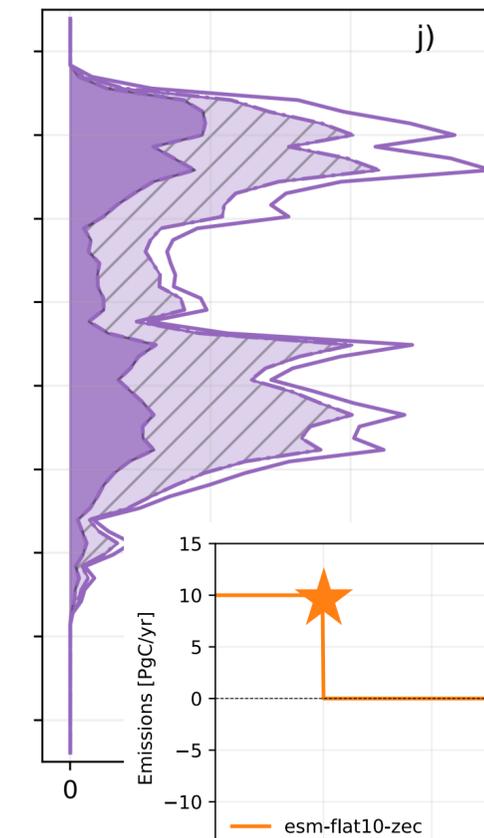
UKESM1.2



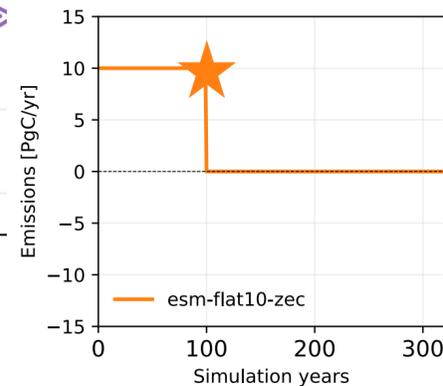
HadCM3LC-Bris



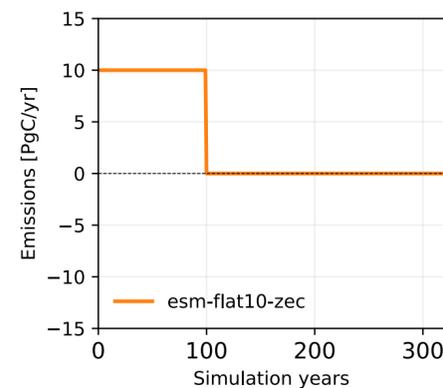
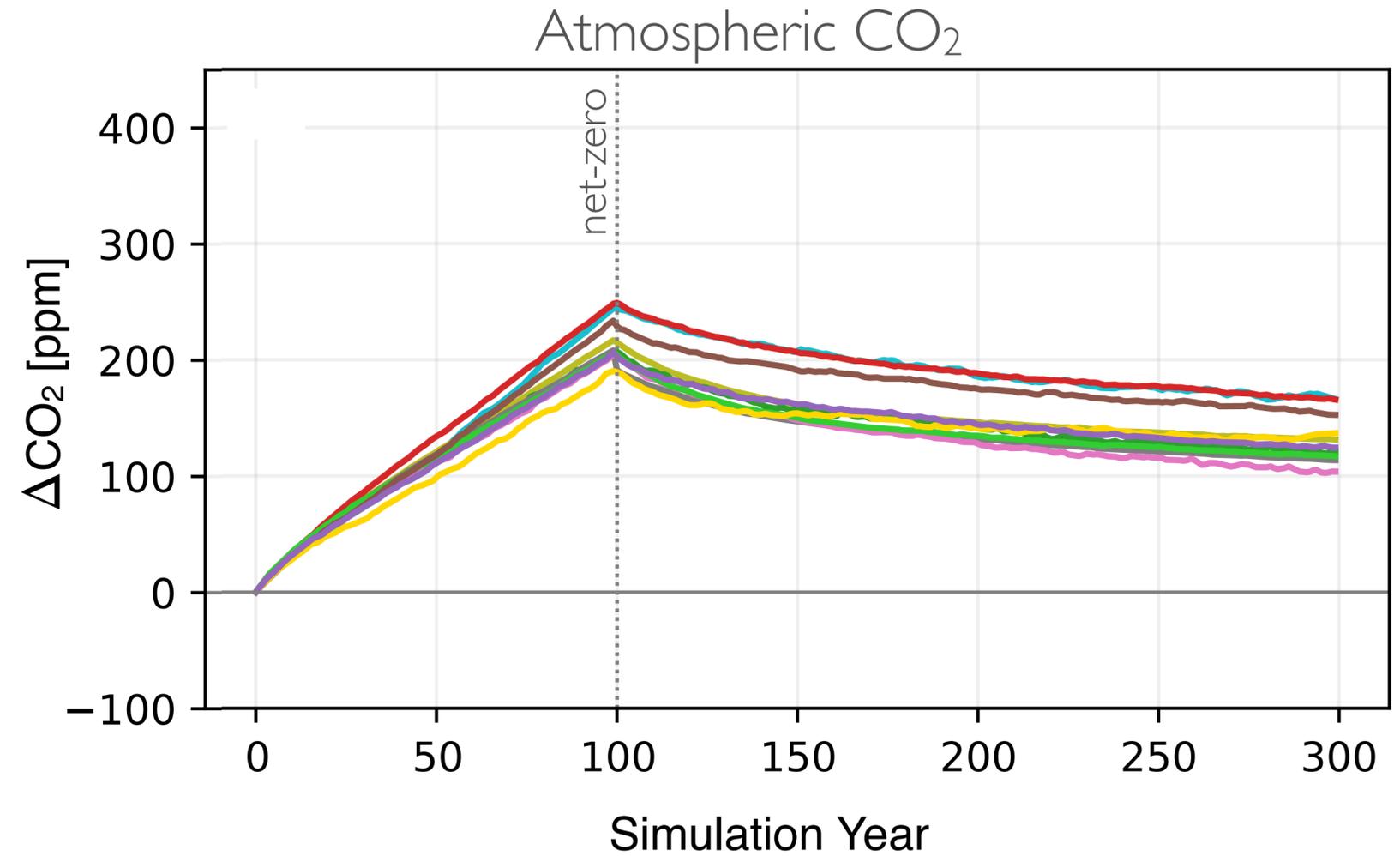
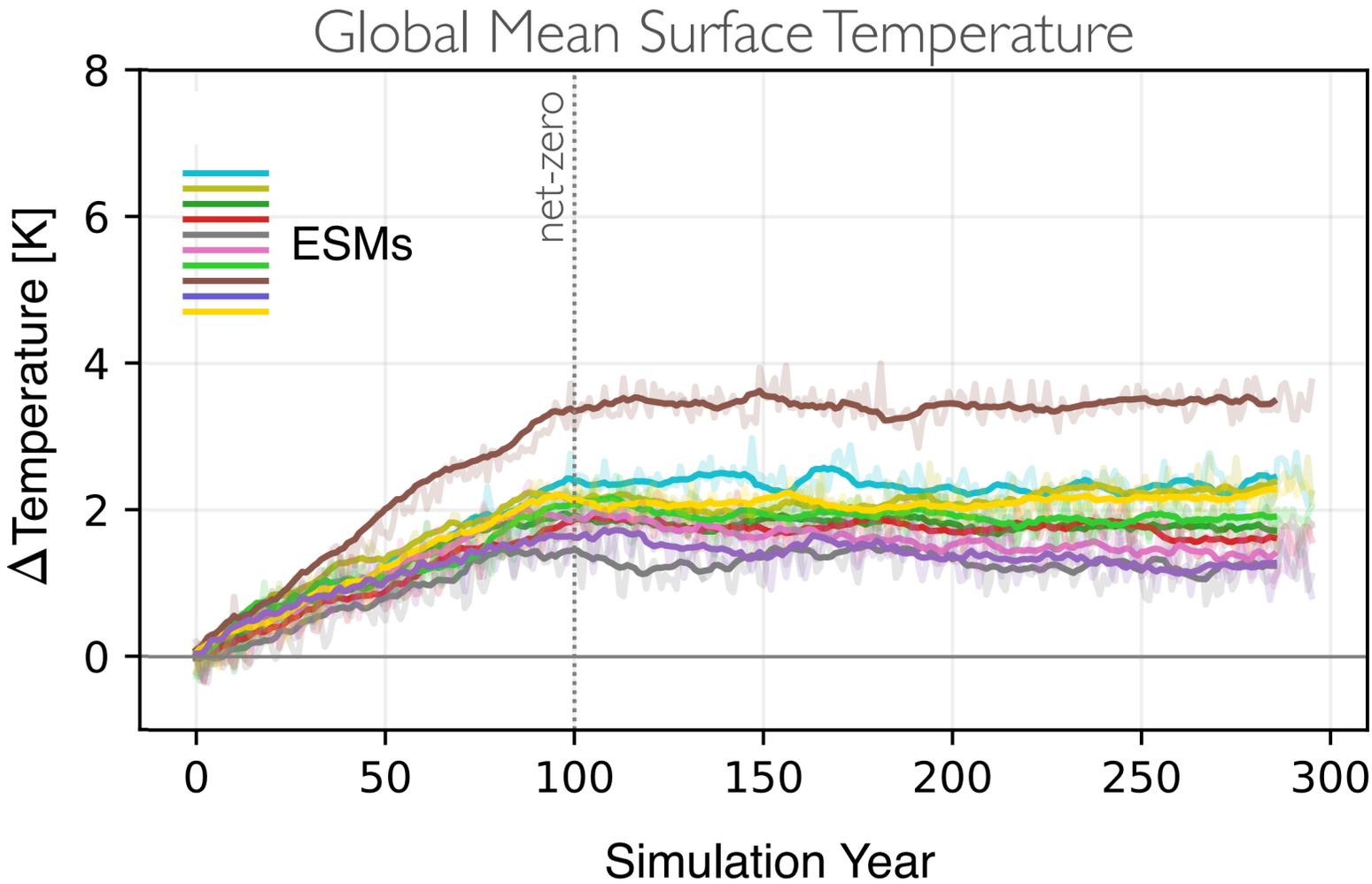
MIROC-ES2L



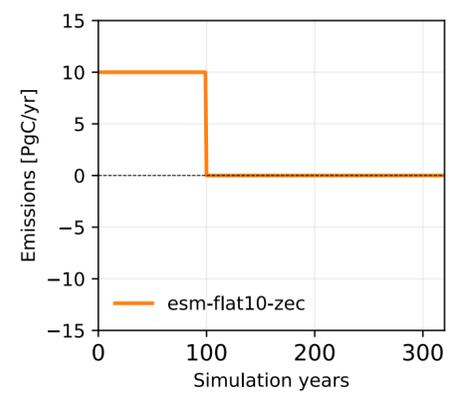
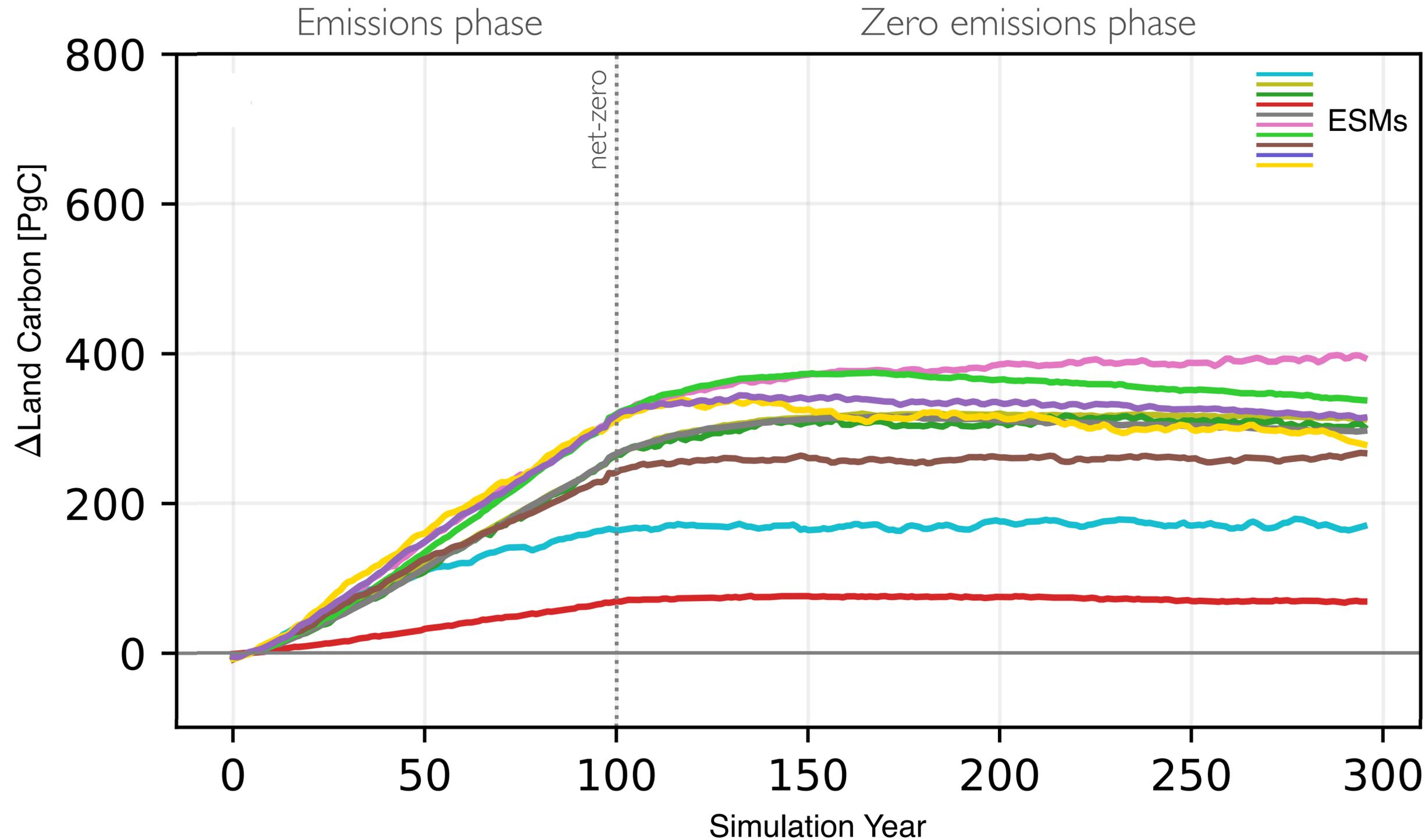
Tropical carbon gain mostly in vegetation



Hot Temp , high CO₂ ⇒ Land sink?

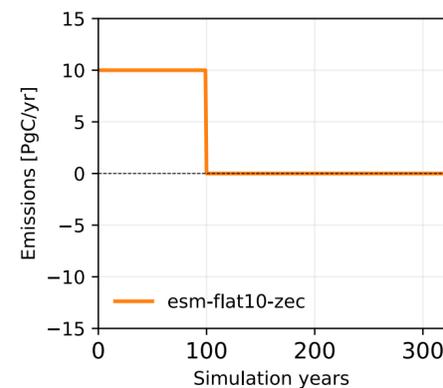
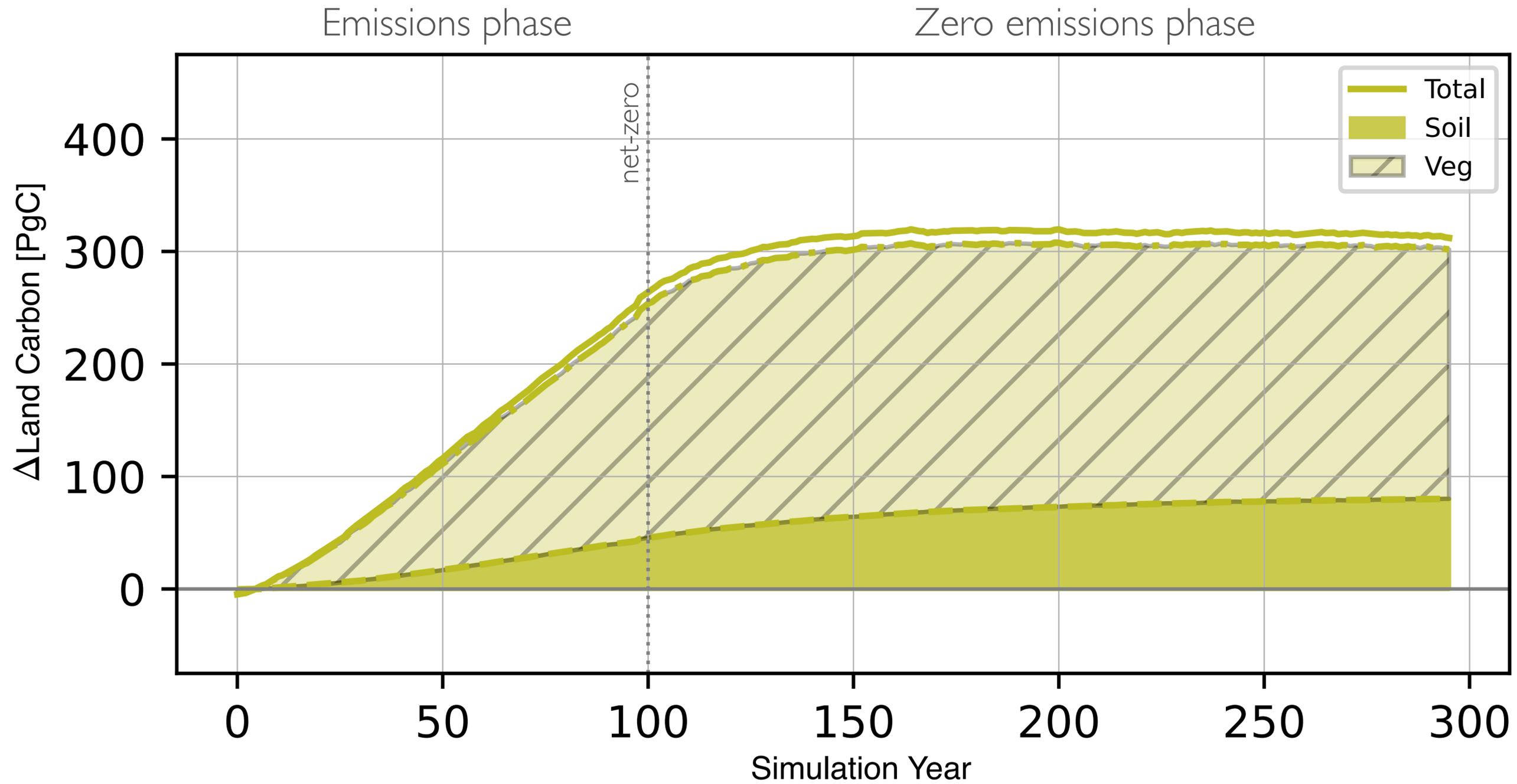


Global land carbon doesn't change much during zero emissions



But more is changing than total land carbon!

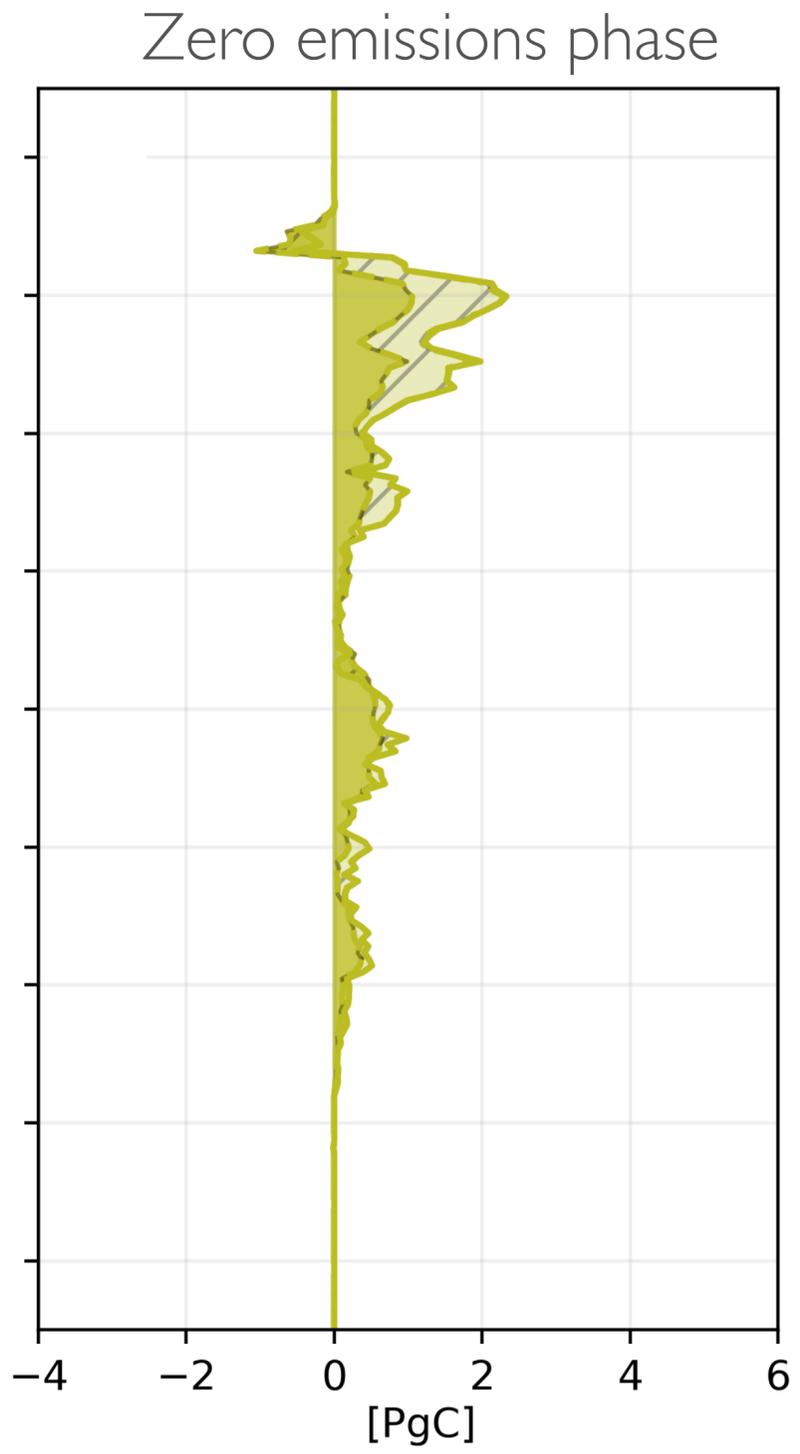
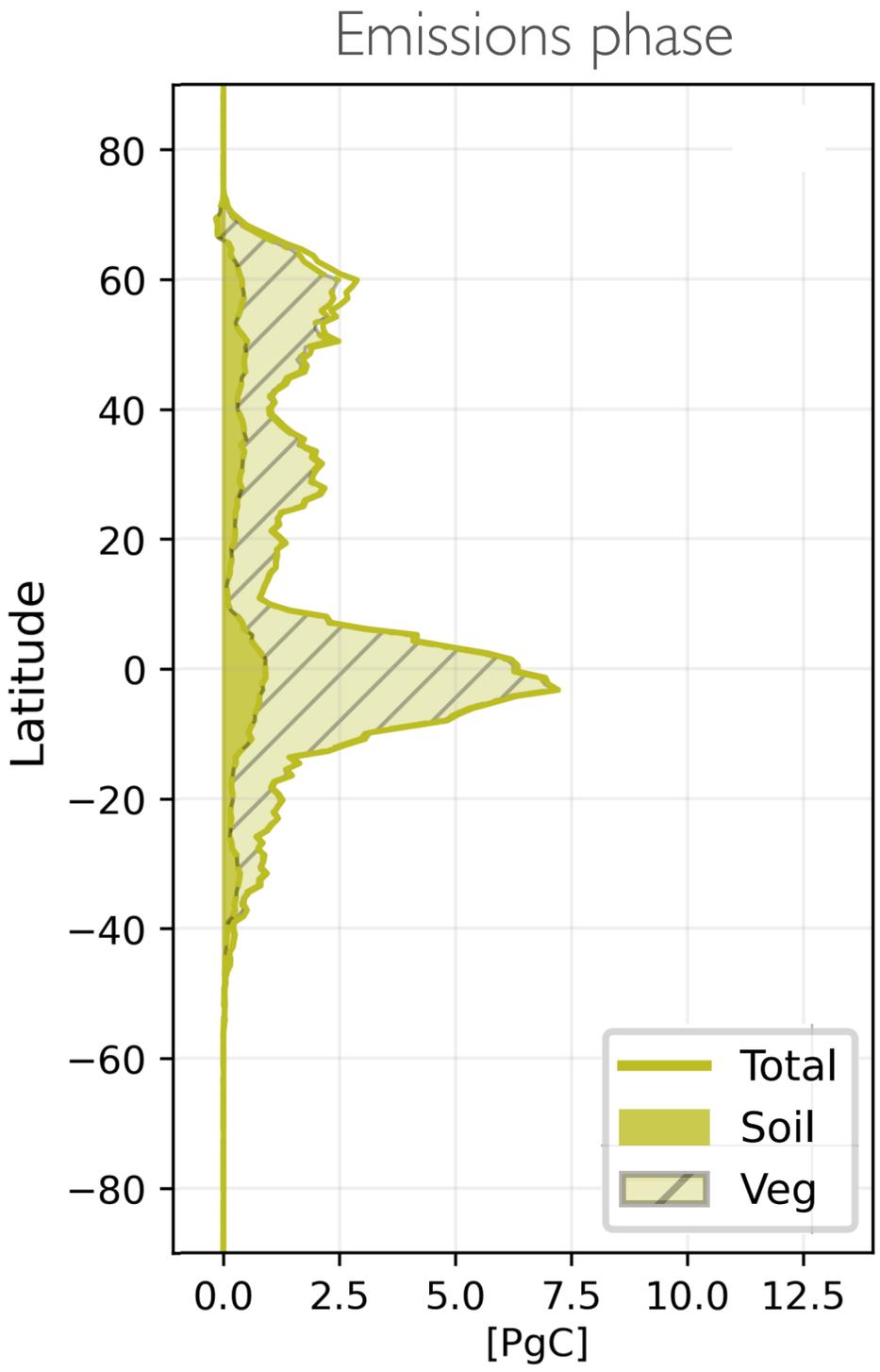
Vegetation takes up most of the extra carbon, but declines under zero emissions



Land sink → source in the tropics when temp is high and CO₂ is dropping

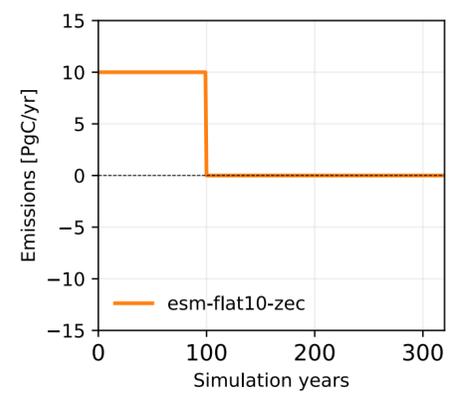
Carbon gained in mid+high latitudes

Tropical carbon gain all in vegetation



Carbon gained in mid+high latitudes

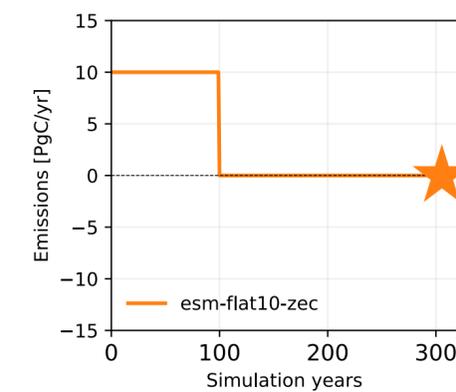
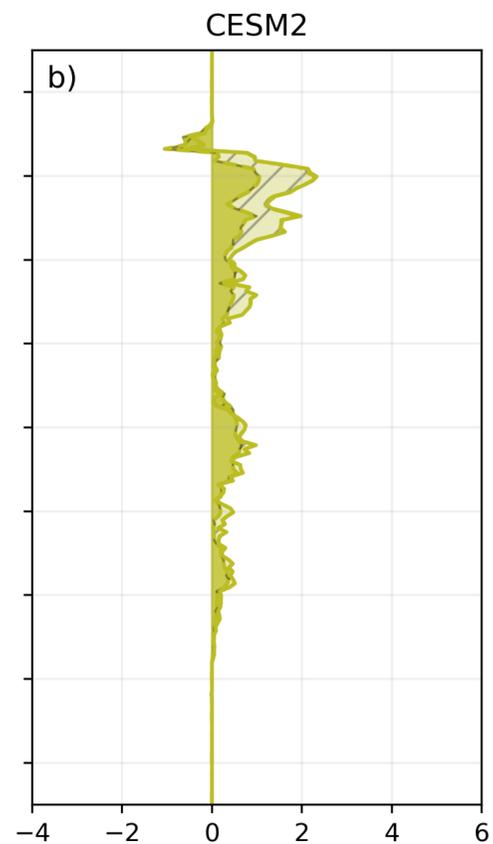
Tropical carbon neutral or lost



Zero emissions

Carbon
gained in
mid+high
latitudes soils

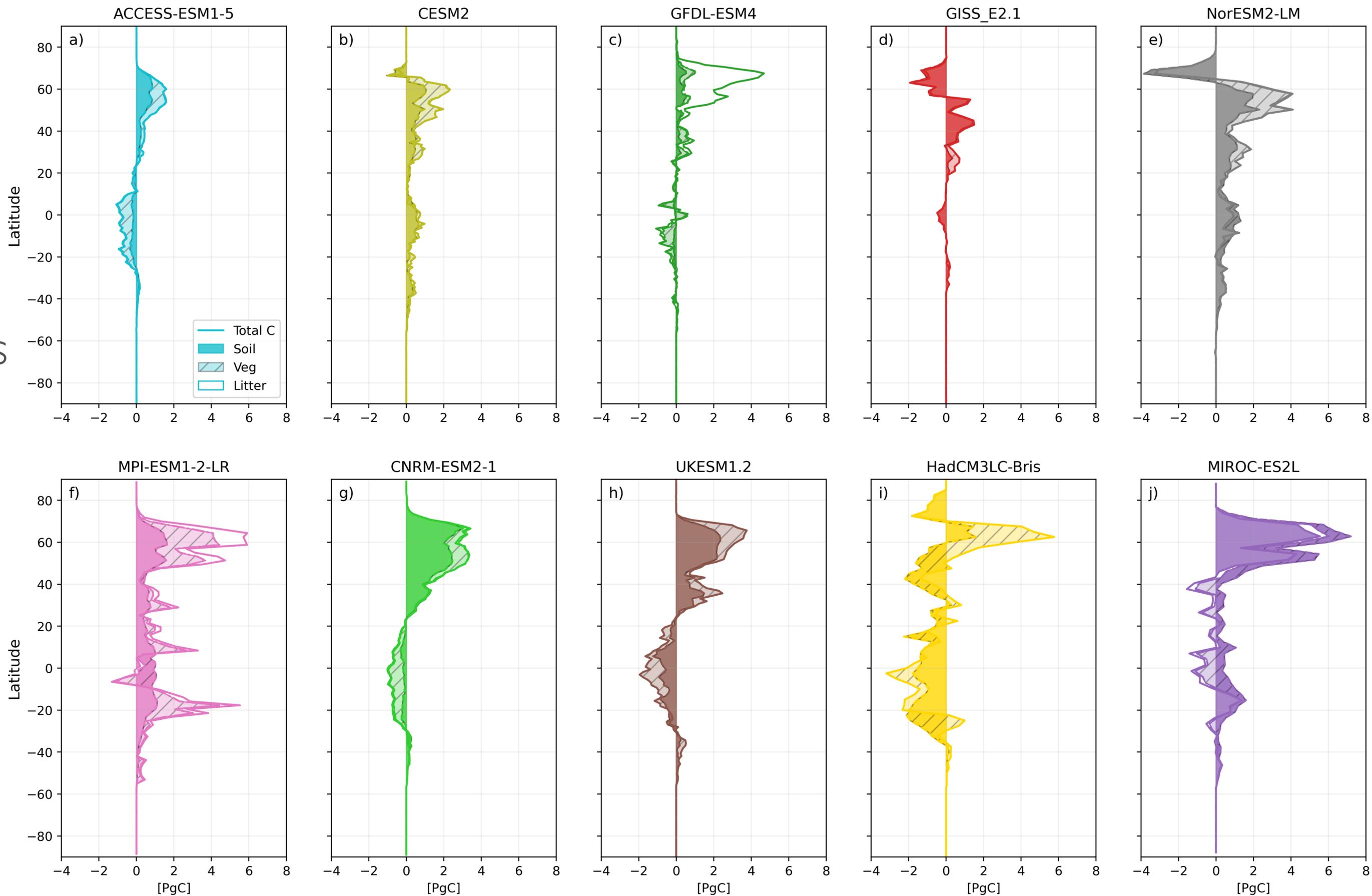
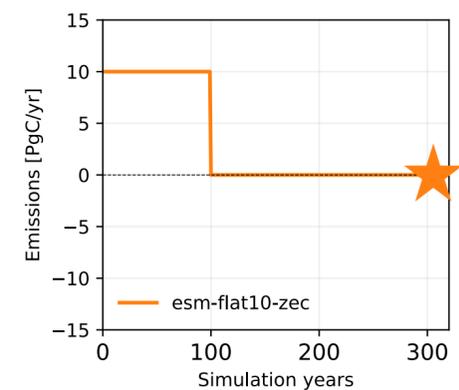
Tropical
carbon lost



Zero emissions

Carbon gained in mid+high latitudes soils

Tropical carbon lost

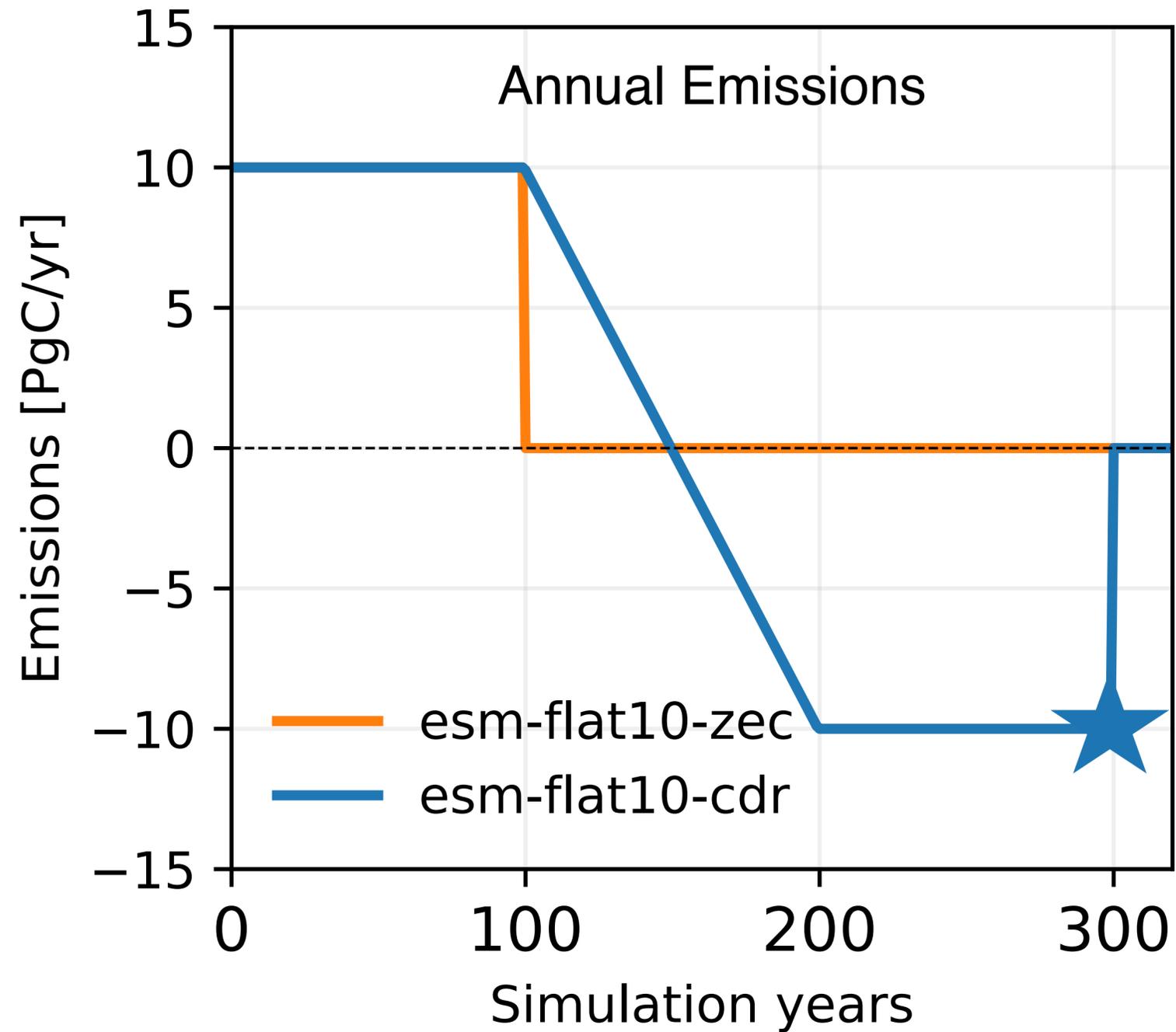


ESMs: land takes up carbon while CO₂ is rising,

but tropical sinks \Rightarrow sources under hot
conditions with declining CO₂

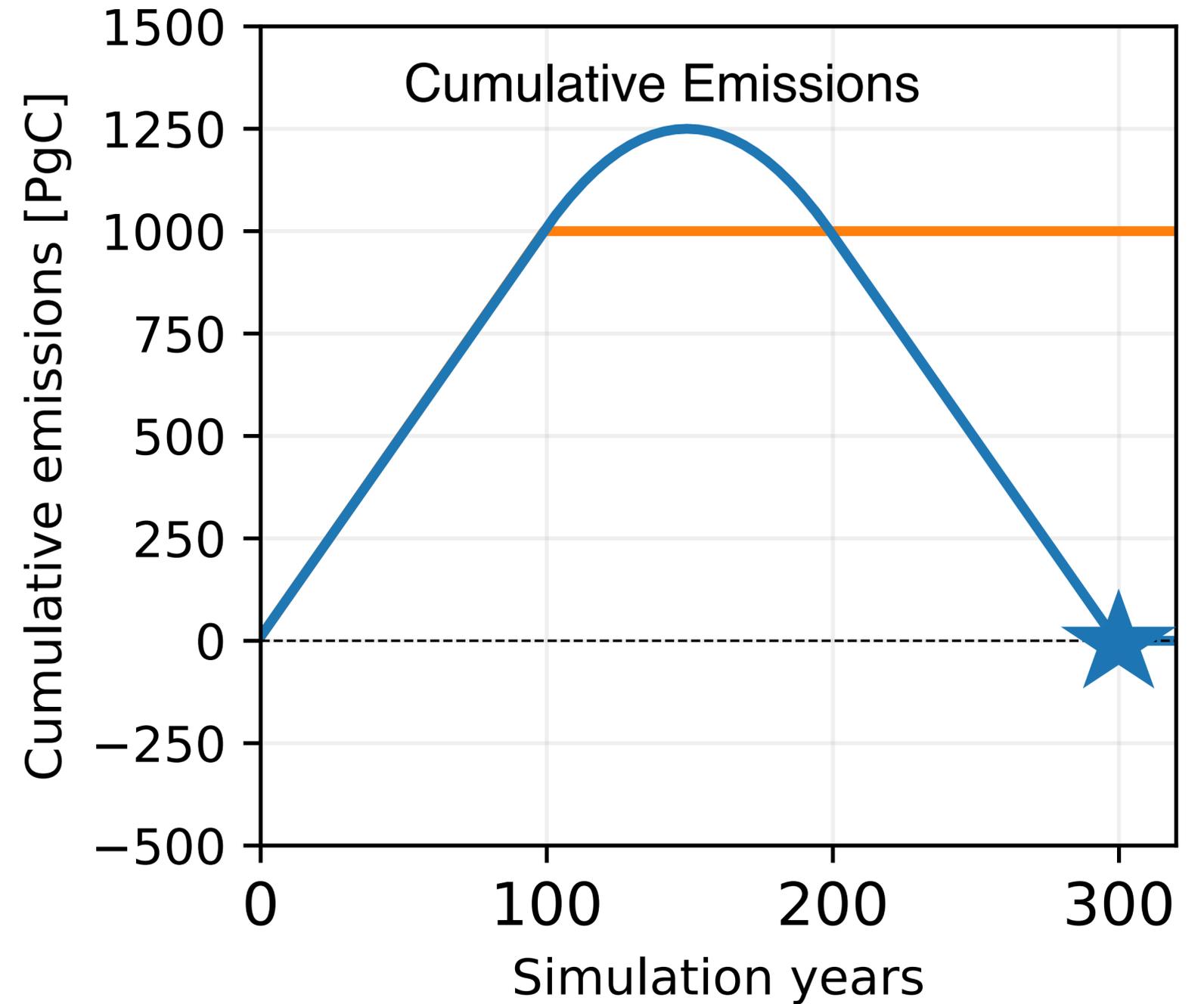
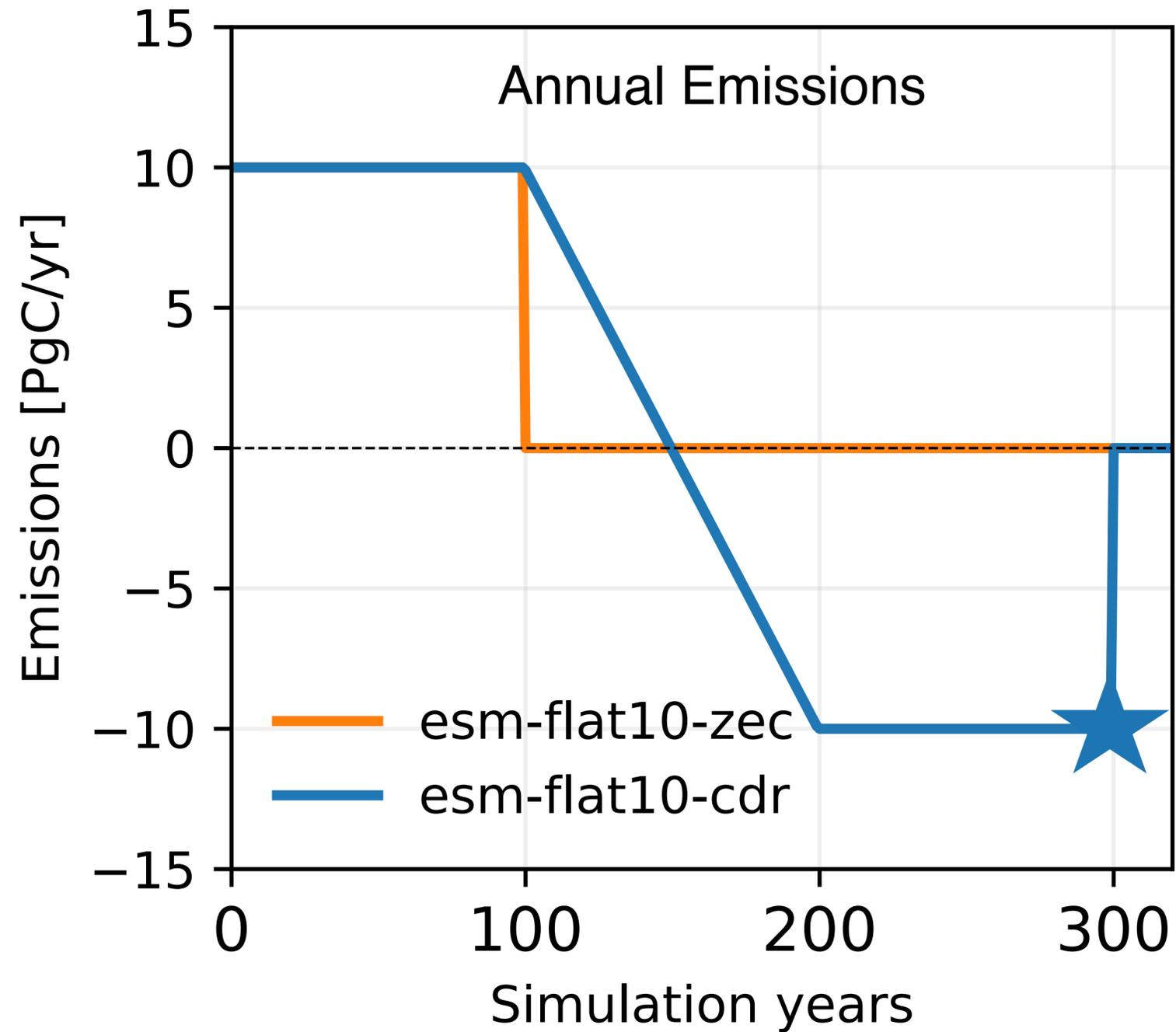
Mid and high latitudes gain carbon, largely in soil

What happens to land carbon under declining and negative emissions?

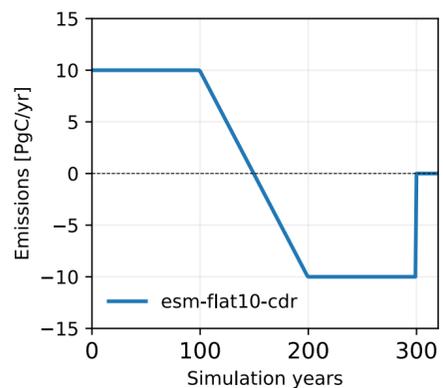
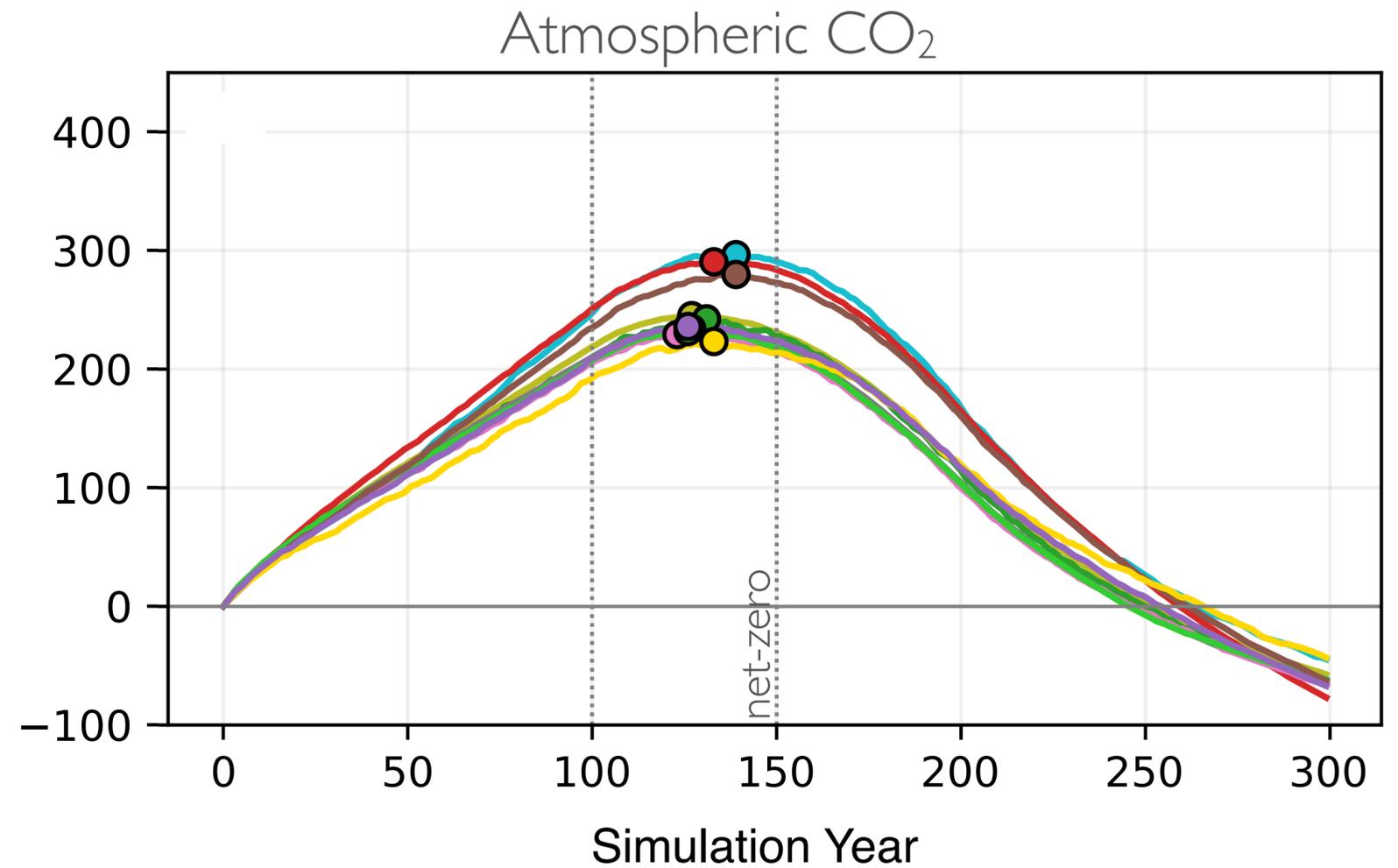
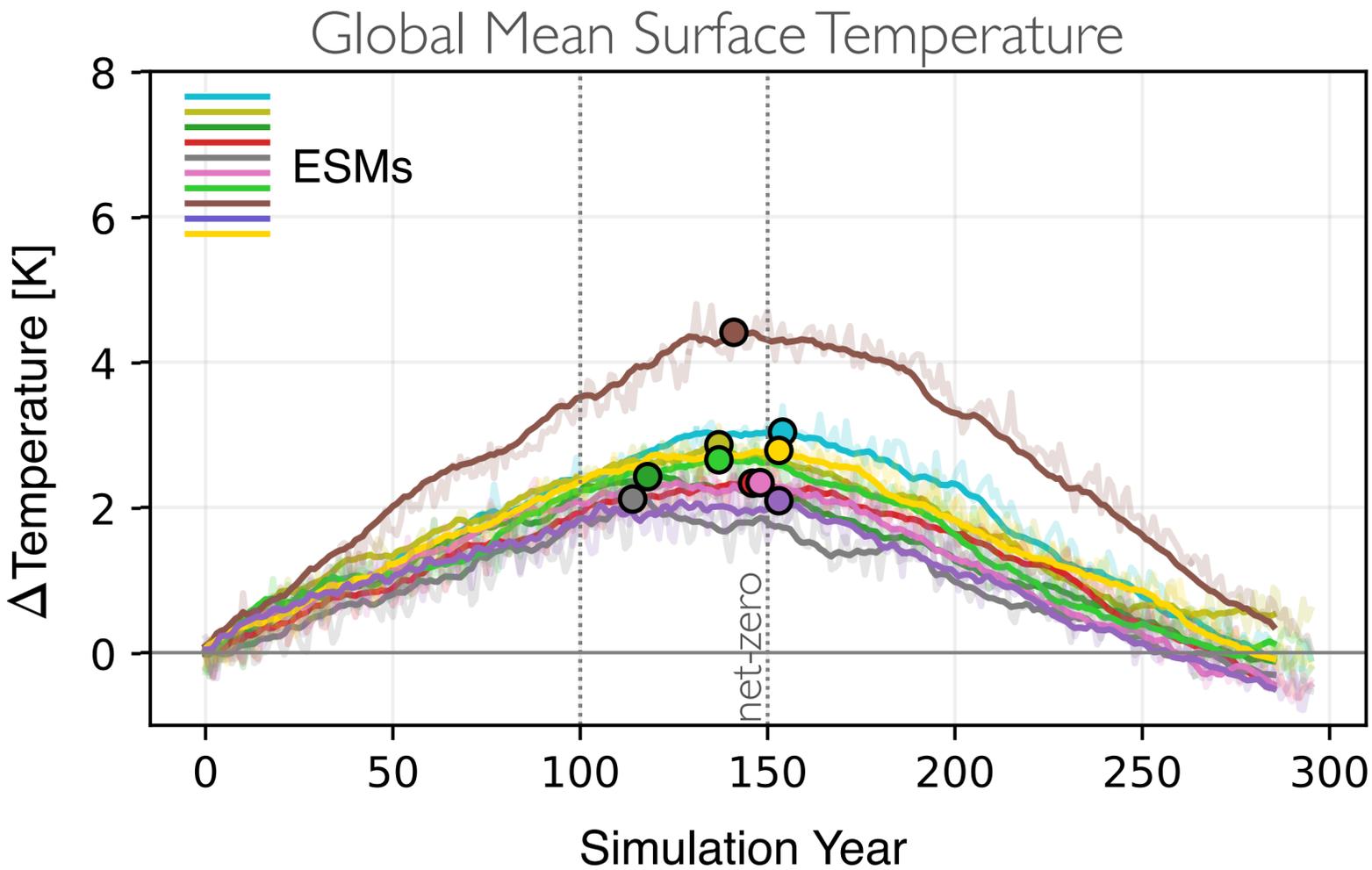


After -emissions
“cumulative-zero”

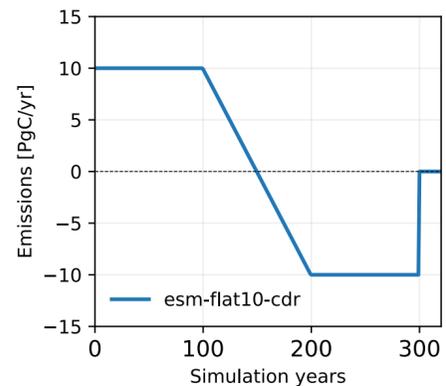
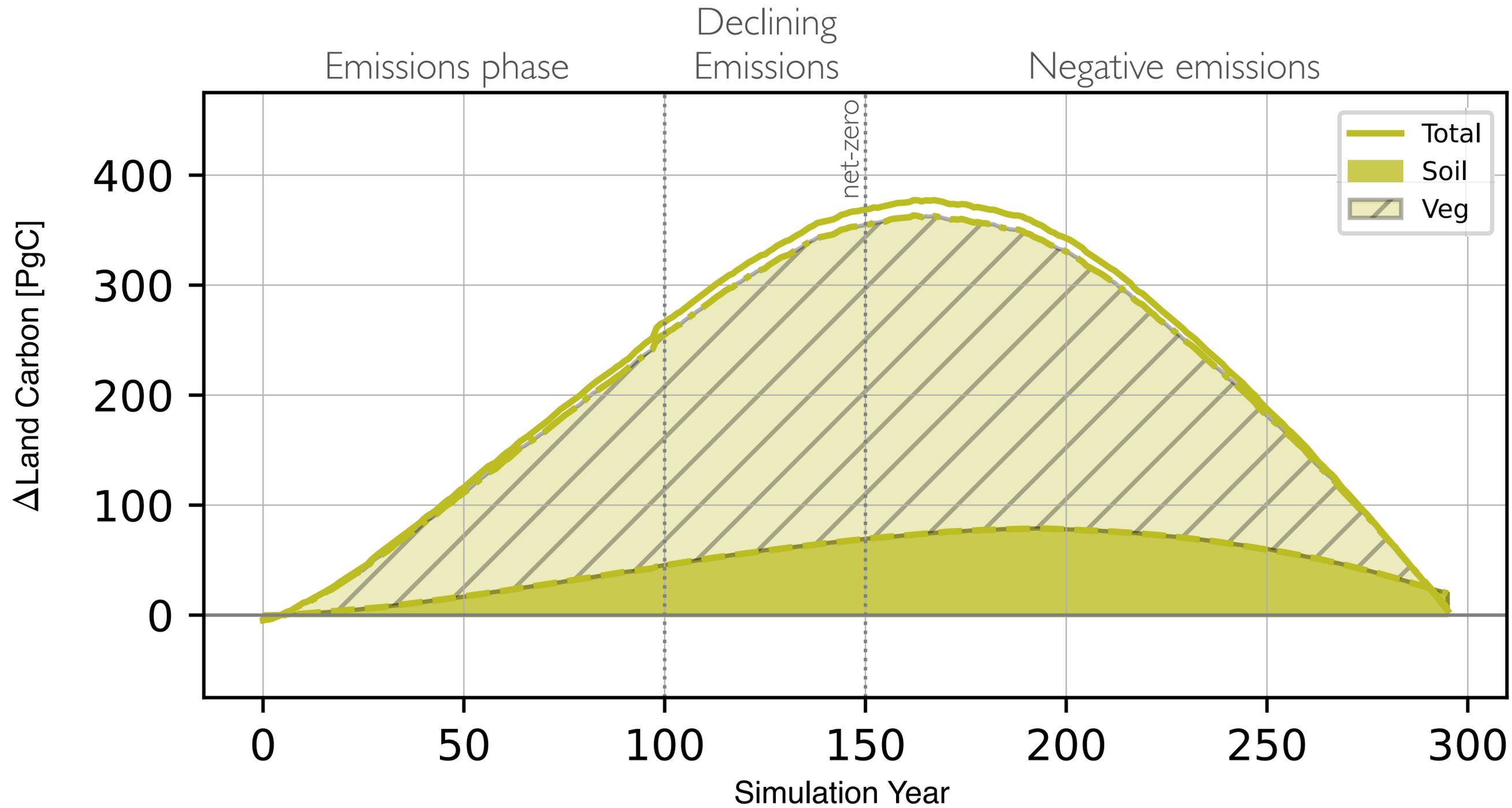
What happens to land carbon under declining and negative emissions?



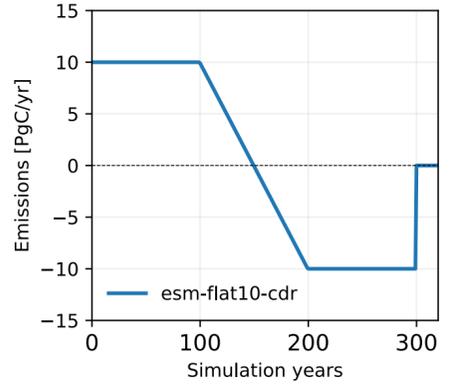
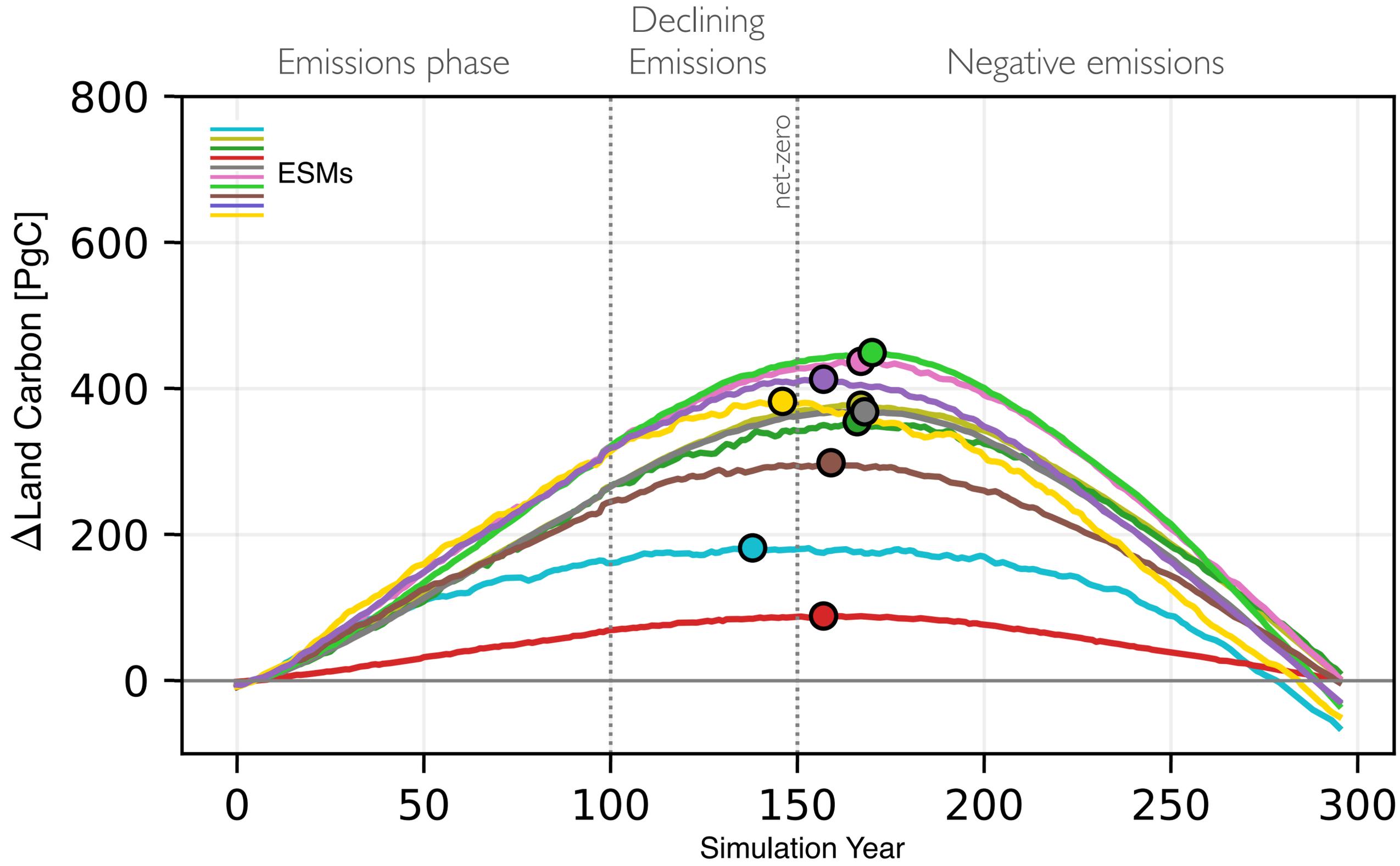
Negative emissions: Temperature and CO₂ peak and decline



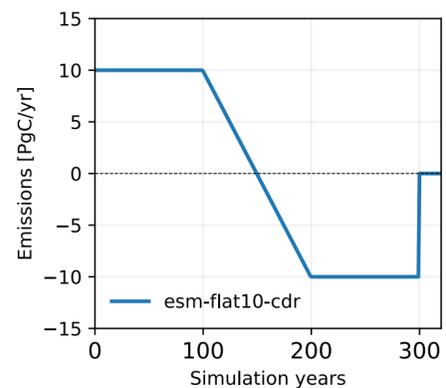
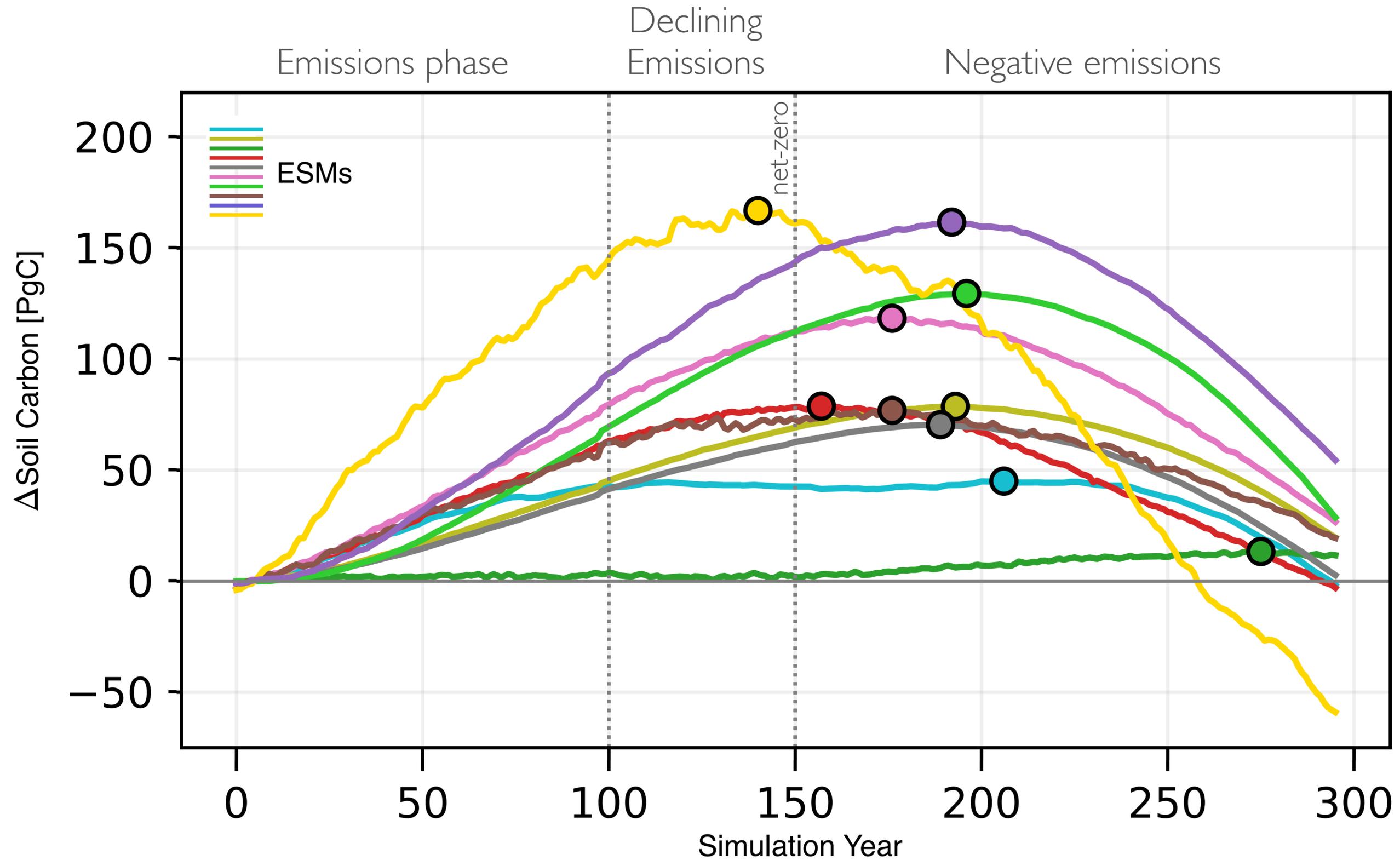
Vegetation peaks earlier than soil



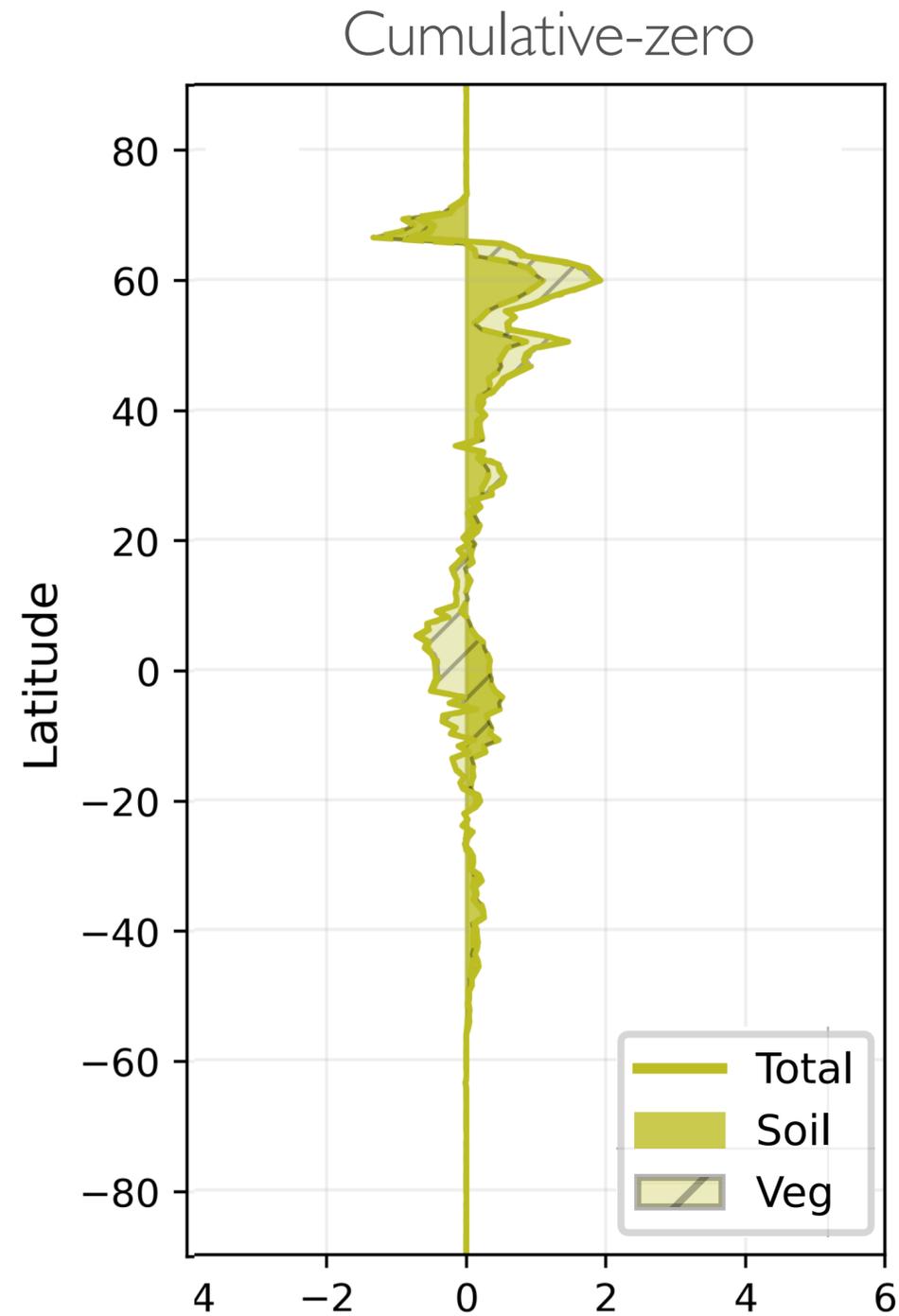
Some spread in when land carbon sink peaks



Big spread in timing of peak soil carbon across ESMs

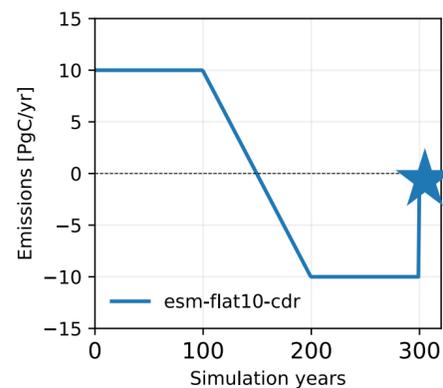


Land becomes a source in the tropics at cumulative zero



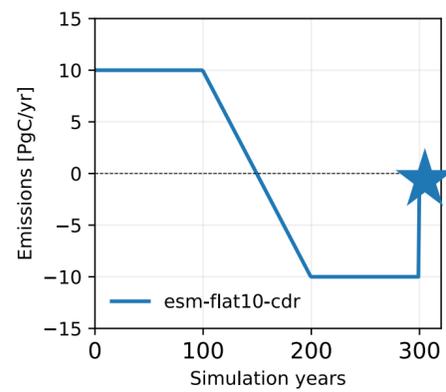
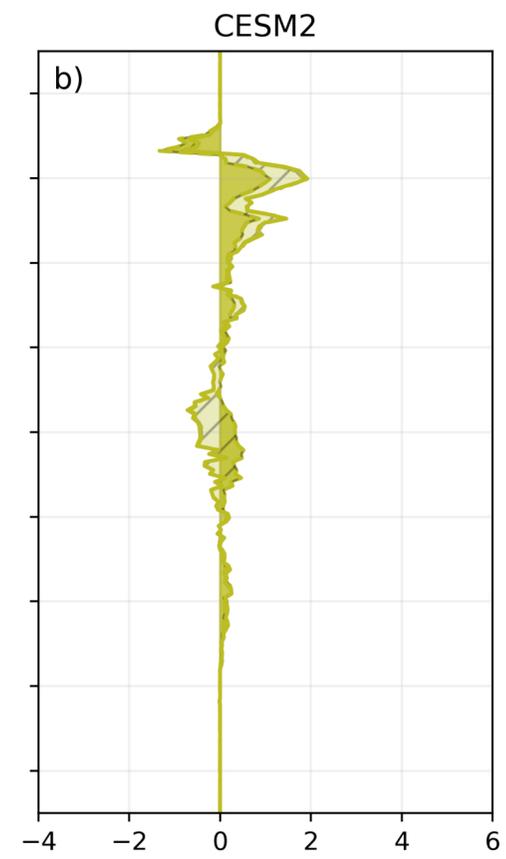
Carbon gained in mid+high latitude soil

Tropical carbon becomes a source (Modest in CESM2, larger in other ESMs)



Cumulative-zero

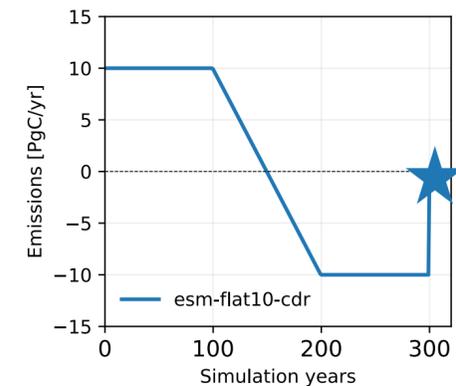
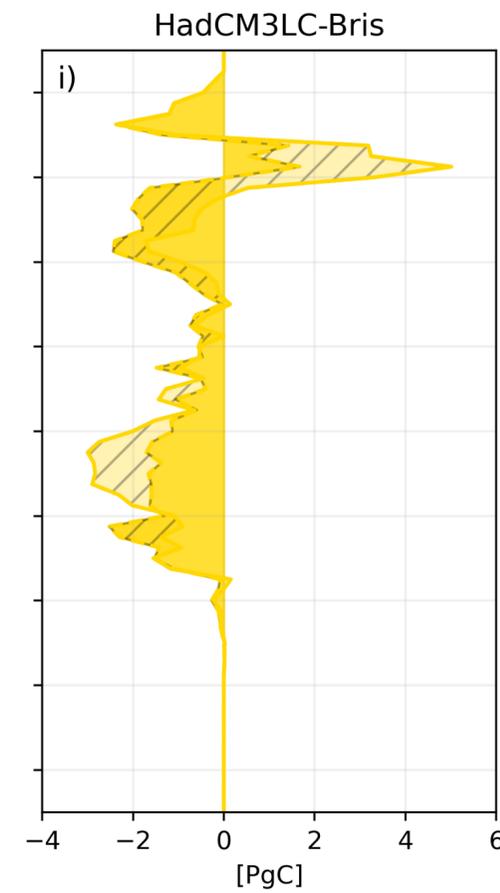
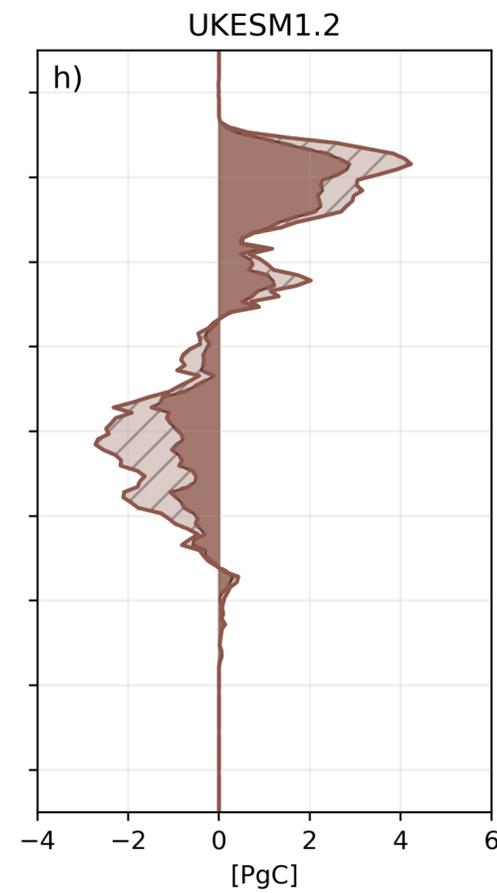
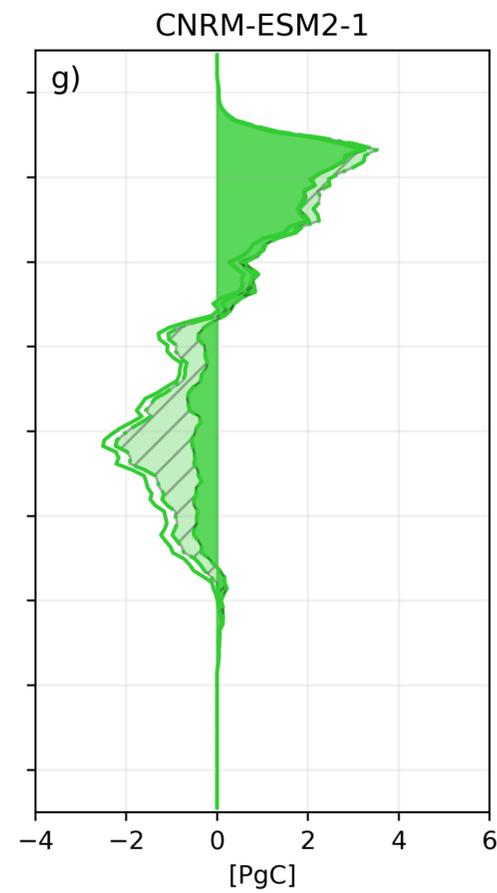
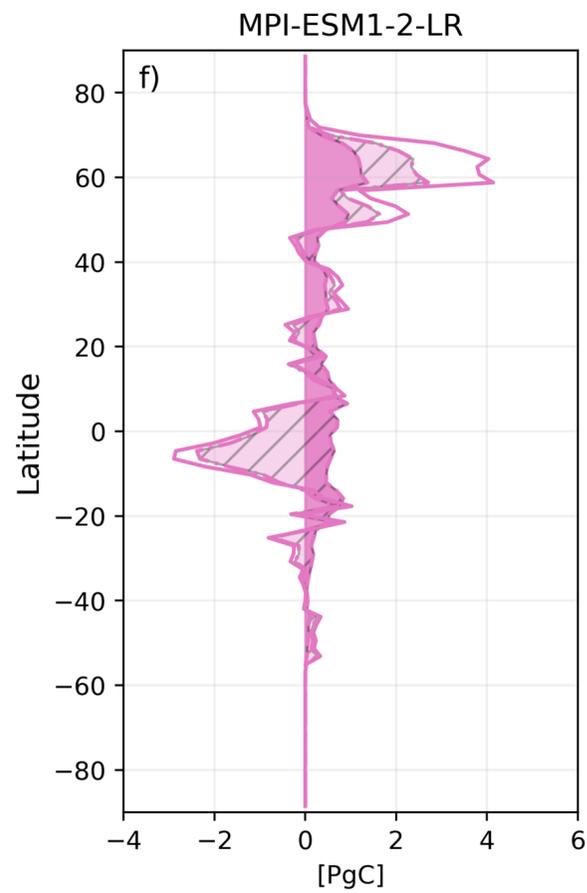
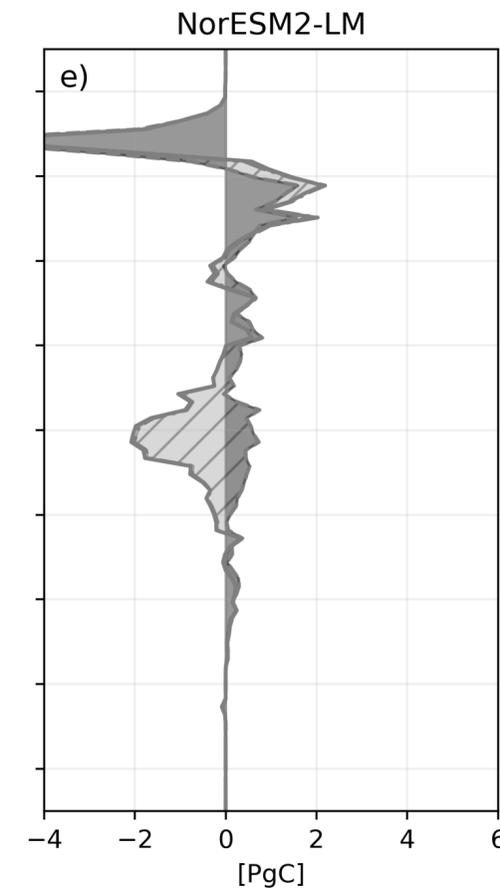
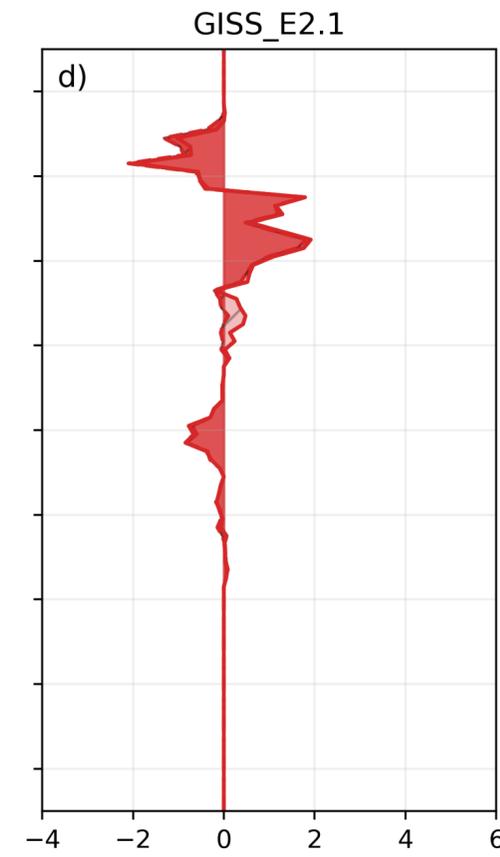
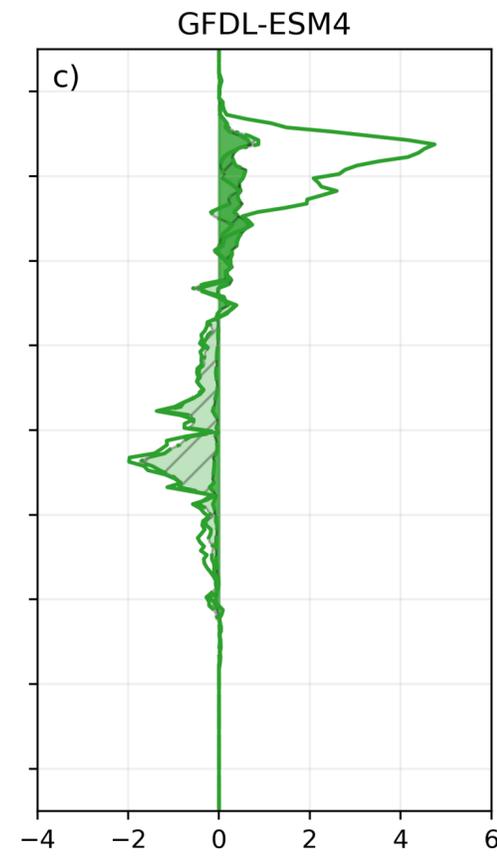
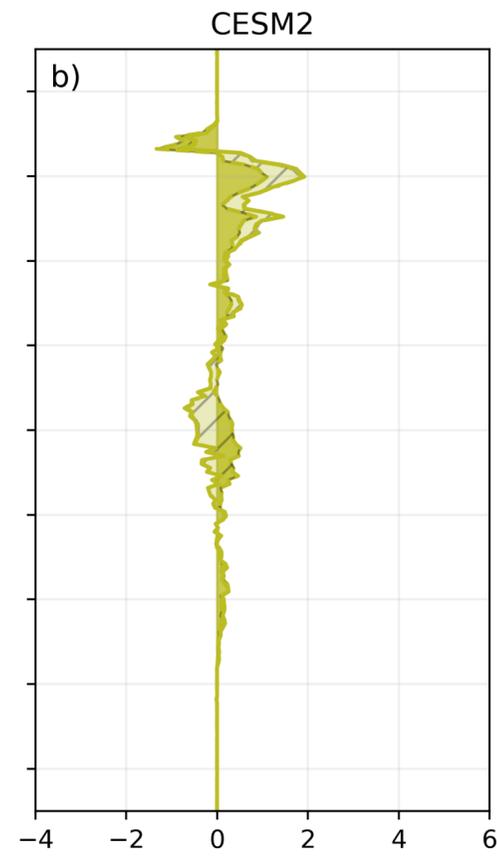
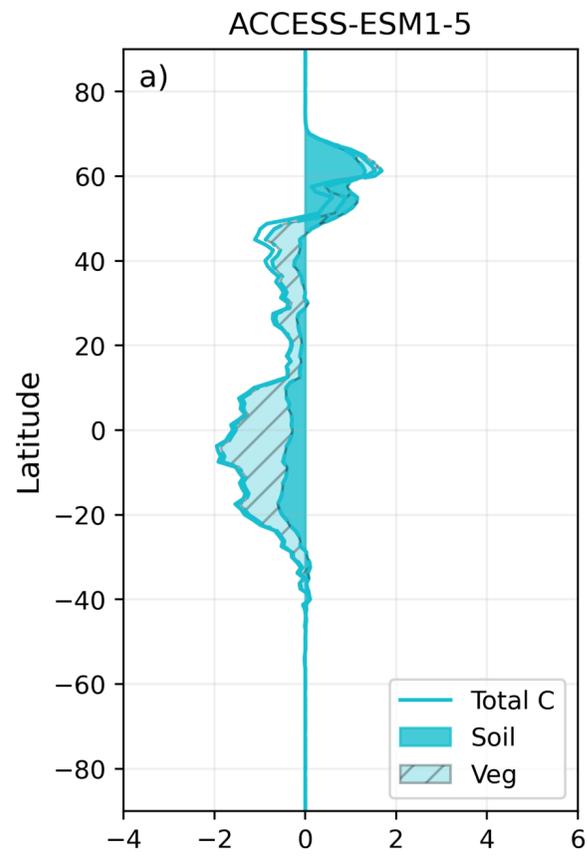
Tropical
carbon
becomes a
source



Cumulative-zero

Tropical carbon becomes a source

Mid and high latitudes gain carbon in most ESMs



Take home points

- Tropical carbon has big gains w/ emissions, but also big losses under zero and negative emissions
 - ➔ Vulnerable tropical ecosystems?
- Mid and high latitudes tend to gain carbon after zero and negative emissions
- ESM Land C sink is probably optimistic, missing things that make carbon stocks vulnerable
 - ➔ Tropics even more vulnerable? Mid- and high- latitudes gaining less?
- Big range in timing of soil carbon changes across models
 - ➔ This sets the longer timescales for land carbon responding to change