Multi-century Dynamics of the Climate and Carbon Cycle under Both High and Net Negative Emissions Scenarios

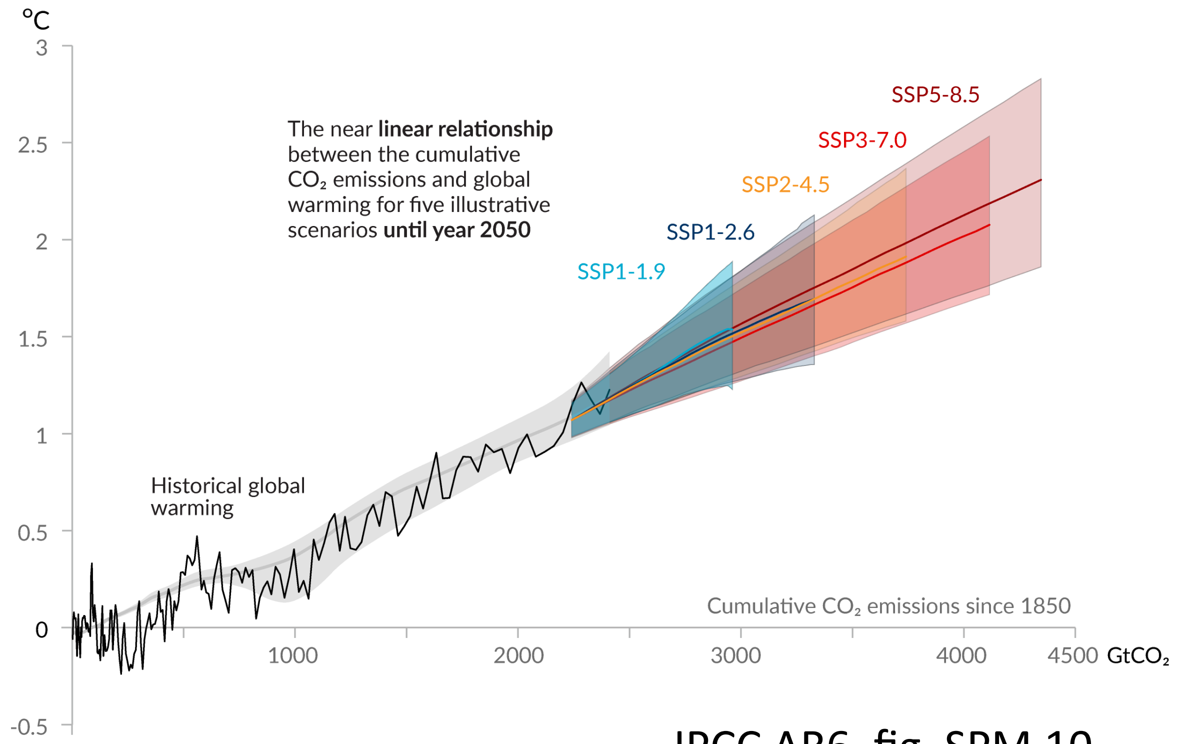
Charles D. Koven[1], Vivek K. Arora[2], Patricia Cadule[3], Rosie A. Fisher[4,5,6], Chris D. Jones[7], David M. Lawrence[4], Jared Lewis[8], Keith Lindsay[4], Sabine Mathesius[9], Malte Meinshausen[8,10], Michael Mills[4], Zebedee Nicholls[8,10], Benjamin M. Sanderson[4,5], Roland Séférian[11], Neil C. Swart[2], William R. Wieder[4,12], Kirsten Zickfeld[9]

RUBISCO Biogeochemistry Science Friday 11/12/2021

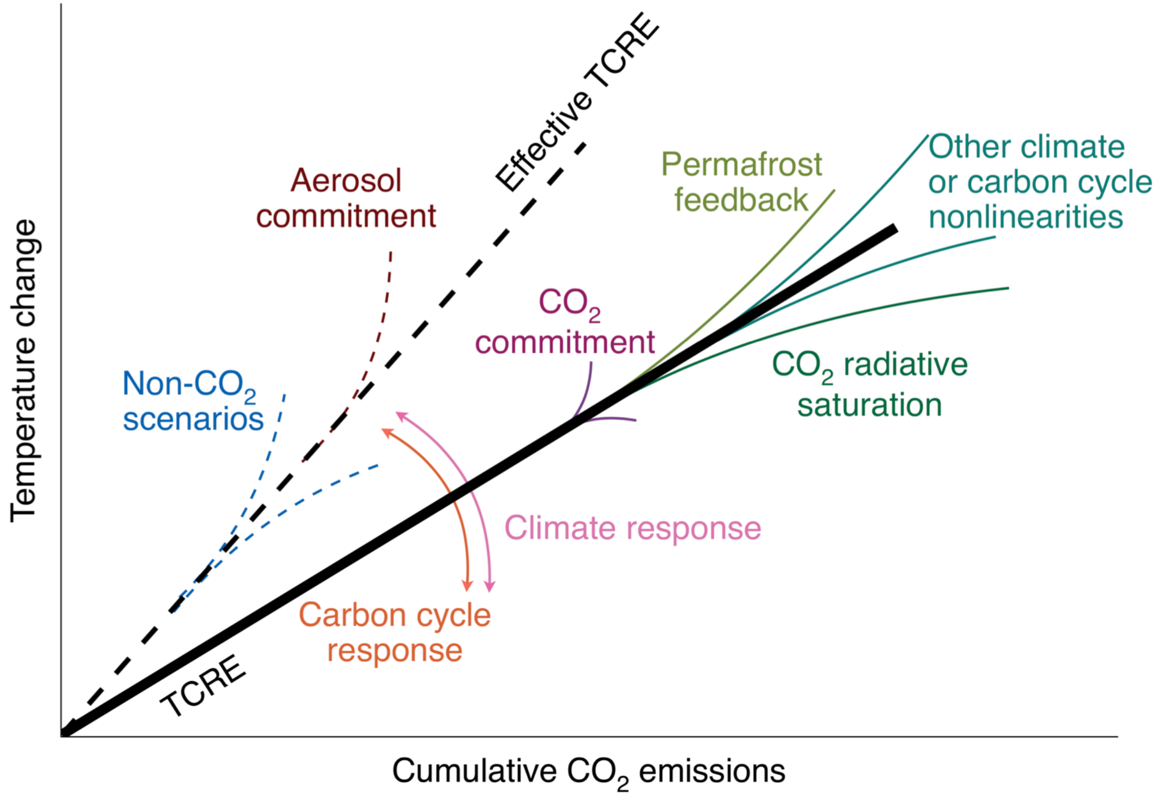
[1]Climate and Ecosystem Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California, USA
[2]Canadian Centre for Climate Modelling and Analysis, Environment and Climate Change Canada, University of Victoria, Victoria, British Columbia, Canada
[3]IPSL, CNRS, Sorbonne Université, Paris, France
[4]Climate and Global Dynamics Laboratory, National Center for Atmospheric Research, Boulder, Colorado, USA
[5]Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique, (CERFACS), Toulouse, France
[6]Évolution & Diversité Biologique, University of Toulouse Paul Sabatier III, Toulouse, France.
[7]Met Office Hadley Centre, Exeter, UK
[8]Climate and Energy College, School of Geography, Earth and Atmospheric Sciences, The University of Melbourne, Parkville, Victoria, Australia
[9]Department of Geography, Simon Fraser University, Burnaby, British Columbia, Canada
[10]Climate Resource, Victoria, Australia
[11]CNRM (Université de Toulouse, Météo-France, CNRS), Toulouse, France
[12]Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado, USA

Proportionality of warming to cumulative CO2: does it have limits, and if so, what are they?

Global surface temperature increase since 1850-1900 (°C) as a function of cumulative CO_2 emissions ($GtCO_2$)



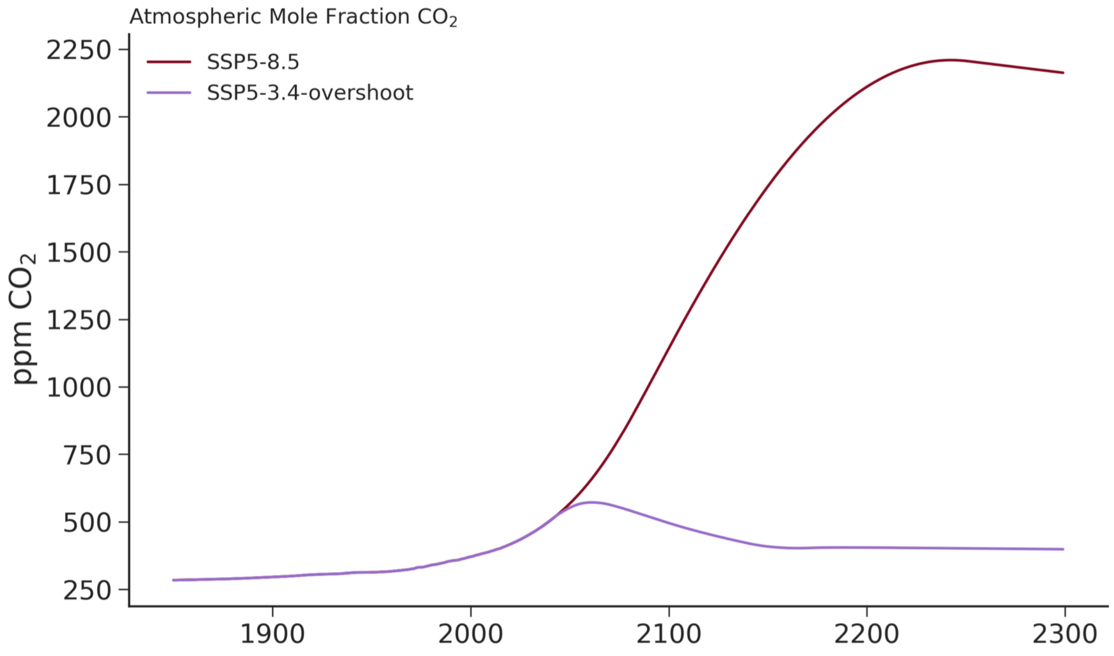
IPCC AR6, fig. SPM.10

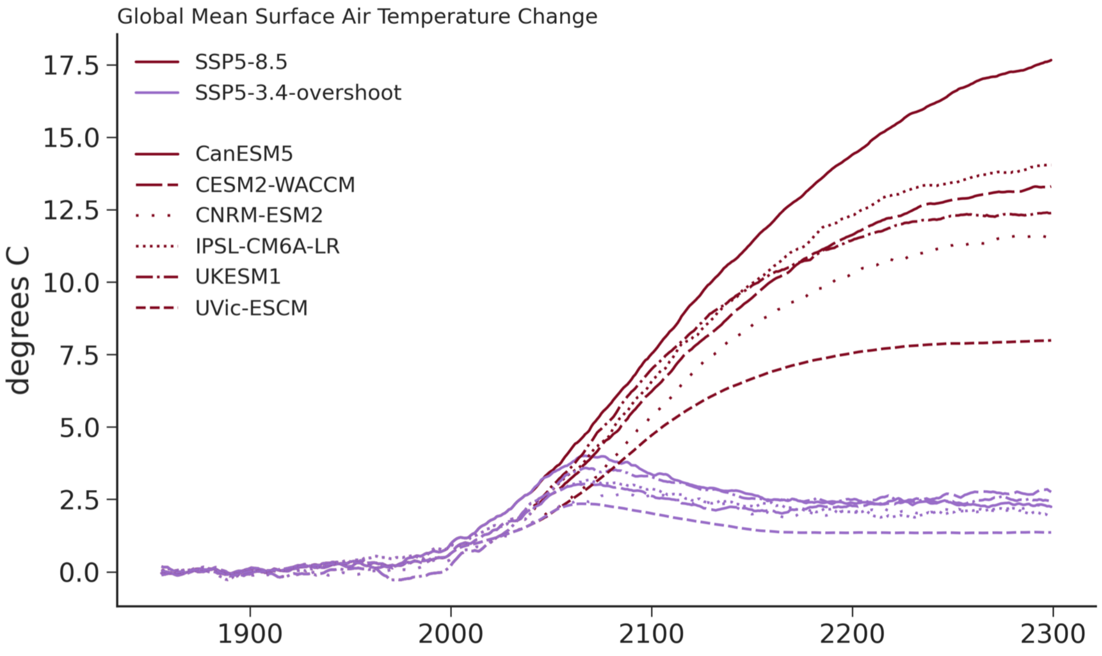


Matthews et al., 2020

Perhaps most importantly, does the relationship hold under net-negative CO_2 emissions?

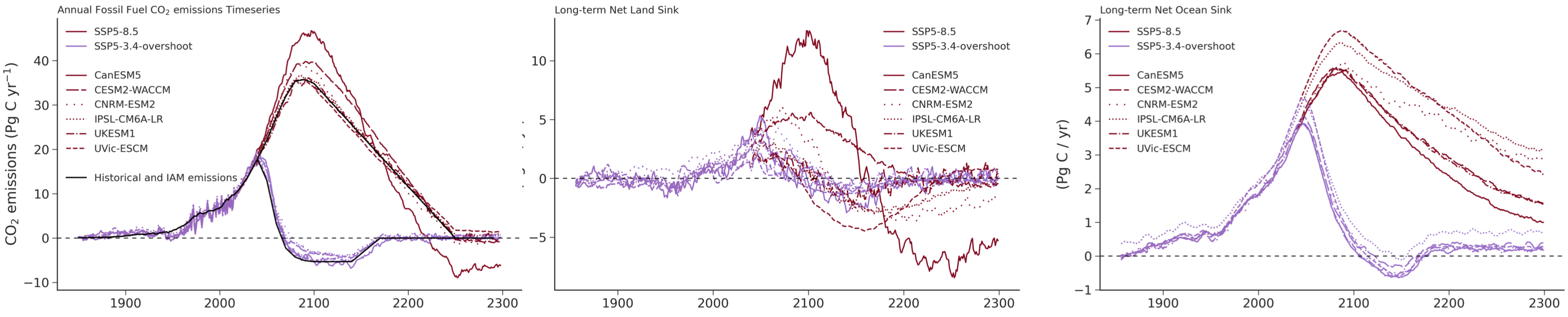
Comparing two long-term scenarios: very-high emissions, and peak-and-overshoot



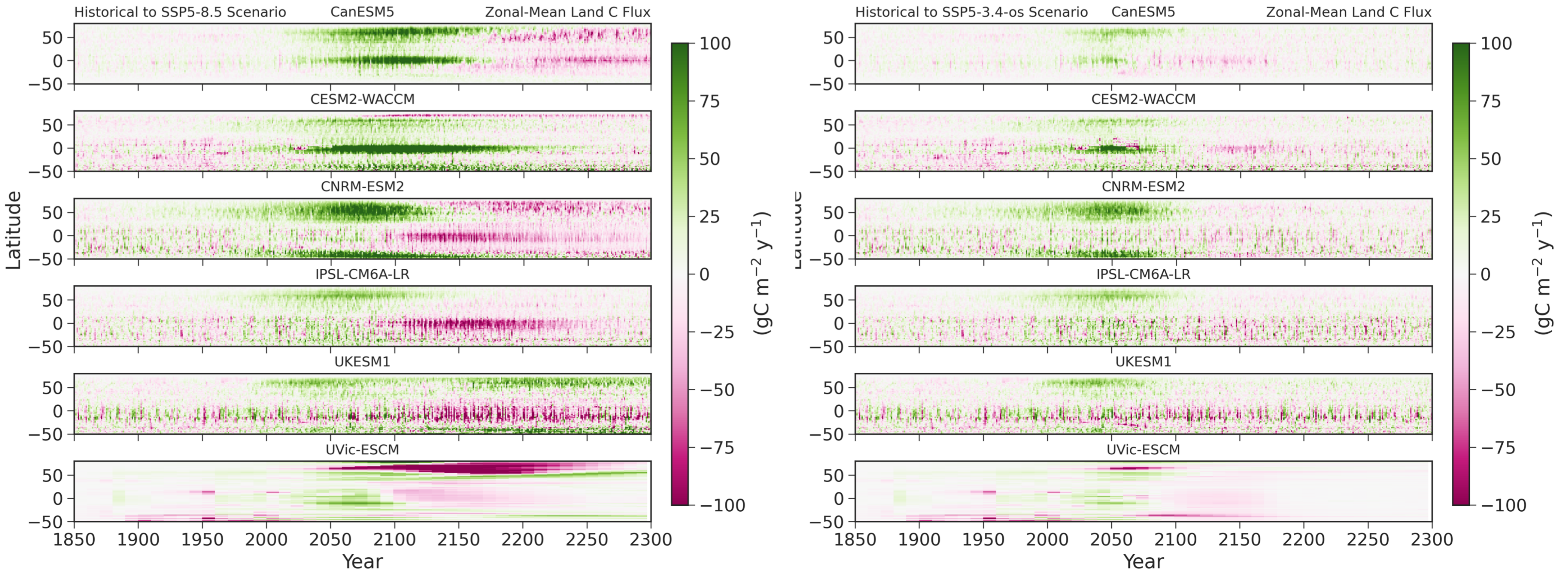


All unlabeled figures in talk are in revisions manuscript in review at https://doi.org/10.5194/esd-2021-23

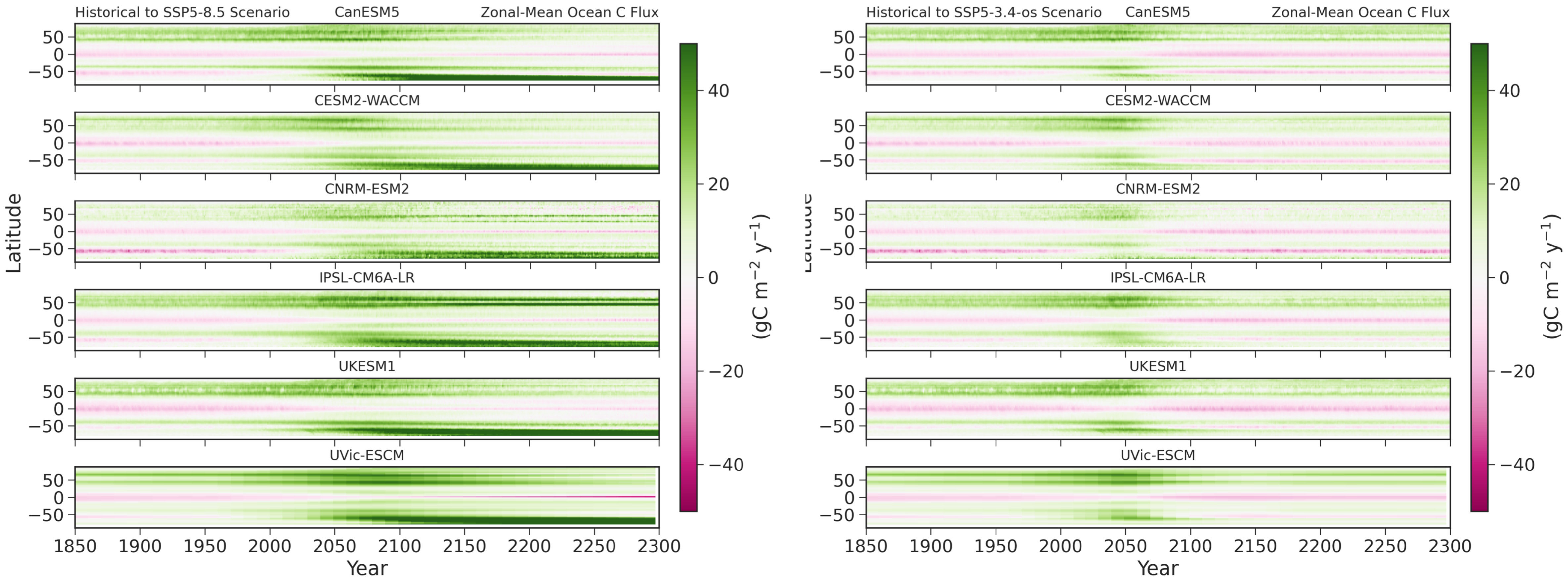
Land and ocean carbon fluxes: land switches from sink to source under both scenarios, ocean follows emissions and switches to source during overshoot period



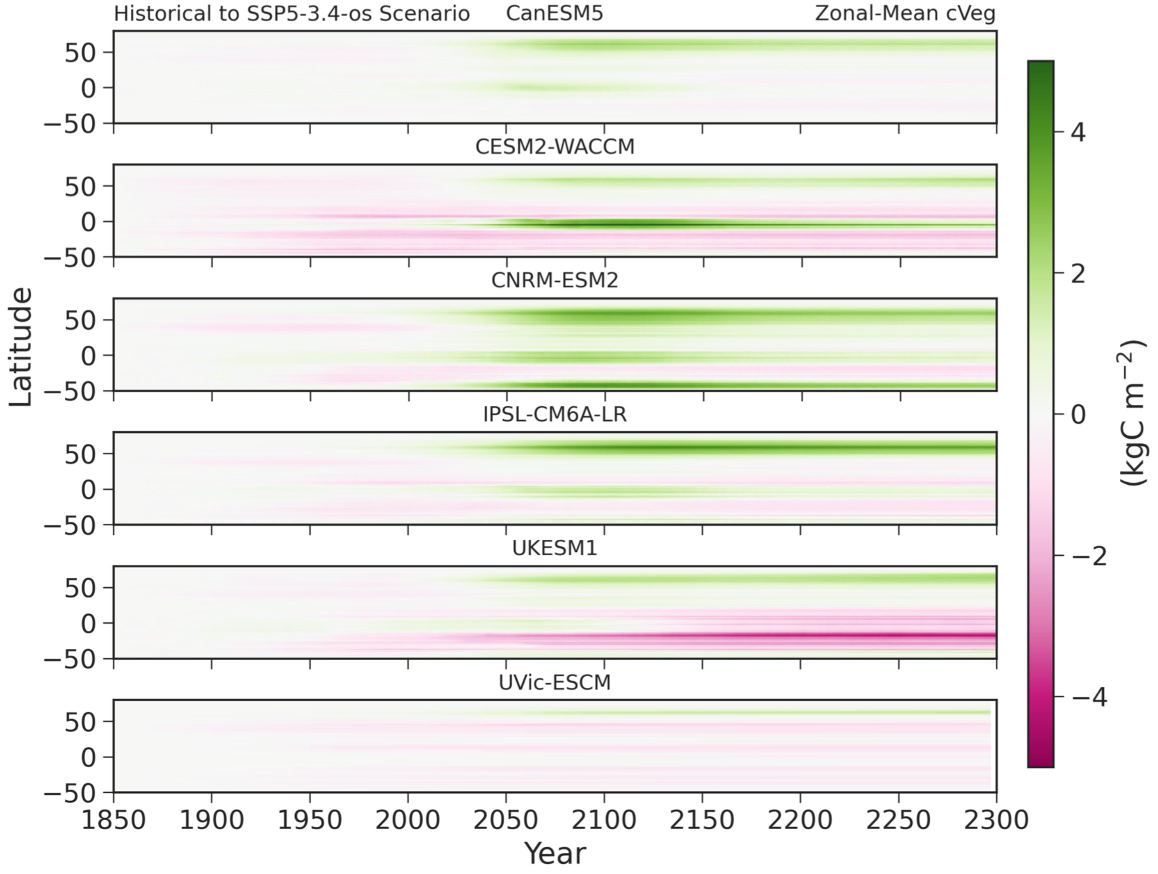
Looking regionally, models disagree on the timing, location, and strength of feedbacks over land, particularly under high very-high emissions scenario.

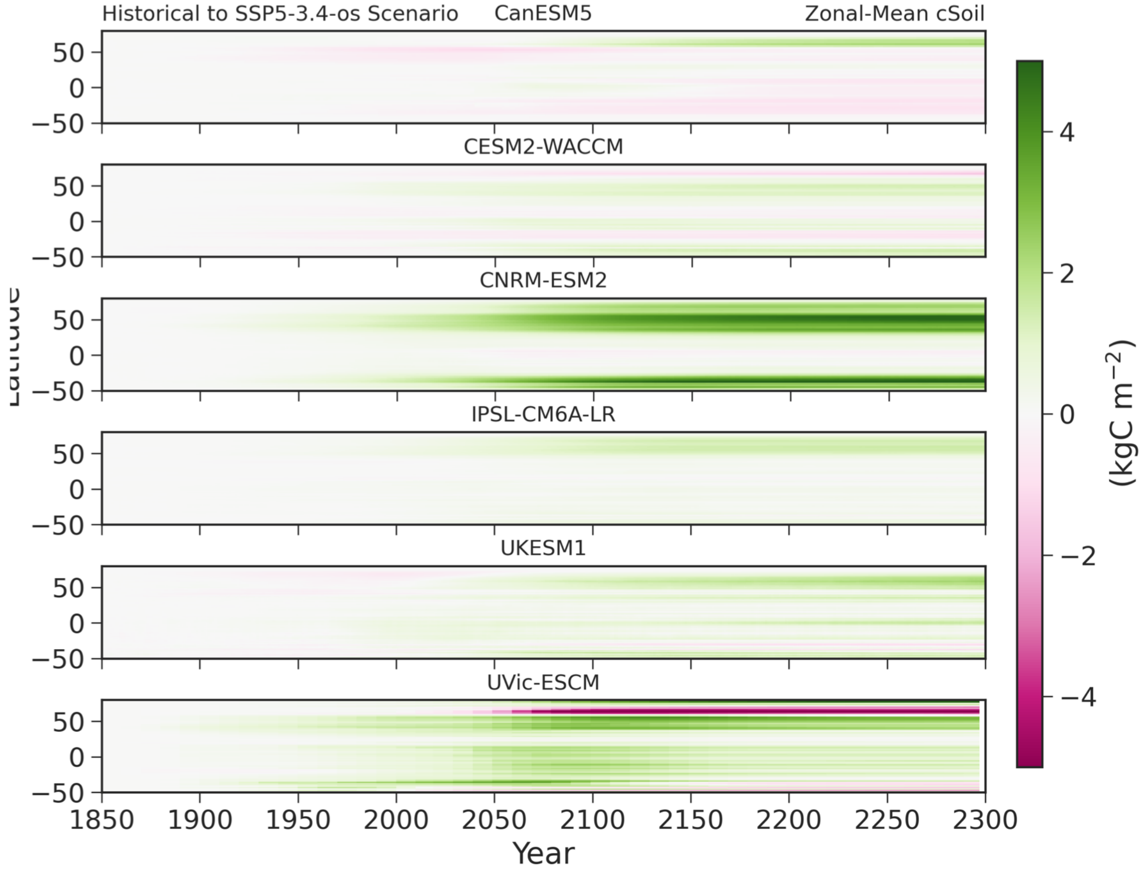


For ocean, models agree on timing and location, only some disagreement on magnitude of feedbacks.

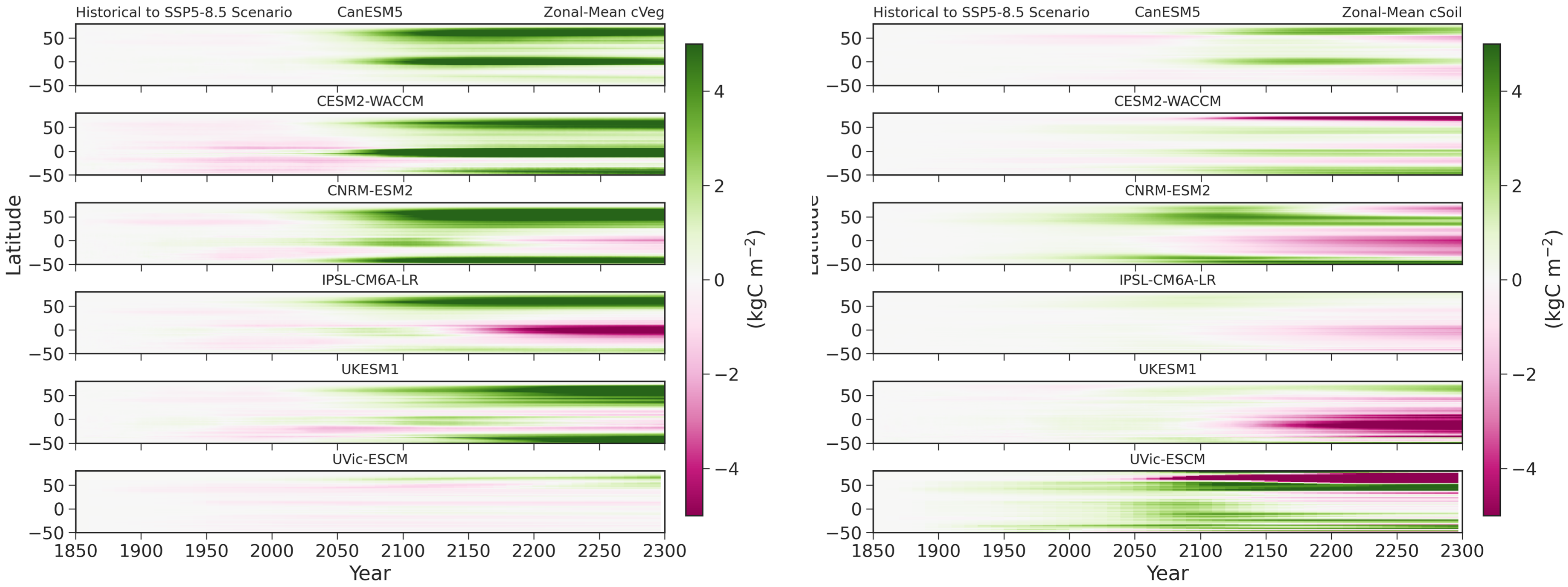


Comparing the veg and soil carbon responses, again wide disagreement on timing, location, magnitude and veg/soil split, but also whether feedbacks are reversible after overshoot.

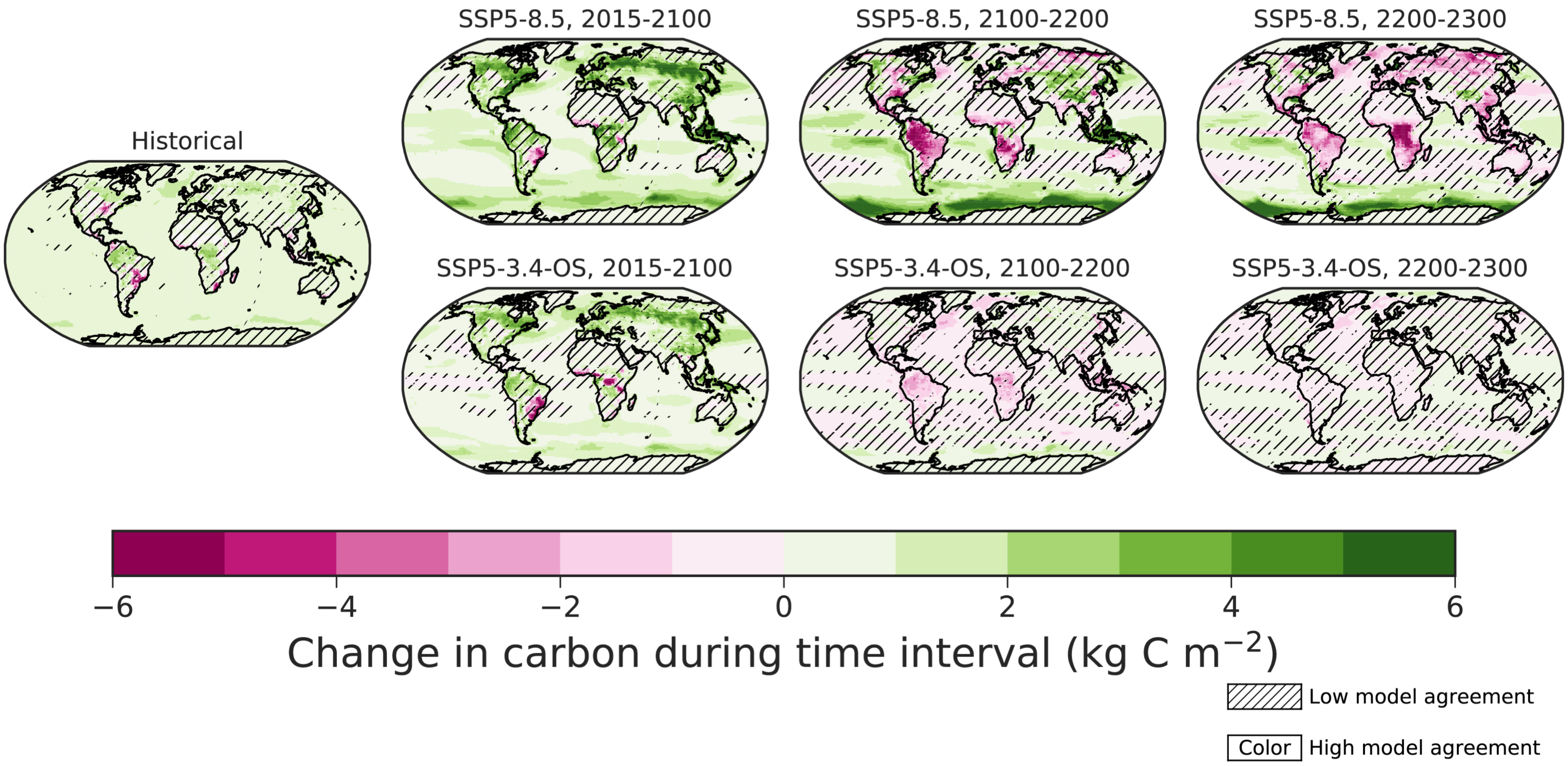




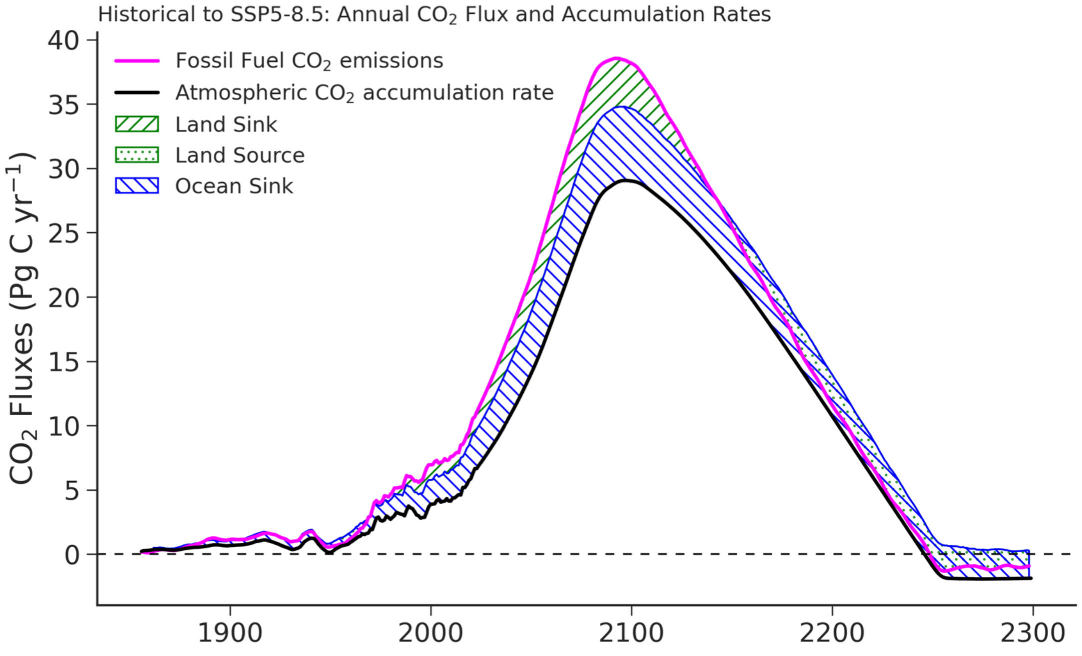
Comparing the veg and soil carbon responses under very high emissions, all models agree that high latitudes gain veg. carbon, but disagree on much else.

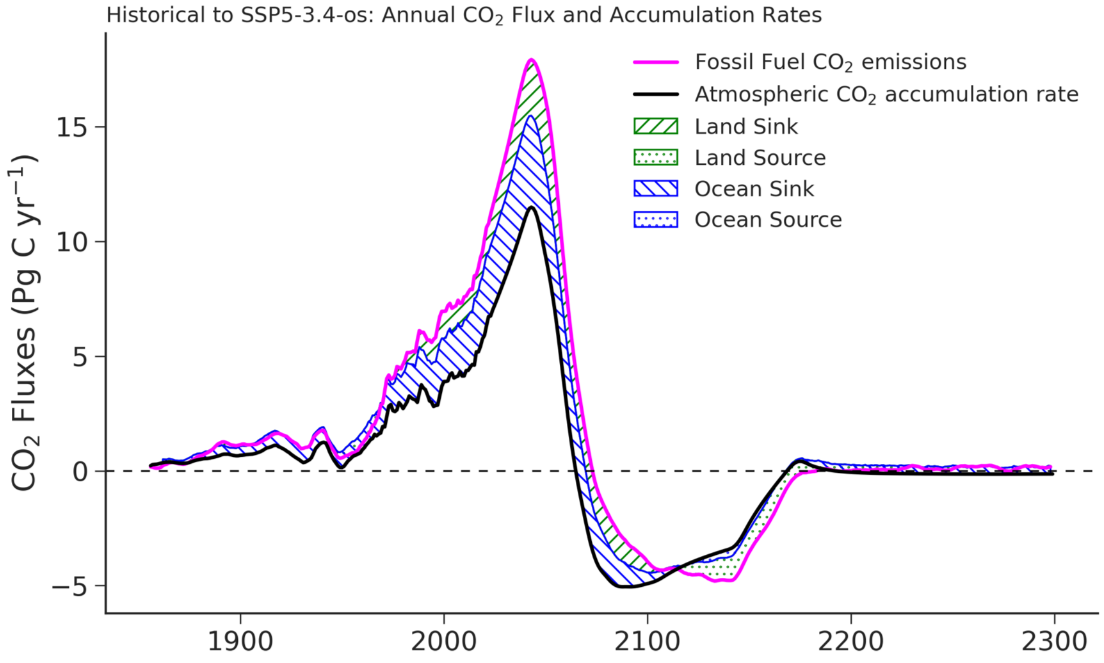


Maps of integrated carbon change show that there are also key longitudinal differences, e.g. that Amazon tends to show earlier vulnerability than African and Maritime tropical forests.

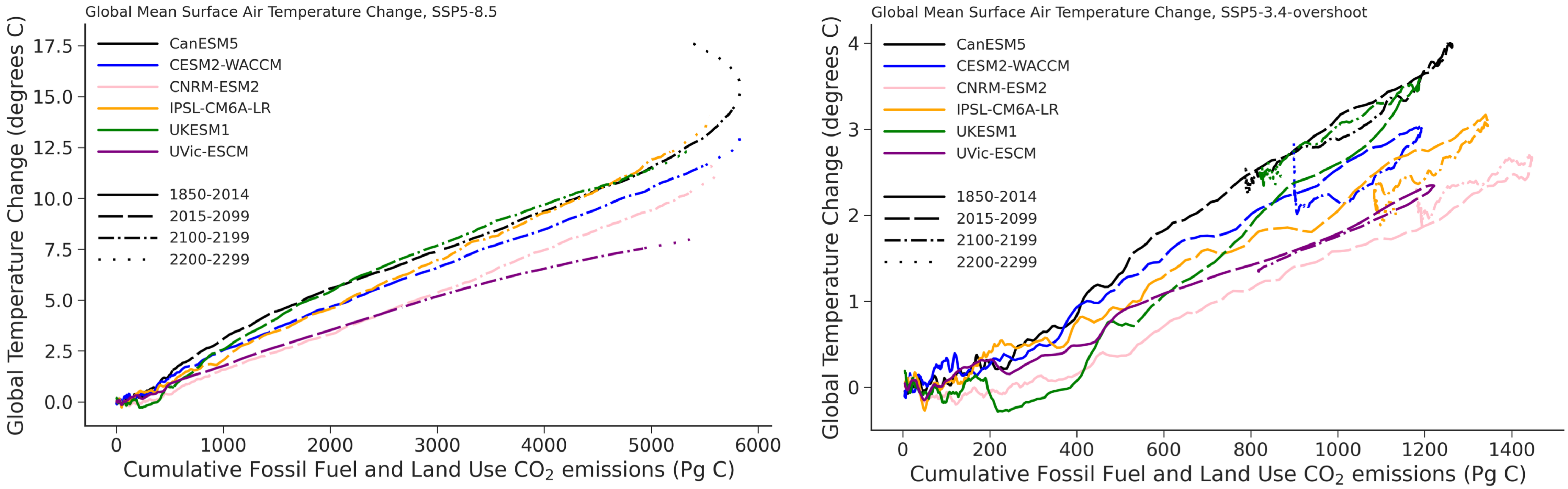


Plotting all fluxes into a single plot allows seeing the relative lags between carbon emissions and feedbacks.

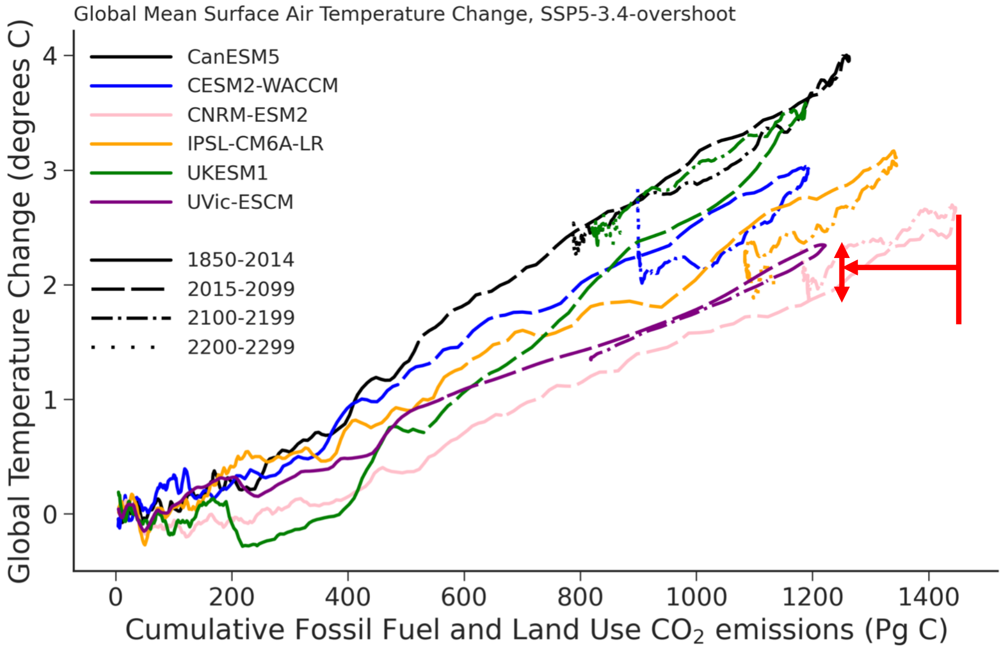




Proportionality of warming to cumulative emissions roughly holds, under both scenarios, with some exceptions.



Overshoot asymmetry consistent with 100-year Zero Emissions Commitment (ZEC_{100})



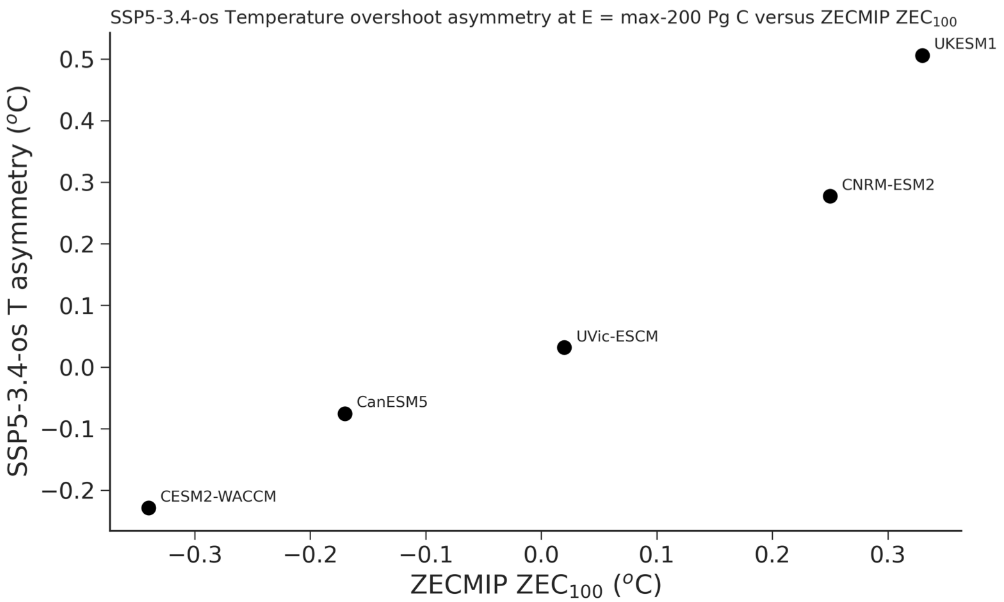
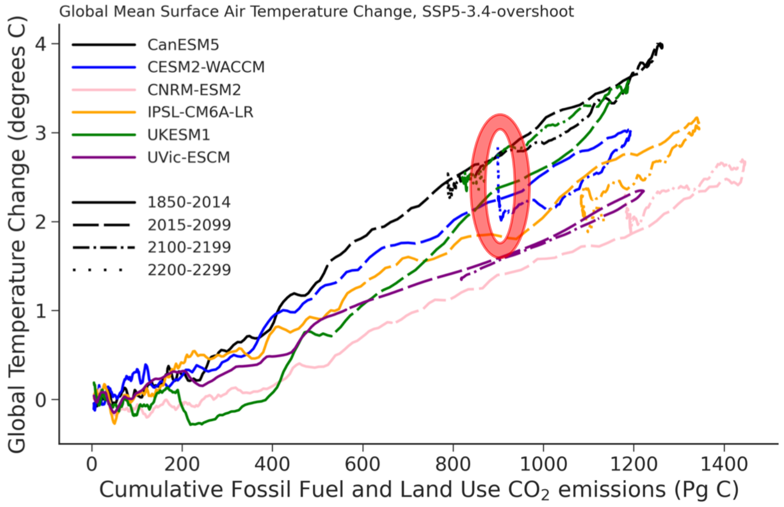
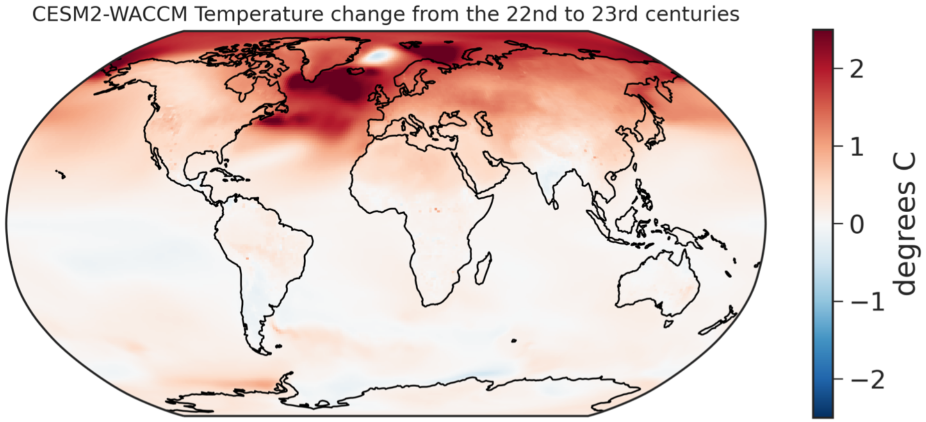


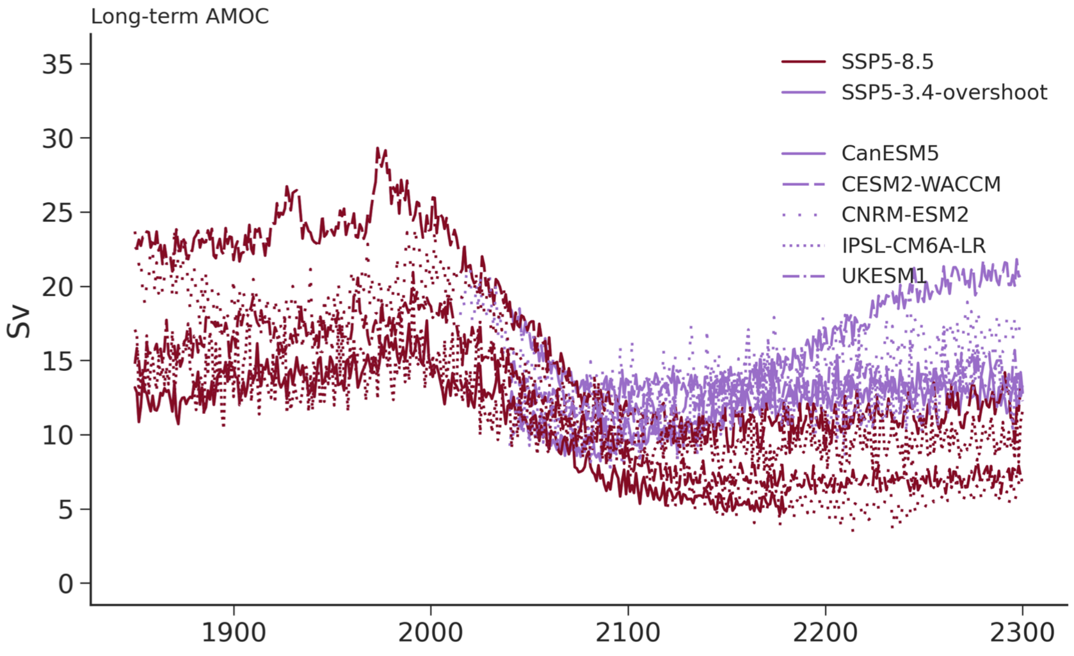
Figure made just this morning so not in revised manuscript

ZEC_{100} values from MacDougall et al., 2020 (https://doi.org/10.5194/bg-17-2987-2020); IPSL-CM6A-LR not included in ZECMIP

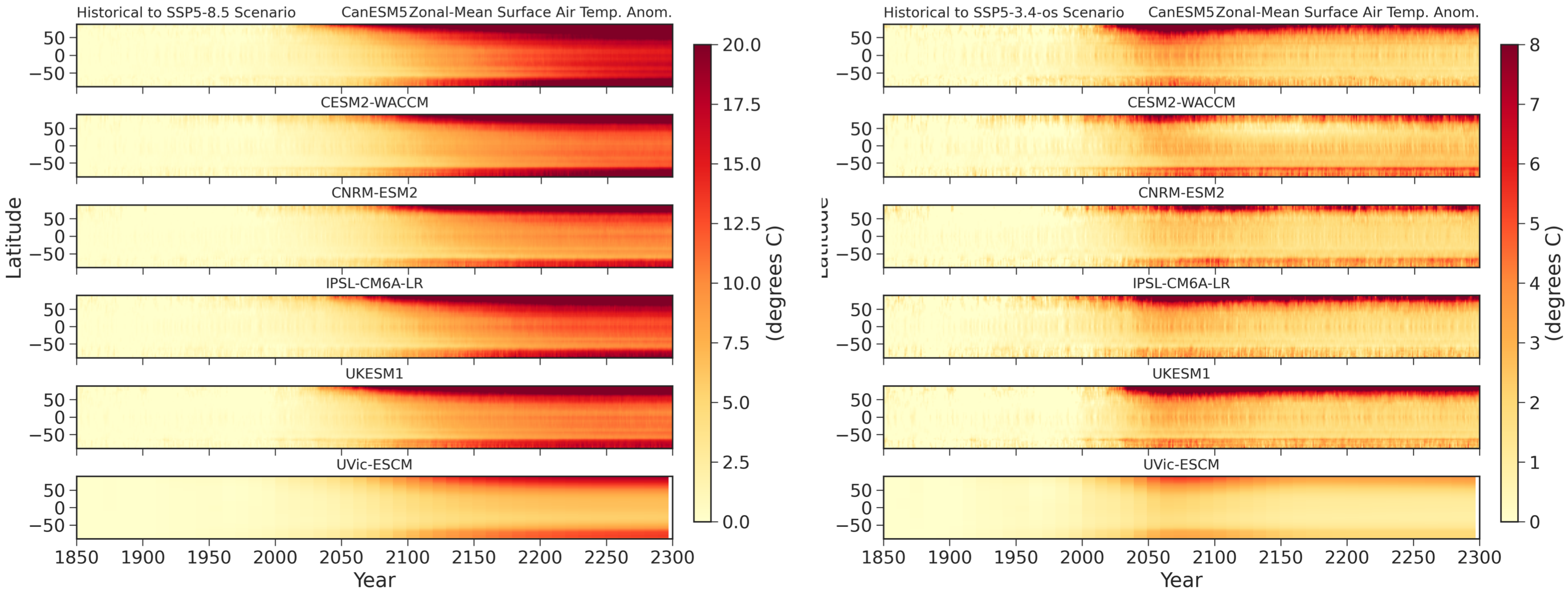
23rd-century warming in CESM2 under SSP5-3.4-overshoot concentrated in northern hemisphere, consistent with driving by AMOC recovery







Zonal-mean temperature changes show expected patterns of polar amplification, and also shows signature of 22^{nd}-century northern mid-high latitude cooling in CESM2



Conclusions

- Carbon cycle responses in both long-term scenarios include reversals of global sink to source in land and/or ocean, for very different reasons
  - Land may become source under both net-negative and long-term very-high emissions, whereas ocean only become transient source under strong net-negative emissions
- Wide model disagreements in land sink are particularly strong under high emissions scenarios, model disagree on timing, location, strength, and veg/soil partitioning. Somewhat better agreement in overshoot scenario
- Ocean models agree much more on patterns, but ensemble spread still diverges after 2100
- Overall the proportionality of warming to cumulative emissions still generally holds under both scenarios
- Asymmetry under overshoot largely consistent with ZEC
- Long-term divergence from proportionality to warming can be seen in both scenarios though, e.g. due to AMOC recovery in CESM2 under overshoot, or lagged warming in CanESM5 under very-high-emissions

Acknowledgements: RUBISCO SFA and DOE Early Career Research Program