Productivity and turnover controls on terrestrial carbon feedbacks in the CMIP5 ESMs

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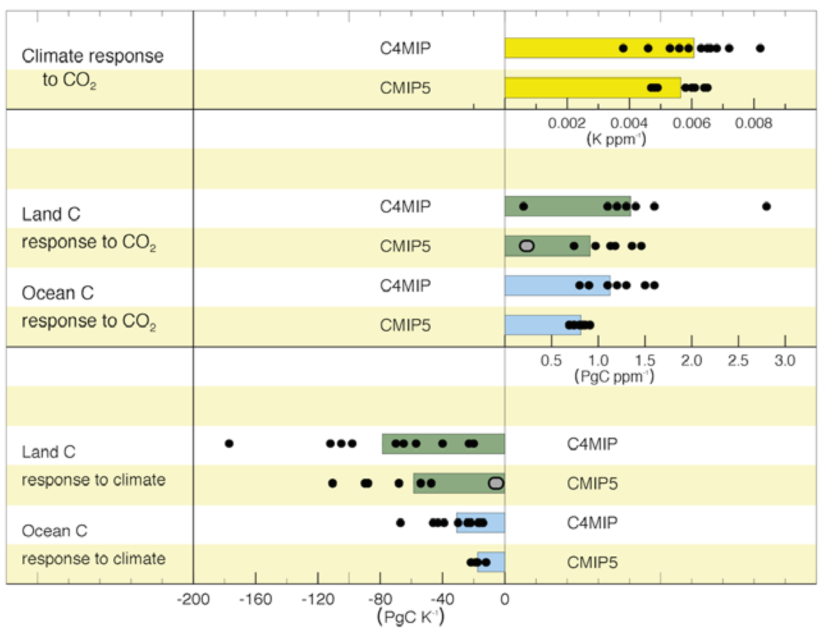
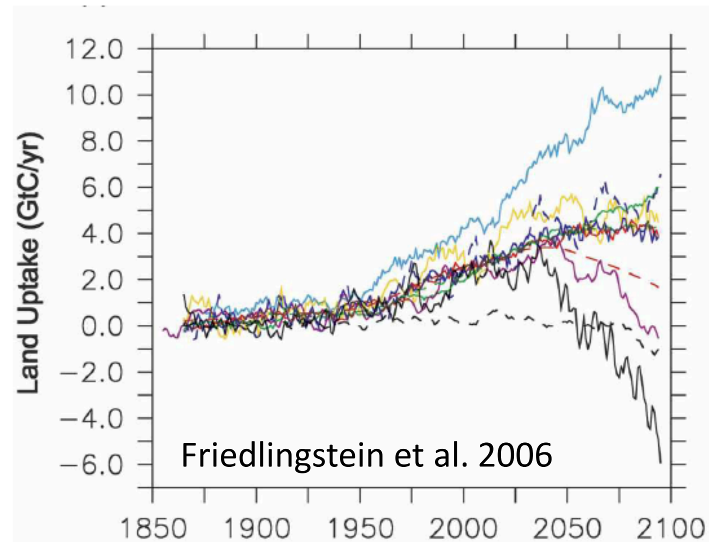
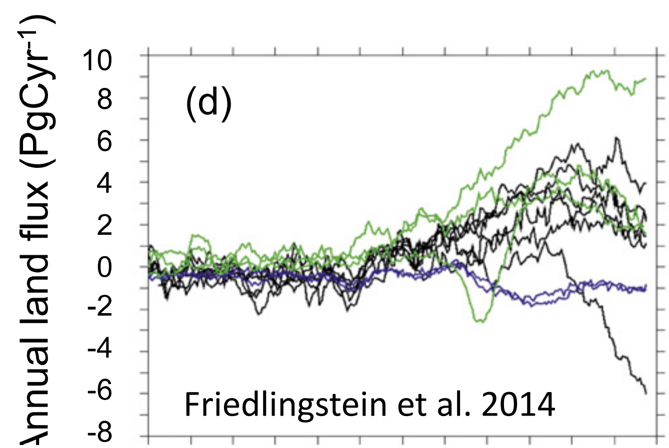
Problems: we know the model uncertainty is awful, but why? And, do we trust the models even when they agree?



IPCC-AR5 (Ciais et al., 2013)





Approach: disaggregate controls on C changes via a linear analysis of equilibrium C changes

$$C_t = C_l + C_d$$

Live C Pools

$$\frac{dC_l}{dt} = f_{npp} - \frac{C_l}{\tau_l}$$

$$\widehat{C_l} = f_{npp}\tau_l$$

$$\frac{d\widehat{C_l}}{dt} = \frac{df_{npp}}{dt}\tau_l + \frac{d\tau_l}{dt}f_{npp}$$

Productivity-driven live C change

Turnover-driven live C change

Dead C Pools

$$\frac{dC_d}{dt} = f_{l\rightarrow d} - \frac{C_d}{\tau_d}$$

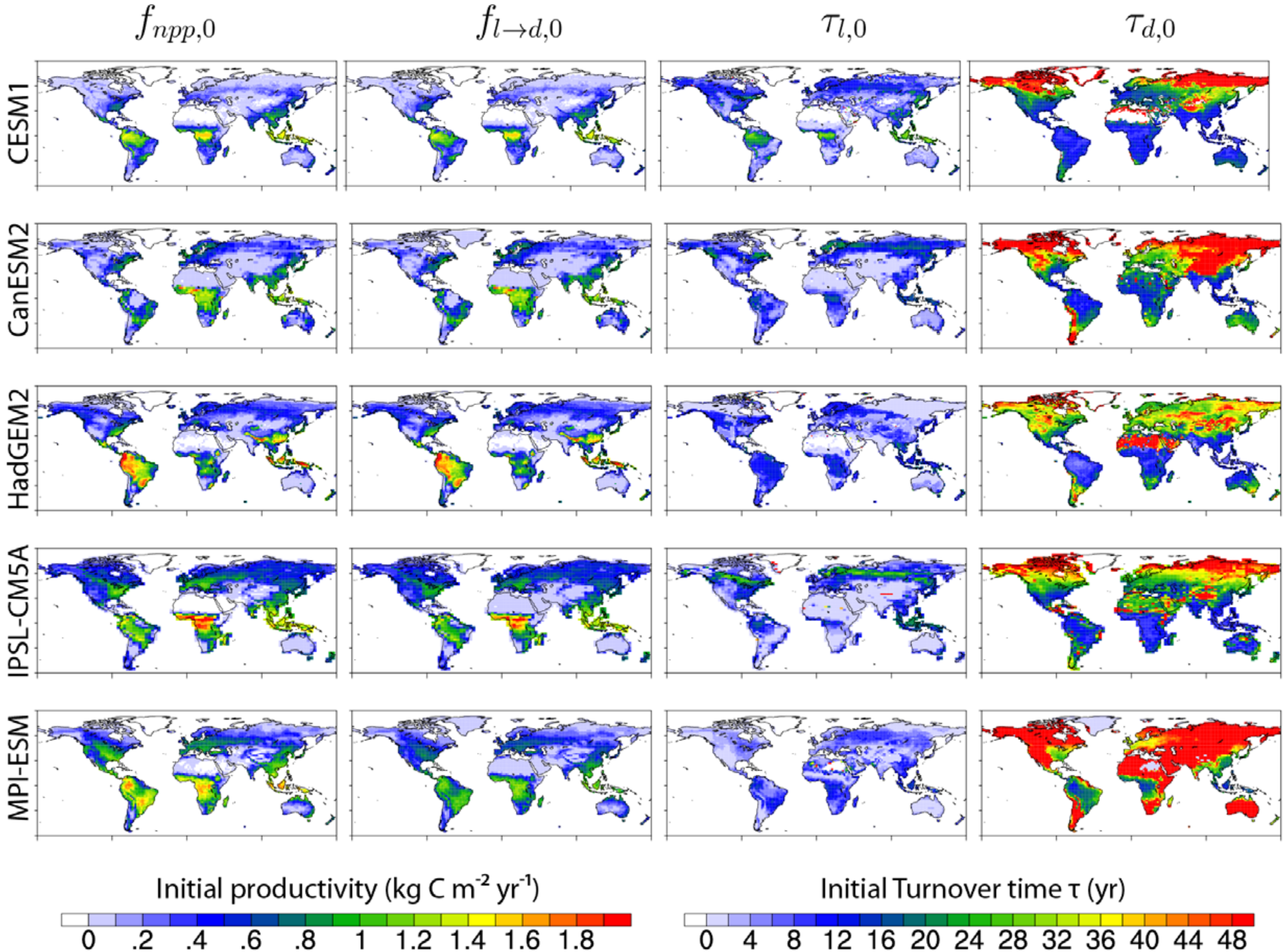
$$\widehat{C_d} = f_{l\rightarrow d}\tau_d$$

$$\frac{d\widehat{C_d}}{dt} = \frac{df_{l\rightarrow d}}{dt}\tau_d + \frac{d\tau_d}{dt}f_{l\rightarrow d}$$

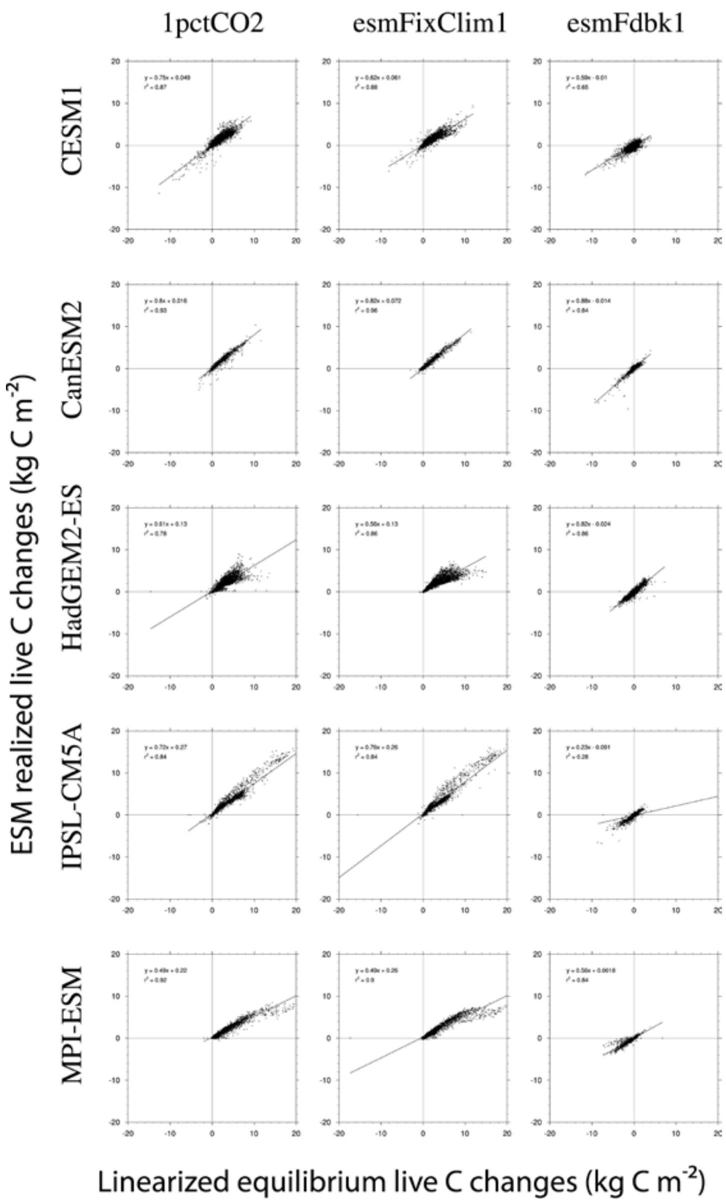
Productivity-driven Dead C change

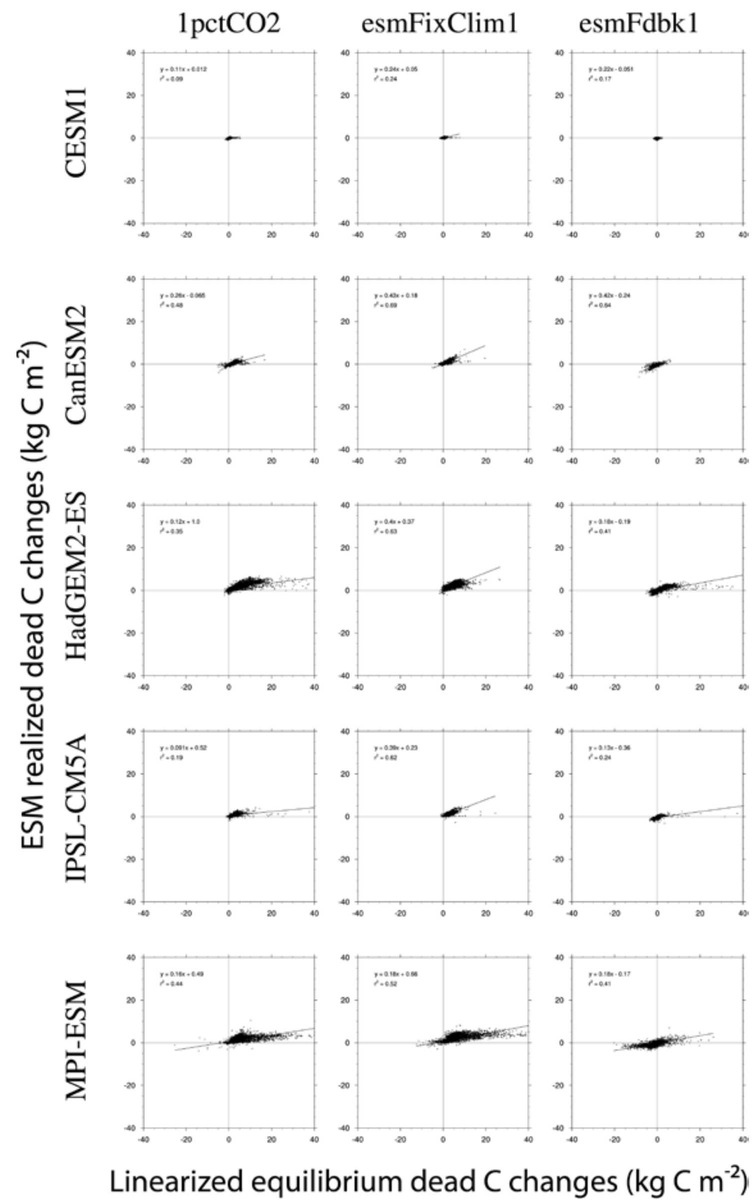
Turnover-driven Dead C change

Initial NPP and turnover times



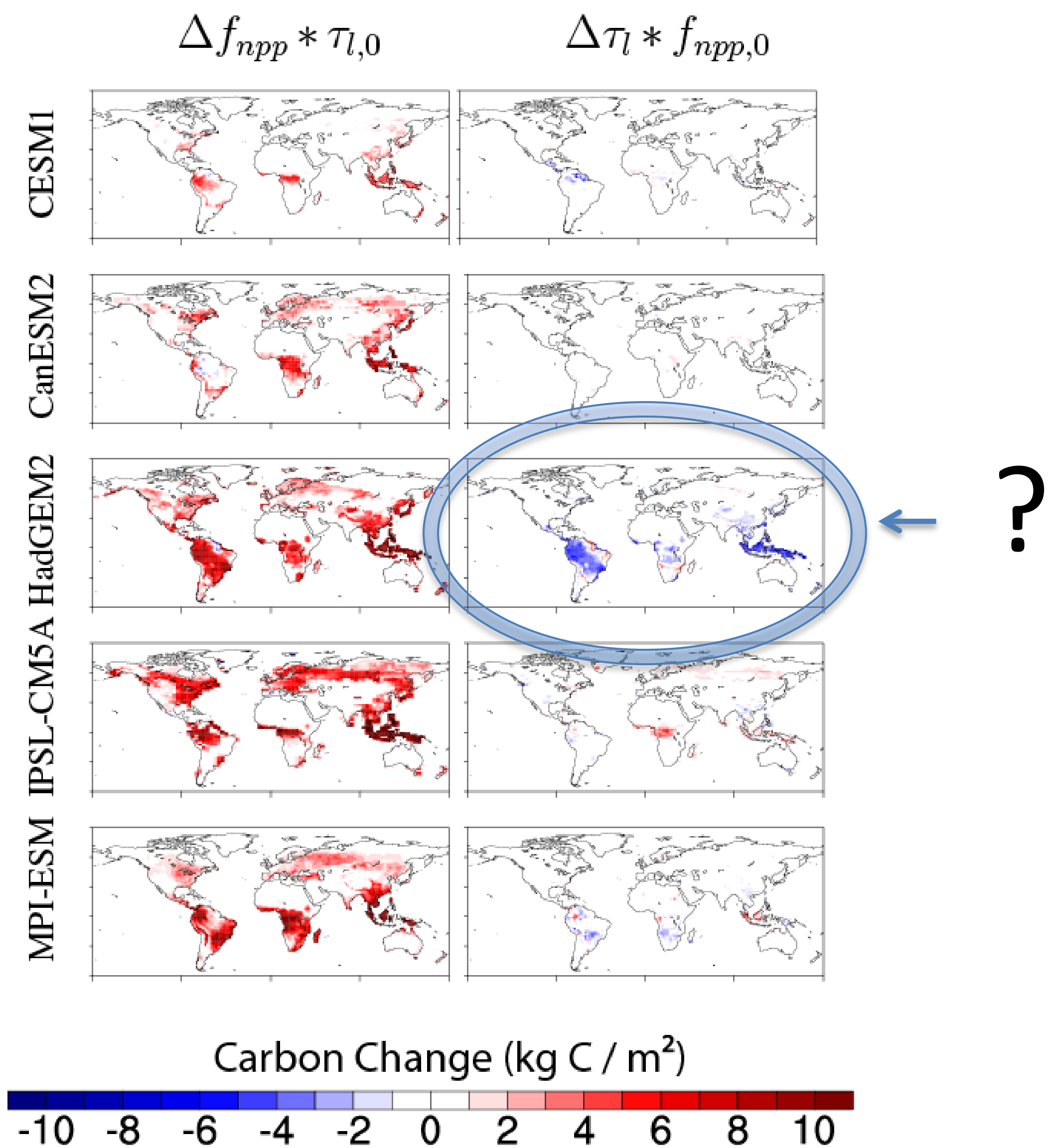
Does this approach work?



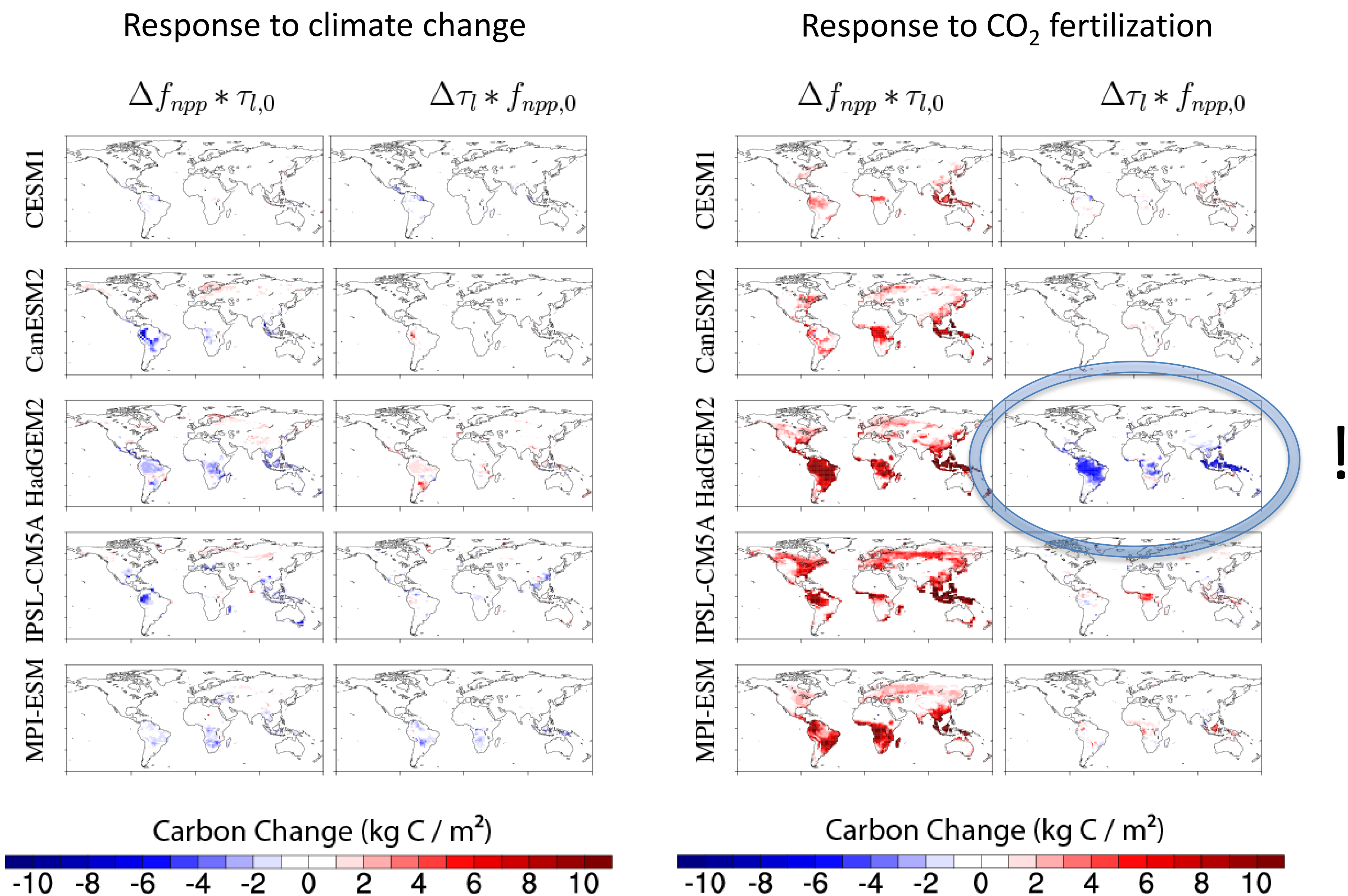


Answer: Yes, but better for live than dead C pools

C response in veg pools: mostly driven by NPP, with one exception

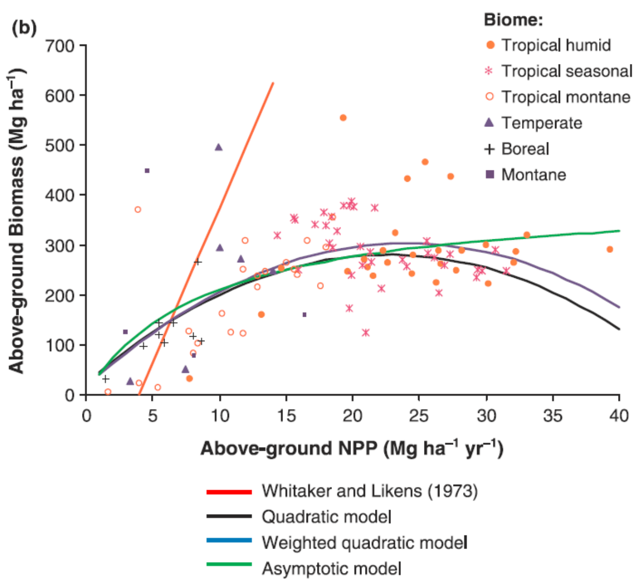


What is driving changes: climate or CO_2?



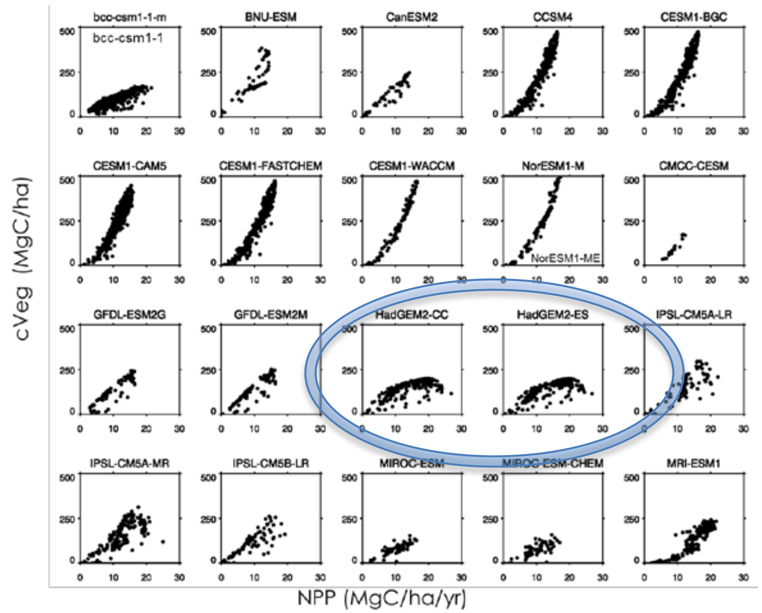
Note that HadGEM is the only one to get the right shape to the tau-productivity relationship as seen in observations

Observations



Keeling and Phillips, 2007

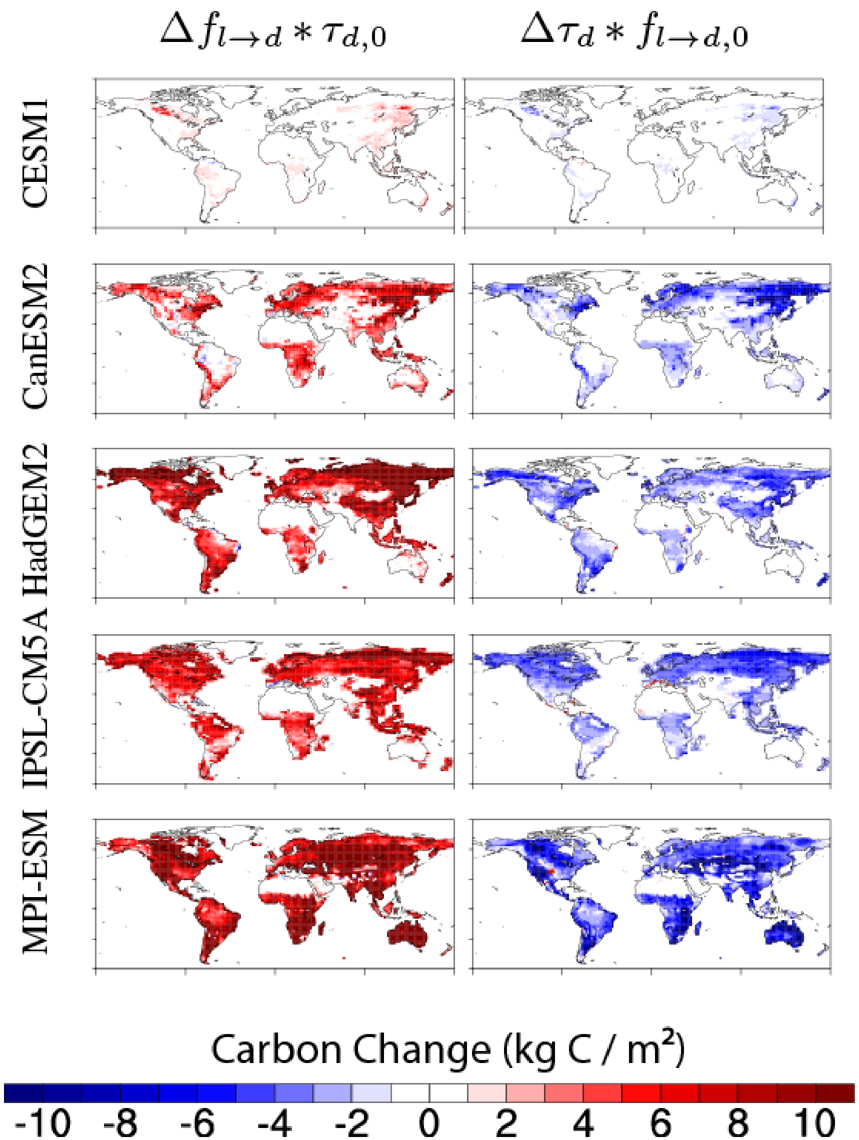
CMIP5 ESMs



Negron-Juarez et al., *submitted*

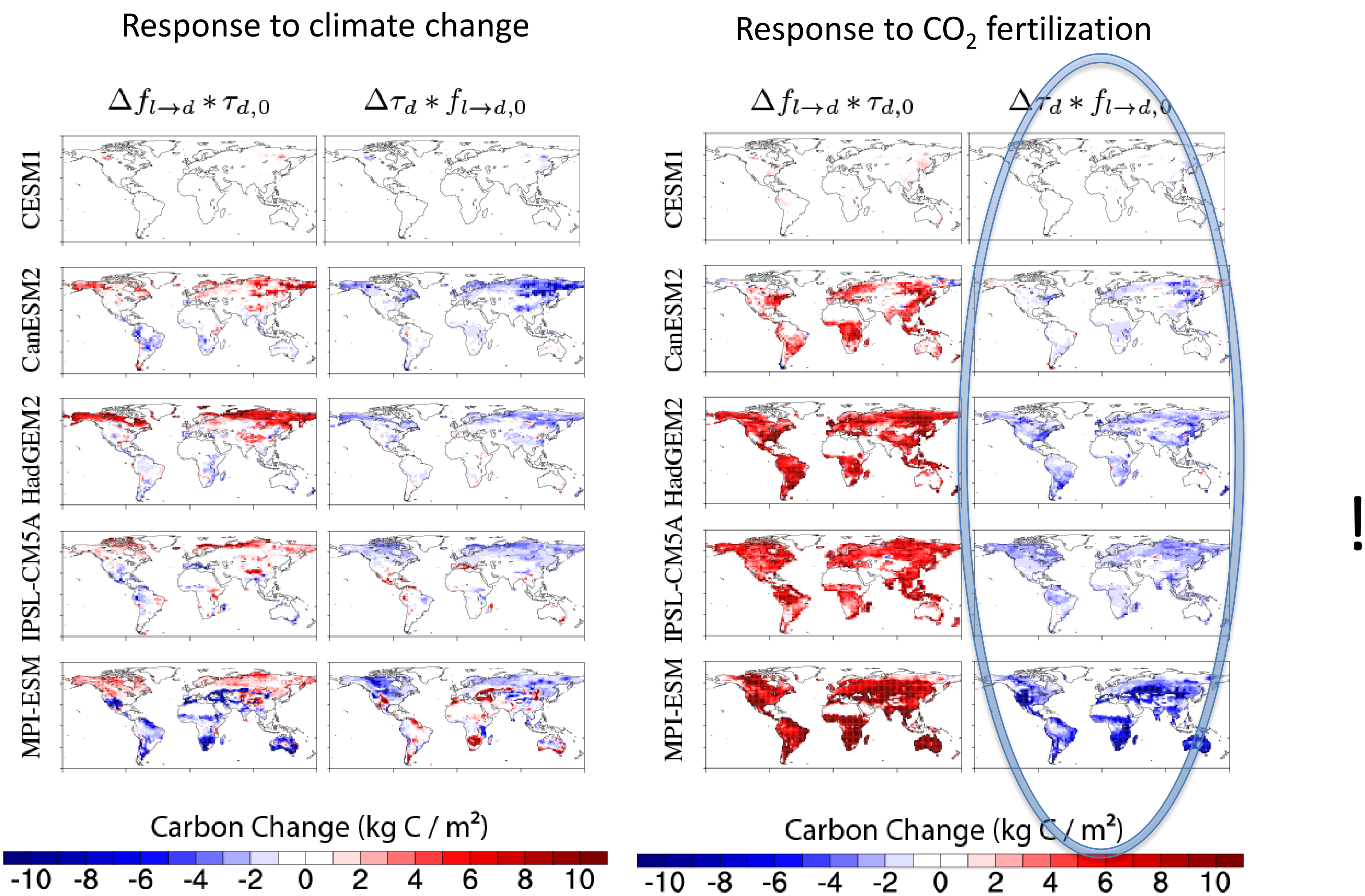
So the real question, which none of these models address, is: do the mechanisms that cause turnover times to be anti-correlated with productivity across spatial gradients also hold for the change in time, particularly for the case of elevated CO_2?

C response in dead pools: productivity increases, turnover times decrease. Makes sense, right? But wait… why are the (anti-)correlations so strong?

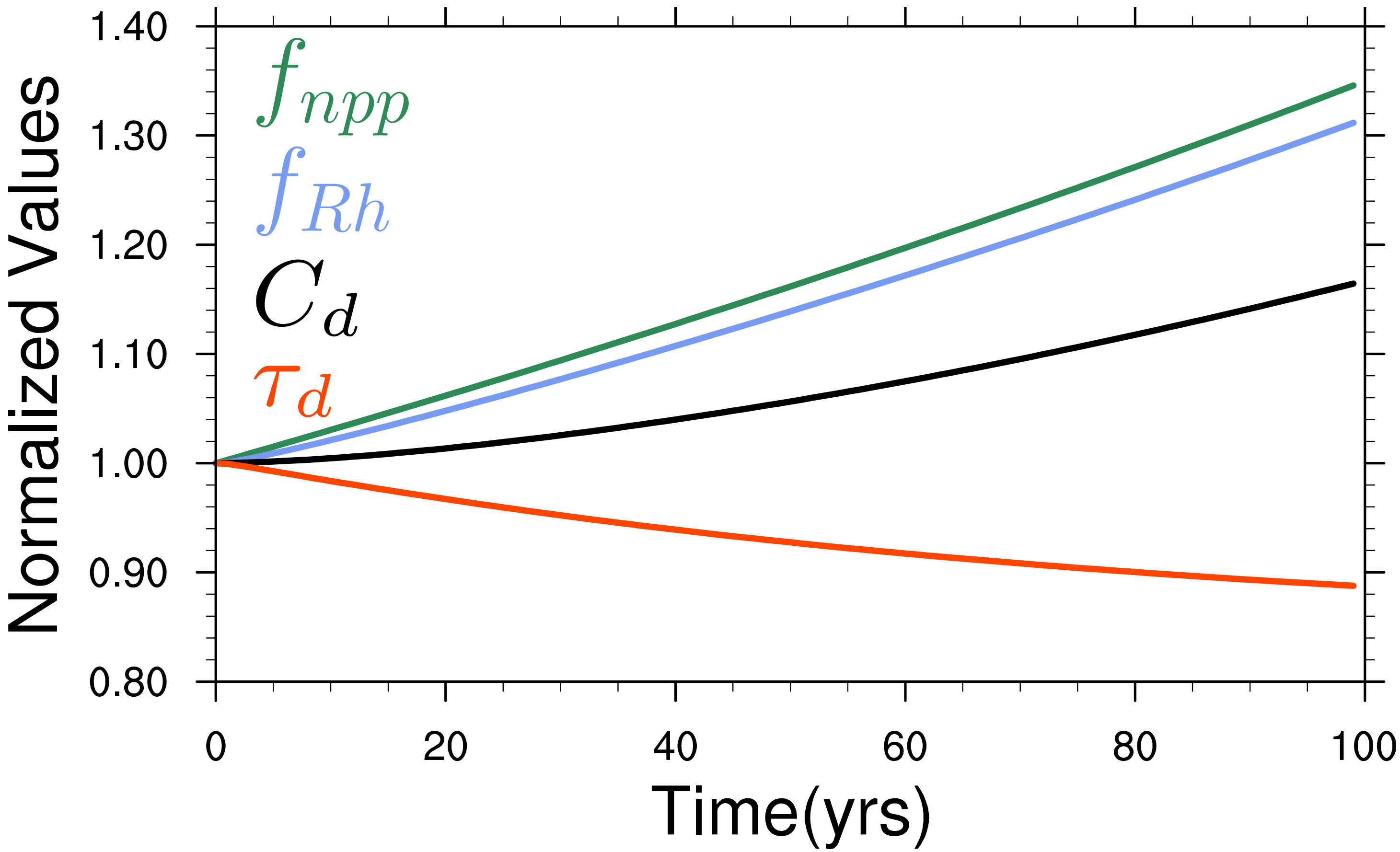


?

OK, need to look at the singly-coupled runs again



“False Priming”



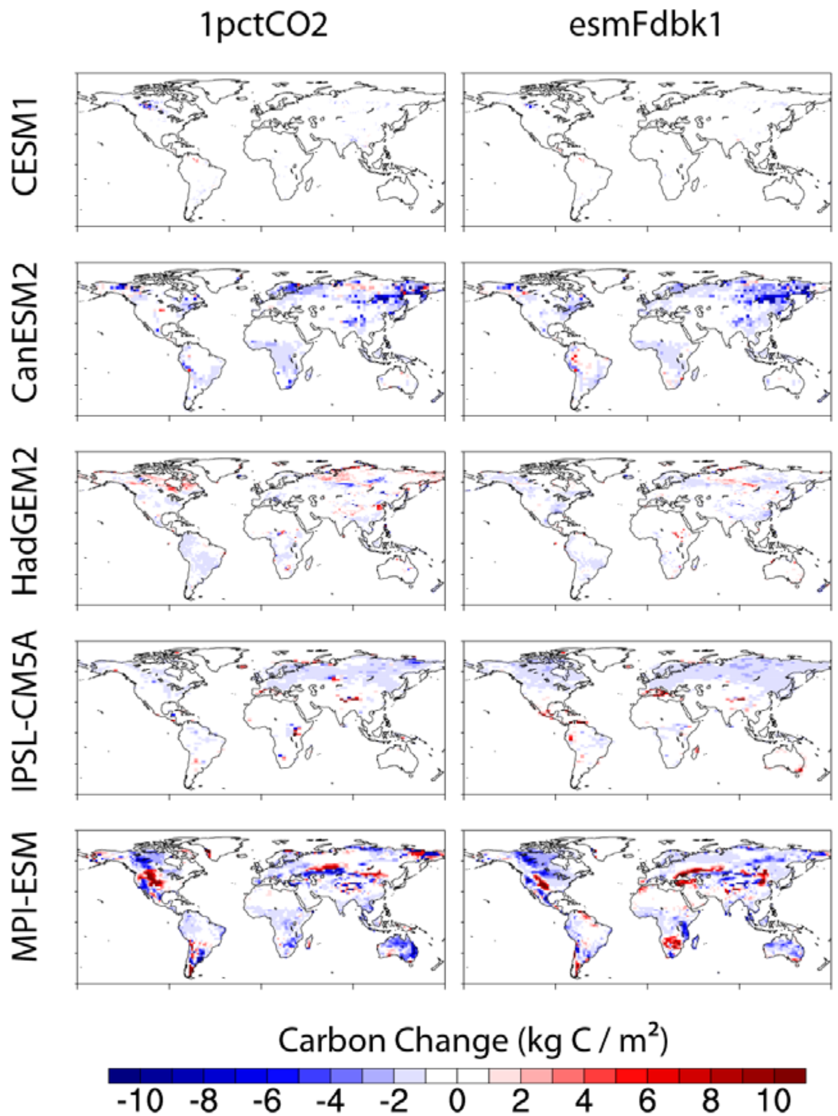
Toy model experiment: take a multi-pool model (here 3 pool) with fixed turnover times for each pool. Start from steady-state and increase the inputs. What happens to the bulk turnover time?

Subtract false priming to get "real" turnover-driven dead C changes

- Define False Priming constant as ratio of changes to turnover over changes in productivity

$$c_{fp} = \frac{\Delta \tau_d f_{l \to d,0}}{\Delta f_{l \to d} \tau_{d,0}} = \frac{\Delta \tau_d / \tau_{d,0}}{\Delta f_{l \to d} / f_{l \to d,0}}$$

- Diagnose False Priming constant in BGC-coupled runs.
- Use to identify climate control in fully-coupled and radiatively-coupled runs
- Result: Δ turnover from climate smaller than it originally looked



Last step: separate contributions to uncertainty from initial conditions versus proportional change

- Define initial and change terms:

$$f_{NPP,0}, \tau_{l,0}, \frac{\Delta f_{NPP}}{f_{NPP,0}}, \frac{\Delta \tau_l}{\tau_{l,0}}, f_{l\rightarrow d,0}, \tau_{d,0}, \frac{\Delta f_{l\rightarrow d}}{f_{l\rightarrow d,0}}, \frac{\Delta \tau_d}{\tau_{d,0}}$$

- For each of these, use each model for that term only, and multi-model ensemble mean for all other terms; spread in results is therefore due to the ensemble uncertainty in that spread

Overall process contributions to uncertainty

- Initial condition uncertainty is large and dominated by model disagreement on turnover times
- Transient uncertainty is dominated by model disagreement on changes to productivity
- Holds for both response to warming and CO_2 fertilization
- Holds for both live and dead C pools

Equilibrium Terrestrial C Change (Pg C)

$_{,0}$ $\frac{\Delta\tau_d}{\tau_{d,0}}$

$f_{npp,0}$ $\tau_{l,0}$

Conclusions

- Real uncertainty due changes in productivity, both under climate change and CO2 fertilization. Nutrients, optimal temperature for photosynthesis, etc. are really unknown.
- False uncertainty due to initial productivity and turnover times. These are measurable. Benchmark!
- False certainty that the change in live C turnover times is small. Models need to include dynamics of mortality and allocation to assess their role in governing C changes. *In particular for changing CO_2 effects!*
- Soil C is a bit of a mess. We strongly suspect that priming effects, mineral surface limitation, etc. are real; none of the models include them and they need to. But there are confounding issues we need to deal with, as evidenced by the false priming effect.
- That said, these models also don't include the permafrost C dynamics, so are missing the most vulnerable turnover-driven soil pool. Will change for CMIP6.