Using Observed Carbon Residence Times to Improve Simulation of Total CO_2 and $^{13}CO_2$ Land Carbon Fluxes

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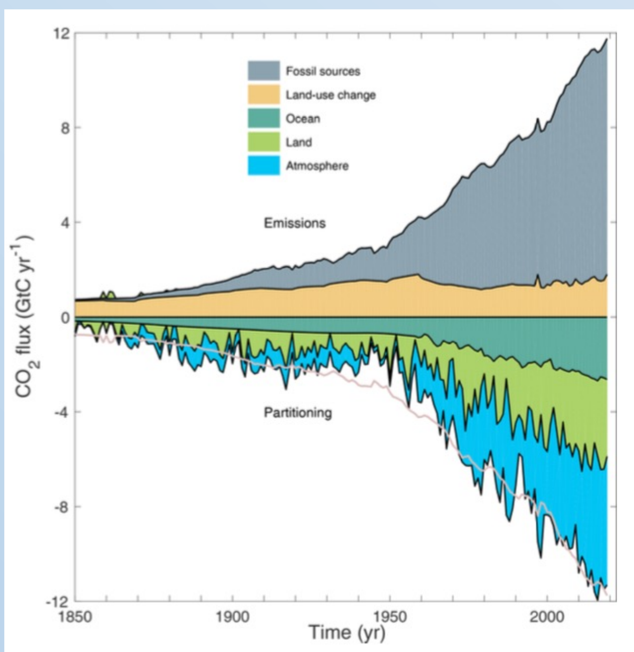
Summary

- We optimized a biosphere model (SiB4) based on observations of carbon residence times. The new model shows:

1. better correspondence with observed residence times for vegetation and soil
2. better agreement with the global atmospheric C13 growth rate
3. improved performance when benchmarked using observed carbon and water cycle variables

Background

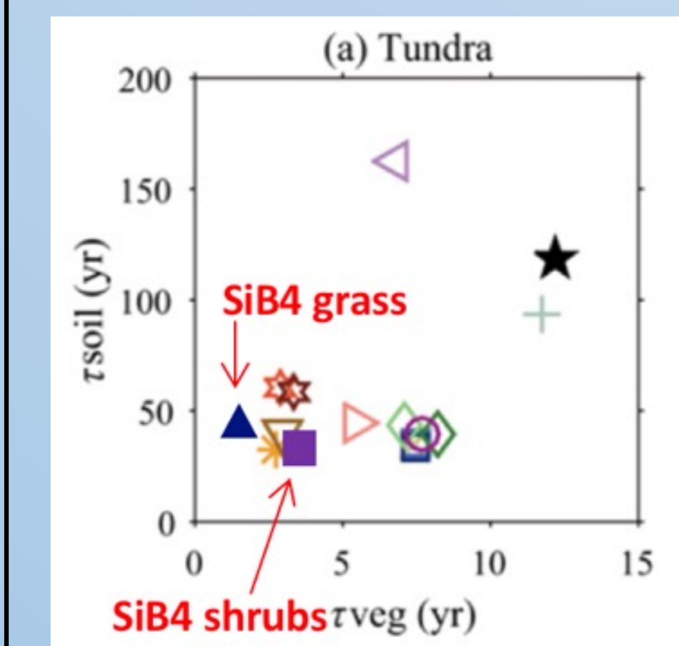


- CO_2 Airborne fraction is strongly tied to variability and uncertainty from land processes
- Variations in δ13C-CO_2 are related to plant stomatal conductance which is linked to carbon, water and energy fluxes
- Improving representation of these fluxes will aid predictability of future airborne fraction and impacts of climate change

$$\delta^{13}C = \left(\frac{R_{spl}}{R_{std}} - 1\right) x\ 1000 \quad ; \quad R = \frac{^{13}C}{^{12}C}$$

$$\Delta PS_{C_3} = \Delta_b\left(\frac{C_a - C_s}{C_a}\right) + \Delta_s\left(\frac{C_s - C_i}{C_a}\right) + (\Delta_{diss} + \Delta_{aq})\left(\frac{C_i - C_c}{C_a}\right) + (\Delta_f)\frac{C_c}{C_a}$$

(2.9‰, 4.4‰, 1.1‰, 0.7‰, 28.2‰, $r_s A_n \times p$)



- Most earth system models underestimate carbon pool turnover times (Wu et al. 2018)

$$Respiration \approx \frac{1}{alpha * \tau_{pool}} * C_{pool}$$

scalar adjustment per PFT

$$\tau_{soil} = {}^{C_{soil}}/_{NPP}\ ;\ C_{soil} = soil + litter$$

$$\tau_{veg} = {}^{C_{veg}}/_{NPP}\ ;\ C_{veg} = leaf + roots + stem/wood$$

References

Haynes, K.D., I.T. Baker, A.S. Denning, R. St¨ockli, K. Schaefer, E.Y. Lokupitiya, J.M. Haynes (2019). Representing ecosystems using dynamic prognostic phenology based on biological growth stages: Part 1. Implementation in the Simple Biosphere Model (SiB4). J Adv Mod Earth Sys, 11, 4423-4439 https://doi.org/10.1029/ 2018MS001540.

Haynes, K.D., I.T. Baker, A.S. Denning, S. Wolf, G. Wohlfahrt, G. Kiely, R.C. Minaya (2019). Representing ecosystems using dynamic prognostic phenology based on biological growth stages: Part 2. Grassland carbon cycling. J Adv Mod Earth Sys, 11, 4440-4465. https://doi.org/10.1029/ 2018MS001541

Wu, D., S. Piao, Y. Liu, P. Ciais, Y. Yao (2018) Evaluation of CMIP5 Earth System Models for the spatial patterns of biomass and soil carbon turnover times and their linkages with climate. J Clim., 31, 5947-5960. https://doi.org/10.1175/JCLI-D-17-0380.1

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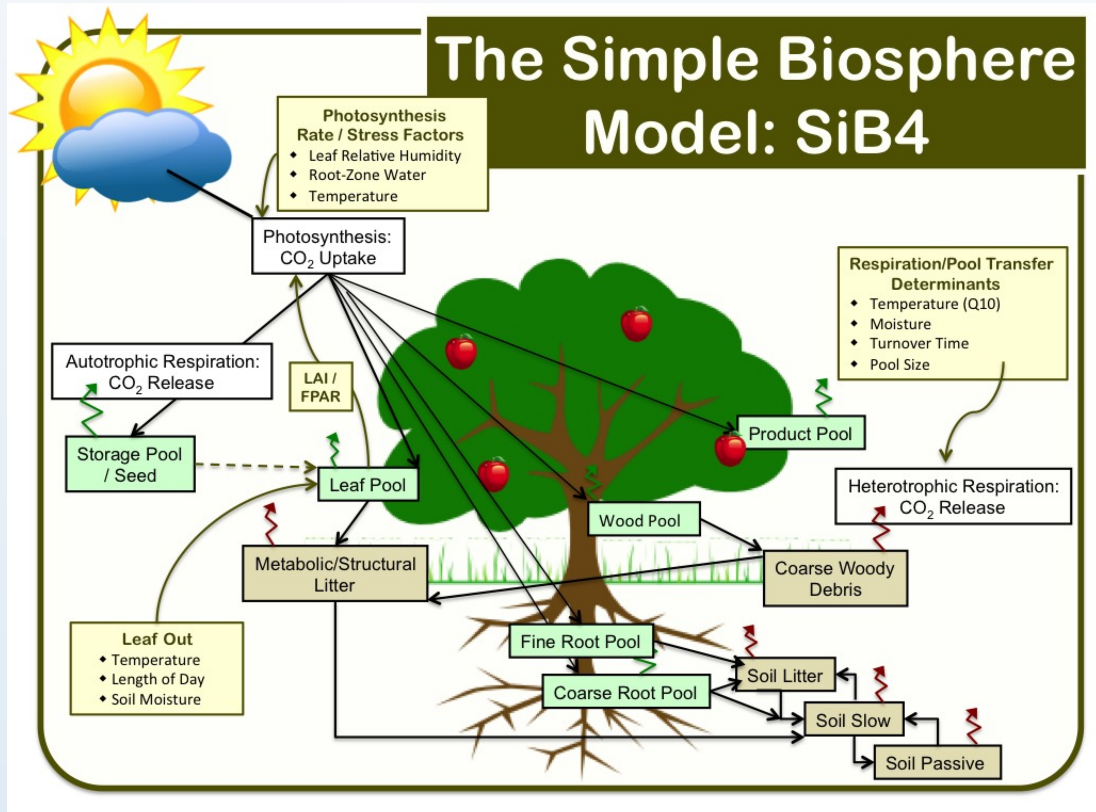
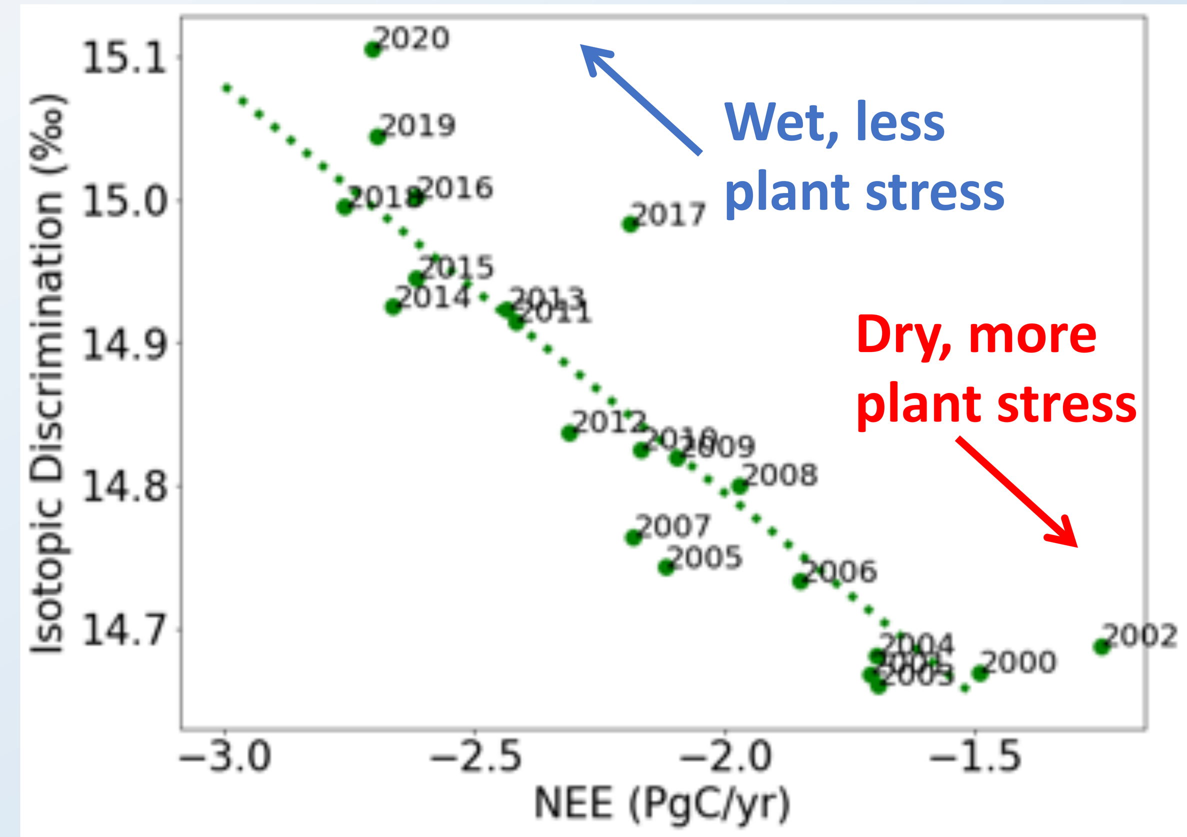
Simulating $^{13}CO_2$ with the Simple Biosphere Model v4.2

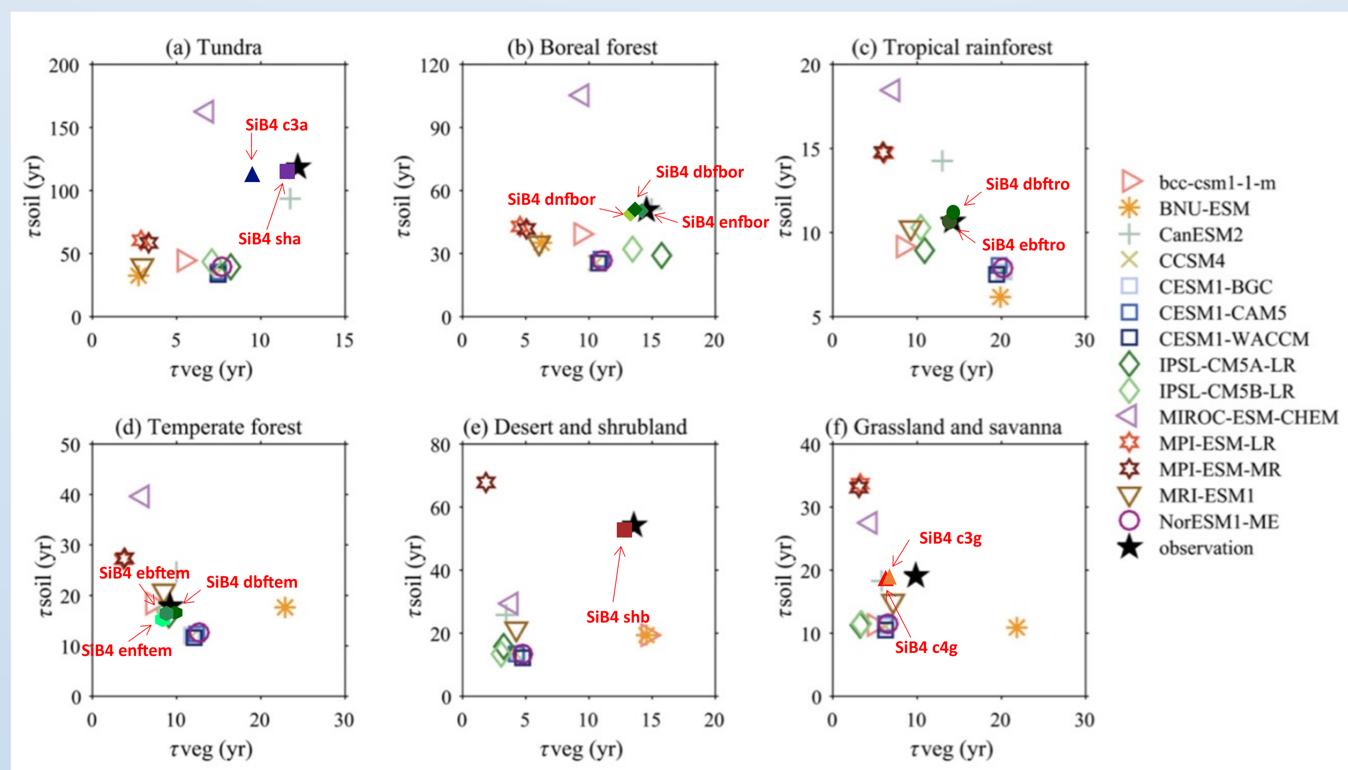


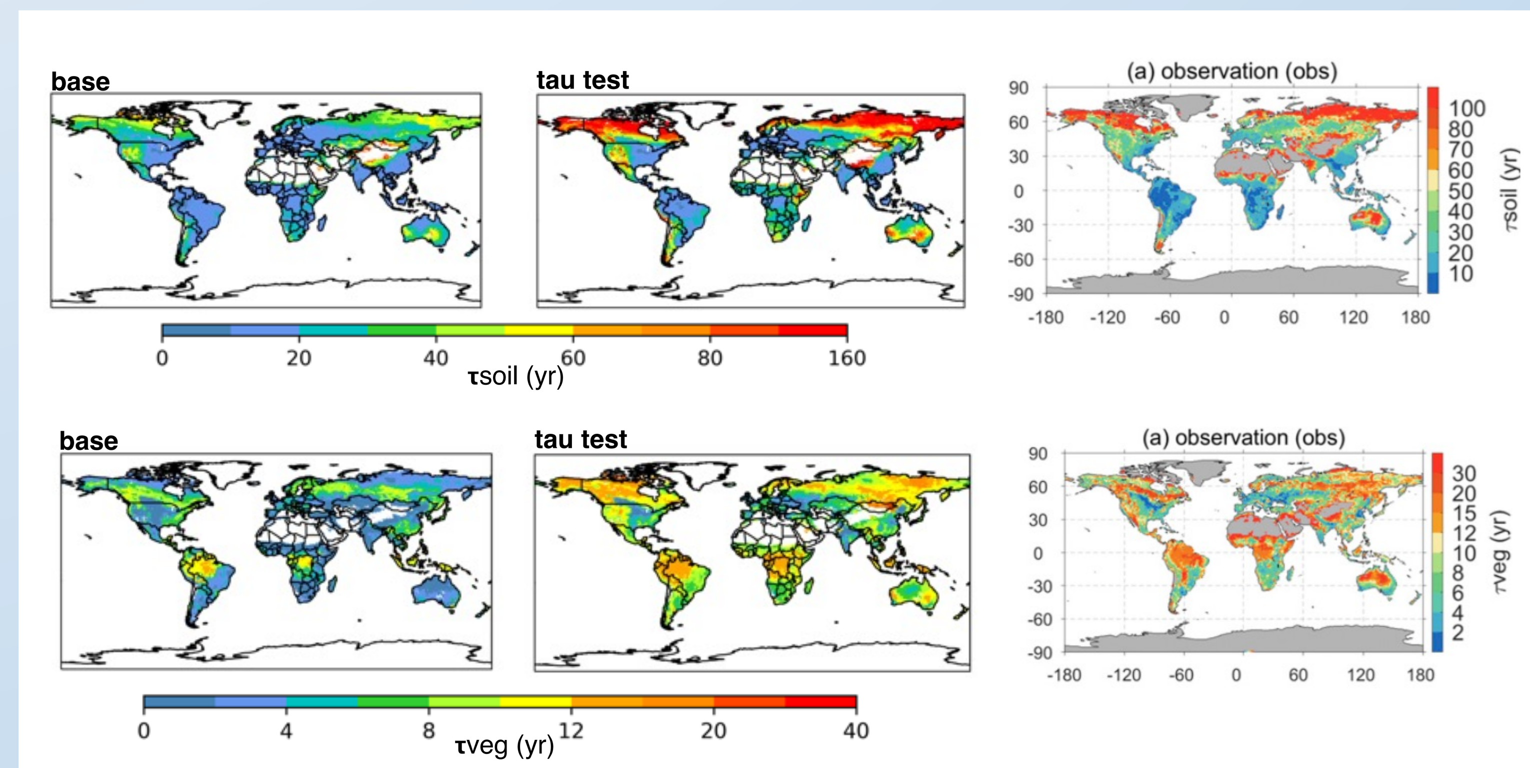
- SiB4 produces carbon cycle fluxes driven by 0.5-degree MERRA2 reanalysis climatology (Haynes et al., 2019 a,b)
- Carbon-13 was simulated by implementing a parallel pool structure & fractionation during photosynthesis
- Stomatal conductance is impacted by water stress, so isotopic fractionation should be a tracer for water stress
- Isotope simulations were run from 1850-2020 and used atmospheric δ^{13}C-CO_2 and CO_2 observations as background conditions



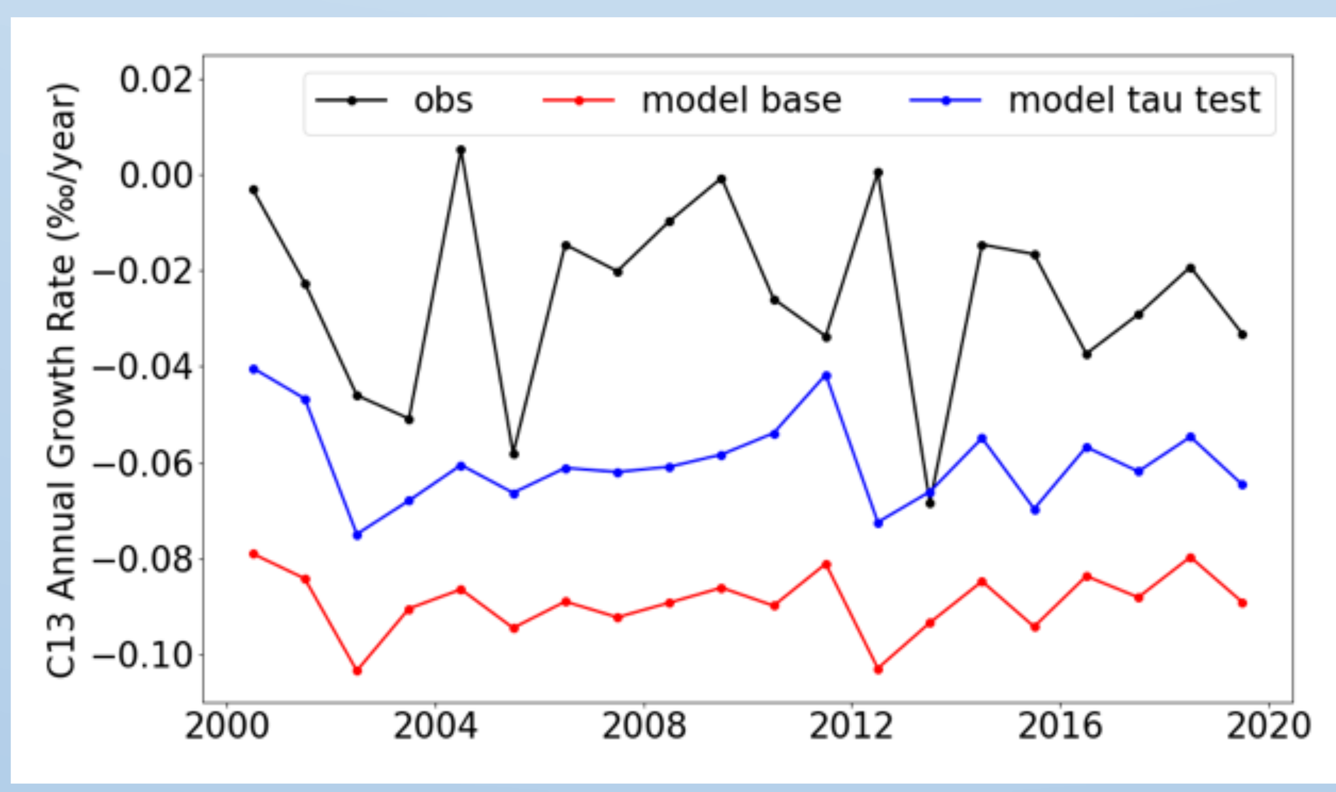
Results

1. Optimized SiB4 shows better correspondence with vegetation and soil carbon turnover times for both mean and spatial values





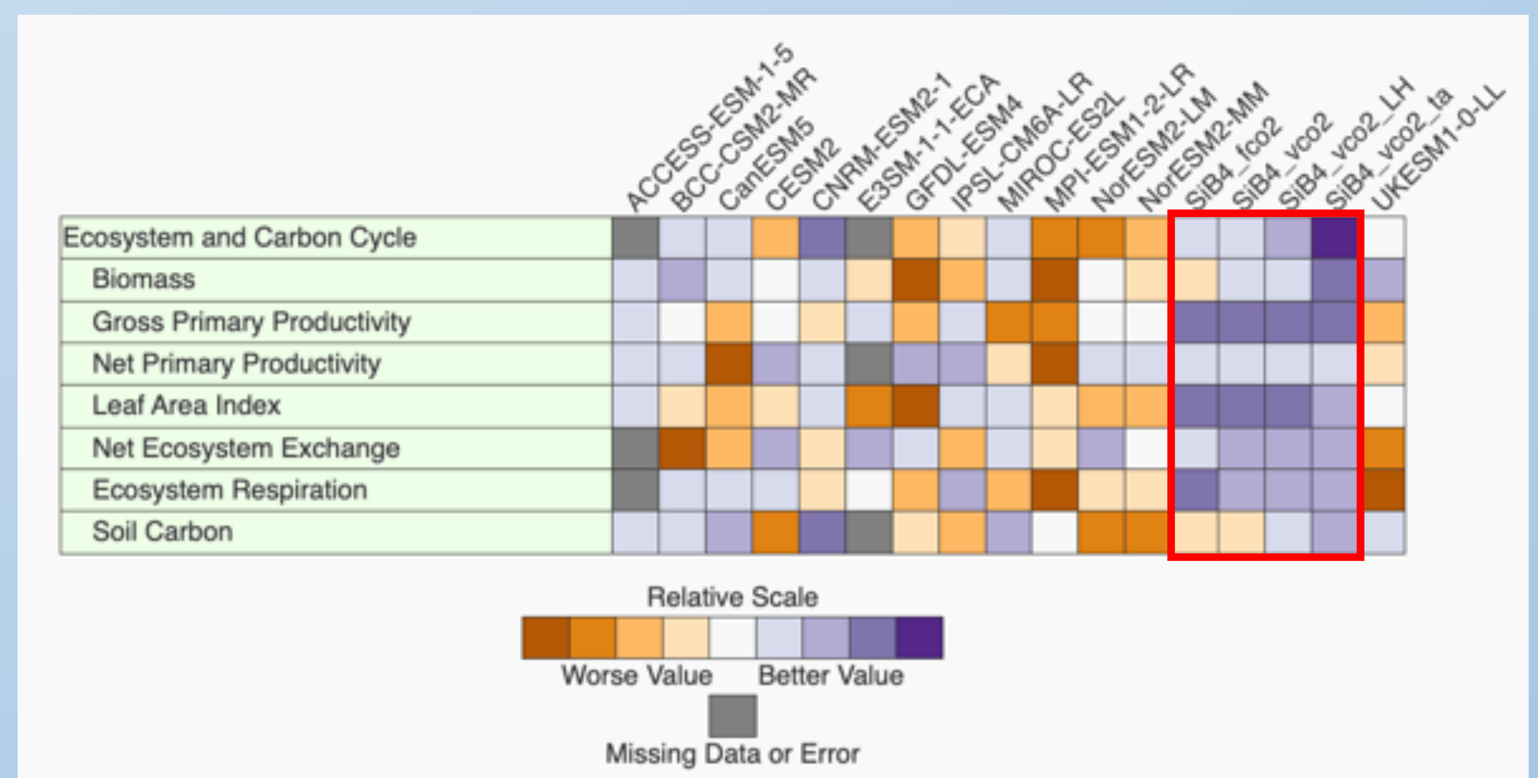
2. Optimized SiB4 results in better agreement with global atmospheric C13 growth rate observations



Atmospheric δ^{13}C signal ≈ Fossil + Net land + Land diseq. + Fire + Net ocean + Ocean diseq.

49 ± 7 % gain

3. SiB4 models show better agreement with observed carbon cycle datasets for 2000-2014 compared to CMIP6 models



The optimally tuned version (*SiB4_vco2_ta*) shows the most improvement in agreement for vegetation and soil carbon biomass compared to other SiB4 variants