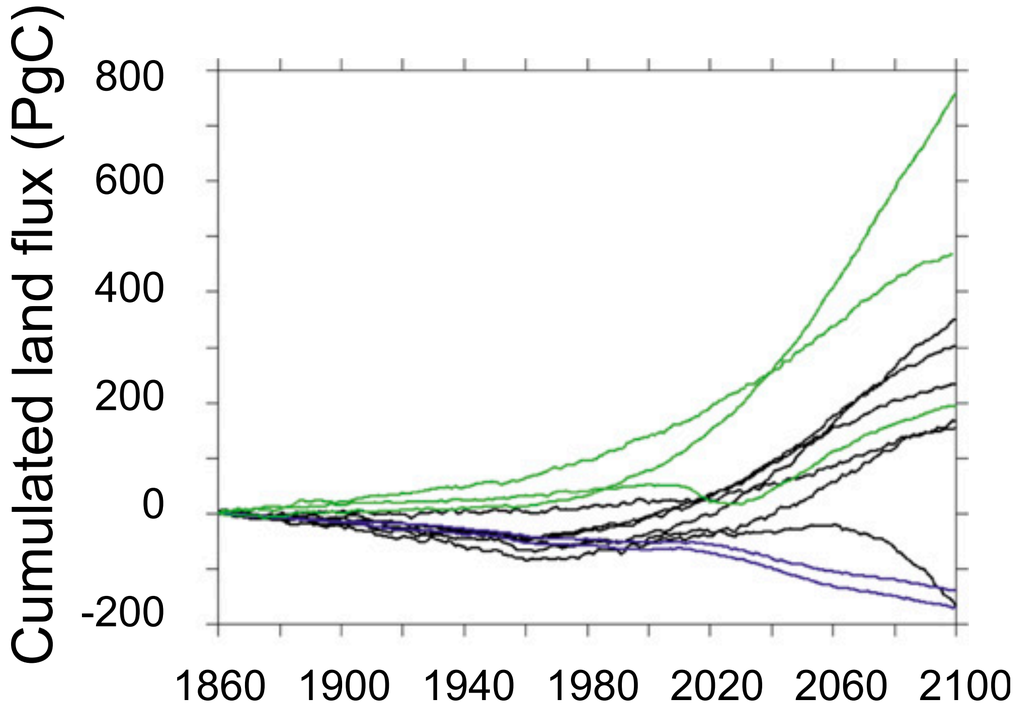
Global radiocarbon observations for calibration and validation of Earth system models

Paul Levine[1], James Randerson[1], Qing Zhu[2], William Riley[2], Alison Hoyt[2,3] Susan Trumbore[1,3], Zheng Shi[4], Steven Allison[1,4], Forrest Hoffman[5], and the International Soil Radiocarbon Database (ISRaD) Team[6]

1. Department of Earth System Science, University of California, Irvine
2. Climate Sciences Department, Earth & Environmental Sciences Area, Lawrence Berkeley National Laboratory
3. Department of Biogeochemical Processes, Max Planck Institute for Biogeochemistry
4. Department of Ecology and Evolutionary Biology, University of California, Irvine
5. Climate Change Science Institute and Computational Earth Science Group, Oak Ridge National Laboratory
6. Visit https://international-soil-radiocarbon-database.github.io/ISRaD/about/ for ISRaD credits

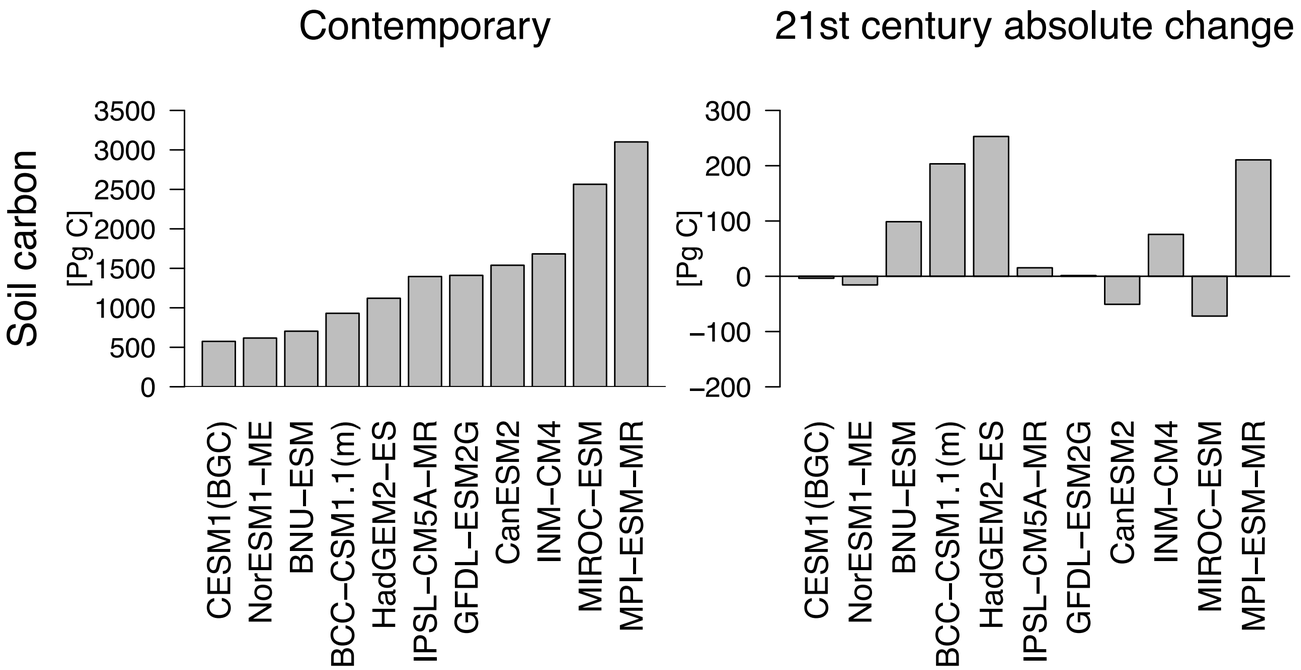
CESM Land Model and Biogeochemistry Working Group Meeting , Feburary 12, 2019

Soil organic carbon in Earth System Models



Cumulative terrestrial carbon flux projections from CMIP5 models

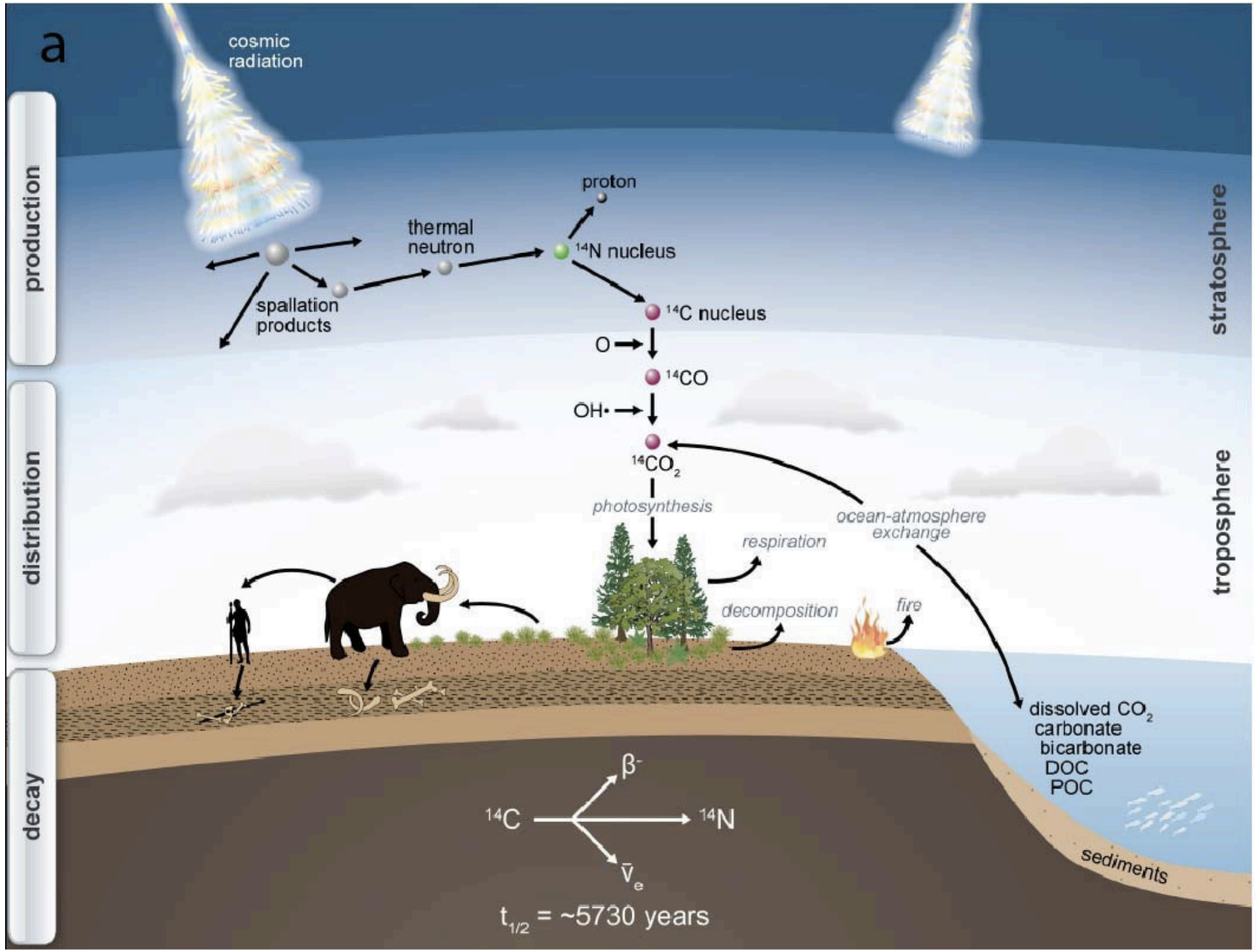
Friedlingstein et al, 2014, *J. Clim.*

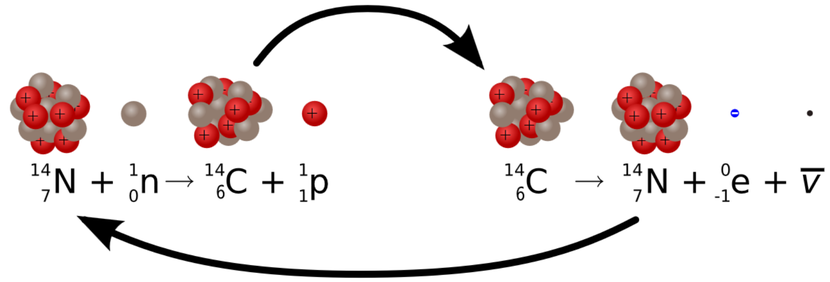


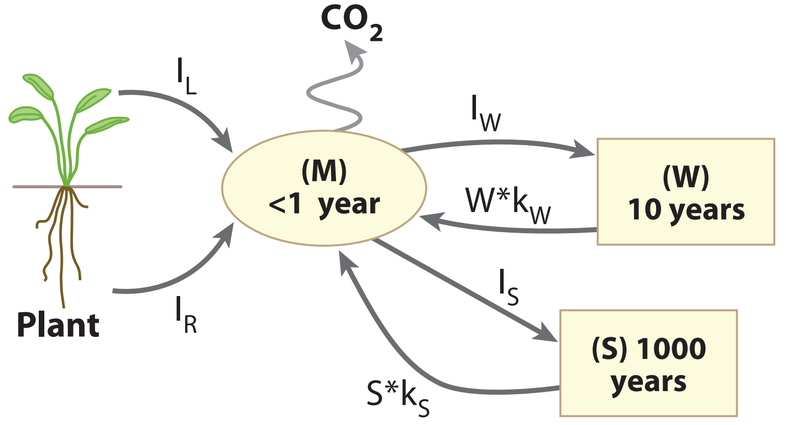
Contemporary soil carbon storage and 21st-century change in CMIP5 models

Todd-Brown et al, 2014, *Biogeosciences*

Global radiocarbon cycle

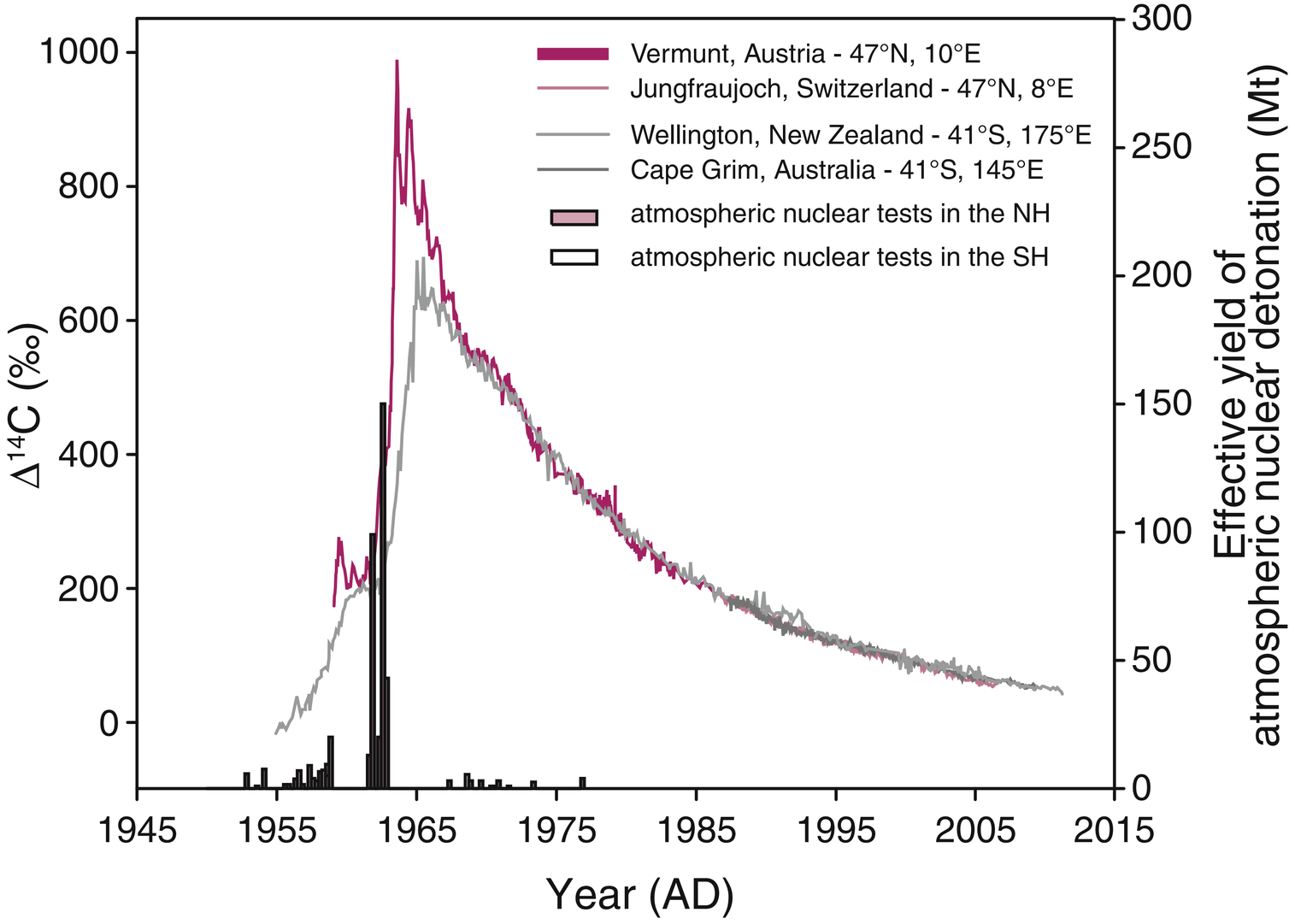


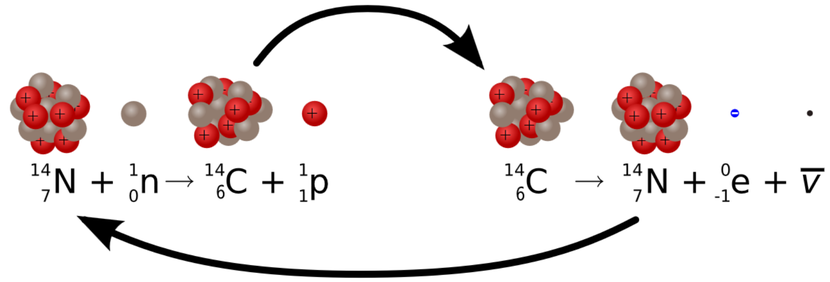


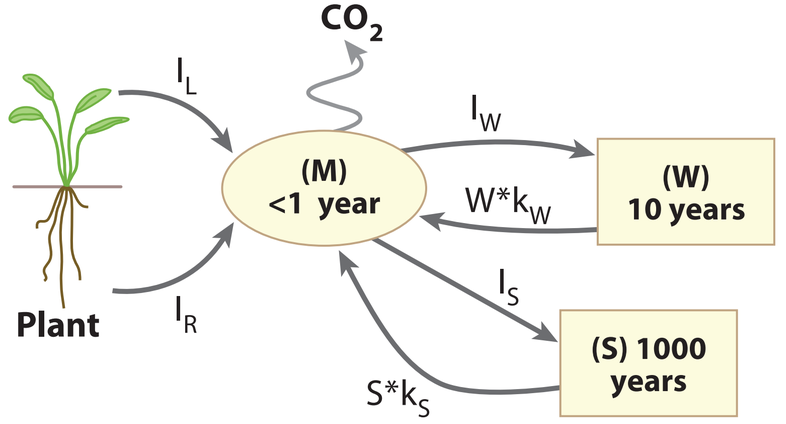


$$\Delta^{14}C = \left[\frac{\left[\frac{^{14}C}{^{12}C} \right]_{\text{sample},-25}}{0.95 \left[\frac{^{14}C}{^{12}C} \right]_{\text{OX1},-19} e^{\left((y-1950)/8267 \right)}} - 1 \right] 1000.$$

Global radiocarbon cycle

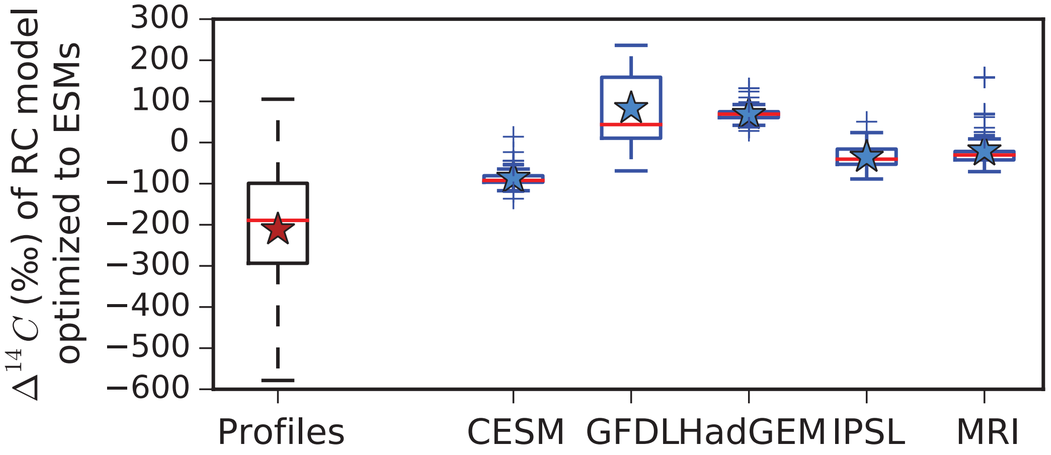




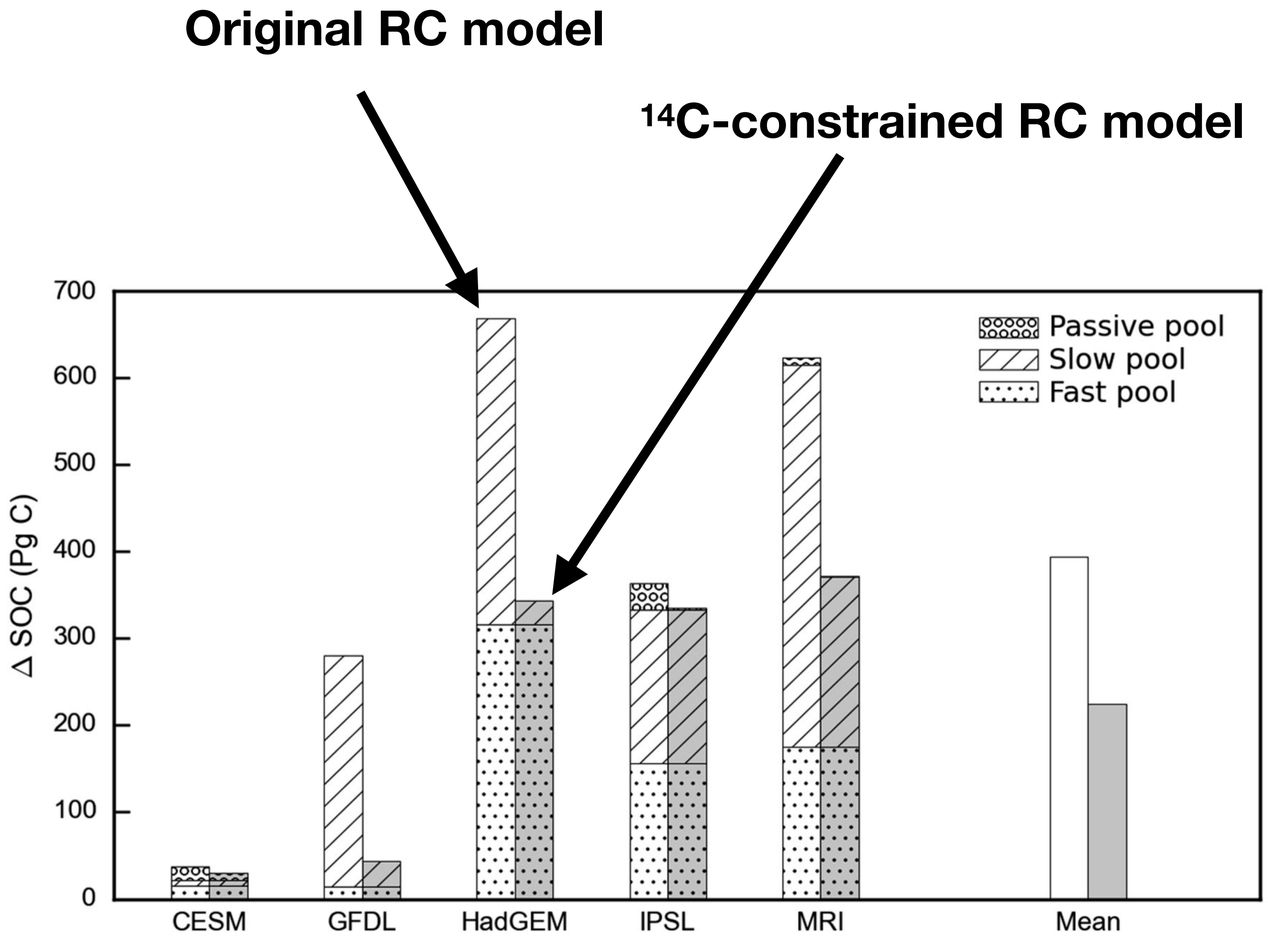


$$\Delta^{14}C = \left[\frac{\left[\frac{^{14}C}{^{12}C}\right]_{\text{sample},-25}}{0.95 \left[\frac{^{14}C}{^{12}C}\right]_{\text{OX1},-19} e^{\left((y-1950)/8267\right)}} - 1 \right] 1000.$$

Radiocarbon constraint on Earth System Models



Radiocarbon in observations and RC models

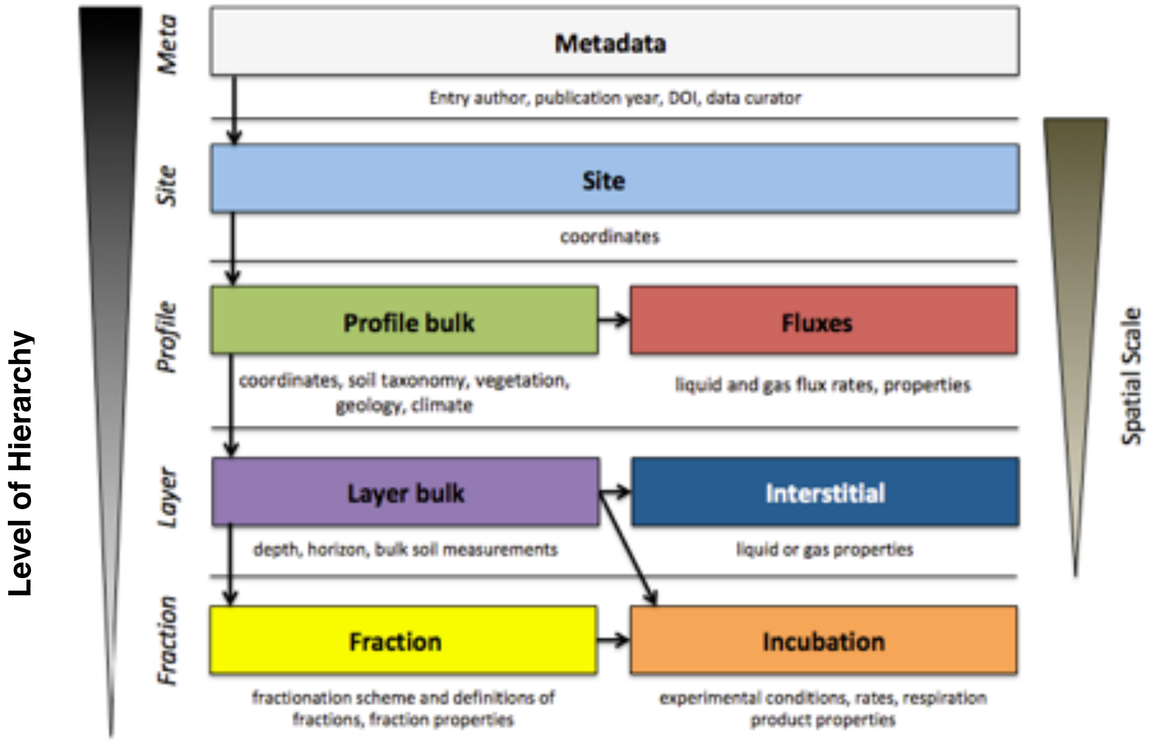


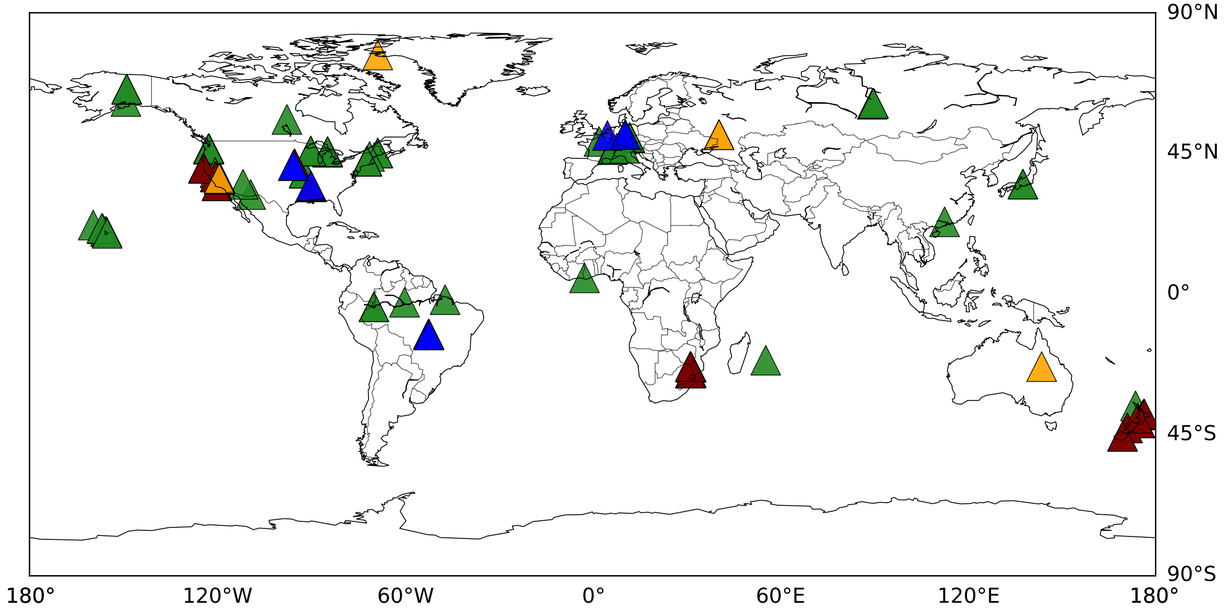
Soil carbon sink in original and constrained RC models

He et al, 2016, *Science*

International Soil Radiocarbon Database (ISRaD)

ISRaD
Int'l Soil Radiocarbon Database



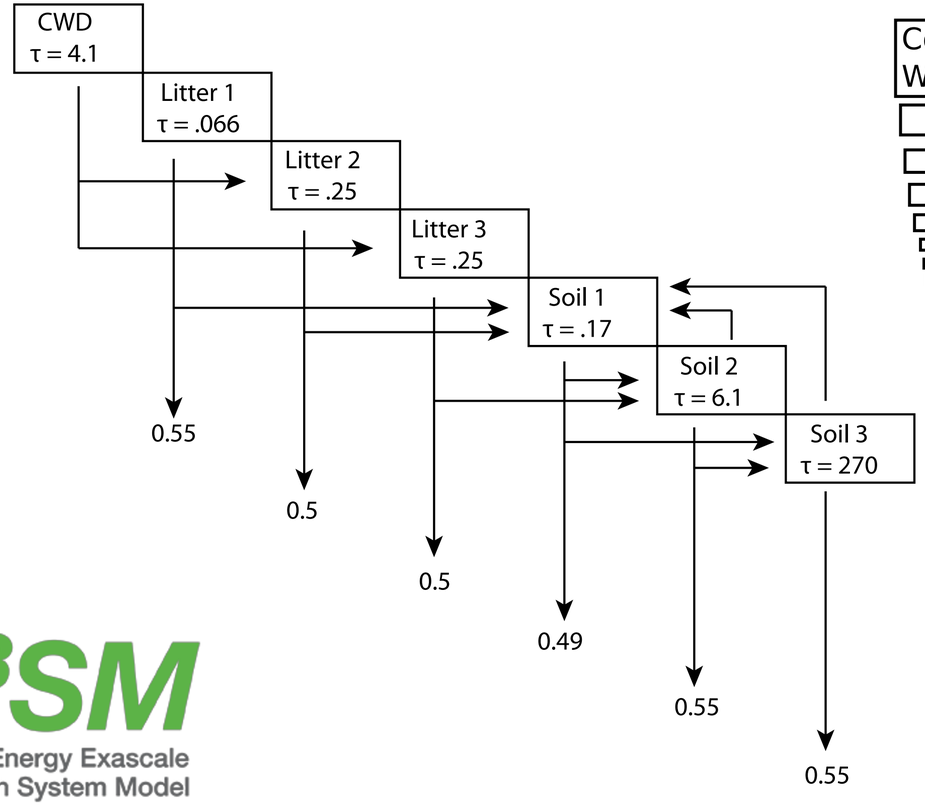


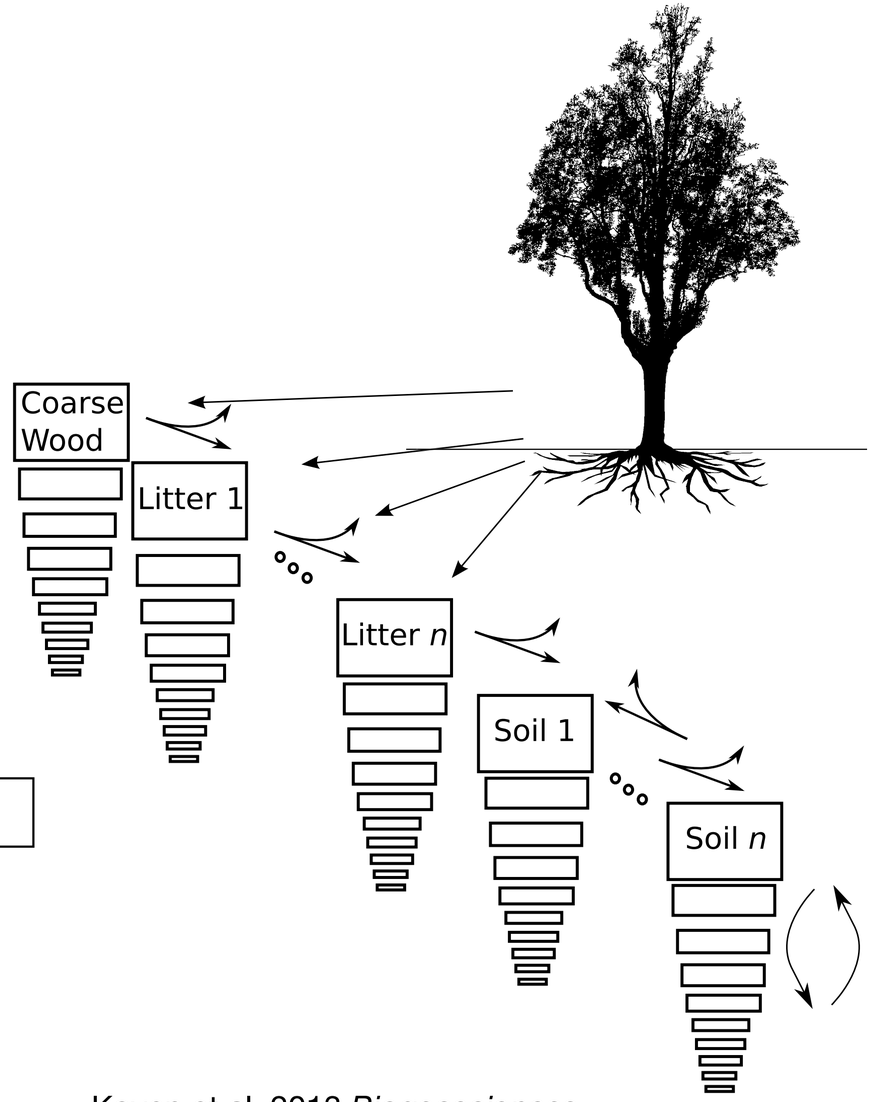
Latitude	> 50°	25-50°	< 25°
forest	13	49	18
grassland	0	19	22
shrubland	4	1	1
cultivated	3	4	4

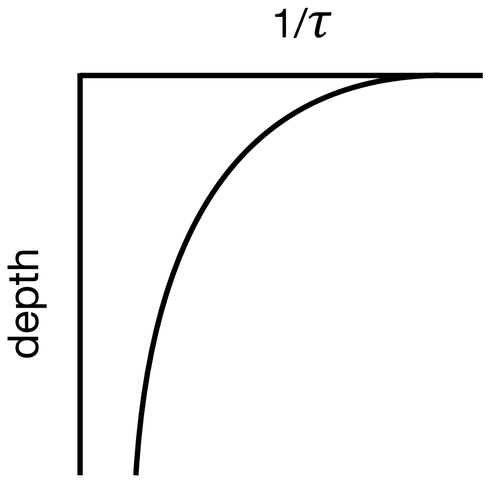
http://soilradiocarbon.org https://github.com/International-Soil-Radiocarbon-Database/ISRaD @soilradiocarbon

Energy Exascale Earth System Model (E3SM)

Century Soil C pool structure





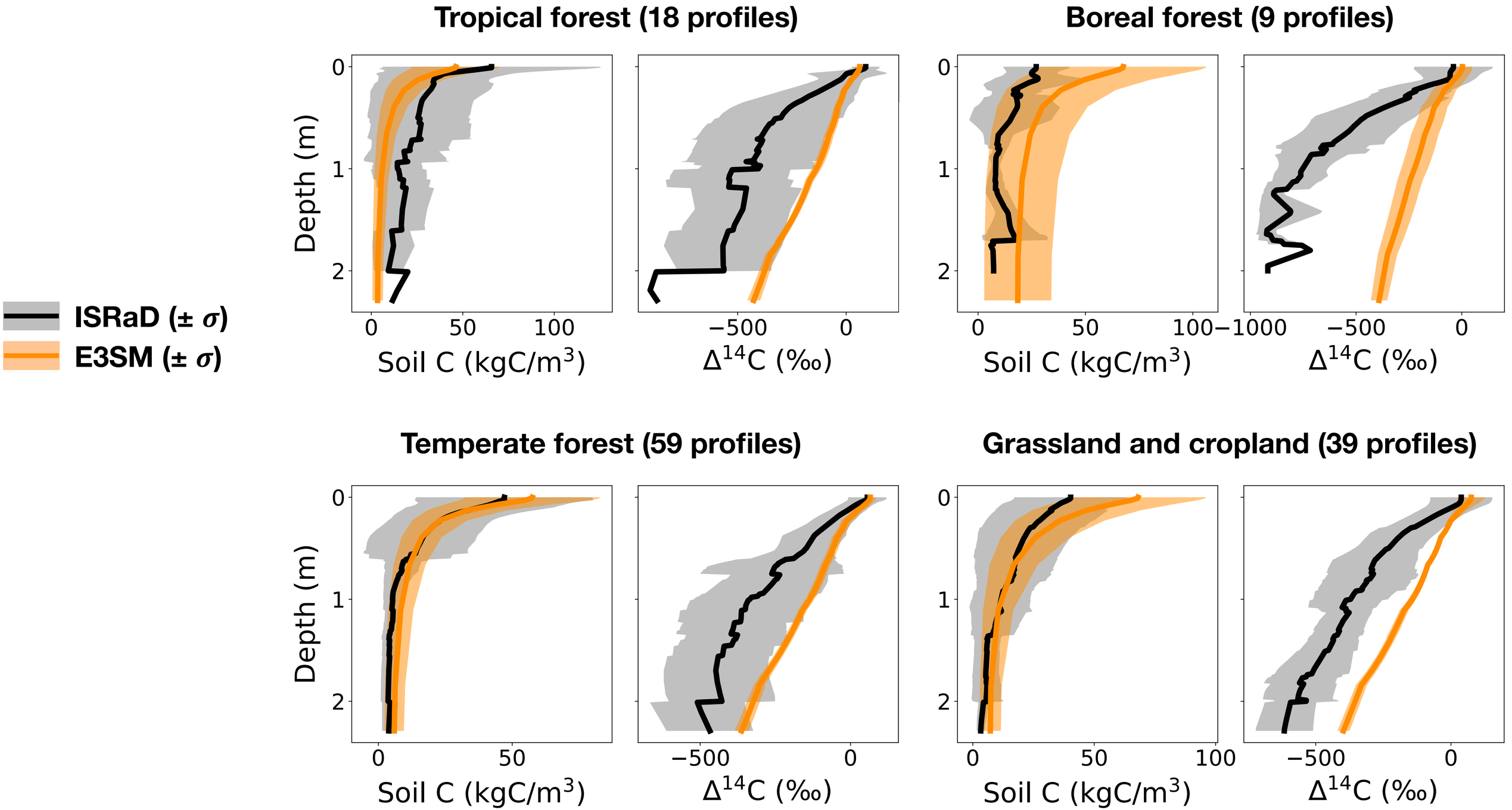


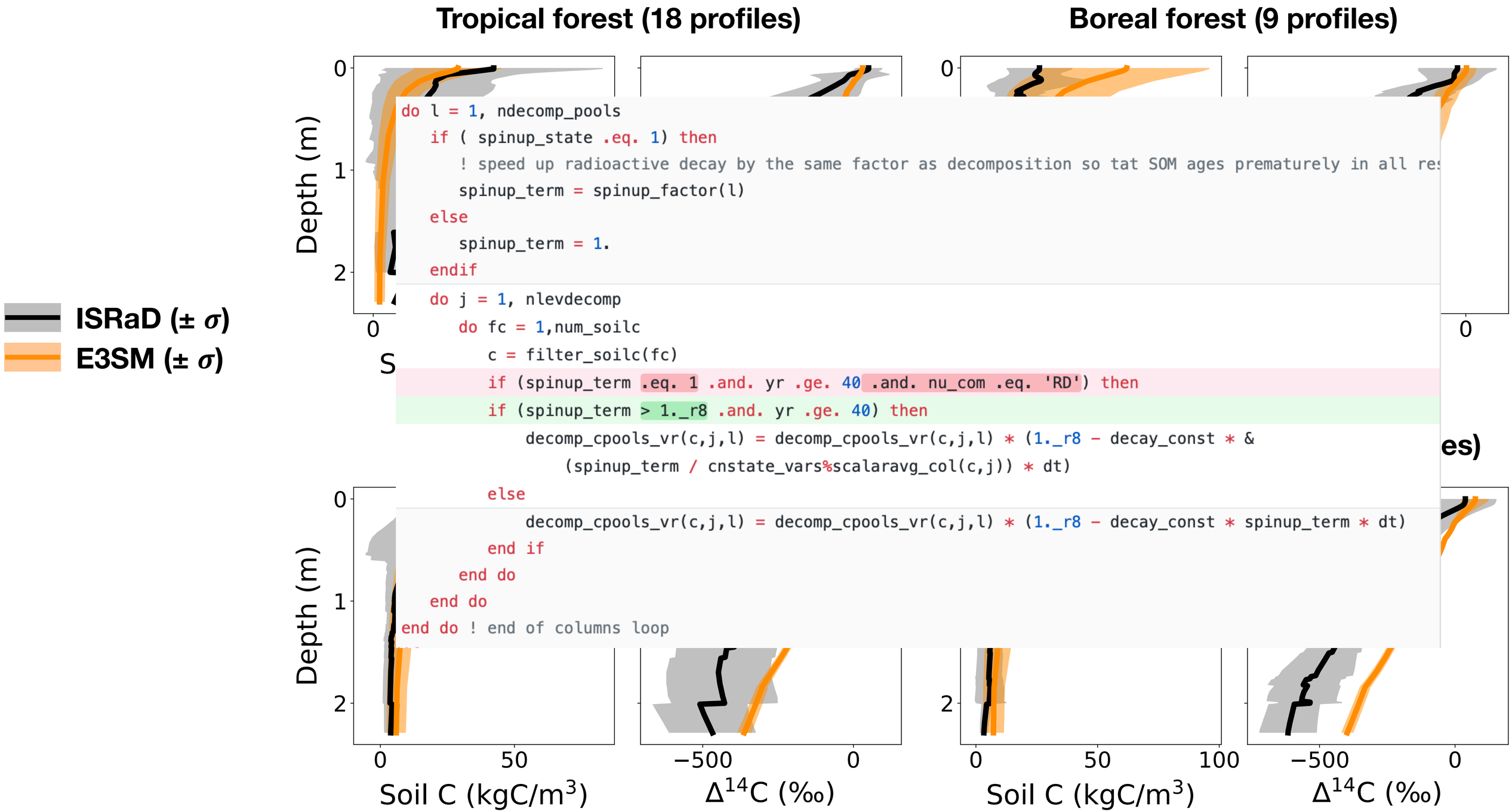
Koven et al, 2013 *Biogeosciences*

E3SM Energy Exascale Earth System Model

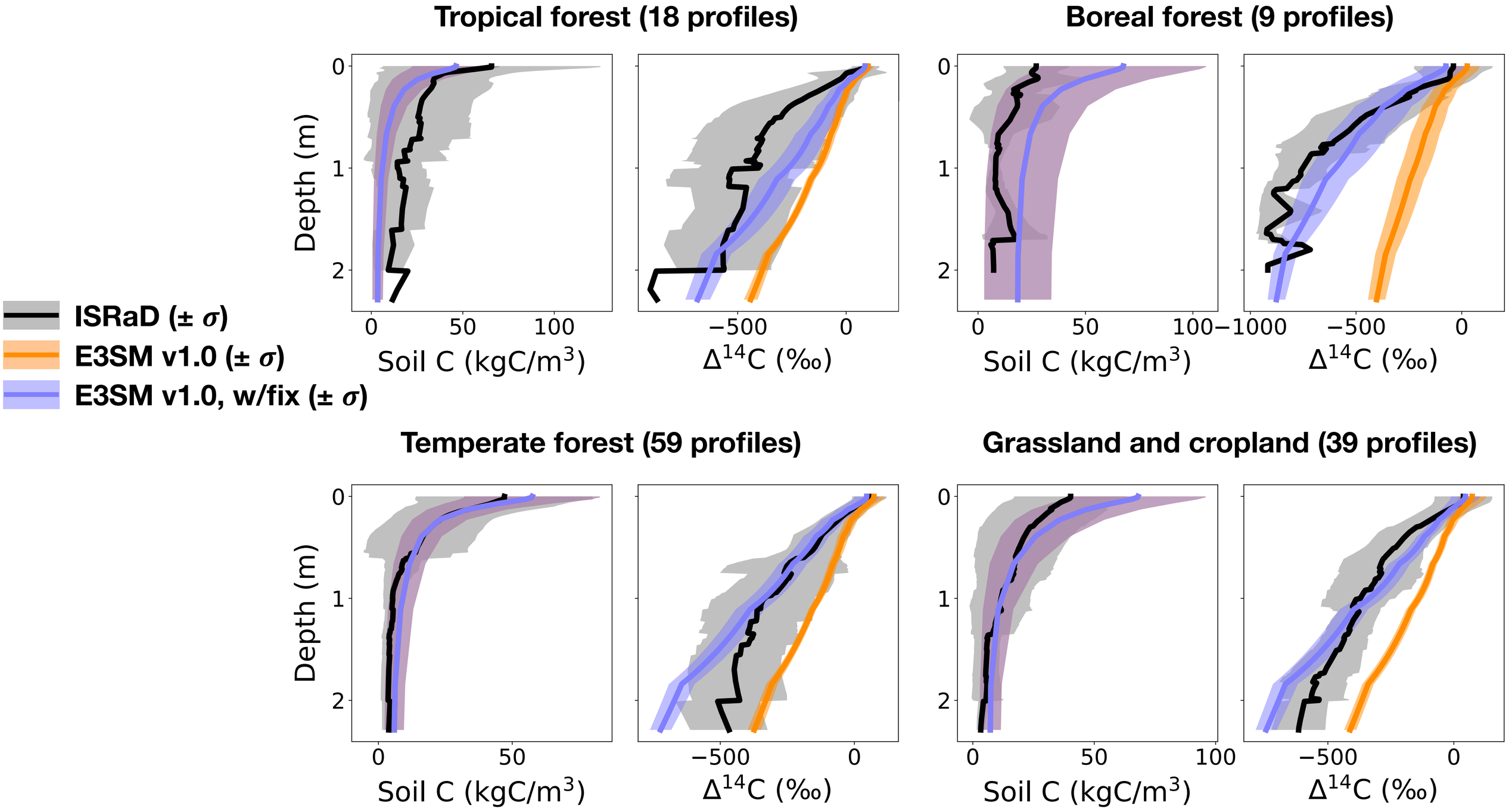
U.S. DEPARTMENT OF ENERGY

Office of Science

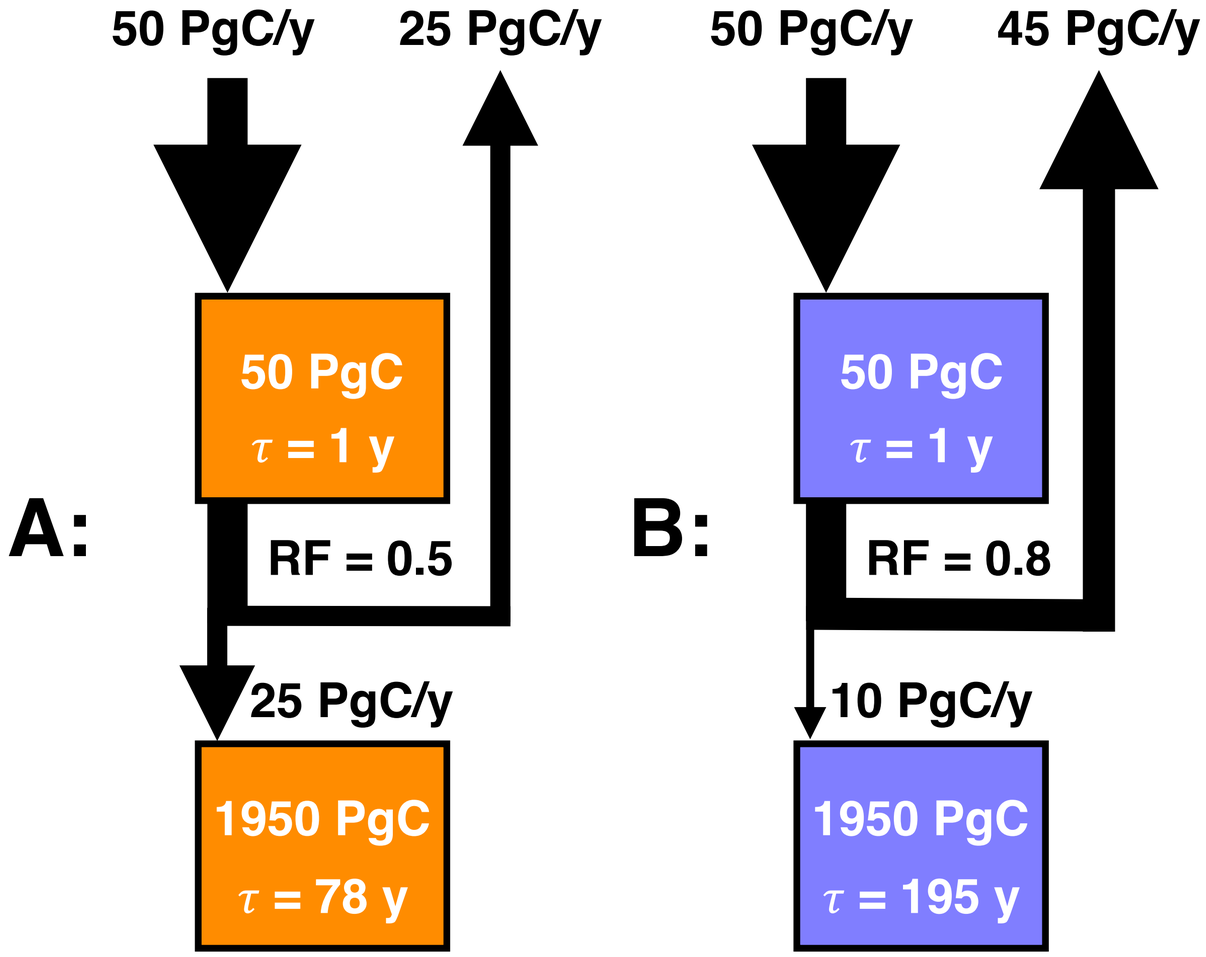

ISRaD (± σ)
E3SM (± σ)
Tropical forest (18 profiles)
Boreal forest (9 profiles)
Temperate forest (59 profiles)
Grassland and cropland (39 profiles)
Depth (m)
Soil C (kgC/m3)
Δ14C (‰)




```
do l = 1, ndecomp_pools
   if ( spinup_state .eq. 1) then
      ! speed up radioactive decay by the same factor as decomposition so tat SOM ages prematurely in all res
      spinup_term = spinup_factor(l)
   else
      spinup_term = 1.
   endif
   do j = 1, nlevdecomp
      do fc = 1,num_soilc
         c = filter_soilc(fc)
         if (spinup_term .eq. 1 .and. yr .ge. 40 .and. nu_com .eq. 'RD') then
         if (spinup_term > 1._r8 .and. yr .ge. 40) then
            decomp_cpools_vr(c,j,l) = decomp_cpools_vr(c,j,l) * (1._r8 - decay_const * &
               (spinup_term / cnstate_vars%scalaravg_col(c,j)) * dt)
         else
            decomp_cpools_vr(c,j,l) = decomp_cpools_vr(c,j,l) * (1._r8 - decay_const * spinup_term * dt)
         end if
      end do
   end do
end do ! end of columns loop
```


Tropical forest (18 profiles)
Boreal forest (9 profiles)
Temperate forest (59 profiles)
Grassland and cropland (39 profiles)
ISRaD (± σ)
E3SM v1.0 (± σ)
E3SM v1.0, w/fix (± σ)
Depth (m)
Soil C (kgC/m³)
Δ¹⁴C (‰)

Proof of concept



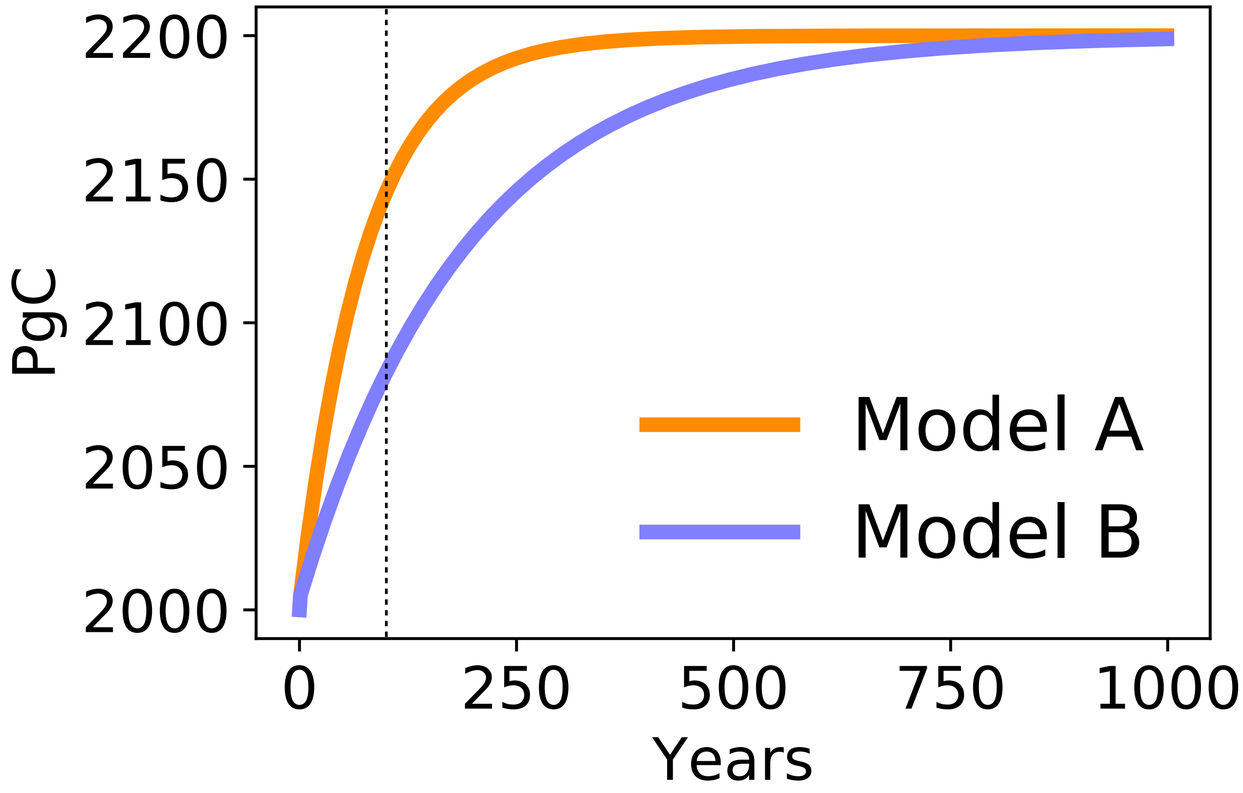
total C = 2000 PgC

mean $\Delta^{14}C$ = -9.1‰

total C = 2000 PgC

mean $\Delta^{14}C$ = -22.5‰

Increase input by 10% (5 PgC/y)?



After 100 years?

- A accumulates: 146 PgC
- B accumulates: 83 PgC

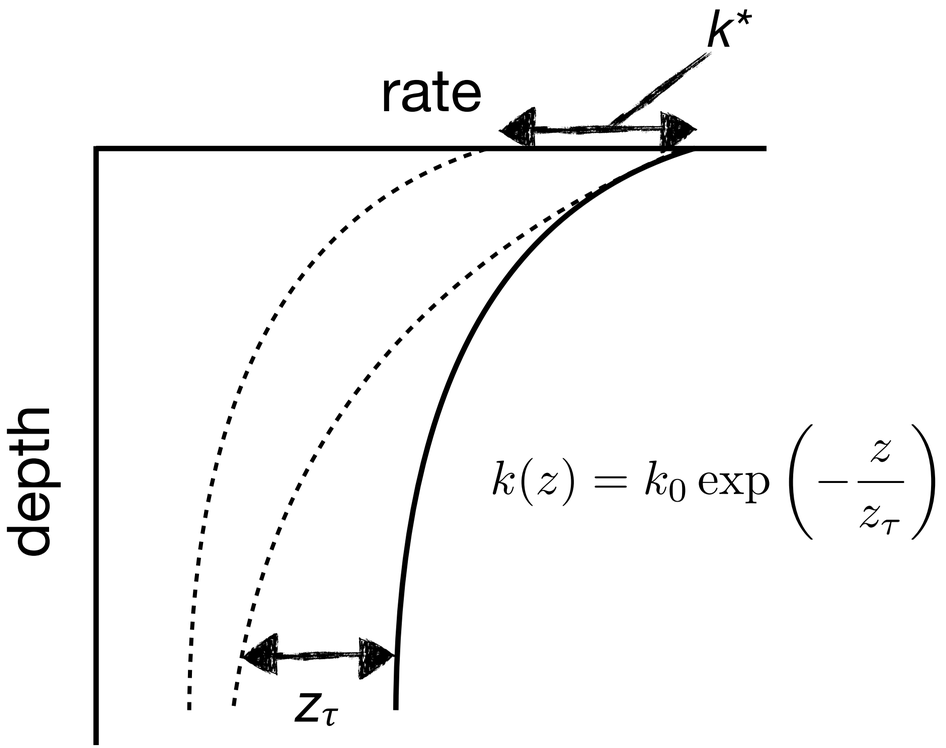
Calibration methods

- Optimize three parameters:

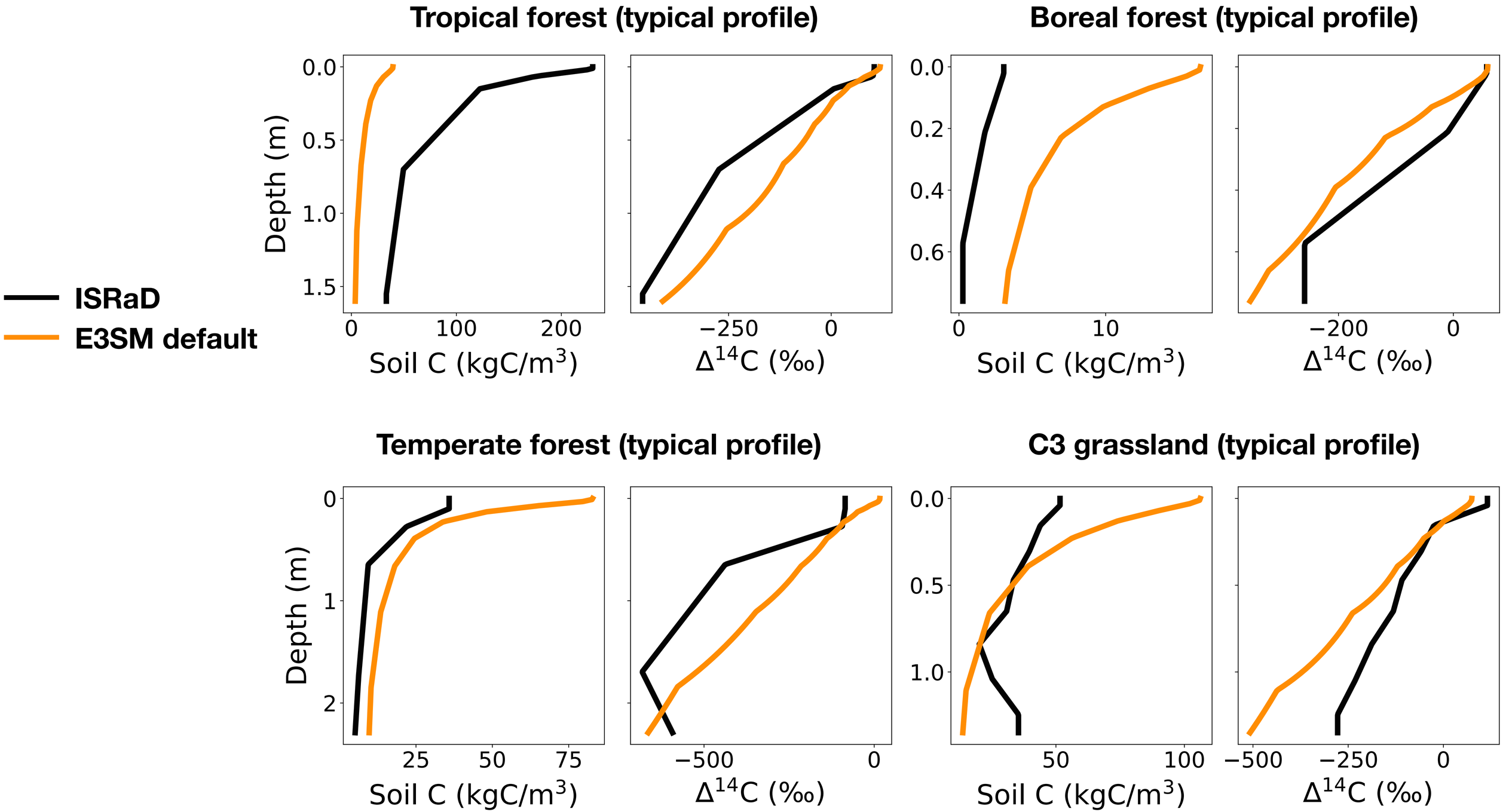
  (1) ***k**** scales soil pool decay rates

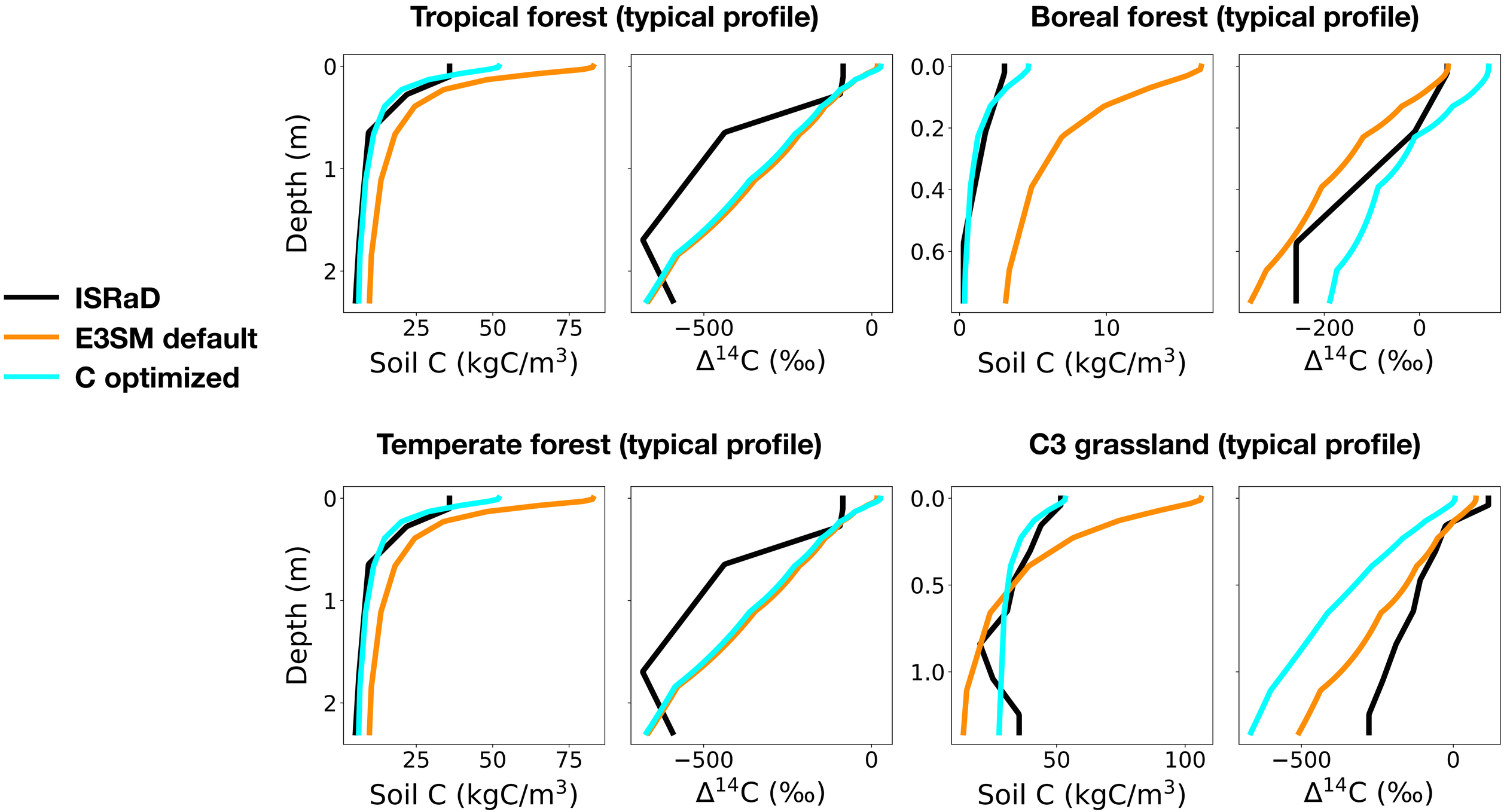
  (2) ***rf**** scales soil pool respired fractions

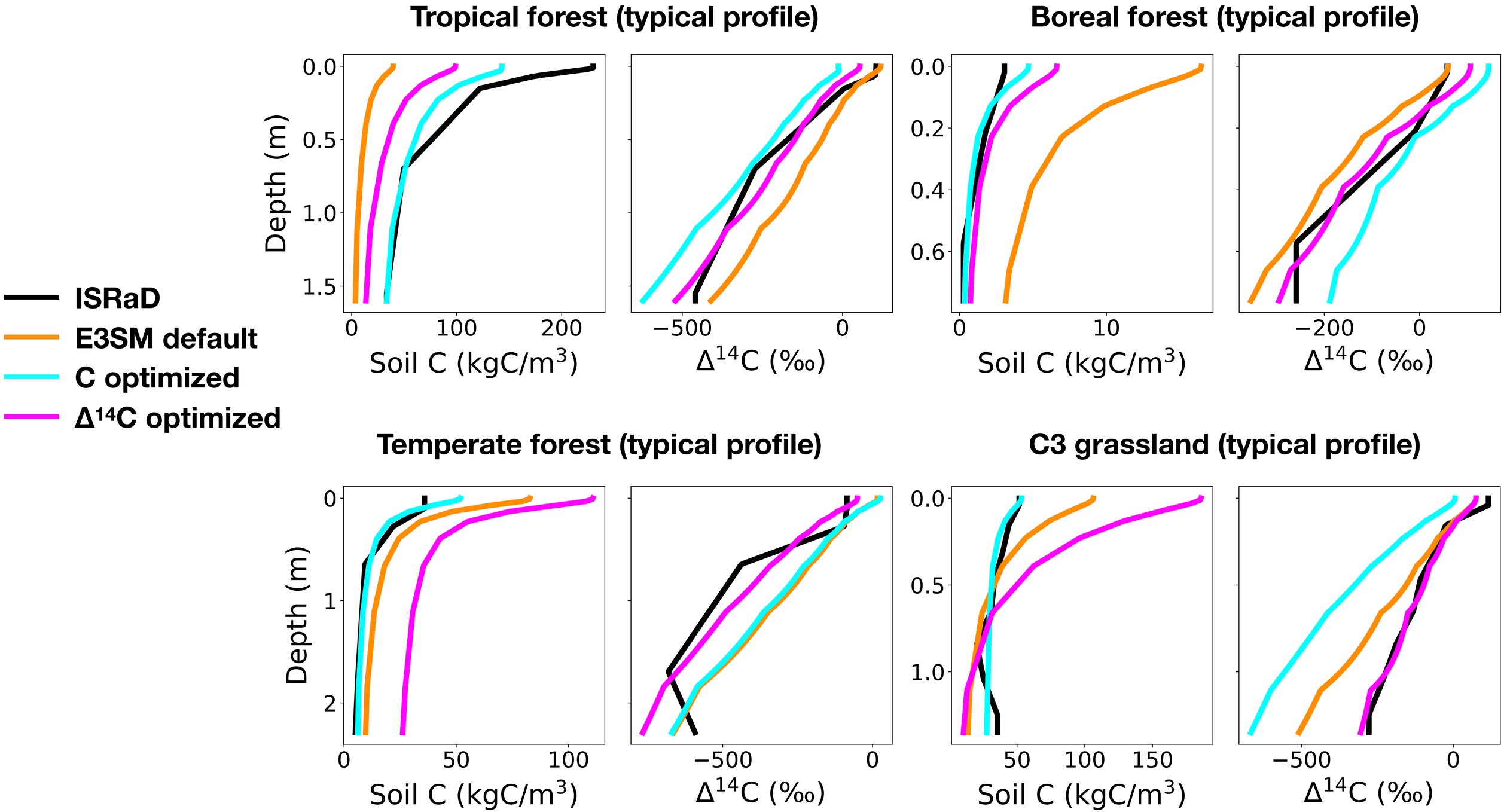
  (3) z_τ is the e-folding depth (in m) of an exponential decrease of decay rates



Parameter	*k**	*rf**	z_τ
default	1.0	1.0	0.5 m
minimum	0.7	0.7	0.2 m
maximum	1.3	1.3	0.8 m
increment	0.1	0.1	0.1 m


Tropical forest (typical profile)
Boreal forest (typical profile)
Temperate forest (typical profile)
C3 grassland (typical profile)
ISRaD
E3SM default
Depth (m)
Soil C (kgC/m^3)
Δ^{14}C (‰)


Tropical forest (typical profile)
Boreal forest (typical profile)
Temperate forest (typical profile)
C3 grassland (typical profile)
ISRaD
E3SM default
C optimized
Depth (m)
Soil C (kgC/m^3)
Δ^{14}C (‰)


Tropical forest (typical profile)
Boreal forest (typical profile)
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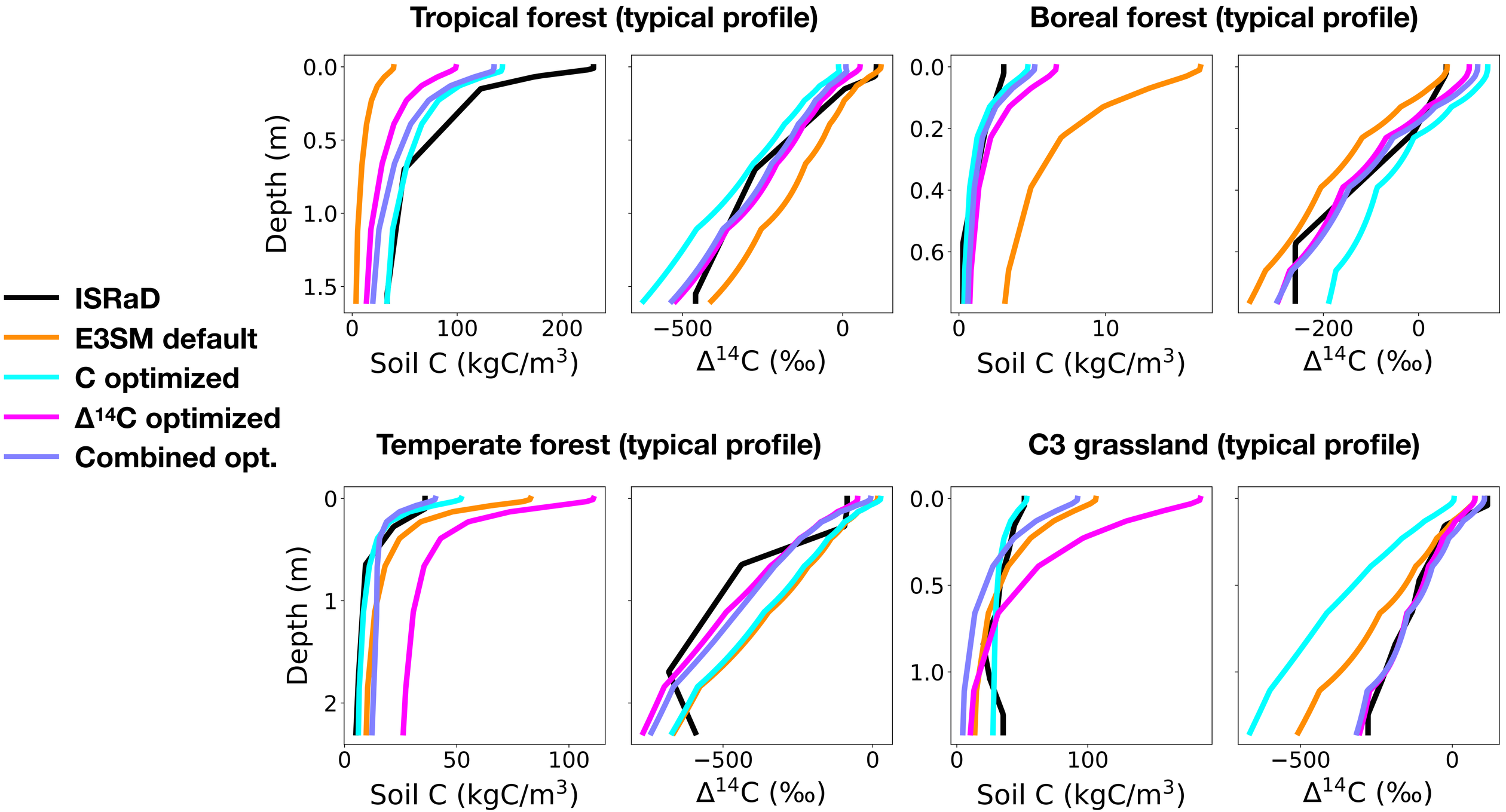
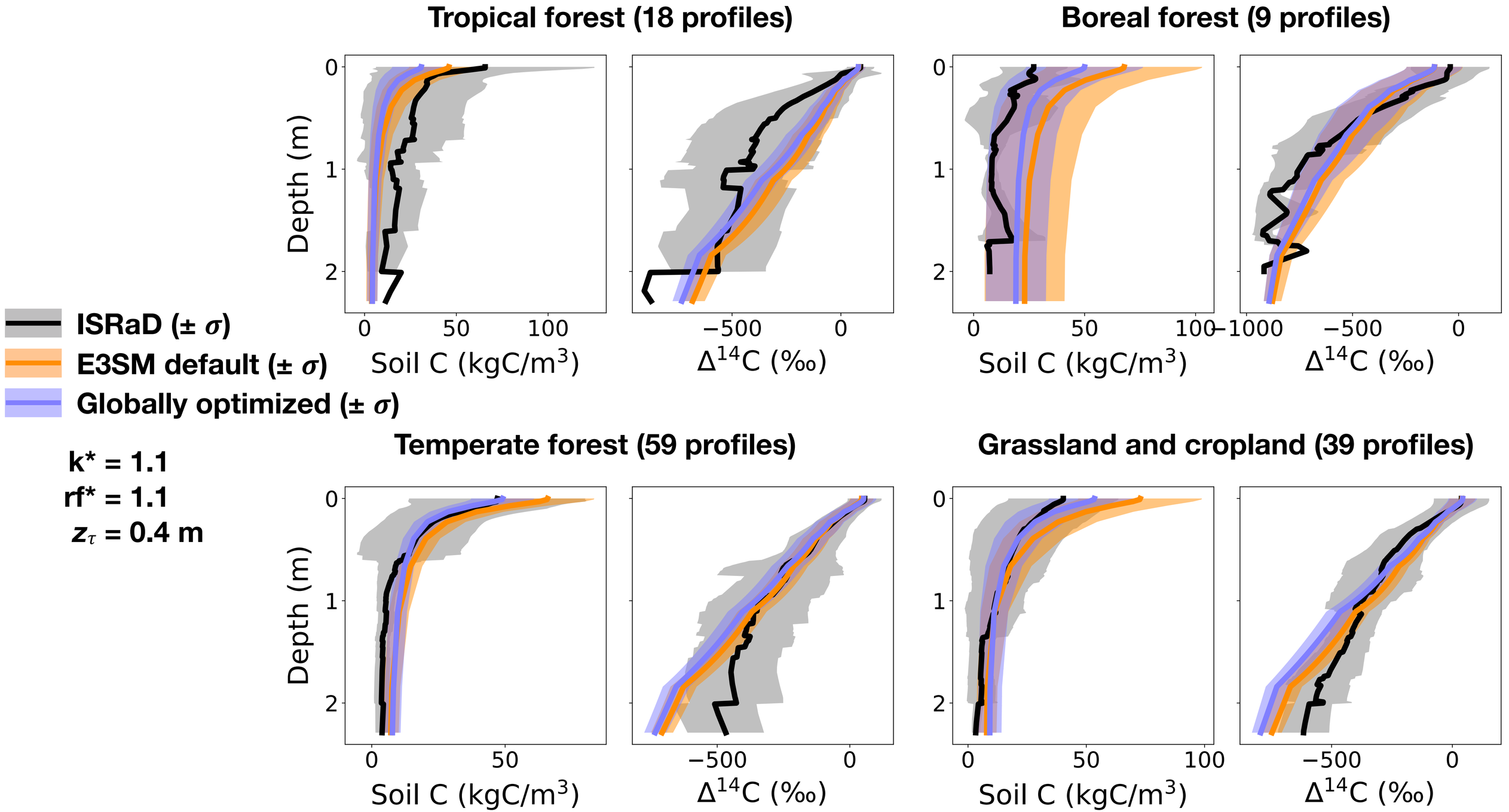
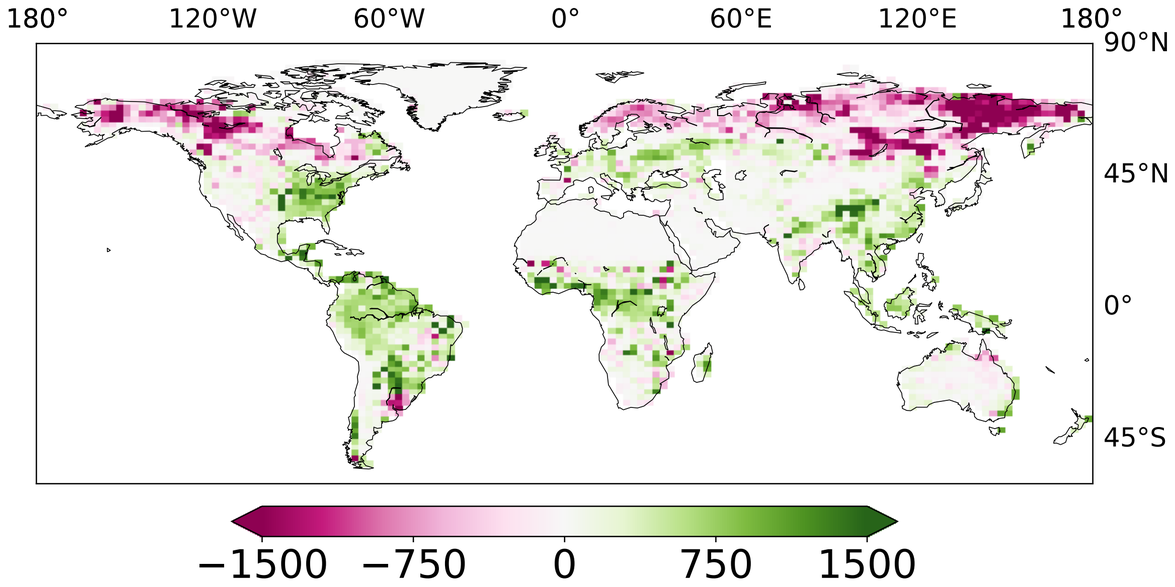
C3 grassland (typical profile)
ISRaD
E3SM default
C optimized
Δ14C optimized
Depth (m)
Soil C (kgC/m3)
Δ14C (‰)

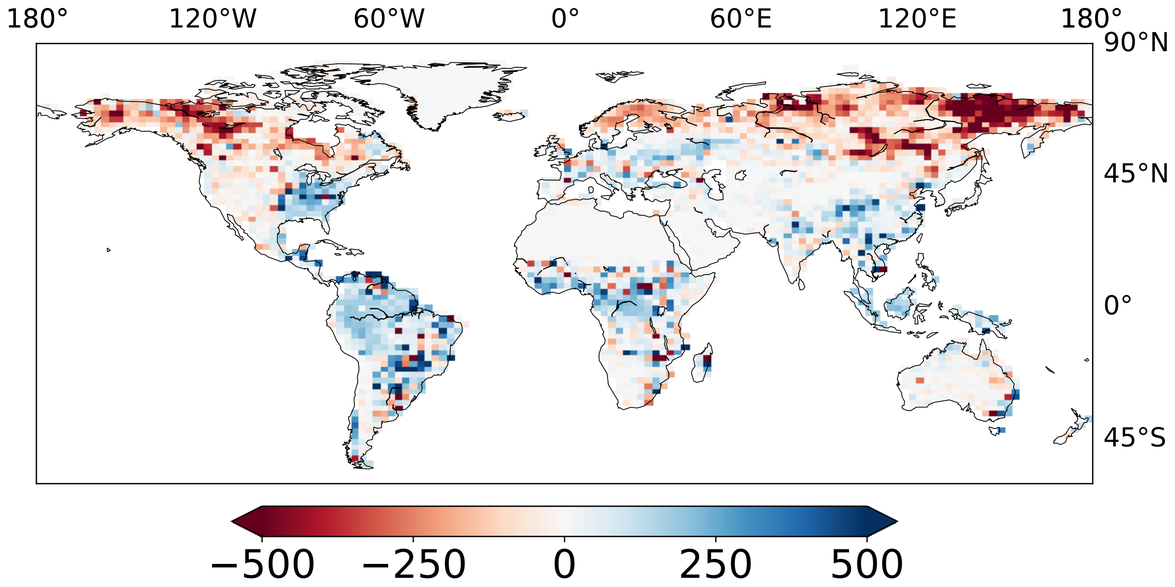

Tropical forest (typical profile)
Boreal forest (typical profile)
Temperate forest (typical profile)
C3 grassland (typical profile)
ISRaD
E3SM default
C optimized
Δ14C optimized
Combined opt.
Depth (m)
Soil C (kgC/m3)
Δ14C (‰)


Tropical forest (18 profiles)
Boreal forest (9 profiles)
Temperate forest (59 profiles)
Grassland and cropland (39 profiles)
ISRaD (± σ)
E3SM default (± σ)
Globally optimized (± σ)
k* = 1.1
rf* = 1.1
z_τ = 0.4 m
Depth (m)
Soil C (kgC/m^3)
Δ^{14}C (‰)

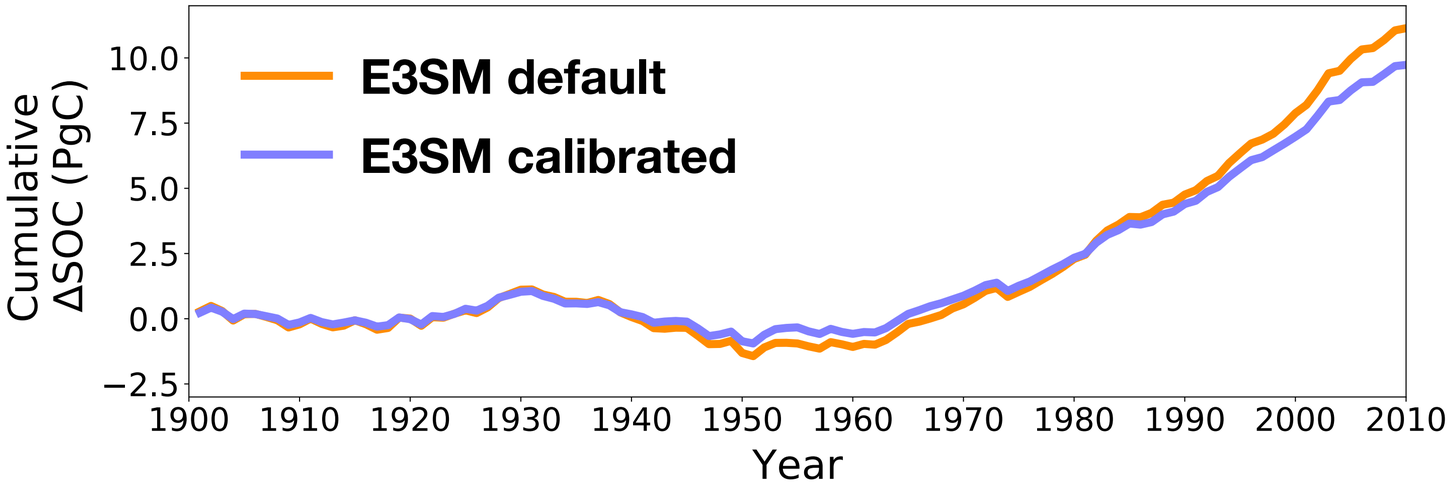
Calibrated 20th-century soil carbon change



Default ΔSOC, 1900–2010 (kgC/m^2)



Default ΔSOC – calibrated ΔSOC (kgC/m^2)



	1900 SOC (PgC)	1900–2010 ΔSOC (PgC)	1959–2010 ΔTot. (PgC)
def.	3261	11.14	137.7
cal.	2753	9.73	139.0

GCP 1959–2010: 105.0 PgC

Next Steps

- Evaluate radiocarbon in CLM5 against ISRaD
- Format ISRaD for ingestion into ILAMB
- Include respired radiocarbon as an additional constraint

Acknowledgments:

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Office of Science
NERSC
RUBISCO
NASA
erc European Research Council