Global radiocarbon observations for calibration and validation of Earth system models

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⁶. Visit https://international-soil-radiocarbon-database.github.io/ISRaD/about/ for ISRaD credits

CESM Land Model and Biogeochemistry Working Group Meeting, February 12, 2019
Soil organic carbon in Earth System Models

Cumulative terrestrial carbon flux projections from CMIP5 models

Contemporary soil carbon storage and 21st-century change in CMIP5 models
Todd-Brown et al, 2014, *Biogeosciences*
Global radiocarbon cycle

Fraction Modern values reflect time elapsed rather than the pathway taken by C in ecosystems. Because it counts atoms rather than waits for them to decay, AMS requires many more samples to be measured with the newer method of accelerator mass spectrometry. Several methods can be used to measure the age of soil organic matter, with AMS being the most accurate. Radiocarbon measurements of phospholipid fatty acids (PLFA) extracted from living soil microbes demonstrate that C being utilized by microbes is derived from substrates that are chemically labile (i.e., decomposes rapidly in soils) can be old in terms of its time elapsed since removal may be determined from the degree to which the sample measured in year y to an absolute standard that is chemically labile (i.e., decomposes rapidly in soils) can be old in terms of its time elapsed since removal may be determined from the degree to which the sample measured in year

\[ \Delta^{14}C = \left[ \frac{14C}{12C} \right]_{\text{sample}} - 25 \times \frac{14C}{12C}\text{OX1}, -19 \times e^{\frac{(y-1950)8267}{1000}} \]
Global radiocarbon cycle

\[ \Delta^{14}C = \left[ \frac{14C}{12C} \right]_{\text{sample, } -25} - 1 \times 1000 \]

\[ 0.95 \times \left[ \frac{14C}{12C} \right]_{\text{OX1, } -19} e^{(y-1950)\times0.8267} \]

Vermunt, Austria - 47°N, 10°E
Jungfraujoch, Switzerland - 47°N, 8°E
Wellington, New Zealand - 41°S, 175°E
Cape Grim, Australia - 41°S, 145°E

atmospheric nuclear tests in the NH
atmospheric nuclear tests in the SH

Effective yield of atmospheric nuclear detonation (Mt)

Year (AD)
Radiocarbon constraint on Earth System Models

He et al, 2016, Science
Energy Exascale Earth System Model (E3SM)

Century Soil C pool structure

CWD $\tau = 4.1$

Litter 1 $\tau = .066$

Litter 2 $\tau = .25$

Litter 3 $\tau = .25$

Soil 1 $\tau = .17$

Soil 2 $\tau = 6.1$

Soil 3 $\tau = 270$

Coarse Wood

Litter 1

Litter $n$

Soil 1

Soil $n$

Koven et al, 2013 Biogeosciences
Boreal forest (9 profiles)

Grassland and cropland (39 profiles)

Temperate forest (59 profiles)

Tropical forest (18 profiles)
Boreal forest (9 profiles)

Grassland and cropland (39 profiles)

Temperate forest (59 profiles)

Tropical forest (18 profiles)

Depth (m)

Soil C (kgC/m³)

$\Delta^{14}C$ (%)
Proof of concept

A: 50 PgC/y  
25 PgC/y  
50 PgC  
RF = 0.5  
\( \tau = 1 \text{ y} \)  
25 PgC/y  
50 PgC  
RF = 0.8  
\( \tau = 1 \text{ y} \)  
10 PgC/y  
1950 PgC  
\( \tau = 78 \text{ y} \)  
1950 PgC  
\( \tau = 195 \text{ y} \)  

total C = 2000 PgC  
mean \( \Delta^{14}C = -9.1\% \)  

B: 50 PgC/y  
50 PgC  
RF = 0.5  
\( \tau = 1 \text{ y} \)  
45 PgC/y  
45 PgC  
RF = 0.8  
\( \tau = 1 \text{ y} \)  
10 PgC/y  
10 PgC  
RF = 0.8  
\( \tau = 1 \text{ y} \)  

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. $z_\tau$ is the e-folding depth (in m) of an exponential decrease of decay rates

$$k(z) = k_0 \exp\left(-\frac{z}{z_\tau}\right)$$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$k^*$</th>
<th>$rf^*$</th>
<th>$z_\tau$</th>
</tr>
</thead>
<tbody>
<tr>
<td>default</td>
<td>1.0</td>
<td>1.0</td>
<td>0.5 m</td>
</tr>
<tr>
<td>minimum</td>
<td>0.7</td>
<td>0.7</td>
<td>0.2 m</td>
</tr>
<tr>
<td>maximum</td>
<td>1.3</td>
<td>1.3</td>
<td>0.8 m</td>
</tr>
<tr>
<td>increment</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1 m</td>
</tr>
</tbody>
</table>
Boreal forest (typical profile)

Tropical forest (typical profile)

Temperate forest (typical profile)

C3 grassland (typical profile)

ISRaD

E3SM default
Boreal forest (9 profiles)

Grassland and cropland (39 profiles)

Temperate forest (59 profiles)

Tropical forest (18 profiles)

**ISRaD (± σ)
E3SM default (± σ)
Globally optimized (± σ)**

\[ k^* = 1.1 \]
\[ r_f^* = 1.1 \]
\[ z_T = 0.4 \text{ m} \]
Calibrated 20th-century soil carbon change

- **1900 SOC (PgC):**
  - Def.: 3261
  - Cal.: 2753

- **1900–2010 ∆SOC (PgC):**
  - Def.: 11.14
  - Cal.: 9.73

- **1959–2010 ∆Tot. (PgC):**
  - Def.: 137.7
  - Cal.: 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: