Addition of Long-lived Soil Carbon to CLMCN

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What carbon pools are missing from CLM4?

- Large stocks of old carbon in terrestrial system
  - Recalcitrant materials
  - Deep soils
  - Permafrost
  - Peats
- Can we represent these in CLM4?
- How do they behave under future warming?
- C-only feedbacks vs. coupled C-N feedbacks?

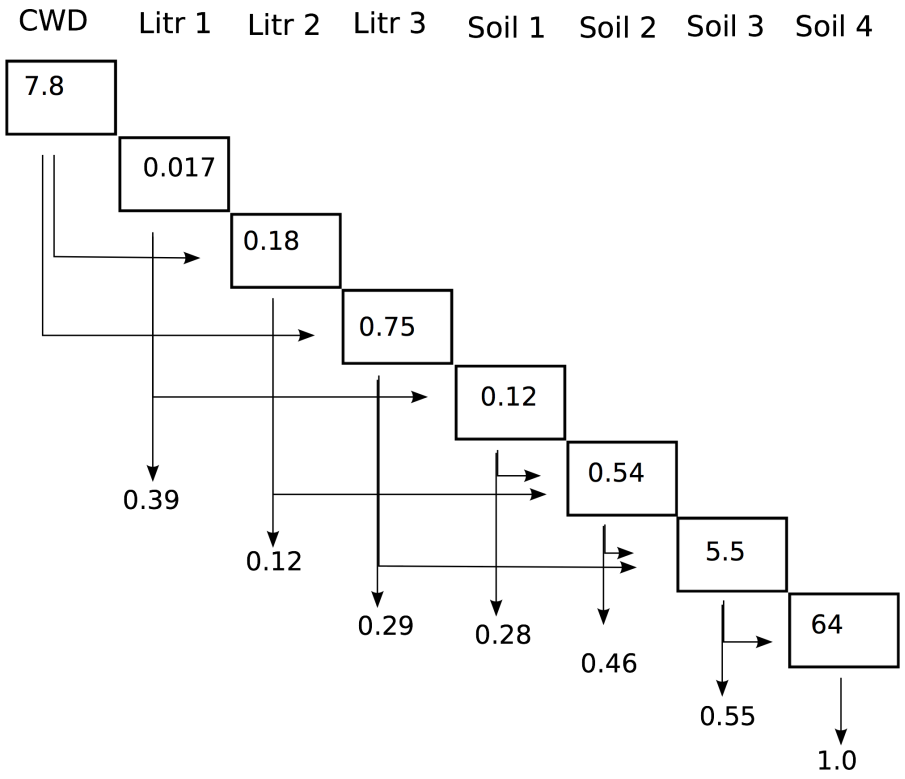
Processes changed/added relative to standard CLM4

- Bonan et al. (2011) photosynthesis
- Swenson et al. arctic hydrology
- Separated decomposition cascade structure from dynamics so that arbitrary pool structure / transfer can be used
- Added optional vertical dimension to entire decomposition cascade
- Changed accelerated decomposition spinup mode
  - Apply acceleration separately for each pools, so that fast pools are not sped up while slow pools are all collapsed to ~1-5 yr turnover
- ^{14}C tracer added to all carbon pools and fluxes for diagnostic purposes
  - Set at atmospheric value during photosynthesis, assume no fractionation such that ∂14C = Δ14C
- Working on numerous issues relating to C-N coupling and N cycle as well (BNF, nitrification/denitrification, etc…)

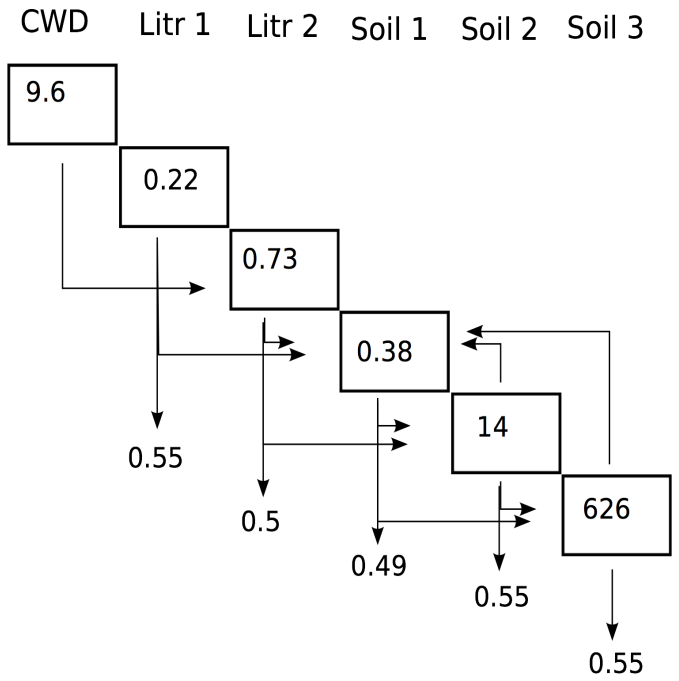
Decomposition cascade structures

$$\frac{\partial C_i}{\partial t} = R_i + \sum_{j \neq i} (1 - r_j) T_{ji} k_j C_j - k_i C_i$$

Original CLM-CN

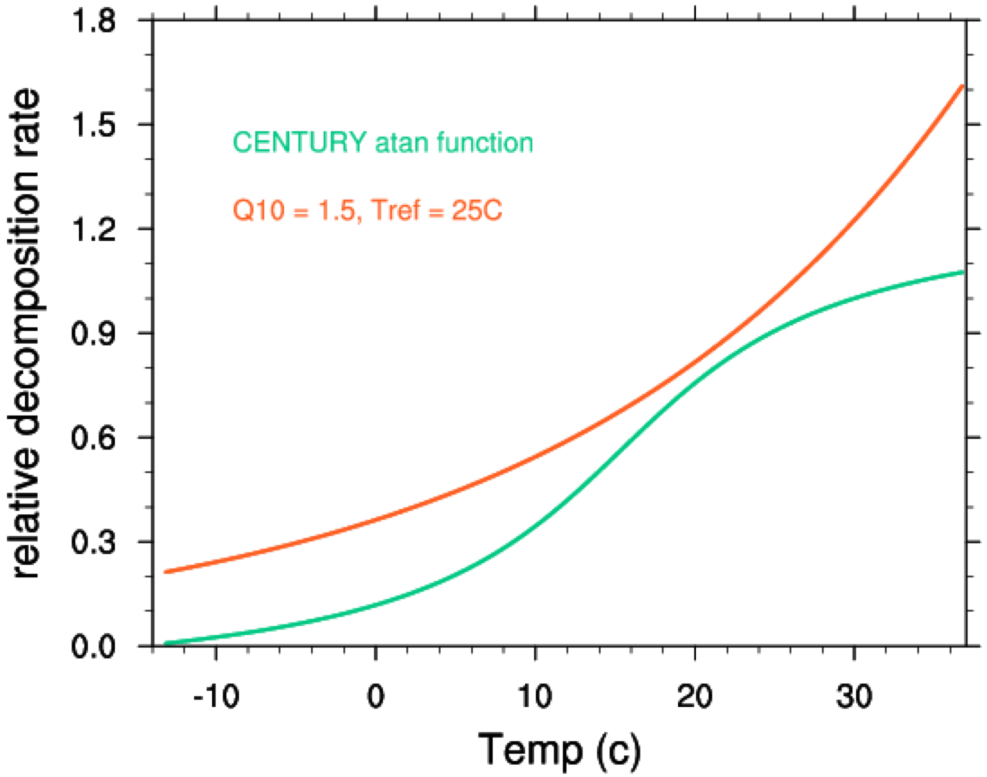


CENTURY



Numbers in boxes are global-mean Tau (=1/k, in years) values

CENTURY and CLM4 also have different temperature sensitivities to decomposition

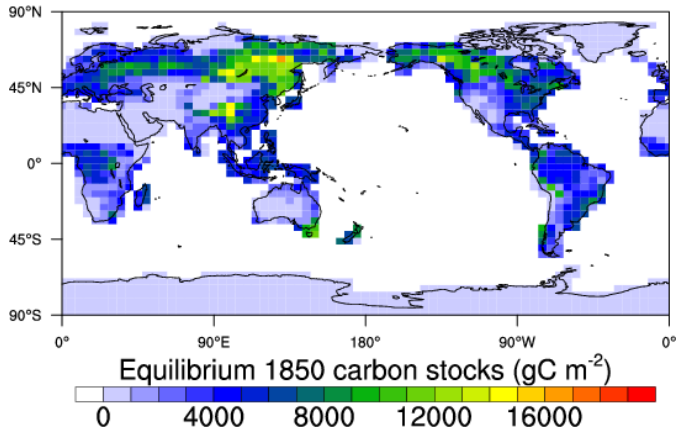


For initial comparison, I calculate equilibrium carbon stocks for (1) CLM4/CN,
(2) CLM4 with CENTURY pools and CLM4 temperature sensitivity, and
(3) CLM4 with CENTURY pools and CENTURY temperature sensitivity

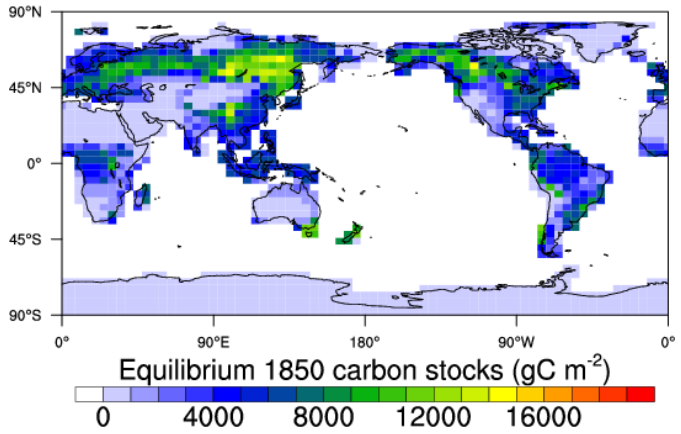
Total soil C stocks

(single level soil C, varied pool structures and temperature functions)

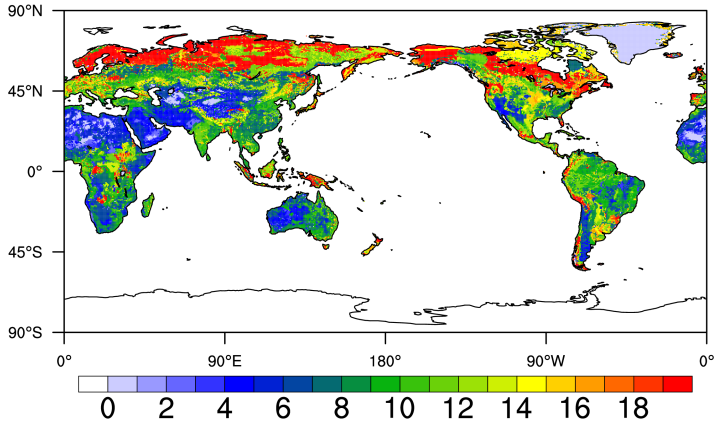
Standard CLM-CN Pools, Q_{10}=1.5



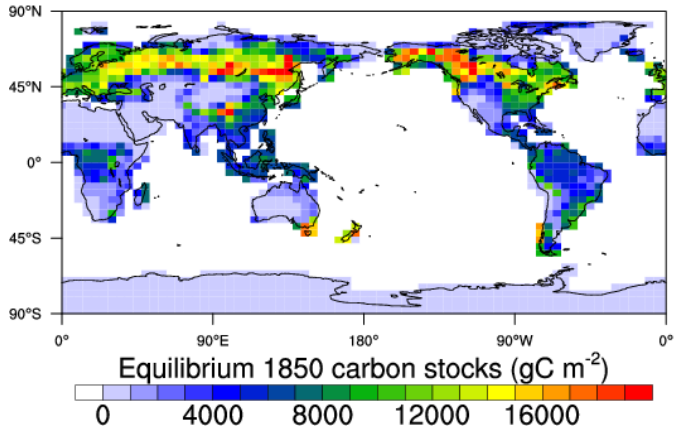
CENTURY Pools, Q_{10}=1.5



IGBP soil carbon (kg m^2)

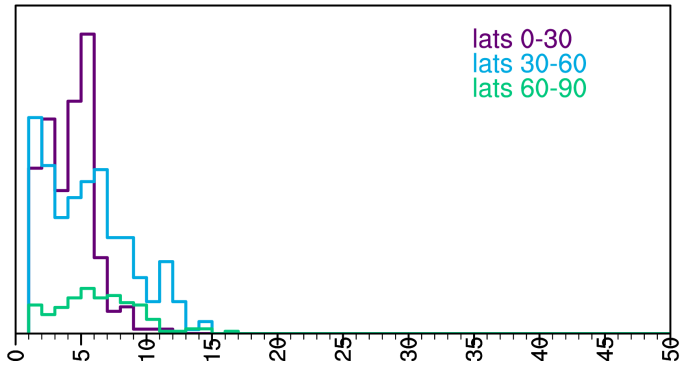


CENTURY Pools and temperature function

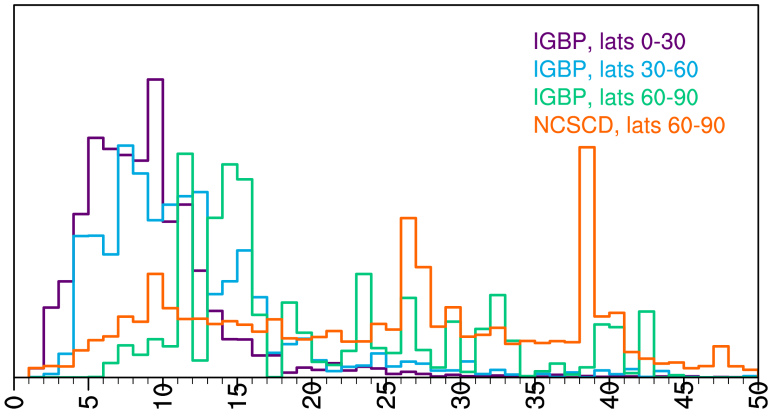


Soil C distributions

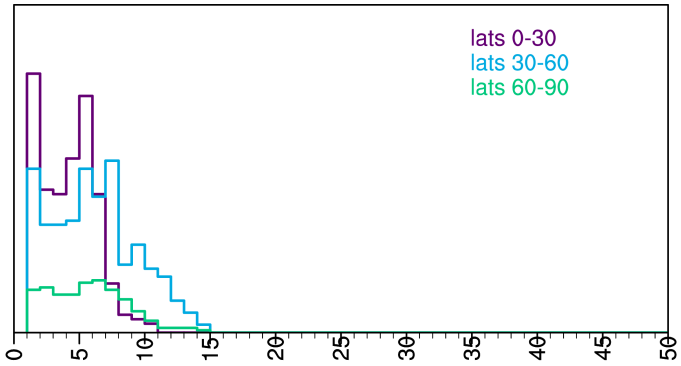
Standard CLM-CN Pools, Q_{10}=1.5 soil C dist. (kg C m^{-2})



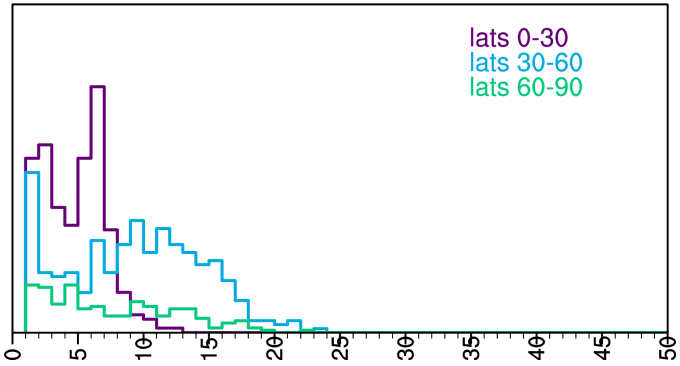
Observed Soil C distributions (kg C m^{-2})



CENTURY Pools, Q_{10}=1.5 soil C dist. (kg C m^{-2})



CENTURY Pools and temp. func. soil C dist. (kg C m^{-2})

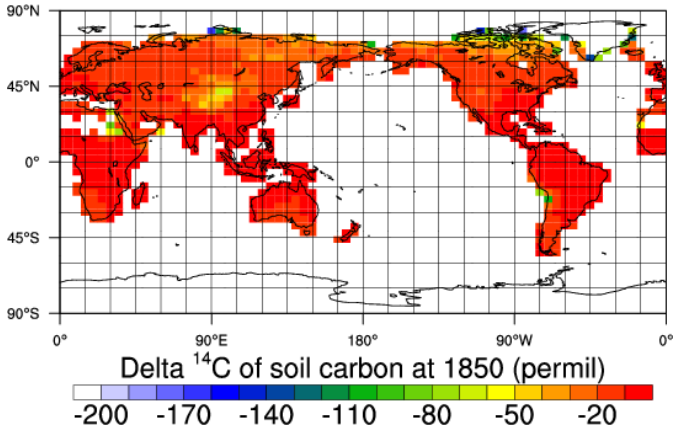


All CLM calculated stocks shown here are using single layer soil model

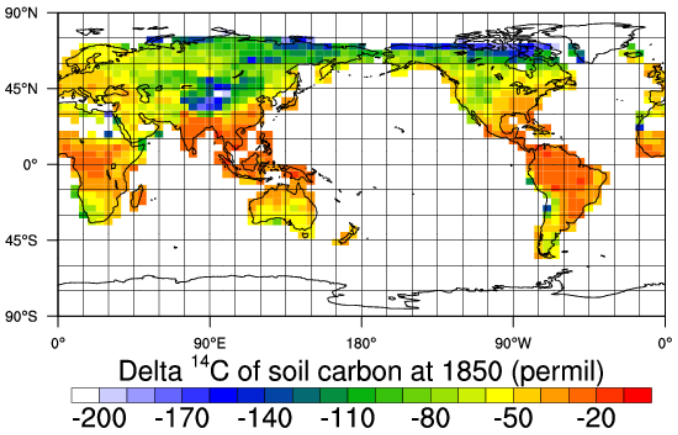
$\Delta^{14}C$ of preindustrial soil carbon

(single level soil C, varied pool structures and temperature functions)

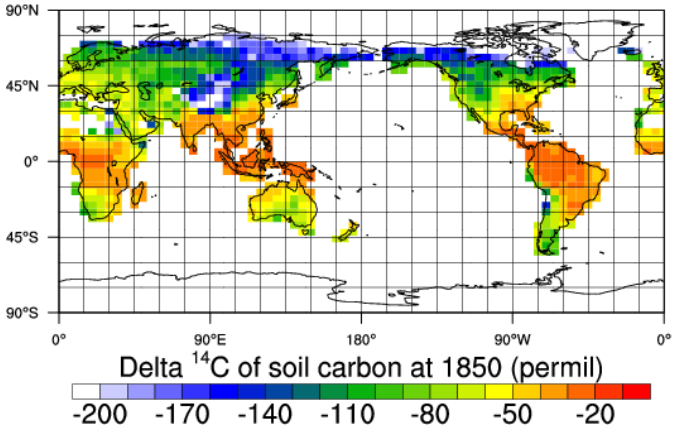
Standard CLM-CN Pools, Q_{10}=1.5



CENTURY Pools, Q_{10}=1.5



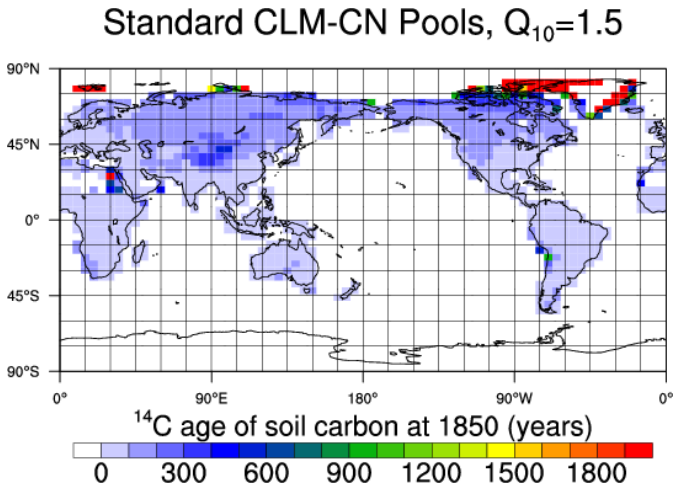
CENTURY Pools and temperature function

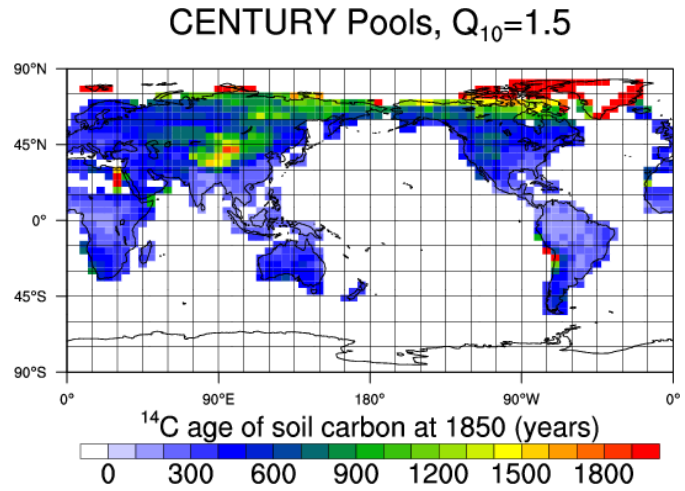


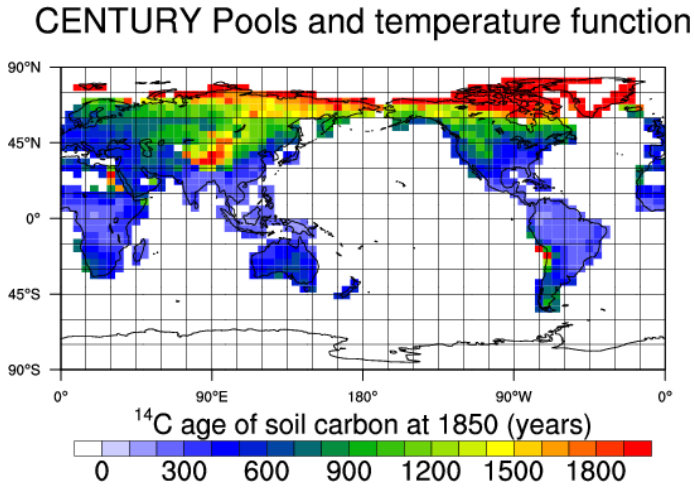
Example data: Torn et al. (2002), archived soil sample (~1900) from Russian steppes: bulk Δ14C = -300

^{14}C age of preindustrial Soil Carbon

(single level soil C, varied pool structures and temperature functions)







Adding vertical dimension to decomposing carbon pools

$$\frac{\partial C_i}{\partial t} = R_i + \sum_{j \neq i} (1 - r_j) T_{ji} k_j C_j - k_i C_i$$

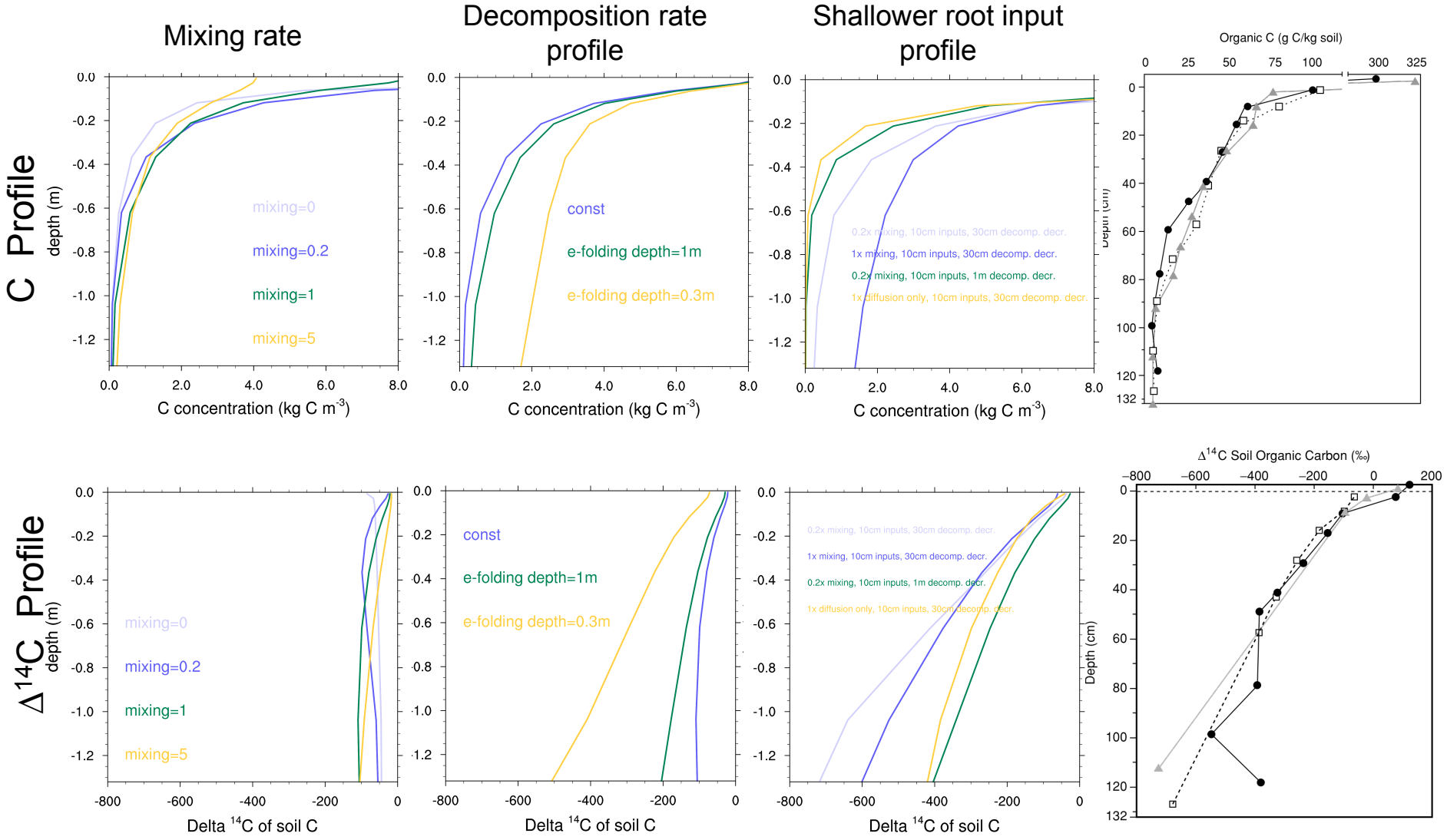
$$\frac{\partial C_i(z)}{\partial t} = R_i(z) + \sum_{j \neq i} (1 - r_j) T_{ji} k_j(z) C_j(z) - k_i(z) C_i(z) + \frac{\partial}{\partial z}\left(D(z)\frac{\partial C_i}{\partial z}\right) + A(z)\frac{\partial C_i}{\partial z}$$

4 new parameters:

- Advective transport rate A
- Diffusive transport rate D
- Decomposition profiles k(z)
- Root, leaf, and stem input profiles R(z)

Reference	diffusion coefficient	advection coeficient	location
Elzein and Balesdent, 1995	5.15 cm^2 /yr	0.13 mm/yr	Kattinkar, India
Elzein and Balesdent, 1995	16.58 cm^2 /yr	0.34 mm/yr	Para, Brazil
Elzein and Balesdent, 1995	5.29 cm^2 /yr	0.48 mm/yr	Bahia, Brazil
Elzein and Balesdent, 1995	0.94 cm^2 /yr	0.6 mm/yr	Bezange, France
Elzein and Balesdent, 1995	1.48 cm^2 /yr	0.42 mm/yr	Marly, France
Bruun et al., 2007	0.71 cm^2/ yr	0.081 mm/yr	Sweden
Jarvis et al., 2010	0.3 cm^2/yr		Sweden
Yoo et al., 2011		3.4±2.3 cm/yr	Delaware Coastal Plain
Yoo et al., 2011		0.8± 0.2 cm/yr	Delaware Coastal Plain
Yoo et al., 2011		0.6 ± 0.1 cm/yr	Delaware Coastal Plain
Yoo et al., 2011		2.7 ± 0.5 cm/yr	Delaware Coastal Plain

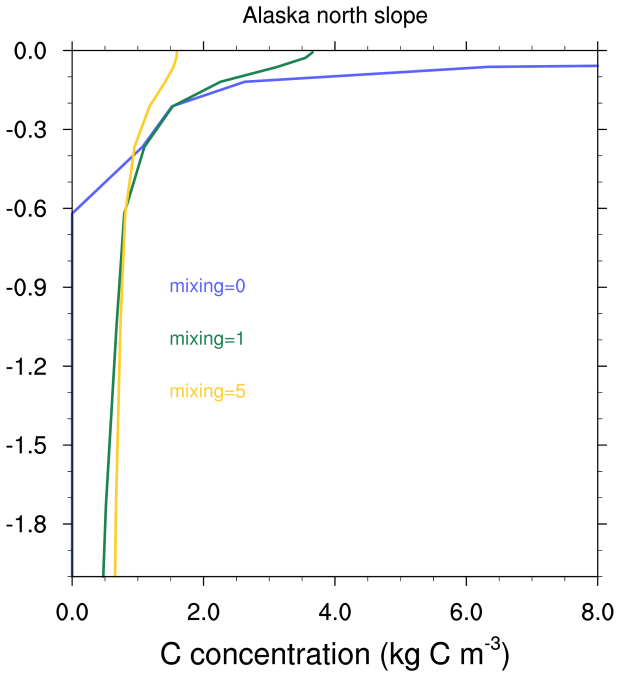
Parameter Sensitivities: (1) Russian steppe site

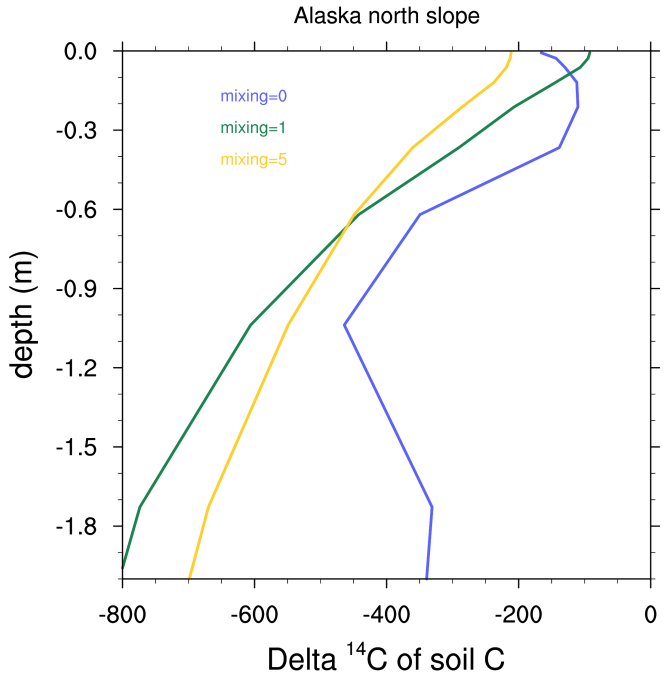


Base mixing rate:
0.1mm/yr advection; 0.1 cm^2/yr diffusion

Observations: (Torn et al., 2002):
Vertical e-folding depth of carbon = 0.38m
Δ14C at 1m = -625 permil

(2): Permafrost, North Slope Alaska

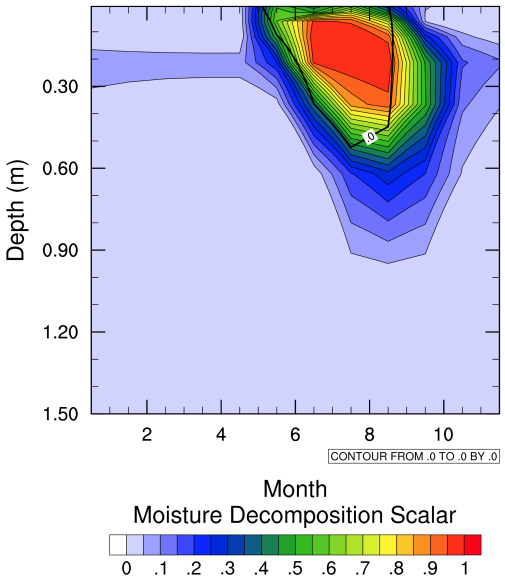


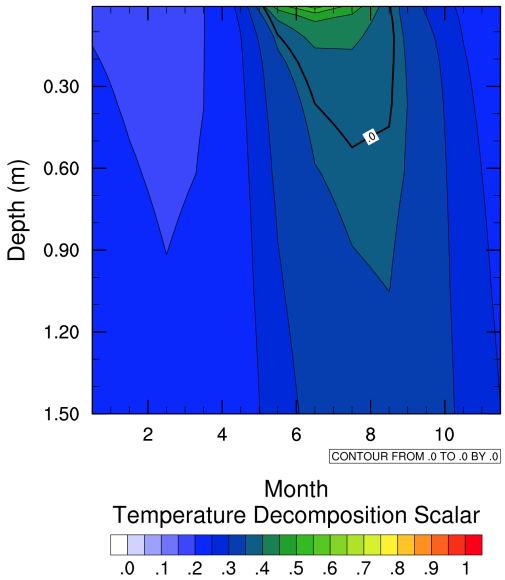


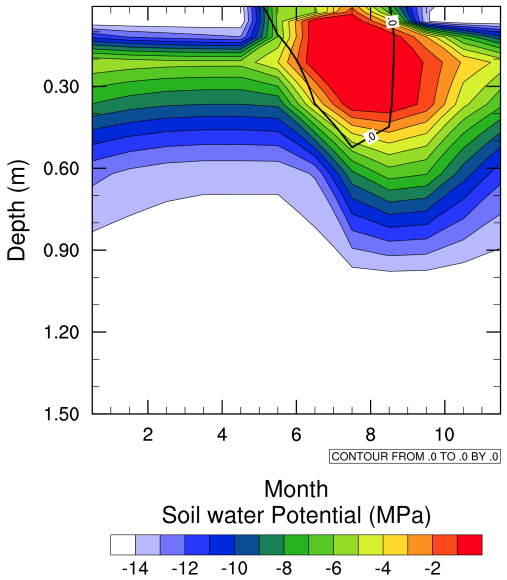
Some issues here:

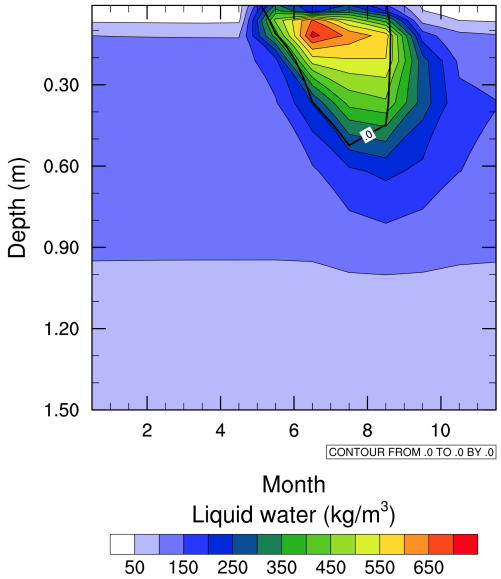
- Productivity dies under standard N regime when SOM is transported into permafrost.
- Interim fix: substituting Cleveland et al. (ET-based) N fixation parameterization for standard (NPP-based) N fixation.
- How well do we understand how decomposition rates change across the freeze-thaw barrier?

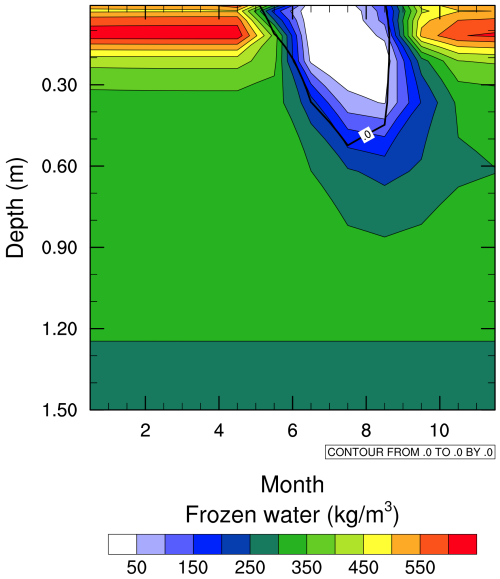
Mean Seasonal Cycle for Alaska North Slope

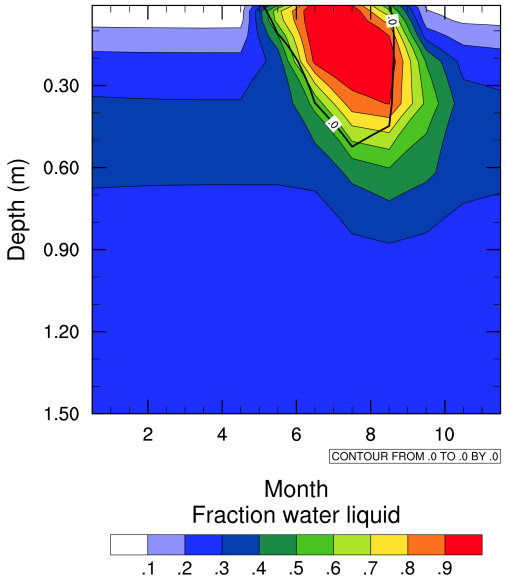












Conclusions

- Default CLM4 is missing old carbon
- Substitution of CENTURY pool structure improves the situation, but bulk (single-pool) ages are still too young
- Addition of vertical dimension, with shallow C inputs, slow mixing, and sharp reduction of decomposition rates with depth (priming effect?) allows reasonable agreement between CLM4 with CENTURY pools and steppe carbon ^{14}C profile observations
- Need to compare to ^{14}C profiles at a variety of sites to estimate vertical profile parameters
- Need to solve a variety of issues for permafrost carbon case…