Development of a vertically-resolved soil C and N model in CLM4

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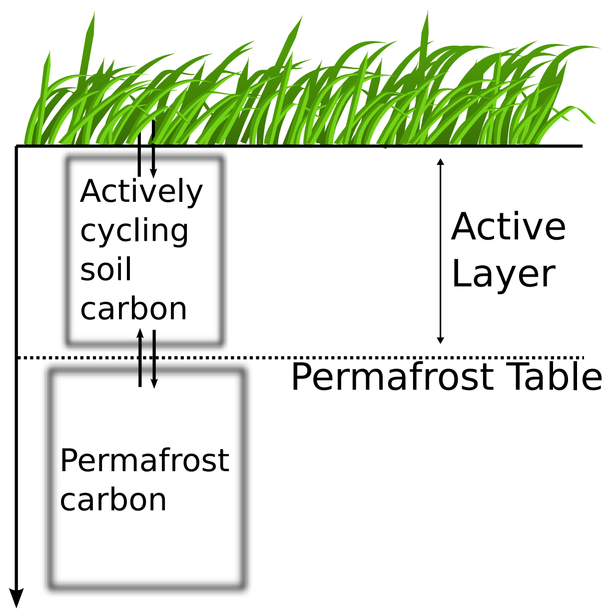
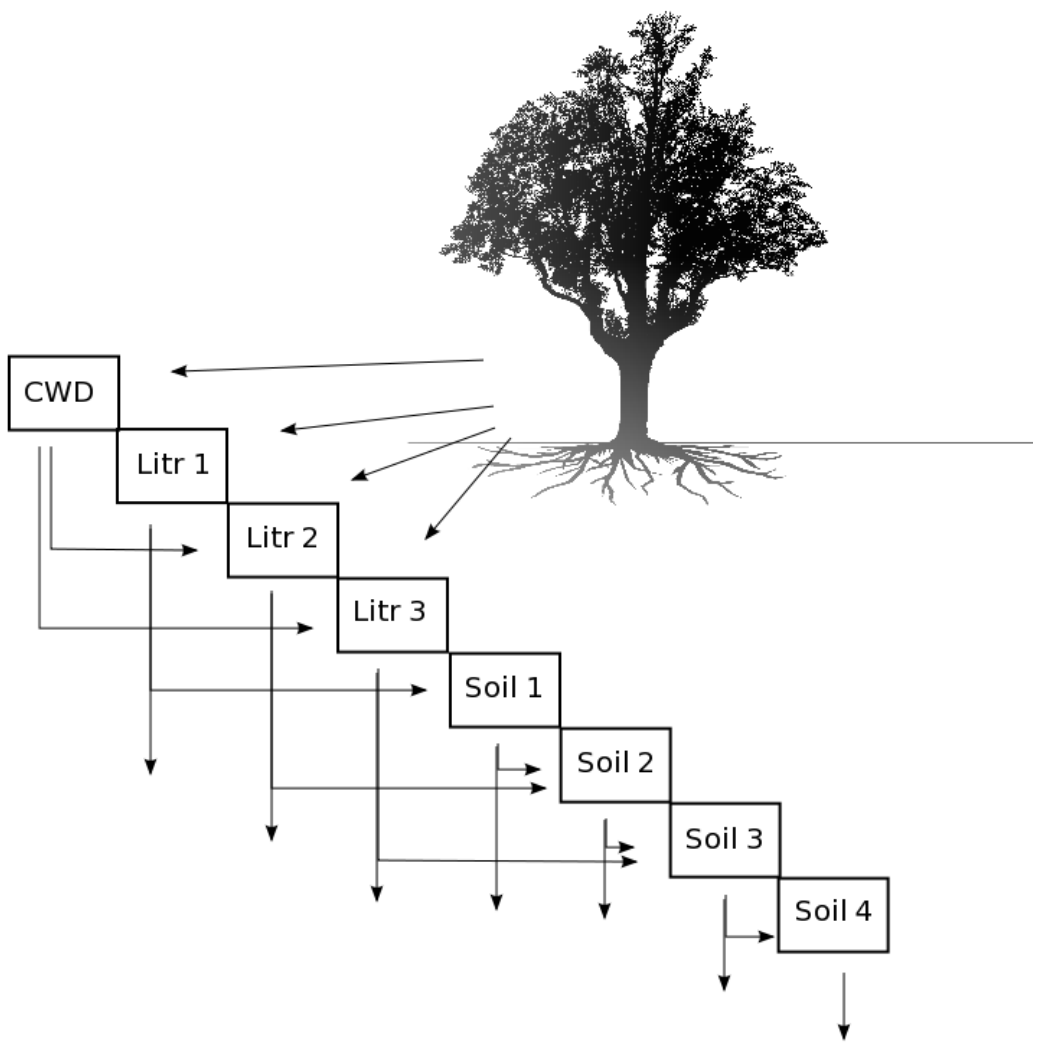
Why consider vertical dimension to soil biogeochemistry?

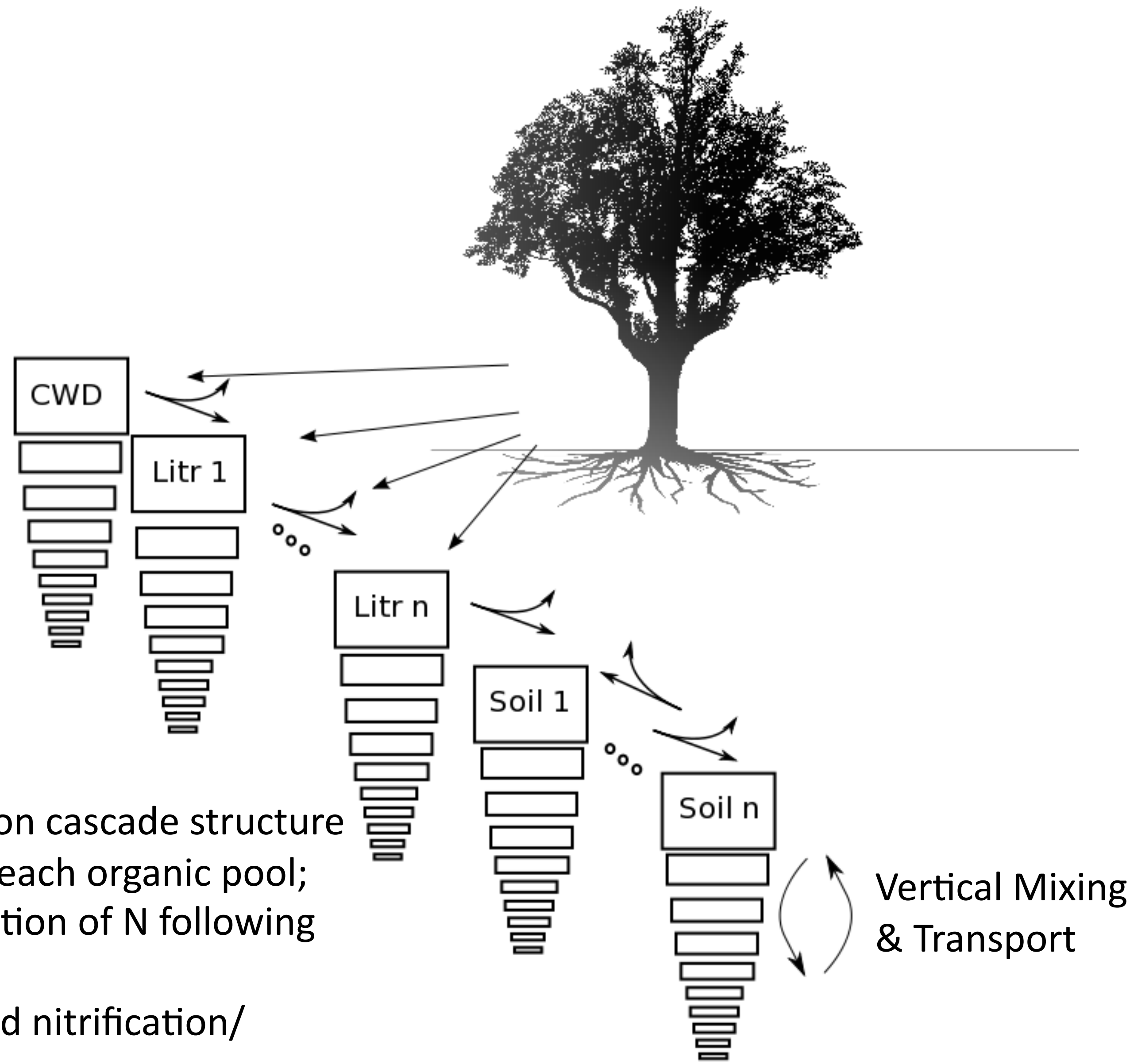
- Large stocks of carbon below surface layers of soils
- Mostly recalcitrant; however could be vulnerable to disturbance, e.g.:
  - Permafrost thaw
  - Peatland hydrology changes



Standard CLM4 decomposition structure



Modified Structure



- Generalized decomposition cascade structure
- Track C and N content of each organic pool; immobilization/mineralization of N following standard CLM equations
- Inorganic N speciation and nitrification/ denitrification

Decomposition cascade structures

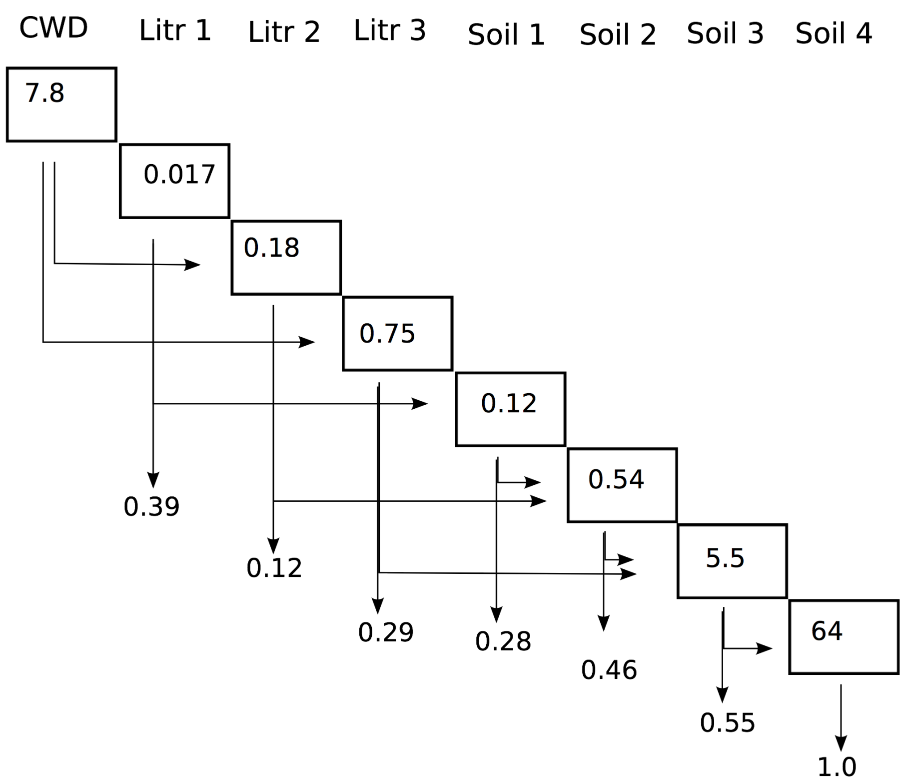
$$\frac{\partial C_i}{\partial t} = R_i + \sum_{j \neq i} (1 - r_j) T_{ji} k_j C_j - k_i C_i$$

Plant inputs

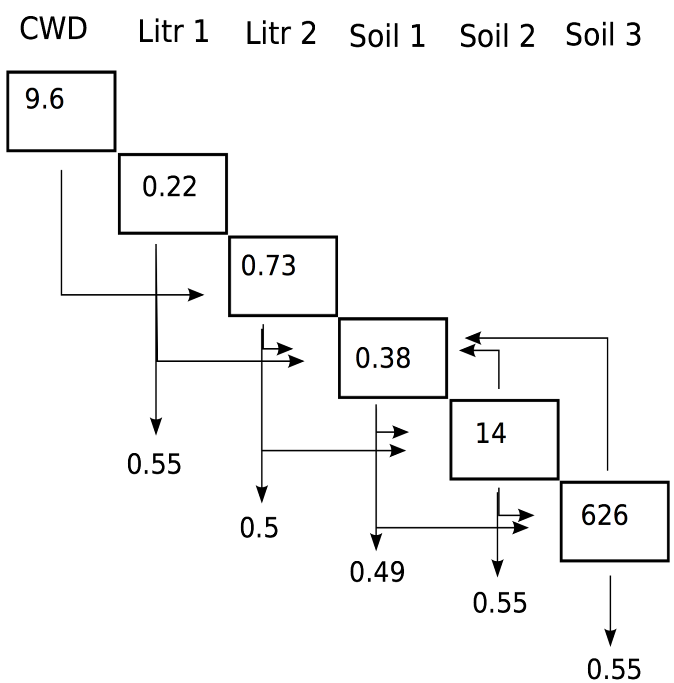
Inputs from upstream pool(s)

First-order decay

Original CLM-CN



CENTURY



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

Adding vertical dimension to decomposing carbon pools

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

↓

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

Diffusive mixing by bioturbation, cryoturbation

Advective fluxes by aqueous flow, sedimentation

4 new parameters:

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

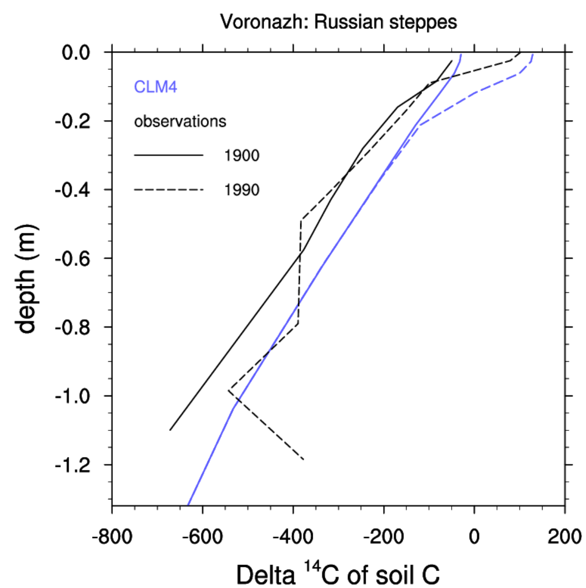
Vertical Soil C parameters and uncertainty from literature

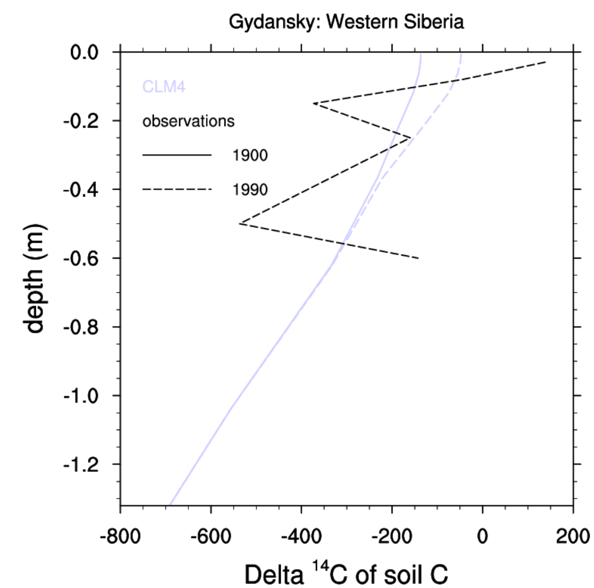
Physical mixing / transport	Advection: 0.1-4 mm/yr Diffusion: 0.3-20 cm^2/yr	Elzein and Balesdent (1995), Yoo et al. (2011), Jarvis et al. (2010), Bruun et al. (2010), Baisden et al (2002)
Root C input profile	Standard CLM rooting profiles (double exponential); single exponential	Zeng (2001), Jackson et al. (1996)
Depth control on Decomposition	No effect, e-folding depth of 0.3-1.0 m	Jenkinson and Coleman (2008)

Link to anoxic processes

- O_2 profiles used in CH_4 model used here to limit decomposition rates
  - Currently implemented only in non-wetland soils, next steps are to integrate in wetland soils to allow peat soil formation
- O_2 profiles also used to calculate oxic/anoxic fractions of soils, with nitrification occurring in oxic fraction and denitrification occurring in anoxic fraction

^{14}C profiles of soil C





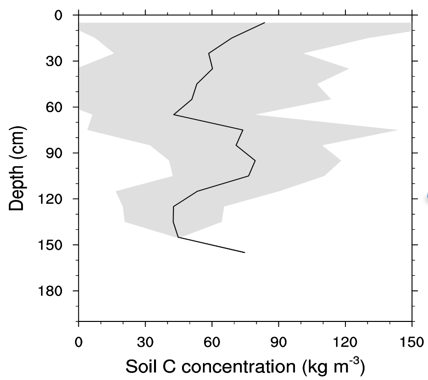
Case 1: grassland soil
Model can give reasonable age-depth slope for soil C, with Century decomposition structure and slowing of decomposition with depth

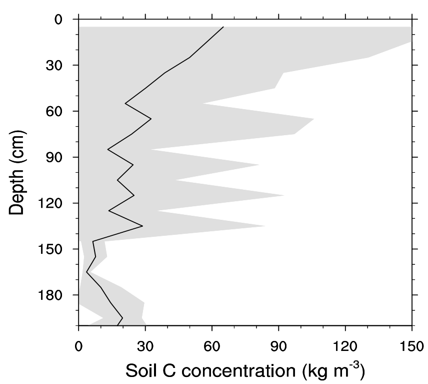
Data: Torn et al., 2002

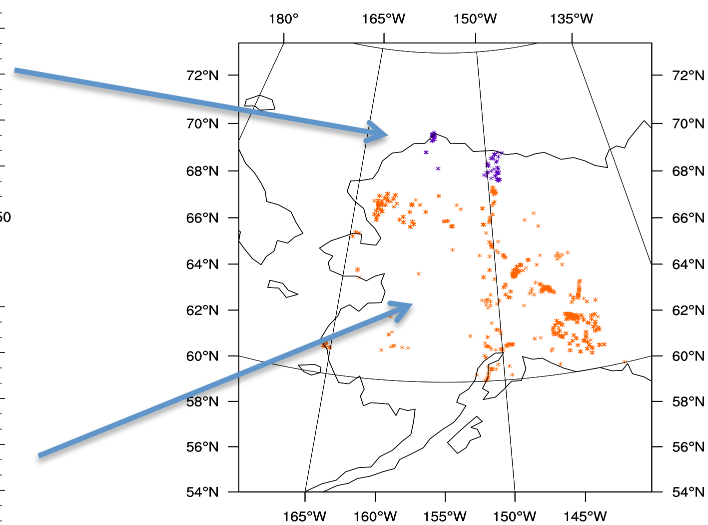
Case 2: cryoturbated warm permafrost
-cryoturbated layers show younger 14C ages, higher C content; large variability through a single soil column cannot captured through diffusion approach

Data: Kaiser et al., 2007

Tundra soils: significant C in upper permafrost layers

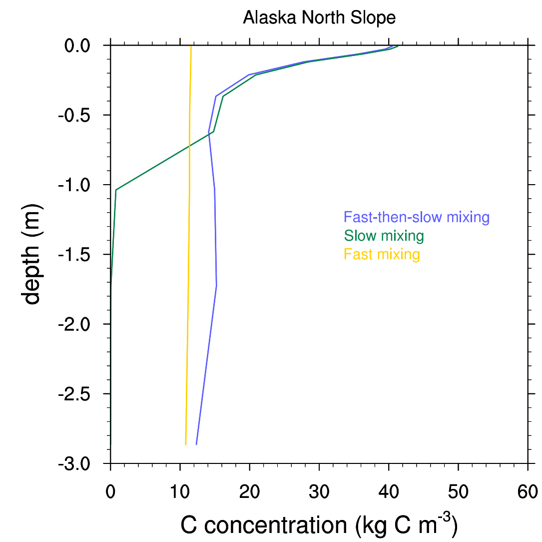






Data from National Soil Carbon Network (NSCN)
www.fluxdata.org/NSCN

CLM4 with vertical mixing

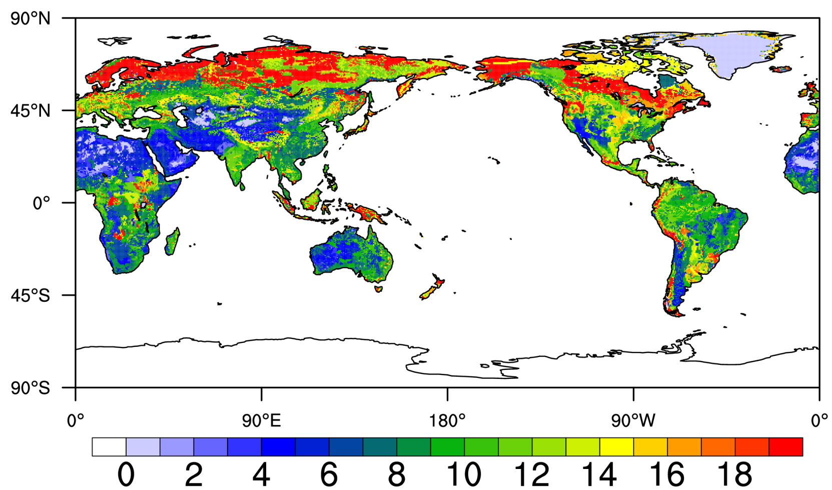


Green: Slow mixing
Yellow: Fast mixing
Blue: Fast-then-slow mixing

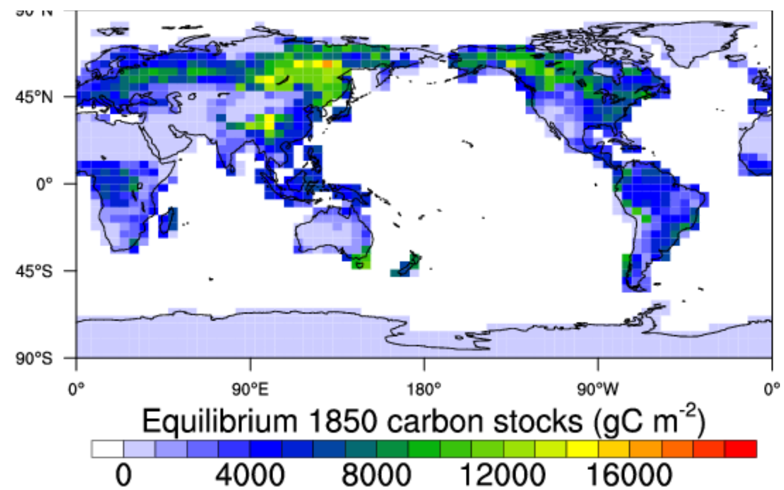
Steady-state spinup assumption may not be appropriate

Soil C distributions

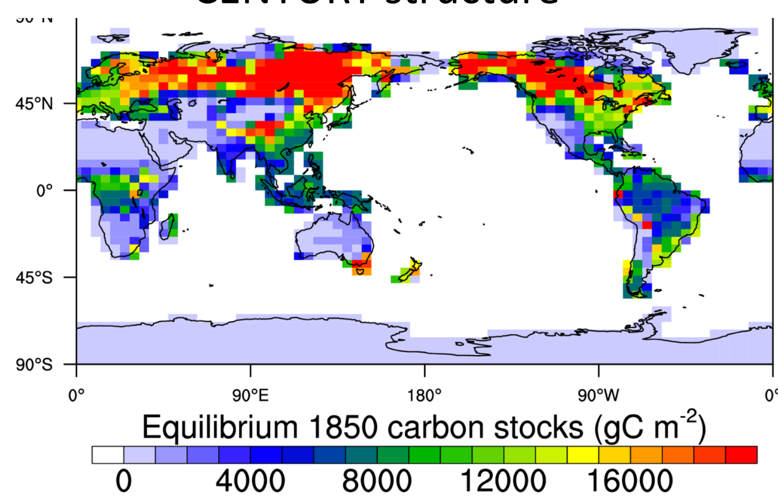
Observations: IGBP soil C map



Base CLM4 single-level soil structure

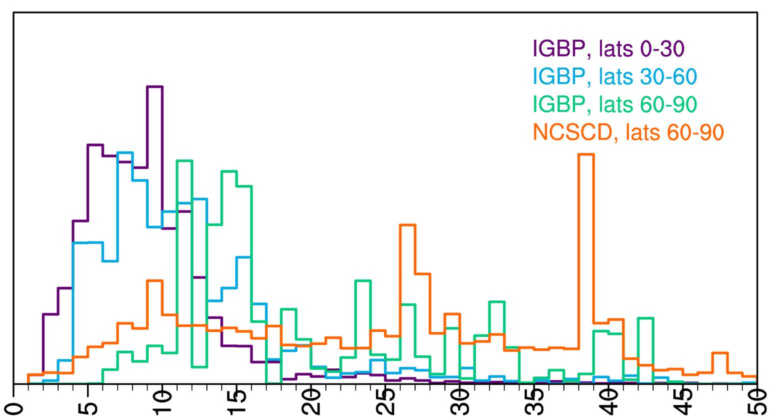


CLM4 with vertical soils and CENTURY structure



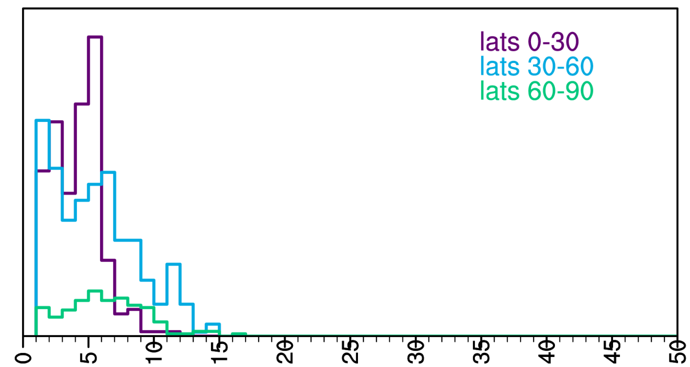
Soil C distributions (to 1 meter)

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

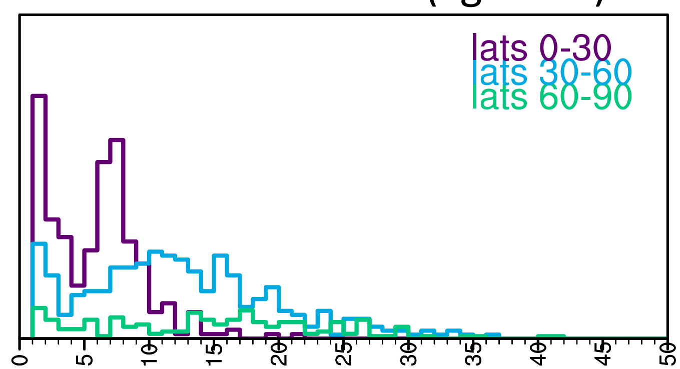


Data: IGBP (2000);
NCSCD: Tarnocai et al. (2007)

Base CLM4 single-level soil structure (kg C m^{-2})



CLM4 with vertical soils and CENTURY structure (kg C m^{-2})



Conclusions

- Including vertical soil C allows formation of permafrost C stocks, reduces low carbon bias at high latitudes
- C profiles of permafrost regions suggest fast mixing at some point in the past, which is subsequently frozen in; may be possible to mimic this using fast mixing to build up permafrost C, followed by slow mixing to build up active layer C.
- Model is able to roughly reproduce ^{14}C depth profiles outside of permafrost regions