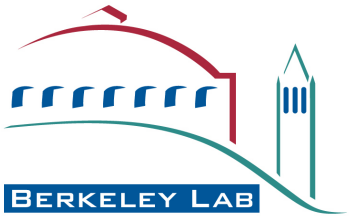

Permafrost C and N Dynamics in CLM4

Charles D. Koven[1], William J. Riley[1], Zachary M. Subin[1], Jinyun Tang[1], Margaret Torn[1], Jennifer Harden[2], David Lawrence[3], Gordon Bonan[3], Sean Swenson[3]

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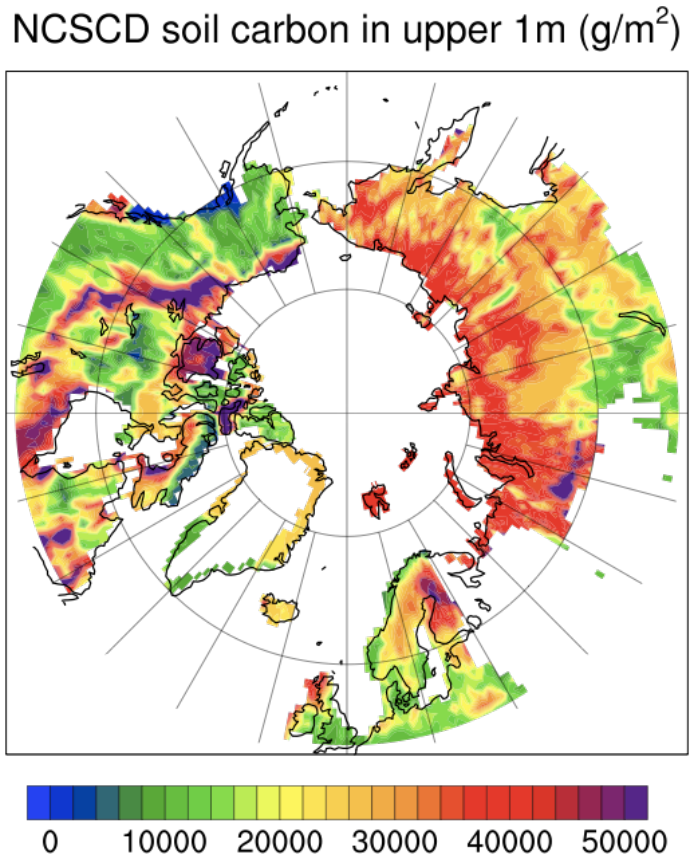
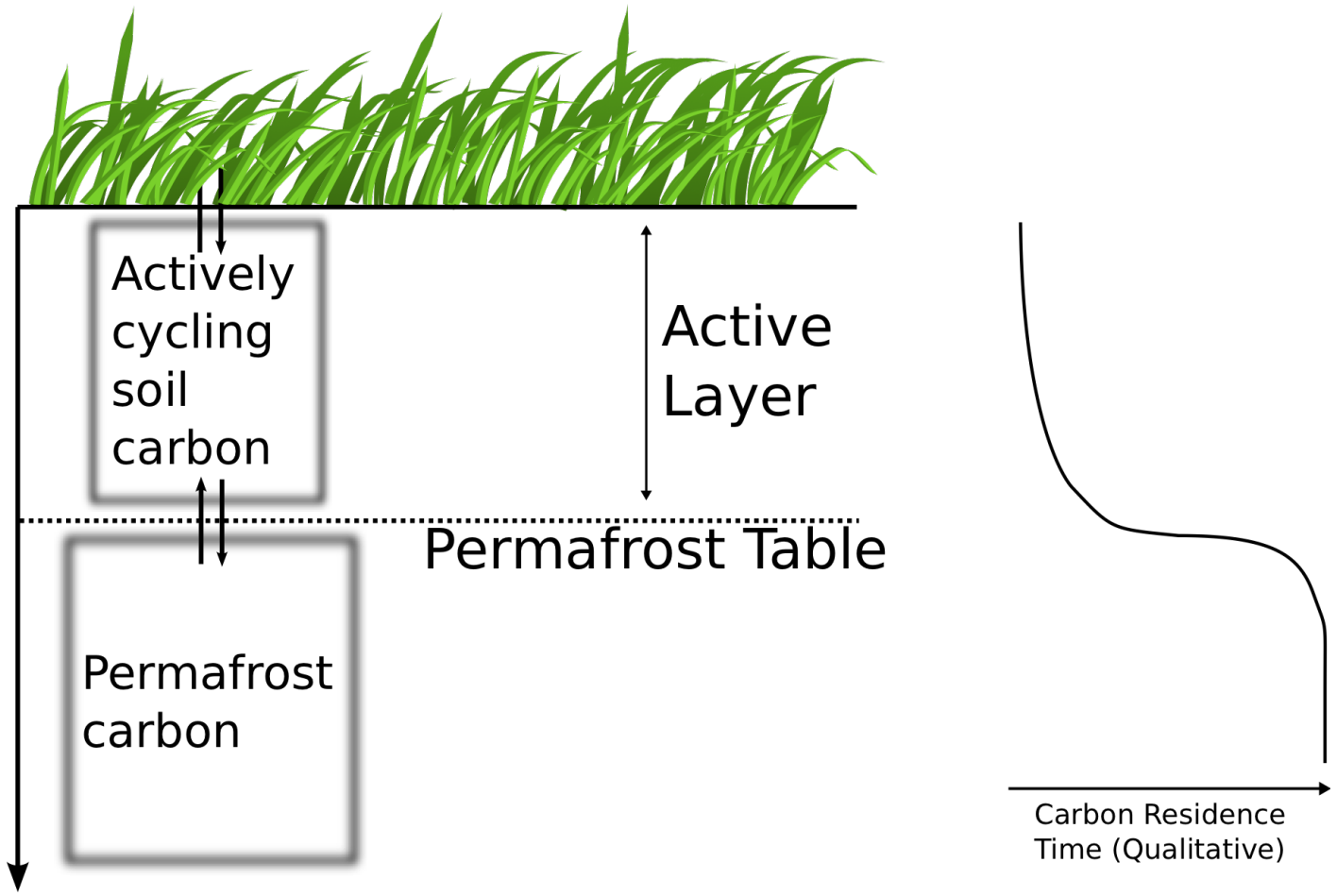
2. United States Geological Survey, Menlo Park, CA
3. National Center for Atmospheric Research, Boulder, CO

High-latitude terrestrial ecosystems store a vast amount (>1000 Pg in top 3 meters of permafrost soils) of soil C.



Northern Circumpolar Soil Carbon Database (Tarnocai et al., 2007)

Problem: Can we represent permafrost C dynamics in ESMs?

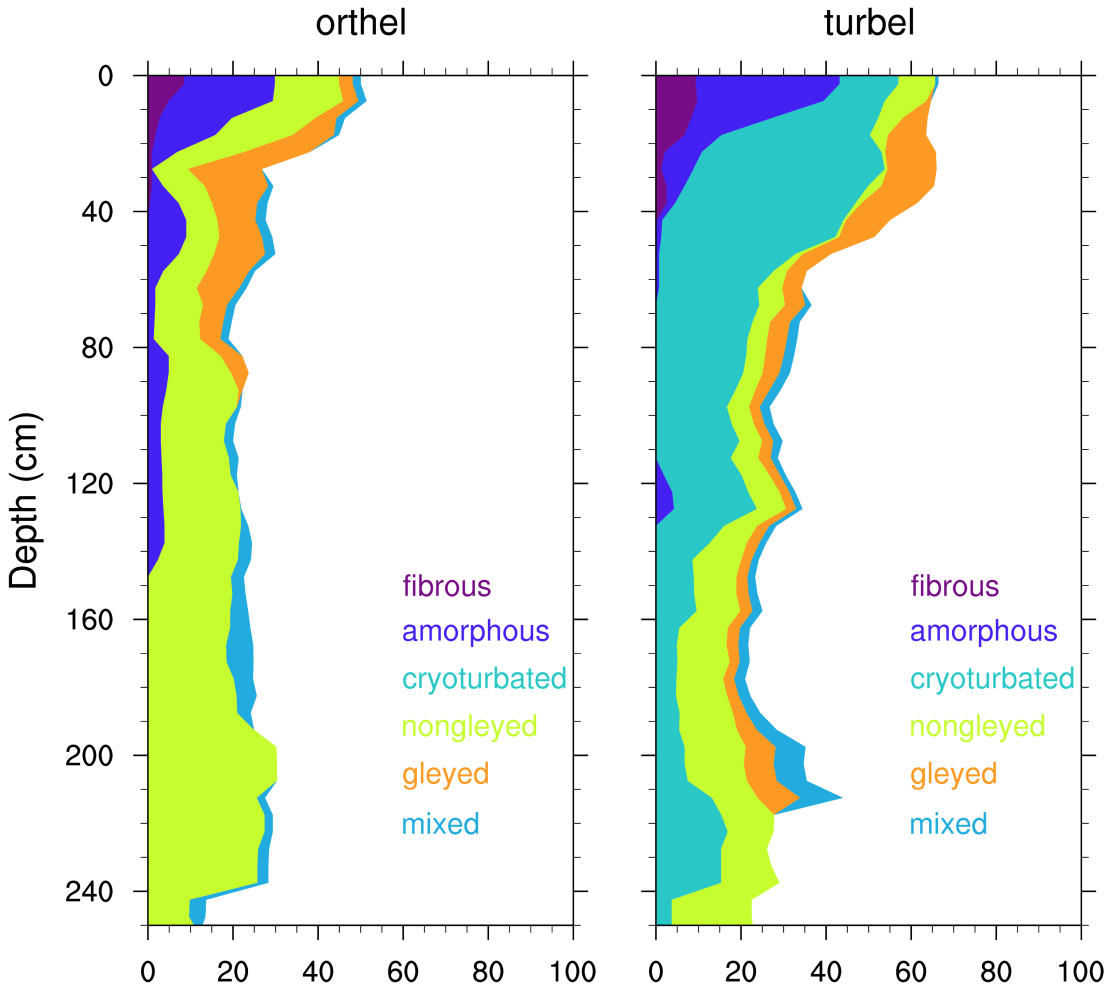


Deep Soil C profiles for mineral permafrost soils

Orthel = not cryoturbated

Turbel = Cryoturbated

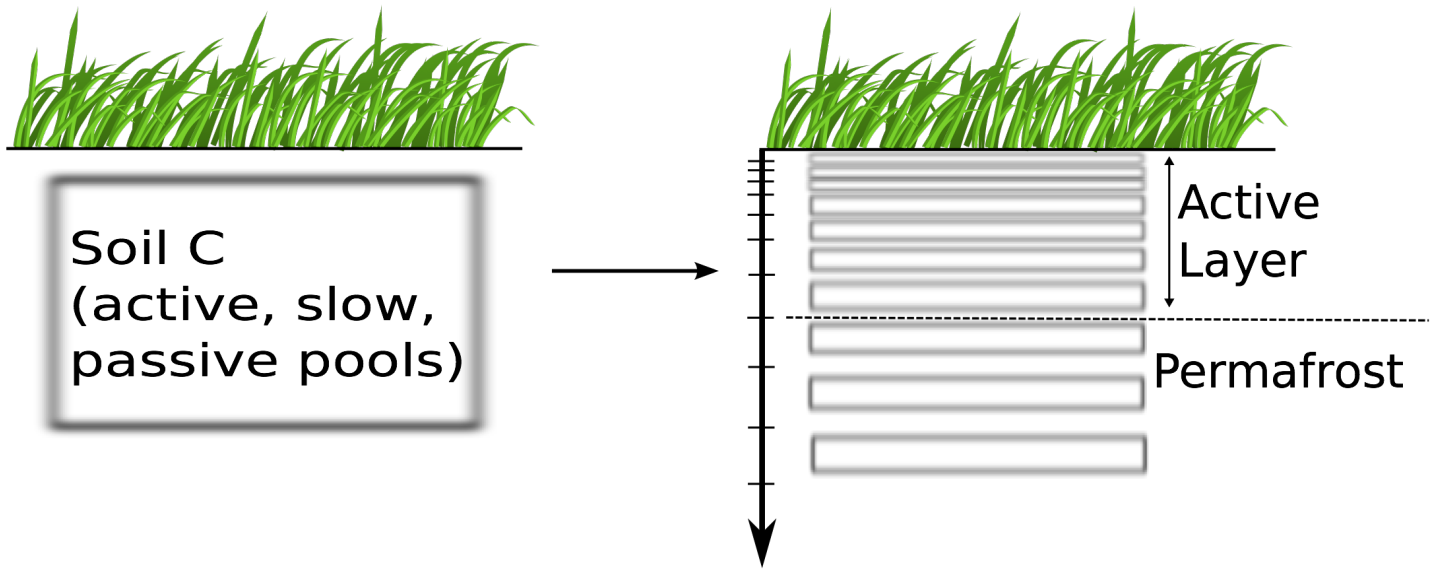
Photos: Soil Atlas of Northern Circumpolar Region



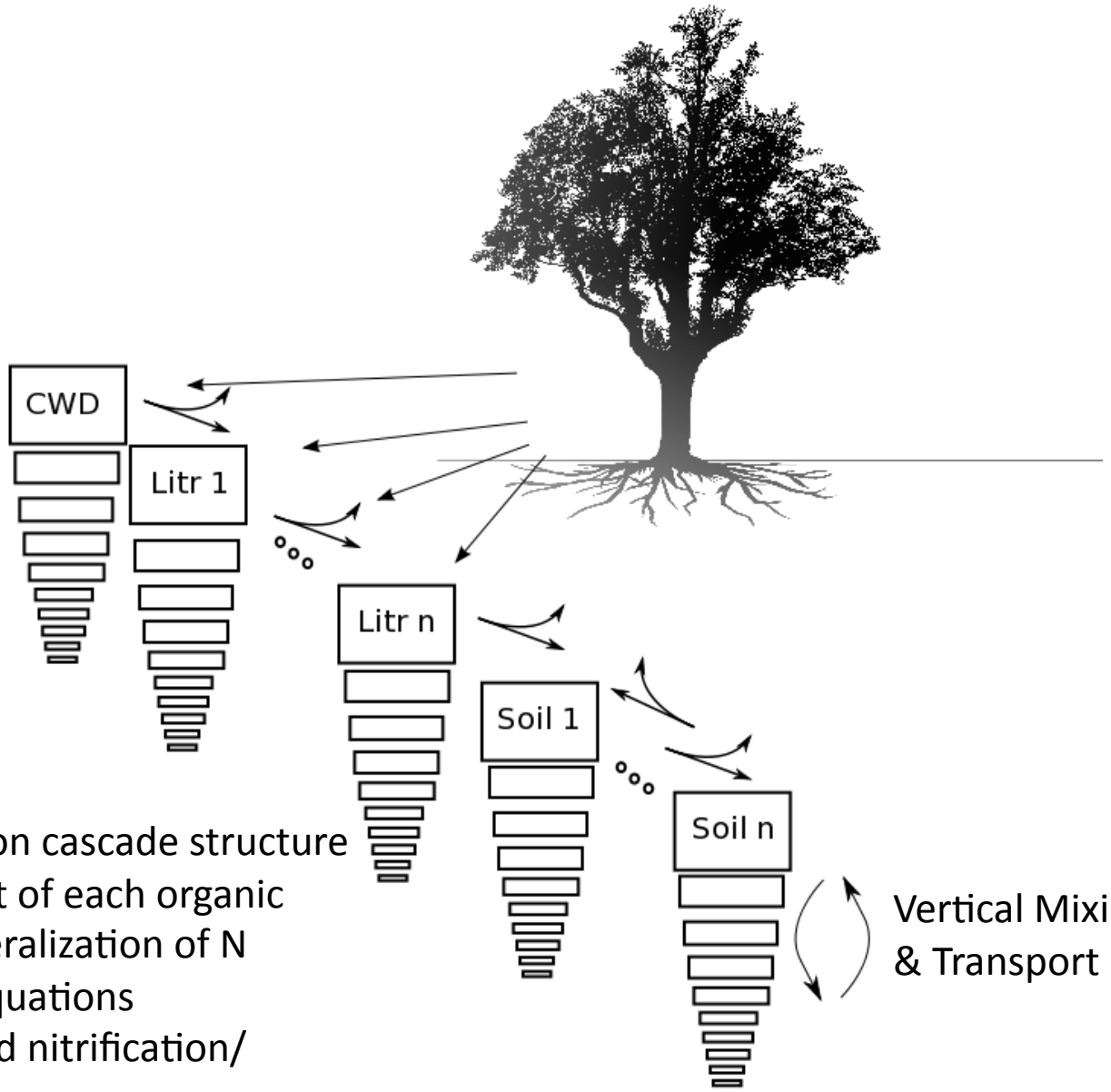
C concentration by profile type (kg C m^{-3})

Harden, Koven, et al., *in prep*

Need to take into account permafrost carbon pools; here we modify CLM to explicitly represent vertical profile of soil carbon and its temperature-dependant residence time



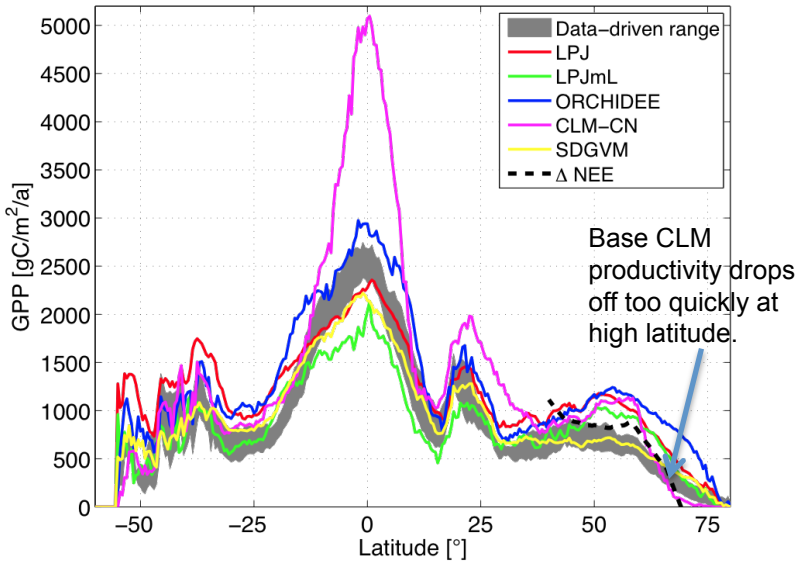
CLM4 Vertical Soil Model Structure



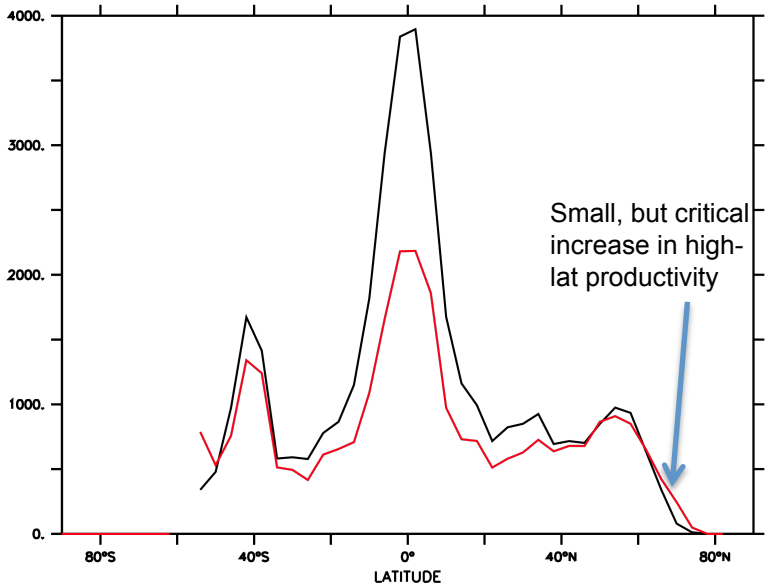
- Generalized decomposition cascade structure
- Track C, ^{14}C and N content of each organic pool; immobilization/mineralization of N following standard CLM equations
- Inorganic N speciation and nitrification/ denitrification

Replace inorganic N cycle and Nitrification/Denitrification

- Base CLM4 has first-order decay of any unused mineral N at each timestep with rapid loss to denitrification
- Replaced this with nitrification/denitrification based on CENTURY approach
  - Nitrification occus as first-order decay of NH_4 pool, with same temperature and moisture limitations as decomposition
  - Denitrification is co-limited by C decomposition and NO_3 availability
  - Explicit O_2 concentration from CH_4 submodel, with anoxic microsite parameterization and denitrification occuring only in anoxic soil fraction
- Leads to decreased tropical productivity; increased high latitude productivity; better agreement with observations



Beer et al., *Science* 2010



Black: CLM4, Red: CLM4-Vertical Soils

Replace inorganic N cycle and Nitrification/Denitrification

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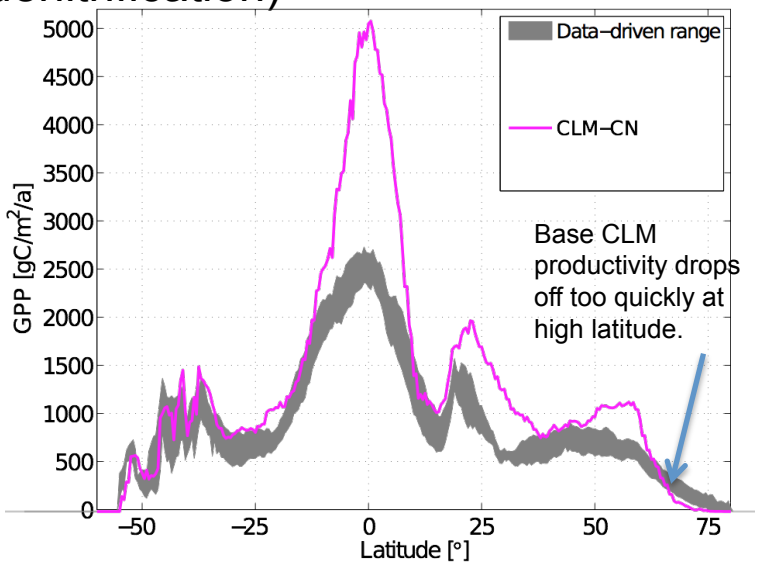
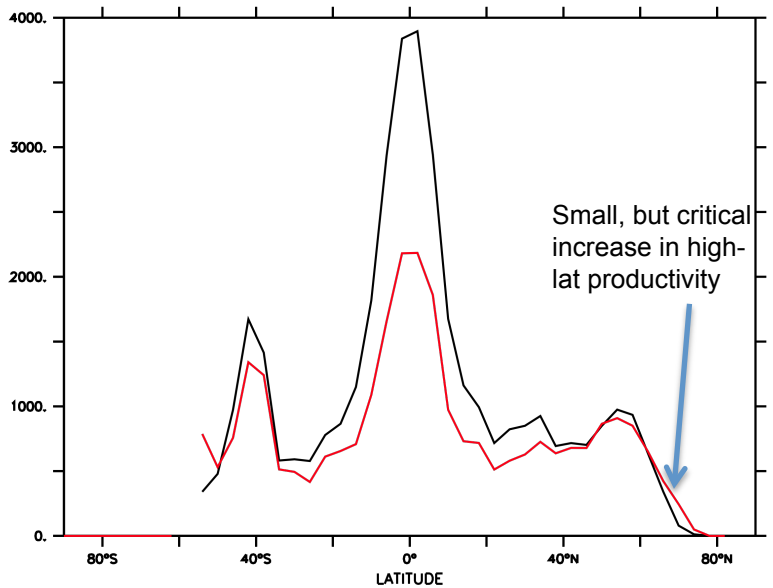
- CLM very sensitive to poorly-constrained slow N cycle processes (N fixation, denitrification)

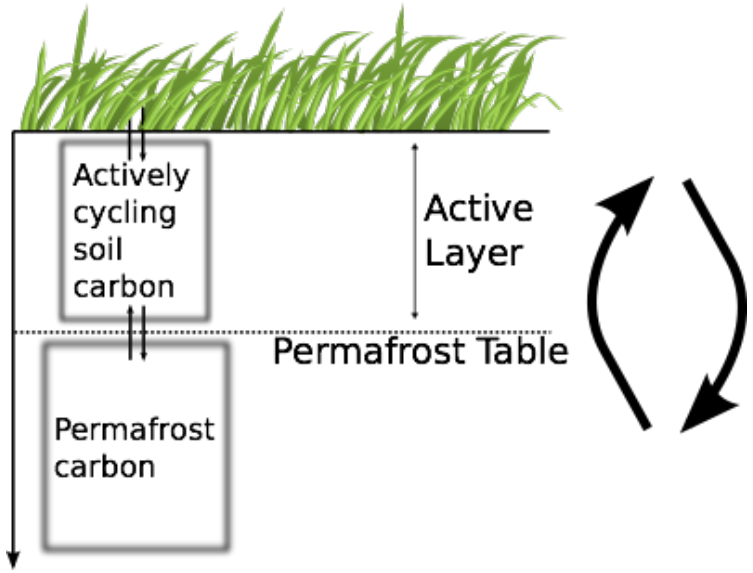


Modified from Beer et al., *Science* 2010, fig. S26



Black: CLM4, Red: CLM4-Vertical Soils

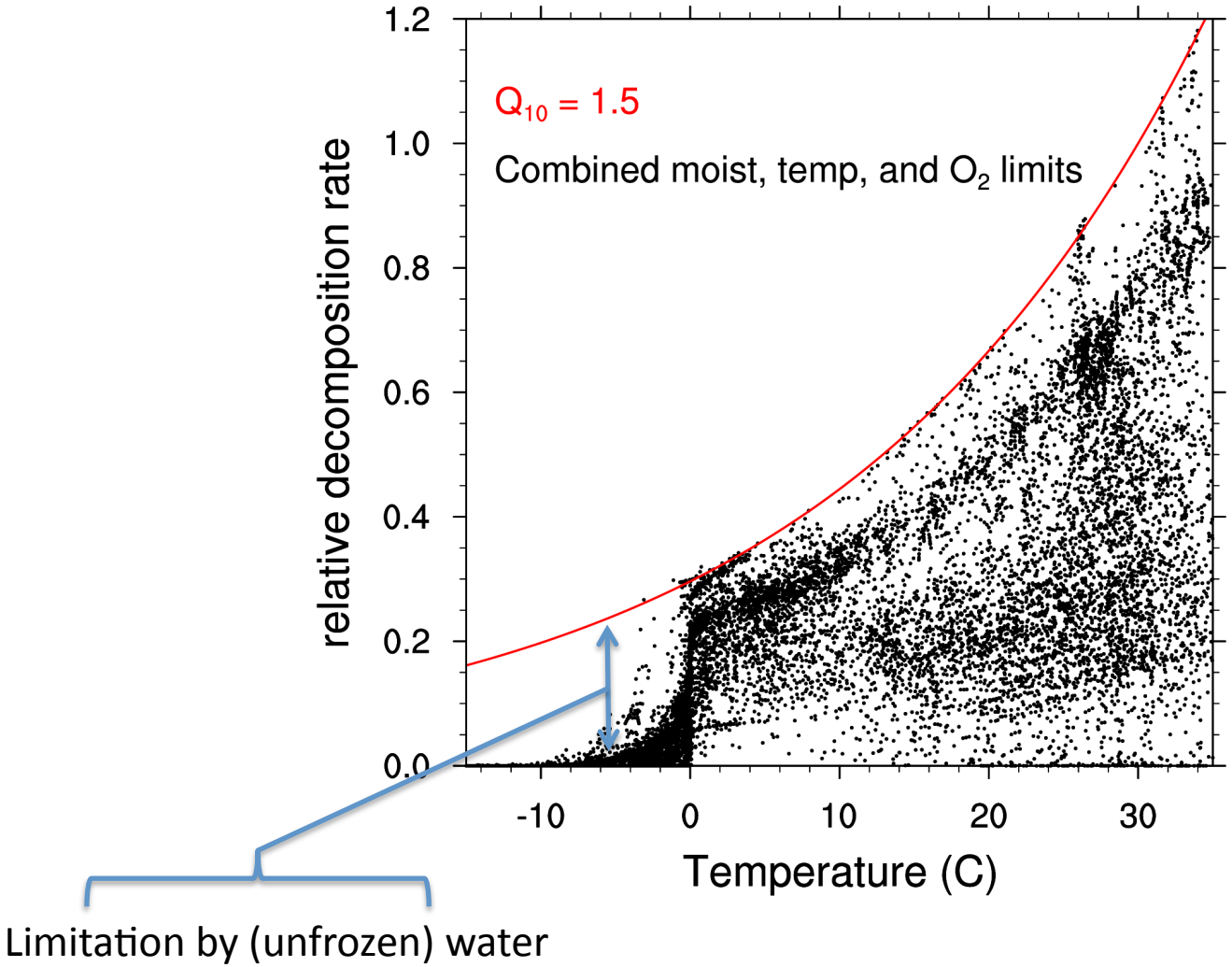
Vertical mixing by cryoturbation modeled as diffusive transport



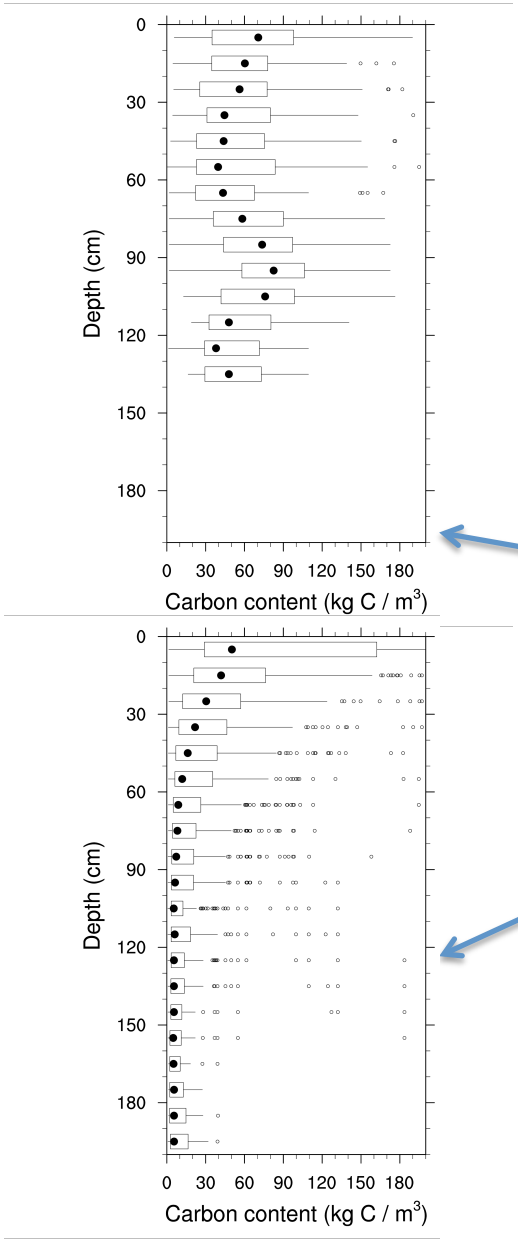
$$\frac{\partial C_i}{\partial t} = D\frac{\partial^2 C_i}{\partial z^2}$$

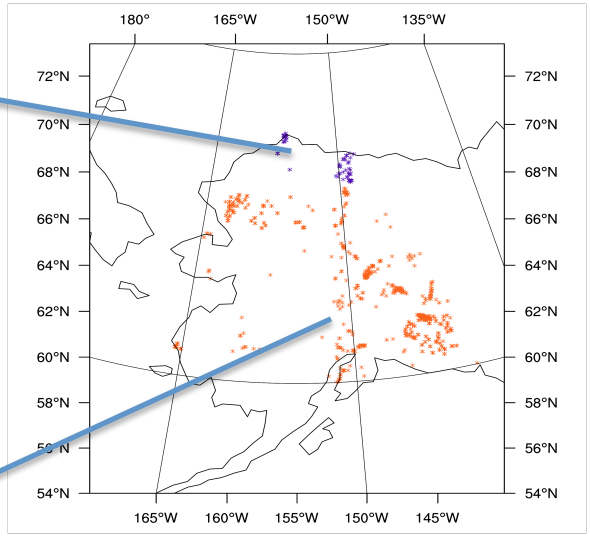
- Carbon input, based on rooting profile, only in the active layer
- D_0, diffusion coefficient is slow to allow mixing on century-millenial time scale: 1-10 $cm^2\ yr^{-1}$
- Mixing below active layer allows carbon to be subducted into upper permafrost

Sharp reduction in modeled decomposition rates across freeze/thaw boundary due to moisture limitation

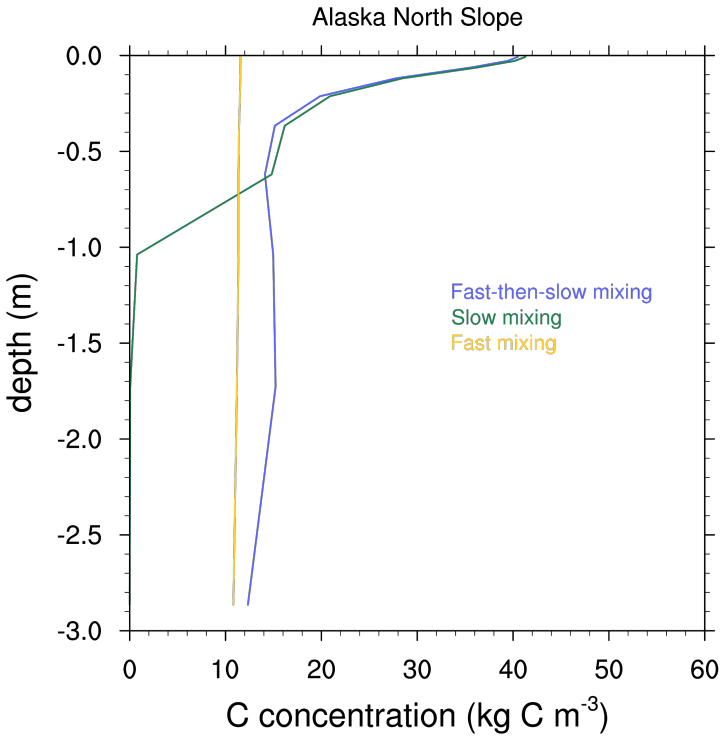


Vertical profiles of SOM: Sensitivity to mixing rate and history





CLM4 with vertical mixing

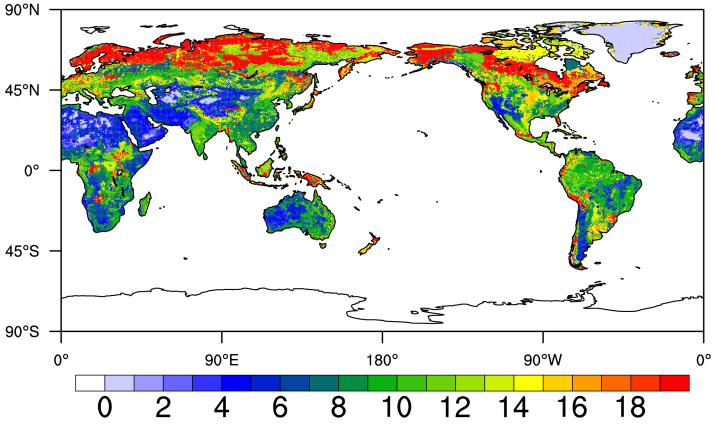


Green: Slow mixing
Yellow: Fast mixing
Blue: Fast-then-slow mixing

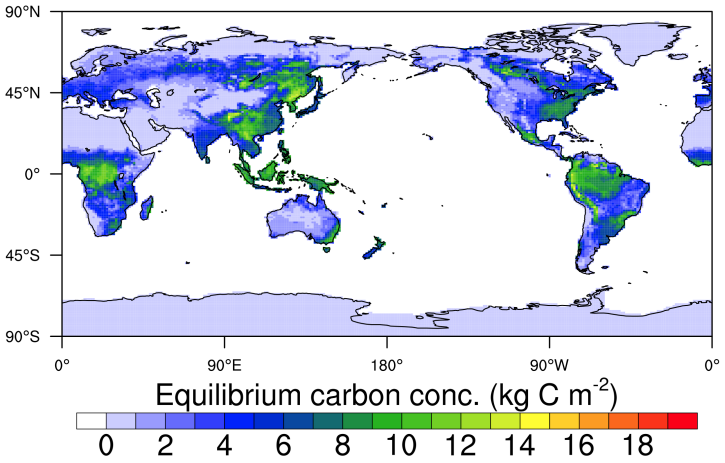
Carbon concentration data:
National Soil Carbon Network, 2011

Soil C stocks

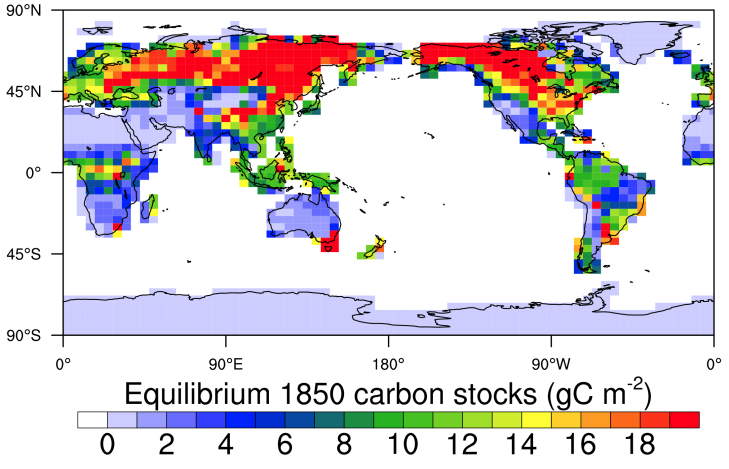
IGBP soil carbon (kg m^2)



CCSM4/CLM3.6 (IPCC-CMIP5)

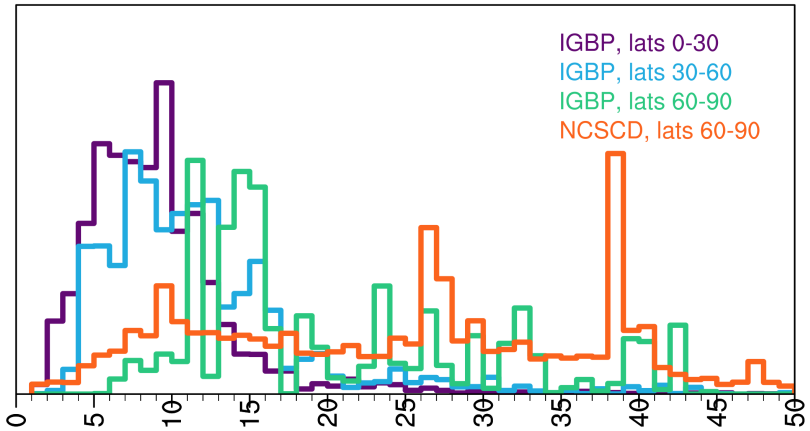


CLM4-Vertical Soil

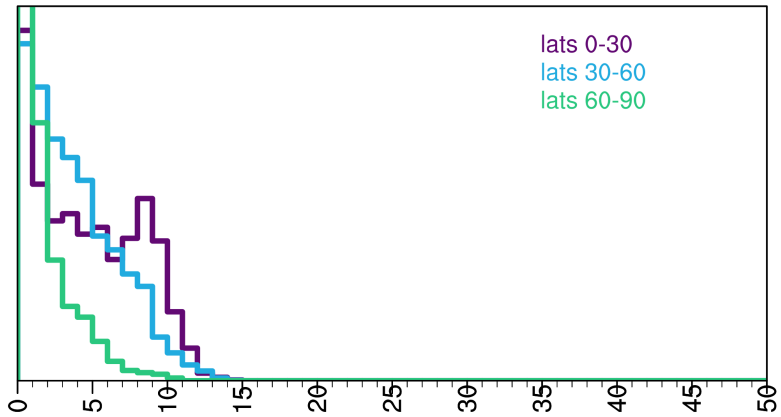


Soil C distributions

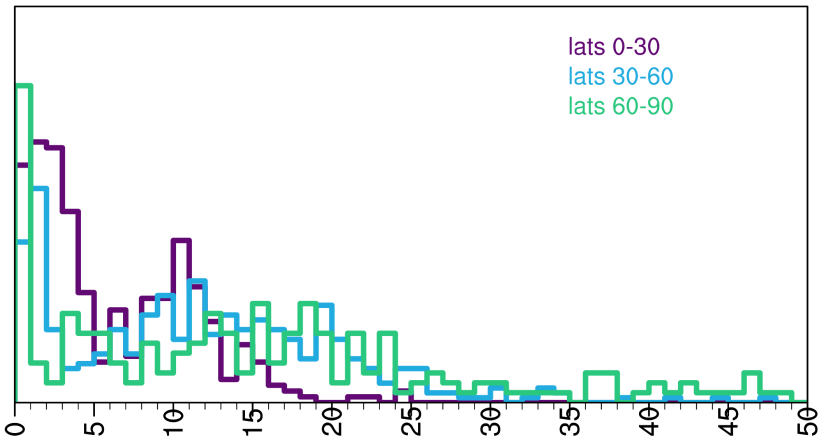
Observed Soil C distributions (kg C m^{-2})



CCSM4 (IPCC-CMIP5) soil C dist. (kg C m^{-2})



CLM4-Vertical Soil C dist. (kg C m^{-2})



Results and Next Steps

- Improved Soil BGC leads to larger, more realistic permafrost C stocks
- Sensitivity of future C balance to soil processes
- Role of released N in enhancing C uptake with warming
- Anoxia and organic soil development

Acknowledgements

- Many colleagues for soil C data
- DOE Contract No. DE-AC02-05CH11231