Supplementary Material for

Permafrost carbon-climate feedback is sensitive to deep soil carbon decomposability but not deep soil nitrogen dynamics

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Supplementary Figures

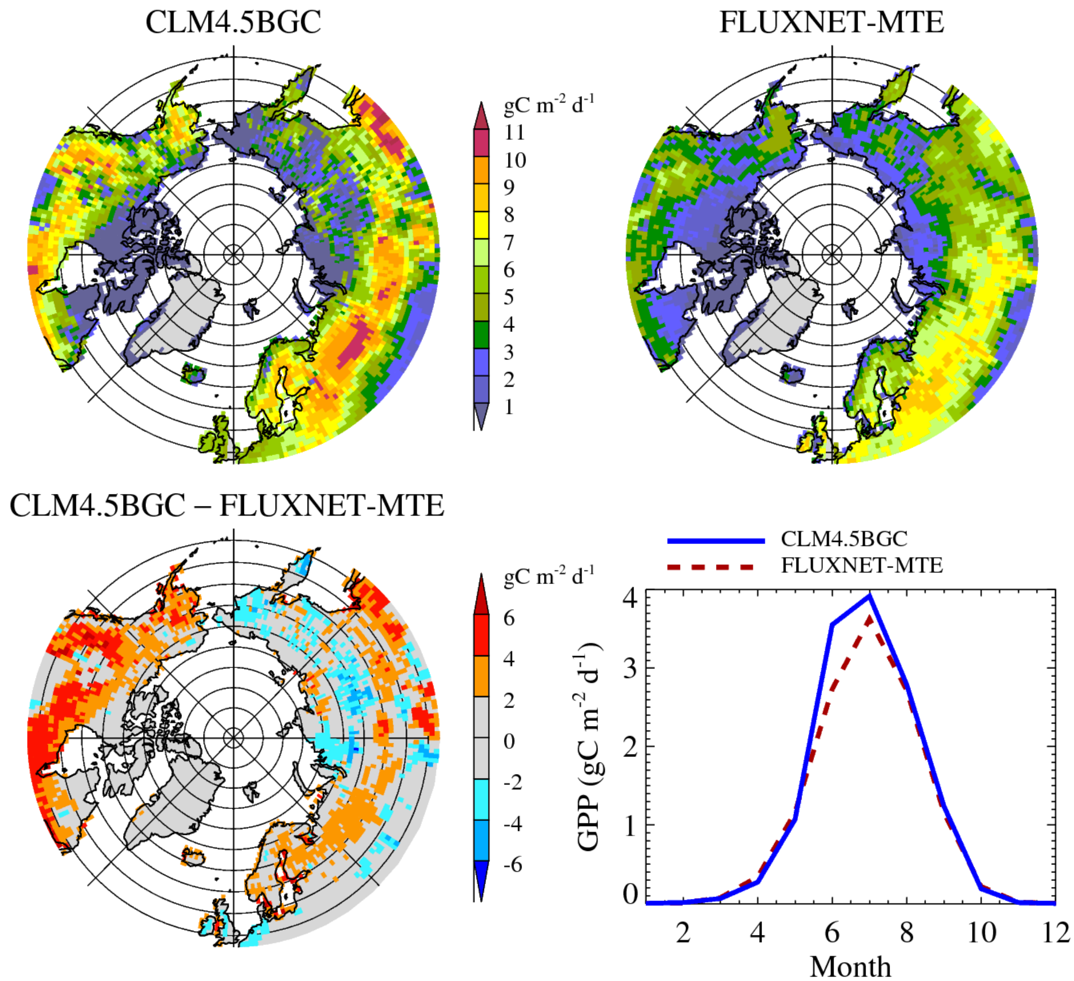

Fig. S1. Comparison of modeled GPP against Fluxnet MTE product (1), for CLM4.5 at high latitudes.

References

1. Beer C*, et al.* (2010) Terrestrial Gross Carbon Dioxide Uptake: Global Distribution and Covariation with Climate. *Science* 329(5993):834--838.

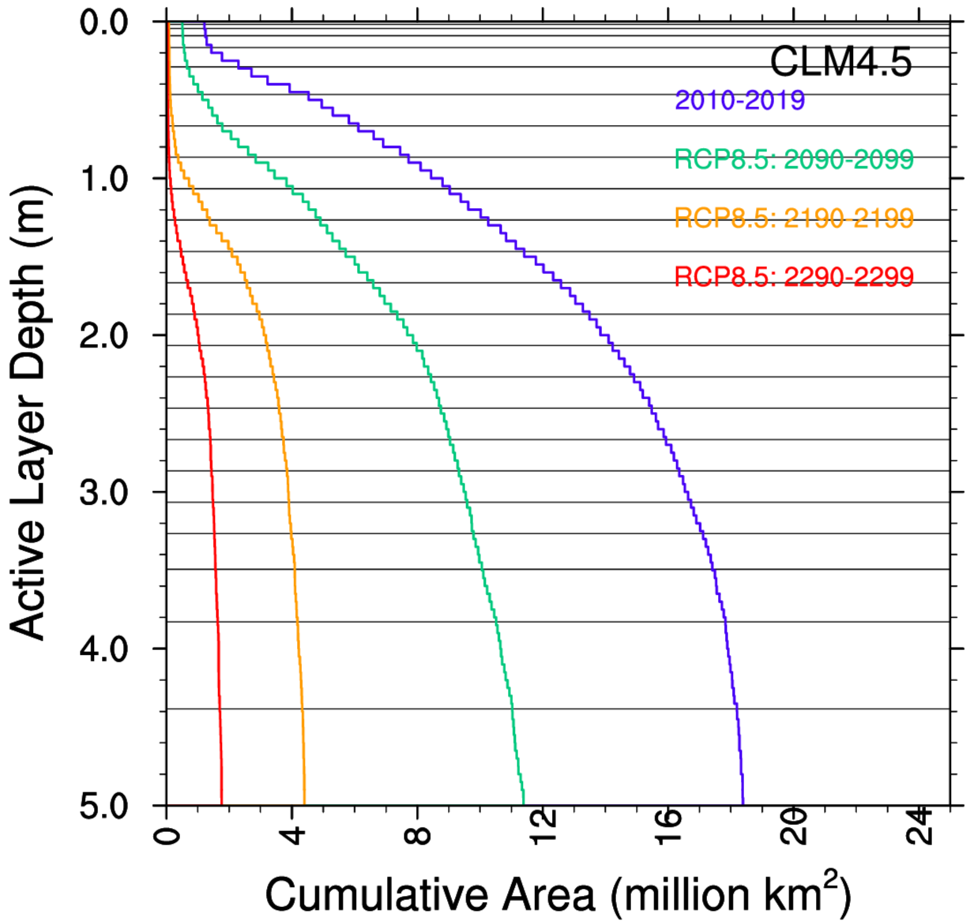

Fig. S2. Cumulative distributions of active layer thickness at four periods in model evolution (after (1)). Curves show the integrated permafrost area (on the horizontal axis) with active layers less than or equal to a given depth (vertical axis). Horizontal lines correspond to the vertical gridcell edges used for soil thermal and biogeochemical calculations within the 0-5m interval. The area between successive curves is proportional to the total volume of permafrost thawed over that time interval.

References

1. Koven C, Riley WJ, & Stern A (2012) Analysis of permafrost thermal dynamics and response to climate change in the CMIP5 Earth System Models. *Journal of Climate*.

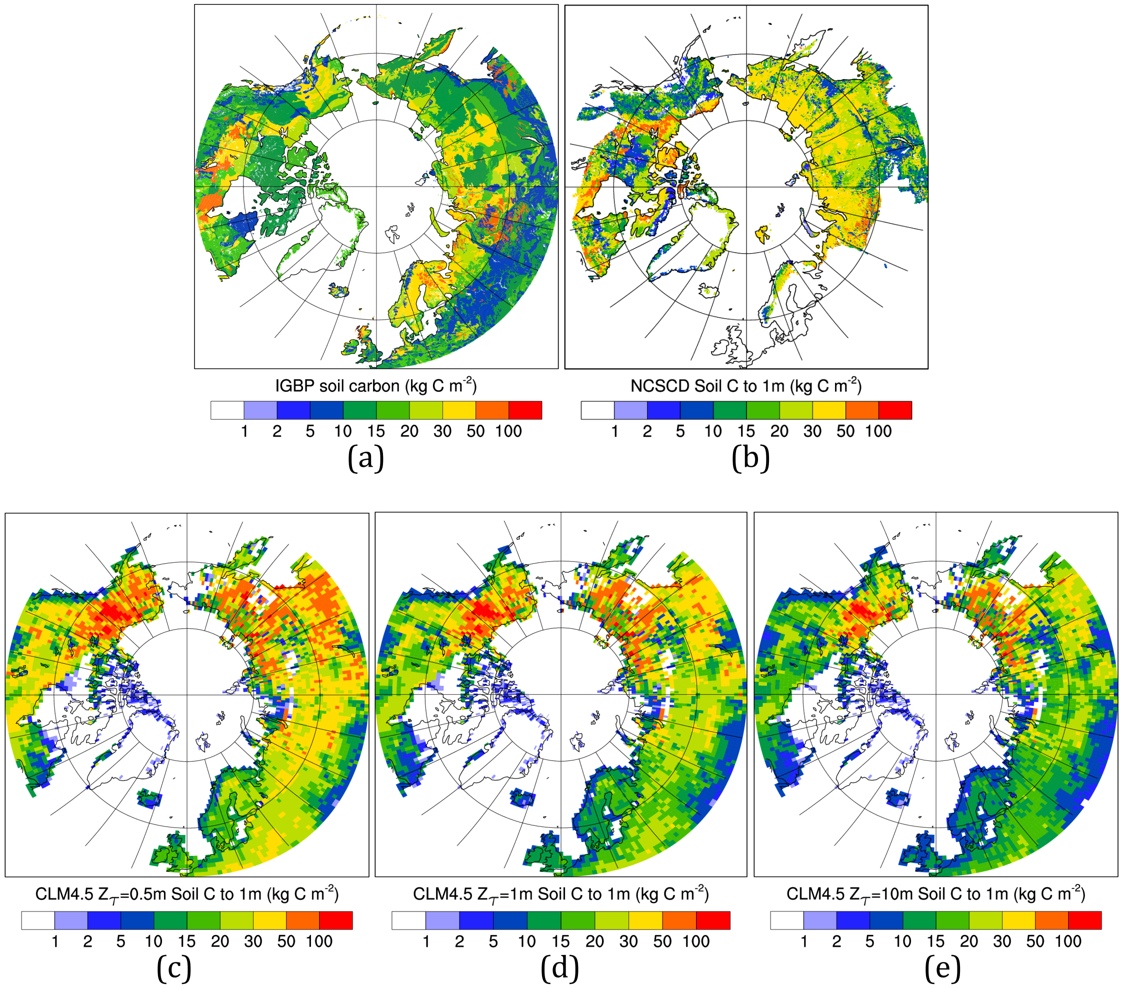

Fig. S3: Soil C to 1m depth for CLM4.5 at start of scenarios and for pan-arctic soil C maps. (a) IGBP soil C, (b) NCSCDv2 soil C (1), (c) CLM4.5BGC with Z_τ=0.5m, (d) CLM4.5BGC with Z_τ=1m, (e) CLM4.5BGC with Z_τ=10m.

References

1. Hugelius G*, et al.* (2013) The Northern Circumpolar Soil Carbon Database: spatially distributed datasets of soil coverage and soil carbon storage in the northern permafrost regions. *Earth Syst. Sci. Data* 5(1):3--13.

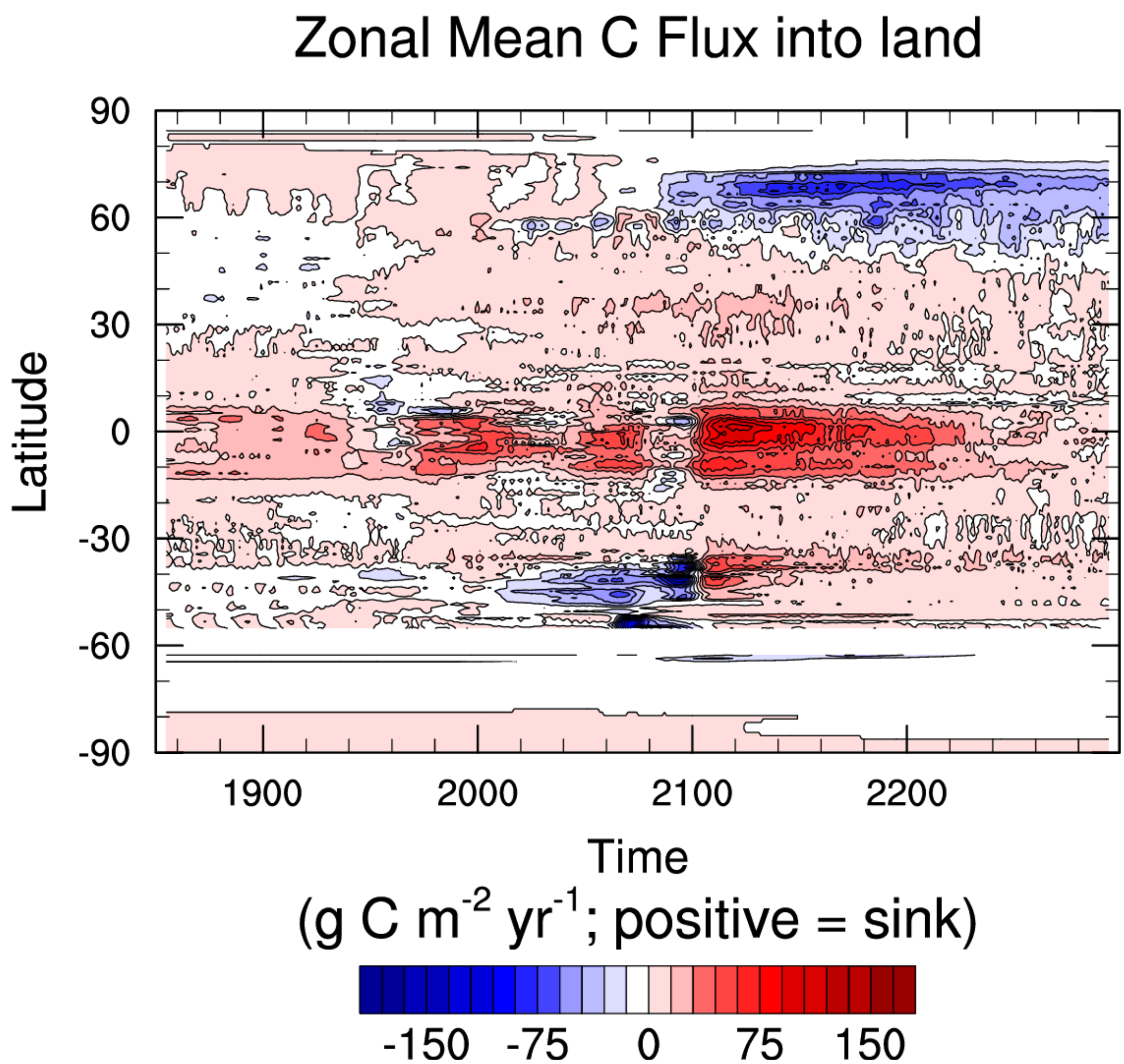

Fig. S4: Zonal-mean C fluxes for transient, fully-forced, coupled C-N run with decomposable deep C (Z_r=10m). Net high latitude fluxes associated with permafrost thaw persist long after the thaw has occurred and are on same order as tropical C uptake due to CO_2 fertilization and changing land-use; thus this represents an important aspect of the global terrestrial carbon cycle response to CO_2 emissions. This figure differs from those shown elsewhere as wood harvest is held constant in the 2100-2300 period instead of going to zero.

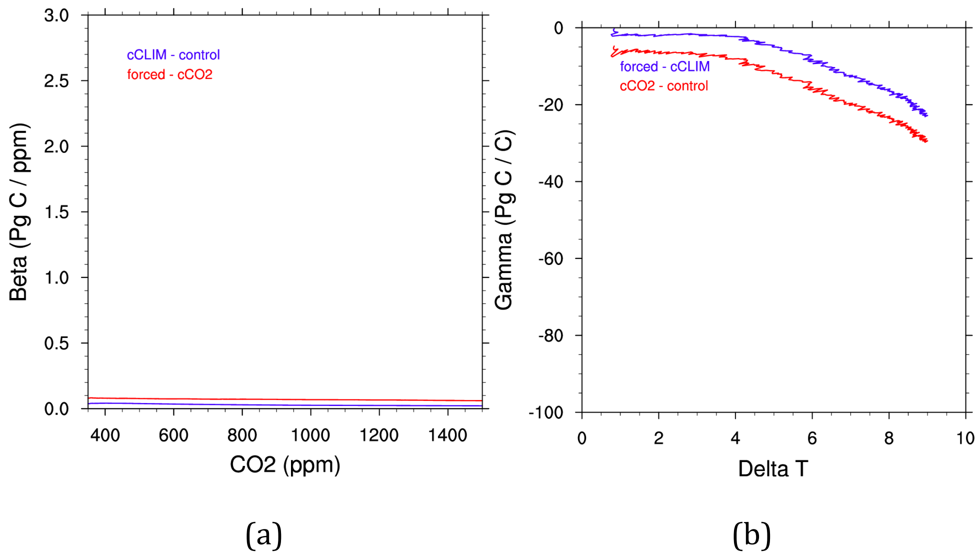

Fig. S5: Feedback analysis for the permafrost region following refs (1, 2). (a) Concentration – carbon feedback term β for the permafrost region, (b) climate-carbon feedback term γ for the permafrost region. Note that the climate-carbon feedback term, γ, shows a threshold response, with initially no C release followed by a strong release after global ΔT exceeds 4°C. The difference between the red and blue lines are different ways of calculating the γ and β terms: blue is calculated following ref. (2) (i.e., fully-forced minus biogeochemically-forced for γ, and biogeochemically-forced minus control for β); red is an alternate method (fully-forced minus climatically-forced for β, climatically-forced minus control for γ) that assigns the synergistic effects to the β rather than the γ term. Vertical axes are at same scale as used by ref. ((1)) for comparison to CMIP5 global values.

References

1. Arora VK, *et al.* (2013) Carbon-concentration and carbon-climate feedbacks in CMIP5 Earth system models. *Journal of Climate*.
2. Friedlingstein P, *et al.* (2006) Climate-carbon cycle feedback analysis: Results from the C4MIP model intercomparison. *Journal of Climate* 19(14):3337-3353.

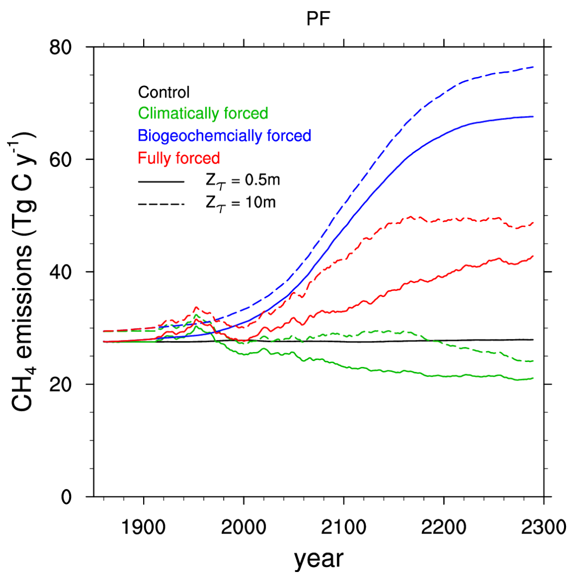

Fig. S6: Permafrost area integrated methane emissions for the C-N run with low (Z_τ=0.5m) and high (Z_τ=10m) deep soil decomposability, for the four experimental cases. Deeper decomposition leads to higher initial CH_4 fluxes since it shifts overall respiration deeper in the soil column where anoxia is more widespread. Transient increase in CH_4 fluxes due to thawing deep permafrost soil C (difference between solid and dashed red or green lines) are present but relatively small in magnitude.

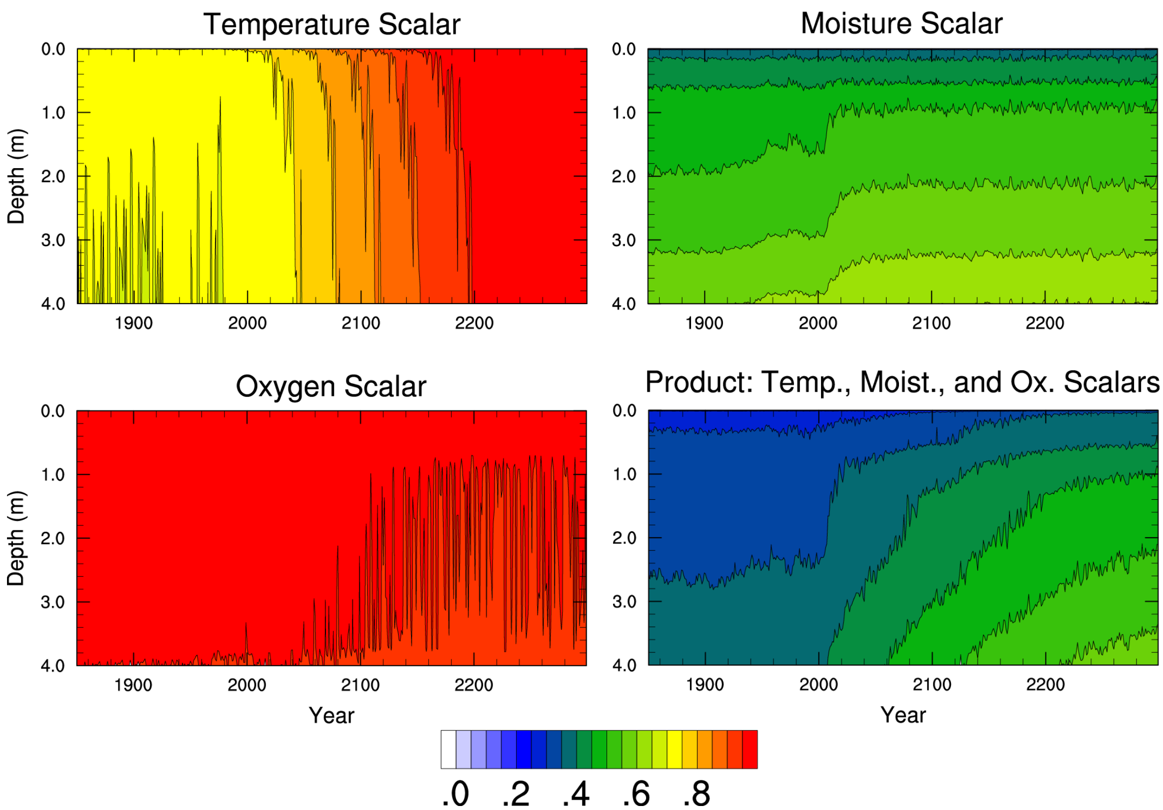

Fig. S7: Vertical profiles of the controls on soil decomposition for the extra-permafrost region—i.e. similar to figure 2 but for the rest of the world. There is only a weak depth dependence to projected changes in decomposition outside of the permafrost region.

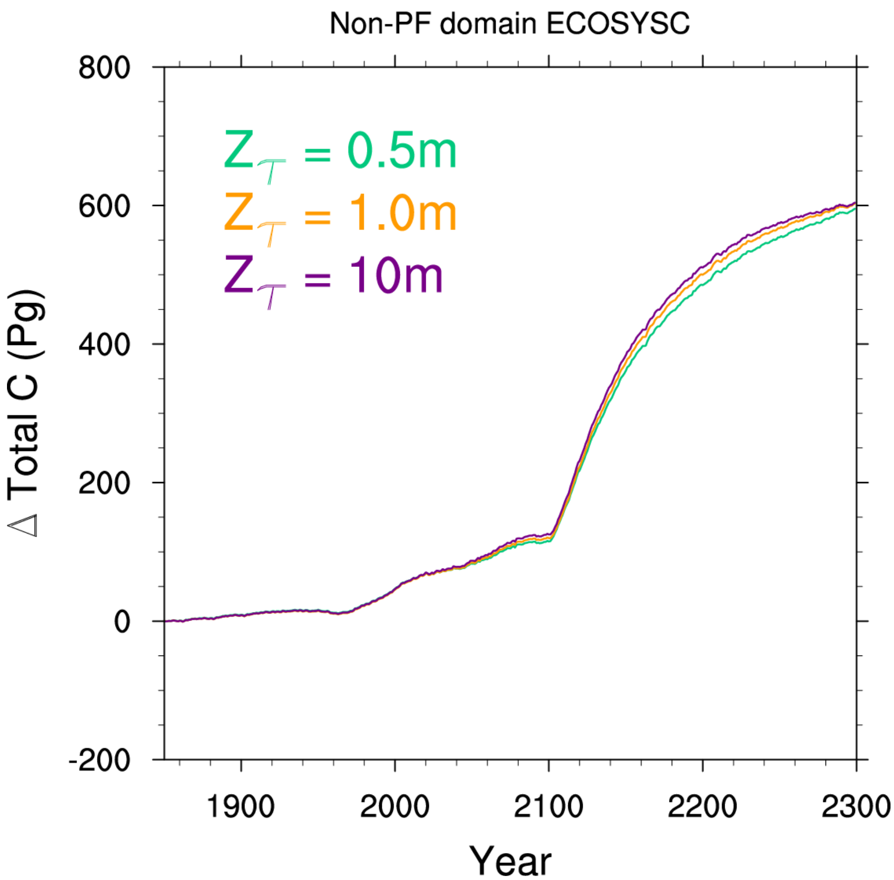

Fig. S8: Total C changes integrated over the extra-permafrost region, as a function of parameter Z_τ—i.e. similar to figure 3a but for the rest of the world. The large C increase after 2100 is due to discontinuation of land-use change and harvest fluxes after 2100.

Plant Functional Type (PFT)	**f_{nitr} value**
not vegetated	1.000
needleleaf evergreen temperate tree	0.824
needleleaf evergreen boreal tree	0.841
needleleaf deciduous boreal tree	0.947
broadleaf evergreen tropical tree	0.950
broadleaf evergreen temperate tree	0.825
broadleaf deciduous tropical tree	0.853
broadleaf deciduous temperate tree	0.682
broadleaf deciduous boreal tree	0.689
broadleaf evergreen shrub	0.813
broadleaf deciduous temperate shrub	0.750
broadleaf deciduous boreal shrub	0.796
c3 arctic grass	0.714
c3 non-arctic grass	0.613
c4 grass	0.294
c3 crop	0.697

Table S1: Limitation factors applied to the C-only model to give initial PFT-specific NPP totals the same as the preindustrial CLM4.5BGC NPP. These values are calculated following reference (1).

References

1. Bonan GB & Levis S (2010) Quantifying carbon-nitrogen feedbacks in the Community Land Model (CLM4). *Geophys. Res. Lett.* 37(7):L07401.

Depth Parameter	**Nutrient Coupling**	**Experimental Forcing**	**Year**			
			2005	**2100**	**2200**	**2300**
Z_r = 0.5m	C-N	Fully-forced	5.9	18.8	16.2	−21.5
		BGC-forced	5.5	18.2	36.0	44.5
		Climate-forced	−0.2	−20.0	−71.1	−124.5
		Control	0.2	−0.6	4.5	7.6
	C-only	Fully-forced	13.5	45.9	49.8	15.4
		BGC-forced	12.0	54.4	109.6	142.7
		Climate-forced	0.1	−19.4	−70.2	−121.3
		Control	−1.8	−4.0	−0.8	0.8
Z_r = 1m	C-N	Fully-forced	4.1	10.9	−22.5	−88.4
		BGC-forced	4.19	16.7	34.6	42.7
		Climate-forced	−0.5	−15.5	−71.4	−130.4
Z_r = 10m	C-N	Fully-forced	3.9	1.0	−81.4	−164.4
		BGC-forced	4.05	16.7	34.5	42.9
		Climate-forced	−3.6	−44.4	−166.5	−259.2
		Global-mean ΔT of fully-forced and climate-forced experiments	0.75	4.5	7.7	8.9

Table S2: Integrated changes in total ecosystem carbon (Pg C) for the permafrost region over the experimental runs. Positive numbers indicate C uptake to the biosphere, negative indicate C losses to the atmosphere. Control cases and C-only cases performed only for the insensitive deep C (Z_r = 0.5m) model configuration. Also shown are global mean temperature anomalies (°C) used to calculate carbon-climate feedback parameter γ.

<<see separate .gif file>>

Movie S1: Animation of permafrost loss and soil C change for transient, fully-forced C-N run with decomposable deep C (Z_τ=10m). Permafrost boundary retreats poleward with warming; C losses from soils follow and loss rates persist long after the period of rapid thaw.