Evaluation of soil carbon dynamics after land use change in CMIP6 models using chronosequences

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Soil carbon chronosequences: example of self-restoration of agricultural soils

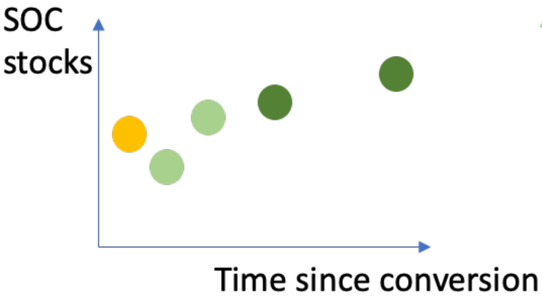
Valdai (Russia) chronosequence

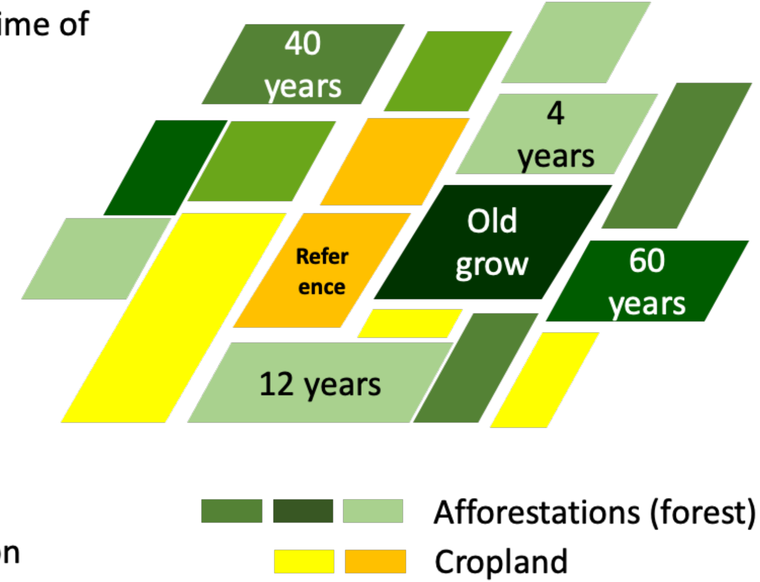
Kalinina et al., Geodema, 2009

Soil Carbon Chronosequences

Assumptions:

- All plots have same soil type/texture
- Same initial soil conditions at time of conversion
- SOC stocks of reference plot (cropland) remain unchanged (steady-state)





Slide from Axel Don: axel.don@thuenen.de

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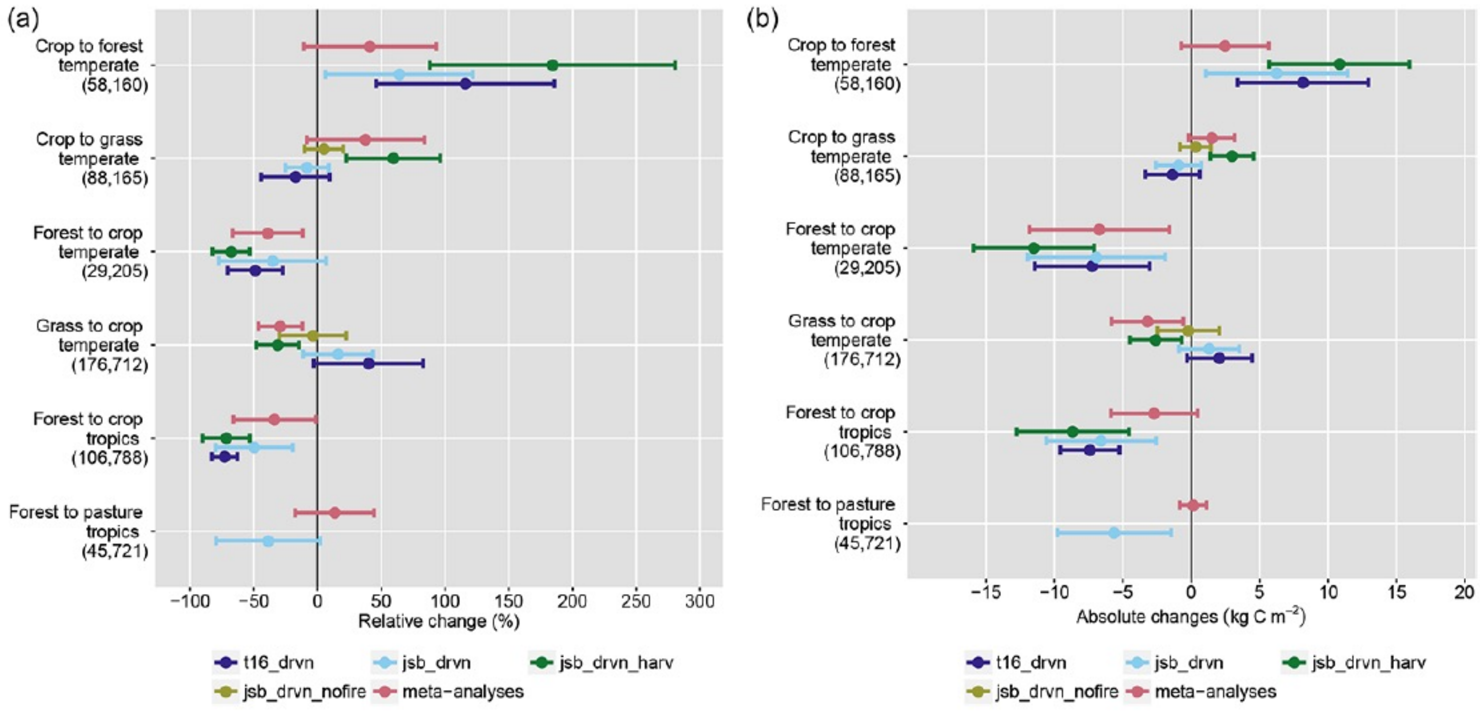
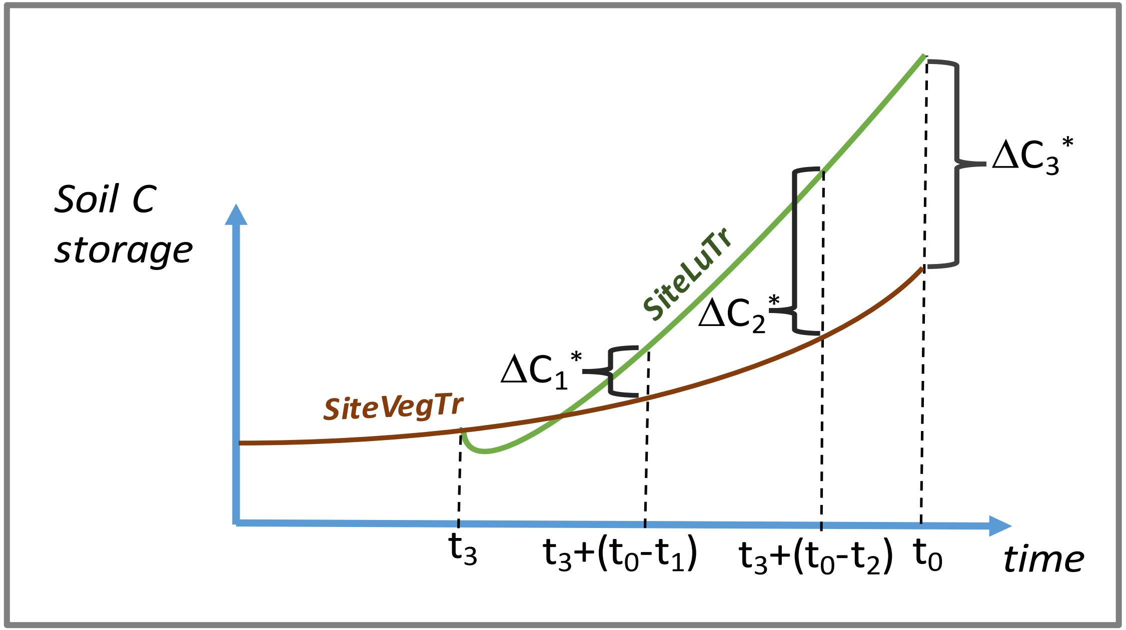
Previous study: equlibrium setup experiments with JSBACH



Nyawira, Nabel, Don, Brovkin, & Pongratz, Biogeosci. (2016)

Novel experimental setup

- Two transient experiments with offline models (with/without landuse transitions)
- Forcings: land use transition, climate (GSWP3), CO_2
- Initial conditions: cycled climatology



Boysen et al., Env. Rese. Lett, in review

Four high-quality sites

Characteristics of selected soil carbon chronosequences (SCC) sites. Mean annual temperature (MAT) at 2 meter height and mean annual precipitation (MAP) from publications and from the model forcing data in parenthesis (GSWP3 by Kim et al.)

SCC Site	MAT [°C]	MAP [mm]	Soil type	Measurement depth [m]	Year of LUC	Last year	Original vegetation	Vegetation after LUC	Ref
Valday (Rus)	5.2 (5.3)	717 (719)	Cambisol, Podsol	0.20	1907	2004	Arable land	spruce	(Kalinina et al., 2009)
Gejlvang (DK)	8.0 (8.1)	883 (882)	Durorthod / Spodosols	0.25	1960	1997	cropland	Norway spruce	(Vesterdal et al., 2007)
SW France	12.0 (12.1)	614 (611)	Veracrisol, Vermic Haplumbrepts	0.26	1962	1987	Pine forest	Maize	(Arrouays and Pelissier, 1994)
Costa Rica	25.3 (25.3)	3265 (3280)	Humitropept	30.0	1974	1992	Forest	pasture	(van Dam et al., 1997)

Boysen et al., Env. Rese. Lett, in review

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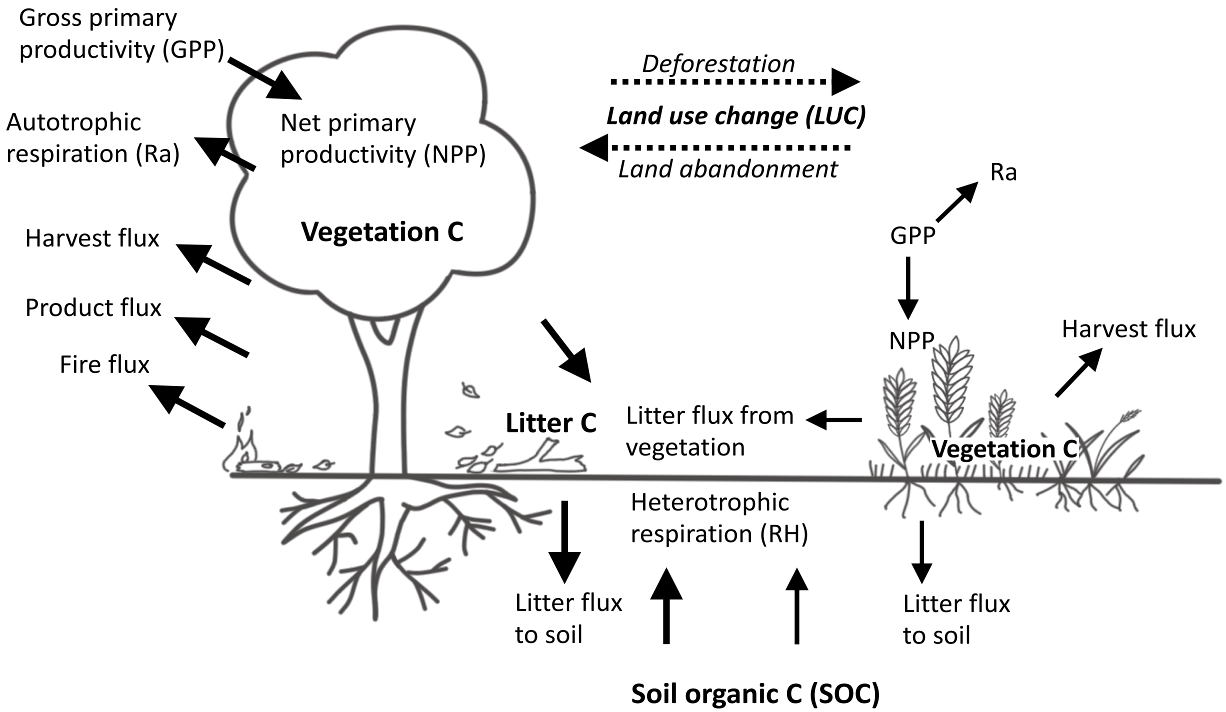
Models

Model	PFT transitions per site	Soil layers	Spinup
JSBACH	V: c3 Crop to extra tropical EG G: c3 Crop to extra tropical EG F: extra tropical EG to c4 crop CR: Tropical EG to c4 pasture	5 layers for physics, 1 for soil C	cycled the climatology from 1901-1920
ISBA	V: C3 grass 1 to Boreal needleleaved EG tree G: C3 grass to Temperate needleleaved EG tree F: Temperate needleleaved EG tree to C4 crop CR: Tropical broadleaved EG tree to C4 grass	1 layer for C; up to 13 for physics	Cycled through the years of 1901 to 1910
LPJ-GUESS	V: Crop to Boreal needleleaved EG tree and understory C3 grass G: Crop to Boreal needleleaved EG tree and understory C3 grass F: Temperate needleleaved EG tree and understory C3 grass to crop CR: Tropical broadleaved EG tree, etc. to C4 pasture	1 layer for C and N, 2 layers for physics	Start in 1850; cycled through the 1901-1930 climatology
ORCHIDEE	V: C3 Crop to Boreal EG G: C3 Crop to temperate EG F: Temperate EG to C4 cropland CR: Trop EG to C3 pasture	1 layer for C, T and W. T(z) and W(z) reach 2m	Start in 1850; cycled through the 1901-1930 climatology
CLM45-CMCC	V: C3 crop to Boreal needleleaved EG tree boreal G: C3 crop to Boreal needleleaved EG tree boreal F: NET temperate to C3 crop CR: BET tropical to C4 grass (no pasture in CLM4.5)	15 layers for physics, 1 for soil C	Start in 1850; cycled through the 1901-1930 climatology
JULES	V: c3 to needleaved EG G: c3 to needleleaved EG F: c3 to needleleaved EG CR: Tropical broadleaved EG tree to c4	4 layers for physics, 1 for soil C	Random years of 1901-1920

Changes in soil C under land use change



Schematic illustration of the carbon cycle in forests (left) and croplands (right). Land use change - deforestation or land abandonment - leads to significant changes in the soil organic carbon. Land use change results in changing litter flux to soil and, consequently, soil carbon storage. Carbon pools are shown in bold, carbon fluxes in regular font. The arrow sizes and thicknesses are schematic and illustrate approximate changes in fluxes (e.g. in harvest).

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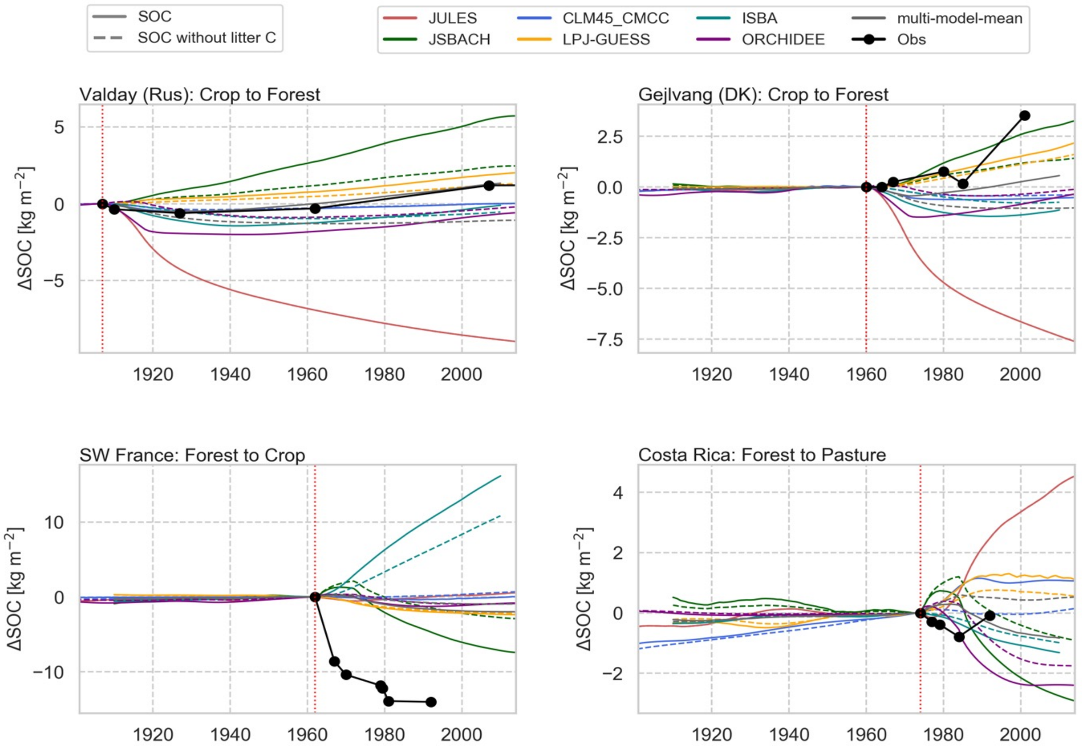
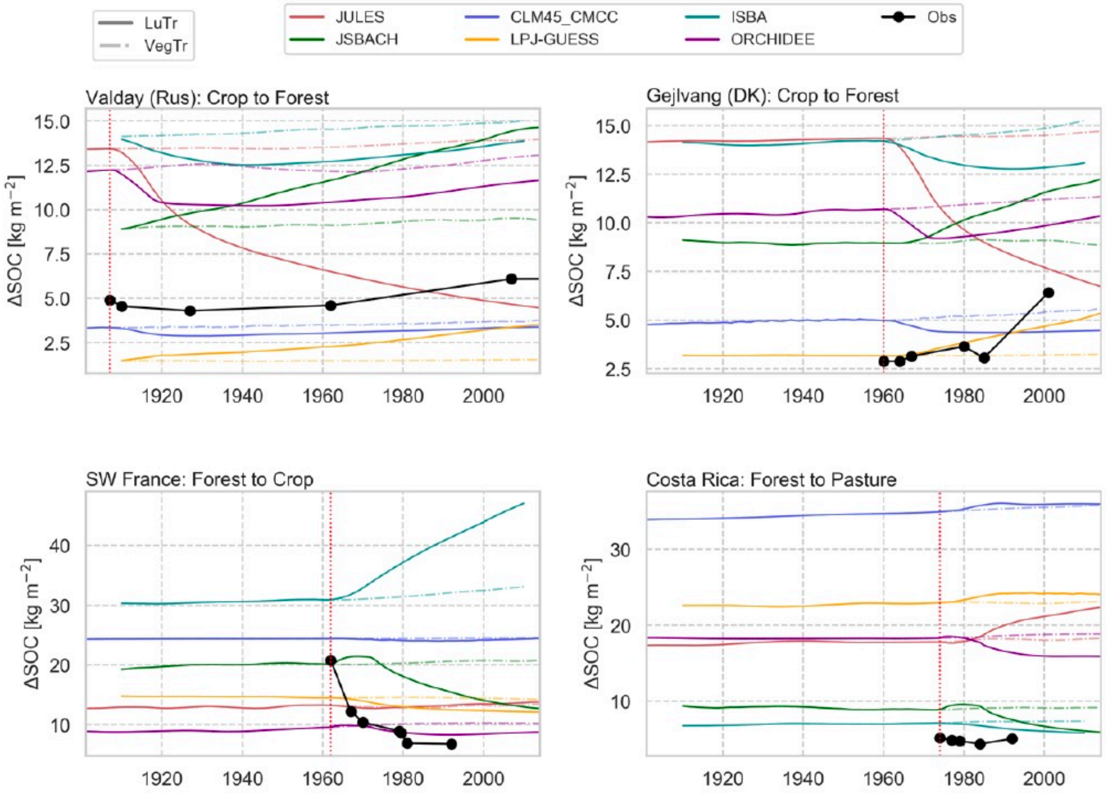
Results: changes in cSoil and cLitter



Absolute soil C changes relative to the 10-year-mean prior to LUC (kg m^{-2}). Solid lines account for both changes in soil C and litter C, while dashed lines depict changes in soil C alone. Black dots depict the time of SCC measurements. The multi-model mean at Valday, Gejlvang and Costa Rica excludes JULES; The multi-model mean at SW France excludes ISBA.

Results: Dynamics of cSoil plus cLitter



Absolute total soil C changes (including litter C). Dashed lines represent the VegTr simulation without LUC, thus including only climate change effects. A 10-year running mean was applied.

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Comparison with chronosequences

Site	Model	Initial C [kg m^{-2}] (year of LUC)	ΔC after LUC [kg m^{-2}] (last year of observ)	ΔC after LUC [kg m^{-2}] (year 2015)	ΔC no LUC [kg m^{-2}] (last year of observ)	Timing (T50) [years until +/- 50%]
Valdai (Rus)	SCC	4.9	1.3	--	--	↑ 30*
	JULES	13.4	-8.8	-9.1	0.5	↓ 17
	JSBACH	8.9	5.7	5.8	0.7	↑ 54
	CLM45_CMCC	3.3	0.1	0.1	0.4	↑ 42*
	LPJ-GUESS	1.5	1.9	2.1	0.0	↑ 60
	ISBA	14.1	-0.3	-0.1	0.8	↑ 46*
	ORCHIDEE	12.3	-0.8	-0.6	0.7	↑ 46*
	Multi-model mean	8.9 (8.0)	-0.3 (1.3)	-0.3 (1.4)	0.5 (0.5)	↑45* (↑ 57*)
Gejlvang (DK)	SCC	2.9	3.5	--	--	↑ 31 (20)
	JULES	14.3	-6.7	-7.9	0.2	↓ 11
	JSBACH	8.9	2.8	3.6	0.3	↑ 21
	CLM45_CMCC	5.0	-0.6	-0.5	0.5	↑ 16
	LPJ-GUESS	3.2	1.6	2.4	0.0	↑ 25
	ISBA	14.3	-1.4	-1.0	0.6	↑ 13*
	ORCHIDEE	10.7	-0.8	-0.2	0.5	↑ 27 *
	Multi-model mean	9.4 (8.4)	-0.9 (0.3)	-0.7 (0.7)	0.4 (0.4)	↑15* (↑ 4*)
SW France	SCC	20.8	-14.0	--	--	↓ 16
	JULES	13.2	0.1	0.7	-0.2	↑ 22
	JSBACH	20.0	-4.5	-7.6	0.7	↓ 11
	CLM45_CMCC	24.4	-0.4	-0.2	0.0	↑ 3
	LPJ-GUESS	14.5	-2.0	-2.4	0.1	↓ 7
	ISBA	30.8	10.4	17.3	1.2	↑ 20
	ORCHIDEE	9.7	-1.4	-1.0	0.6	↑ 14
	Multi-model mean**	18.7 (16.3)	0.4 (-1.6)	1.3 (-2.0)	0.5 (0.3)	↑34* (↓ 9*)
Costa Rica	SCC	5.2	-0.1	--	--	↓ 3 (8.0)
	JULES	17.8	3.1	4.8	0.3	↑ 8
	JSBACH	8.9	-1.9	-3.1	0.3	↓ 5
	CLM45_CMCC	35.0	0.9	1.0	0.5	↑ 4
	LPJ-GUESS	23.0	1.7	0.6	-0.1	↑ 2
	ISBA	7.2	-1.1	-1.5	0.1	↓12
	ORCHIDEE	18.3	-2.3	-2.4	0.4	↓ 2
	Multi-model mean	18.4 (18.5)	0.1 (-0.6)	-0.1 (-1.0)	0.2 (0.2)	↑2* (↓3*)

Conclusions

- Direction of soil C changes is mostly captured, but an amplitude of changes across models is large
- “Crop to forest” changes are easier to capture than deforestation ones
- More high-quality data sites are needed