Diving deeper into Land Use in CLM5: Shifting cultivation, fire and wood harvest

Peter Lawrence

NCAR – Terrestrial Sciences Section

co authors: Dave Lawrence, Brian O’Neill, George Hurtt and many others here at NCAR

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The Land Use Model Intercomparison Project (LUMIP) contribution to CMIP6: rationale and experimental design

Geoscientific Model Development

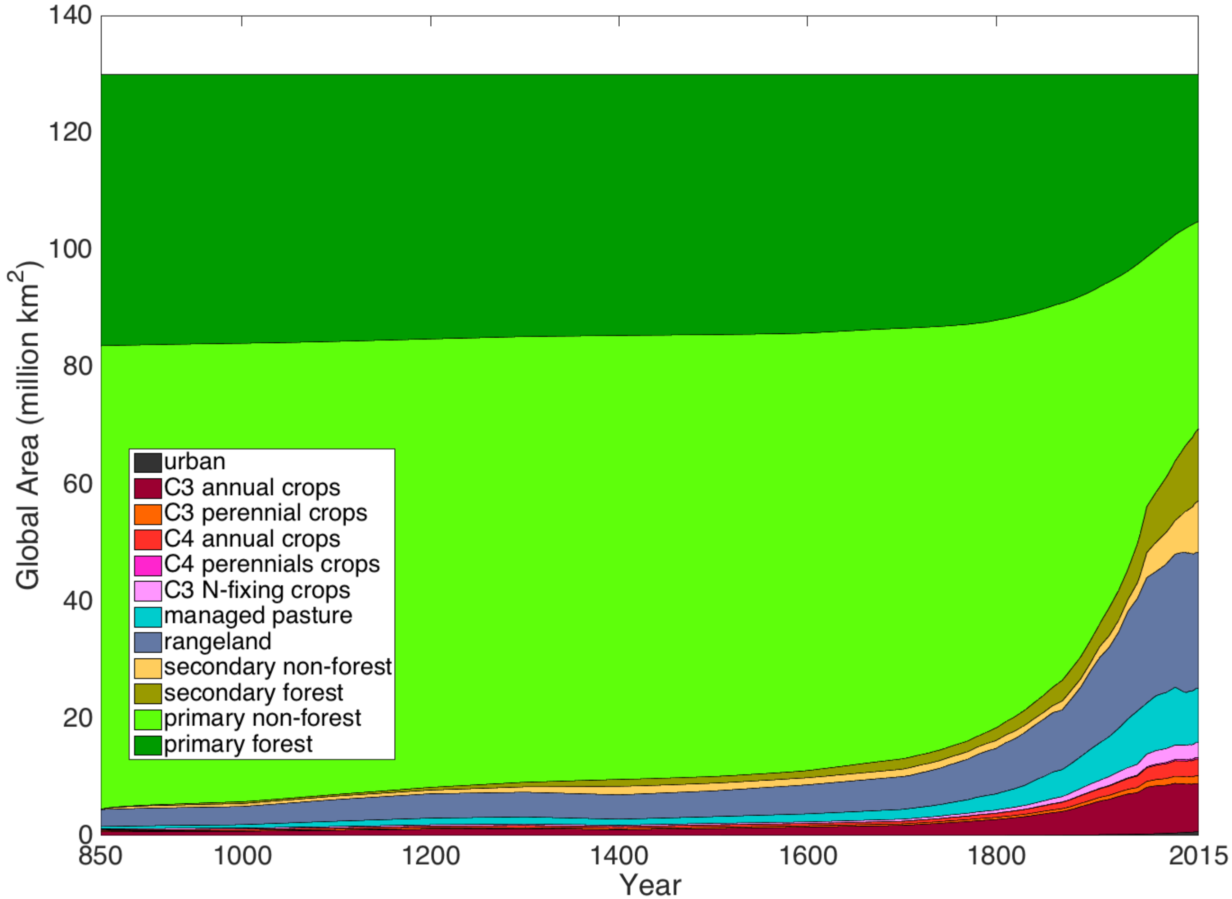
David M. Lawrence[1], George C. Hurtt[2], Almut Arneth[3], Victor Brovkin[4], Kate V. Calvin[5], Andrew D. Jones[6], Chris D. Jones[7], Peter J. Lawrence[1], Nathalie de Noblet-Ducoudré[8], Julia Pongratz[4], Sonia I. Seneviratne[9], and Elena Shevliakova[10]

New Resolution
0.25° grid-cell fraction

New History
Hyde 3.2, FAO based
Landsat F/NF
Multiple crop types (5)
Multiple pasture types (2)
Updated Forest Cover/Biomass
Updated Wood harvest
Updated Shifting Cultivation
Extended time domain (850-2015)

New Management Layers
Agriculture
Fraction of cropland irrigated
Fraction of cropland flooded
Fraction of cropland fertilized
Industrial Fertilizer application
Fraction of cropland for biofuels
Crop rotations
Wood Harvest
Fraction industrial products
Fraction commercial biofuels
Fraction fuelwood

New Future Scenarios
Six futures, SSP-based



CLM5 New Human Landscape Management

The new CLM5 capabilities and the LUMIP/CMIP6 scenarios require that annual grid cell data is provided that represents:

- Changes in forest cover through time from the Forest / non forest information provided by the LUH2 time series (this was inferred in CMIP5).

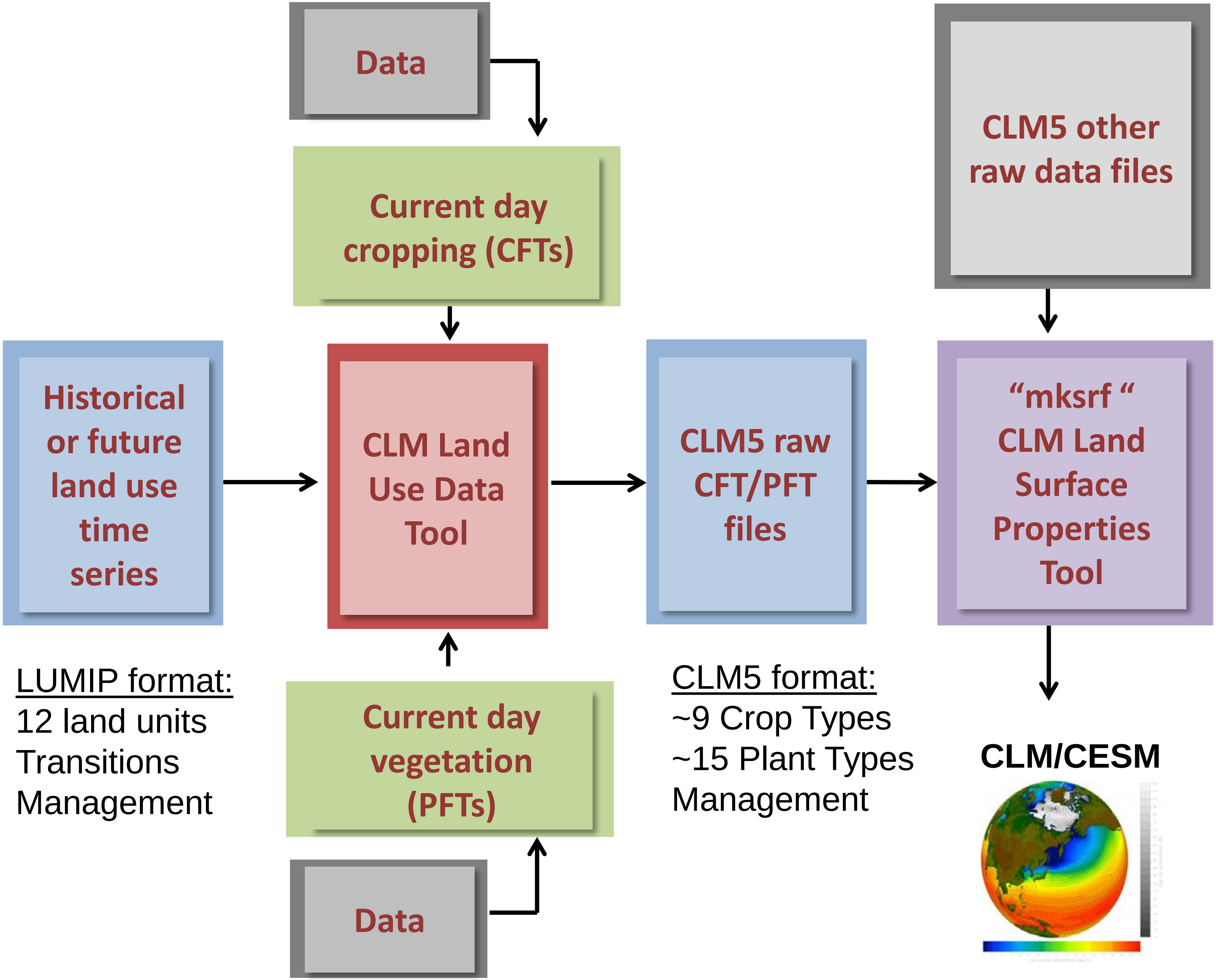
- Wood Harvest prescribed in a carbon amount to be extracted as biomass rather than a fraction of trees as was done in CLM4 CN

- The transient C3/C4 Crops of the LUMIP time series modeled with the CLM5 Crop model which specifies planting dates, life histories and harvest rules for individual crops for each grid cell and each year

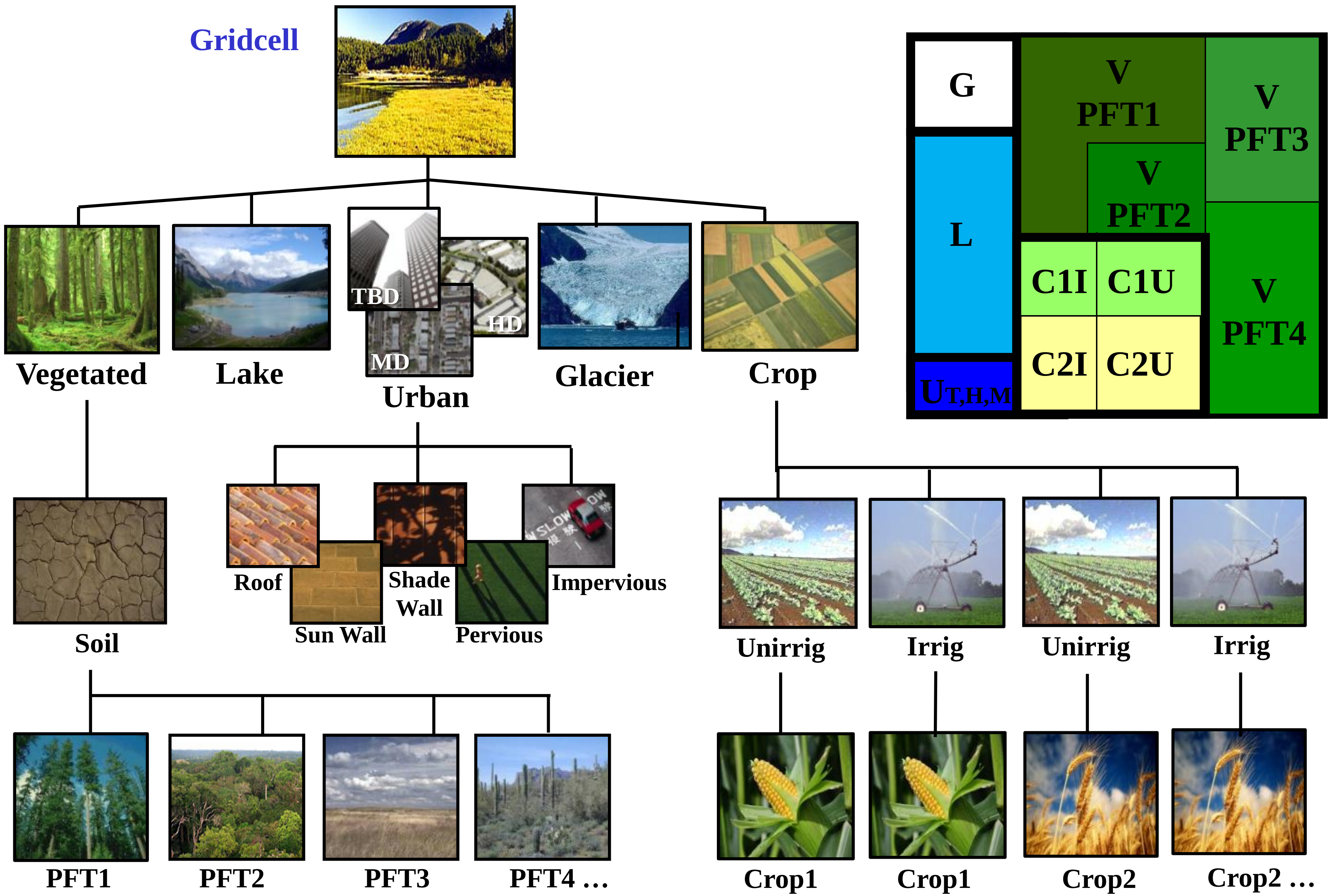
- Crops all simulated by: Temperate corn, tropical corn, cotton, rice, sugarcane, temperate soybean, tropical soybean, spring wheat

- Fertilizer and irrigation management is specified by crop and grid cell every year

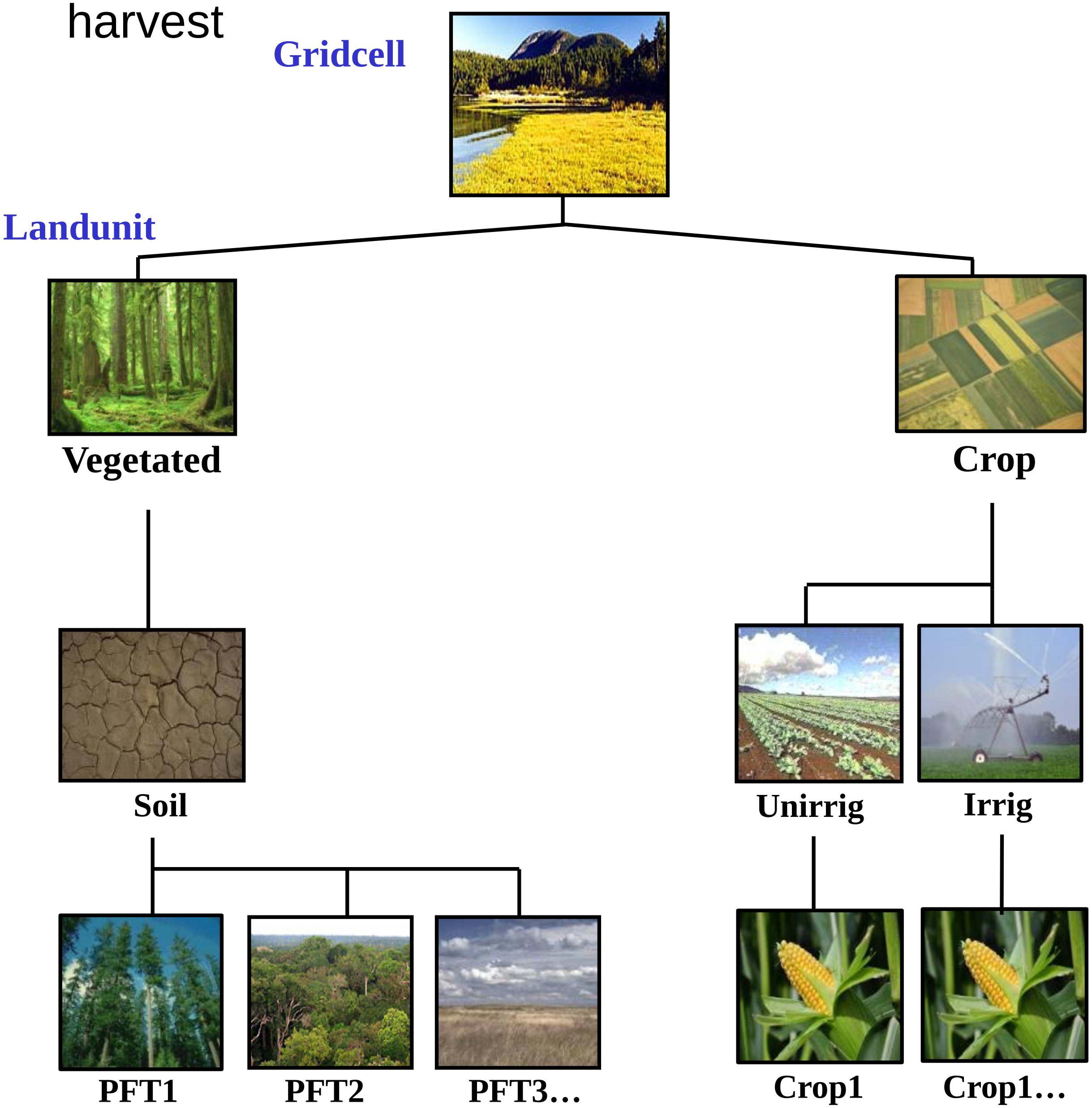
- New Gross Unrepresented LULCC to capture Shifting Cultivation

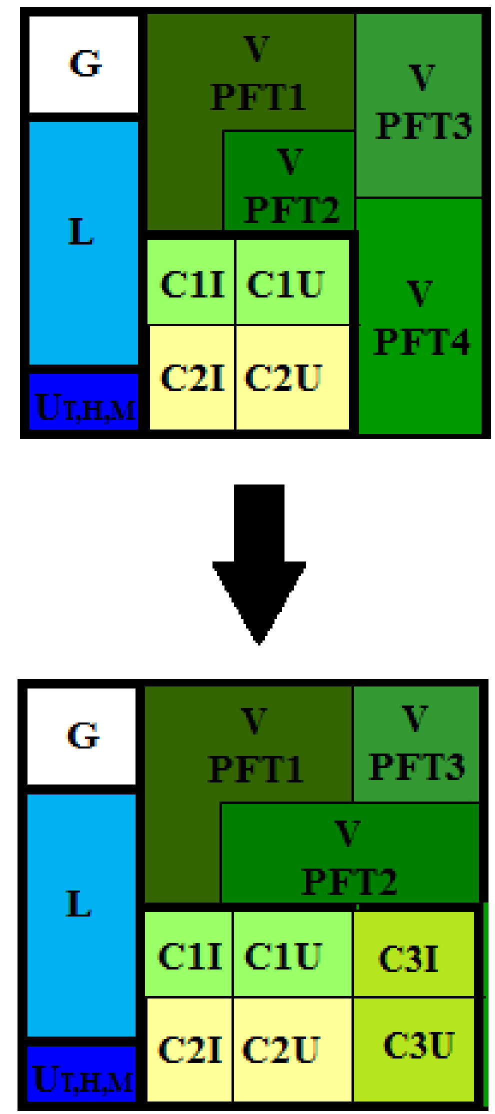

Data
Current day cropping (CFTs)
CLM5 other raw data files
Historical or future land use time series
CLM Land Use Data Tool
CLM5 raw CFT/PFT files
"mksrf " CLM Land Surface Properties Tool
LUMIP format:
12 land units
Transitions
Management
Current day vegetation (PFTs)
CLM5 format:
~9 Crop Types
~15 Plant Types
Management
CLM/CESM
Data

CLM5 New Human Landscape Management

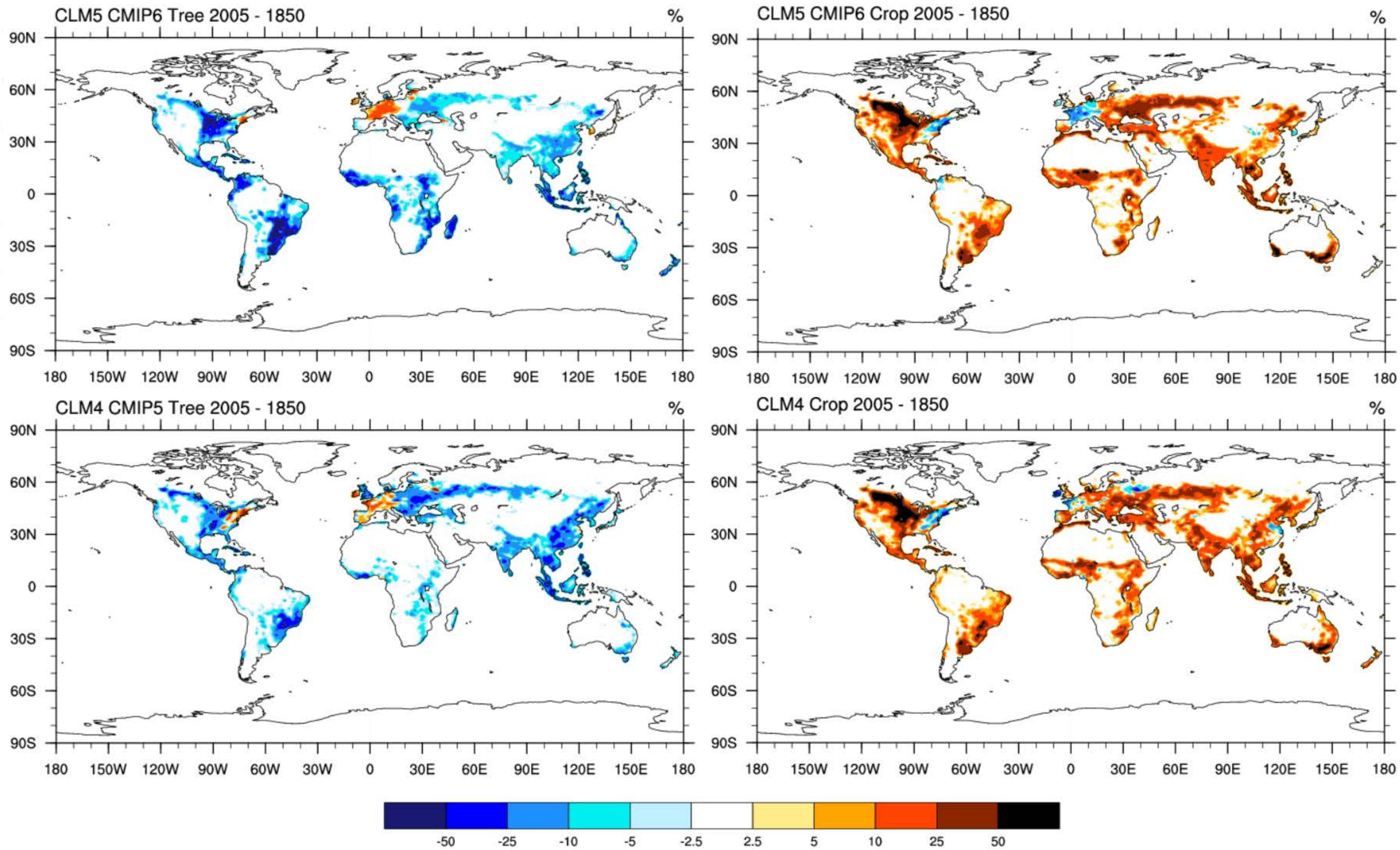


The transient land use time series data set provides annual information on, Natural Vegetation and Crop distributions as well as fertilizer and wood harvest





CLM5 LUMIP vs CLM4 CMIP5 Land Cover in 1850 – 2005



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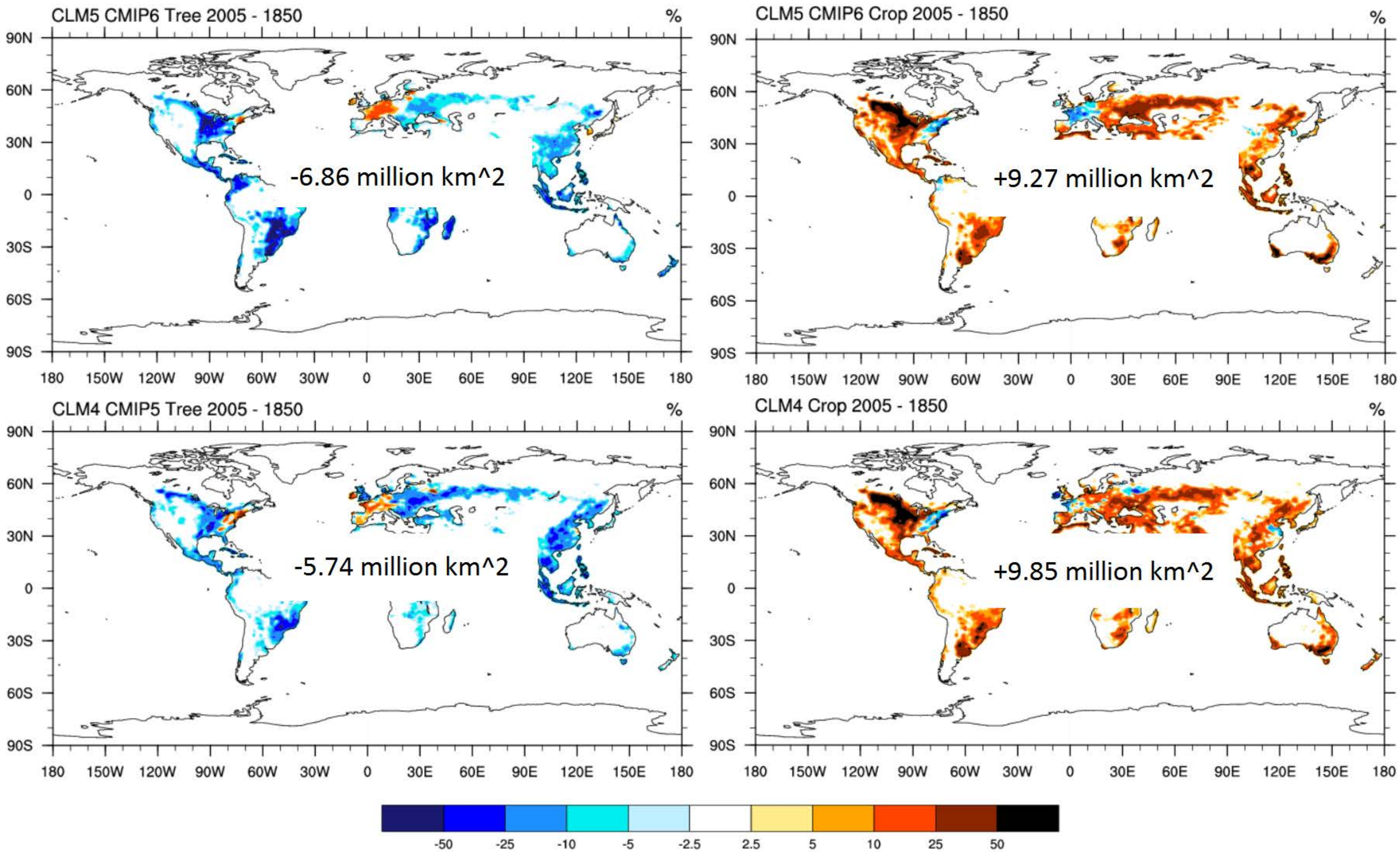


CLM5 vs CLM4: +20% of Tree Loss and -5% of Crop Gain

CLM5 Carbon Cycle impacts of Land Use Land Cover Change

1. Assess the Carbon Cycle response of CLM5 to LUMIP Land Use Land Cover Change (LULCC) data for the Historical under changing climate and CO_2.

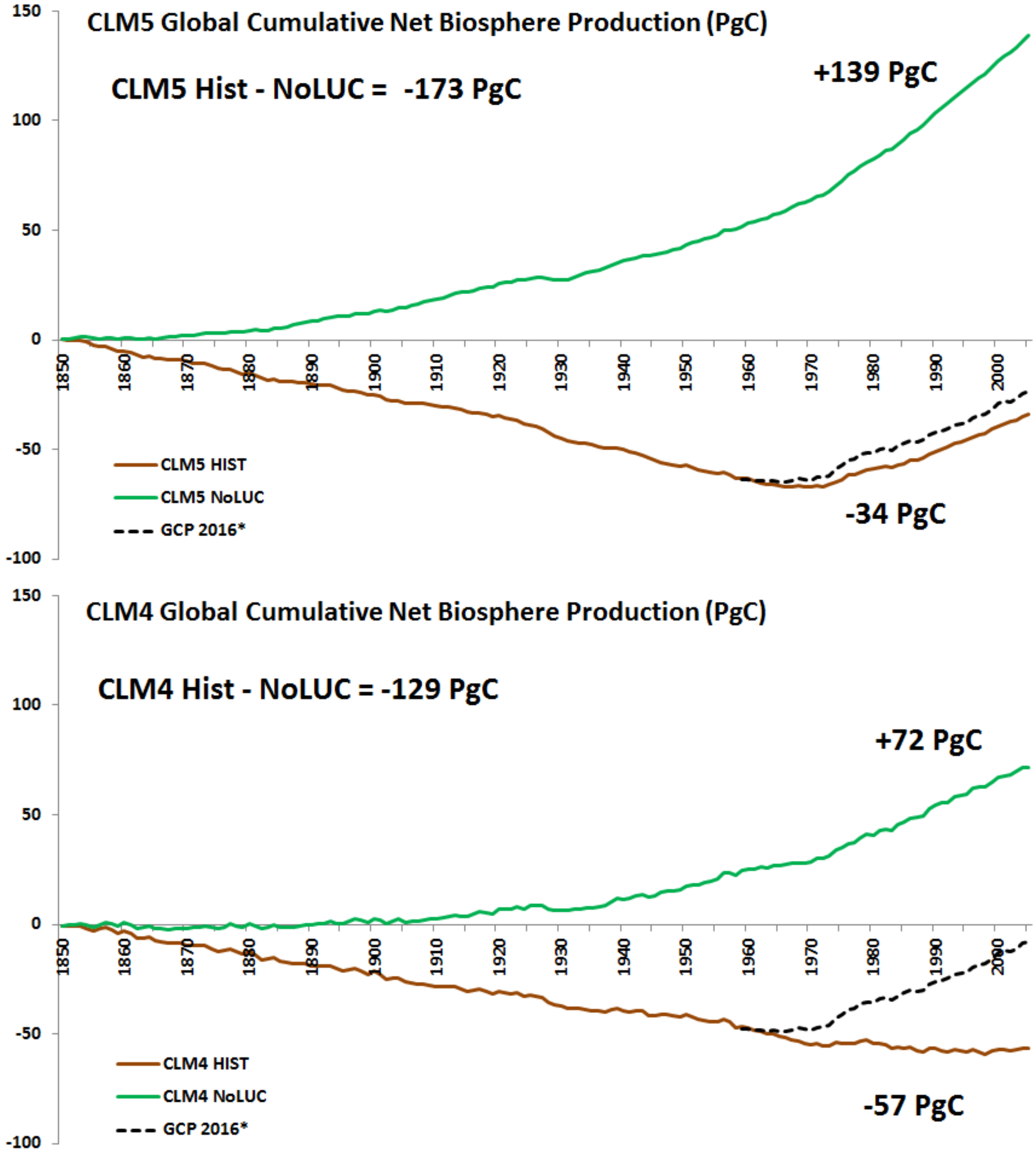
2. To do this we run CLM5 simulations with transient LULCC compared to the same simulations performed with no LULCC.

3. The CLM5 LULCC results are then compared to same experiments run with CLM4 and the CMIP5 Historical LULCC data against CLM4 with no LULCC.

4. All experiments use 1850 – 2010 GSWP3 Prescribed Meteorology which has been shown to provide the best forcing and transient model response

5. There are no larger scale climate feedbacks in these studies.

New CLM5 LUMIP vs CLM4 CMIP5 LULCC – NBP Carbon



CLM5 NoLUC had much larger uptake of carbon from CO_2 fertilization, Climate and N Deposition
CLM5 +139 PgC
CLM4 +72 PgC

Global Historical LULCC Estimates ~160 PgC
CLM5 = 173 PgC
CLM4 = 129 PgC

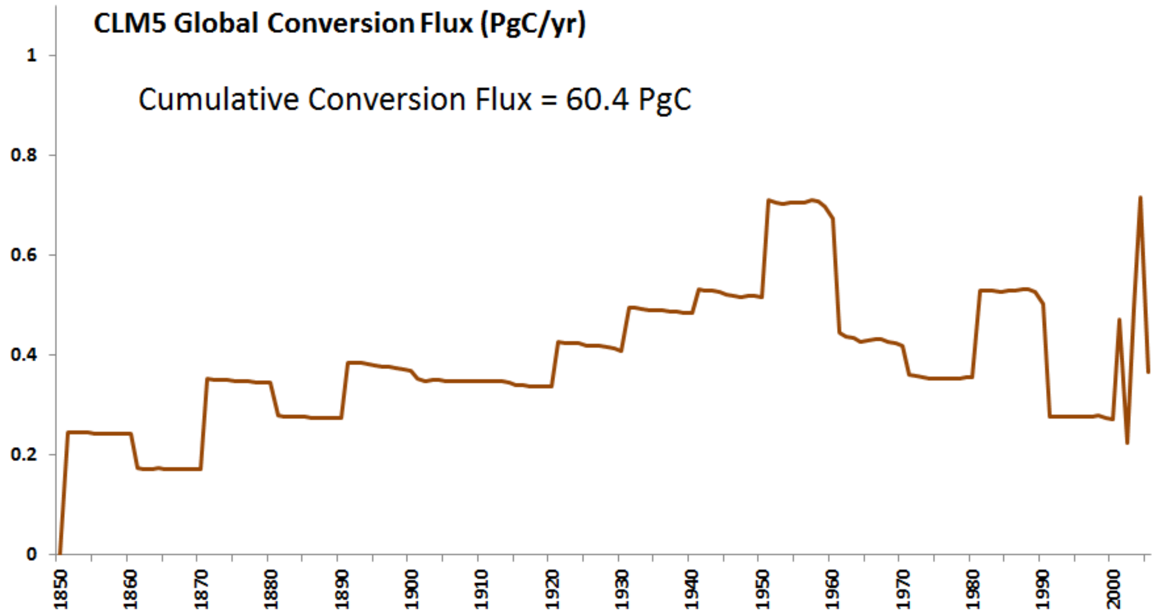
CLM5 had an additional 44 PgC of LULCC

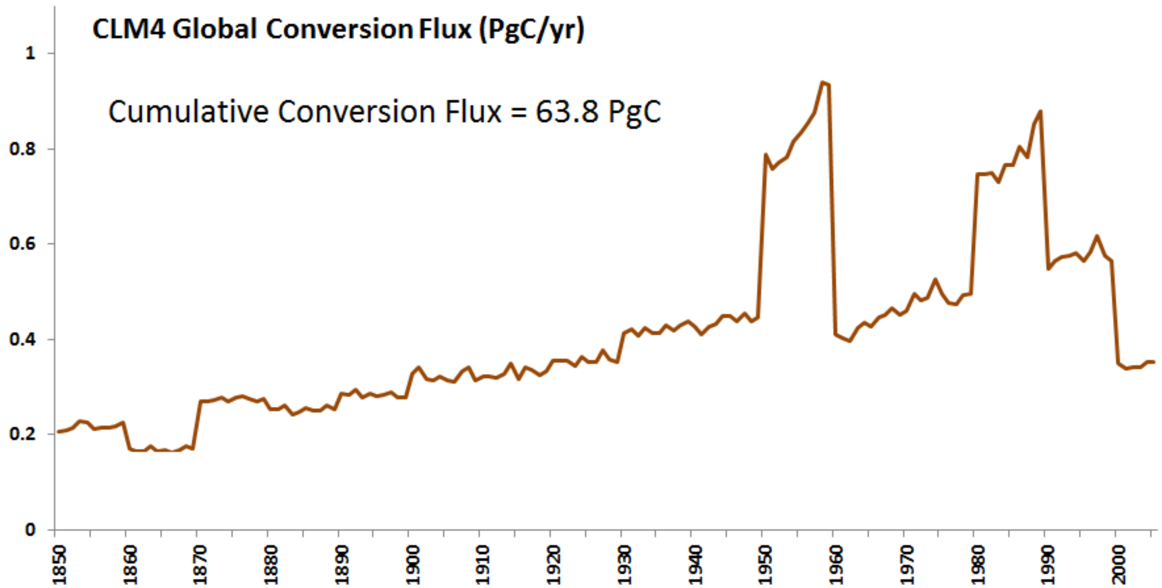
*Global Carbon Project Land Sink - LULCC 1959 – 2016

CLM5 has very similar net uptake of carbon from 1959 onwards

CLM4 has continued loss carbon as LULCC larger than residual sink

New CLM5 LUMIP vs CLM4 CMIP5 LULCC – Conversion C





CLM5 conversion of PFTs and CFTs results in a cumulative loss of 60.4 PgC

CLM4 conversion of PFTs results in a cumulative loss of 63.8 PgC

CLM5 loses -3.4 PgC less carbon through conversion than CLM4 despite losing 20% more trees over the period

CLM5 tree biomass is lower than CLM4

LUMIP data has much stronger decadal signal and reduced clearing in the 1950s and 1980s.

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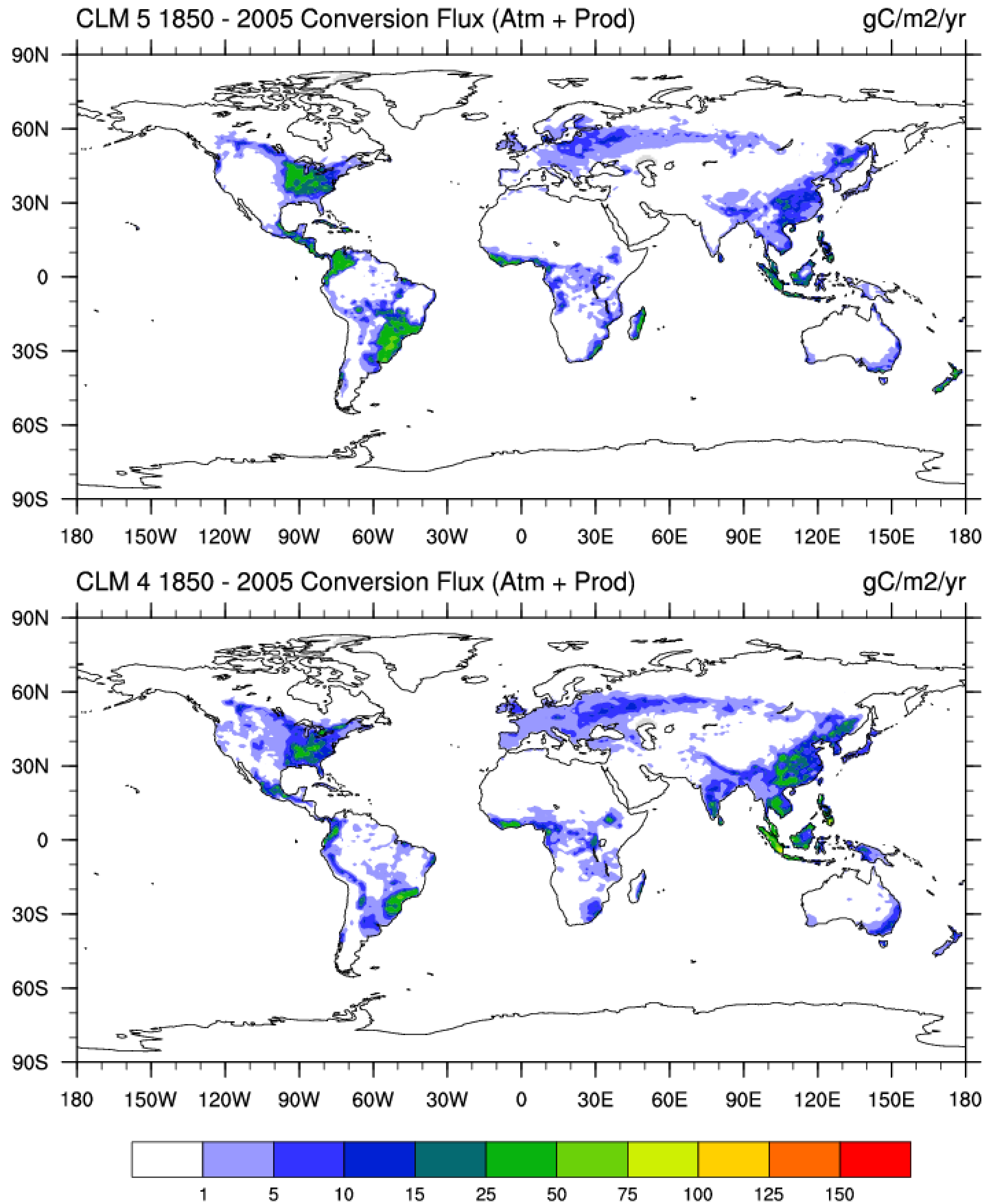

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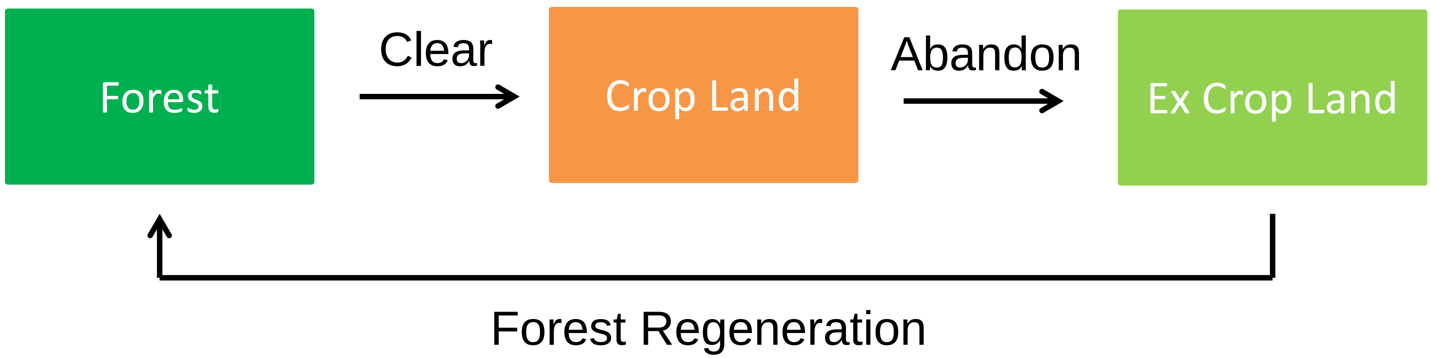
CMIP6 – CLM5 Carbon Cycle impacts of Shifting Cultivation

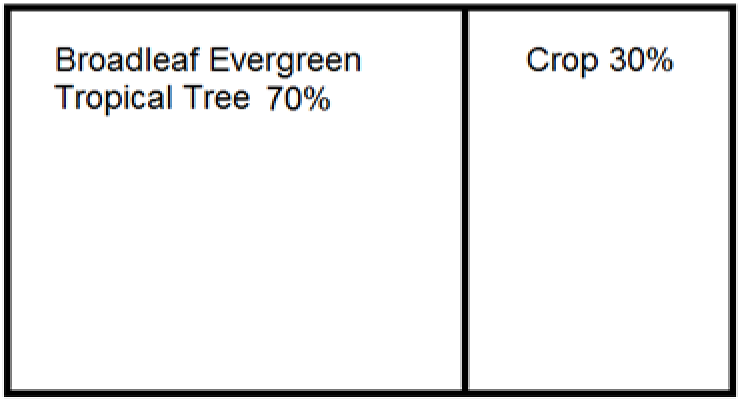
One element not included in the current CLM5 or CLM4 simulations is the impact of Shifting Cultivation.



In a Shifting Cultivation regime clearing of forest and abandonment of crop land can occur at the same rate so there can be no net change forest area or crop area from year to year. The state of the forest however is continually degraded.

CMIP6 Gross versus Net LULCC in CLM5 – Shifting Cultivation

Initial State Yr 1.

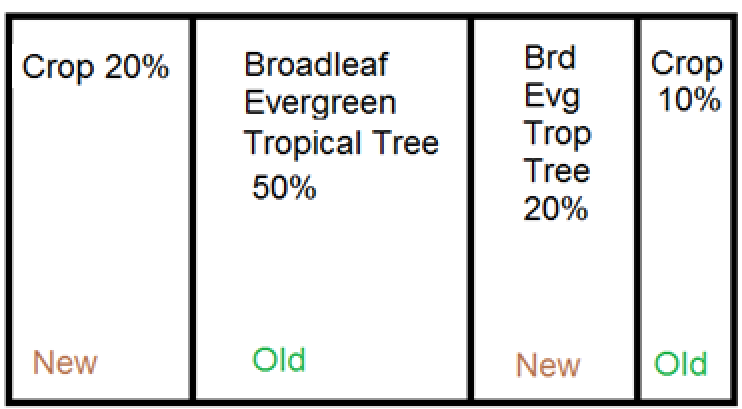


Gross Transitions
1. Broadleaf Evergreen Tropical Tree -> Crop 20%
2. Crop -> Broadleaf Evergreen Tropical Tree 20%

Net Transitions:
0% Change

Unrepresented Gross Transitions:
BET 20% Crop 20%

Updated State Yr 2.



Even though there are no Net Transitions we can still remove vegetation biomass for the Unrepresented Gross Transition area. Additional LULCC fluxes done in the same manner as wood harvest

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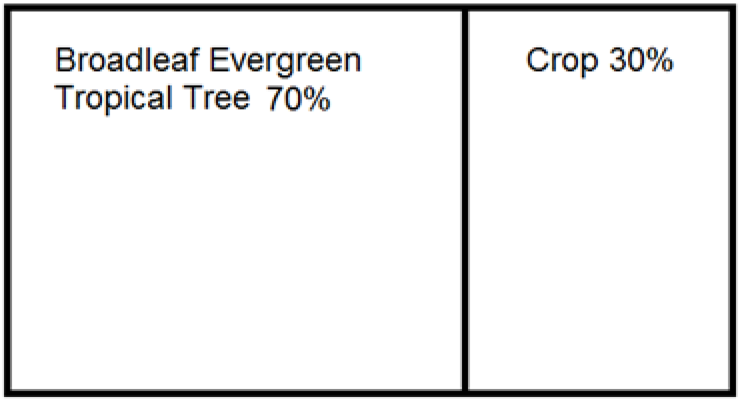

New Historical Simulations with a modified version of CLM5 - SC that represents Shifting Cultivation

New PFT grid level field on the landuse.timeseries file:

UNREPRESENTED_PFT_LULCC

Gross Transitions

1. Broadleaf Evergreen Tropical Tree -> Crop 20%
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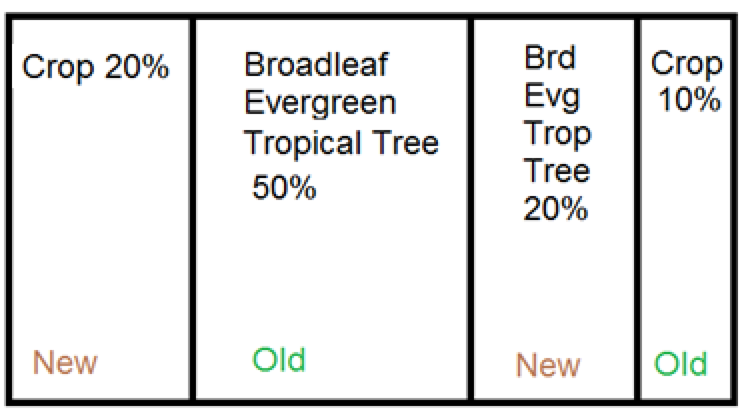

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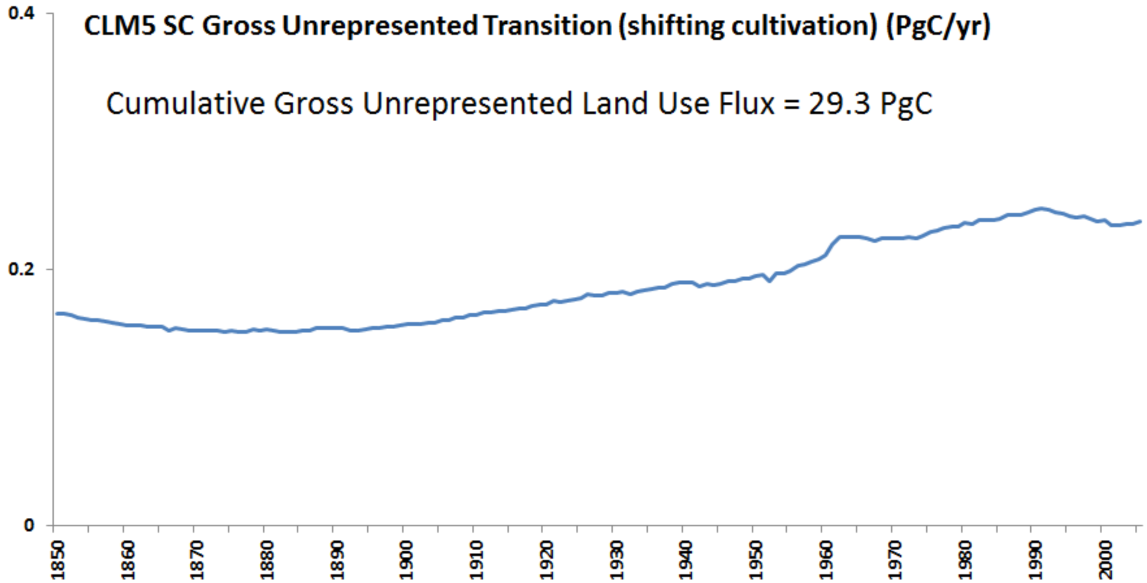
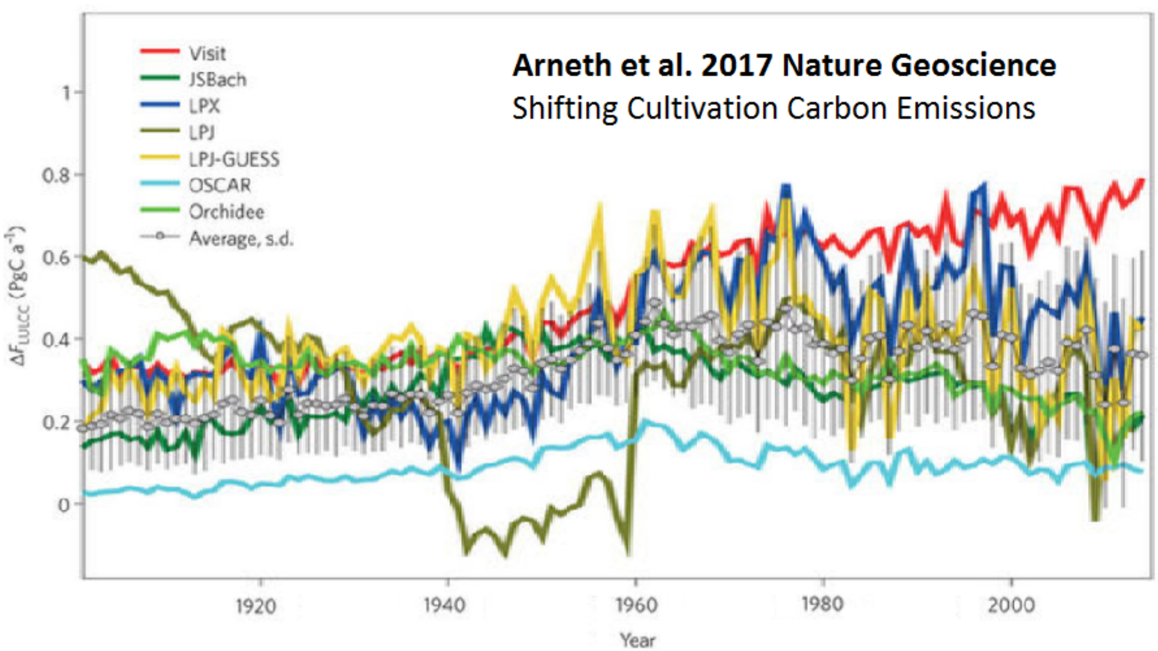
CLM5 – SC – Gross Unrepresented Land Use C



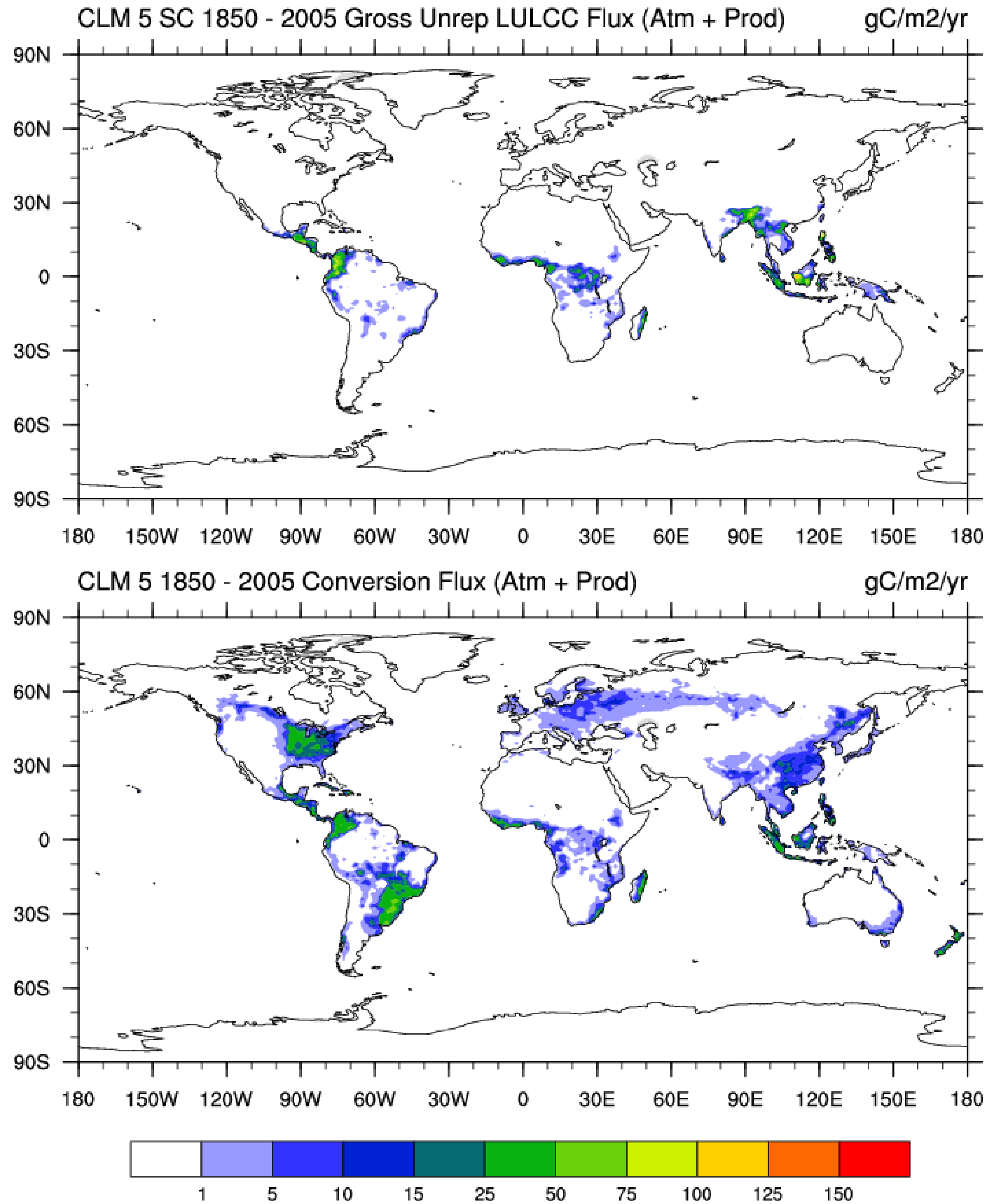


CLM5 SC Gross Unrepresented Land Use Flux results in a cumulative loss of 29.3 PgC

Compares to the CLM5 conversion flux cumulative loss of 60.4 PgC

Compares well with the model mean Shifting Cultivation flux of 0.2 – 0.3 PgC/yr found in the study by Arneth et al 2017.

CLM5 – SC – Gross Unrepresented Land Use C



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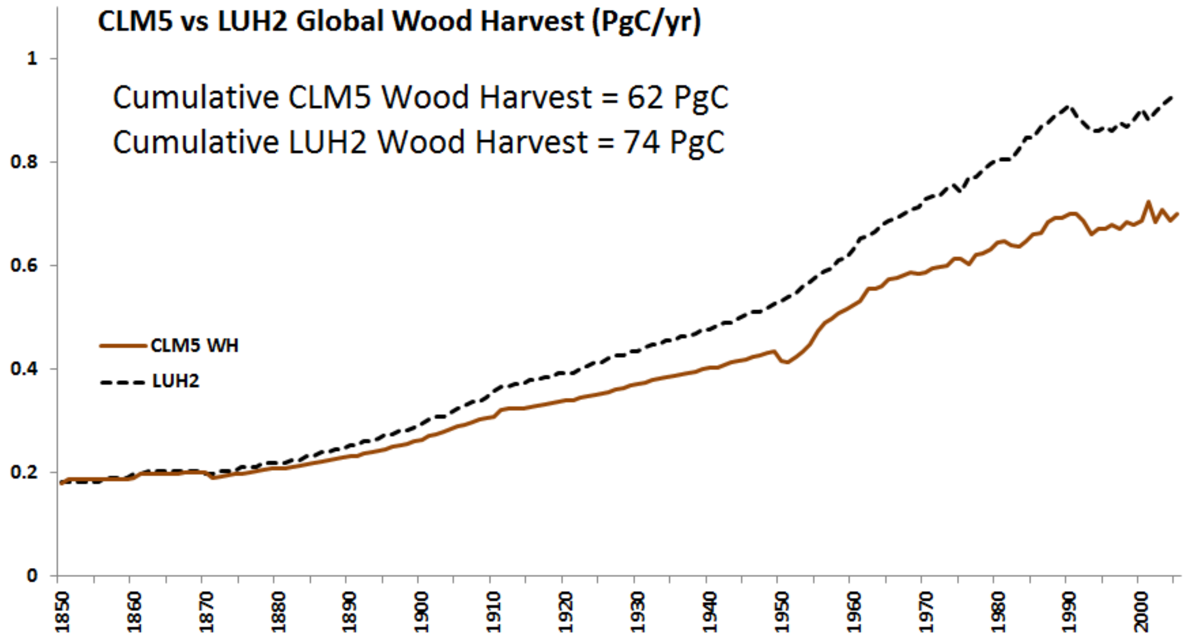
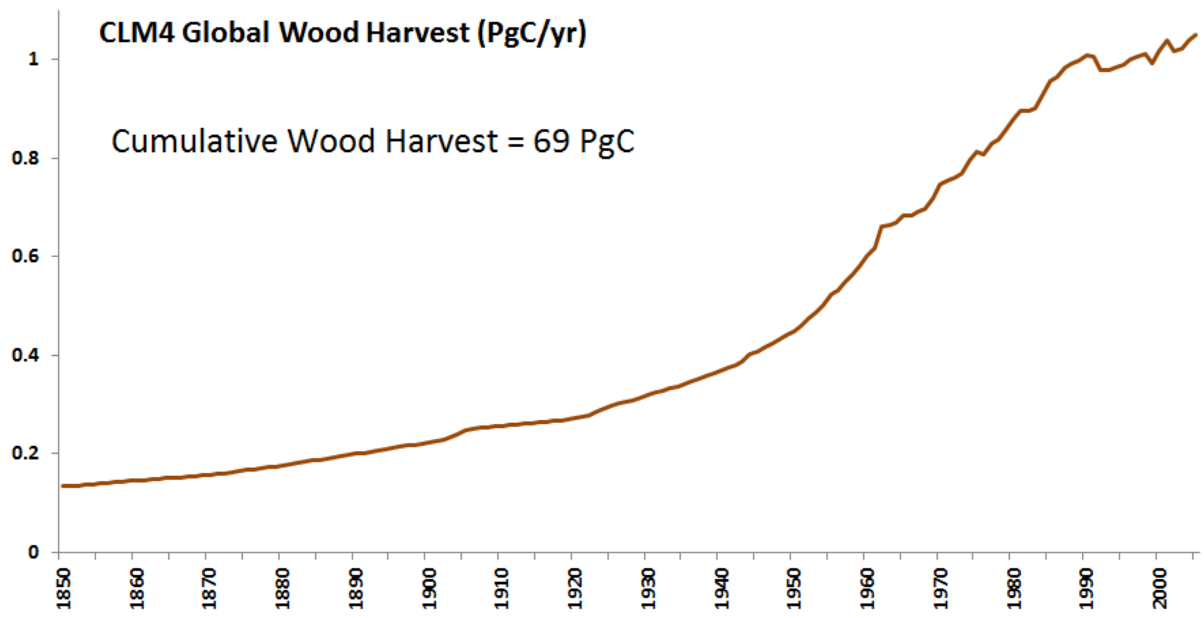
New CLM5 LUMIP vs CLM4 CMIP5 LULCC – Wood Harvest





CLM5 wood harvest of tree PFTs results in a cumulative loss of 62 PgC over the period.

Despite prescribing wood harvest as biomass CLM5 achieves only 83% of LUH2 wood harvest of 74 PgC

CLM4 wood harvest results in a cumulative loss of 69 PgC

CLM5 LUMIP loses -7 PgC less carbon from wood harvest than CLM4

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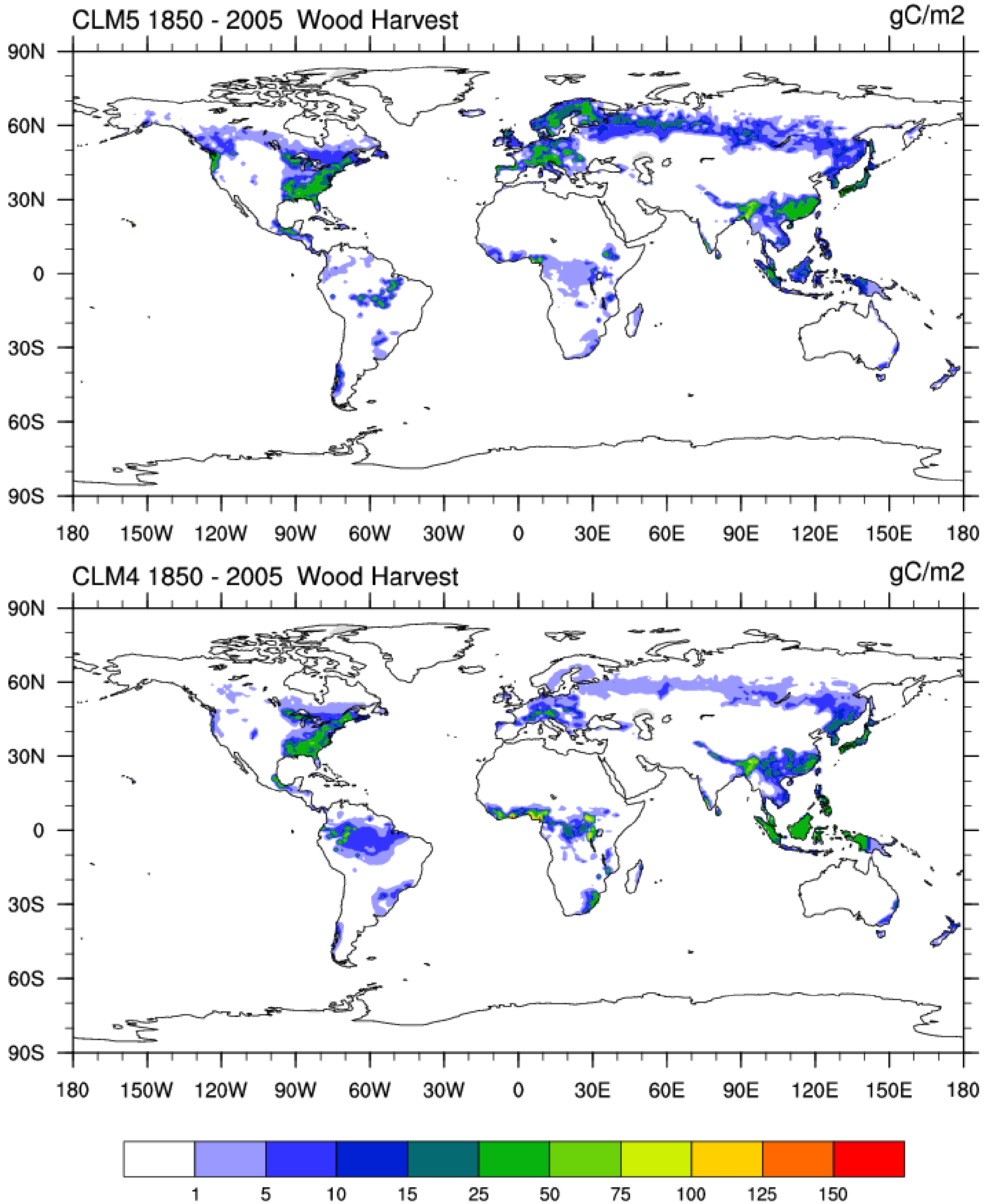

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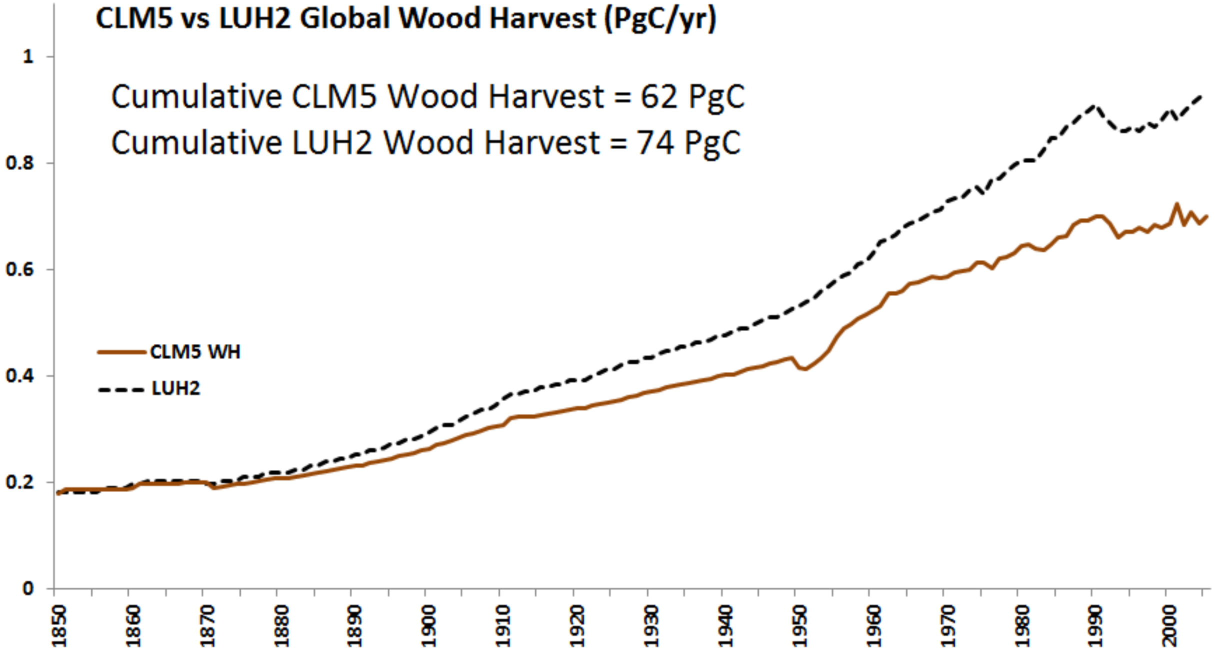
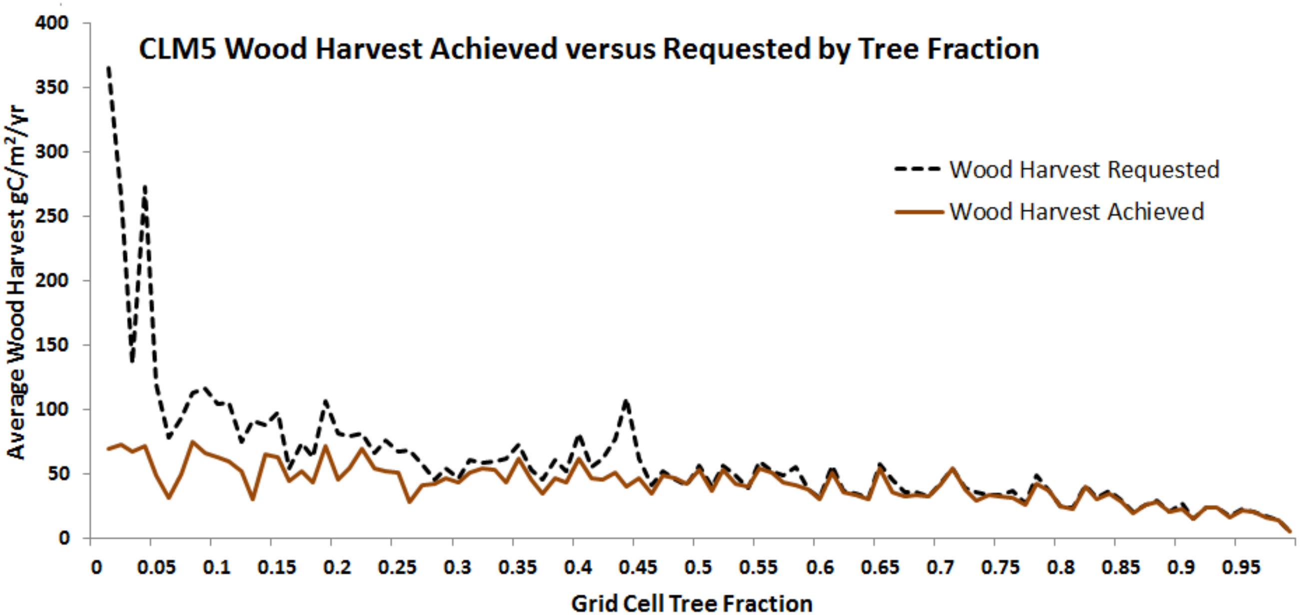
New CLM5 LUMIP – Missing Wood Harvest





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Analysis found that major contribution was coming from prescribing large biomass values in low tree fraction areas

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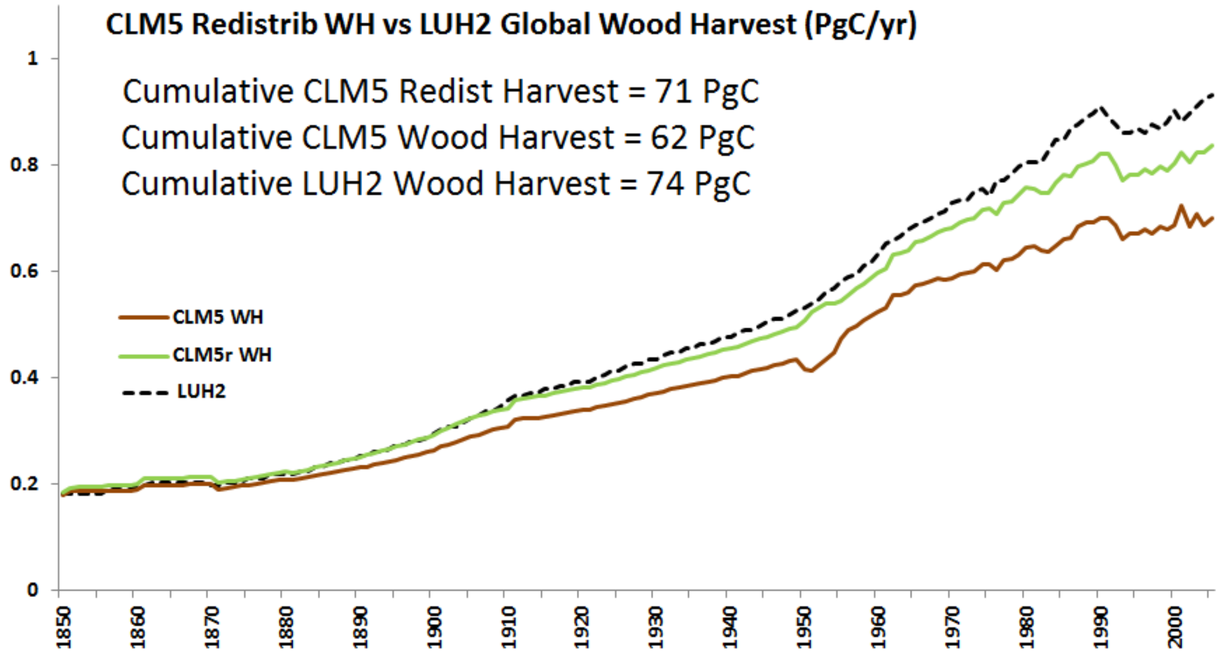

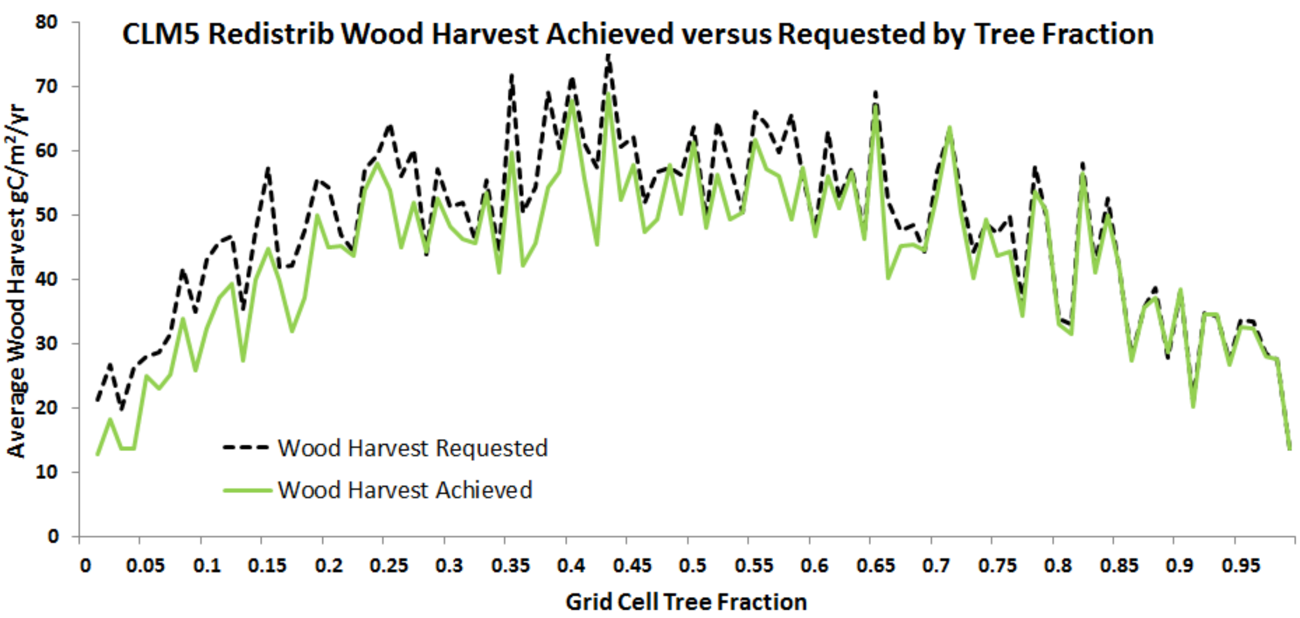

By redistributing excessive wood harvest in low tree fraction grid cells to nearby wood harvest with higher tree cover, wood harvest was increased to 71 PgC or 95% of the LUH2 amount.

Missing WH in CLM5 goes From 12 PgC to 3 PgC

Analysis also shows biomass values in low tree fraction areas were now much closer to requested yet there are still areas where target can not be met

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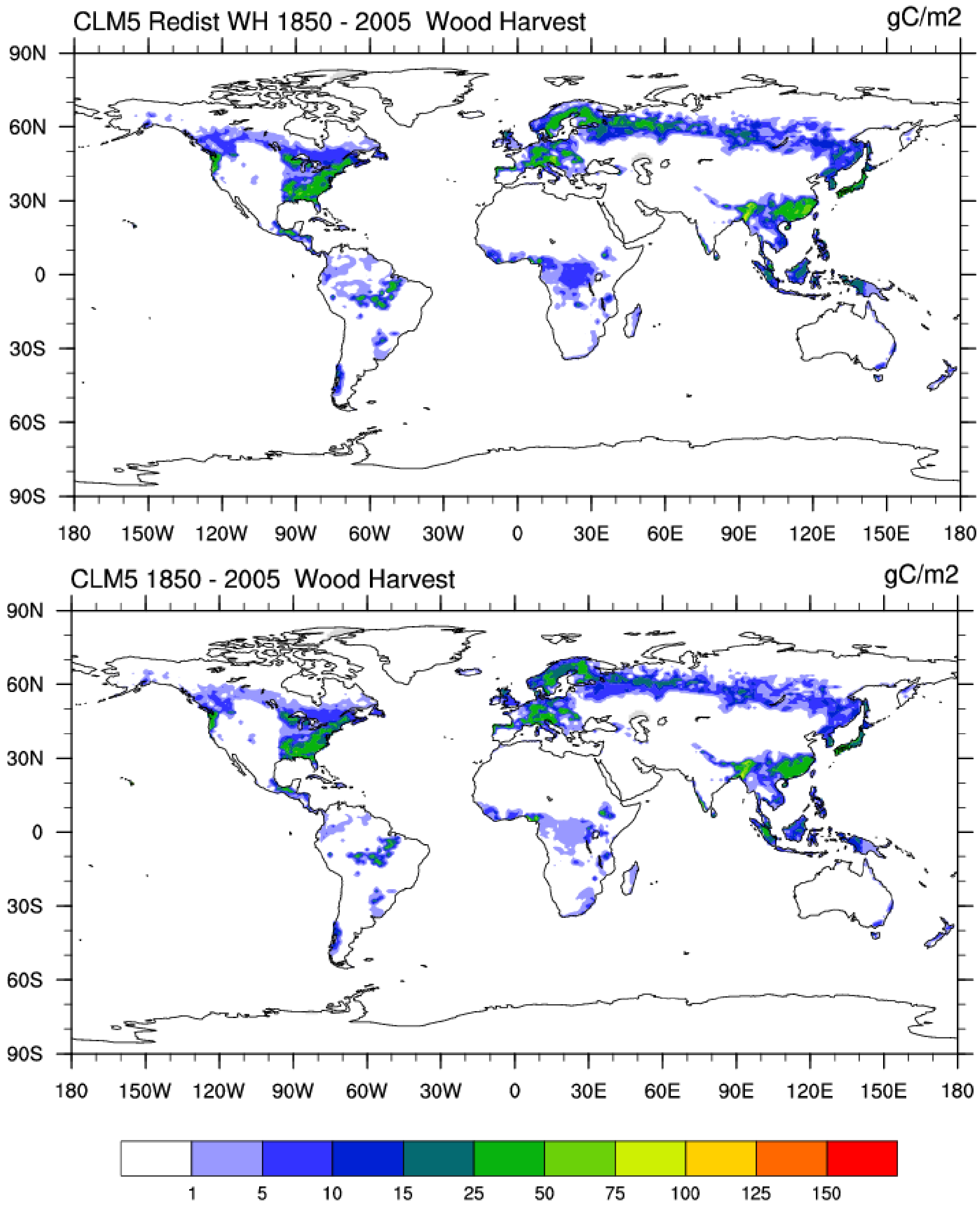

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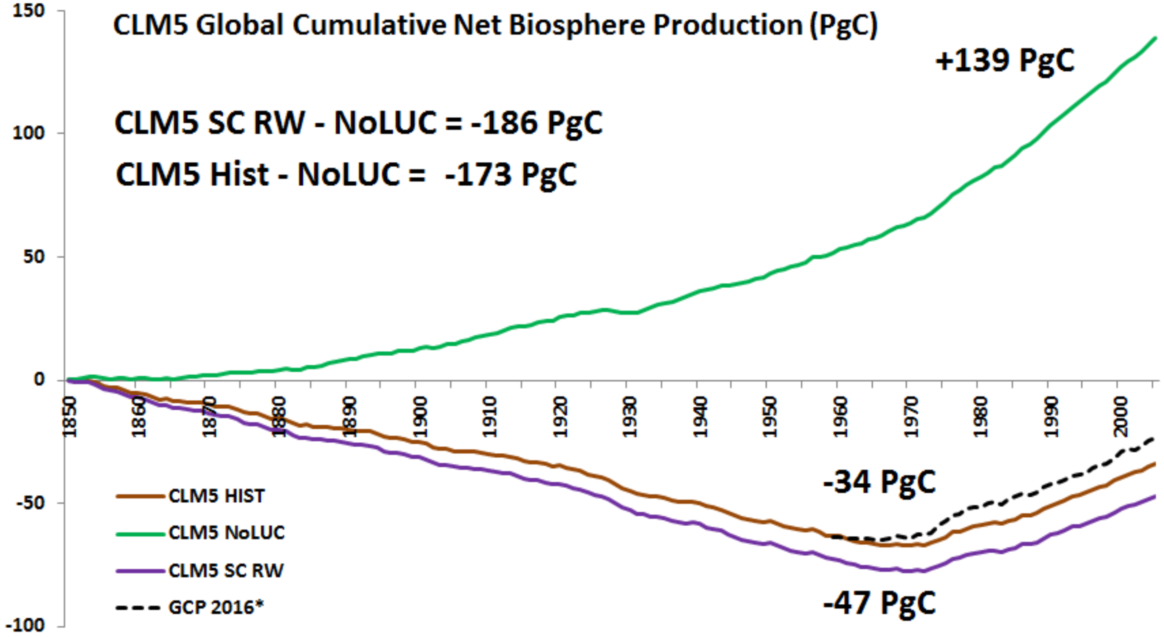
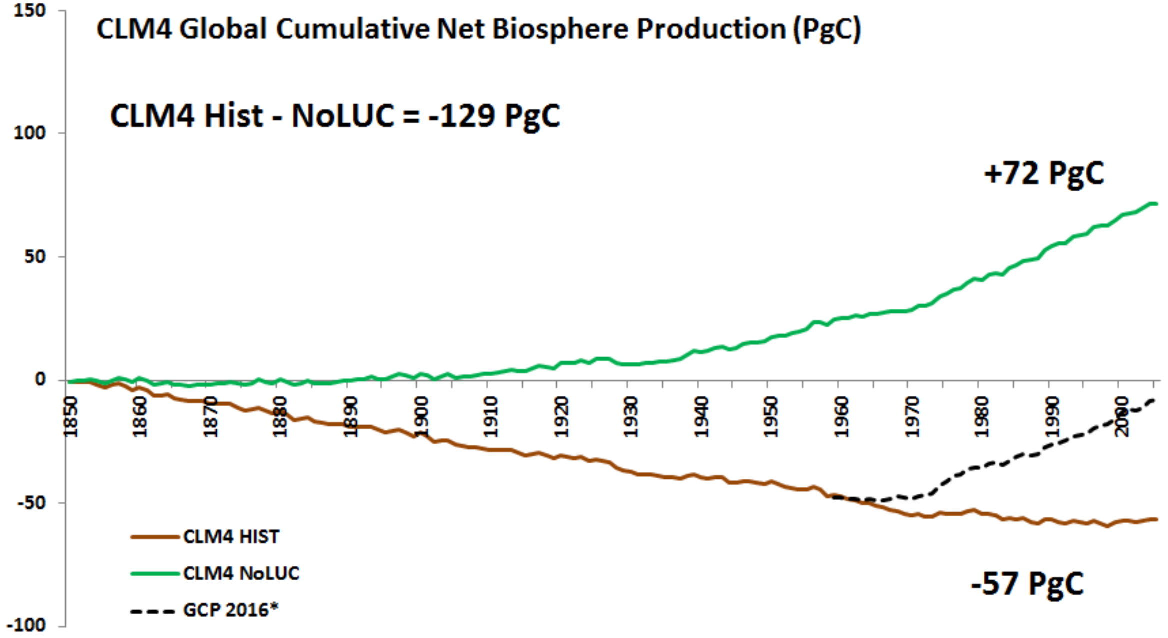
Spatially redistribution does not change wood harvest greatly

New CLM5 vs CLM5 Shifting Cultivation Re WH – NBP



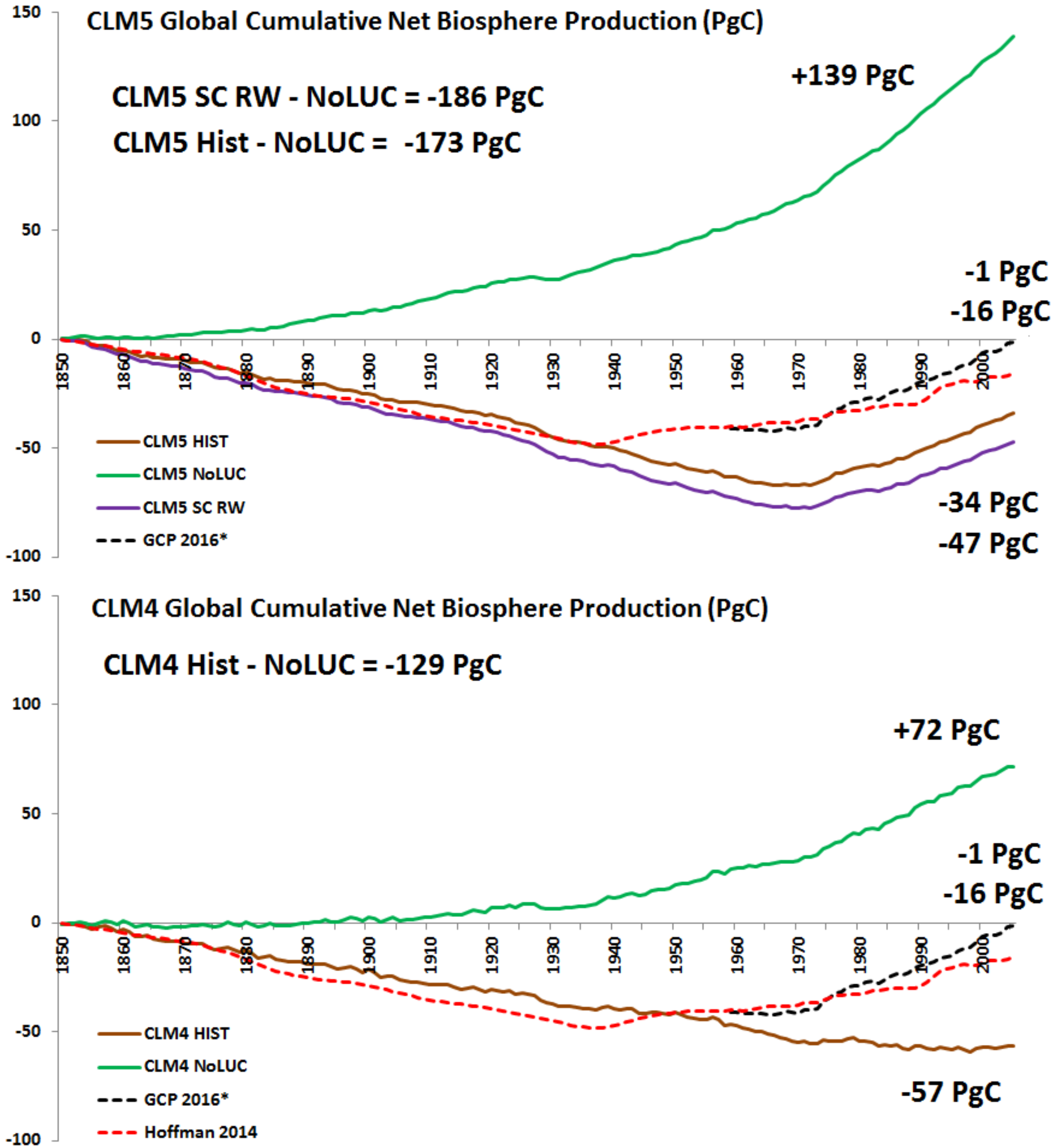


CLM5 with the addition of Shifting Cultivation cumulative flux of 29.3 PgC and Redistributed Wood Harvest of another 9 PgC results in a decrease of cumulative NBP of only -13 PgC.

The additional NBP loss results in an increase in The Land Use flux to 186 PgC over the Historical Period

The timing and change from carbon loss to carbon gain in NBP is almost unchanged

New CLM5 vs CLM5 SC Re WH – NBP Hoffman et al 2014.



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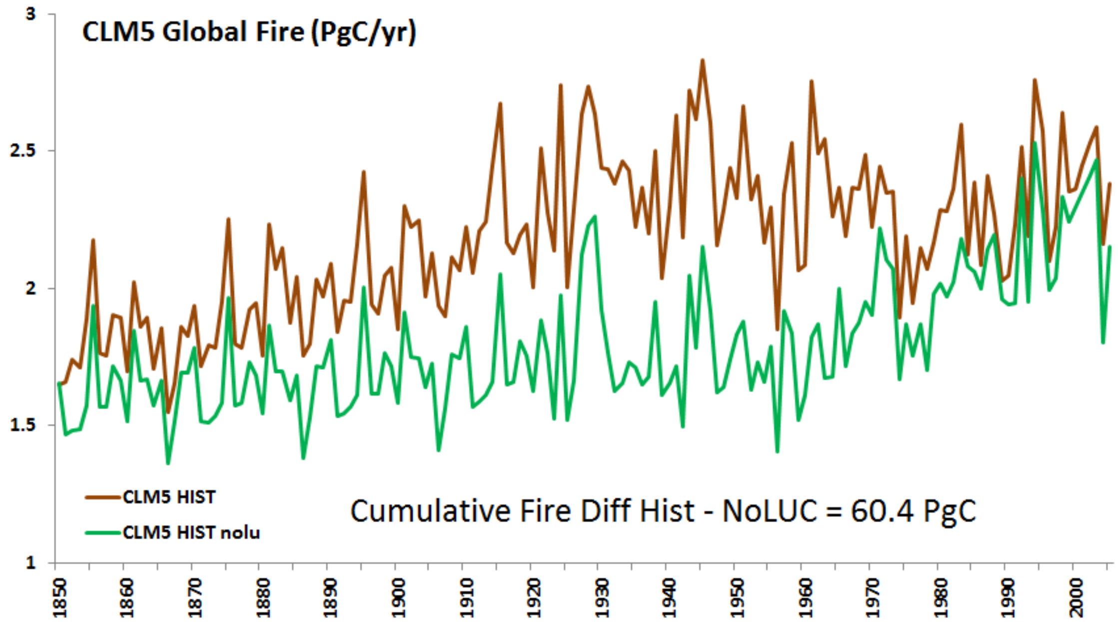
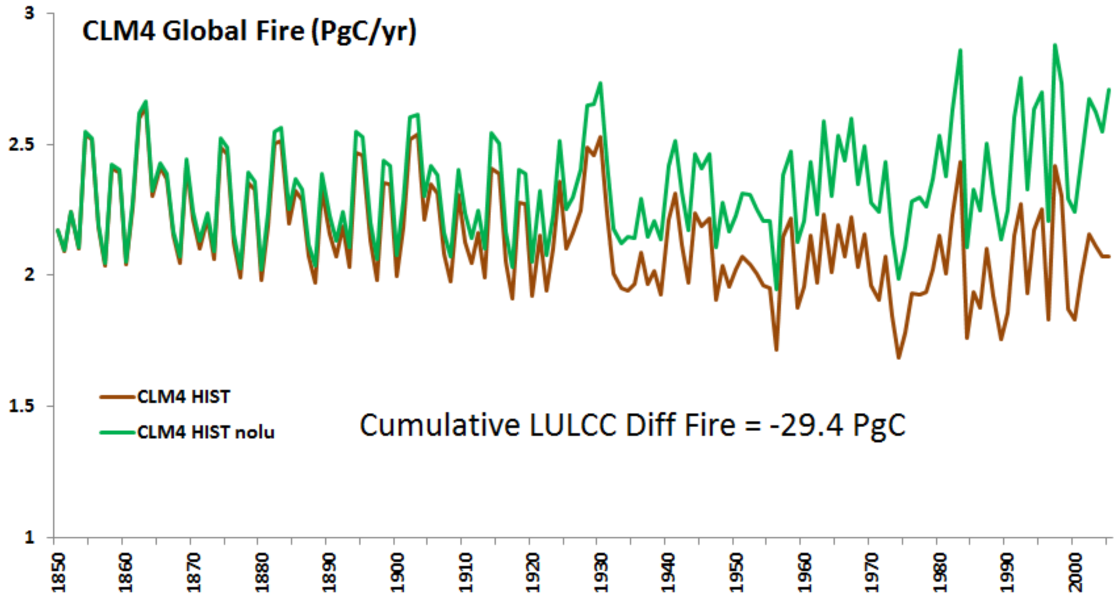
If we compare to Hoffman et al 2014 from ILAMB and start the GCP cumulative NBP in 1959 from Hoffman we get a very different story.

New CLM5 LUMIP vs CLM4 CMIP5 LULCC – Fire





CLM5 LULCC results in large increase in carbon loss through increased fire of +60.4 PgC

CLM4 LULCC results in reduced carbon loss due lower fuel loads and reduced fire of -29.4 PgC

CLM5 LULCC impact of fire is +89.8 PgC larger than in CLM4

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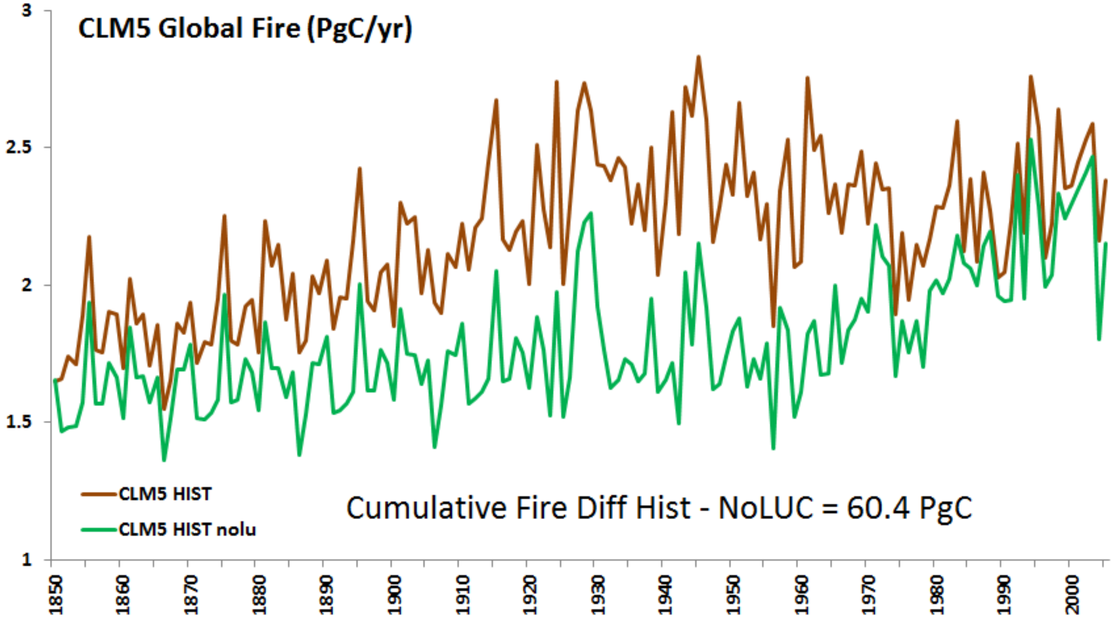

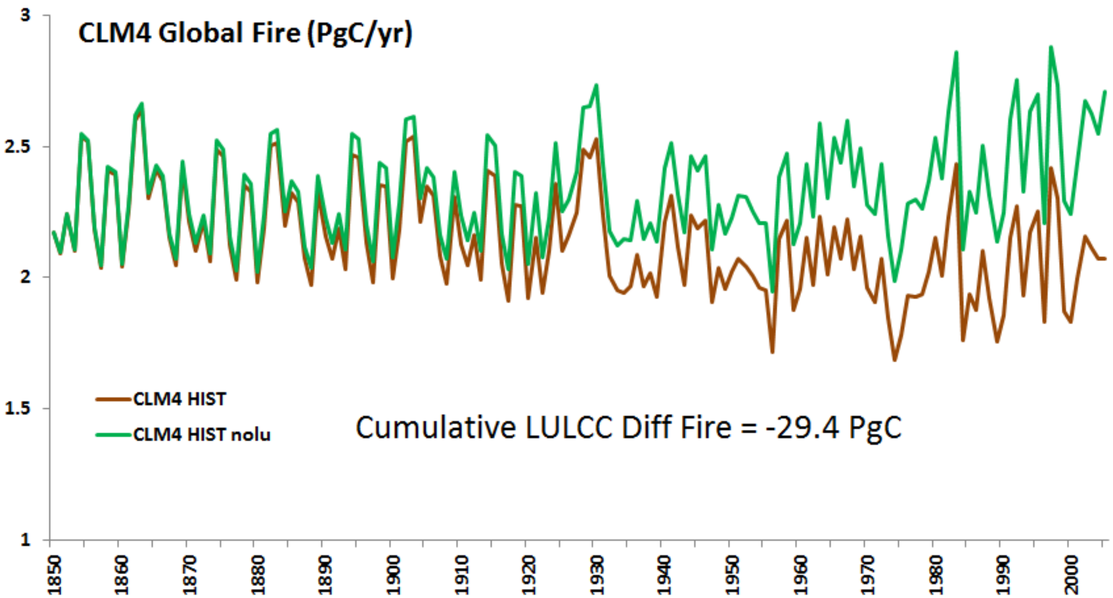

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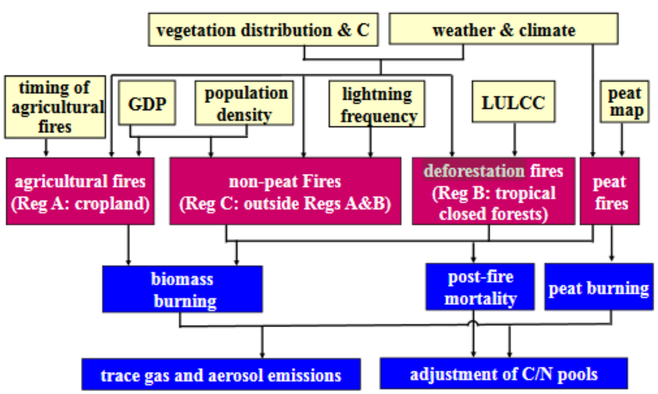
Biggest difference comes from the introduction of deforestation fires Li et al 2013



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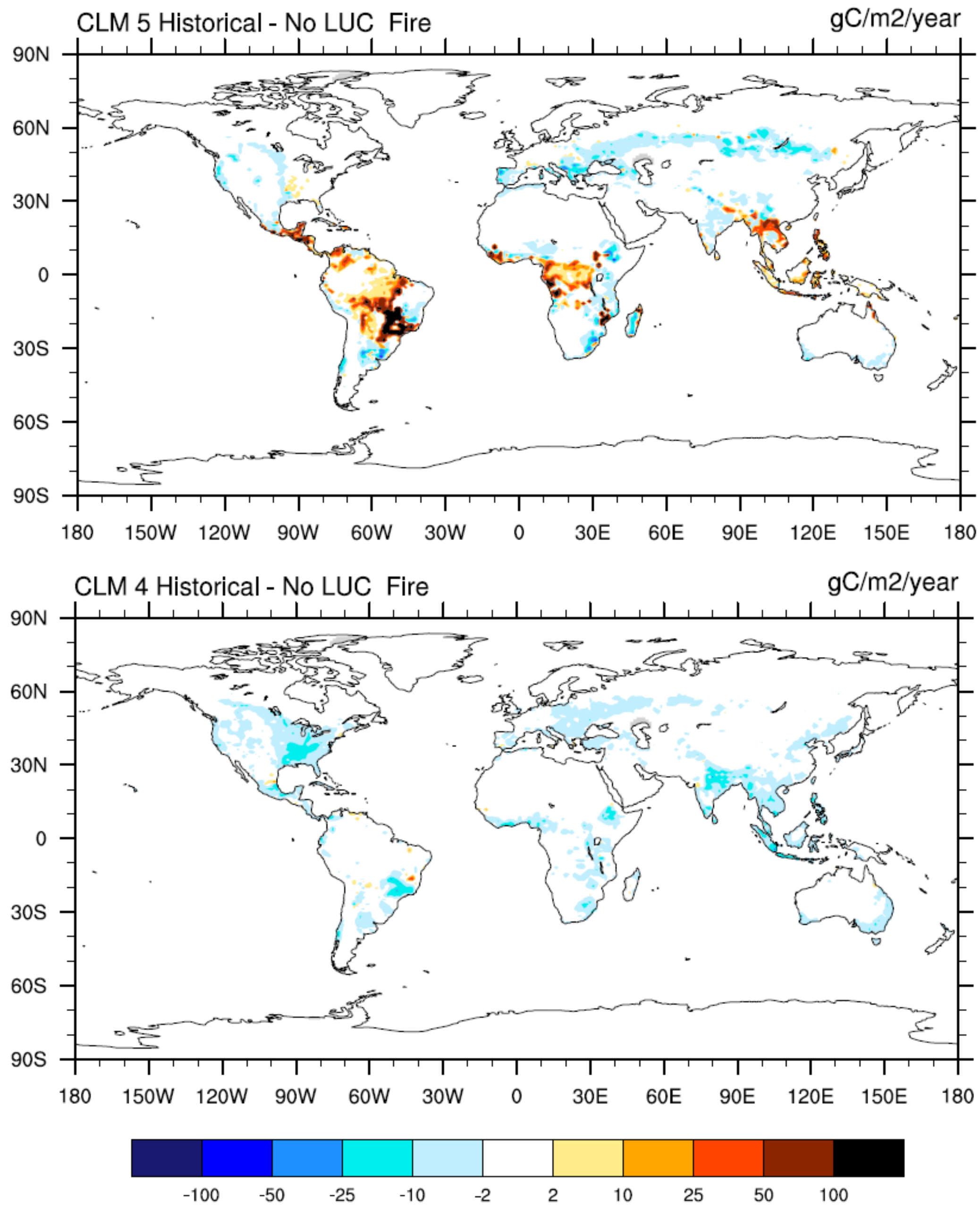

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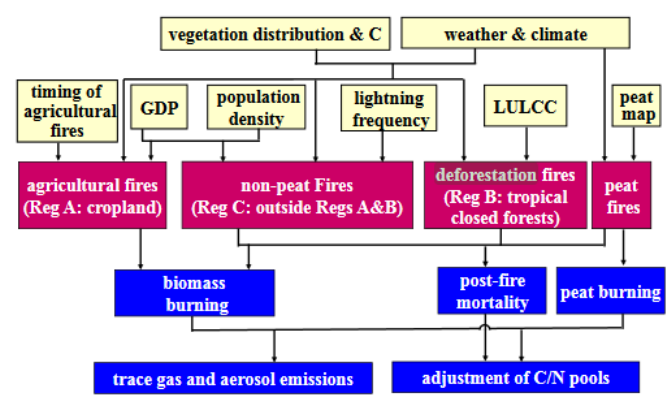
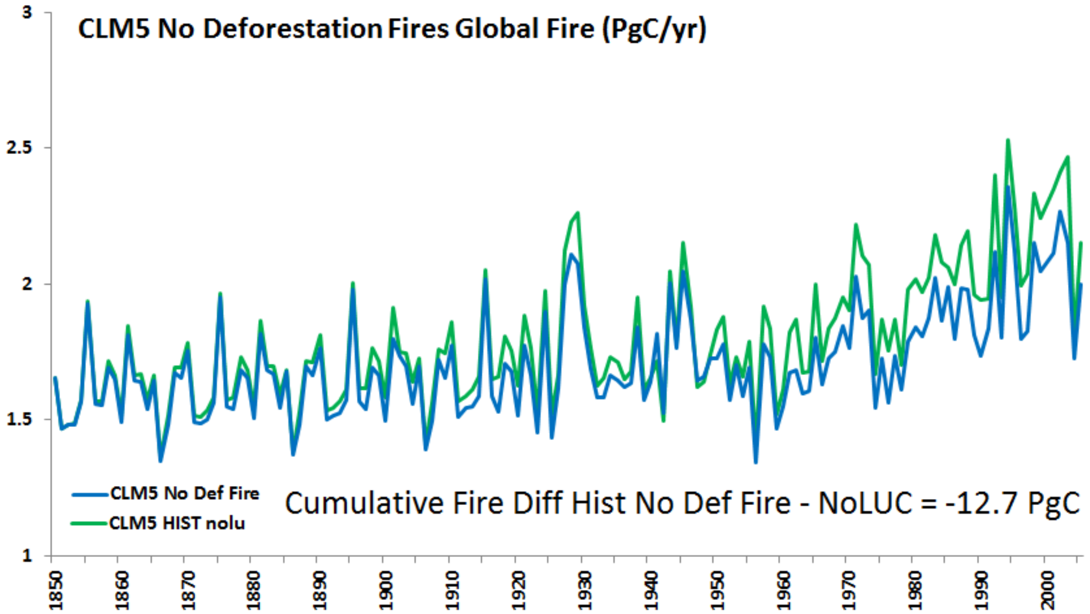
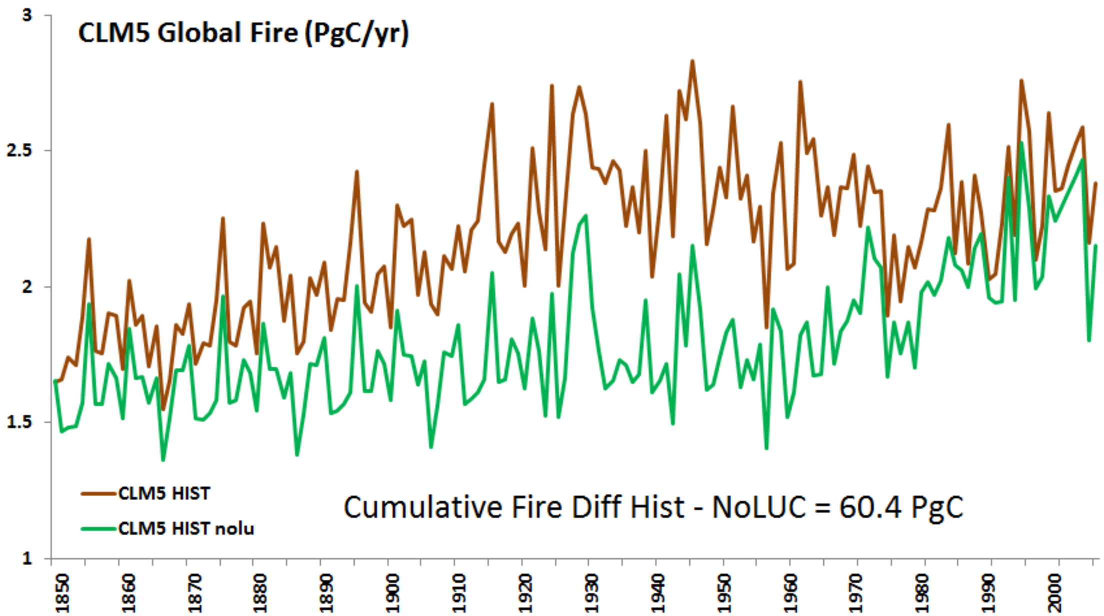


New CLM5 LUMIP vs CLM5 No Deforest Fire – Fire

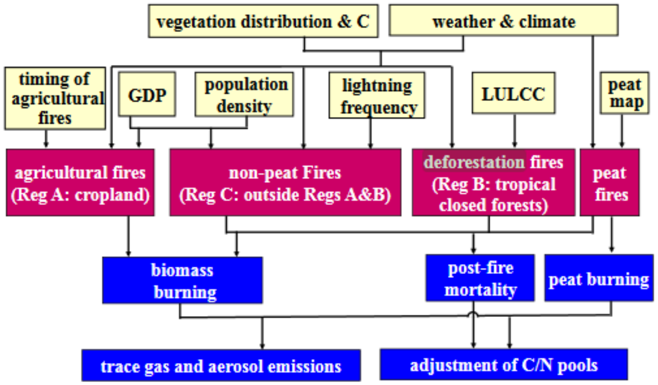




CLM5 LULCC with out deforestation fires results in a decrease in carbon loss through reduced fire of -12.7 PgC compared to an increase of 60.4 PgC with deforestation fires

This means that deforestation fires in CLM5 are contributing 73.1 PgC to LULCC. This is greater than wood harvest or the conversion flux

Also the conversion flux is supposed to account for deforestation through LULCC.



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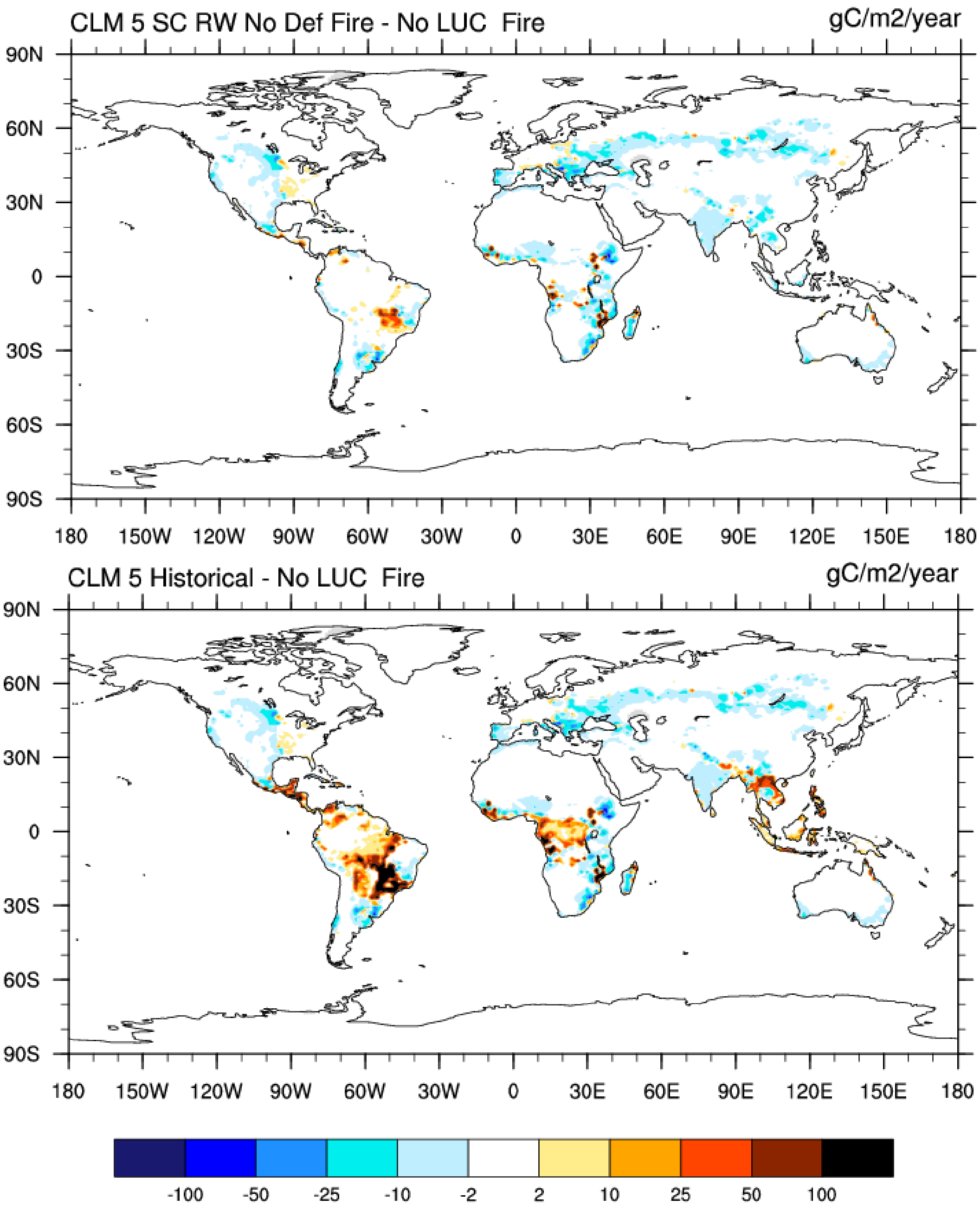

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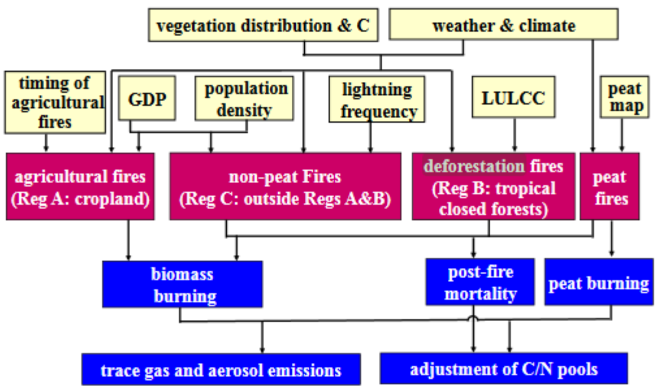
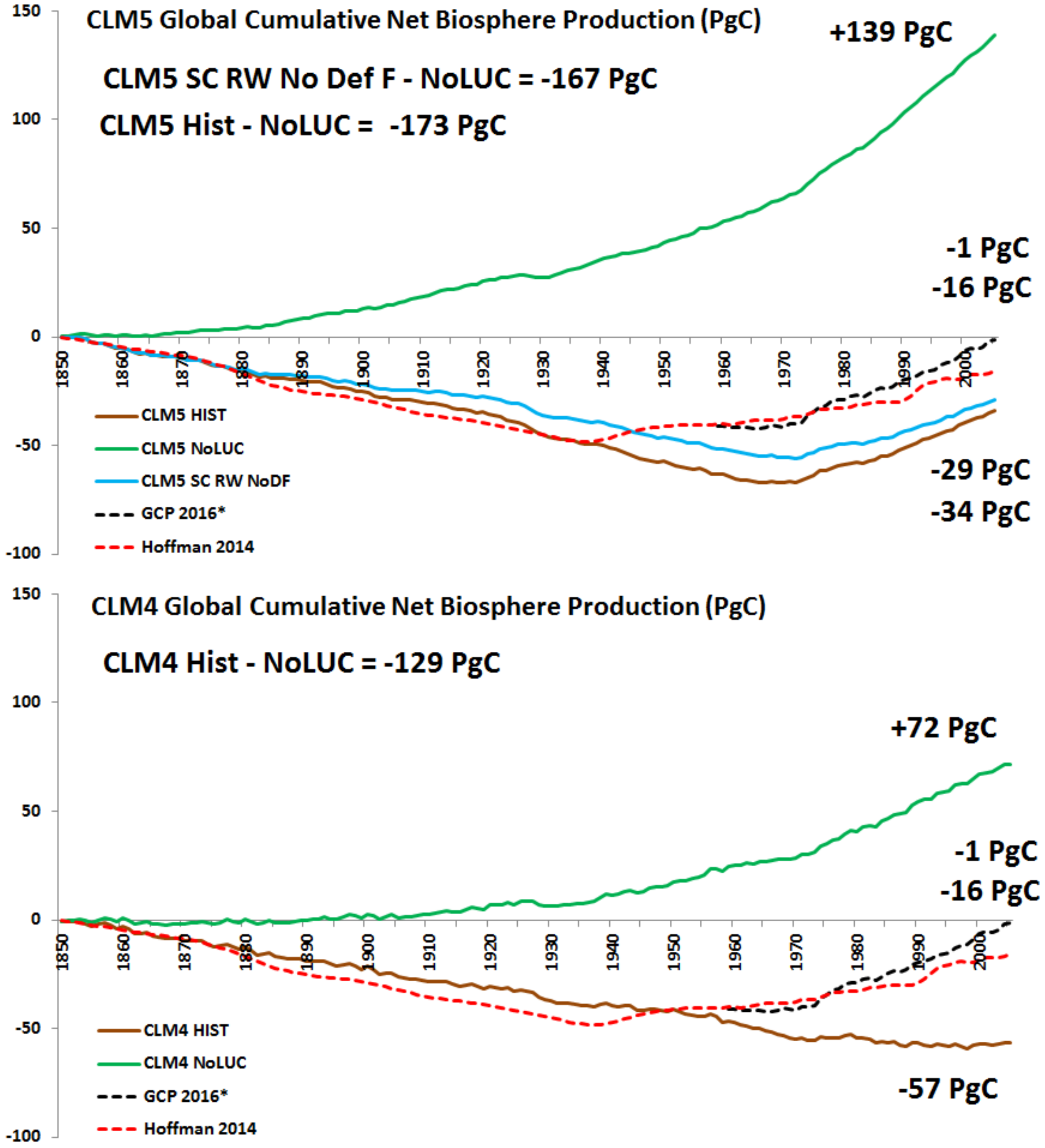


New CLM5 vs CLM5 SC Re WH No Def Fire – NBP



CLM5 with the addition of Shifting Cultivation cumulative flux of 29.3 PgC, Redistributed Wood Harvest of another 9 PgC and removing Deforestation Fires of 73.1 PgC results in an increase in cumulative NBP of only 6 PgC.

The reduced NBP loss results in an decrease in The Land Use flux to 167 PgC over the Historical Period

The timing and change from carbon loss to carbon gain in NBP is similar unchanged

Compared to Hoffman et al 2014 from ILAMB and GCP cumulative NBP these combined changes have only a small impact on the net global carbon flux to the atmosphere.

CLM5 LULCC – Carbon Investigation Summary

1. Explicit prescription of forest areas in LUMIP data resulted in larger tree losses in CLM5 through the Historical time period than CMIP5 and CLM4.

2. Historical crop area is very close in CLM5 LUMIP and CLM4 CMIP5 but we now have crop model with transient crop specific fertilizer, irrigation management and grain harvest at the grid cell.

3. Shifting cultivation (Gross Unrepresented LULCC) is now developed for CLM5 but not in current model release or default simulations. Consistent with other modeling groups at 0.2-0.3 PgC/yr

4. The LUH2 prescription of wood harvest biomass results in prescription of large amounts of wood harvest to low tree fraction areas. This can be addressed in the Land Use data sets through redistribution based on tree fraction

5. LULCC in CLM5 increases fire through Deforestation fires. This appears to be a double counting as this carbon is already being removed through conversion fluxes in the LULCC code.

New CLM5 LUMIP vs CLM4 CMIP5 LULCC – Cumulative Historical Global Carbon Cycle Impacts 1850 – 2005

	CLM5	CLM4	Diff CLM5 – CLM4
Conversion Flux	59.3 PgC	63.8 PgC	-4.5 PgC
Wood Harvest	60.0 PgC	69.0 PgC	-9.0 PgC
∑ Direct LULCC	119.3 PgC	132.8 PgC	-13.5 PgC

New CLM5 LUMIP vs CLM4 CMIP5 LULCC – Cumulative Historical Global Carbon Cycle Impacts 1850 – 2005

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Wood Harvest	60.0 PgC	69.0 PgC	-9.0 PgC
∑ Direct LULCC	119.3 PgC	132.8 PgC	-13.5 PgC

	CLM5	CLM4	Diff CLM5 – CLM4
Δ Fire (LULCC)	+60.5 PgC	-29.4 PgC	+89.9 PgC
∑ LULCC + Δ Fire	179.8 PgC	103.4 PgC	+76.4 PgC

New CLM5 LUMIP vs CLM4 CMIP5 LULCC – Cumulative Historical Global Carbon Cycle Impacts 1850 – 2005

	CLM5	CLM4	Diff CLM5 – CLM4
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	CLM5	CLM4	Diff CLM5 – CLM4
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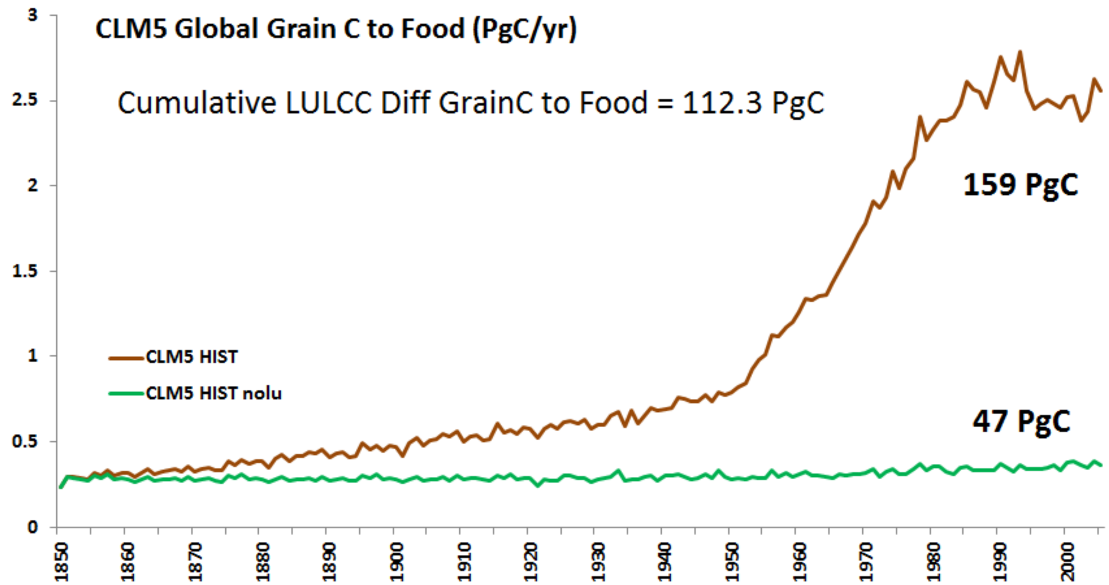
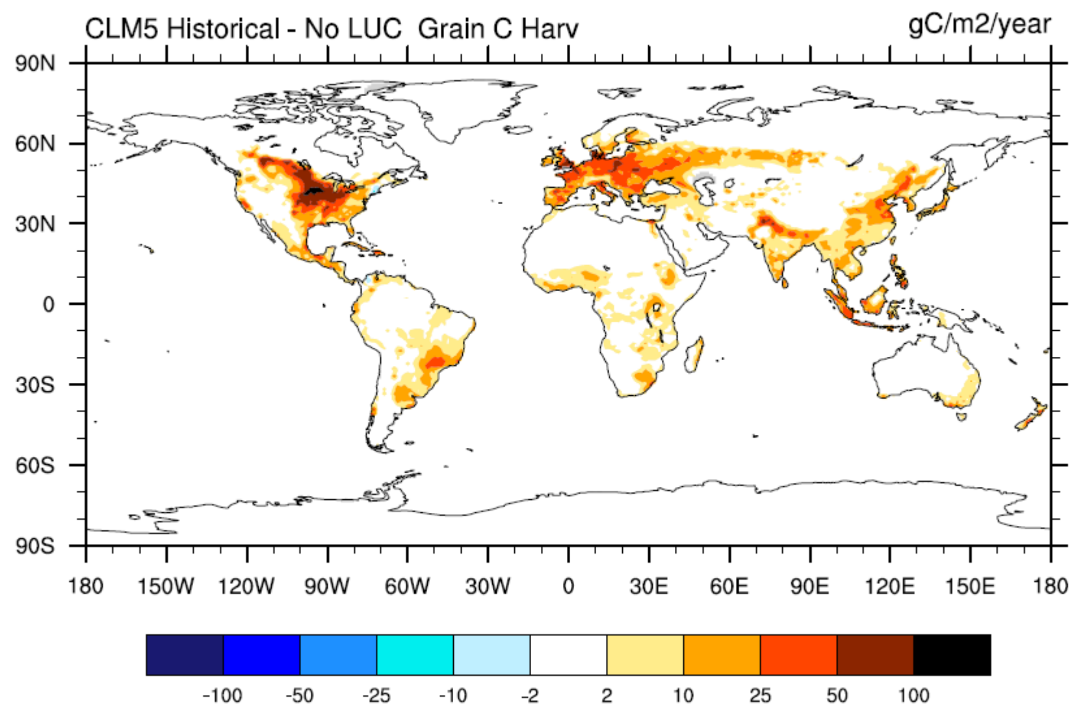
∑ LULCC + Δ Fire	179.8 PgC	103.4 PgC	+76.4 PgC

	CLM5	CLM4	Diff CLM5 – CLM4
Δ NBP (LULCC)	-172.6 PgC	-128.5 PgC	-44.1 PgC

New CLM5 LUMIP – Crop Harvest Grain C

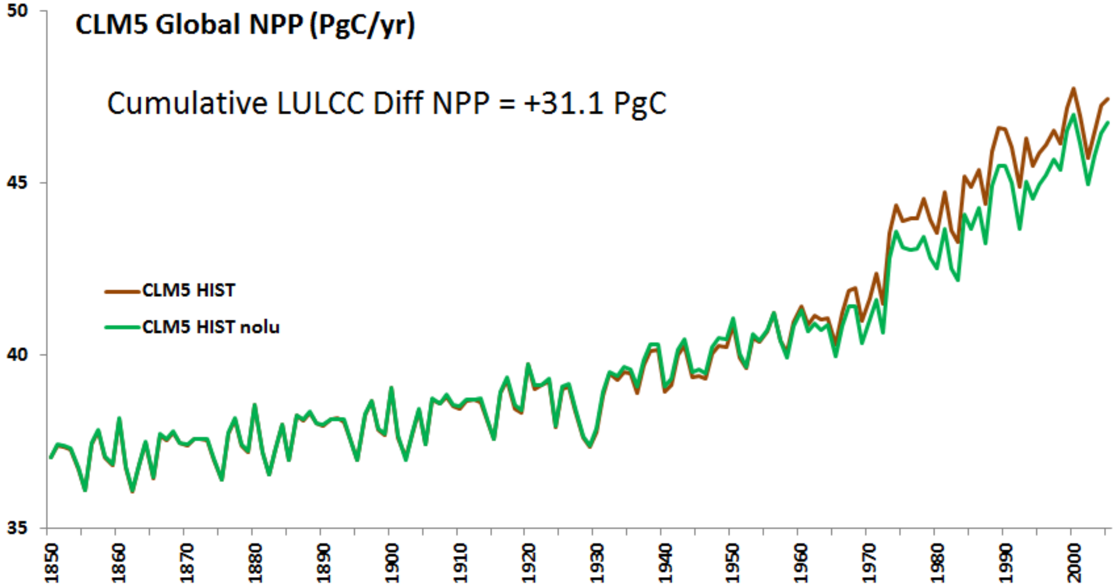


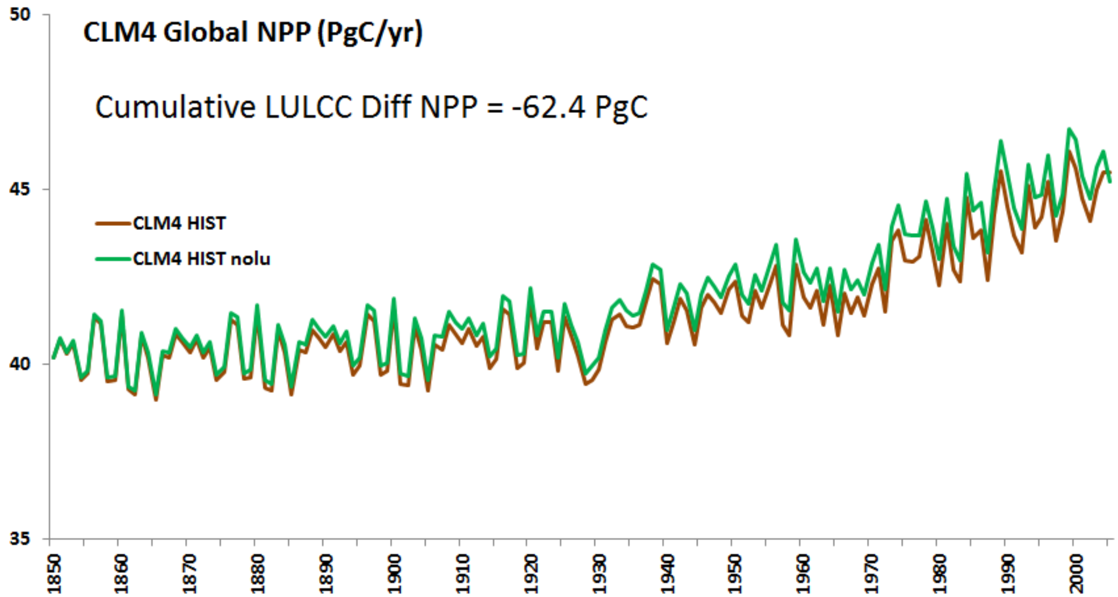


CLM5 LULCC results in large crop harvest flux out of the land of 159 PgC

CLM4 does not represent crops explicitly so has no such flux

New CLM5 LUMIP vs CLM4 LULCC – Net Primary Prod NPP





CLM5 LULCC results in Increased Net Primary Productivity uptake of carbon by the land of +31 PgC

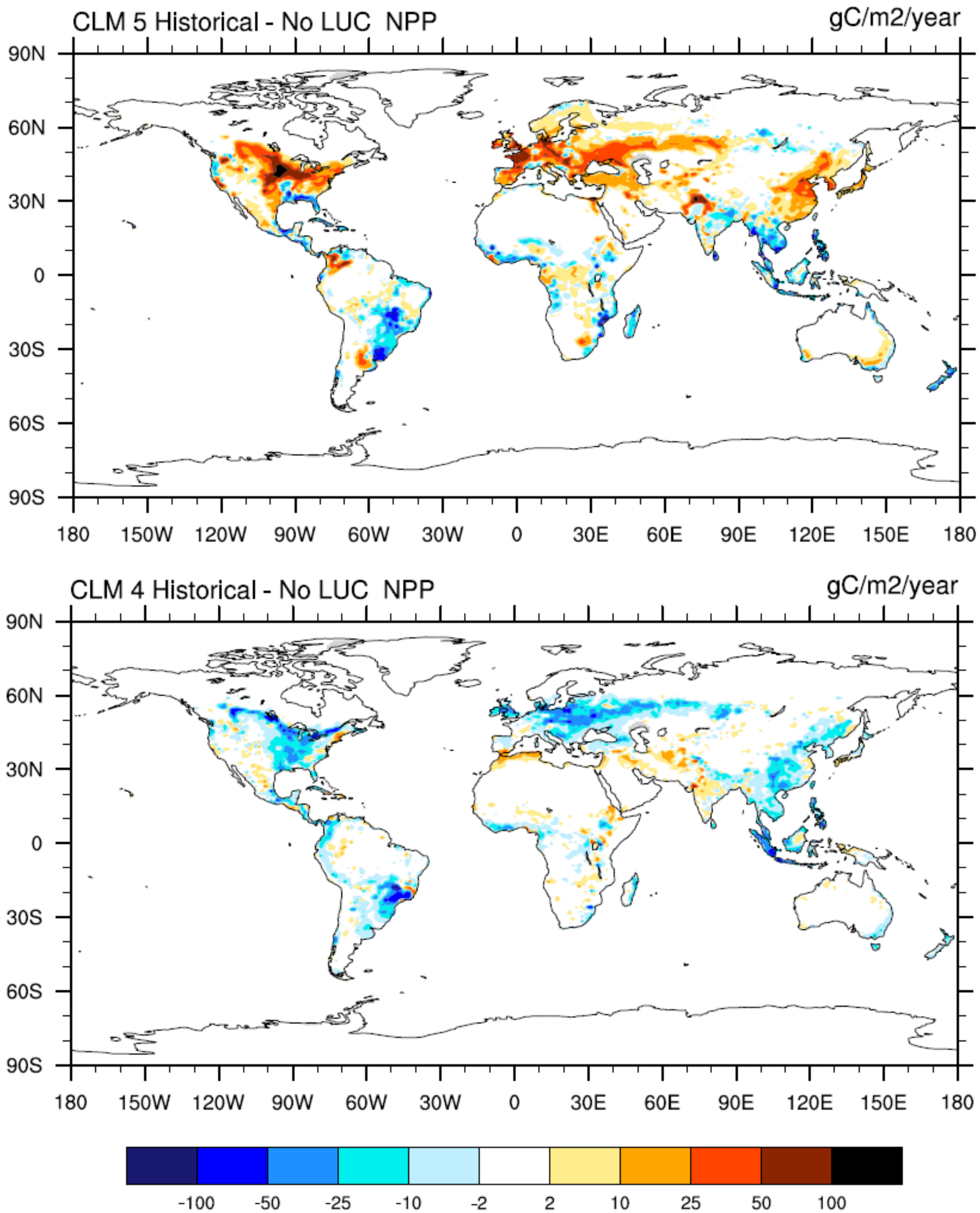
CLM4 LULCC results in lower Net Primary Productivity by -62 PgC

CLM5 LULCC cropping with N fertilizer and irrigation increases NPP over previous vegetation

CLM4 LULCC replaces high NPP forests with lower NPP pastures and crops

CLM5 NPP responds more strongly to elevated CO_2, increased N deposition, and warming climate than CLM4

New CLM5 LUMIP vs CLM4 CMIP5 LULCC – NPP



New CLM5 LUMIP vs CLM4 CMIP5 LULCC – Cumulative Historical Global Carbon Cycle Impacts 1850 – 2005

	CLM5	CLM4	Diff CLM5 – CLM4
Crop Harvest	159.3 PgC		159.3 PgC
Δ NPP (LULCC)	+31.1 PgC	-62.4 PgC	+93.5 PgC
Δ Het Respiration*	-128.2 PgC	-29.6 PgC	-98.6 PgC
∑Crop - ΔNPP + ΔHR	0.0 PgC	32.8 PgC	32.8 PgC

New CLM5 LUMIP vs CLM4 CMIP5 LULCC – Cumulative Historical Global Carbon Cycle Impacts 1850 – 2005

	CLM5	CLM4	Diff CLM5 – CLM4
Crop Harvest	159.3 PgC		159.3 PgC
Δ NPP (LULCC)	+31.1 PgC	-62.4 PgC	+93.5 PgC
Δ Het Respiration*	-128.2 PgC	-29.6 PgC	-98.6 PgC
∑Crop - ΔNPP + ΔHR	0.0 PgC	32.8 PgC	32.8 PgC

	CLM5	CLM4	Diff CLM5 – CLM4
∑LU + Fire + Cr – NPP …	179.8 PgC	136.2 PgC	+43.6 PgC
Δ Wood Product Pools	+7.3 PgC	+7.7 PgC	+0.4 PgC
∑LU + Fire … - Δ Prod	172.6 PgC	128.5 PgC	+44.1 PgC

New CLM5 LUMIP vs CLM4 CMIP5 LULCC – Cumulative Historical Global Carbon Cycle Impacts 1850 – 2005

	CLM5	CLM4	Diff CLM5 – CLM4
Crop Harvest	159.3 PgC		159.3 PgC
Δ NPP (LULCC)	+31.1 PgC	-62.4 PgC	+93.5 PgC
Δ Het Respiration*	-128.2 PgC	-29.6 PgC	-98.6 PgC
∑Crop - ΔNPP + ΔHR	0.0 PgC	32.8 PgC	32.8 PgC

	CLM5	CLM4	Diff CLM5 – CLM4
∑LU + Fire + Cr – NPP …	179.8 PgC	136.2 PgC	+43.6 PgC
Δ Wood Product Pools	+7.3 PgC	+7.7 PgC	+0.4 PgC
∑LU + Fire … - Δ Prod	172.6 PgC	128.5 PgC	+44.1 PgC

	CLM5	CLM4	Diff CLM5 – CLM4
Δ NBP (LULCC)	-172.6 PgC	-128.5 PgC	-44.1 PgC

CLM5 LUMIP vs CLM4 CMIP5 LULCC – Carbon Summary

1. Historical crop area is very close in CLM5 LUMIP and CLM4 CMIP5 but we now have crop model with transient crop specific fertilizer, irrigation management and grain harvest at the grid cell.

2. The CLM5 BGC results show a larger Historical Land Use flux with LUMIP but the model also has much stronger response to CO_2, climate, fertilizer and irrigation than found in CLM4 CN.

3. Explicit prescription of forest areas in LUMIP data resulted in larger tree losses through the Historical time period.

4. Despite the larger decrease in tree PFTs the conversion flux in CLM5 was smaller than in CLM4 with CMIP5 LULCC.

5. The prescription of wood harvest as biomass amount rather than the fraction of trees combined with the revised harvest amounts in LUMIP resulted in lower wood harvest in CLM5 as well.

6. LULCC in CLM5 increases fire where as in CLM4 it decreases it

CLM5 Surface Climate impacts of LULCC – Extra Slides

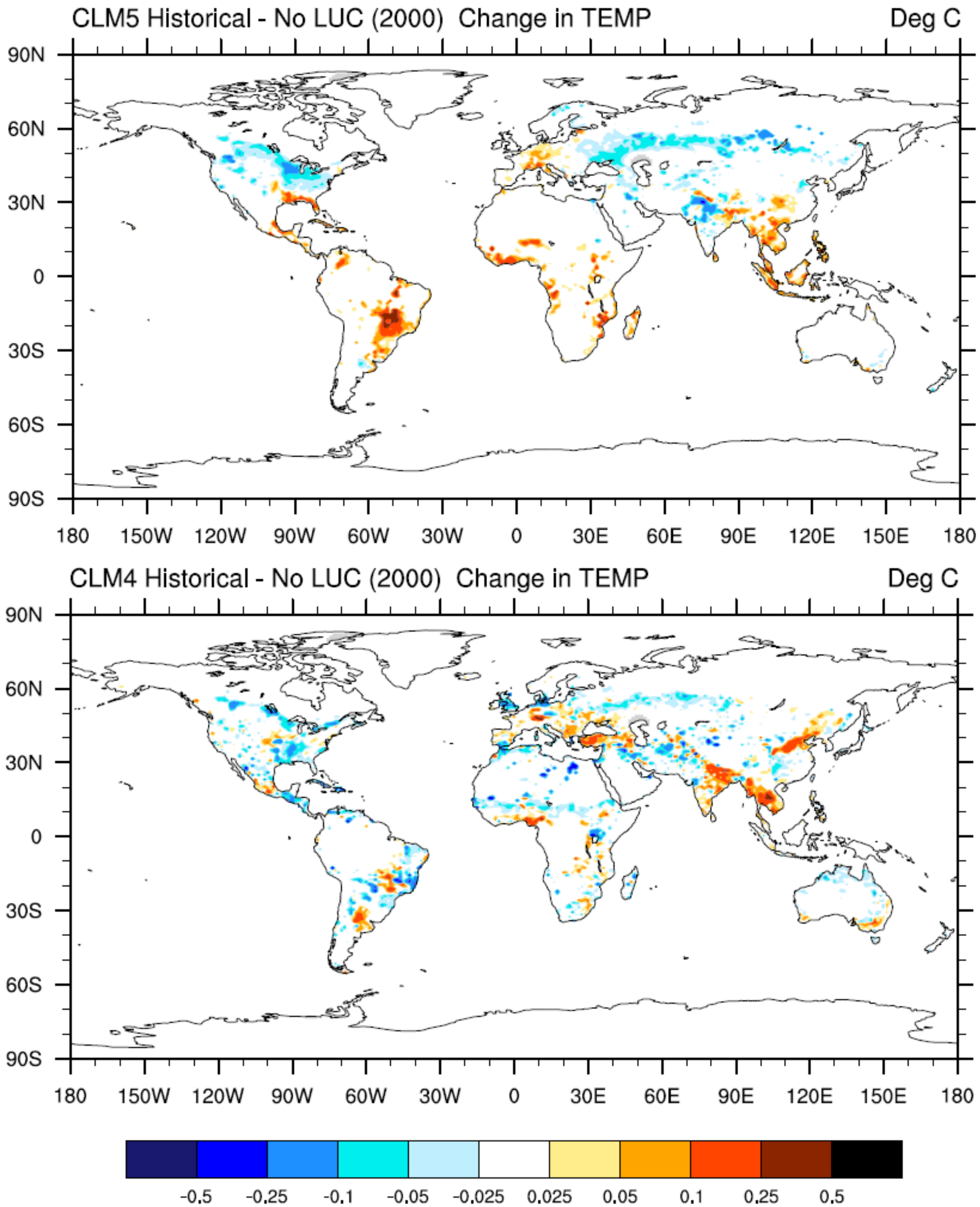
1. Assess the Surface Climate response of CLM5 to LUMIP Land Use Land Cover Change (LULCC) data for the Historical under changing climate and CO_2.

2. Again CLM5 simulations with transient LULCC compared to simulations performed with no LULCC over the same periods. Only compare surface climate for years 1996 – 2005.

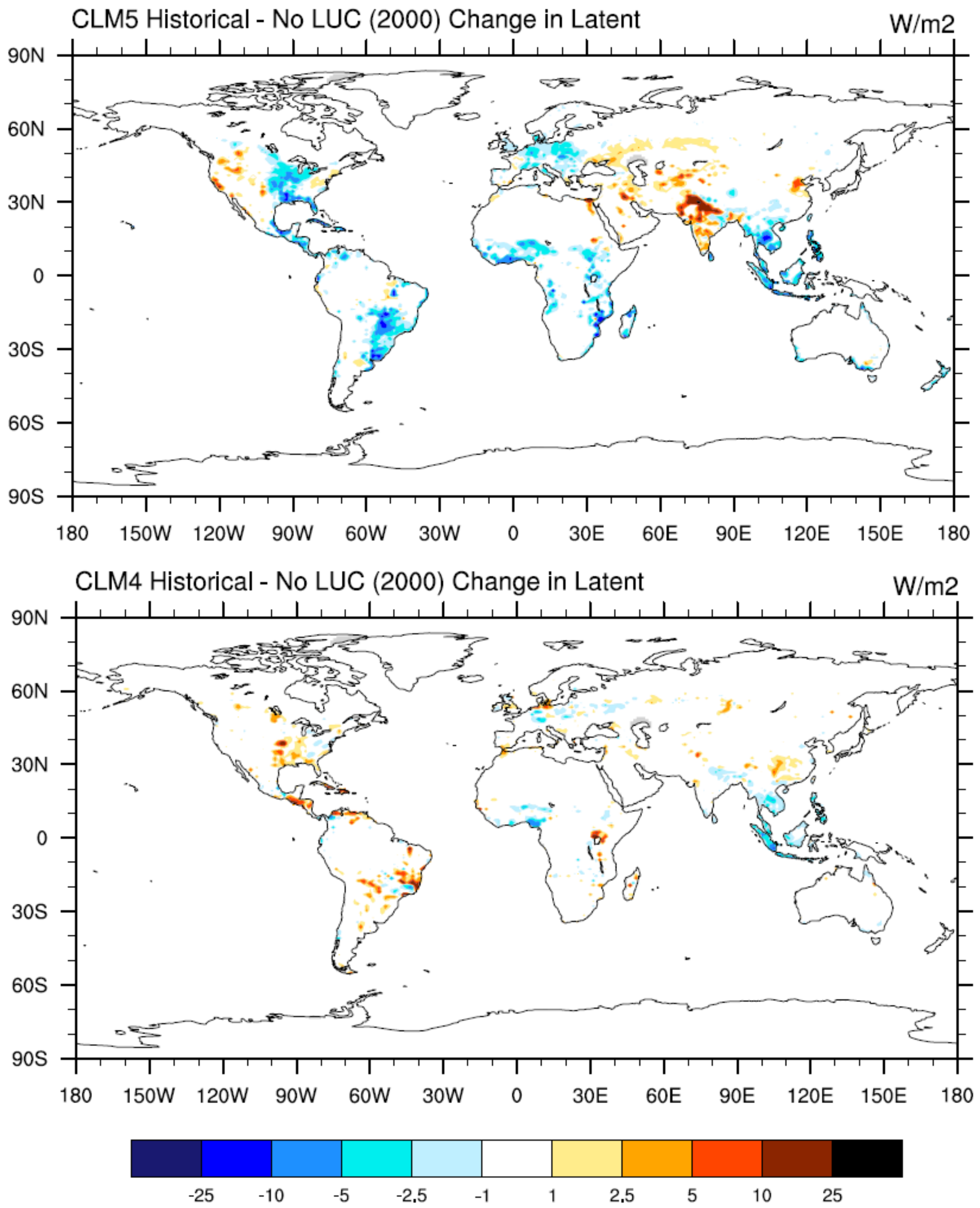
3. Again CLM5 LULCC results are compared to same experiments run with CLM4 and the CMIP5 Historical LULCC data against no LULCC.

4. All experiments have been run with 1850 – 2010 GSWP3 Prescribed Meteorology, so there are no larger scale climate feedbacks in these studies.

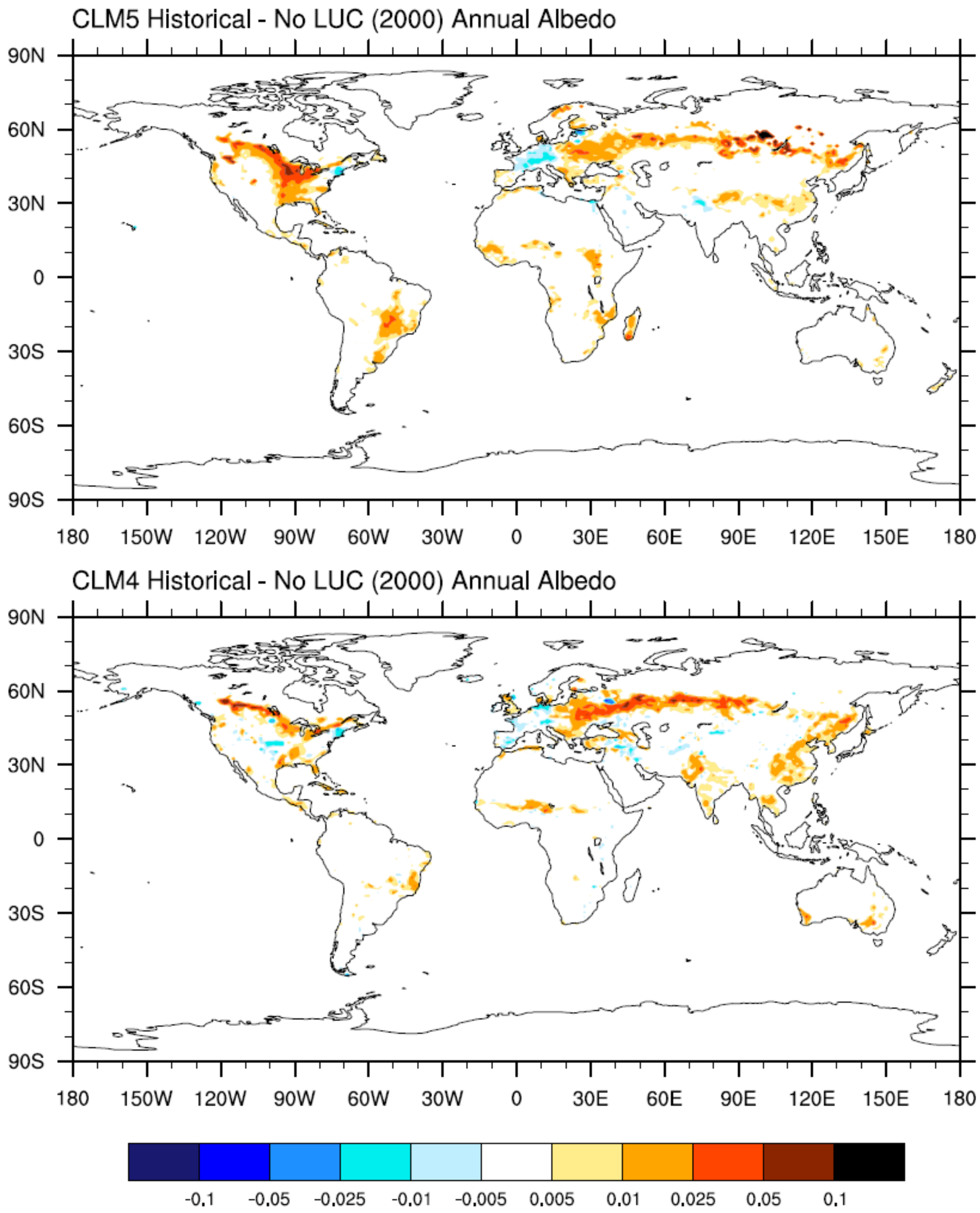
New CLM5 LUMIP vs CLM4 CMIP5 LULCC – 2m Air Temp



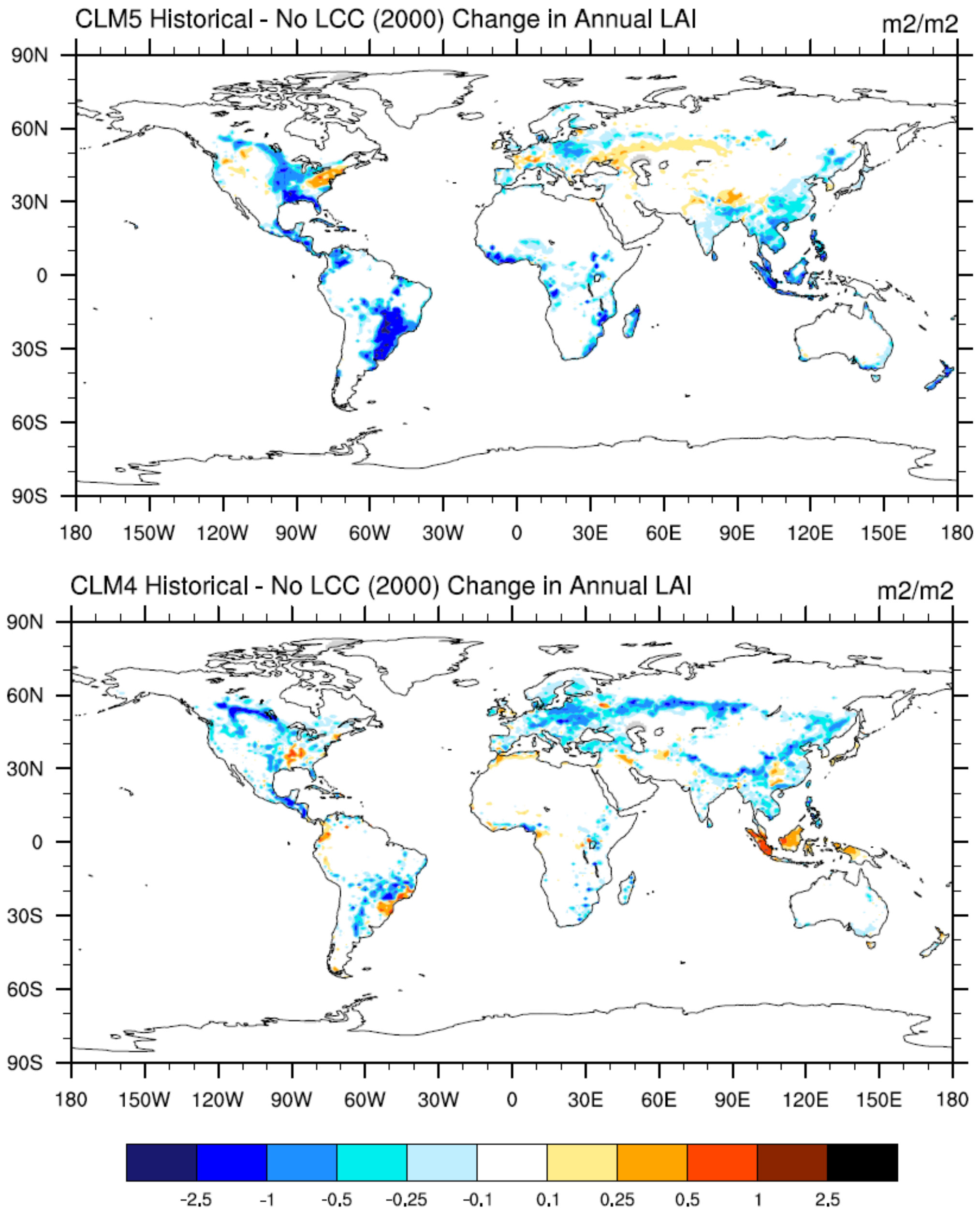
New CLM5 LUMIP vs CLM4 CMIP5 LULCC – Latent Heat



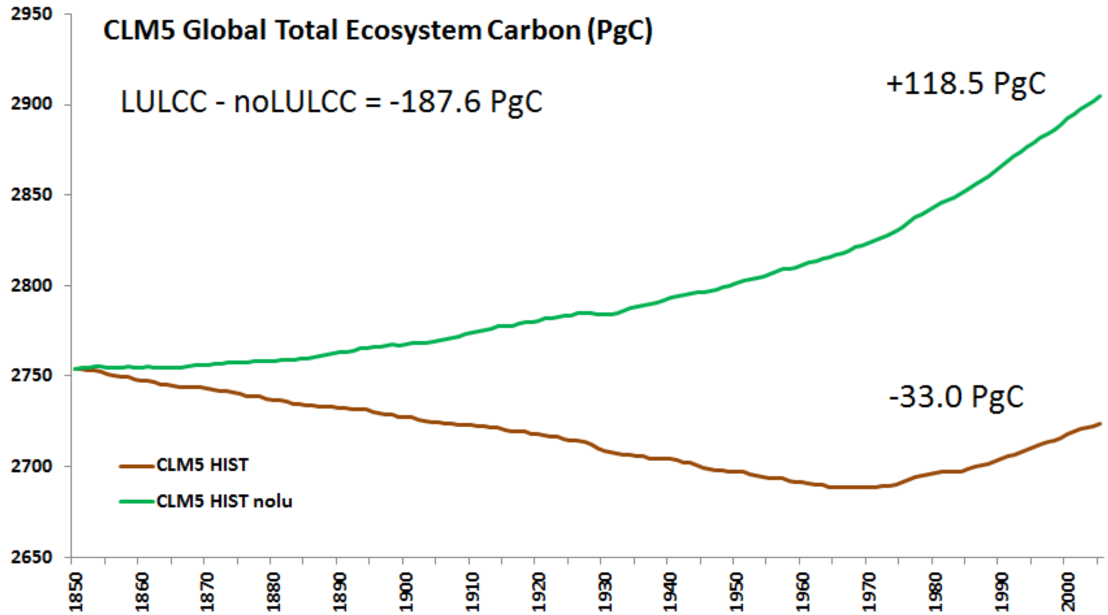
New CLM5 LUMIP vs CLM4 CMIP5 LULCC – Albedo

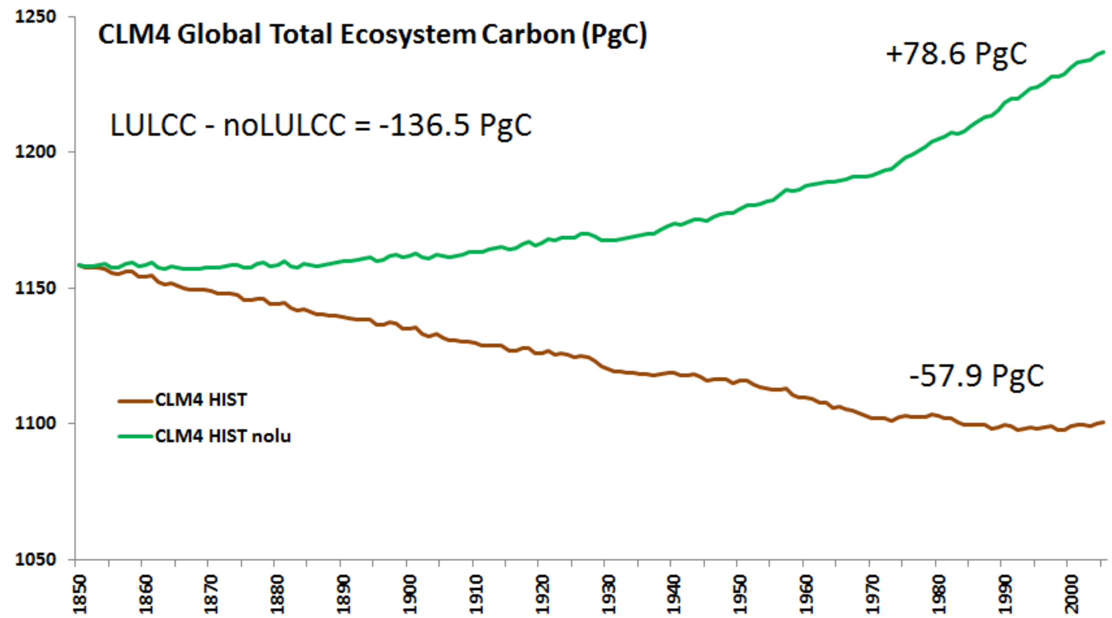


New CLM5 LUMIP vs CLM4 CMIP5 LULCC – Leaf Area

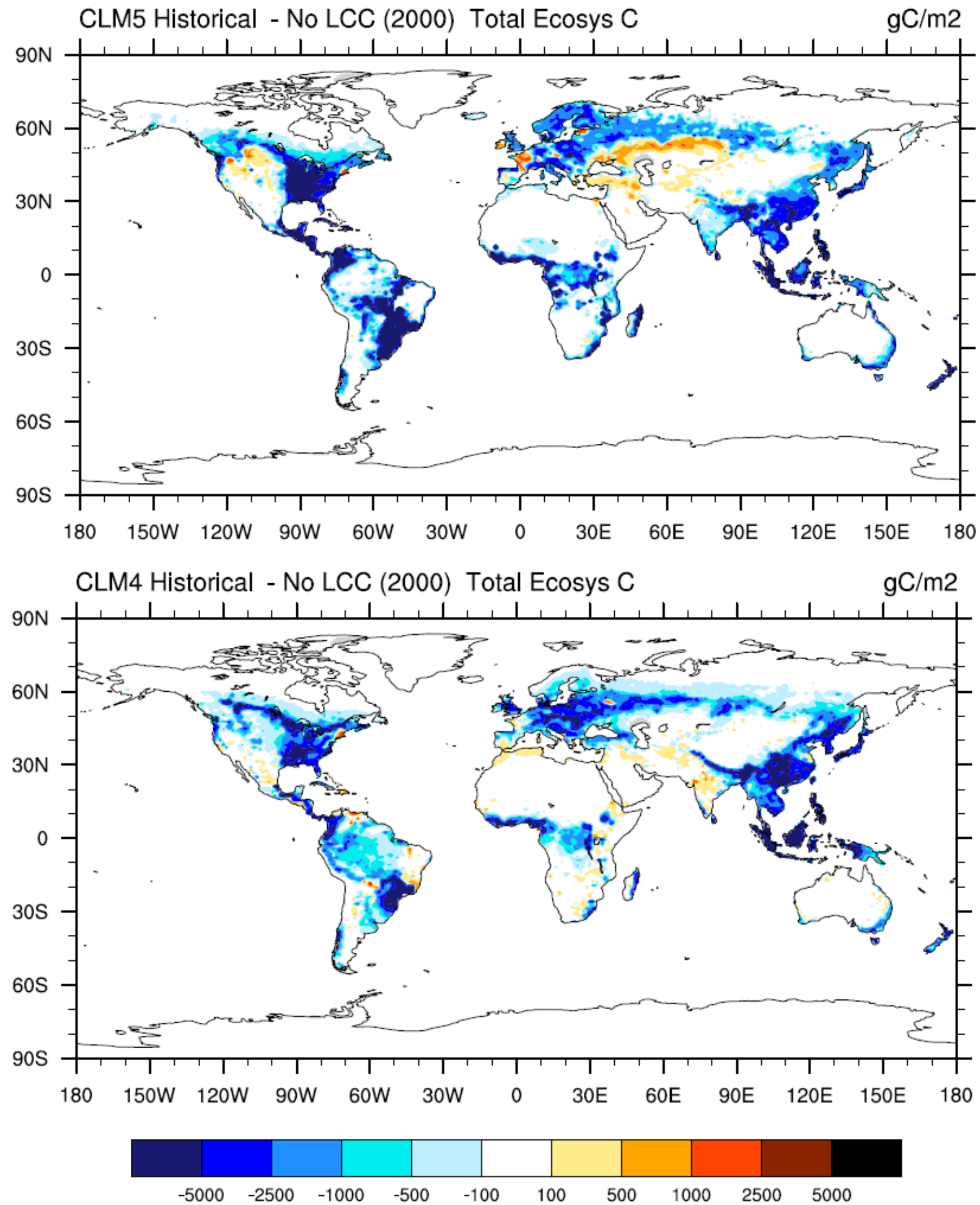


New CLM5 LUMIP vs CLM4 CMIP5 LULCC – Tot Ecosys C

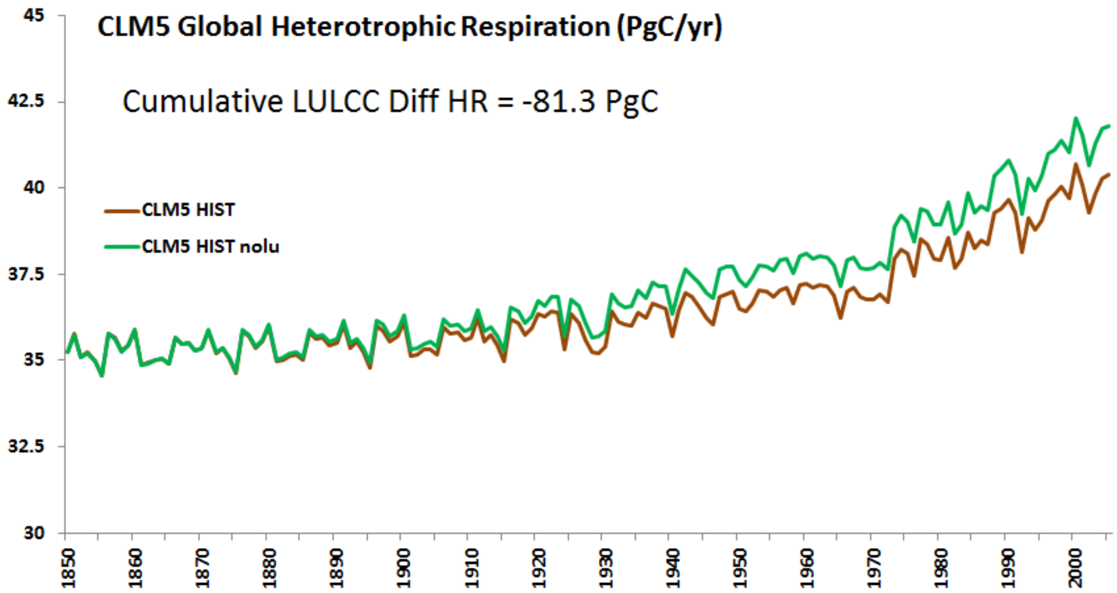


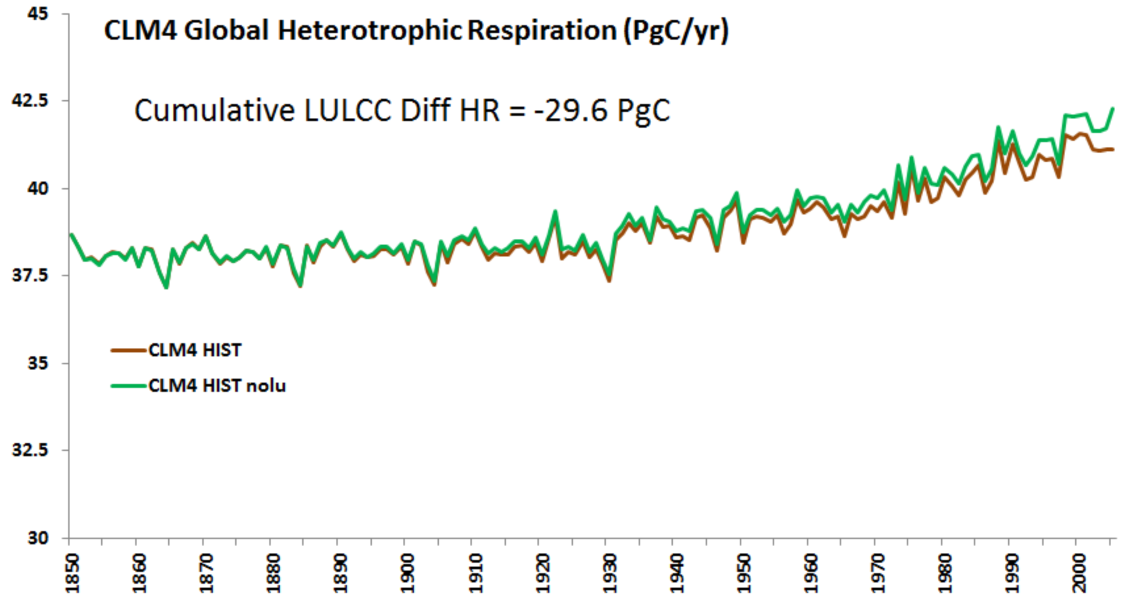


New CLM5 LUMIP vs CLM4 CMIP5 LULCC – Tot Ecosys C

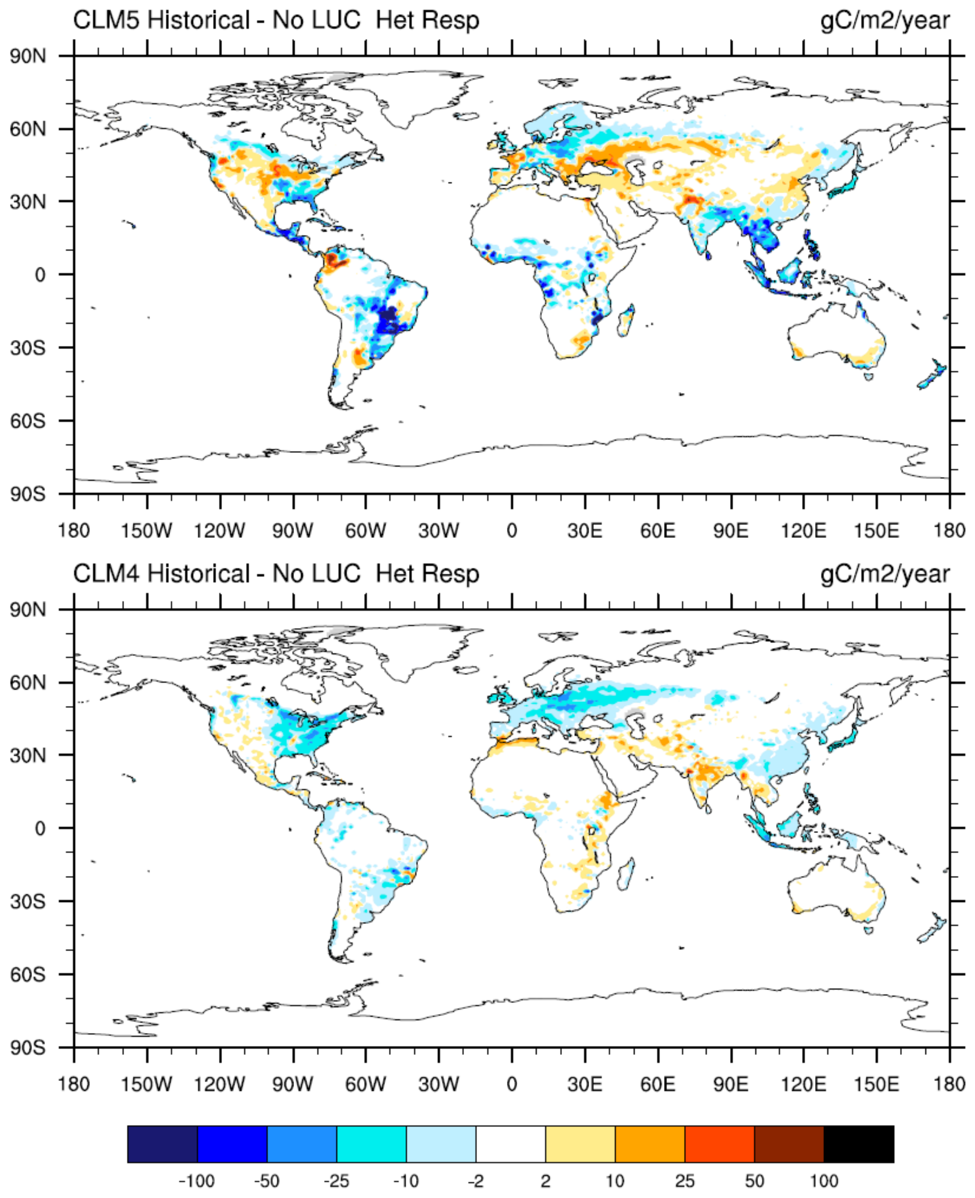


New CLM5 LUMIP vs CLM4 CMIP5 LULCC – Het. Resp.

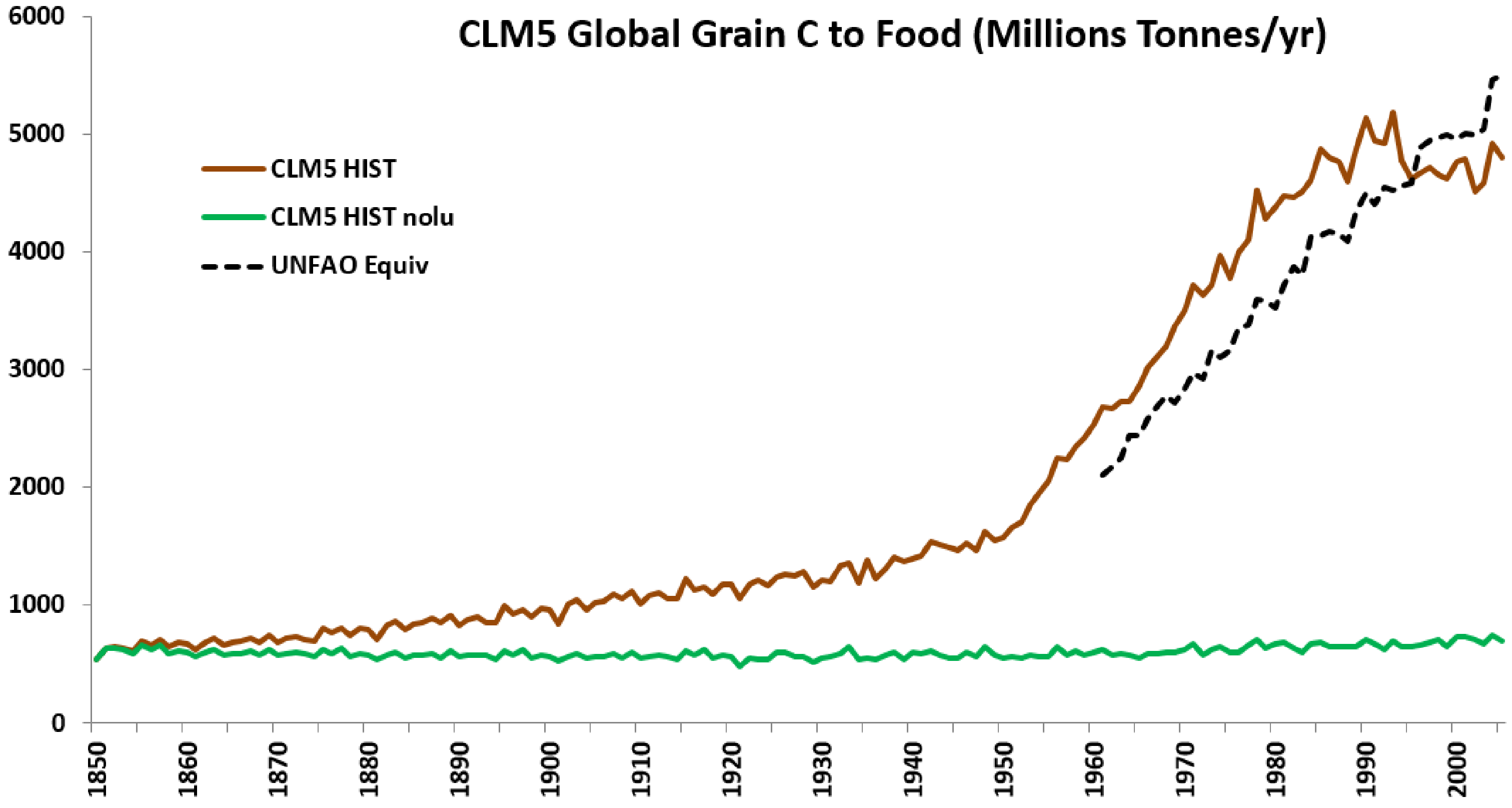




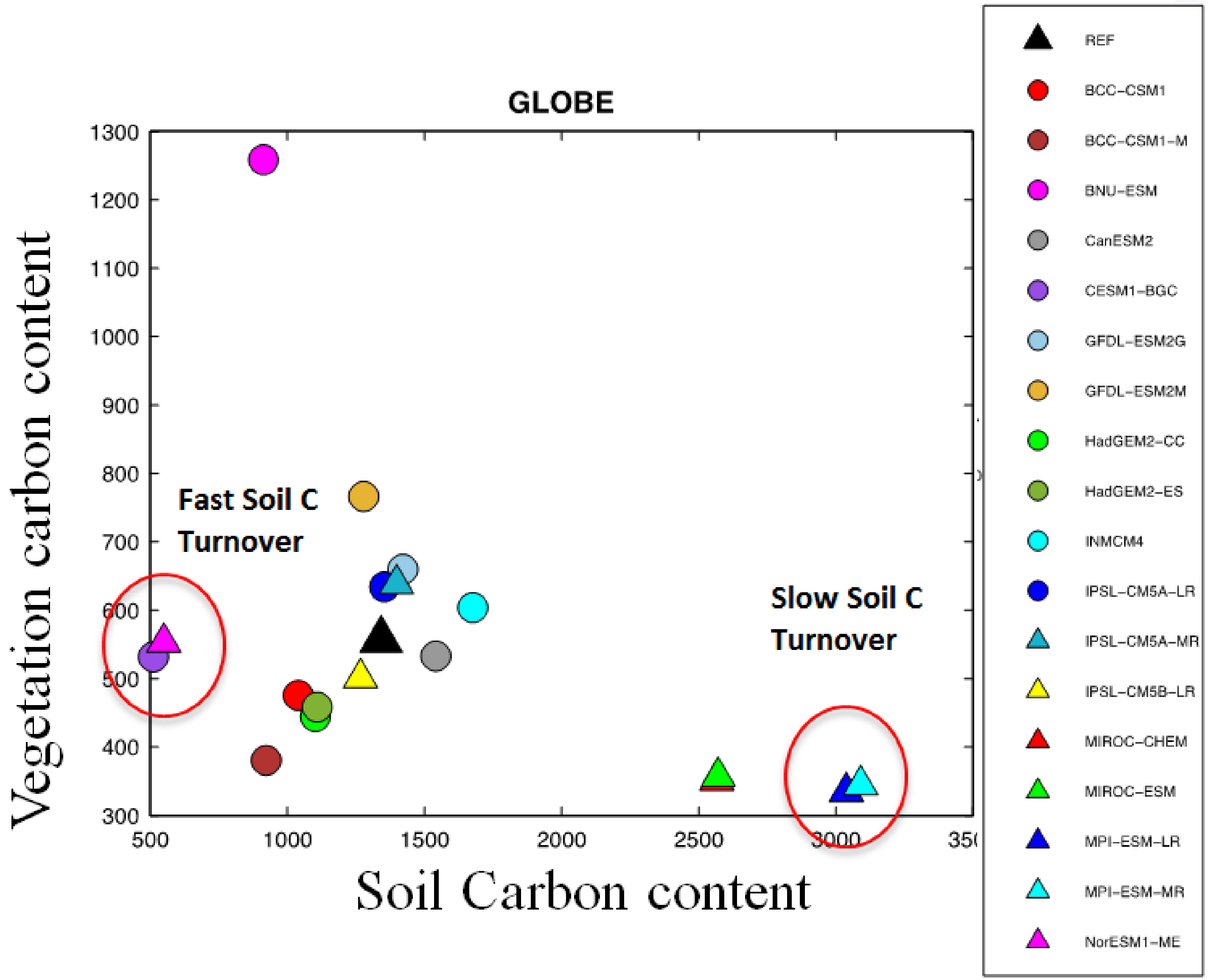
New CLM5 LUMIP vs CLM4 CMIP5 LULCC – Het. Resp.



New CLM5 LUMIP vs CLM4 CMIP5 LULCC – Crops



CMIP5 Current Day Land Carbon Simulations and Historical Land Cover Change – Anav et al. 2012



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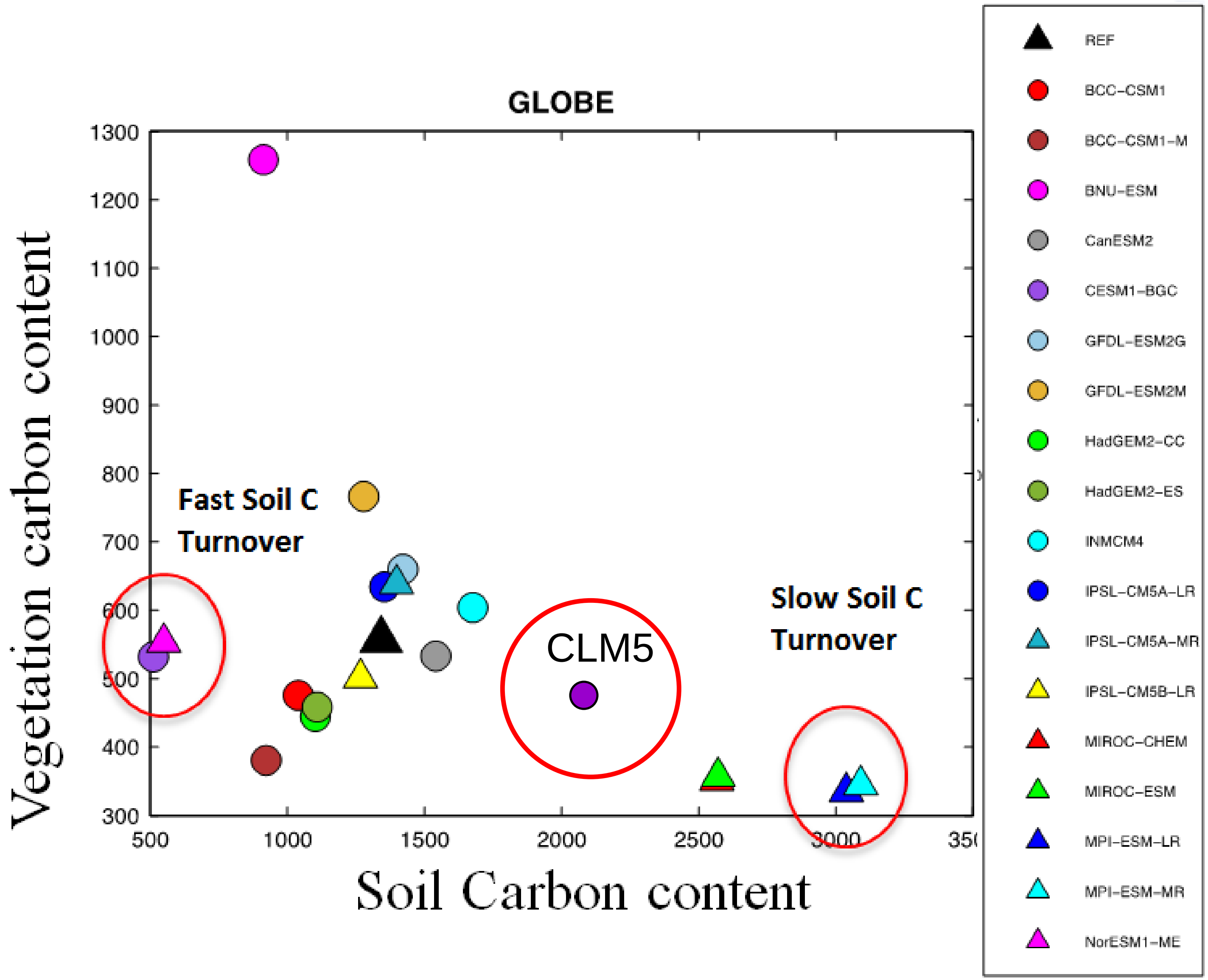

CMIP5 Current Day Land Carbon Simulations and Historical Land Cover Change – Anav et al. 2012