Direct and Indirect Land Use and Land Cover Change Carbon Fluxes in CESM 2

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co authors: Dave Lawrence, Danica Lombardozzi, George Hurtt and many others at NCAR

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1. CLM5 CMIP6 – New Land Surface Data Sets

1. There are new Historical and SSP - RCP land use and land cover change time series compiled through the Land Use and Scenario Model Intercomparison Projects (LUMIP and ScenarioMIP).

2. The Global Land Model (GLM) has been extended to 12 land units to better represent dynamics of agriculture and forests. The new land units include:

- Primary Forest
- Secondary Forest
- Crop C3 Annual
- Crop C3 Nitrogen Fixing
- Crop C4 Perennial
- Grazing Rangeland
- Primary Non Forest
- Secondary Non Forest
- Crop C3 Perennial
- Crop C4 Annual
- Grazing Pasture
- Urban

3. New management information for Crops and Forests is provided with transient N Fertilizer and Irrigation prescription, and new Wood Harvest

2. CMIP6 LUMIP CLM5 Land Use Harmonization (LUH2)

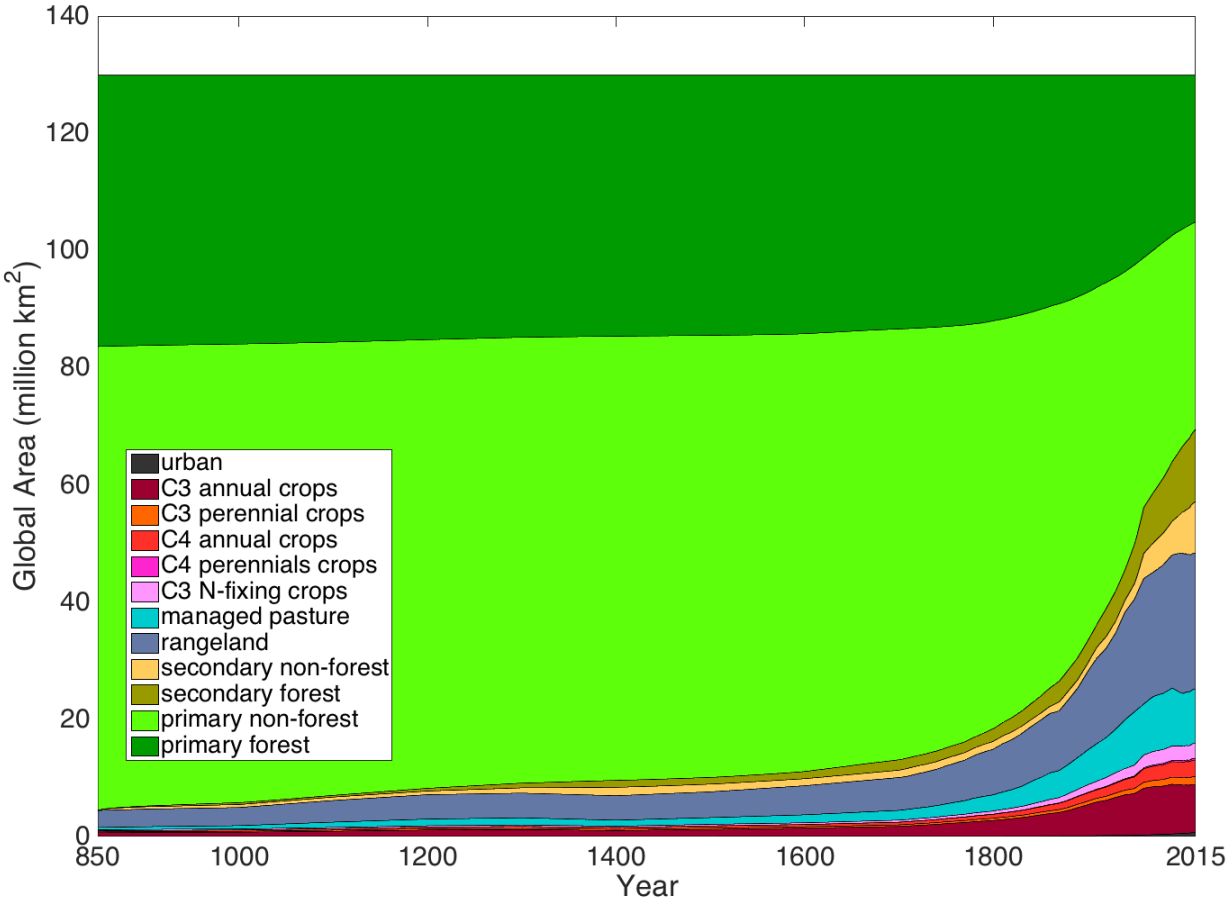
~ 50x information content of CMIP5!

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



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New Future Scenarios
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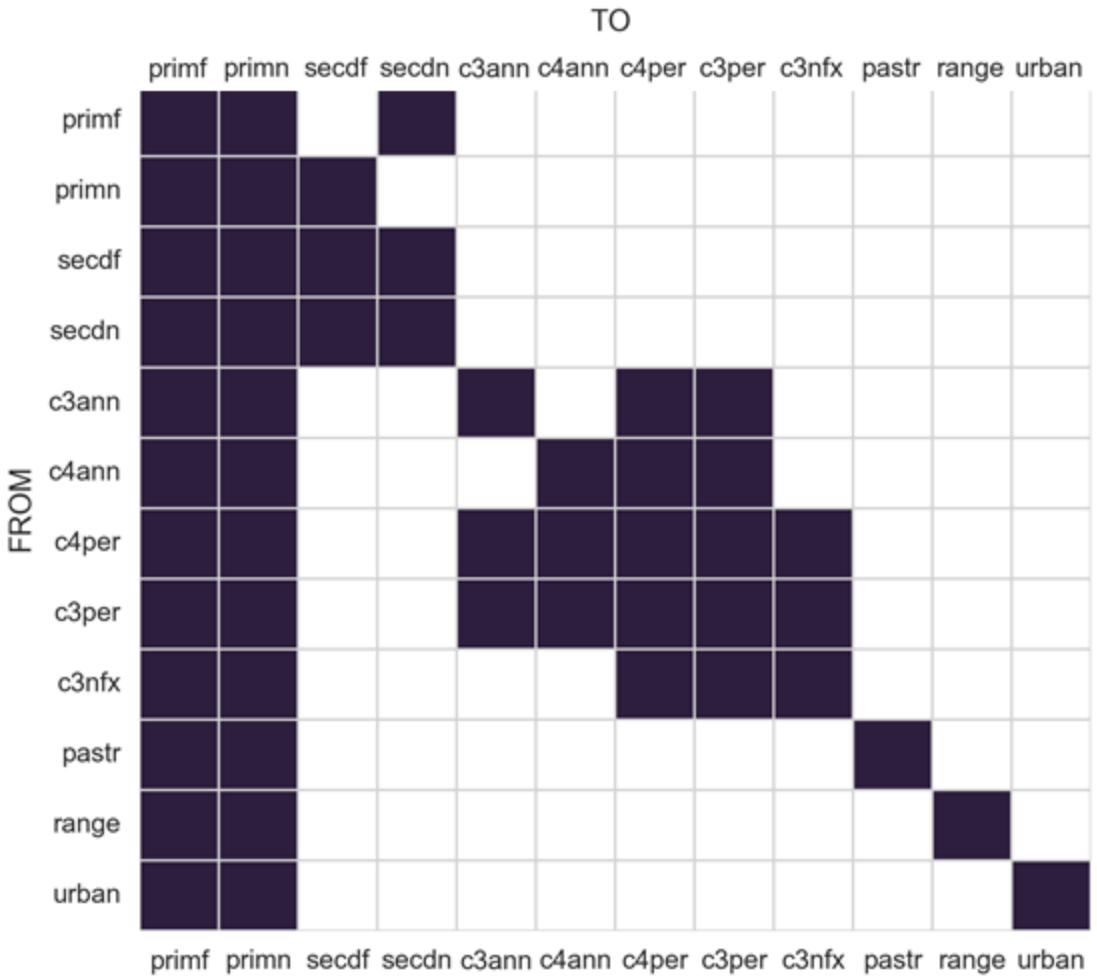
New Transition Matrix



4. 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

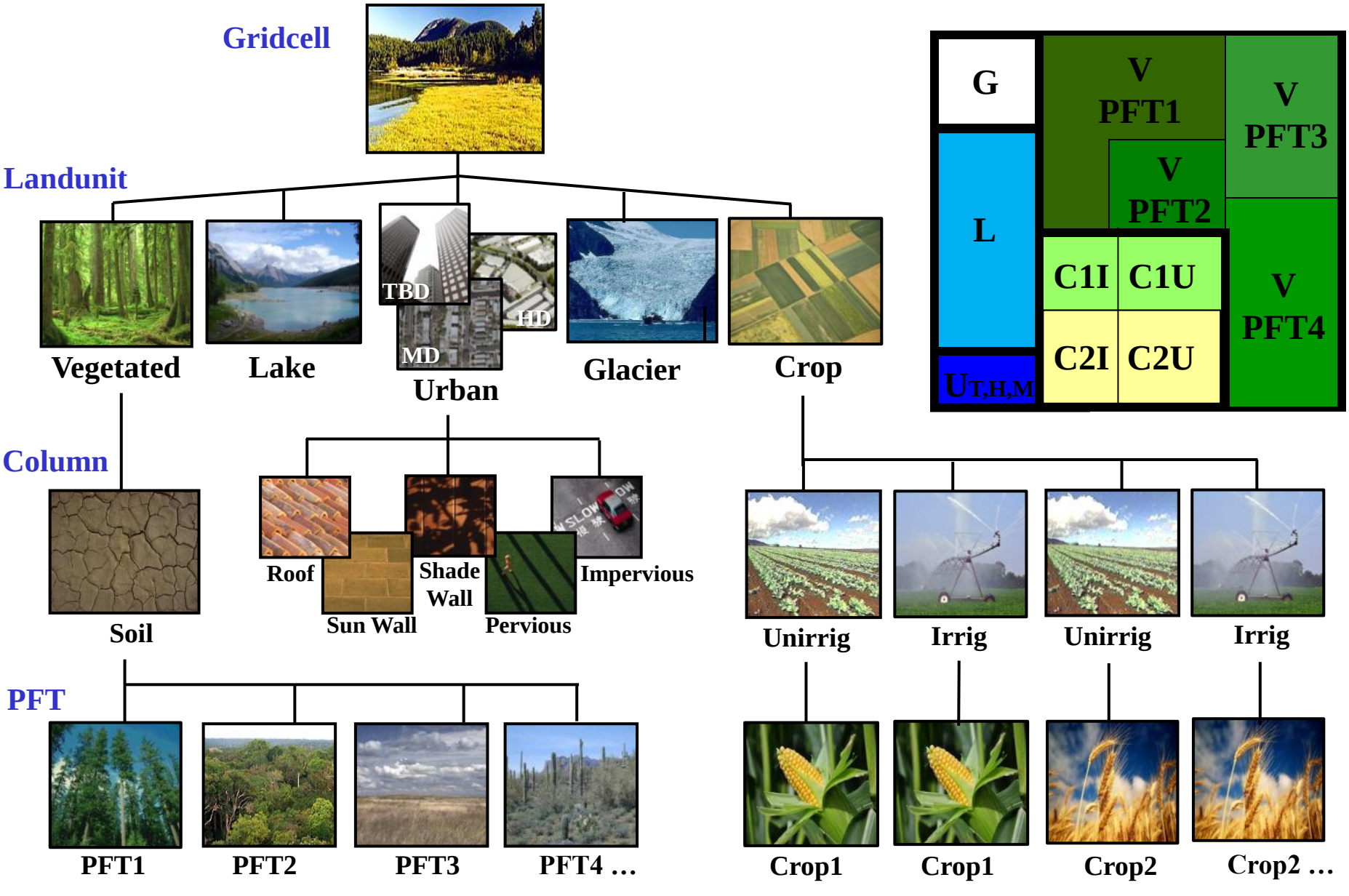
- The transient C3/C4 Crops of the LUMIP time series modeled with the CLM5 Crop model which specifies planting dates, life histories and harvest rules for individual crops for each grid cell and each year

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

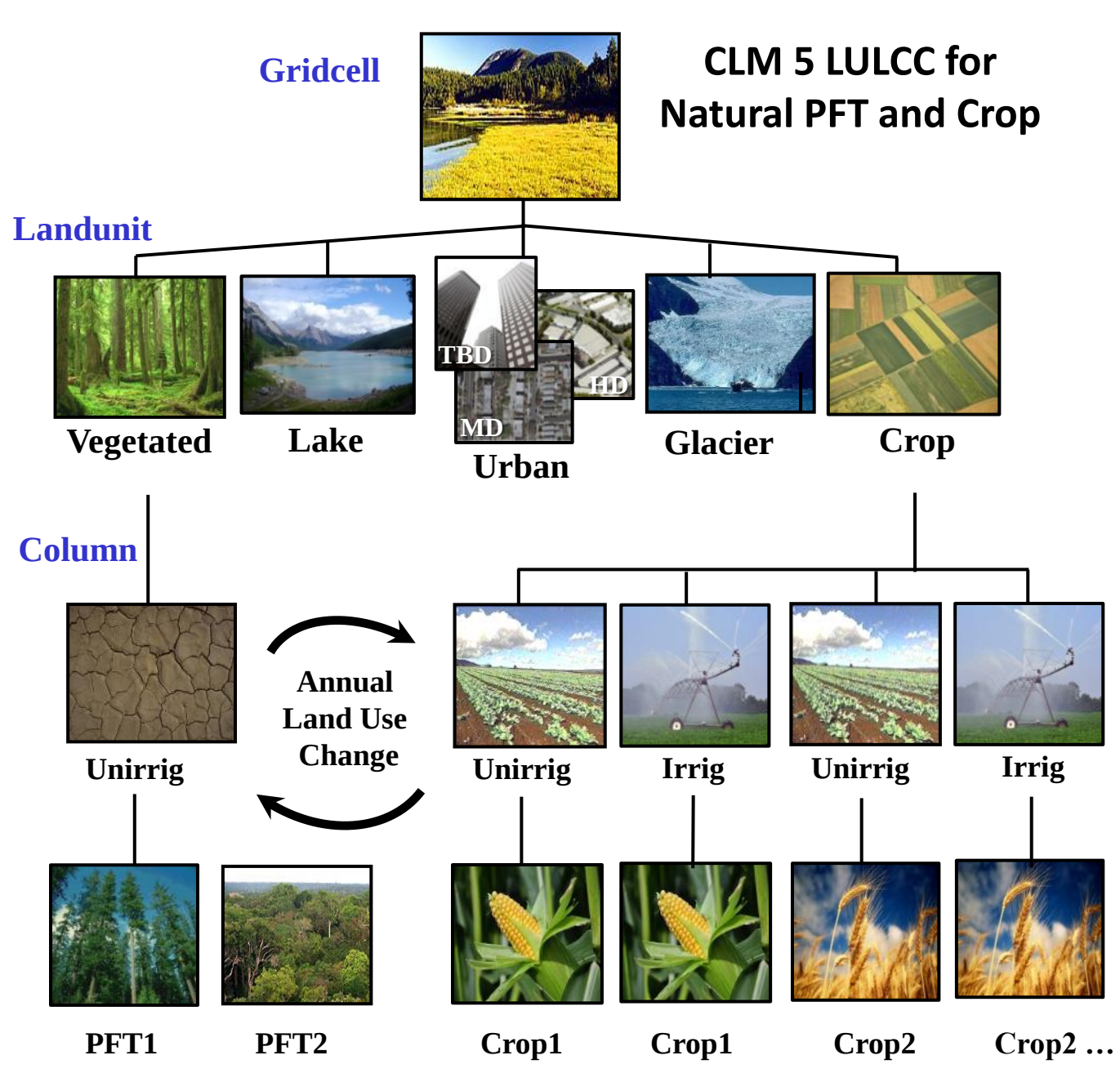
- Fertilizer and irrigation management is specified by crop and grid cell for every year

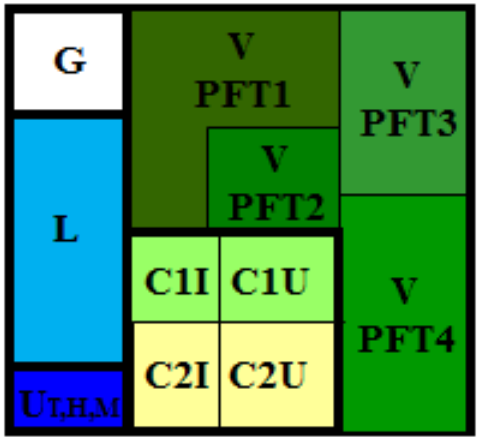
- CLM5 has optional Shifting Cultivation captured through Gross Transitions

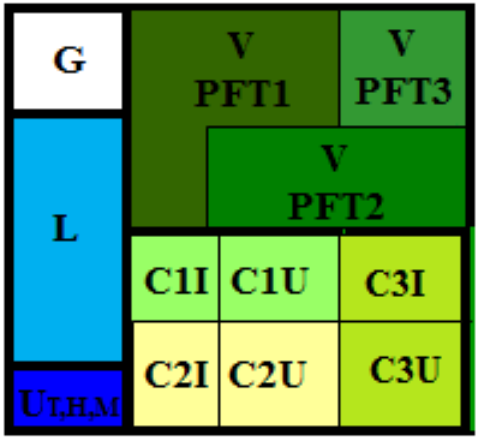
5. CLM5 Land Use and Land Cover Change Representation



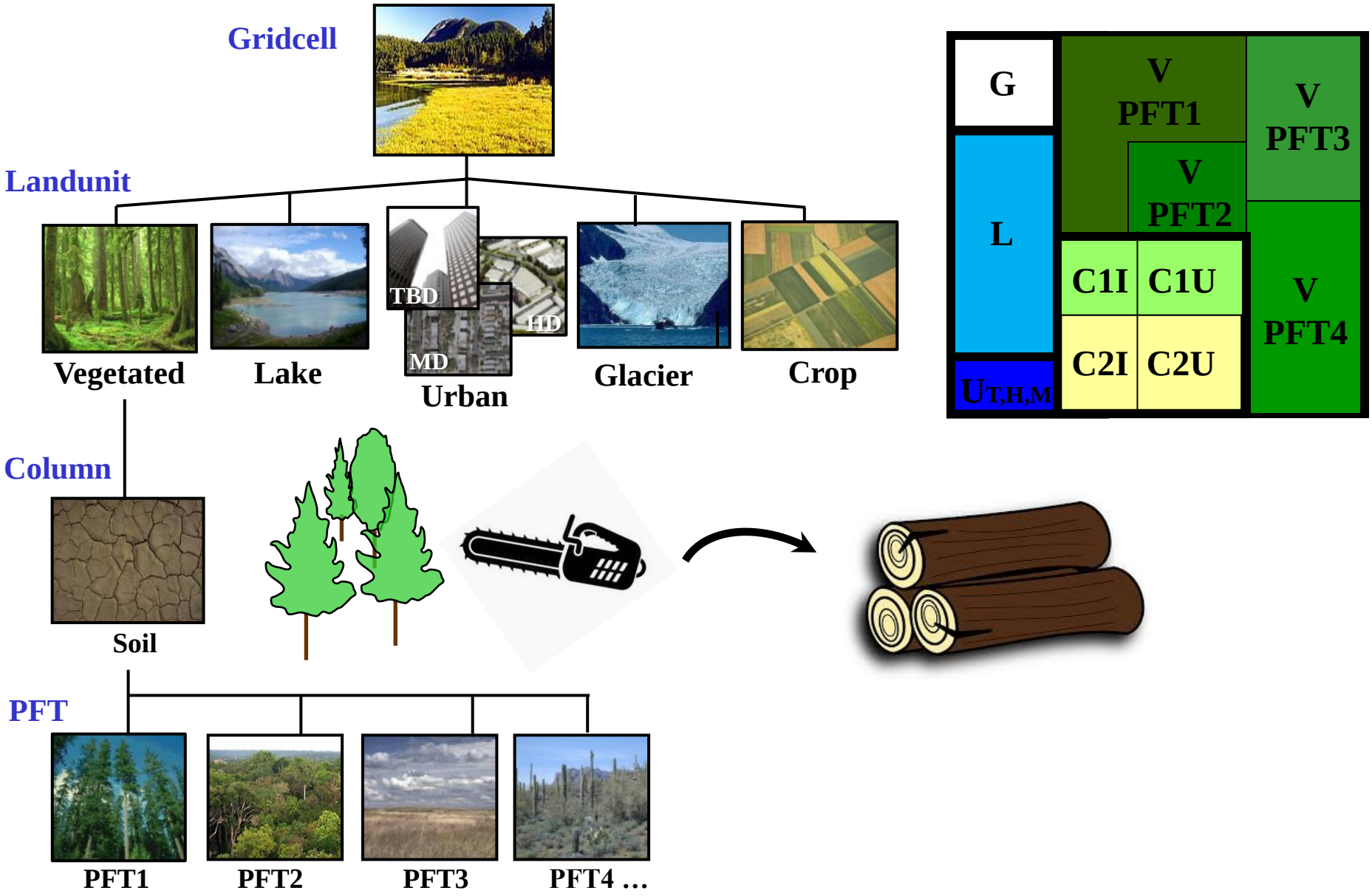
6. CLM5 Land Cover Change – Prescribed Annual Changes







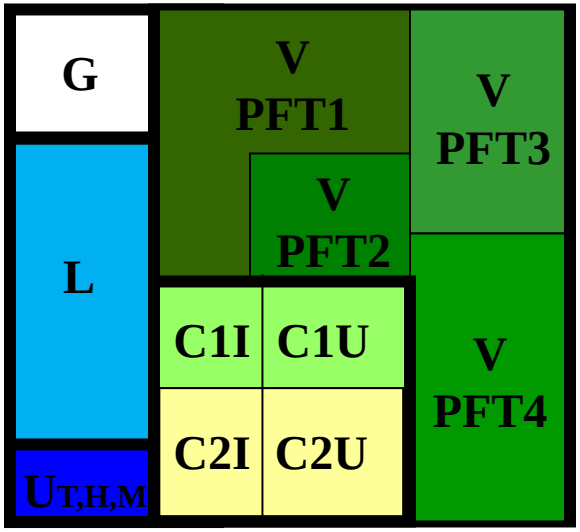
7. CLM5 Land Use – Prescribed Wood Harvest (biomass)



8. CLM5 Land Use – Crop Model Prescribed Management

Gridcell

CLM 5 LULCC for
Natural PFT and Crop



Landunit


Vegetated


Lake

Urban


Glacier


Crop

Crop Model

Planting


Leaf
emergence


Irrig /
Fertilize


Grain fill


Harvest


Unirrig


Irrig


Unirrig


Irrig

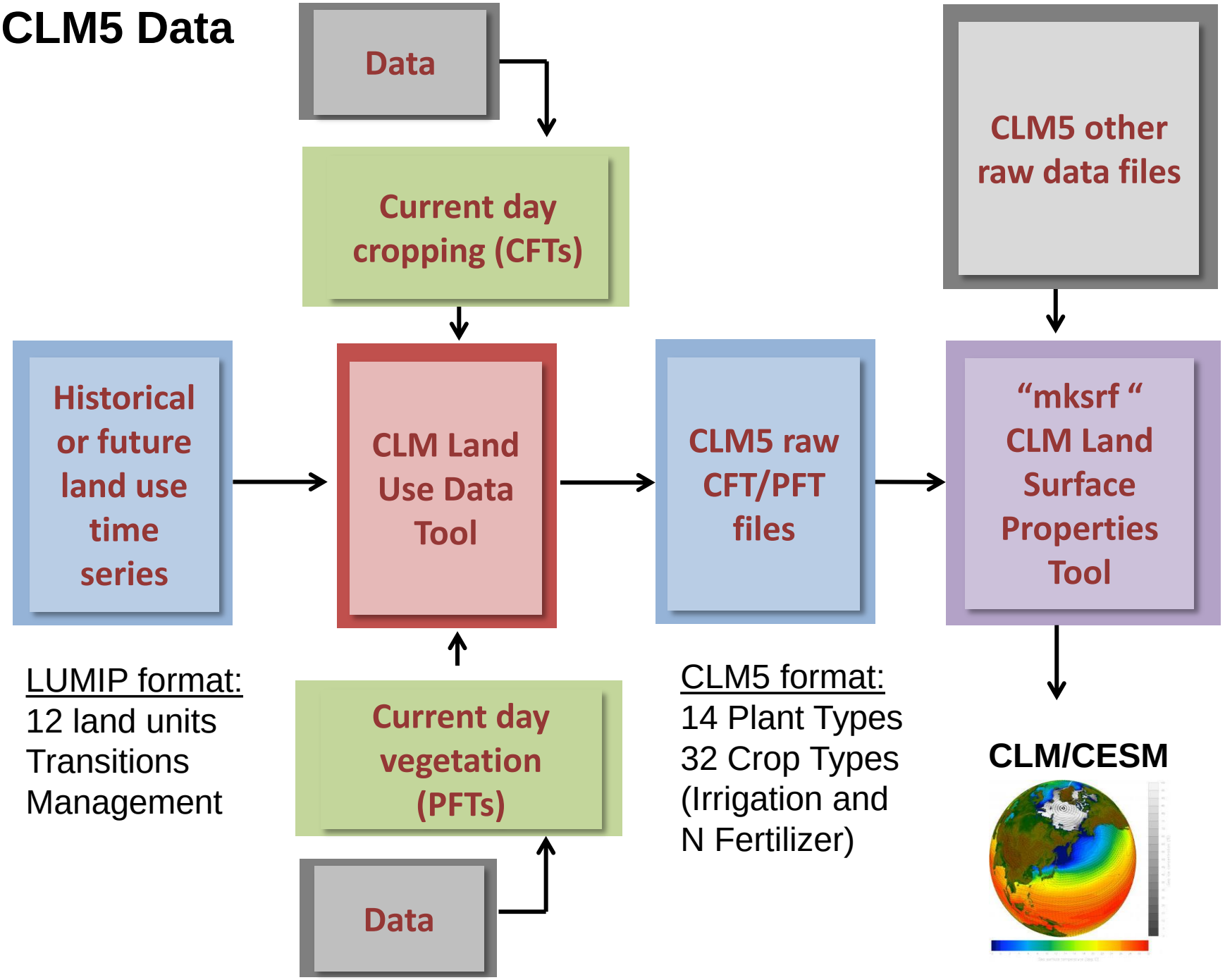

Crop1


Crop1


Crop2


Crop2 …

9. CLM5 Data


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:
14 Plant Types
32 Crop Types
(Irrigation and
N Fertilizer)
CLM/CESM
Data

10. CLM5 Carbon Cycle impacts of Land Use Land Cover Change

1. We can assess the Carbon Cycle responses of Land Use Land Cover Change (LULCC) in CLM5 for a given period under changing climate and CO_2.

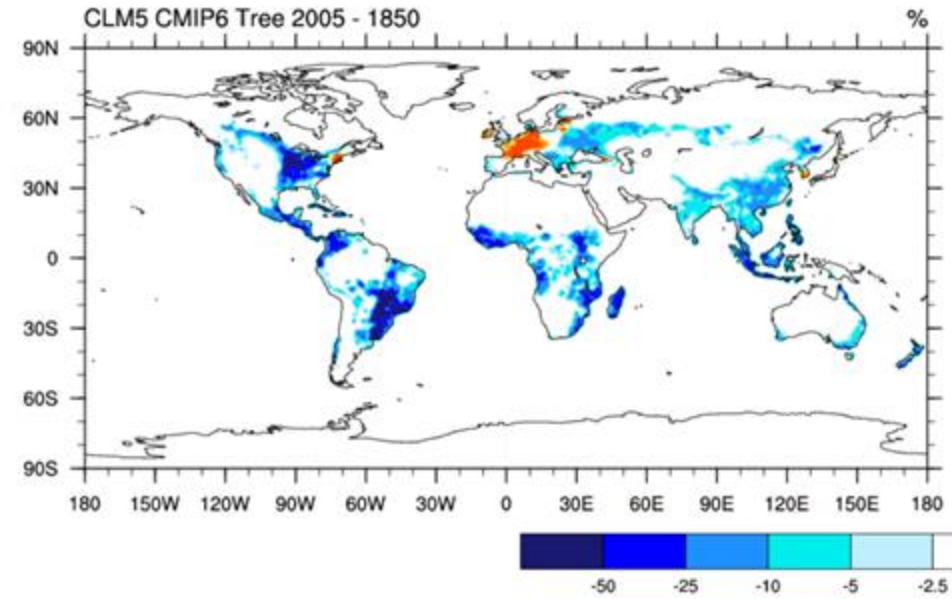
2. To do this we run CLM5 simulations with changing or transient LULCC compared to the same simulations performed without the LULCC.

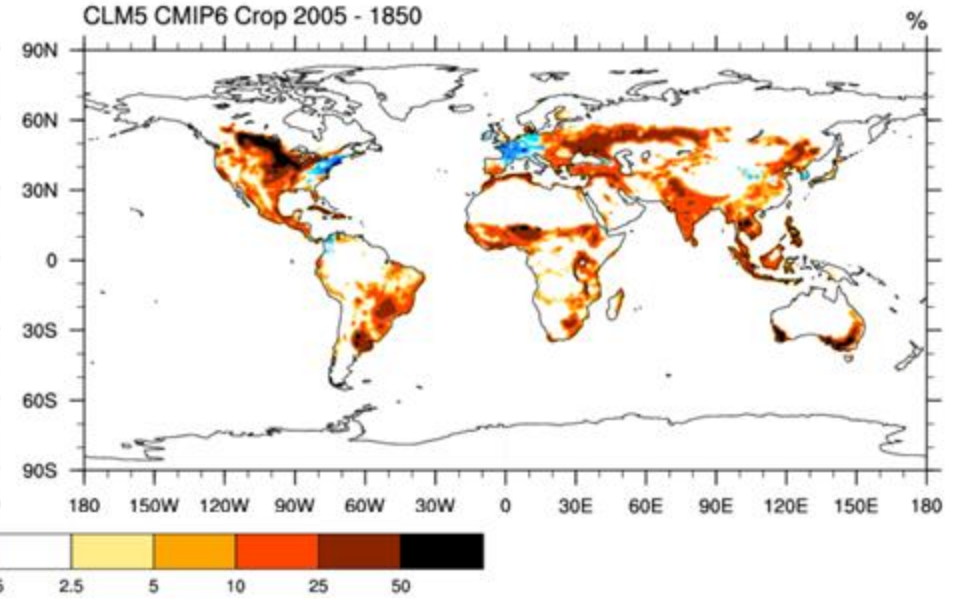
3. The CLM5 LULCC impacts are assessed through looking at differences between the simulations.

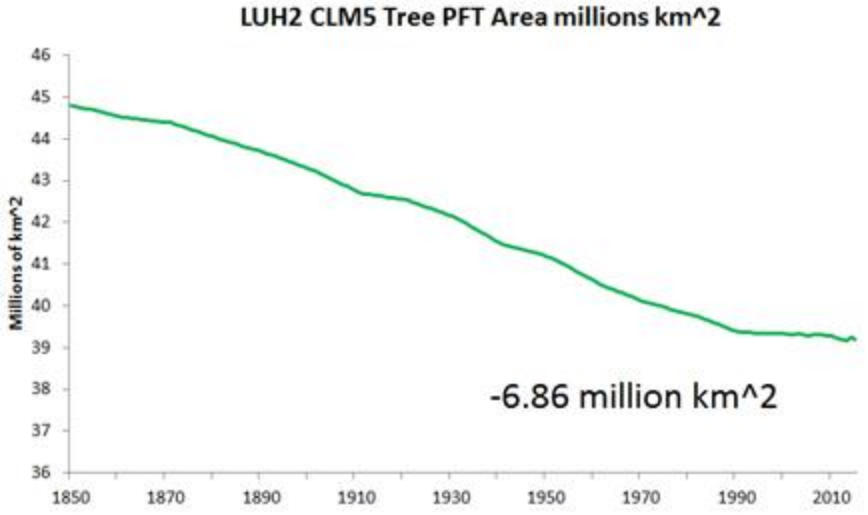
4. All experiments use 1850 – 2010 GSWP3 Prescribed Meteorology which has been shown to provide the best forcing and transient model response

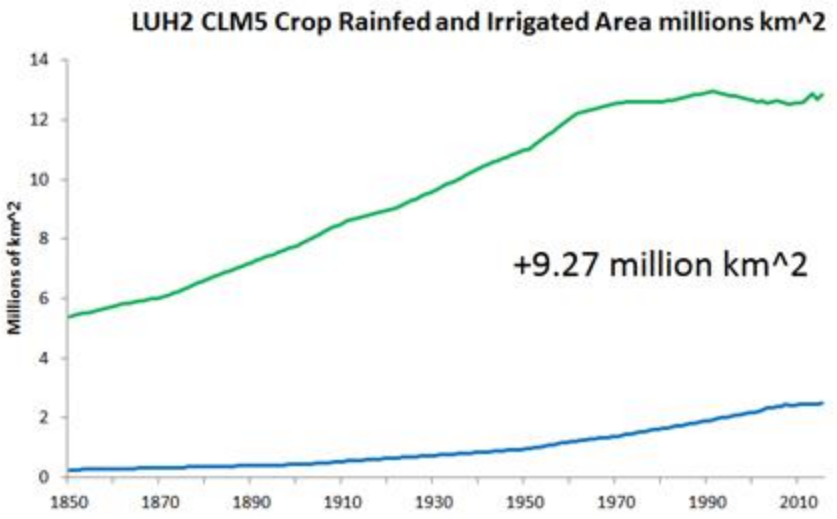
5. There are no larger scale climate feedbacks in these studies as Meteorology is prescribed.

11. CLM5 CMIP6/LUMIP Land Cover in 1850 – 2005

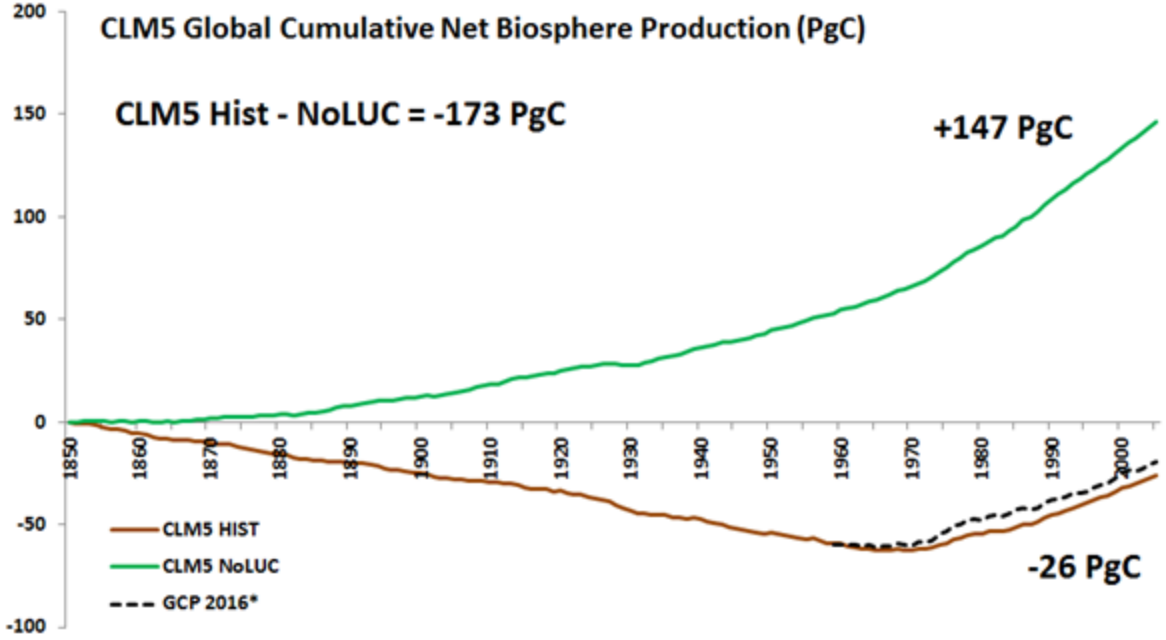








12. New CLM5 LUMIP LULCC vs no LULCC – NBP Carbon



CLM5 NoLUC had large uptake of carbon from CO_2 fertilization, Climate and N Deposition CLM5 +147 PgC

This is offset by LULCC in CLM5 = 173 PgC Global Estimates ~160 PgC

*Global Carbon Project Land Sink - LULCC 1959 – 2016

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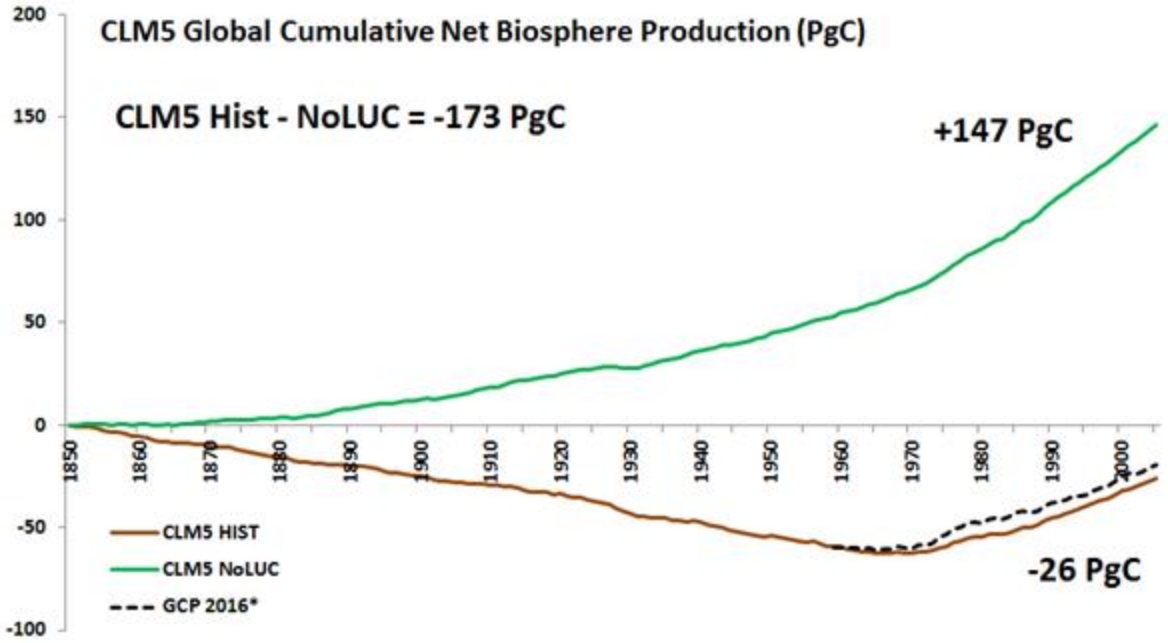

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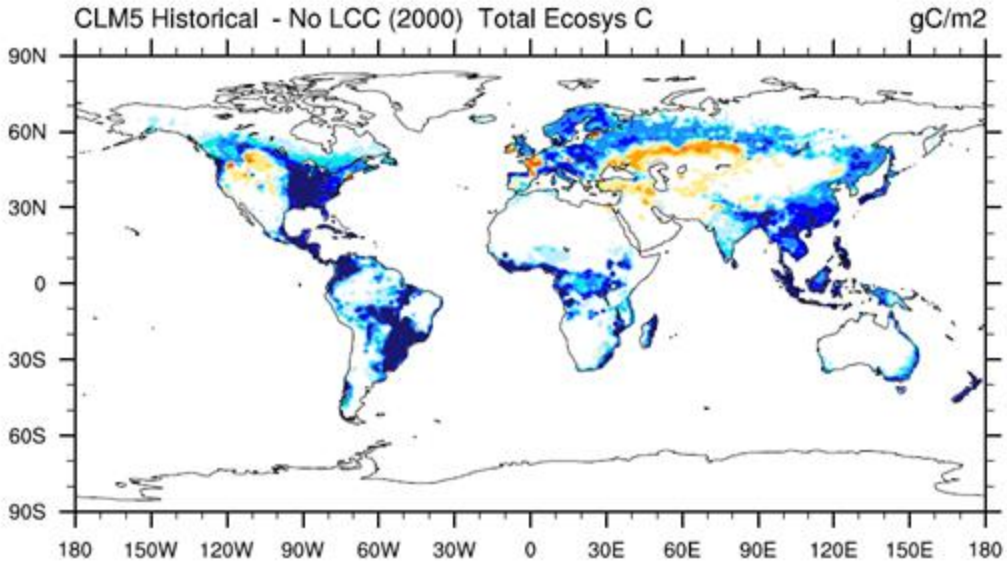
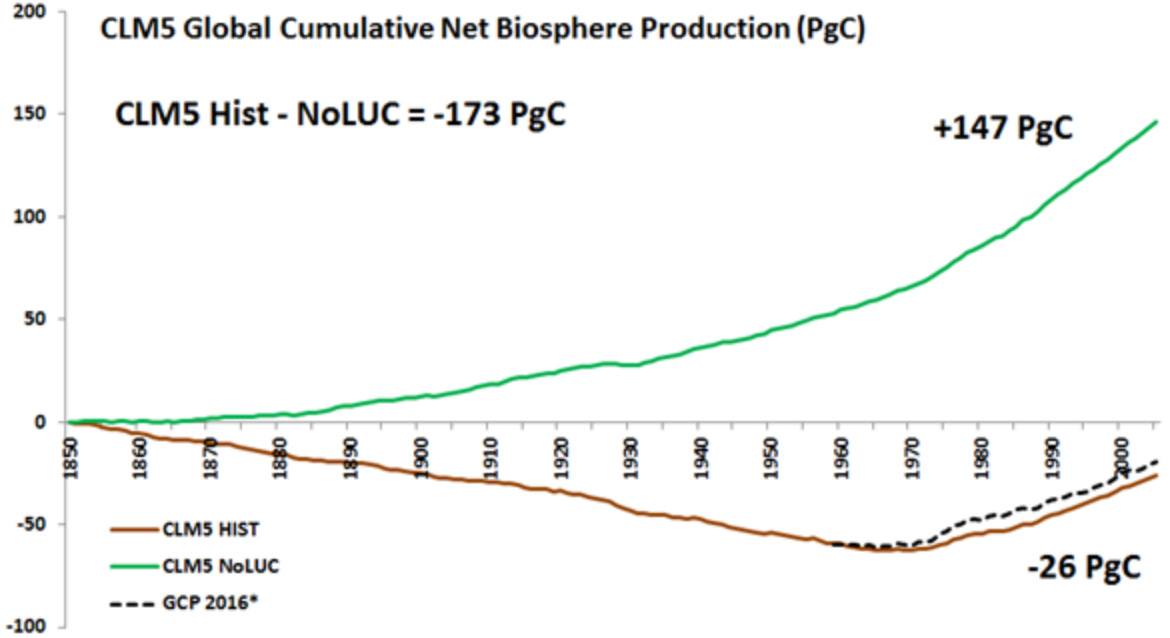
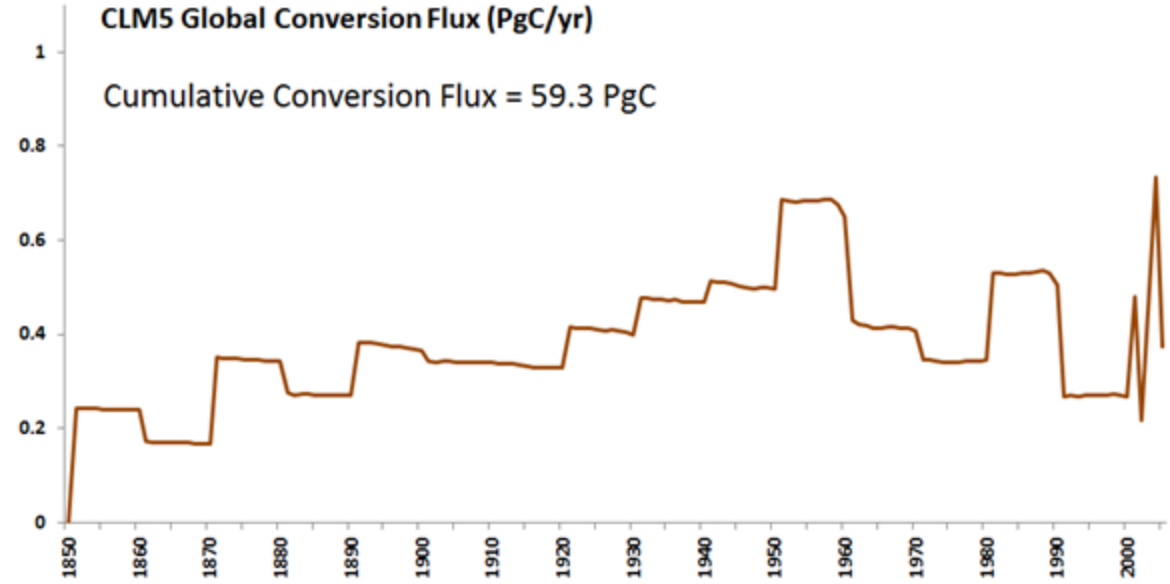
Land Sink - LULCC
1959 – 2016



14. New CLM5 LUMIP LULCC vs no LULCC – Conversion Flux





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CLM5 conversion of PFTs and CFTs results in a cumulative loss of 59.3 PgC

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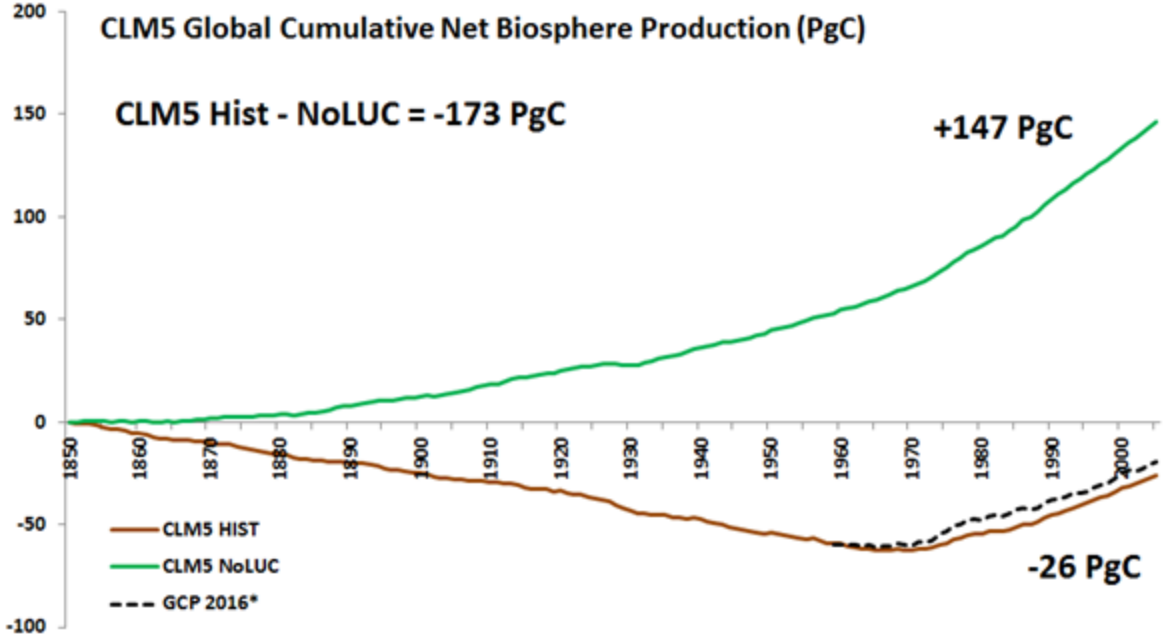

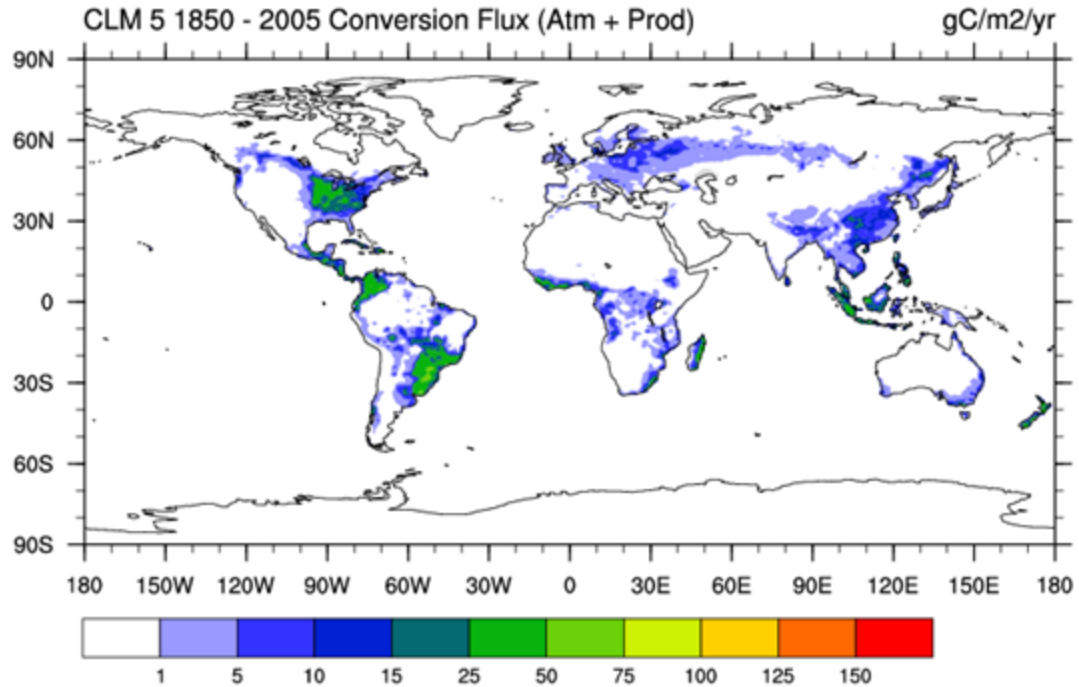

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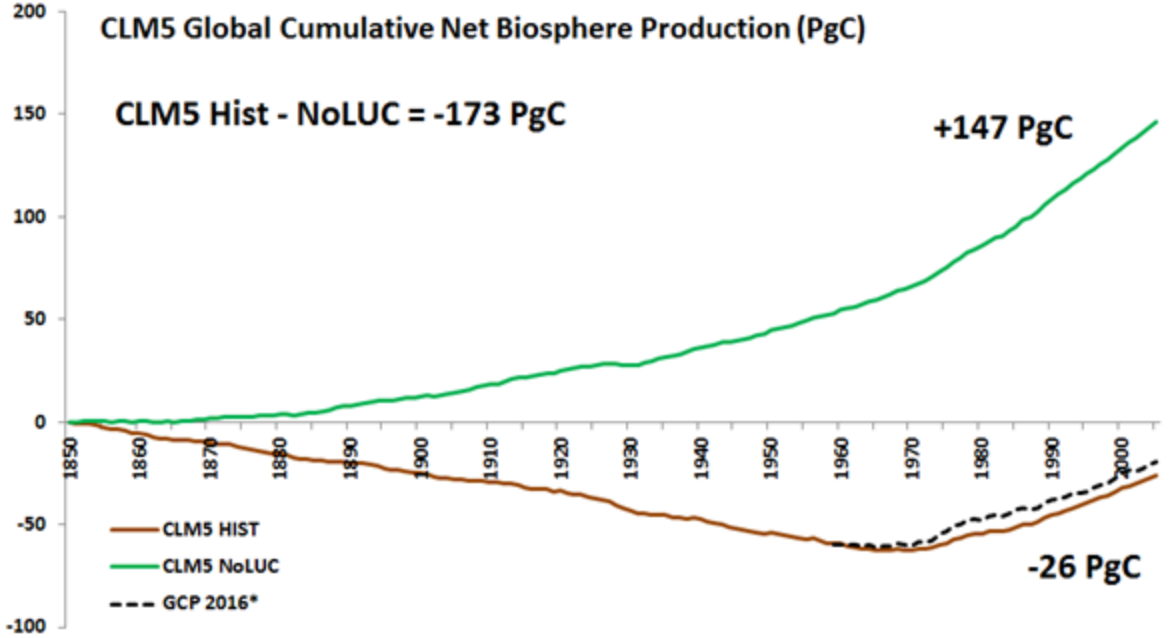
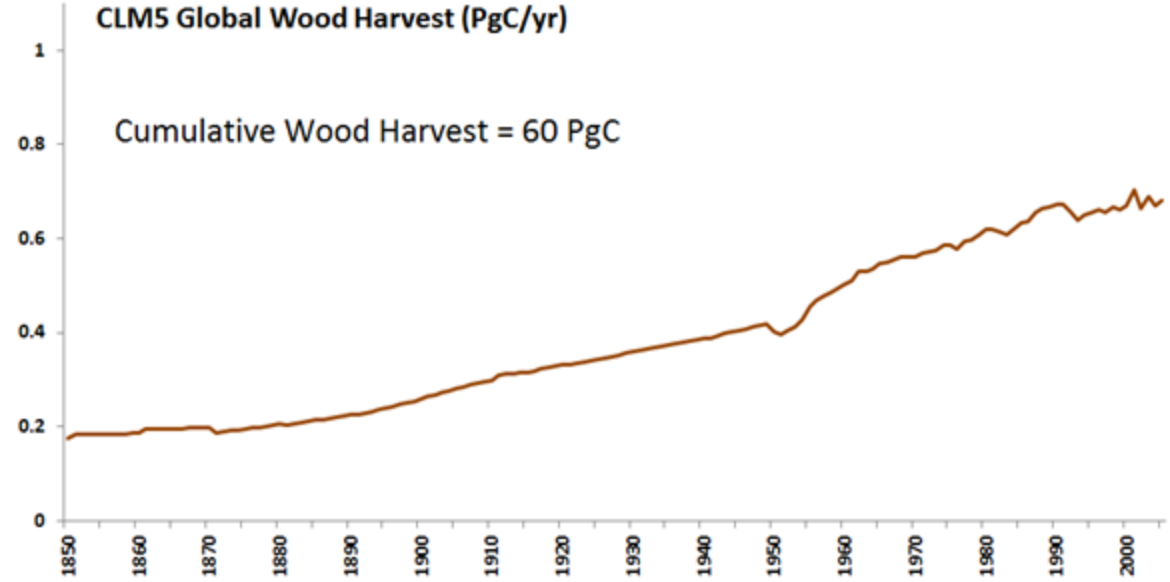
16. New CLM5 LUMIP LULCC vs no LULCC – Wood Harvest





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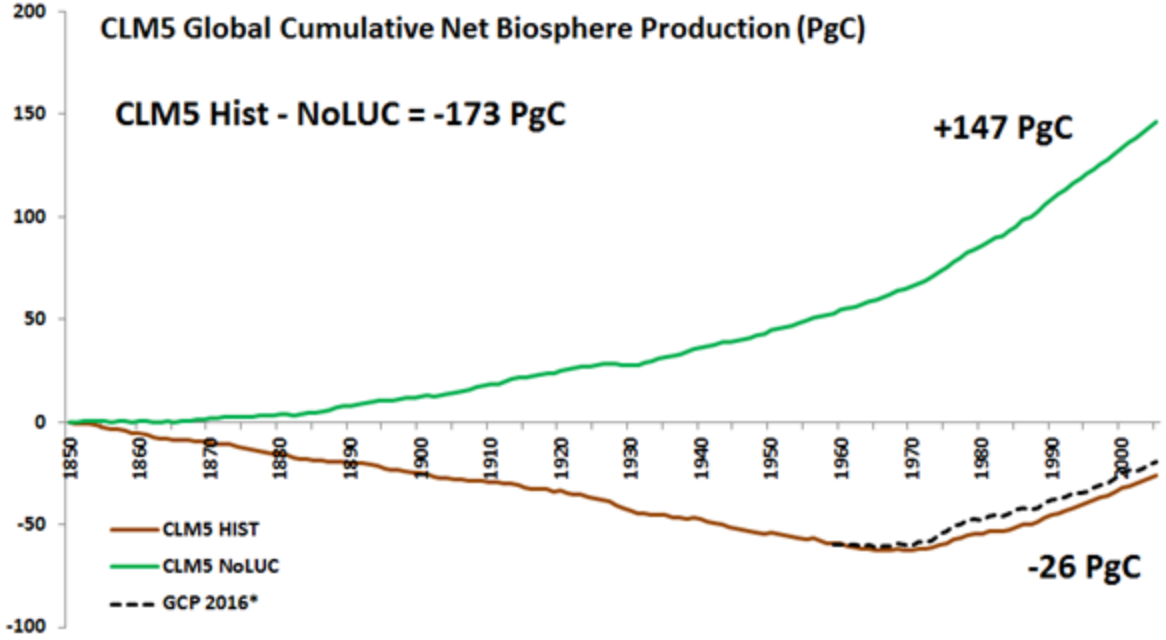

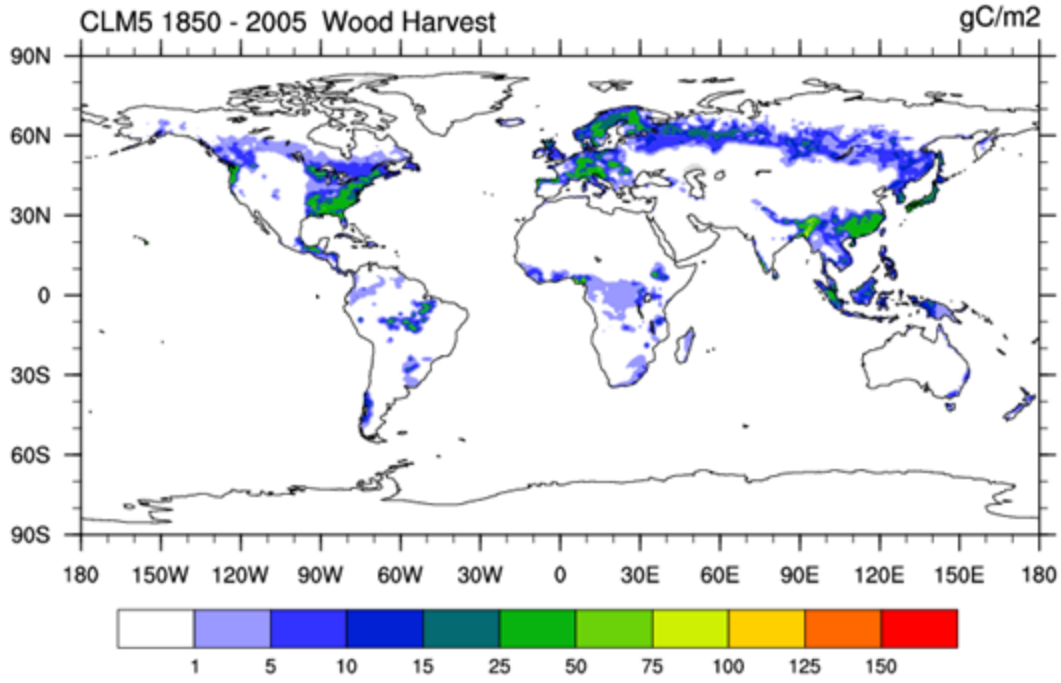

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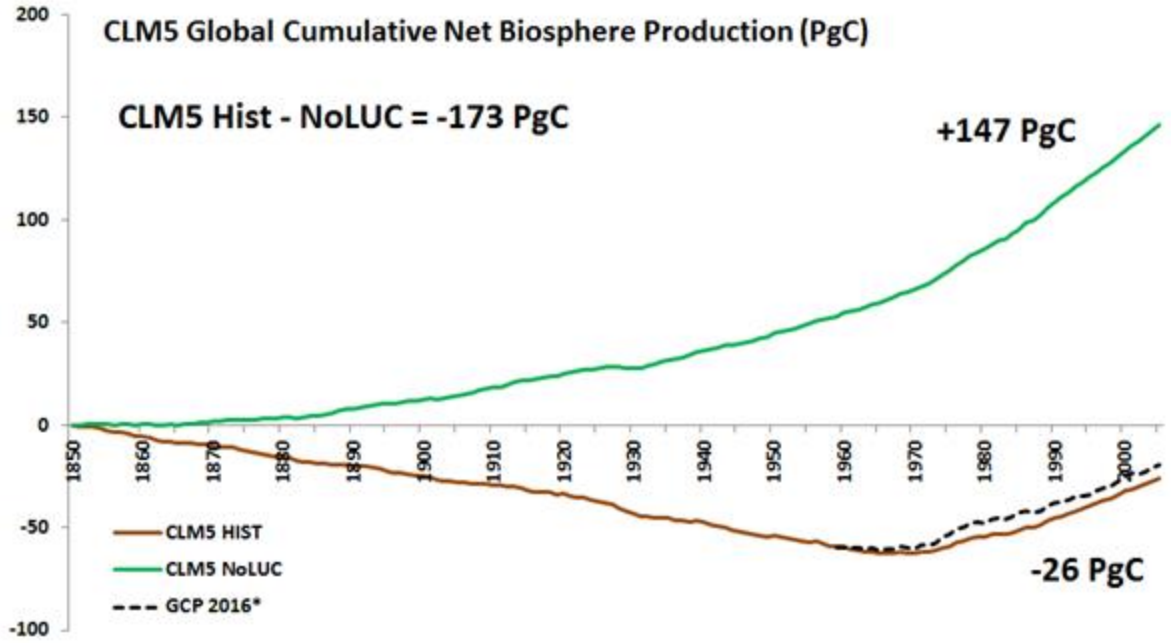
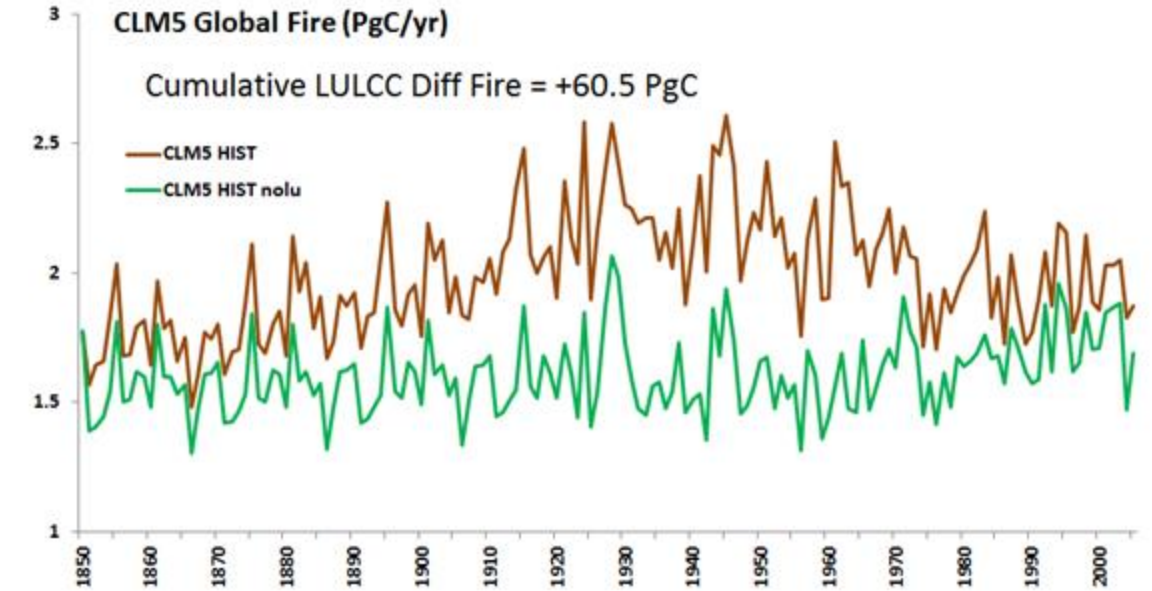
18. New CLM5 LUMIP LULCC vs no LULCC – Wildfire Flux





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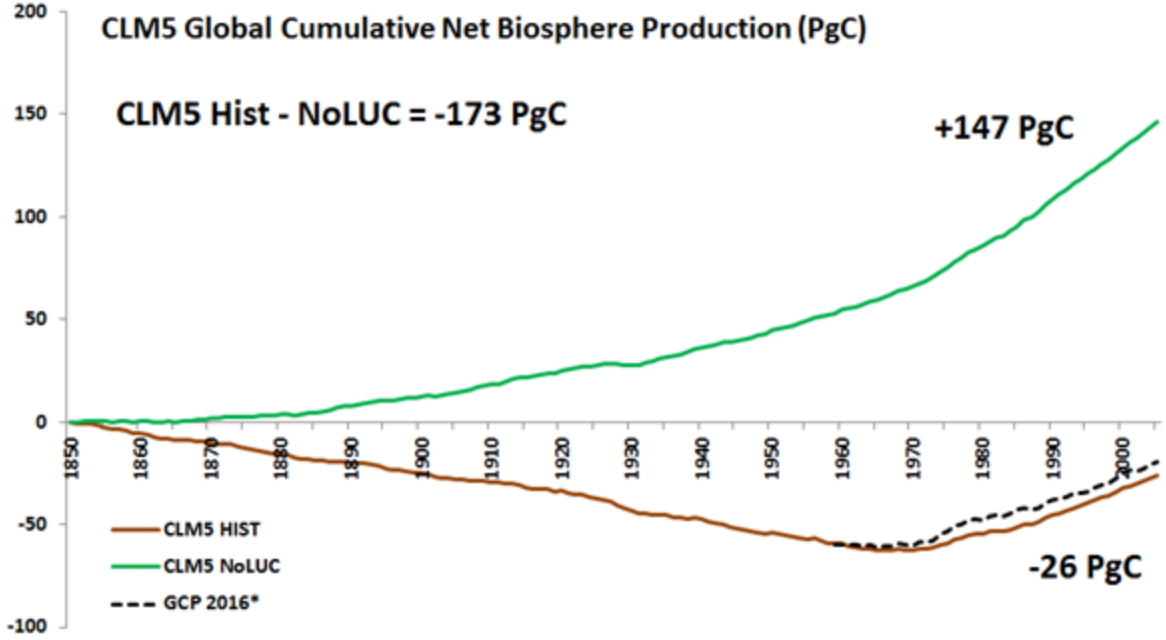
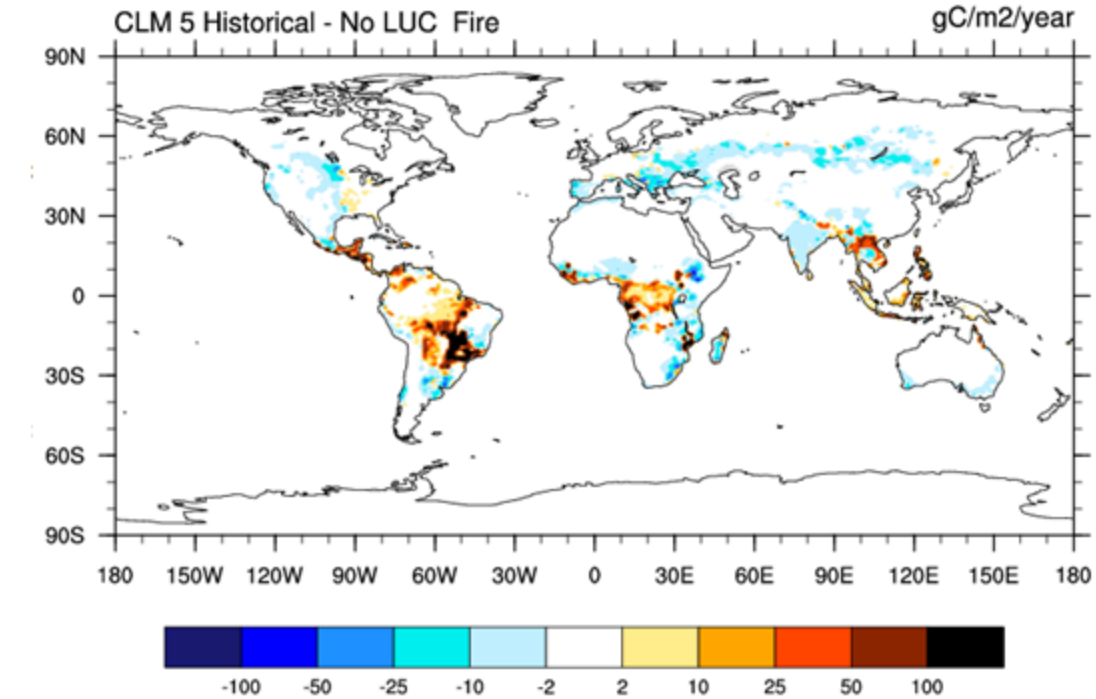
19. New CLM5 LUMIP LULCC vs no LULCC – Wildfire Flux





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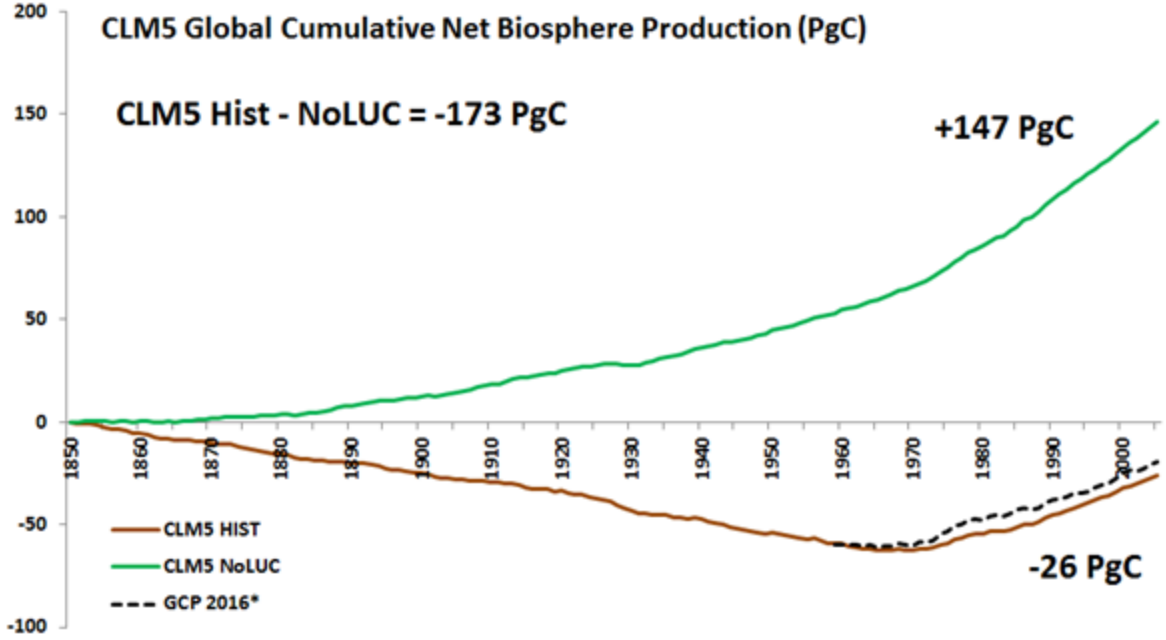
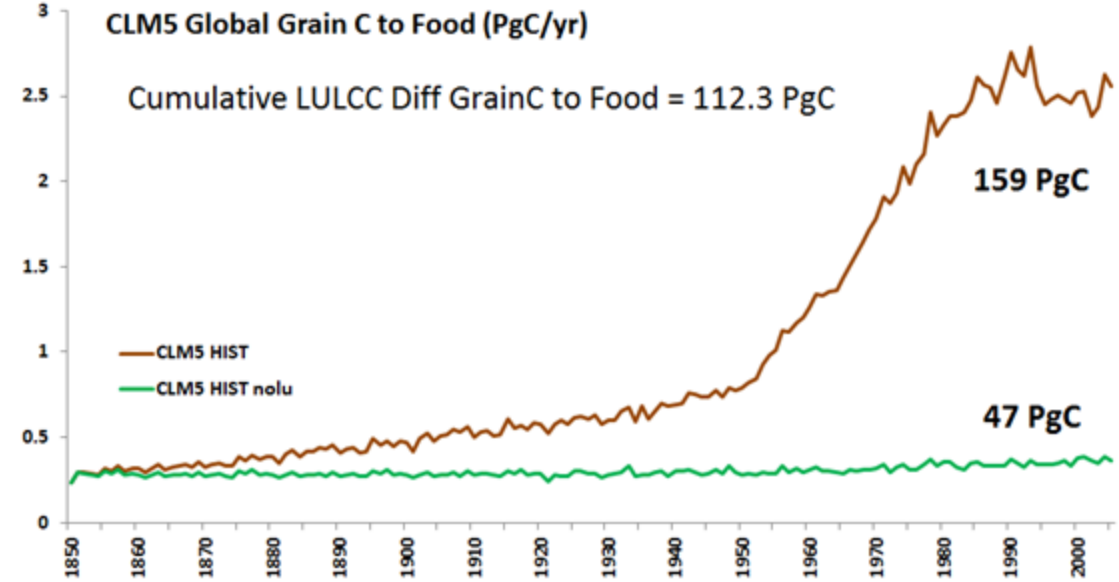
20. New CLM5 LUMIP – Crop Harvest Grain Carbon





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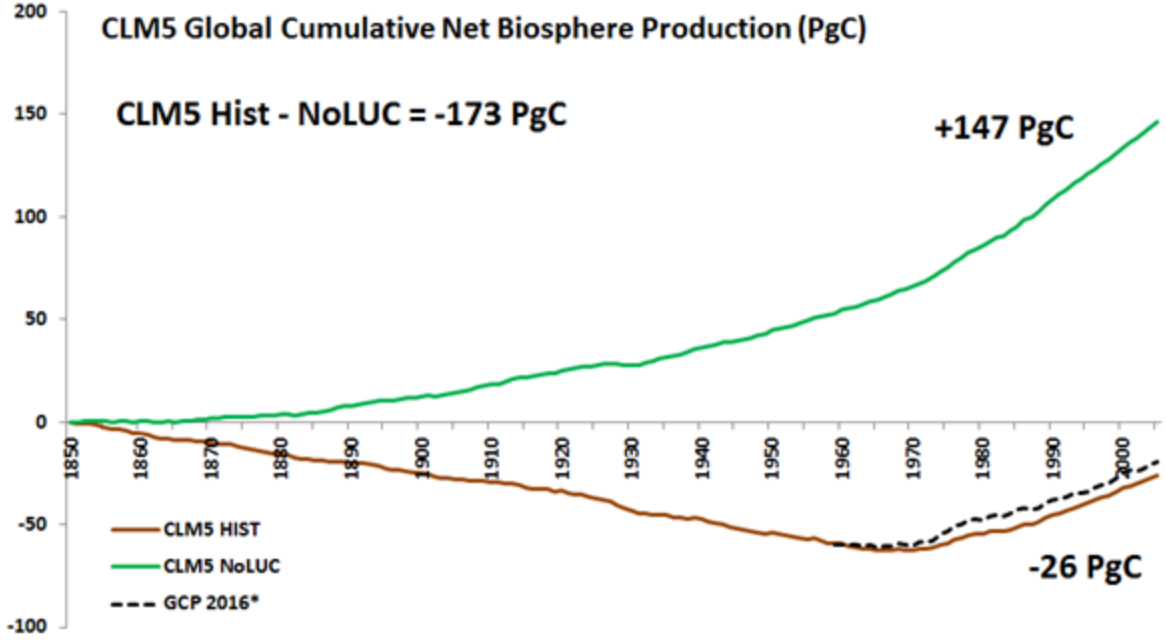
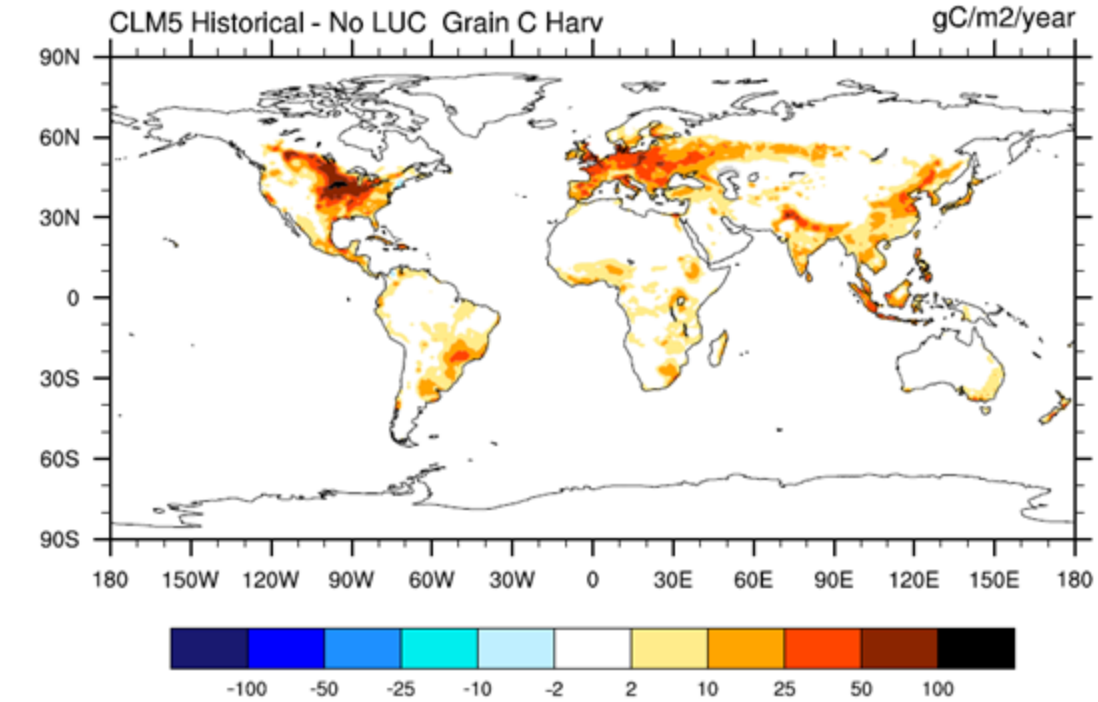
CLM5 LULCC results in large crop harvest flux out of the land of 159 PgC

Much of the crop harvest flux is offset in the LULCC simulation by higher NPP from fertilizer and lower heterotrophic respiration (organic matter decay) from harvest and residue management.

21. New CLM5 LUMIP – Crop Harvest Grain Carbon





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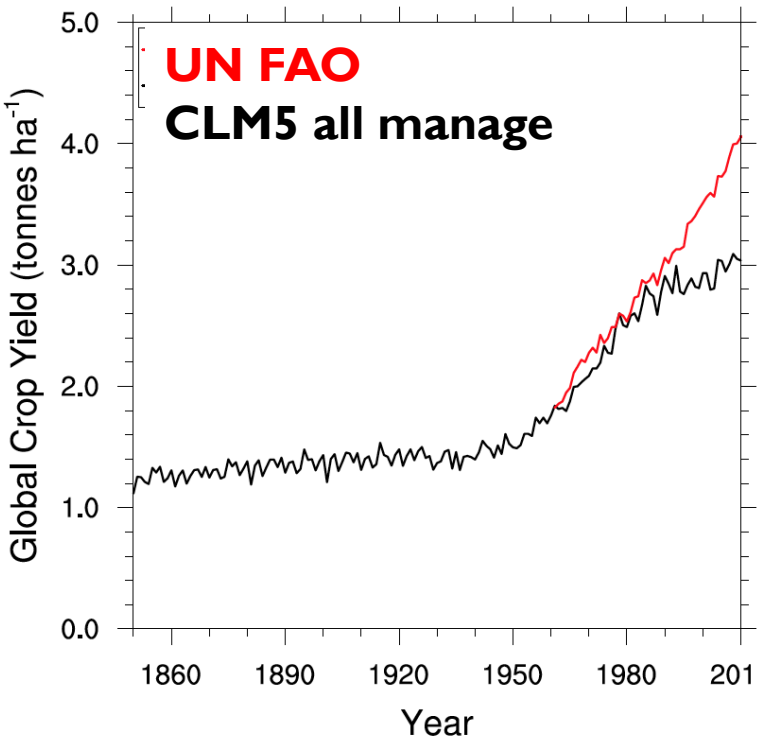
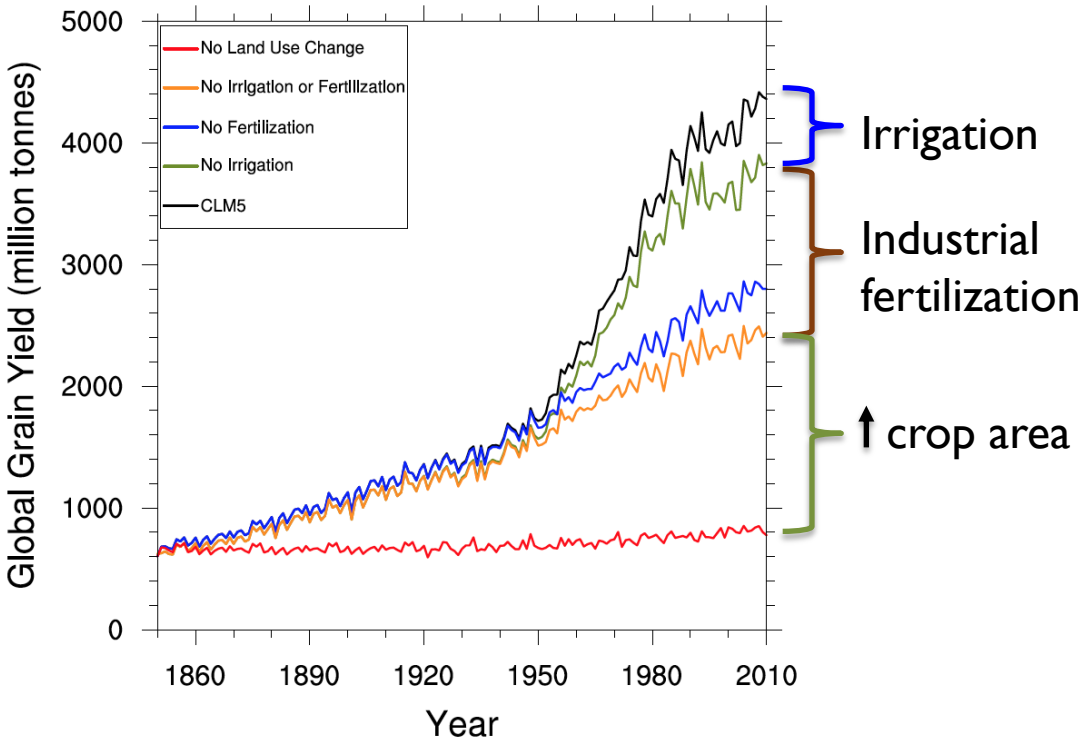
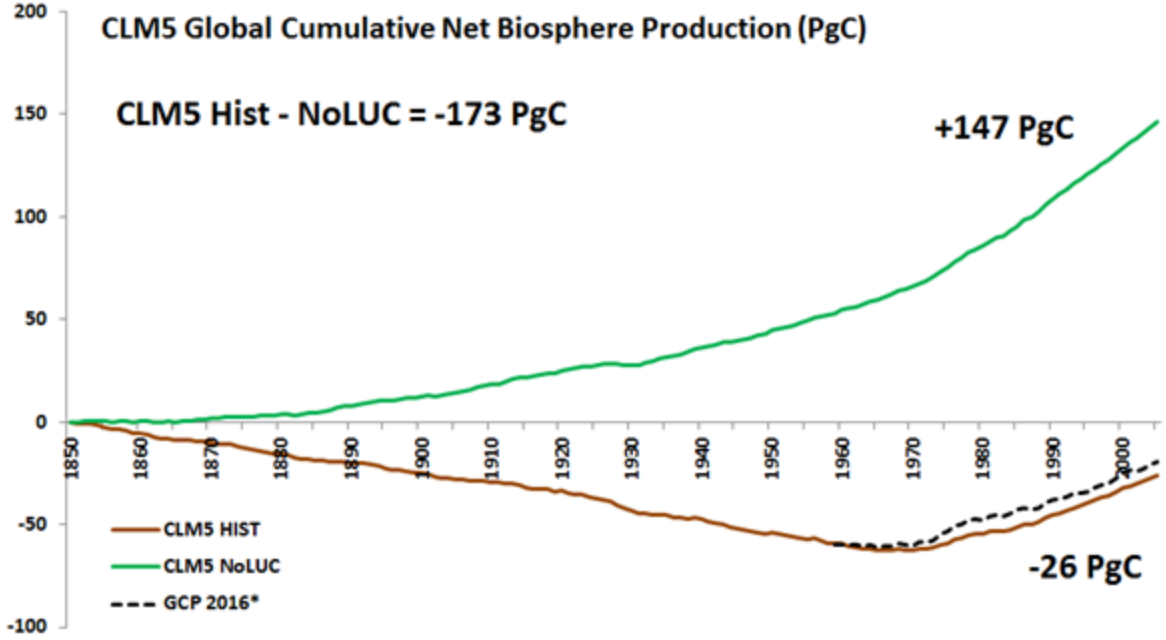
22. New CLM5 LUMIP – Crop Harvest Grain Food

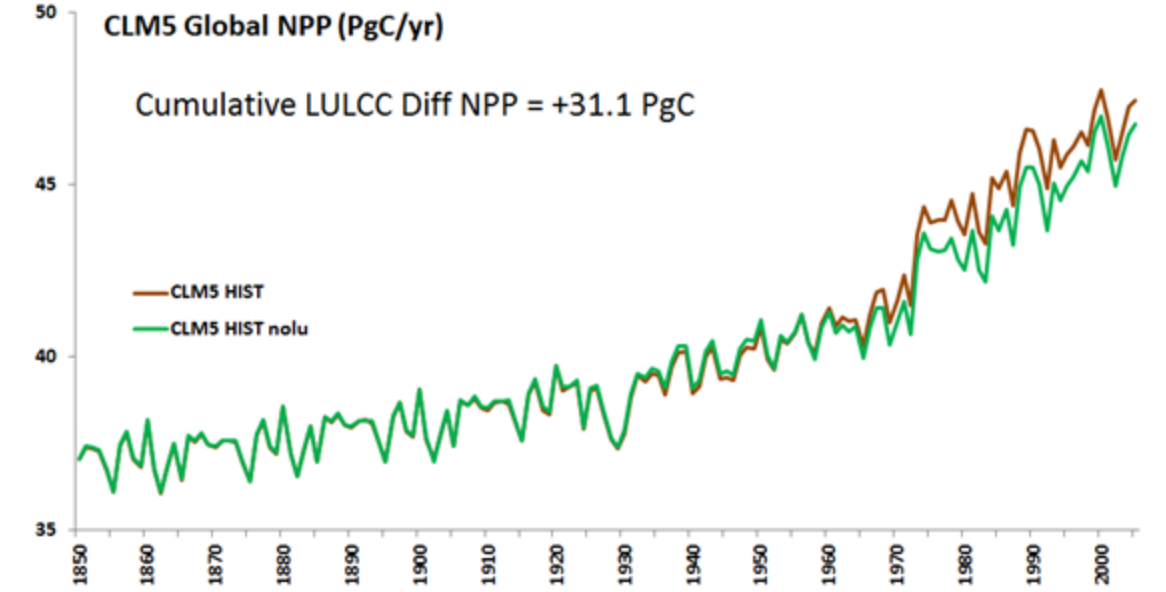
Crop Yield





23. New CLM5 LUMIP LULCC vs no LULCC – NPP





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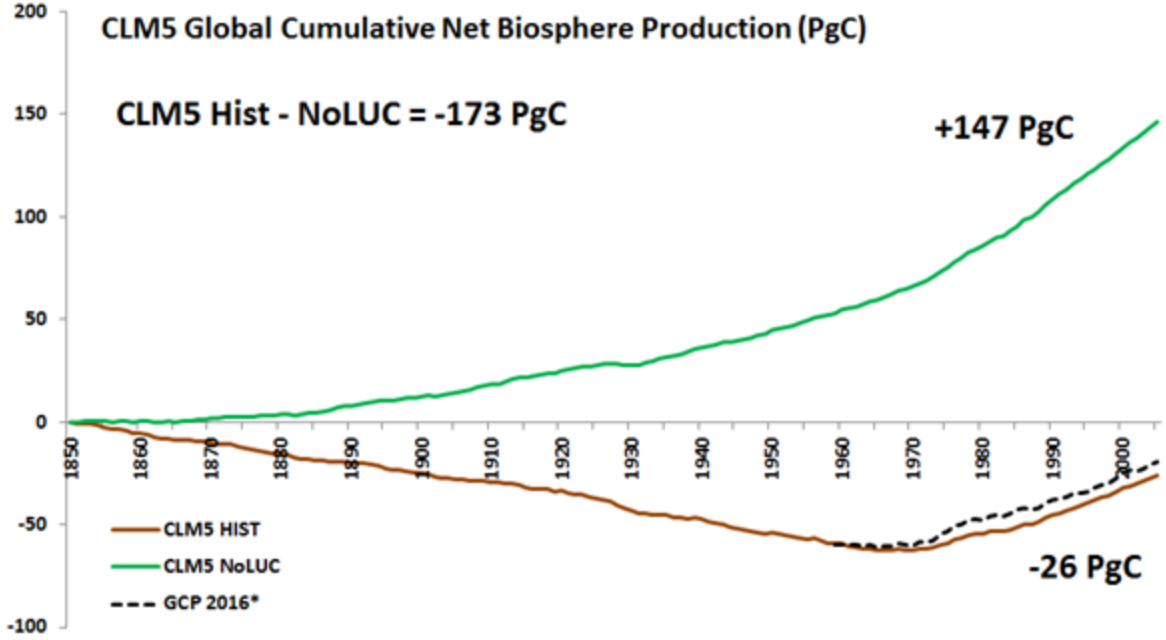
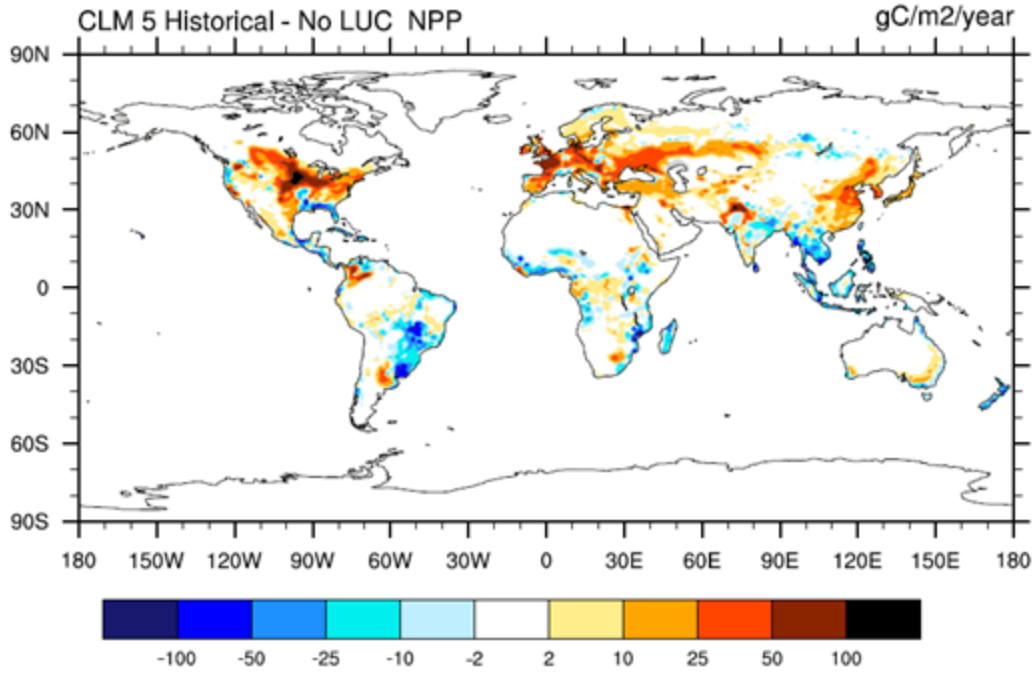
CLM5 LULCC results in Increased Net Primary Productivity uptake of carbon by the land of +31 PgC

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

24. New CLM5 LUMIP LULCC vs no LULCC – NPP





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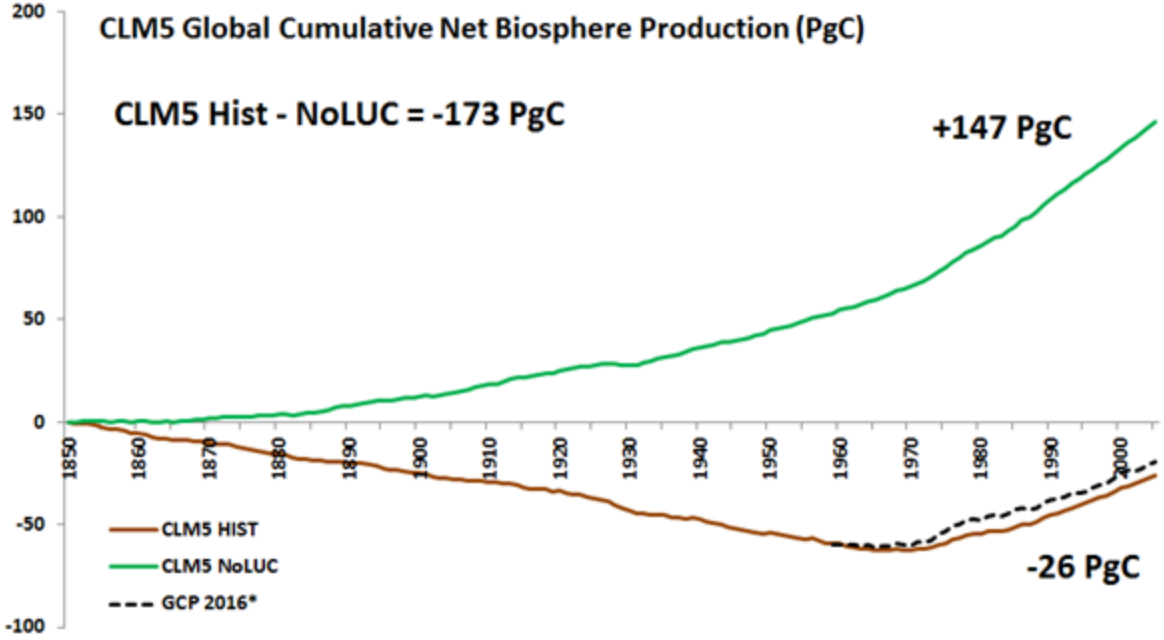
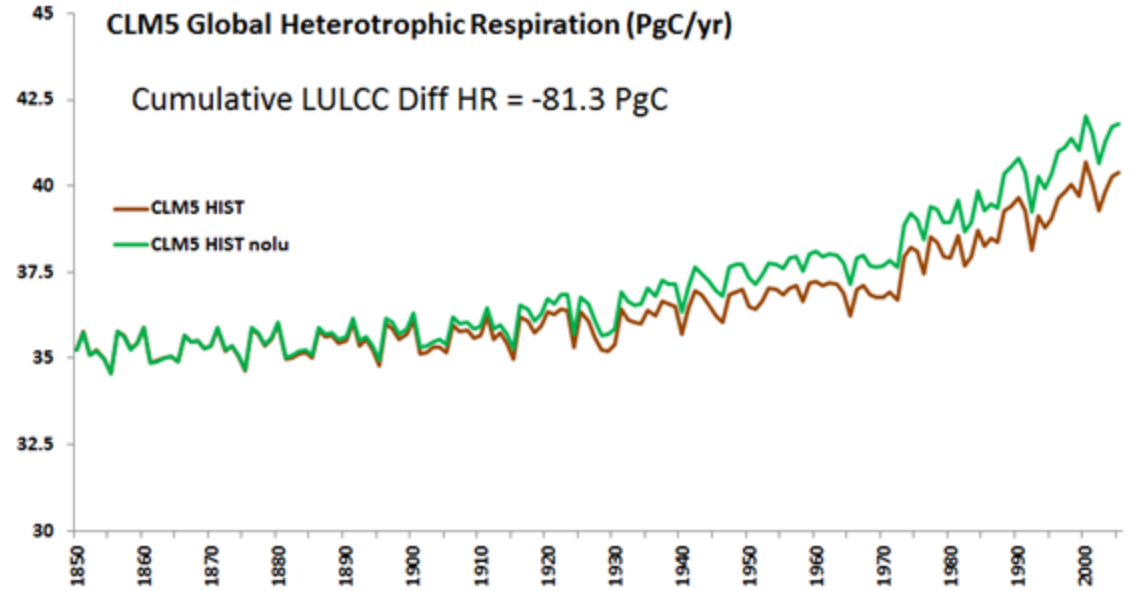
25. New CLM5 LUMIP LULCC vs no LULCC – Het. Respiration





CLM5 NoLUC had large uptake of carbon from CO_2 fertilization, Climate and N Deposition CLM5 +147 PgC

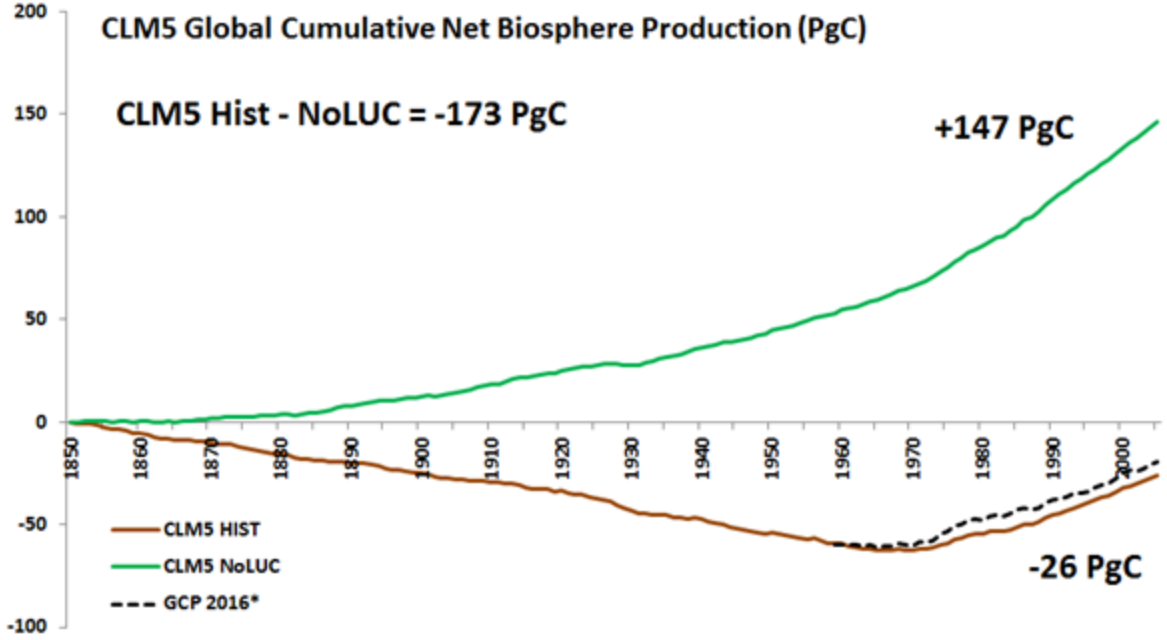
This is offset by LULCC in CLM5 = 173 PgC Global Estimates ~160 PgC

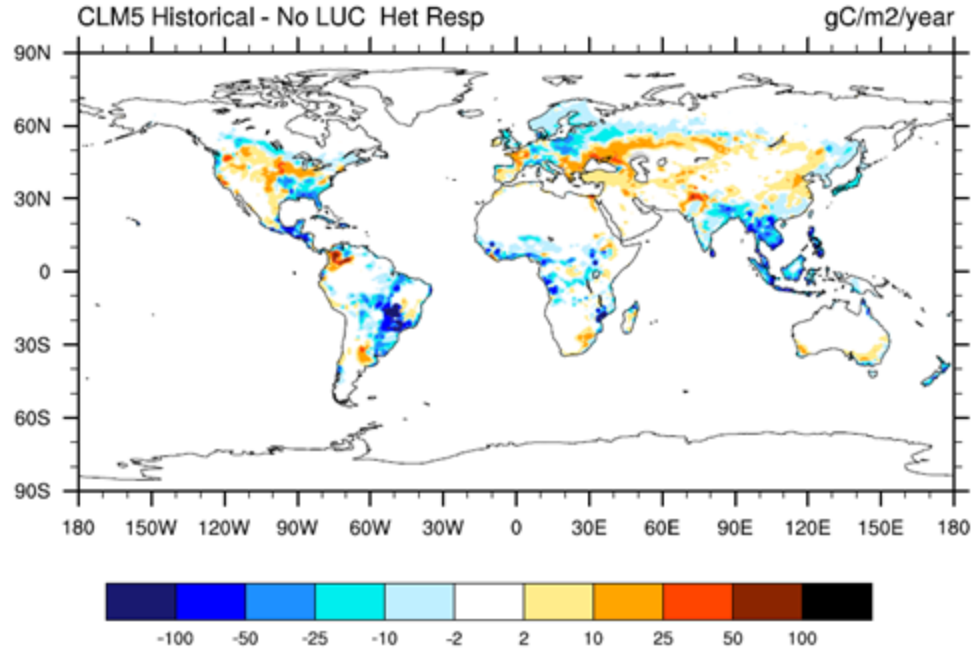
*Global Carbon Project Land Sink - LULCC 1959 – 2016

CLM5 LULCC results in Reduced Heterotrophic Respiration loss of carbon by -81.3 PgC

CLM5 LULCC deforestation, crop harvest and fire changes result in less litter, coarse woody debris and soil carbon to decay

26. New CLM5 LUMIP LULCC vs no LULCC – Het. Respiration





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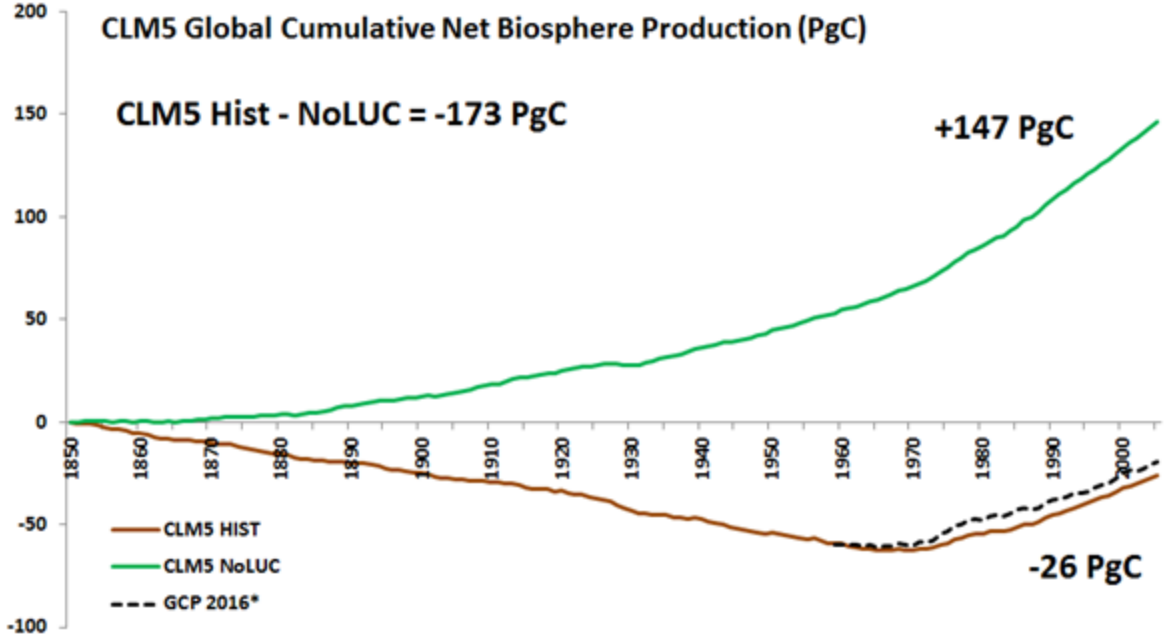
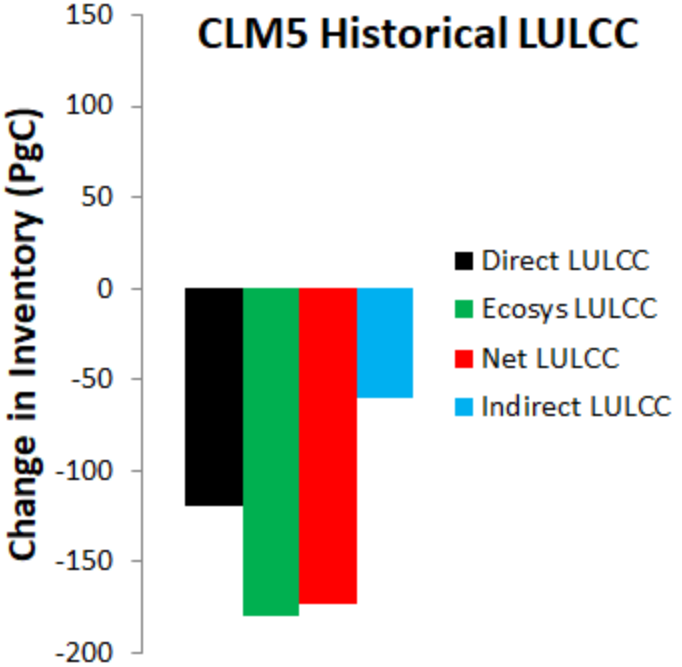
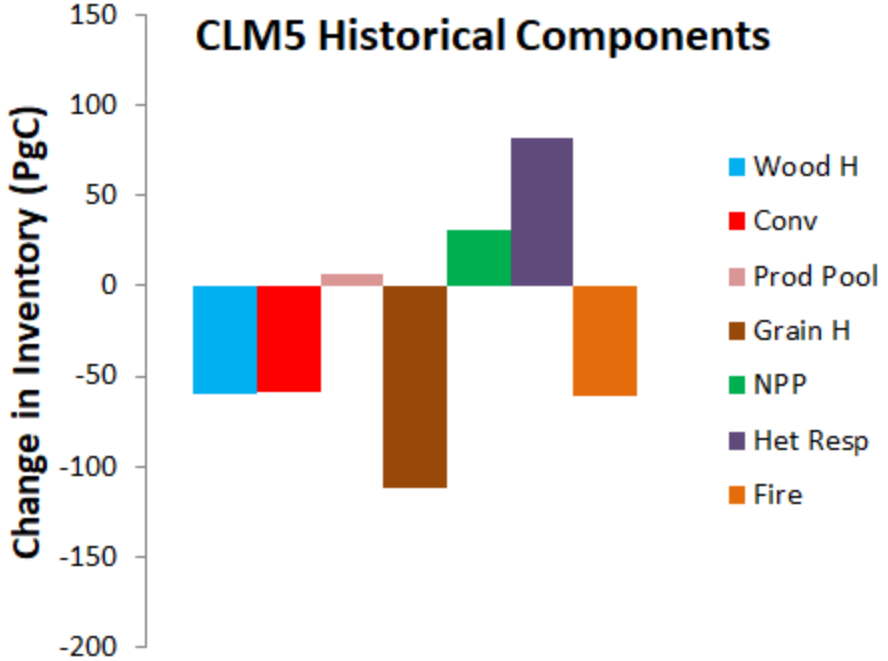
CLM5 LULCC results in Reduced Heterotrophic Respiration loss of carbon by -81.3 PgC

CLM5 LULCC deforestation, crop harvest and fire changes result in less litter, coarse woody debris and soil carbon to decay

27. New CLM5 LUMIP LULCC vs no LULCC – Cumulative

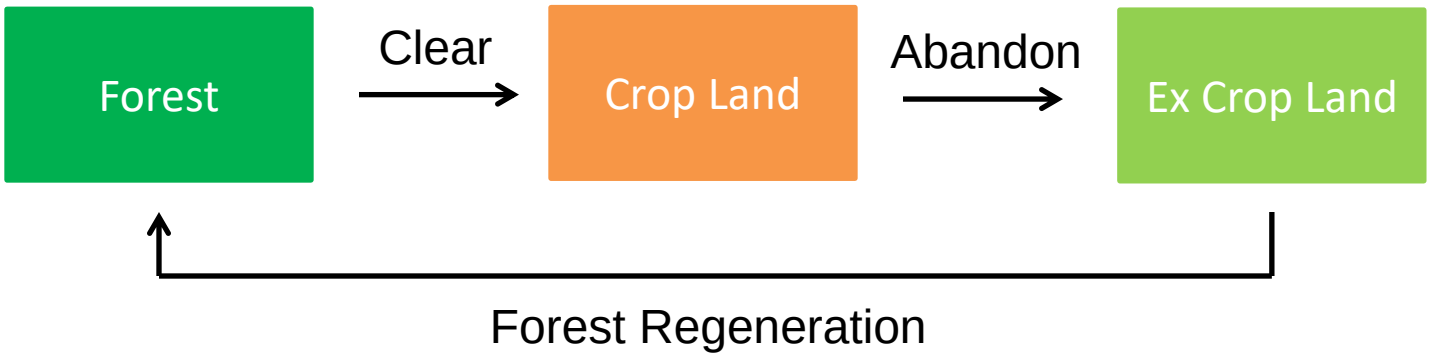






28. CMIP6 – CLM5 Carbon Cycle impacts of Shifting Cultivation

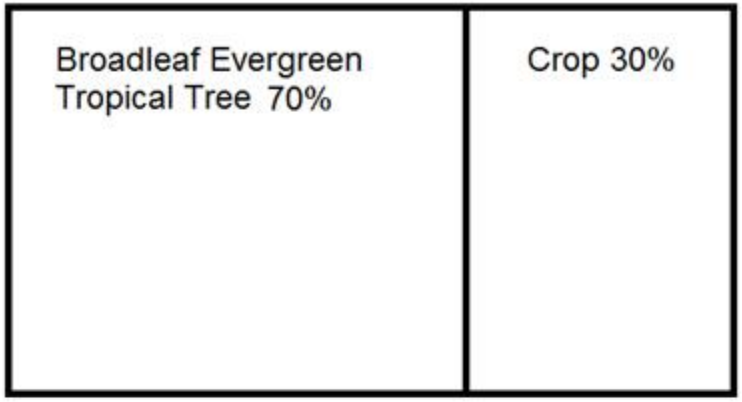
One element not included in the current CLM5 or CLM4 simulations is the impact of Shifting Cultivation.



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.

29. 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%

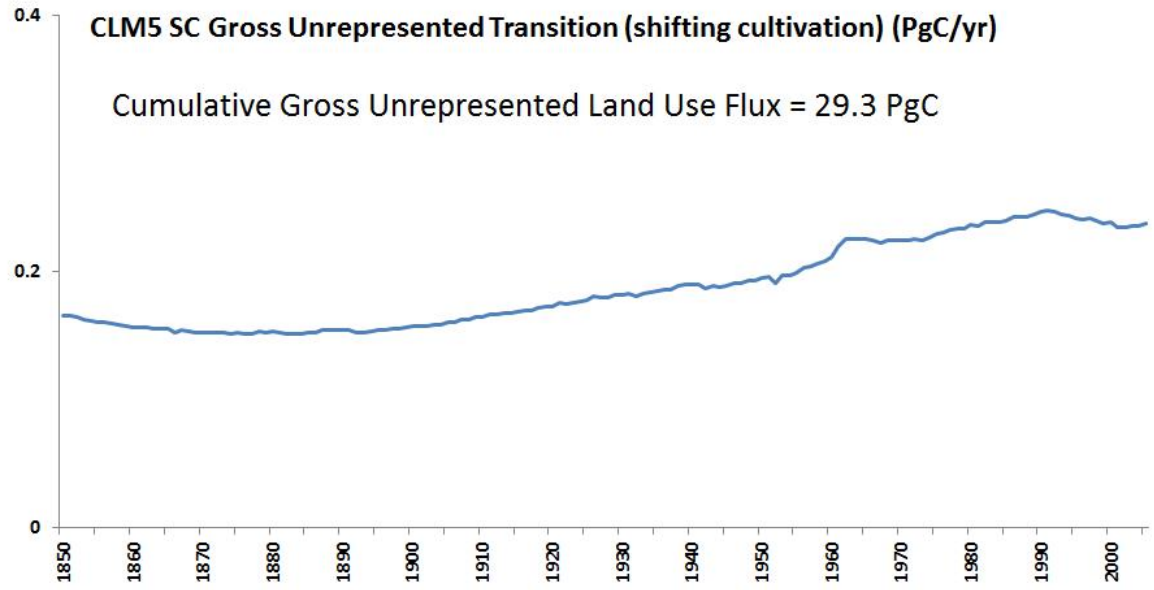
Net Transitions:
0% Change

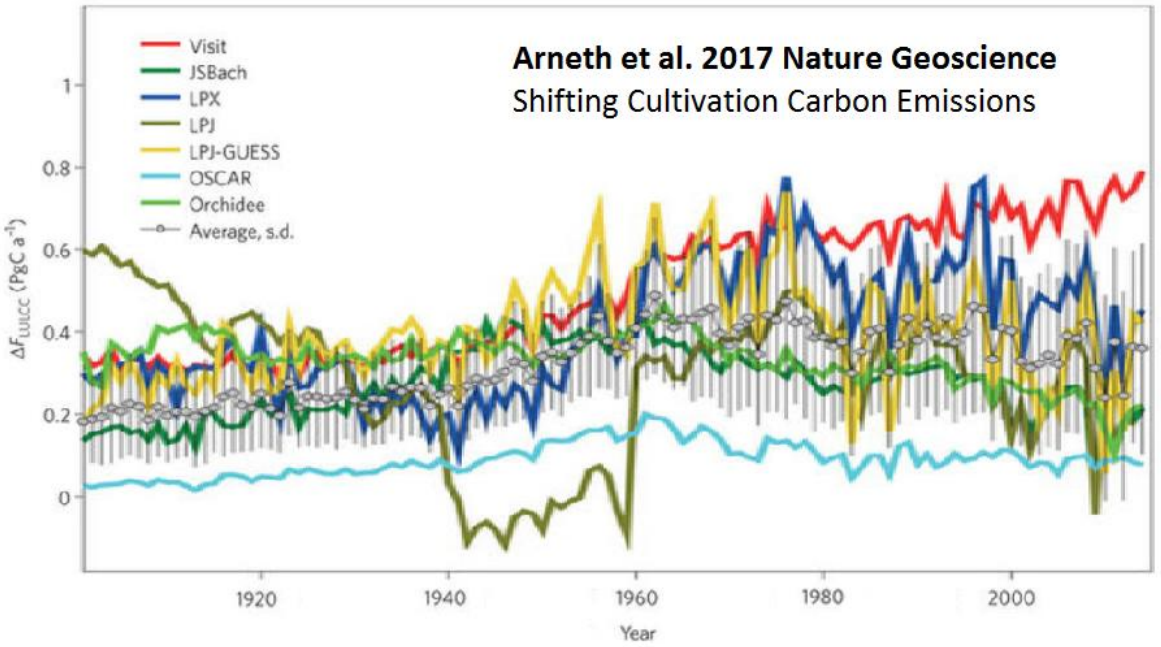
Unrepresented Gross Transitions:
BET 20% Crop 20%

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

30. CLM5 – SC – Gross Unrepresented Land Use Carbon



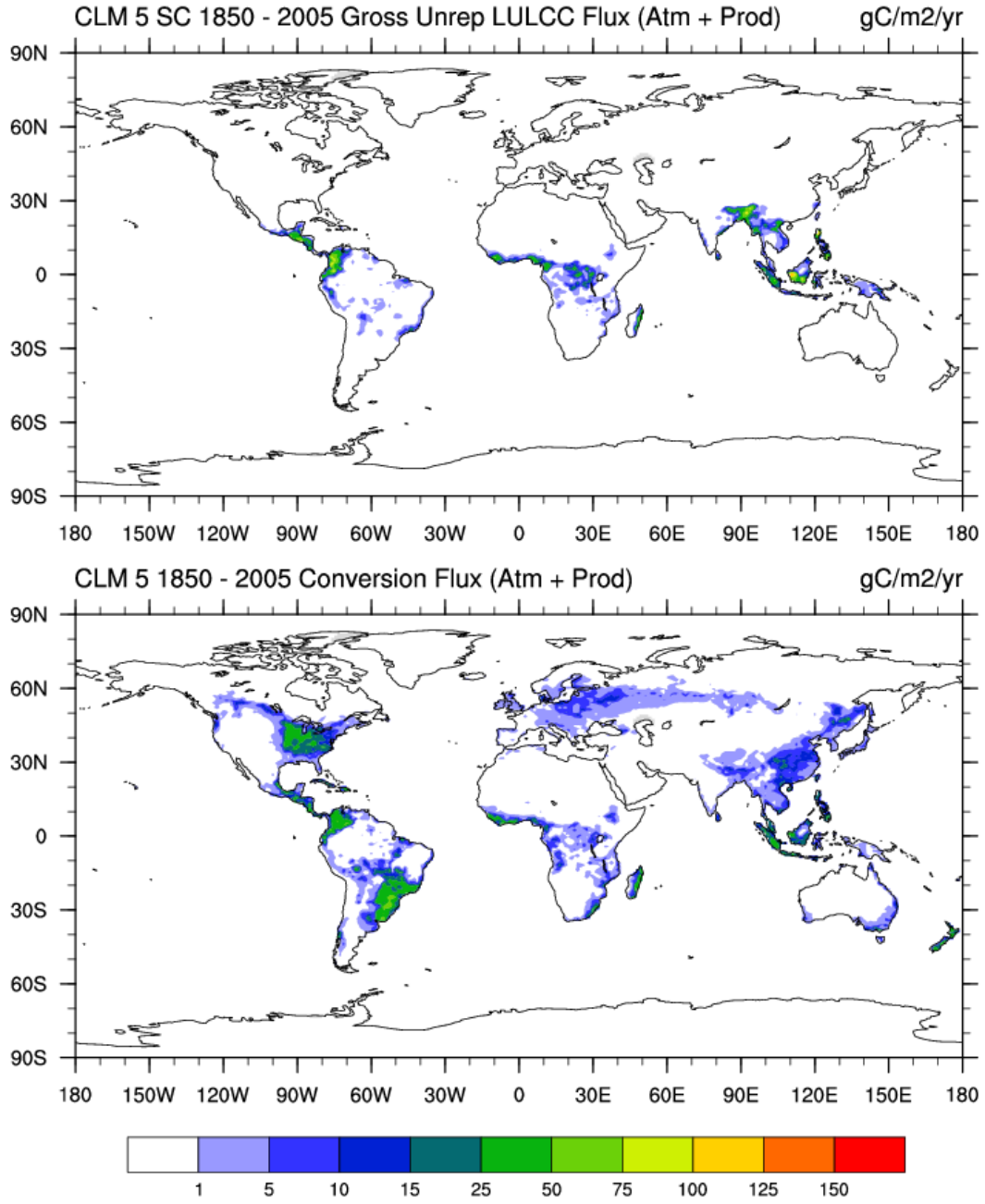


CLM5 SC Gross Unrepresented Land Use Flux results in a cumulative loss of 29.3 PgC

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.

31. CLM5 – SC – Gross Unrepresented Land Use Carbon



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 59.3 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.

32. New CLM5 LUMIP LULCC vs no LULCC – Cumulative