

Land Cover Change in CLM4

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Climate and Global Dynamics Division**

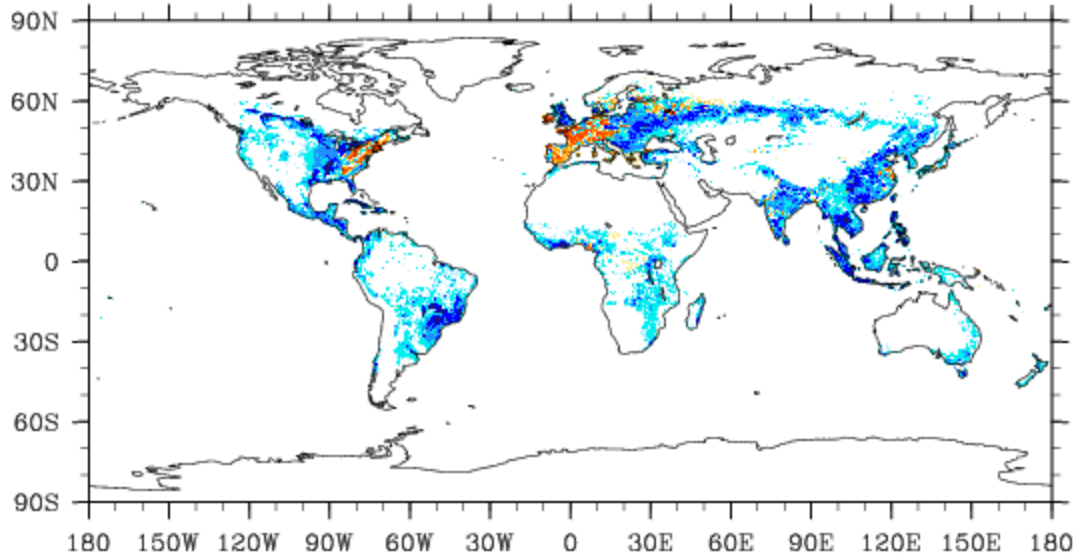
(With thanks to TSS group for their many contributions)



Land Cover Change, Cropping and Forests in CLM4

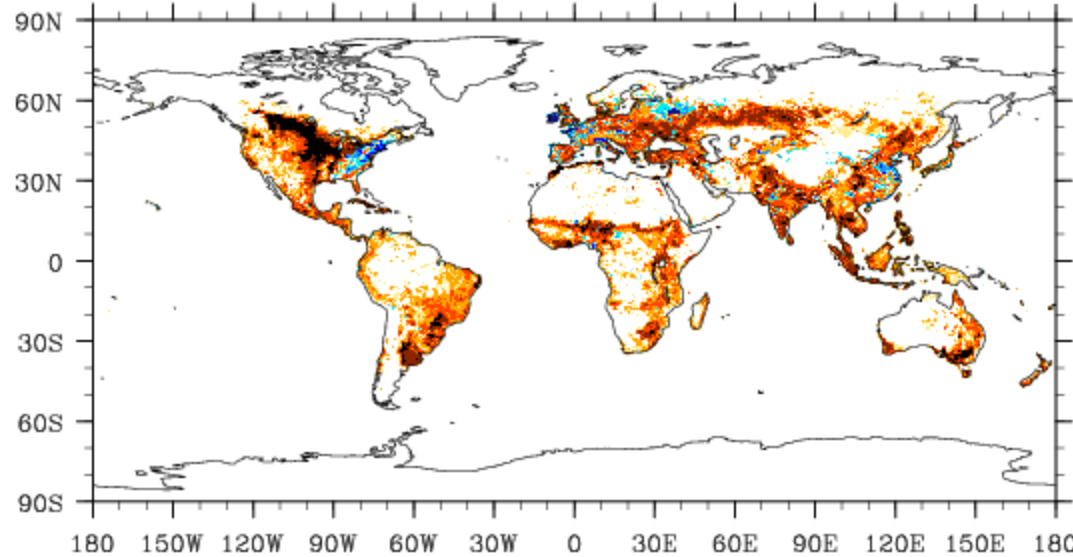
(a) Historical (2005-1850) Tree PFTs

%



(a) Historical (2005-1850) Crop PFTs

%



-50 -25 -10 -2.5 -1 1 2.5 10 25 50



Human Land Cover Change

1. Direct Biogeophysical Impacts:

- Albedo – Radiation (Snow Interactions)
- Surface Hydrology (Irrigation)
- Surface Roughness

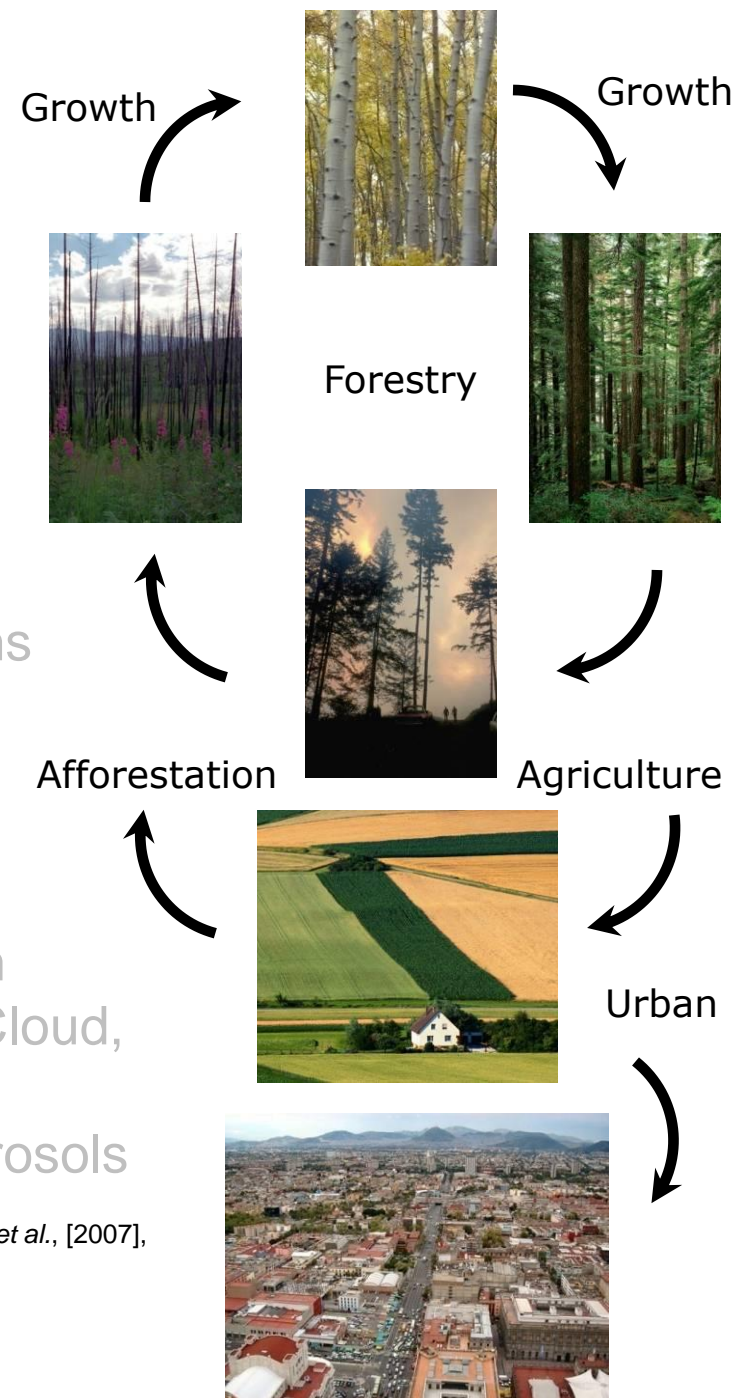
2. Direct Biogeochemical Impacts:

- Vegetation and Soil Carbon Fluxes from Conversion Natural -> Human systems
- Harvesting from Forestry and Agriculture

3. Indirect Impacts:

- Increased Photosynthesis through higher CO₂, Nitrogen, Phosphorus and Potassium
- Atmospheric Responses in Temperature, Cloud, Precipitation and Larger Scale Circulation
- Fire, Methane, Dust, Volatile Organics, Aerosols

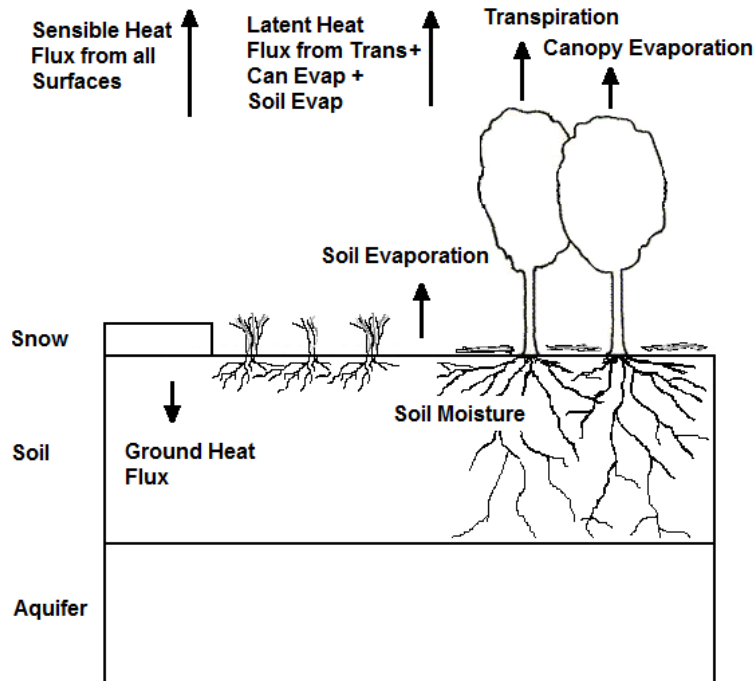
Lawrence et al., [2011], Lawrence and Chase, [2010], Feddema, et al., [2005], Findell, et al., [2007], IPCC, [2007], Bonan, [2008], and Canadell, et al., [2007]



Land Cover Change



CLM4 Heat Fluxes



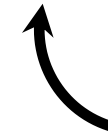
Growth



Growth

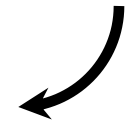


Forestry



Afforestation

Agriculture



Urban



Human Land Cover Change

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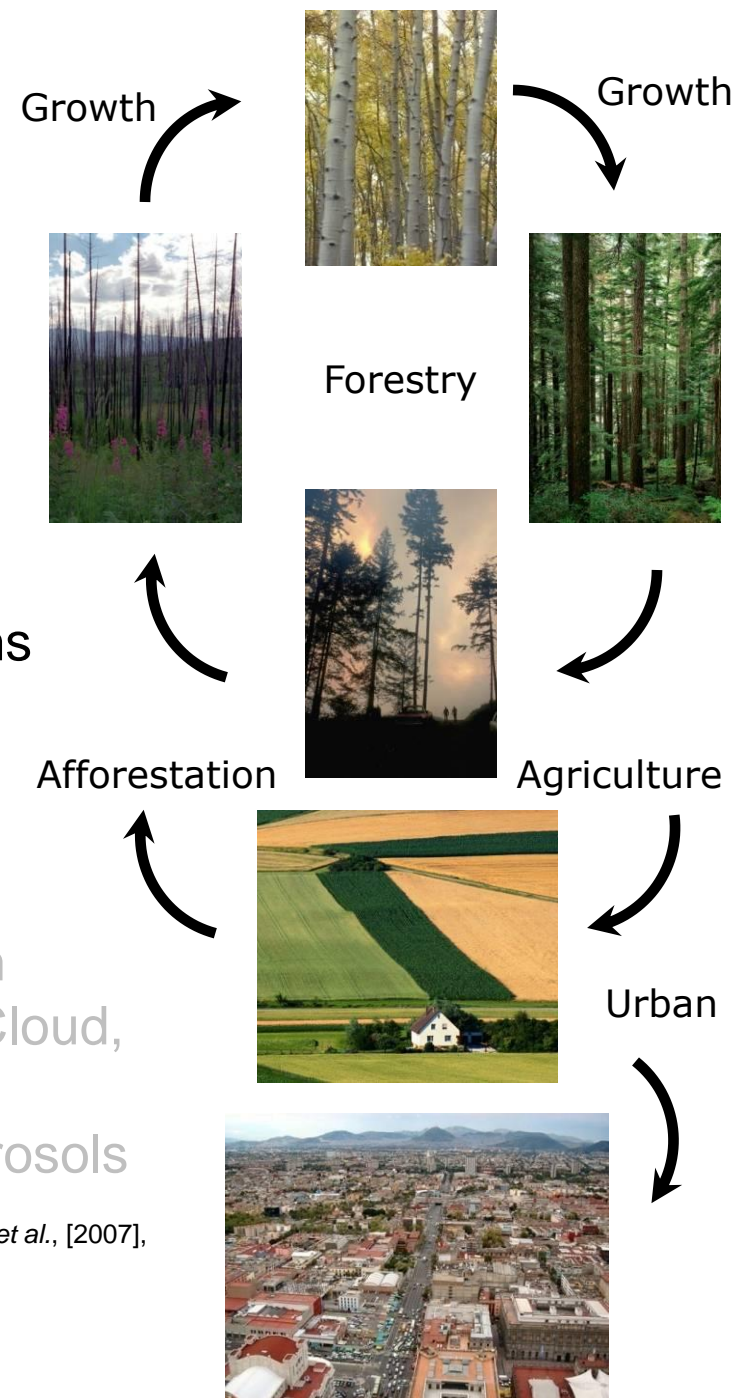
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3. Indirect Impacts:

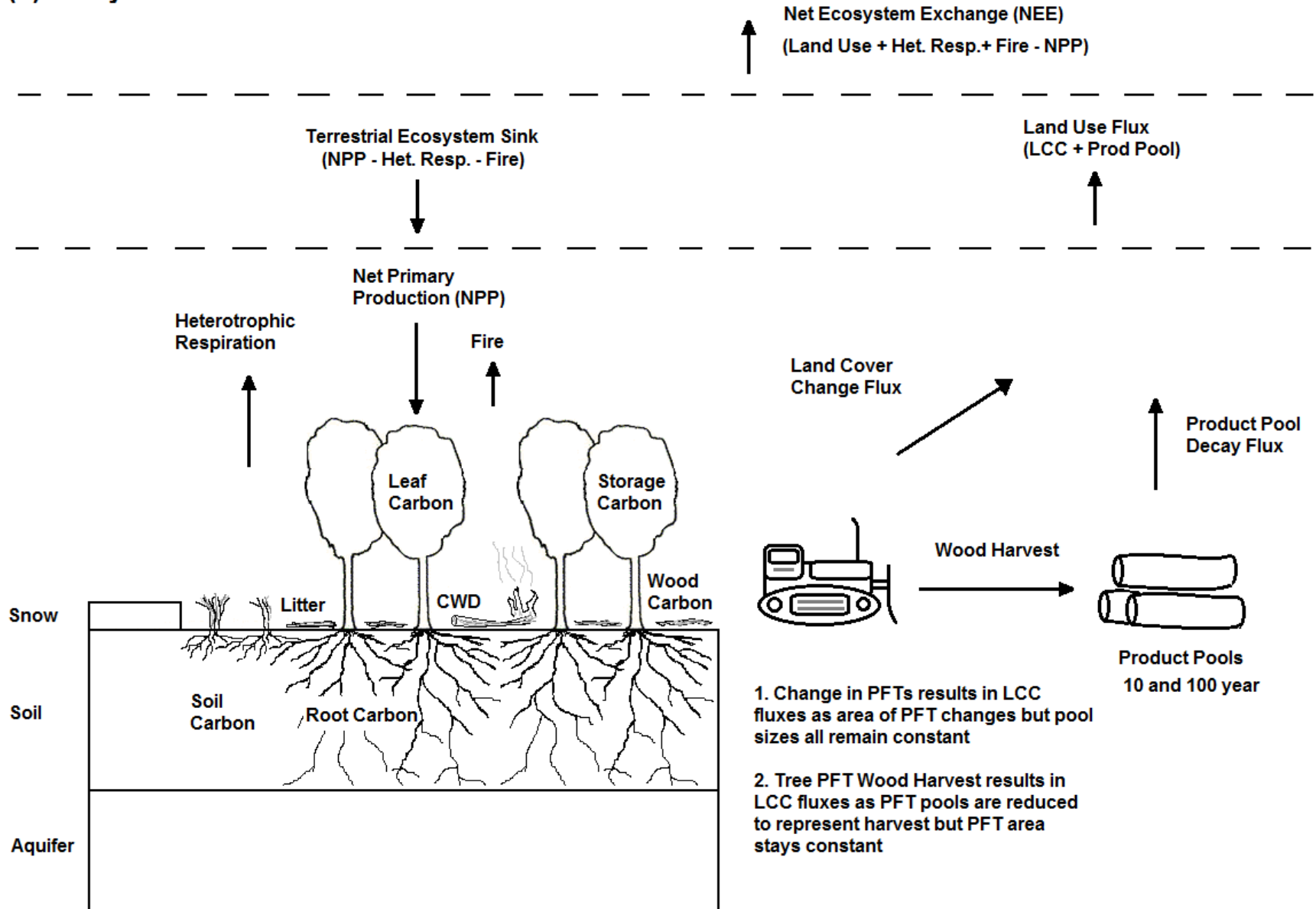
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- Fire, Methane, Dust, Volatile Organics, Aerosols

Lawrence et al., [2011], Lawrence and Chase, [2010], Feddema, et al., [2005], Findell, et al., [2007], IPCC, [2007], Bonan, [2008], and Canadell, et al., [2007]



Land Cover Change in (CLM4 CN)

(a) Analyzed CLM4 CN Carbon Pools and Fluxes



* Ecosystem Carbon = Leaf + Wood + Root + Storage + Litter + Coarse Woody Debris + Soil Carbon

** CWD = Coarse Woody Debris

Human Land Cover Change

1. Direct Biogeophysical Impacts:

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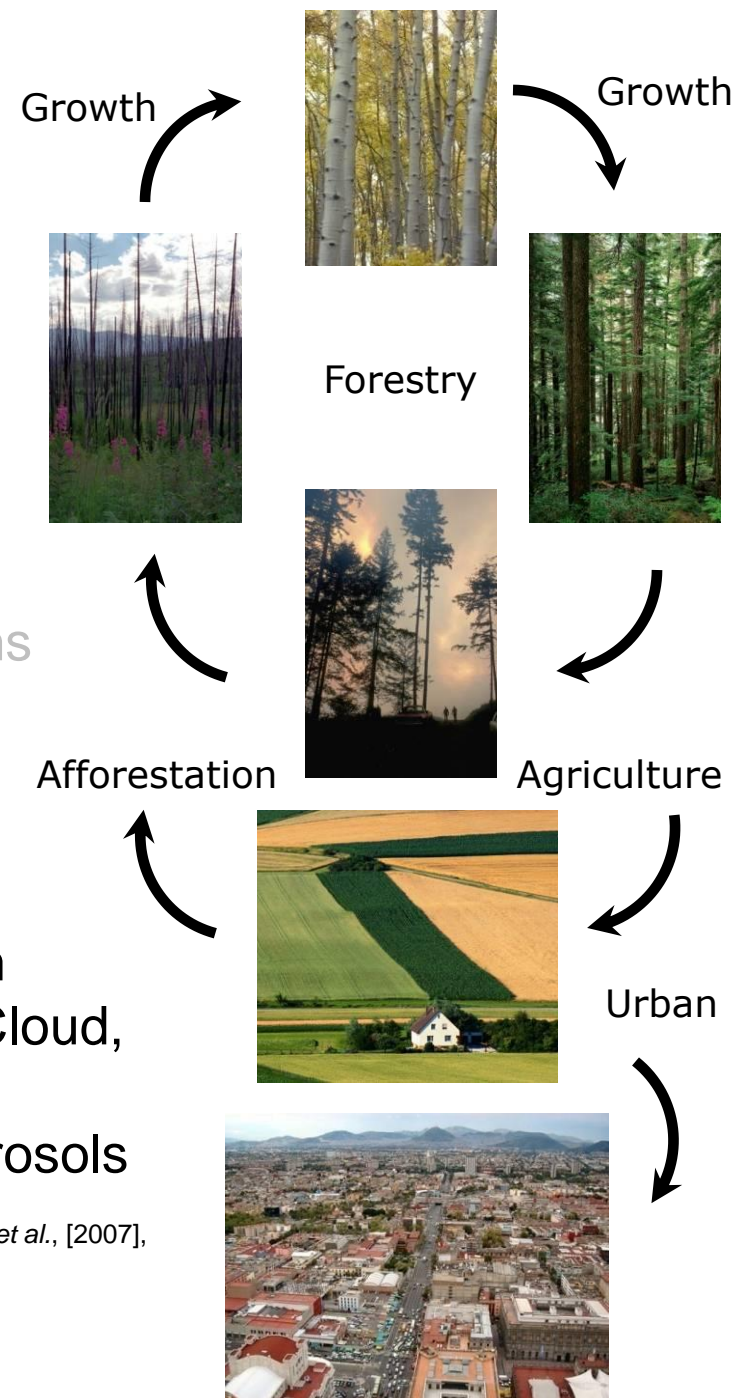
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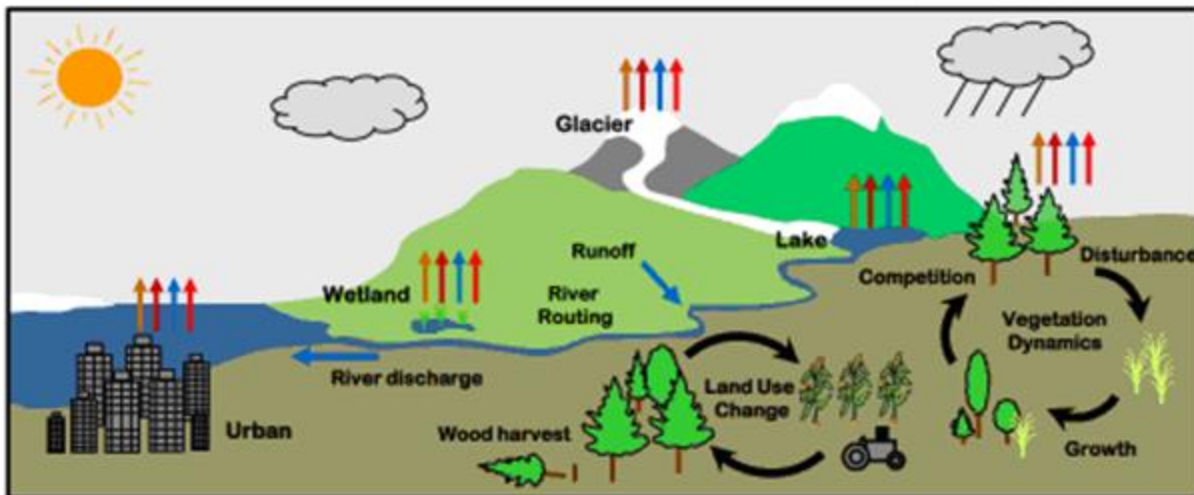
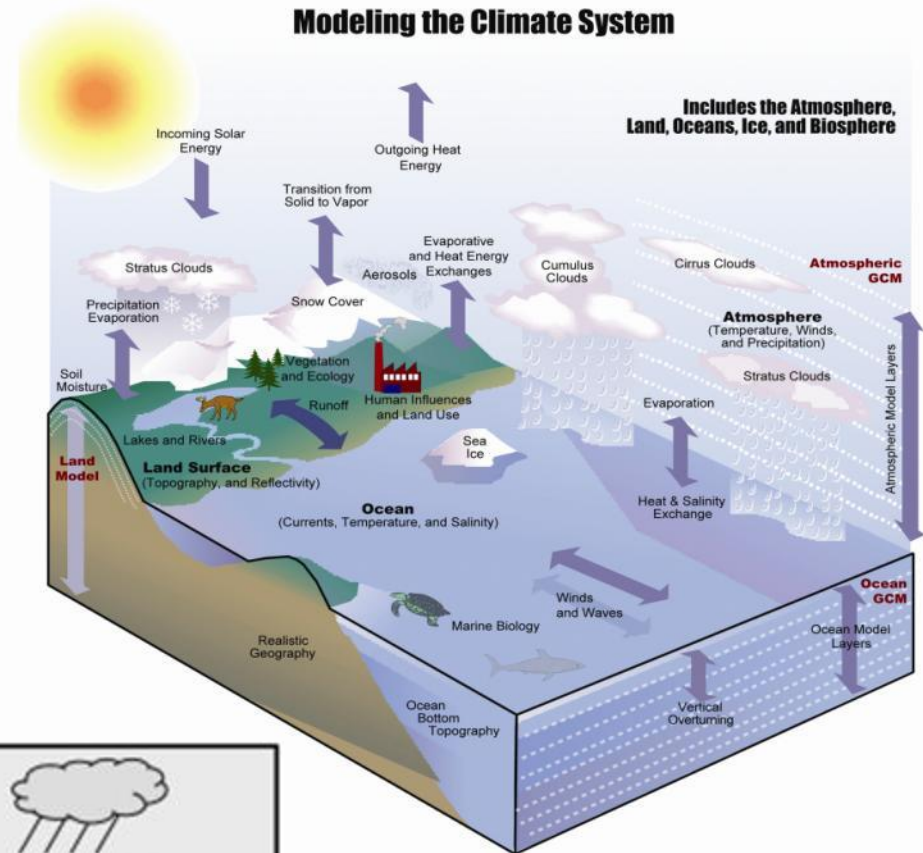
Lawrence et al., [2011], Lawrence and Chase, [2010], Feddema, et al., [2005], Findell, et al., [2007], IPCC, [2007], Bonan, [2008], and Canadell, et al., [2007]



Land Cover Change in the Climate System: Using the Community Earth System Model (CESM)

Global Environmental and Climate Change from the Land Surface in CESM:

- Solar Radiation heating the land surface through snow, ice, vegetation, soils and cities
- Changes in the water stored and returned to the atmosphere and oceans
- Changes in the carbon and nutrient cycles between the land, the atmosphere, and the oceans



Land Cover Change in the CLM4 subgrid tiling

Gridcell



Landunit



Glacier



Wetland



Vegetated



Lake



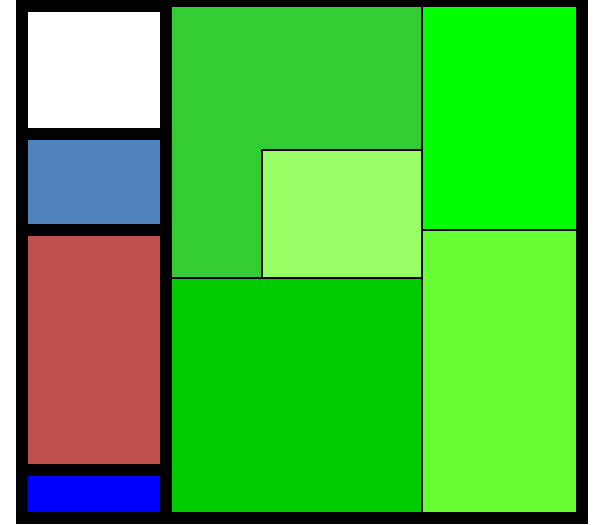
Urban

Columns



**Soil
Type 1**

PFTs



Land Cover Change in the CLM4 subgrid tiling

Gridcell



Plant Functional Types:

0. Bare

Tree:

1. Needleleaf Evergreen, Temperate
2. Needleleaf Evergreen, Boreal
3. Needleleaf Deciduous, Boreal
4. Broadleaf Evergreen, Tropical
5. Broadleaf Evergreen, Temperate
6. Broadleaf Deciduous, Tropical
7. Broadleaf Deciduous, Temperate
8. Broadleaf Deciduous, Boreal

Herbaceous / Understorey:

9. Broadleaf Evergreen Shrub, Temperate
10. Broadleaf Deciduous Shrub, Temperate
11. Broadleaf Deciduous Shrub, Boreal
12. C3 Arctic Grass
13. C3 non-Arctic Grass
14. C4 Grass
15. Crop

Landunit



Glacier



Wetland



Vegetated



Lake



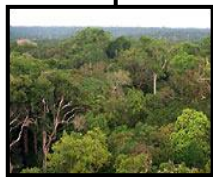
Urban

Columns



Soil
Type 1

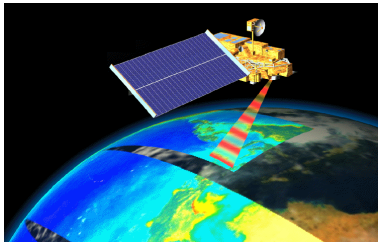
PFTs



Land Cover Change impacts through changes in Plant Functional Type Parameters

- Optical properties (visible and near-infrared):
 - Leaf angle
 - Leaf reflectance
 - Stem reflectance
 - Leaf transmittance
 - Stem transmittance
- Morphological properties:
 - Leaf area index (annual cycle)
 - Stem area index (annual cycle)
 - Leaf dimension
 - Roughness length/displacement height
 - Canopy height
 - Root distribution
- Photosynthetic parameters:
 - specific leaf area ($\text{m}^2 \text{ leaf area g}^{-1} \text{ C}$)
 - m (slope of conductance-photosynthesis relationship)

Mapping Current Day CLM PFTs from MODIS at 0.05 degrees



Plant Functional Type Mapping

MODIS Vegetation Continuous Fields
(tree%, herbaceous%, bare%)

MODIS Land Cover
(IGBP Classes for Shrub% and Grass%)

Ramankutty (2008) Cropping 2000
(Crop %)

0. Bare

Tree:

1. Needleleaf Evergreen, Temperate
2. Needleleaf Evergreen, Boreal
3. Needleleaf Deciduous, Boreal
4. Broadleaf Evergreen, Tropical
5. Broadleaf Evergreen, Temperate
6. Broadleaf Deciduous, Tropical
7. Broadleaf Deciduous, Temperate
8. Broadleaf Deciduous, Boreal

Herbaceous / Understorey:

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12. C3 Arctic Grass
13. C3 non-Arctic Grass
14. C4 Grass
15. Crop

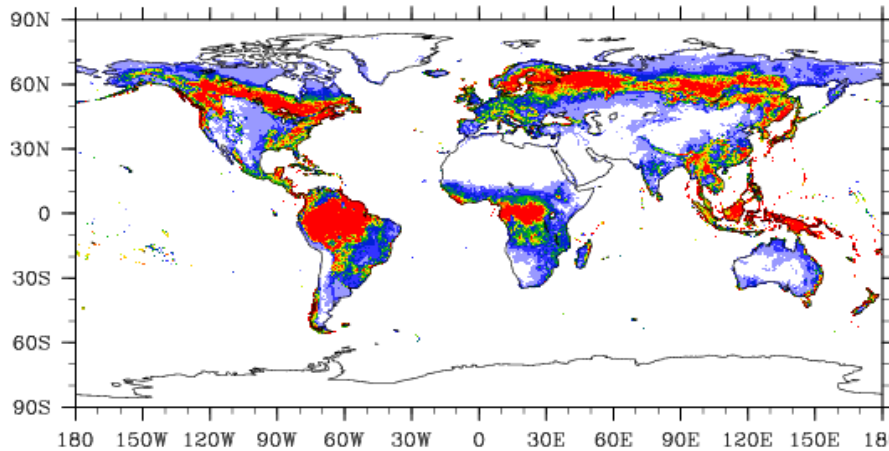
AVHRR Continuous Fields Tree Cover
(Needle%, Broad%, Evergreen%, Decid%)

Willmott and Matsuura Climate
(Air Temperature, Precipitation)

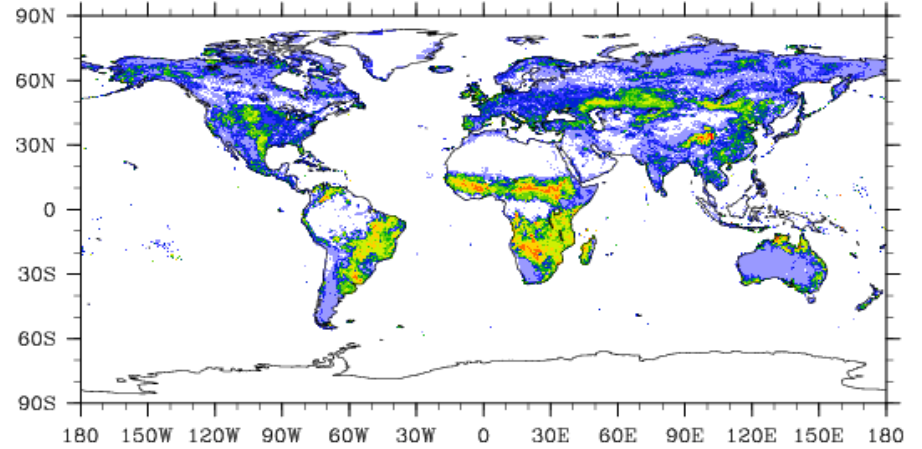
MODIS Monthly LAI
(Monthly LAI for C3/C4 Grass Growing Months)

Mapping Current Day CLM PFTs from MODIS at 0.05 degrees

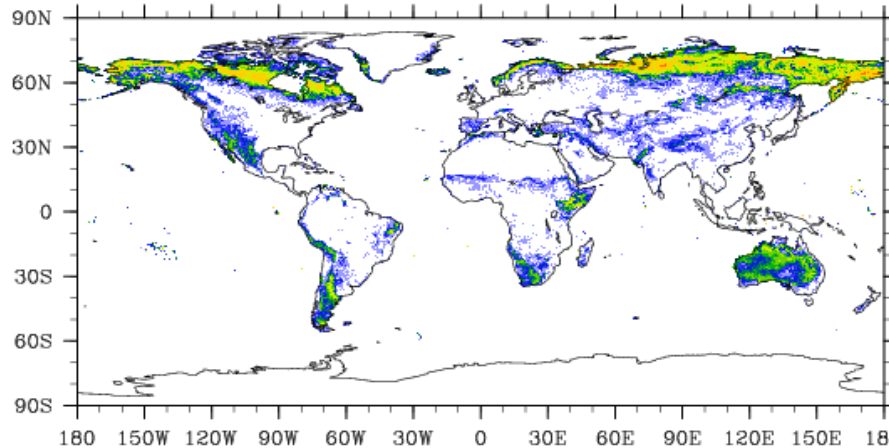
(a) Current Day (2000) Tree PFTs



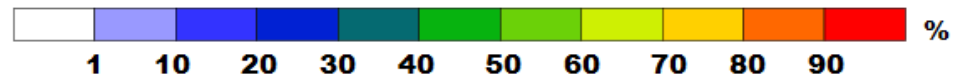
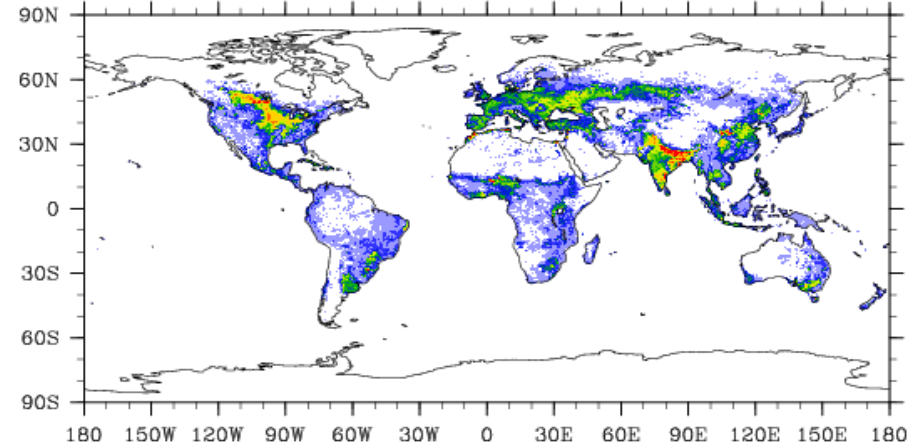
(e) Current Day (2000) Grass PFTs



(c) Current Day (2000) Shrub PFTs

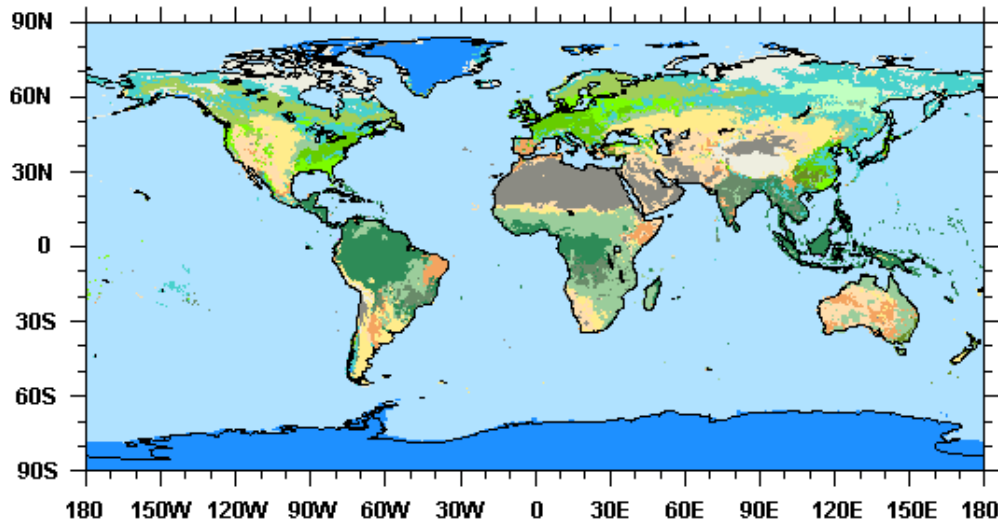


(g) Current Day (2000) Crop PFT



Generating Potential Vegetation CLM PFTs from Biomes

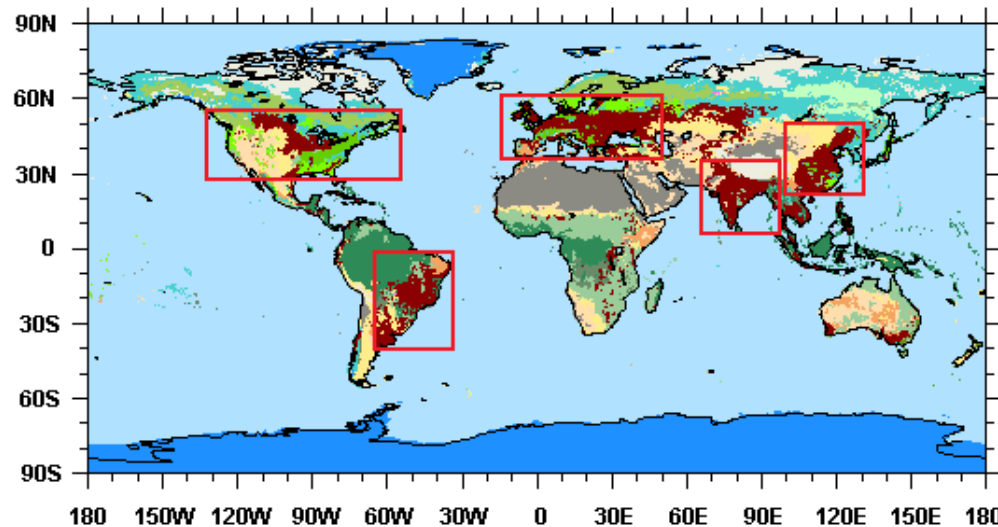
a) Ramankutty and Foley Potential Veg Biomes



Hexaltine and Prentice Biomes

- 0 Water
- 1 Tropical Evergreen Forest
- 2 Tropical Deciduous Forest
- 3 Temperate Broadleaf Evergreen Forest
- 4 Temperate Needleleaf Evergreen Forest
- 5 Temperate Deciduous Forest
- 6 Boreal Evergreen Forest
- 7 Boreal Deciduous Forest
- 8 Mixed Forest
- 9 Savanna
- 10 Grassland
- 11 Dense Shrubland
- 12 Open Shrubland
- 13 Tundra
- 14 Desert
- 15 Polar Desert/Rock/Ice
- 16 Land Use
- 17 Wetland

b) GLCC Current Day Biomes

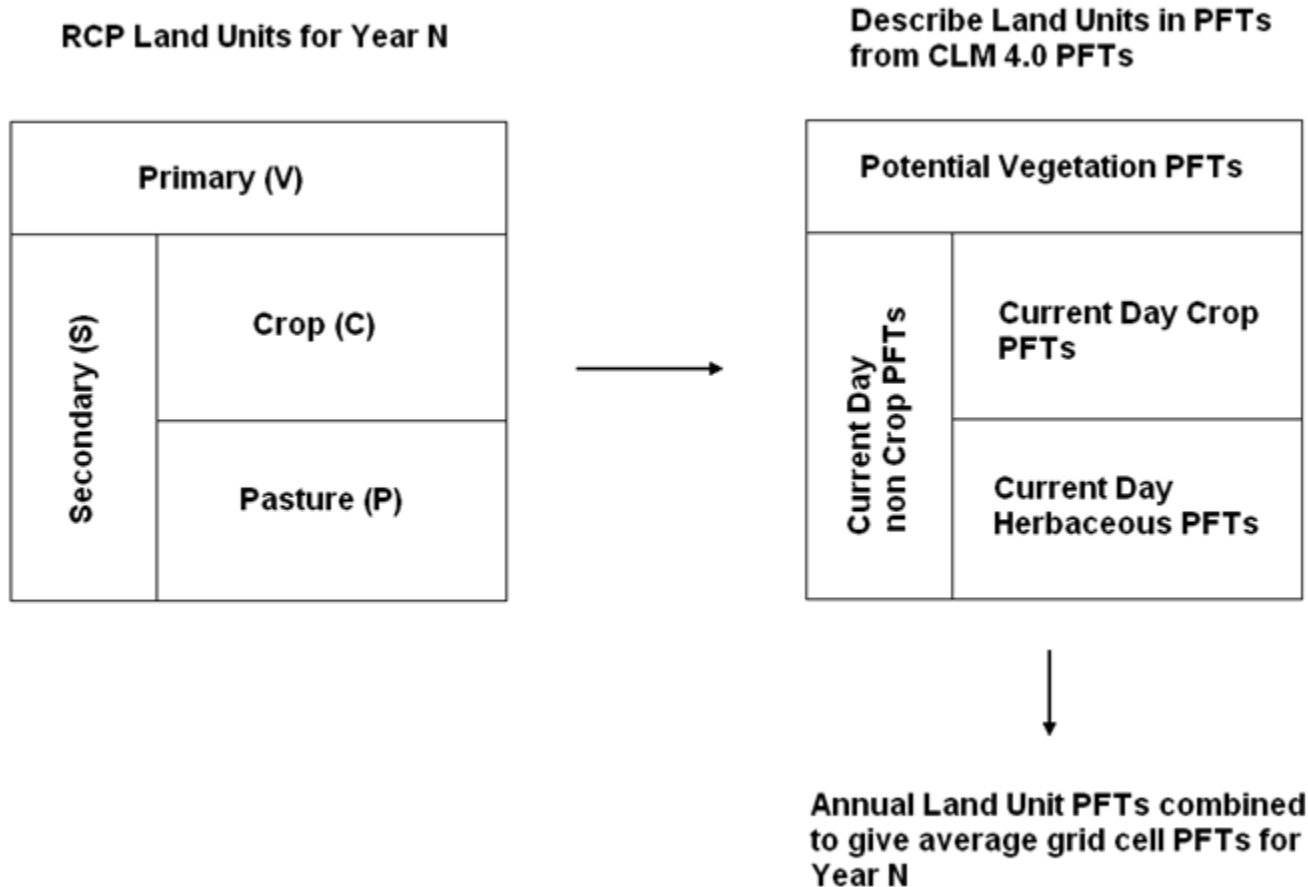


Transient 1850 – 2100 Land Cover Change in CLM

1. Land cover change and wood harvest were included in the Coupled Model Intercomparison Project phase 5 (CMIP5) climate simulations performed by NCAR to inform the latest United Nations – Intergovernmental Panel on Climate Change (UN IPCC) Assessment Report 5 (AR5).
2. The CMIP5 protocol prescribed values for the 1850 – 2005 Historical period and for four different 2006 – 2100 Representative Concentration Pathway (RCP) periods. (Extensions back to 850 AD)
3. For each Historical and RCP period land use and land cover change are described through annual changes in four basic land units:
 - Primary Vegetation (Prior to Human Disturbance)
 - Secondary Vegetation (Disturbed then abandoned or managed)
 - Cropping
 - Pasture (Grazing Lands)
4. Harvesting of woody biomass is also prescribed for both primary and secondary vegetation land units

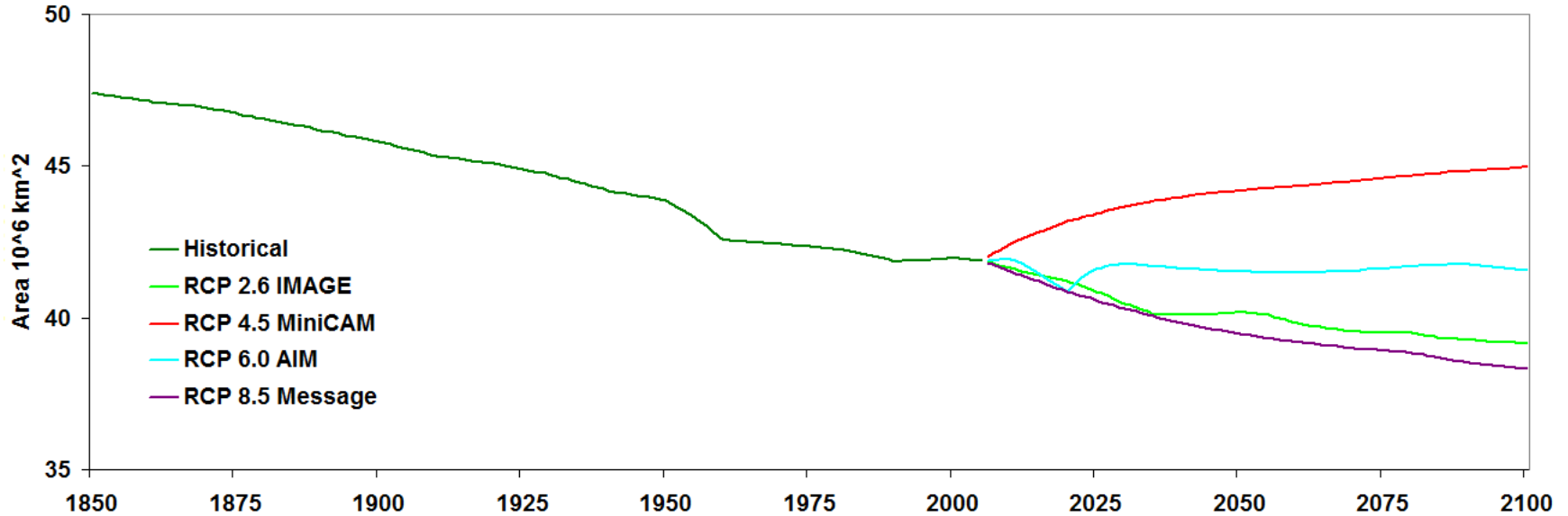
CMIP5 Transient Land Cover in CLM 4 PFTs Method

A time series of annual PFT tile mosaics is generated from the annual CMIP5 Land Cover Classes by combining them with the Current Day and Potential Vegetation PFTs that were previously mapped from satellite and bioclimatic modeling.

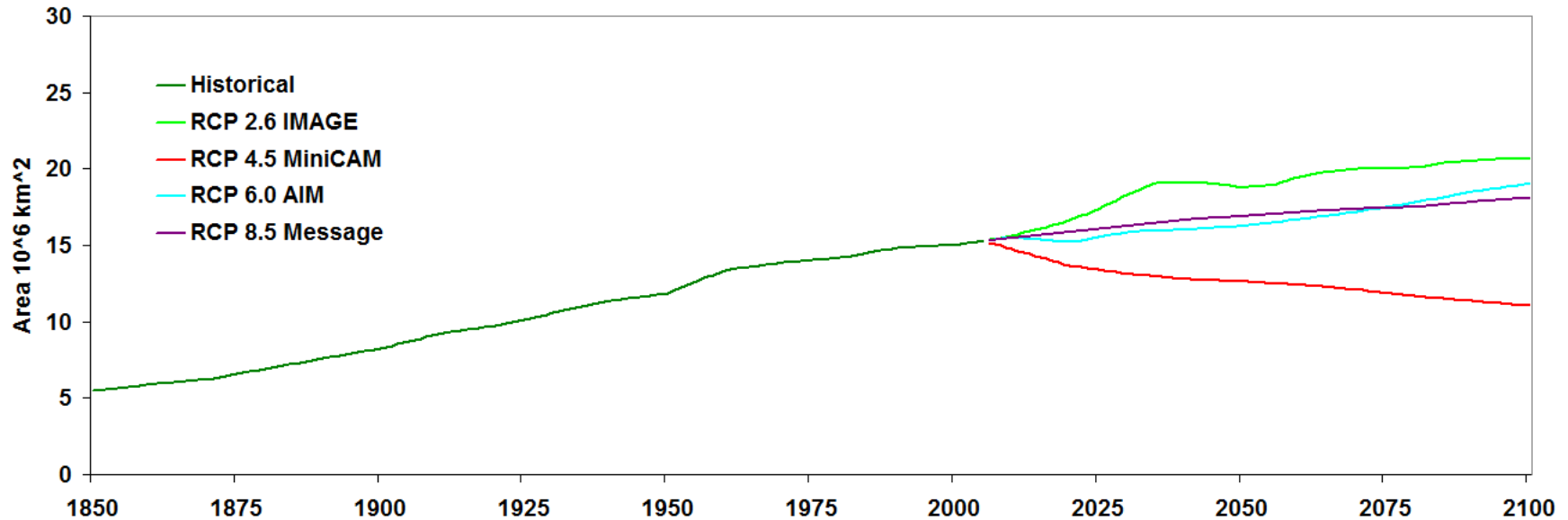


CMIP5 Transient Land Cover in CLM 4 PFTs

CMIP5 Total Global Tree PFT Area

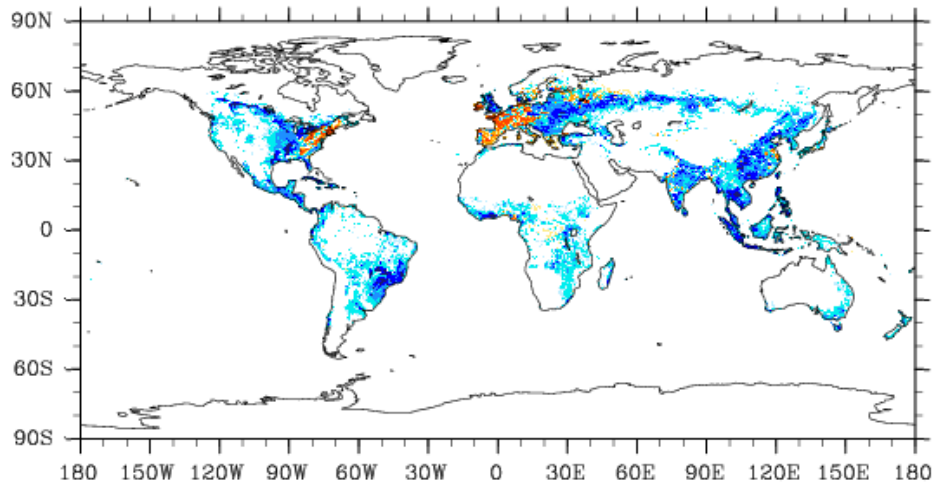


CMIP5 Total Global Crop PFT Area

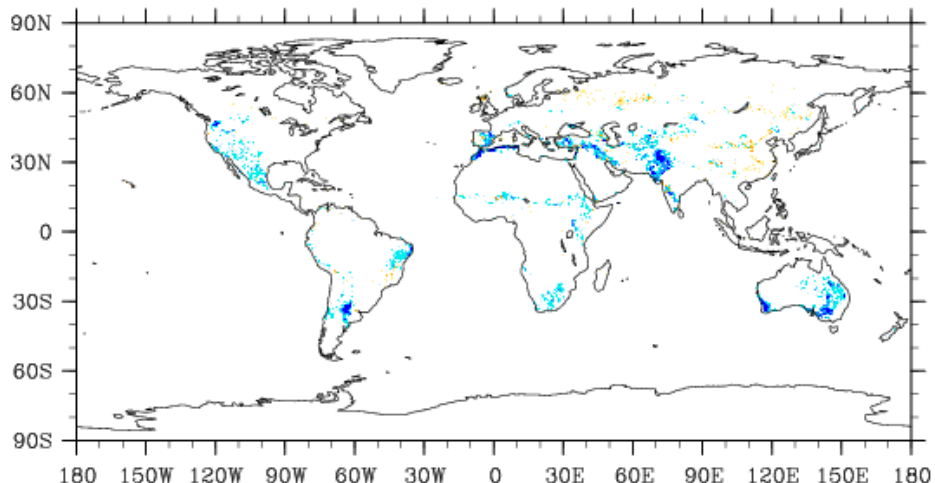


CMIP5 - Historical Land Cover Change – PFTs %area

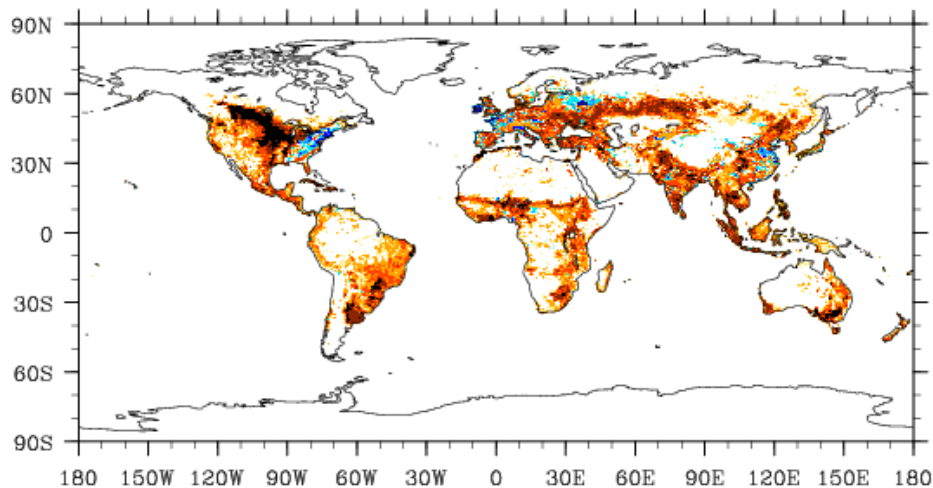
Historical (2005-1850) Tree PFTs



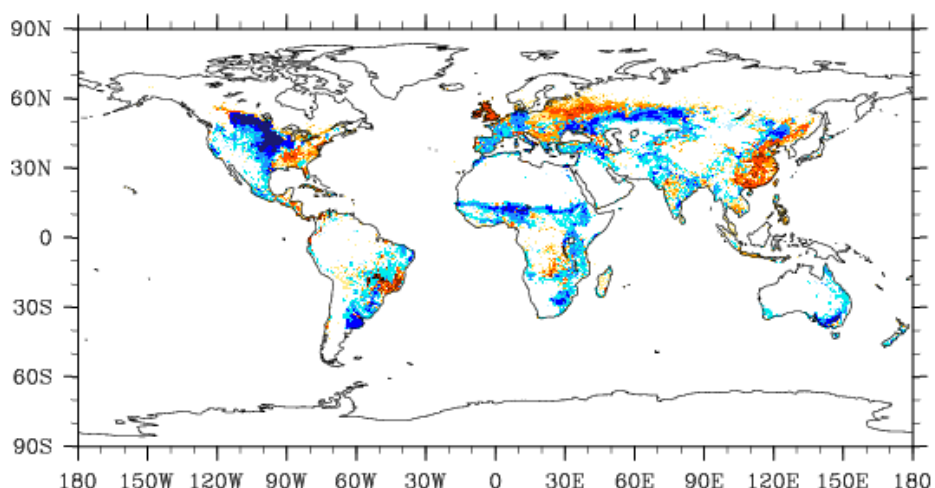
Historical (2005-1850) Shrub PFTs



Historical (2005-1850) Crop

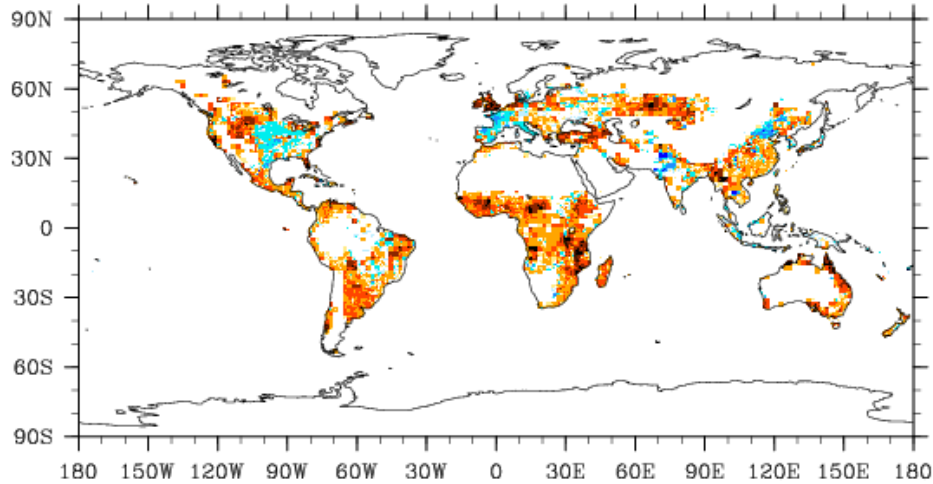


Historical (2005-1850) Grass PFTs

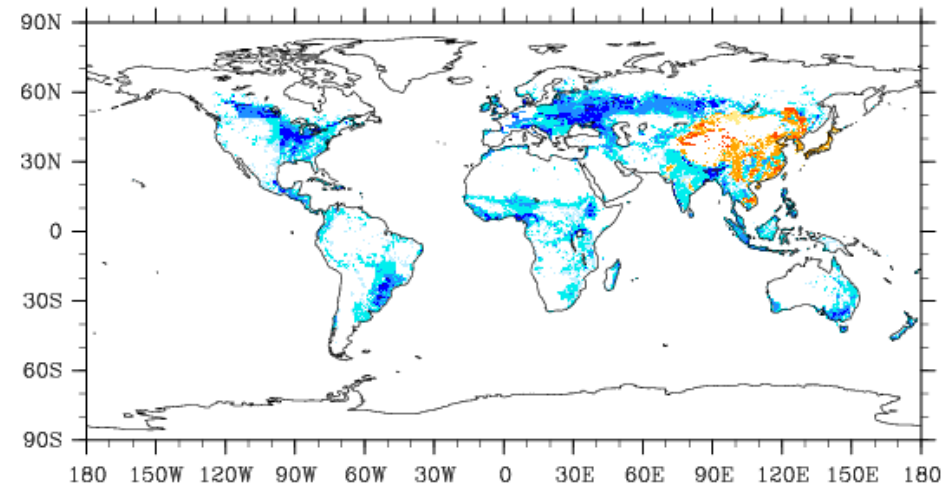


CMIP5 - RCP Land Cover Change PFTs – Crop %area

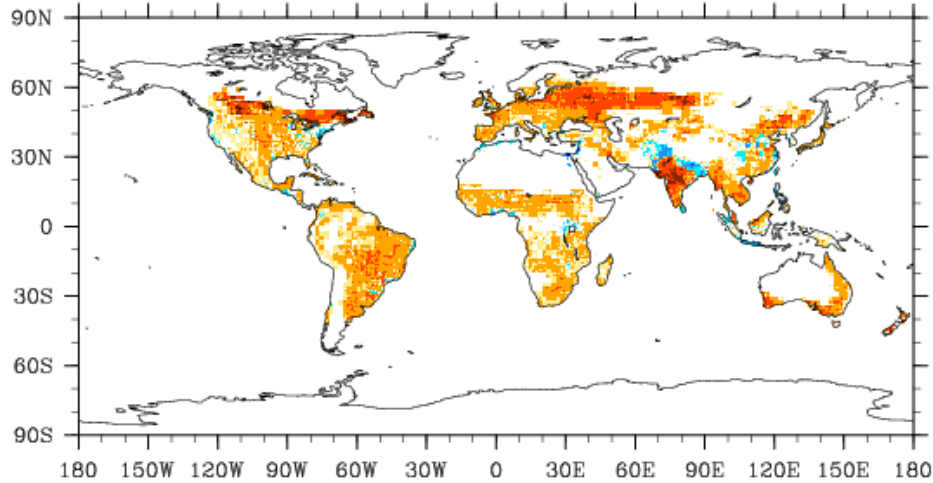
RCP 2.6 IMAGE (2100-2006) Crop



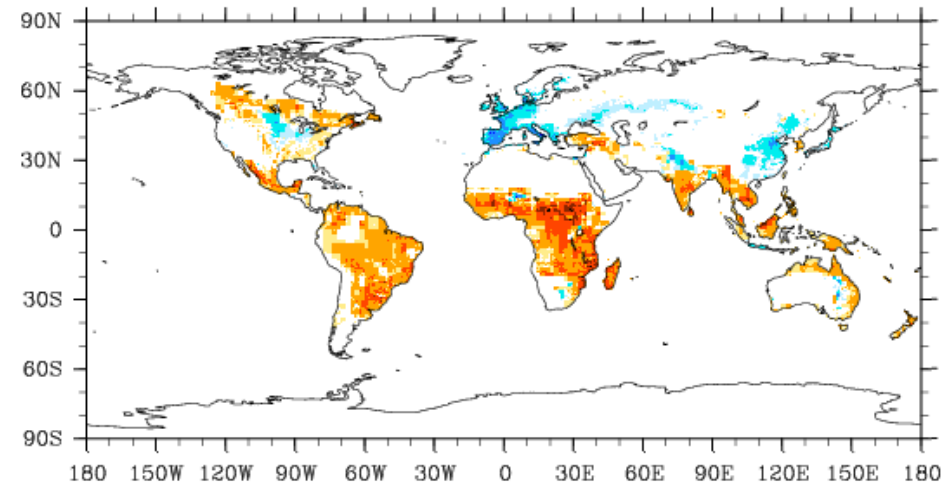
RCP 4.5 MiniCAM (2100-2006) Crop



RCP 6.0 AIM (2100-2006) Crop

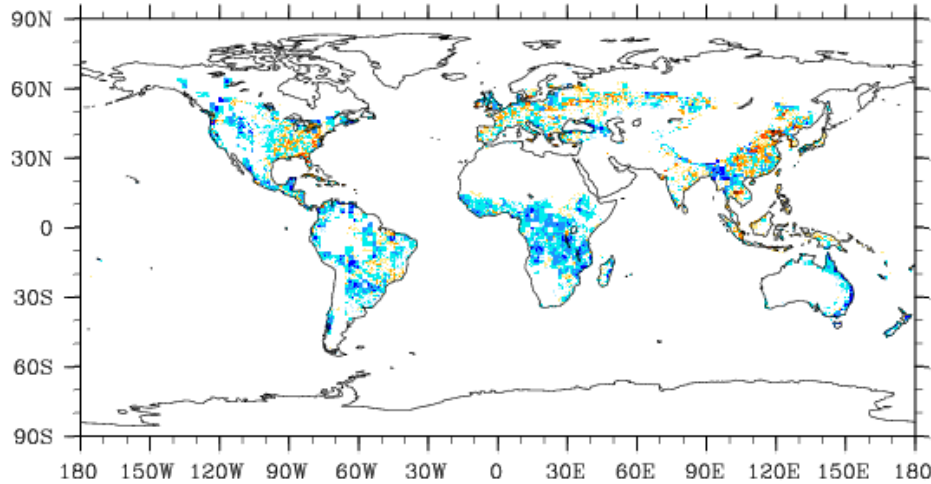


RCP 8.5 Message (2100-2006) Crop

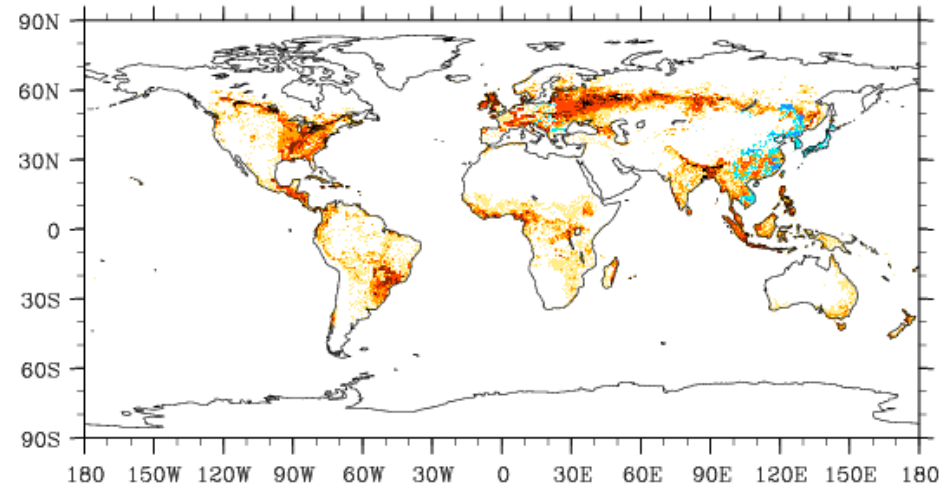


CMIP5 - RCP Land Cover Change PFTs – Trees %area

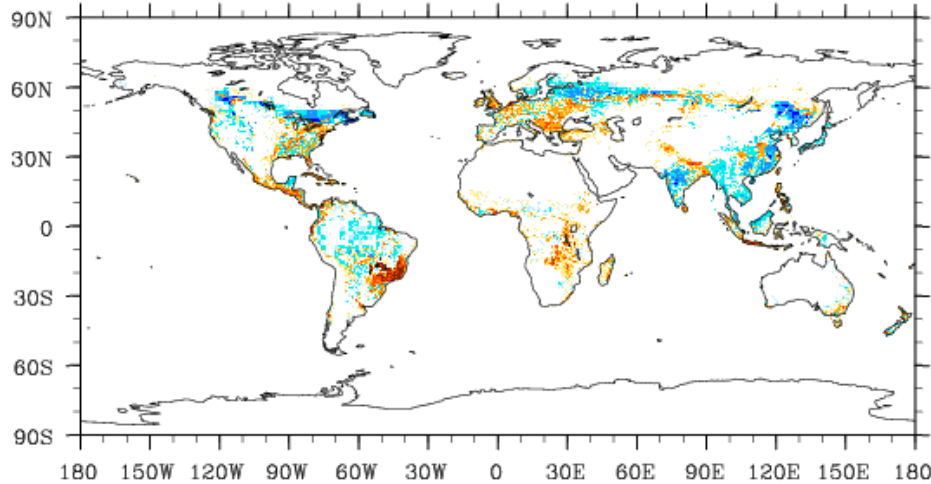
RCP 2.6 IMAGE (2100-2006) Tree PFTs



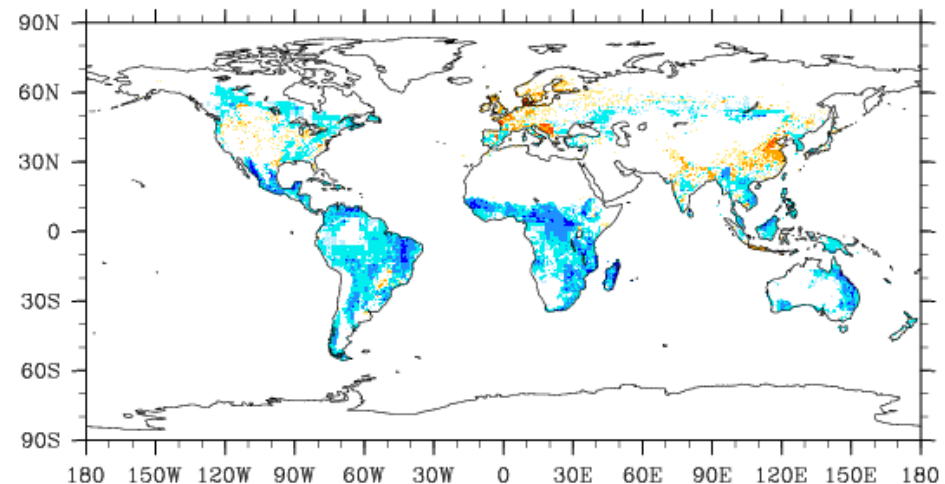
RCP 4.5 MiniCAM (2100-2006) Tree PFTs



RCP 6.0 AIM (2100-2006) Tree PFTs

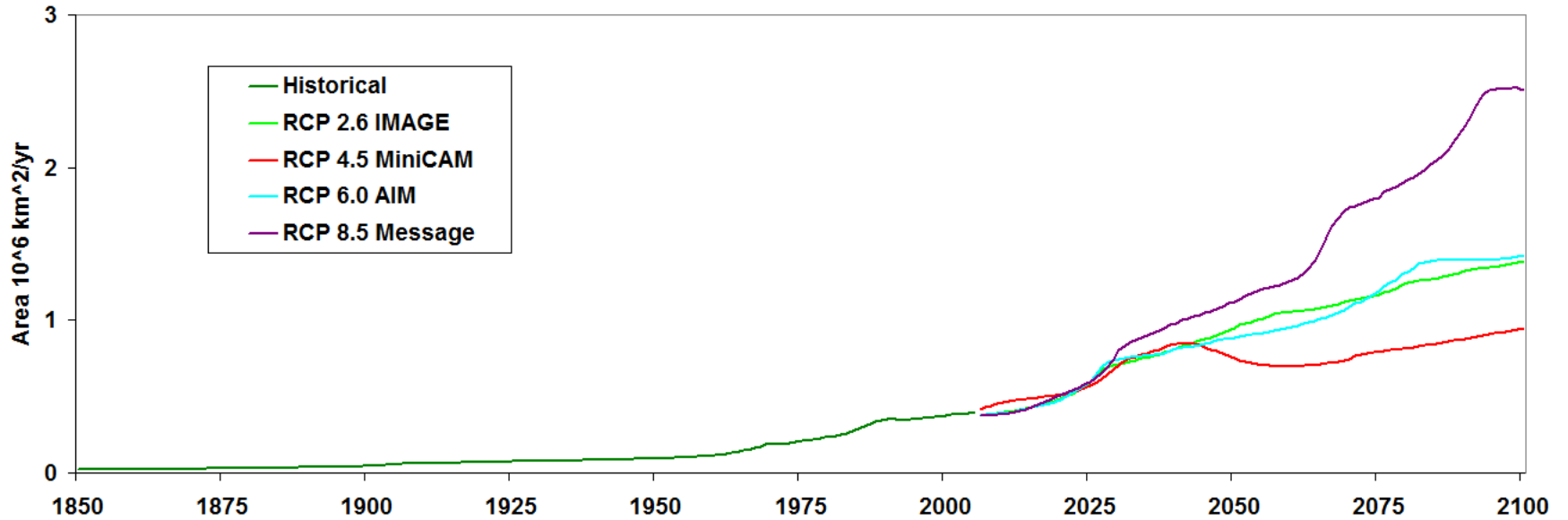


RCP 8.5 Message (2100-2006) Tree PFTs

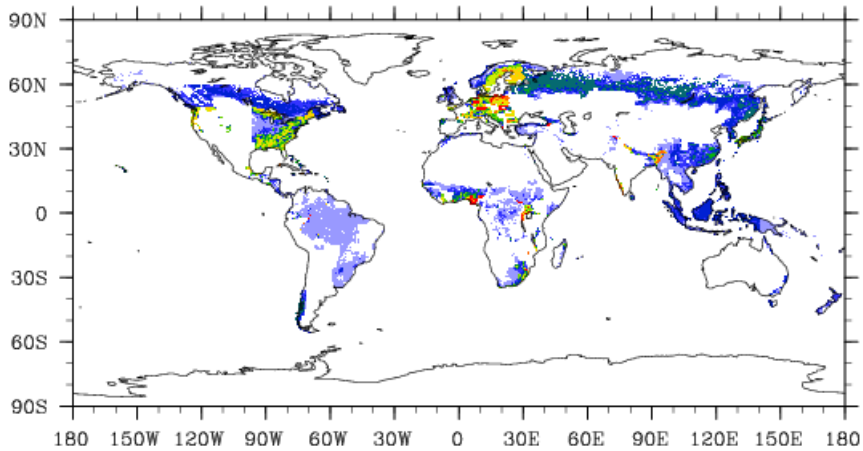


CMIP5 Historical and RCP Tree PFT Harvest

CMIP5 Global Total Annual Tree PFT Harvest Area

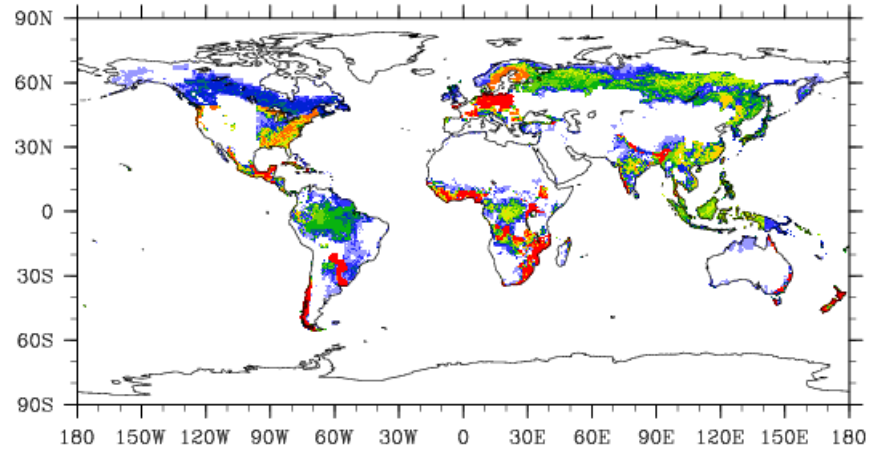


Historical (2005-1850) Tree PFT Harvest



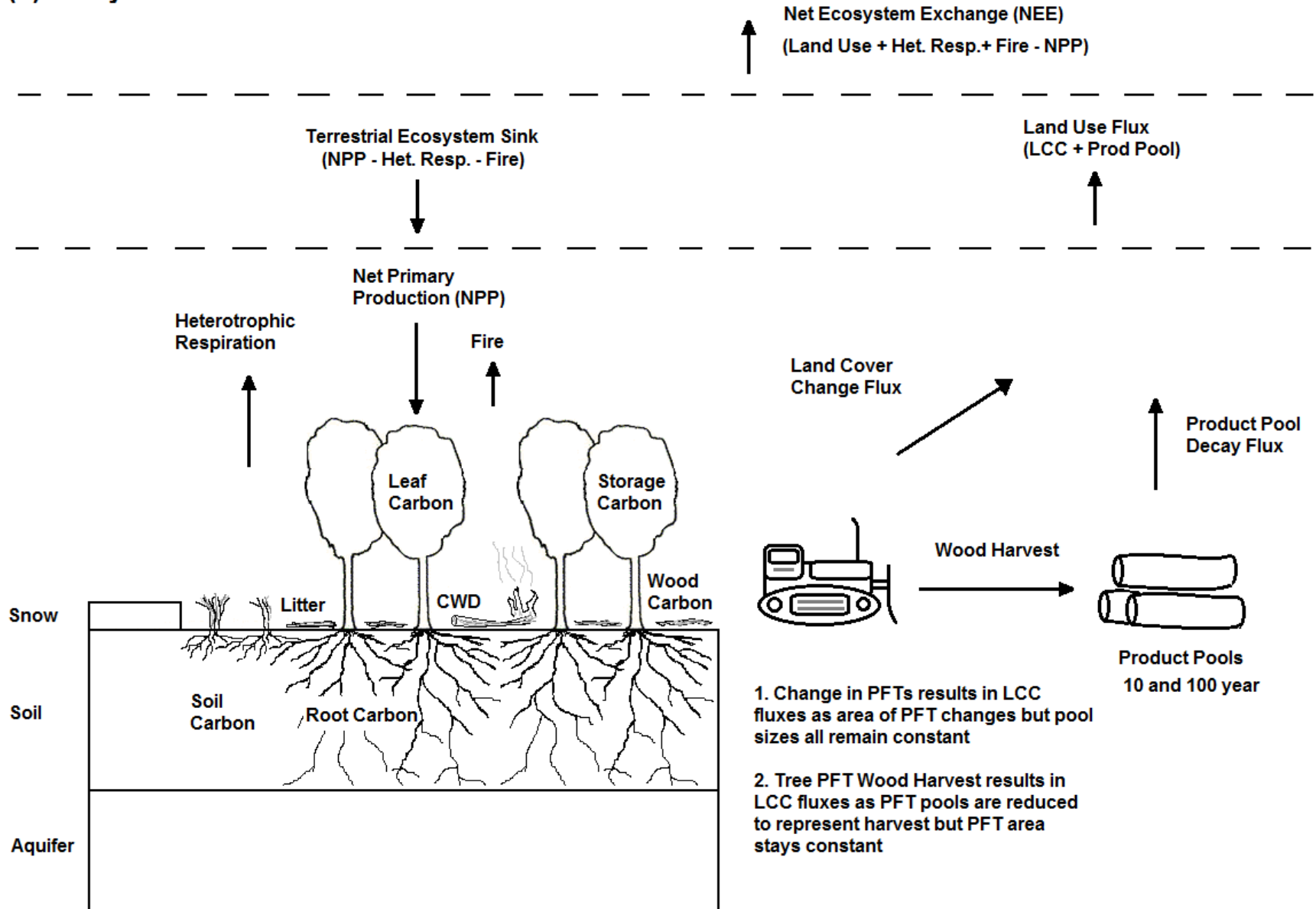
RCP 8.5 Message (2100-2006) Tree PFT Harvest

%



Land Cover Change in (CLM4 CN)

(a) Analyzed CLM4 CN Carbon Pools and Fluxes



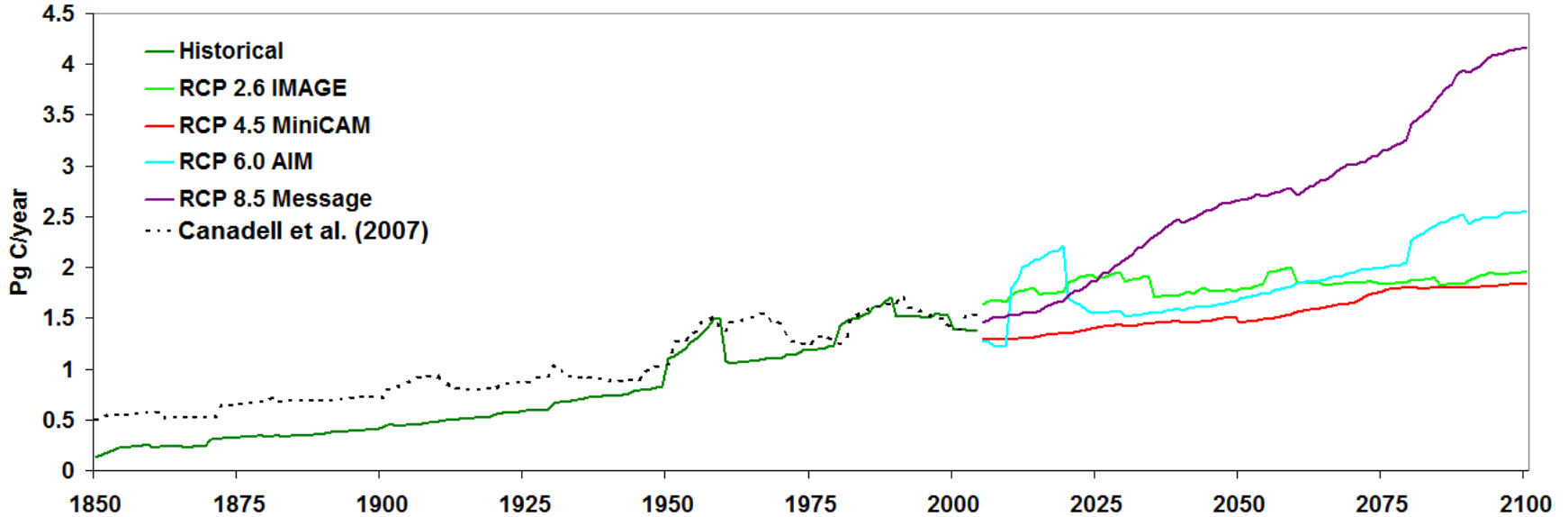
1. Change in PFTs results in LCC fluxes as area of PFT changes but pool sizes all remain constant
2. Tree PFT Wood Harvest results in LCC fluxes as PFT pools are reduced to represent harvest but PFT area stays constant

* Ecosystem Carbon = Leaf + Wood + Root + Storage + Litter + Coarse Woody Debris + Soil Carbon

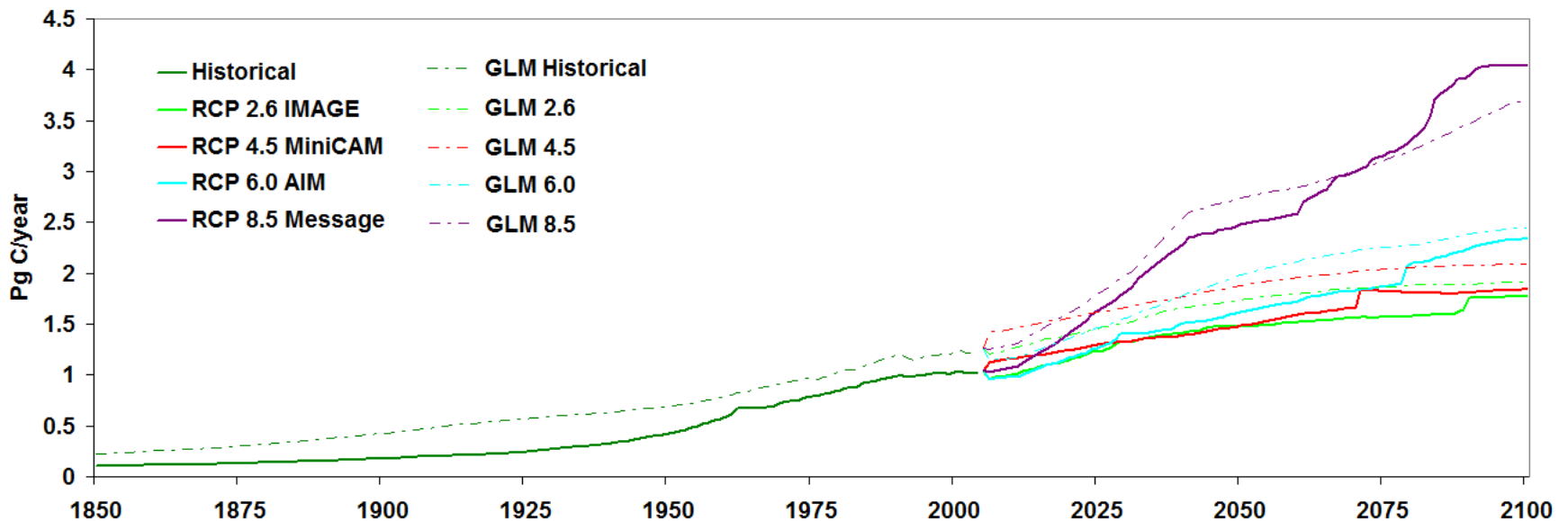
** CWD = Coarse Woody Debris

LCC in CESM – Coupled Climate & Prescribed CO2

CCSM 4.0 Global Total Land Use Carbon Flux to Atmosphere

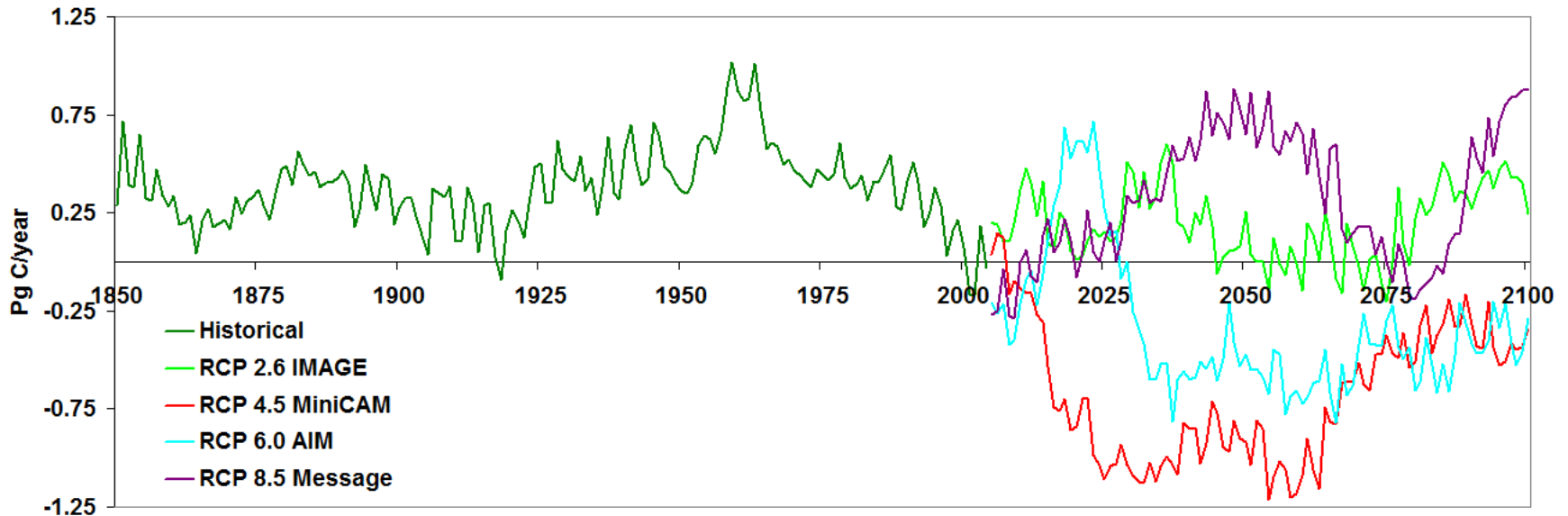


CCSM 4.0 Global Total Wood Harvest Carbon Flux compared to GLM Harvest Carbon Flux

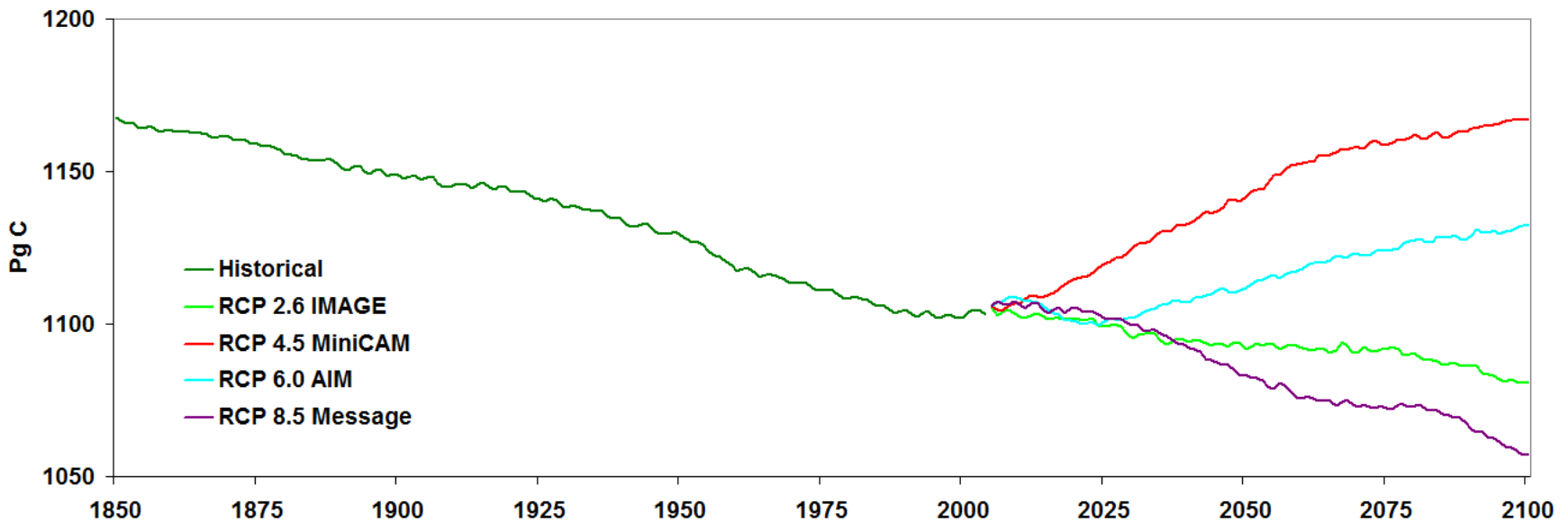


LCC in CESM – Coupled Climate & Prescribed CO2

CCSM 4.0 Global Total Net Ecosystem Exchange (NEE) - 10 year smoothed (Including Land Use Flux)

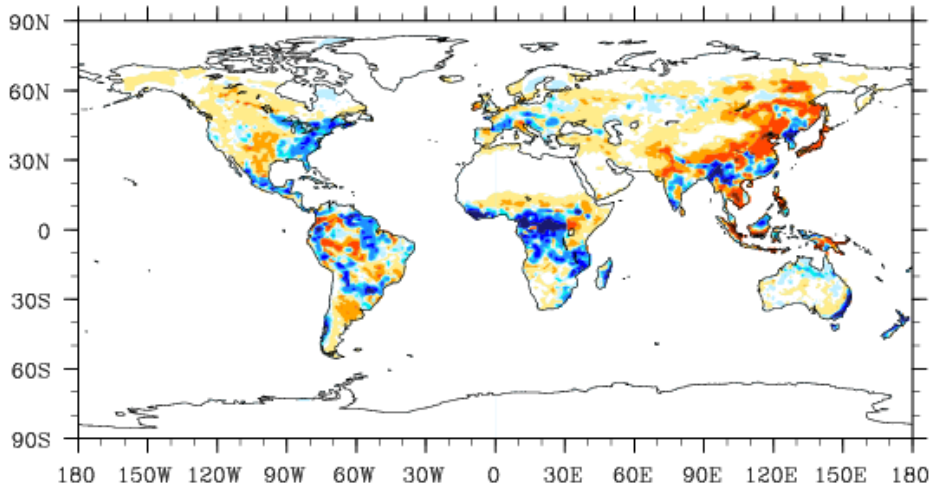


CCSM 4.0 Global Total Ecosystem Carbon (Excluding Product Pools)

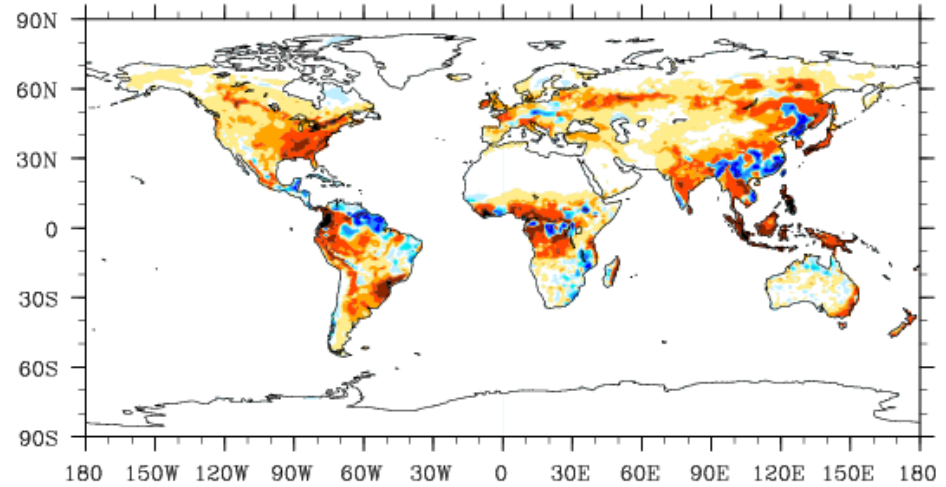


LCC in CESM – Coupled Climate & Prescribed CO₂

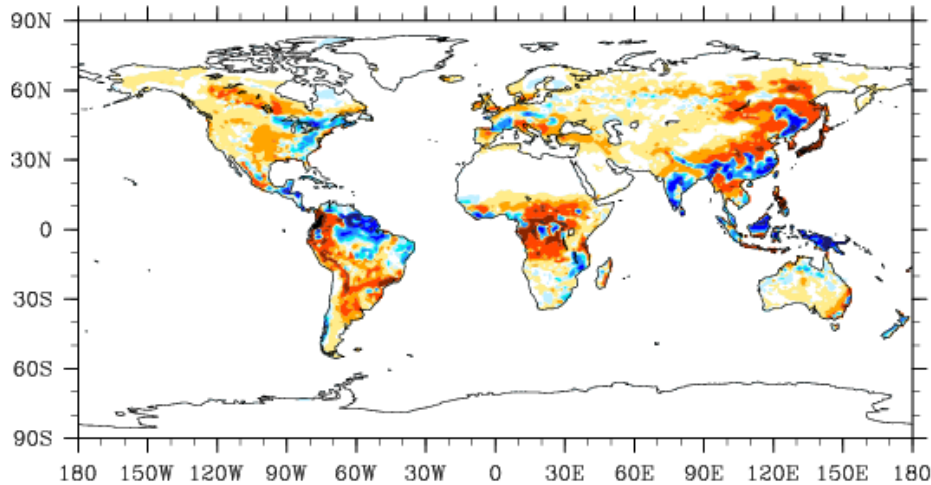
RCP 2.6 IMAGE (2100-2006) All of Ecosystem Carbon gC/m²



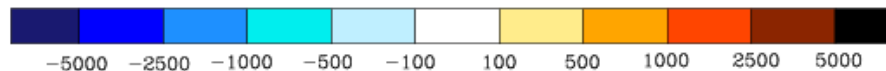
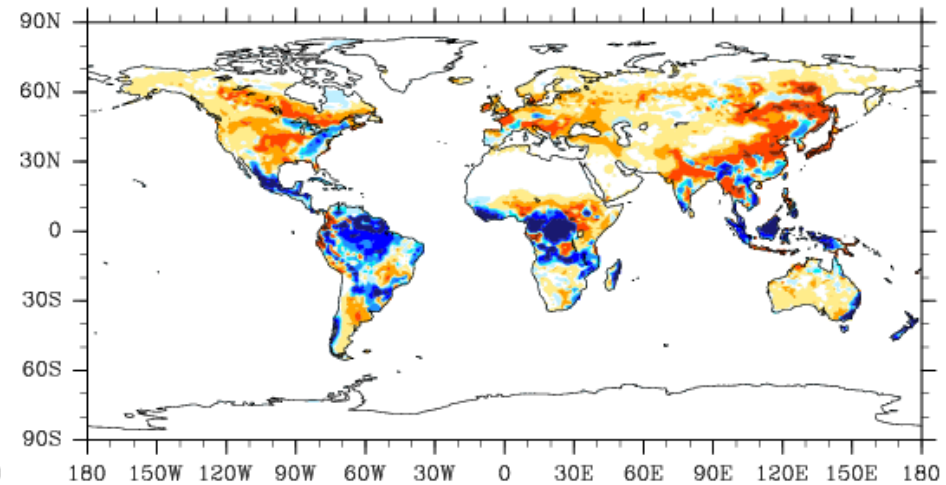
RCP 4.5 MiniCAM (2100-2006) All of Ecosystem Carbon gC/m²



RCP 6.0 AIM (2100-2006) All of Ecosystem Carbon gC/m²

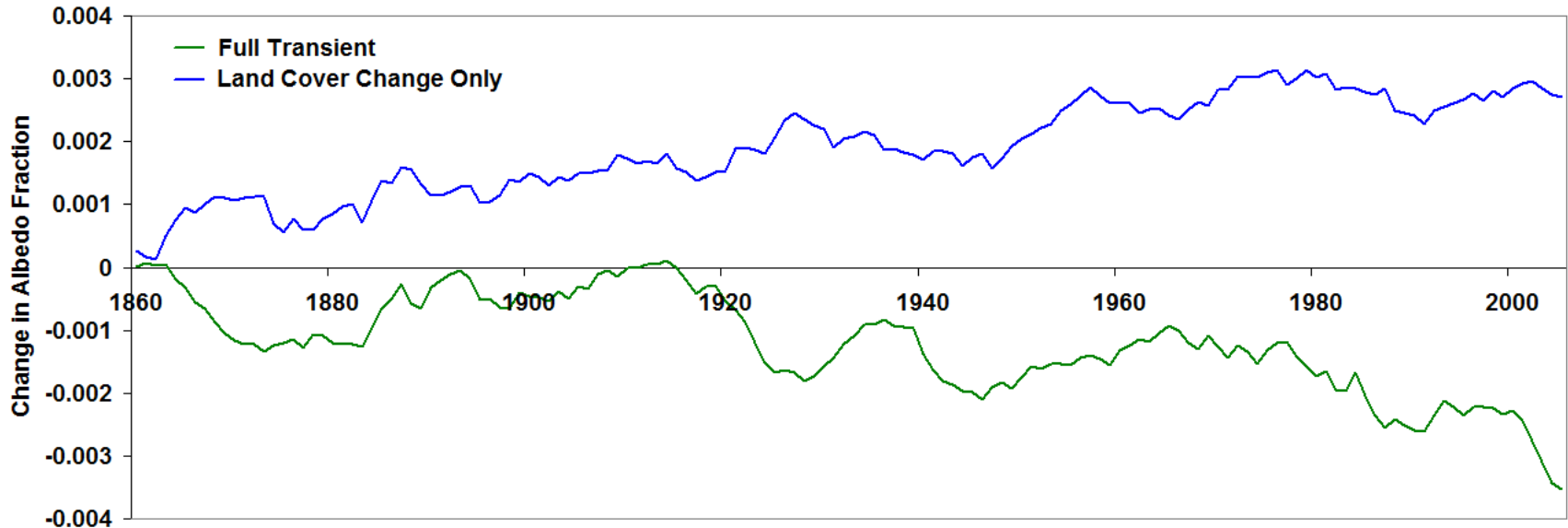


RCP 8.5 Message (2100-2006) All of Ecosystem Carbon gC/m²

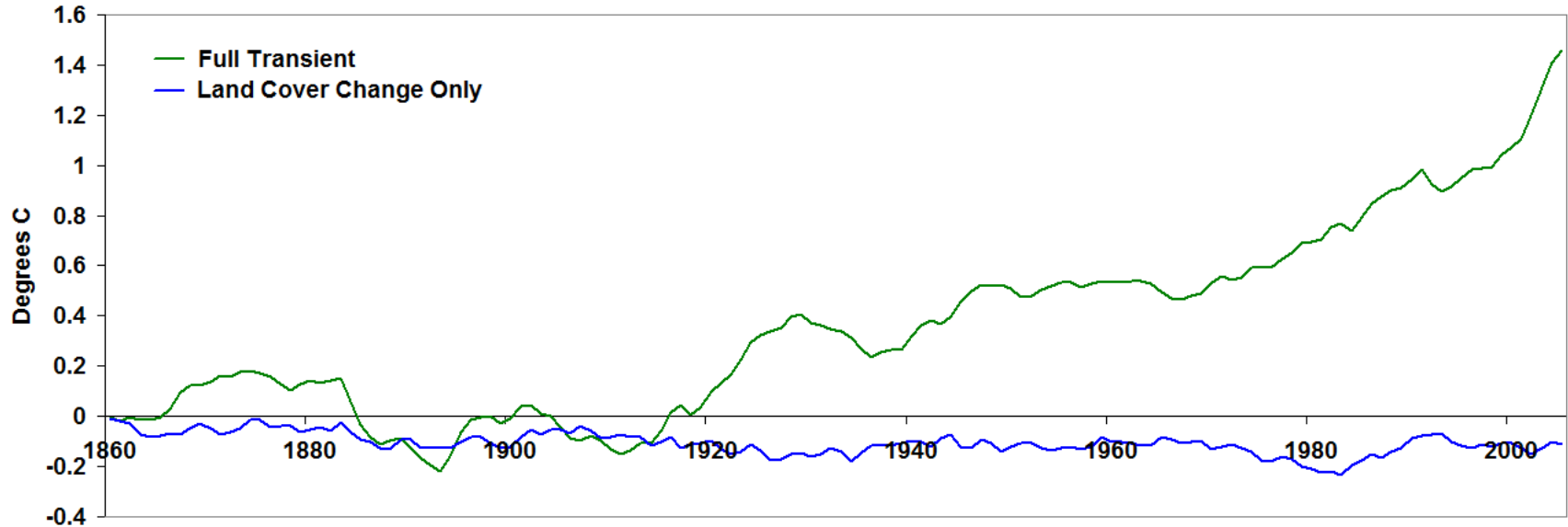


CESM – Historical Full Transient vs Land Cover Change

CCSM 4.0 Change in Global Shortwave Land Surface Albedo - 10 year smoothed

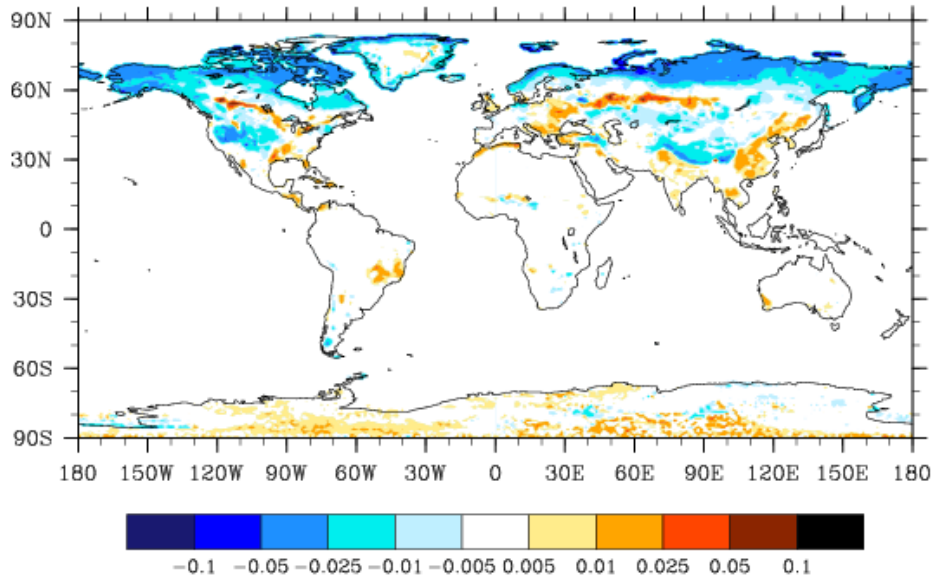


CCSM 4.0 Change in Global Land Air Temperature - 10 year smoothed

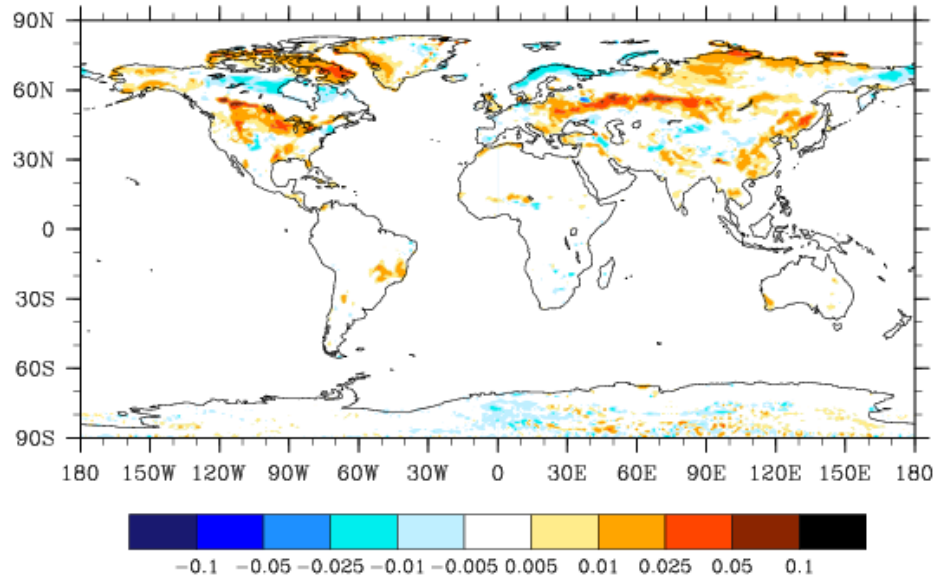


CESM – Historical Full Transient vs Land Cover Change

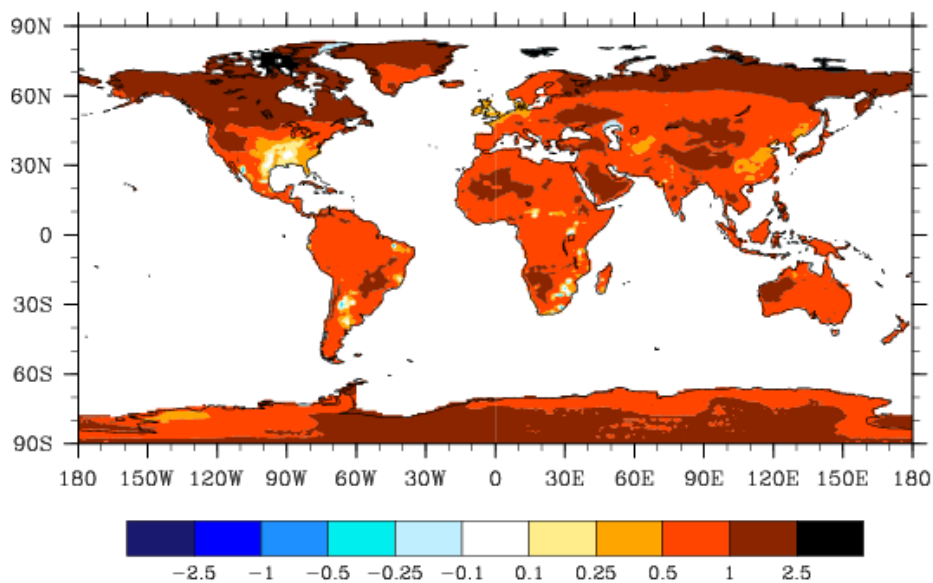
(a) Full Transient - Change in Albedo



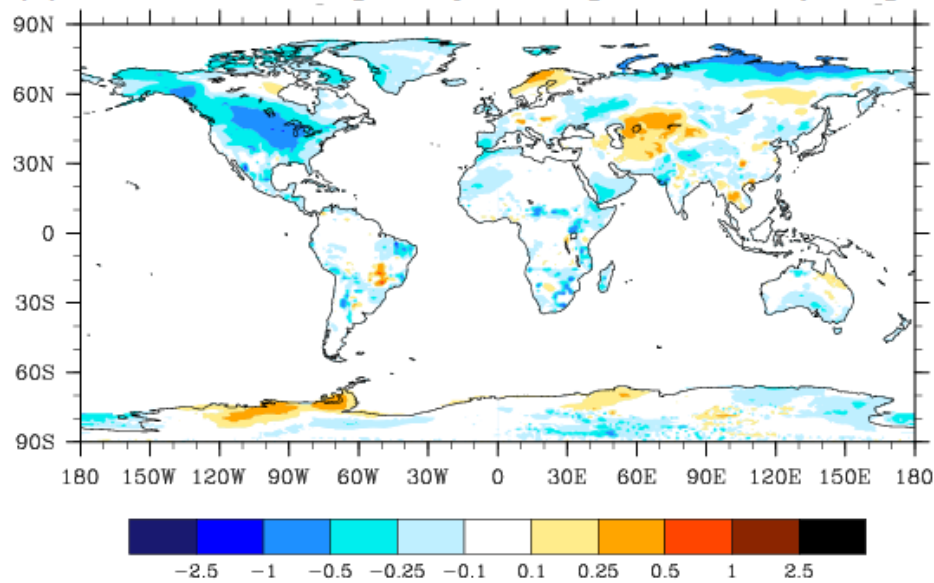
(b) Land Cover Change Only - Change in Albedo



(c) Full Transient - Change in 2m Temperature Deg C



(d) Land Cover Change Only - Change in 2m Temp Deg C



Summary Land Cover Change in CLM4 and CESM

1. Transient CLM4 Land Cover Change is specified as changes in PFTs and wood harvest from the CMIP5 historical and RCP trajectories combined with current day MODIS vegetation and bioclimatically modeled potential vegetation. (1850 – 2100)
2. CLM4 takes these changes in PFTs and wood harvest to change surface fluxes of energy, moisture and carbon. This impacts surface climate and biochemistry as well as larger scale atmospheric processes and chemistry.
3. The future RCP simulations demonstrated that land use can be an effective management tool for carbon. RCP 4.5 resulted in an increase of 64.3 PgC in land carbon through reforestation which offset increasing wood harvest and other land use fluxes.
4. RCP 8.5 on the other hand resulted in a loss of -49.0 PgC of ecosystem carbon