Simulating the Climate Impacts of Land Cover Change and Wood Harvest in the NCAR Community Earth System Model

Peter Lawrence

Terrestrial Science Section

with Johan Feddema, Gordon Bonan, Jerry Meehl, Brian O'Neill, Keith Oleson, Sam Levis, David Lawrence, Erik Kluzek, Keith Lindsay, and Peter Thornton

1. 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
  CO_2, 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]

Growth

Growth

Forestry

Afforestation

Agriculture

Urban
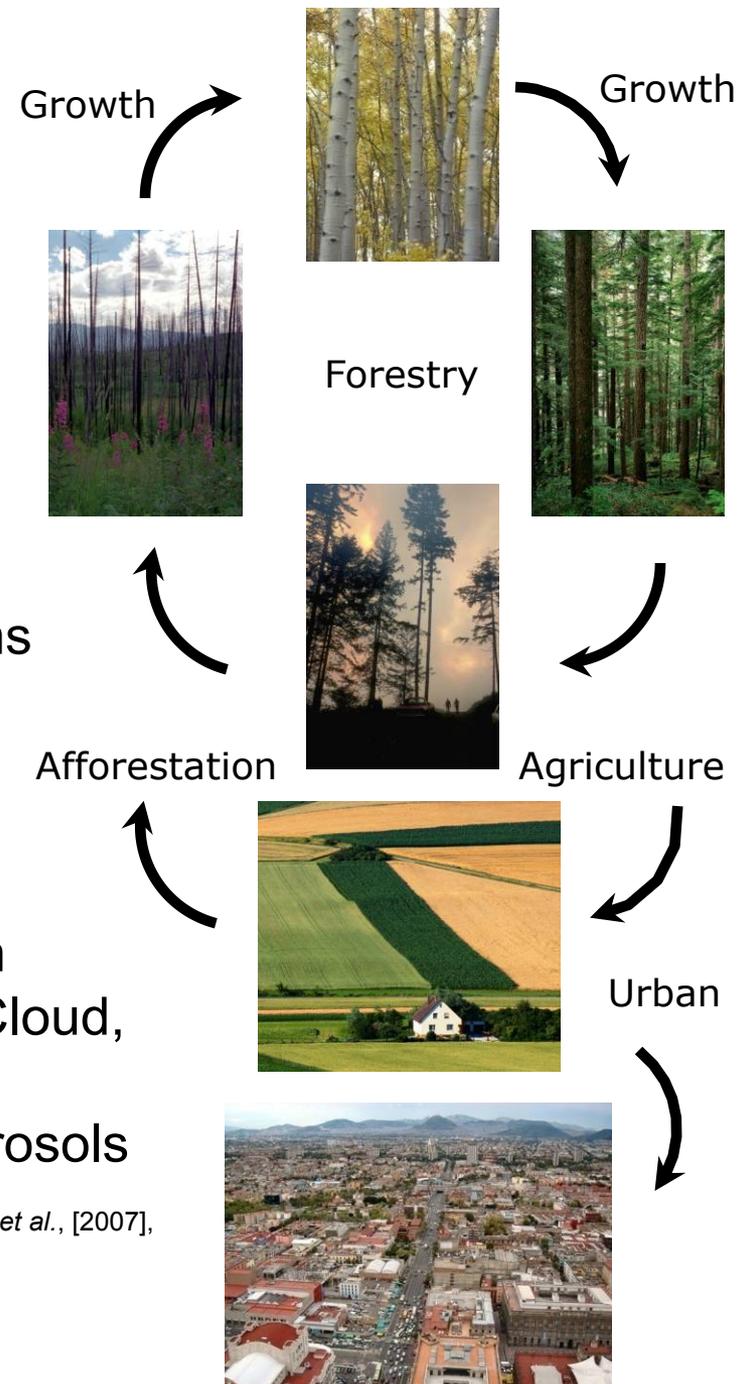
1. Land Cover Change IPCC 4th Assessment Report:

In AR4 the Biogeophysical Impacts of Historical Land Cover Change is listed as radiative cooling of -0.2 W/m² through increased albedo
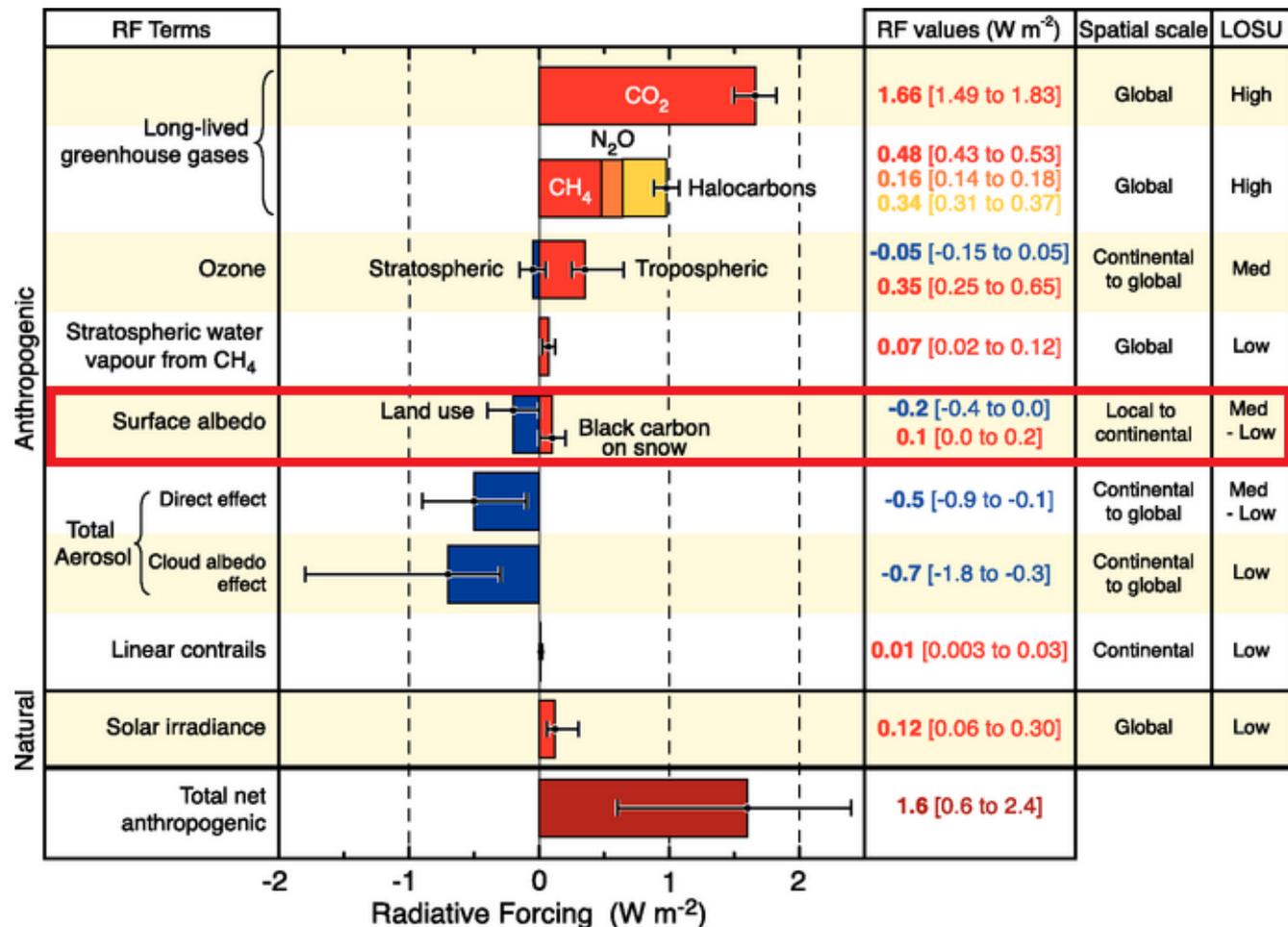
1. Land Cover Change IPCC 4th Assessment Report:

In AR4 the Biogeochemical Impacts of Historical Land Cover Change is listed as 134 Pg C from Houghton (2003) or 12 - 35 ppm increase in CO_2 concentration with equivalent radiative warming of ~ +0.5 W/m^2
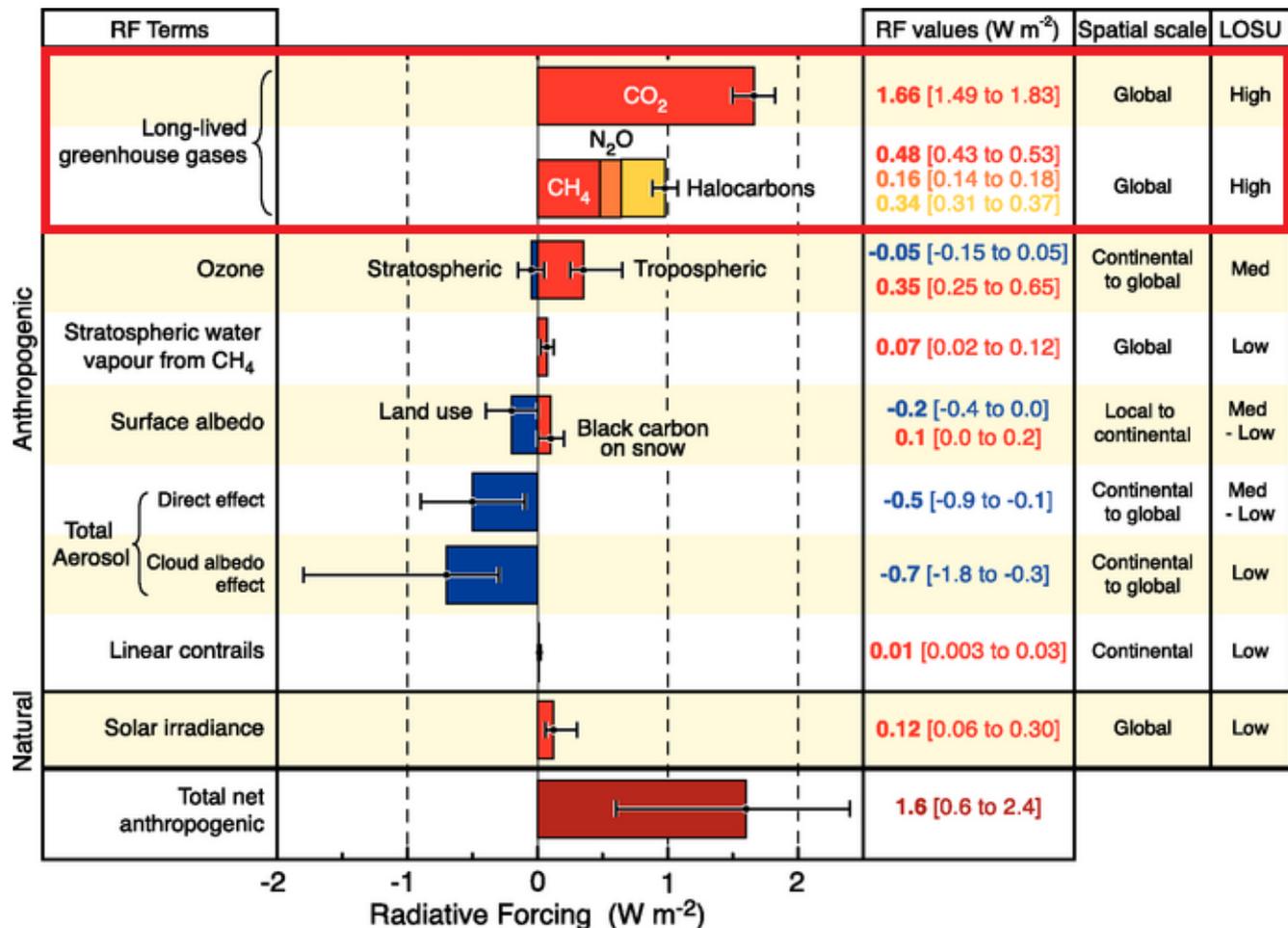
1. Land Cover Change Contribution:

Global Land Carbon Land Emissions

Canadell et al. (2007) 1850 - 2006
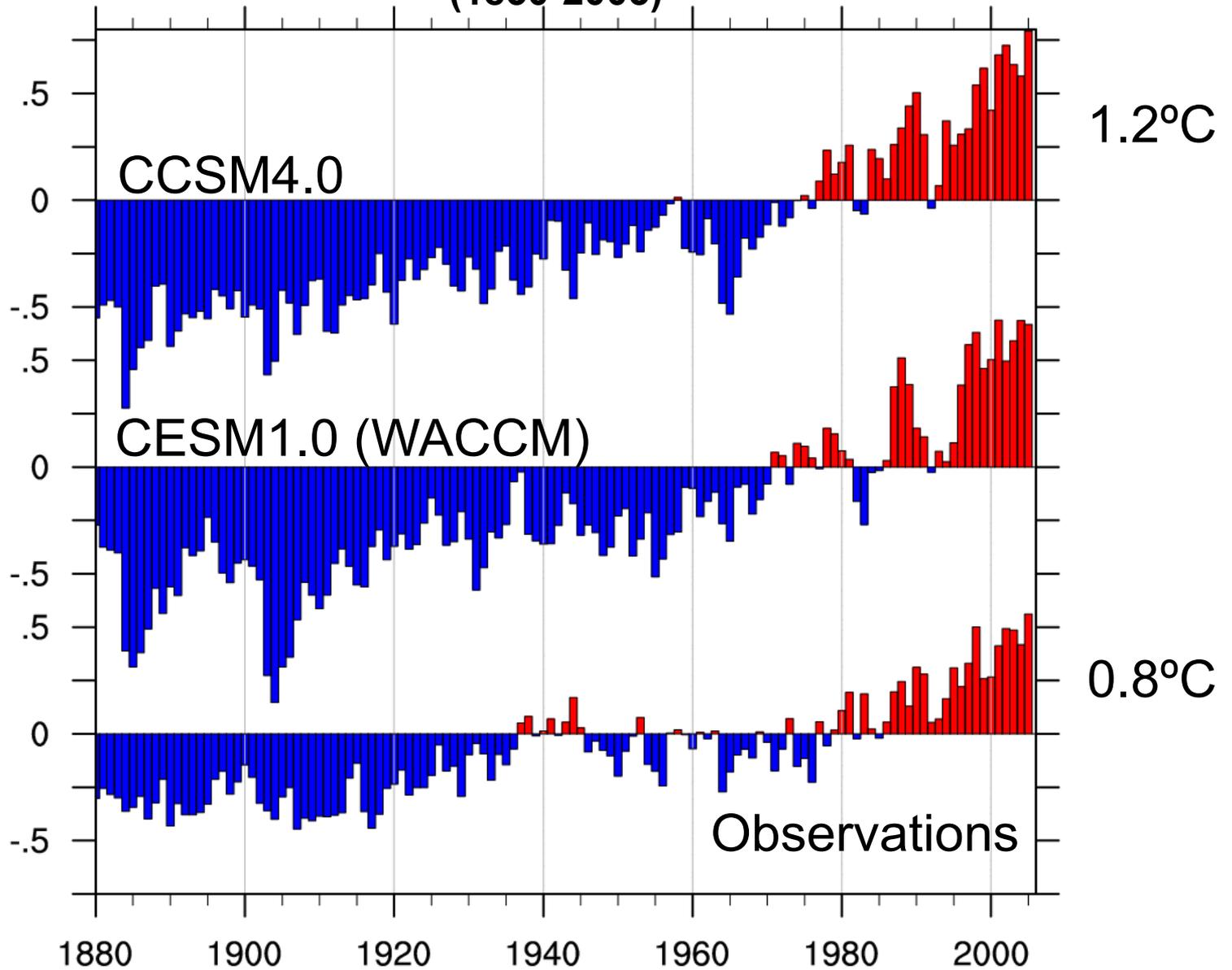
Fossil Fuel   330 Pg C

Land Cover   158 Pg C
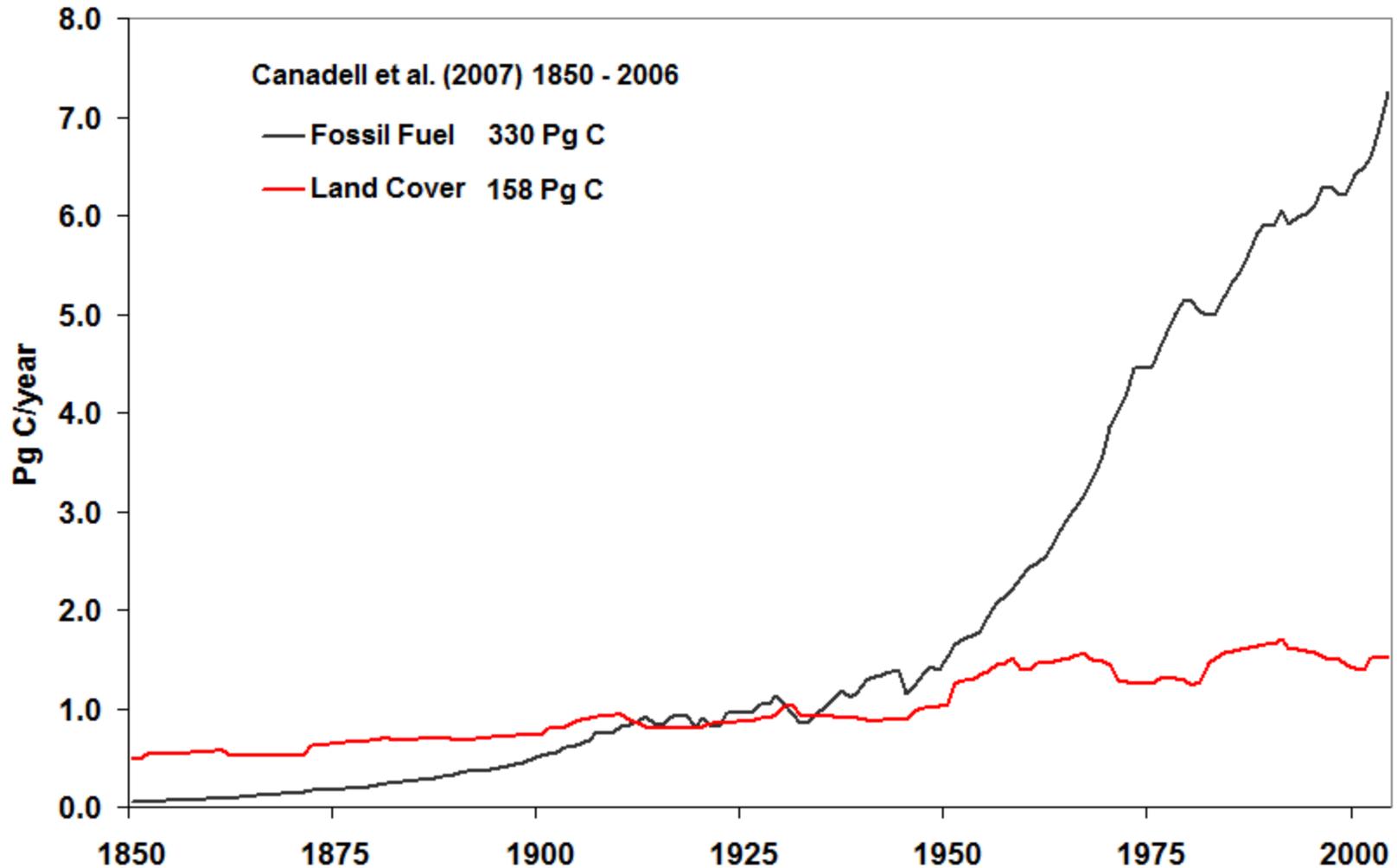
What is the Community Earth System Model (CESM)?

- Comprehensive model to:
  - Investigate and predict seasonal and interannual variability in the climate
  - Explore the history of Earth's climate
  - Estimate future climate and environment for policy formulation
- Collaborations are critical:
  - Developed jointly by NCAR, Department of Energy National Labs and Universities
- Provide support for climate modeling:
  - fully documented and freely available model (portable)
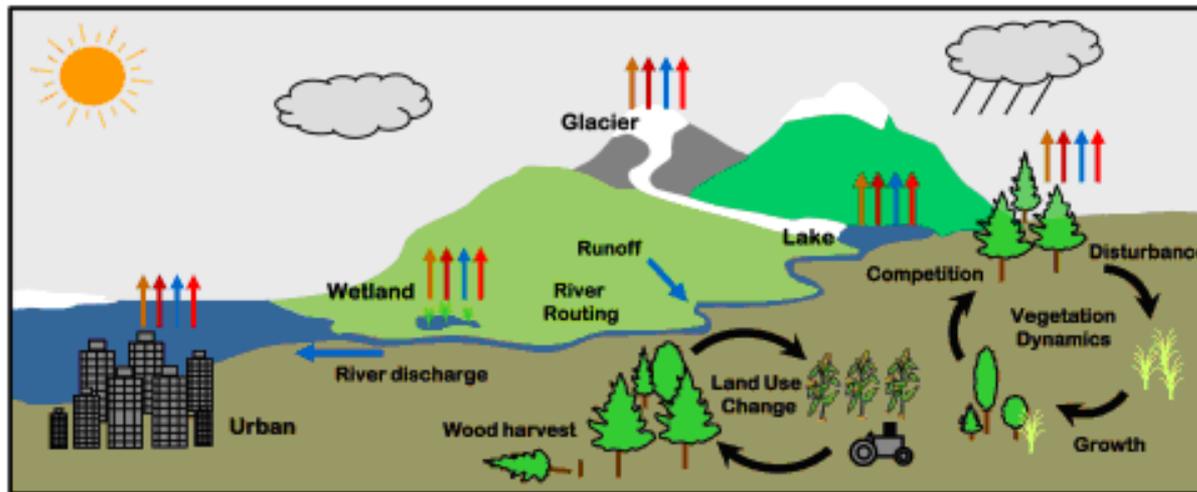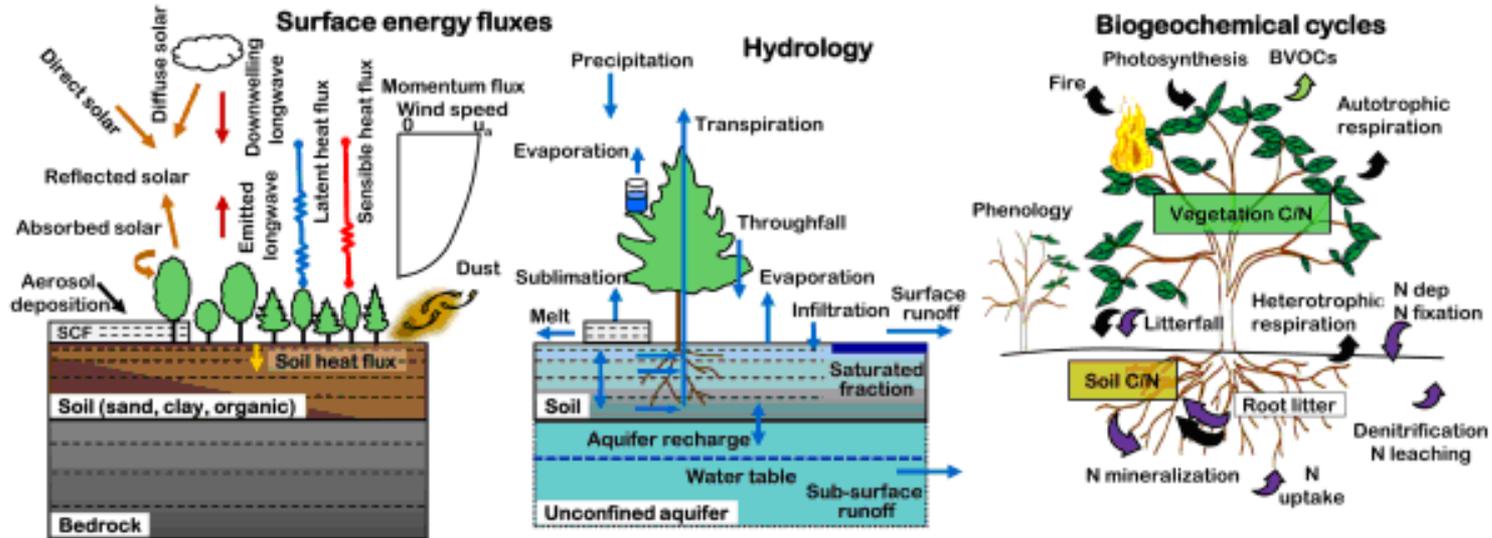 - model data
  - training

Modeling the Climate System

Includes the Atmosphere, Land, Oceans, Ice, and Biosphere
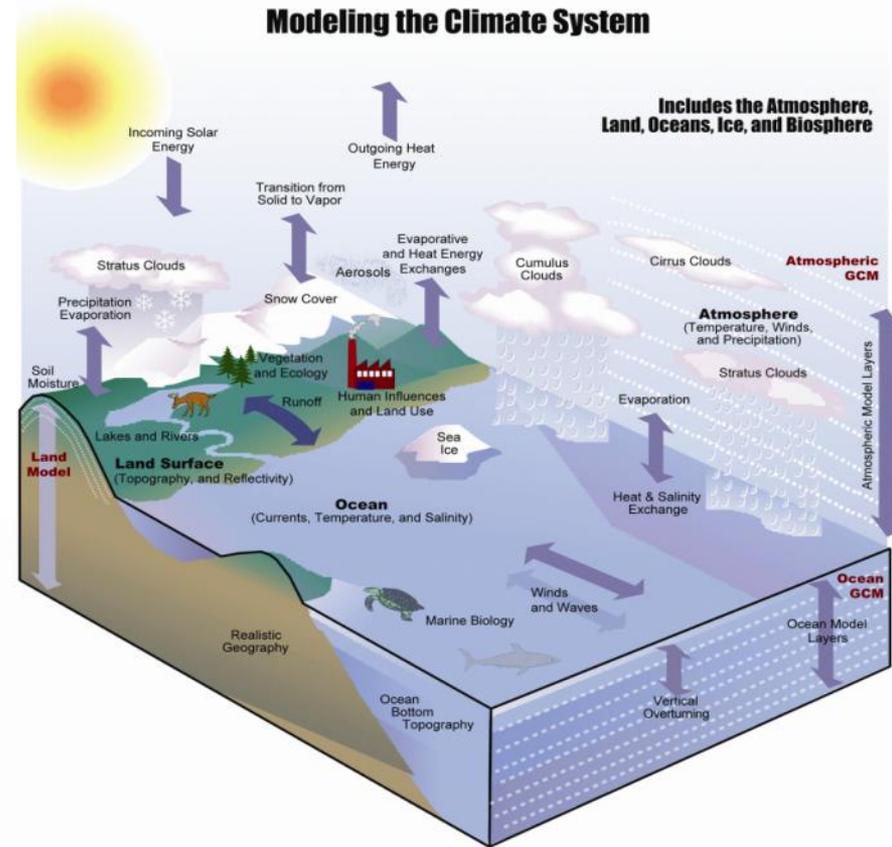
Global Temperature
(1850-2005)
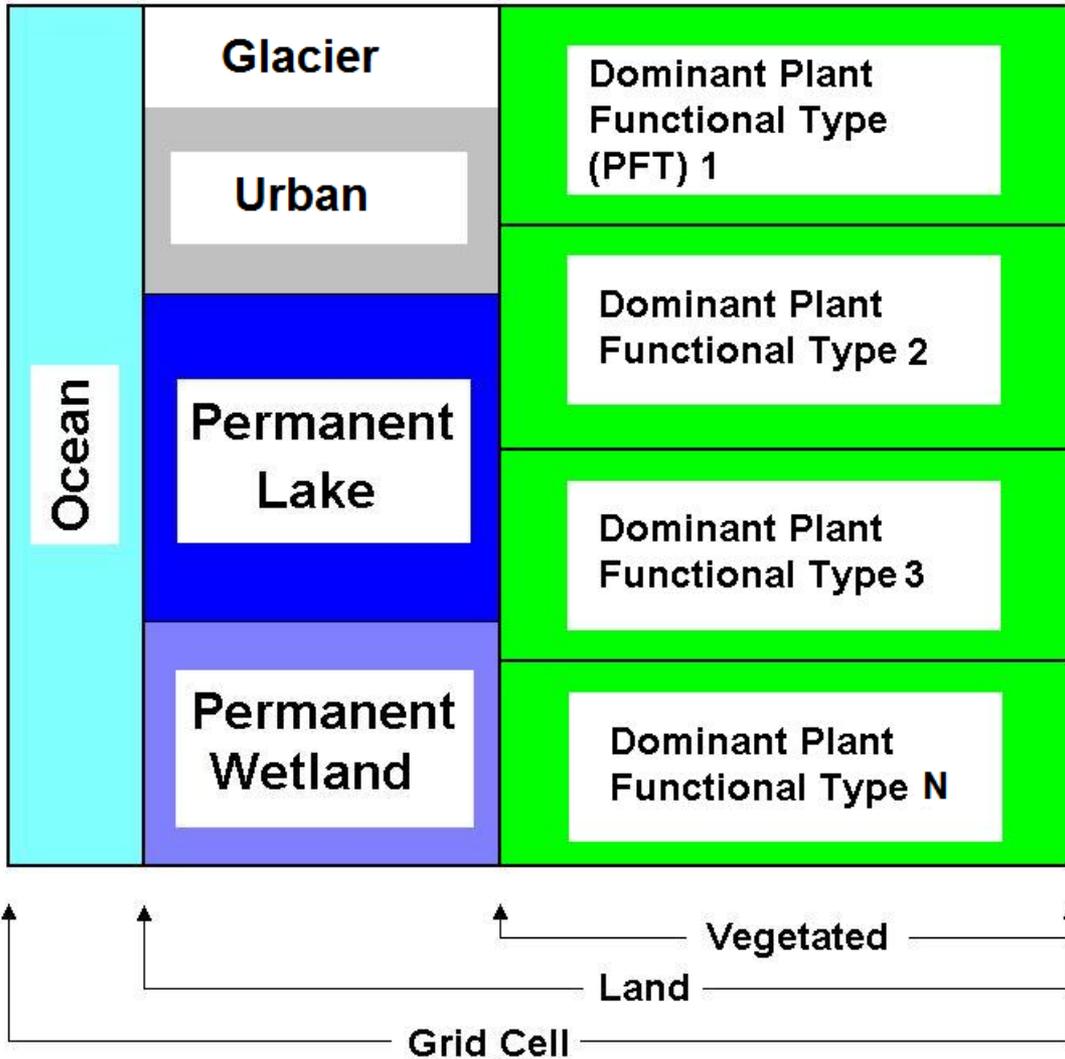

CCSM4.0

1.2ºC

CESM1.0 (WACCM)

0.8ºC

Observations

Community Land Model: NCAR, DOE Labs, University

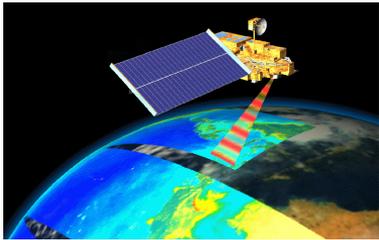# 2. Land Cover Change in CLM4: Plant Functional Types

Tree:
Needleleaf Evergreen Temperate
Needleleaf Evergreen Boreal
Needleleaf Deciduous Boreal
Broadleaf Evergreen Tropical
Broadleaf Evergreen Temperate
Broadleaf Deciduous Tropical
Broadleaf Deciduous Temperate
Broadleaf Deciduous Boreal
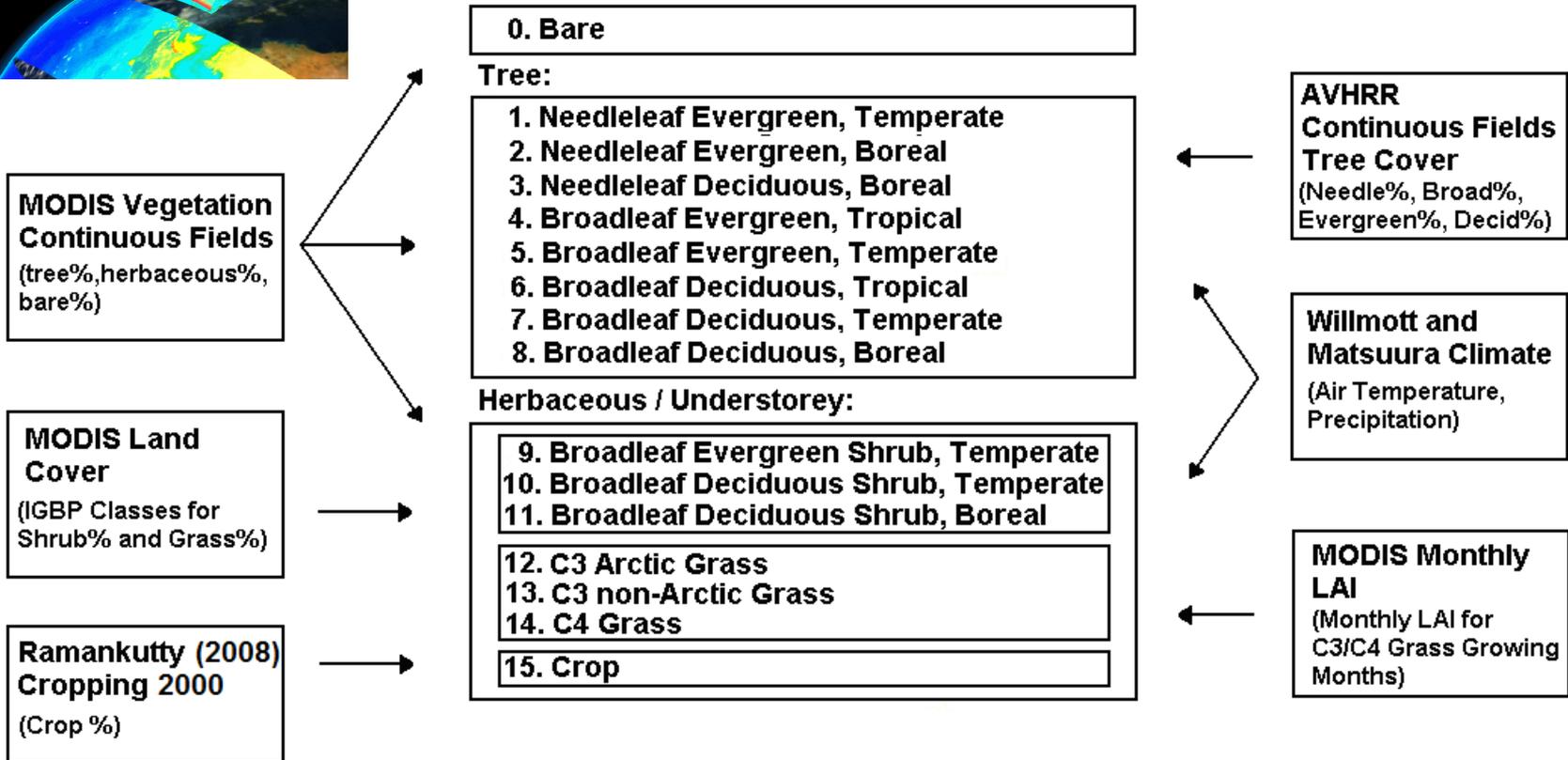
Herbaceous / Understorey:
Evergreen Shrub
Deciduous Temperate Shrub
Deciduous Boreal Shrub
C3 Arctic Grass
C3 non-Arctic Grass
C4 Grass
Crop

Bare

3. Reference point 1: Current Day MODIS PFTs 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:
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

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)
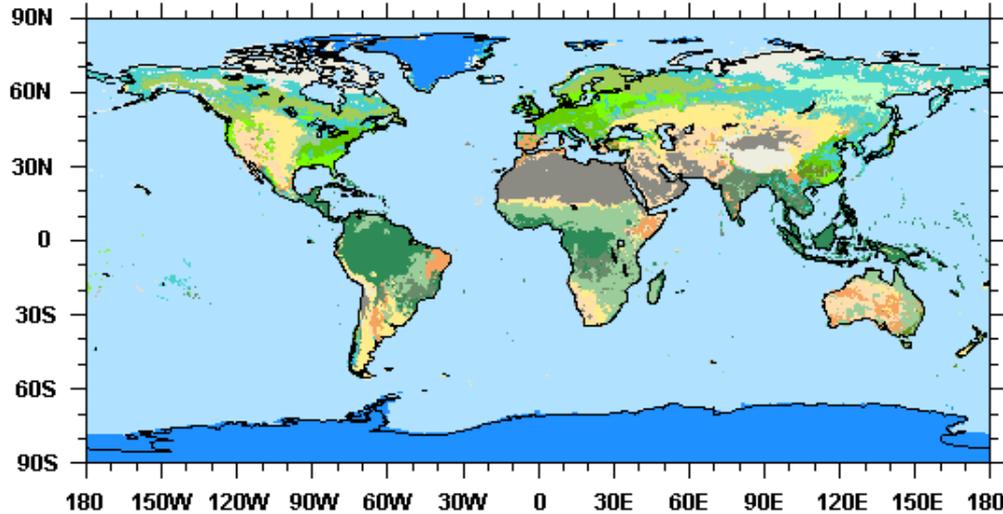
Lawrence and Chase (2007)

3. Reference point 2: Potential Vegetation PFTs from Biome
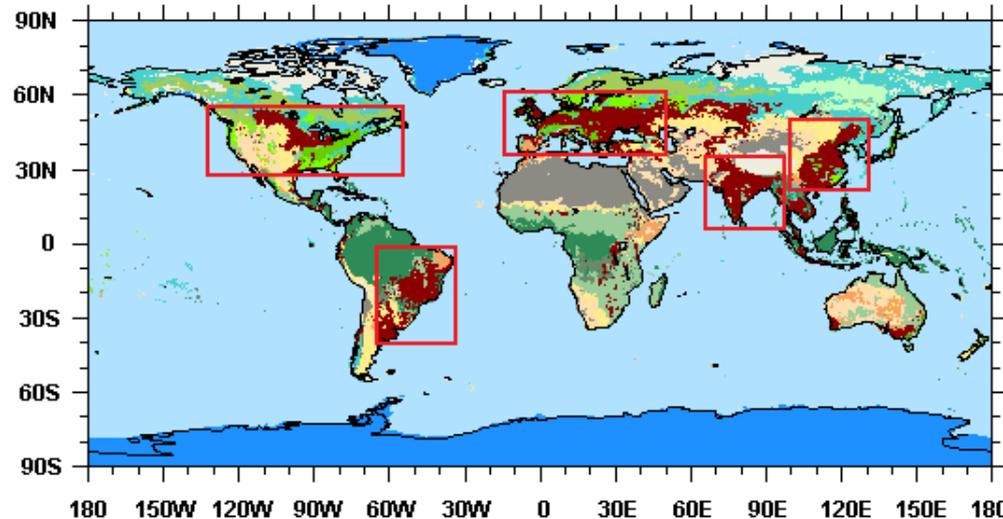

a) Ramankutty and Foley Potential Veg Biomes

b) GLCC Current Day 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

Lawrence and Chase (2010)

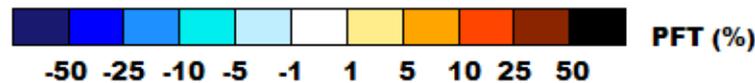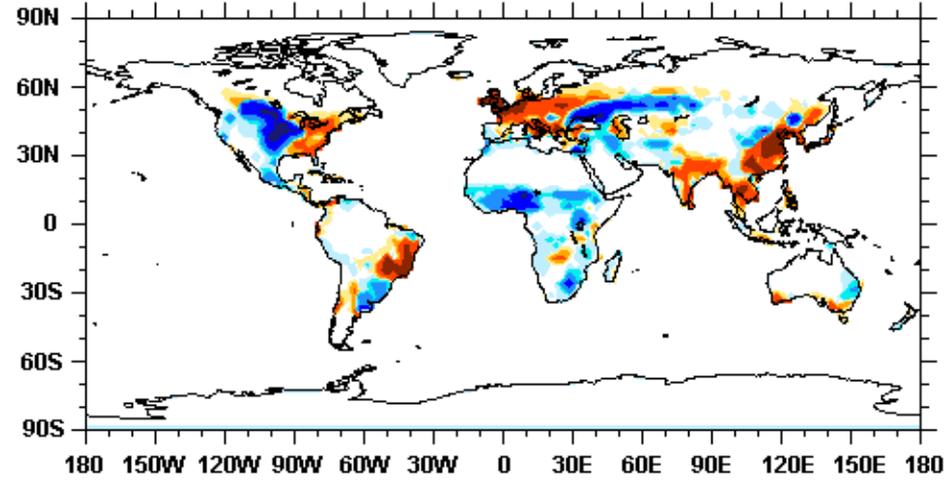# 3. Current Day – Potential Vegetation LCC in CLM PFTs

(a) Current Day - Potential Veg Tree PFTs
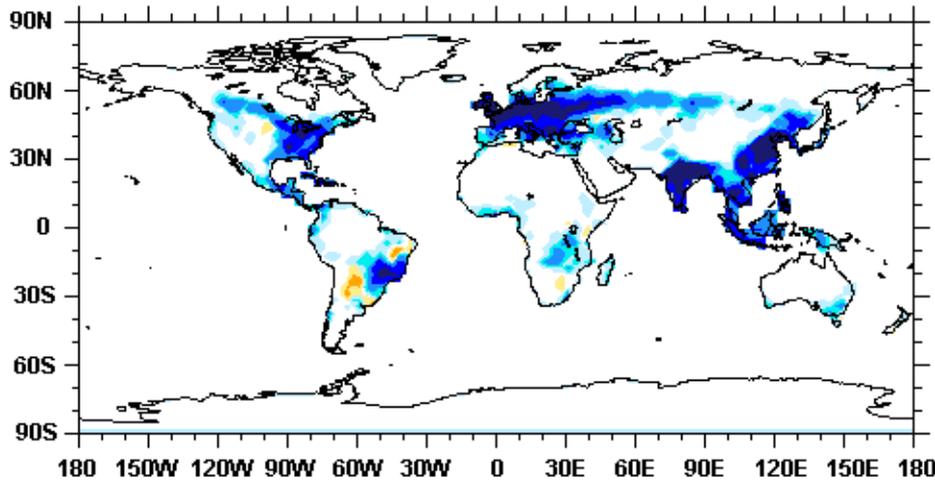
(b) Current Day - Potential Veg Crop PFT
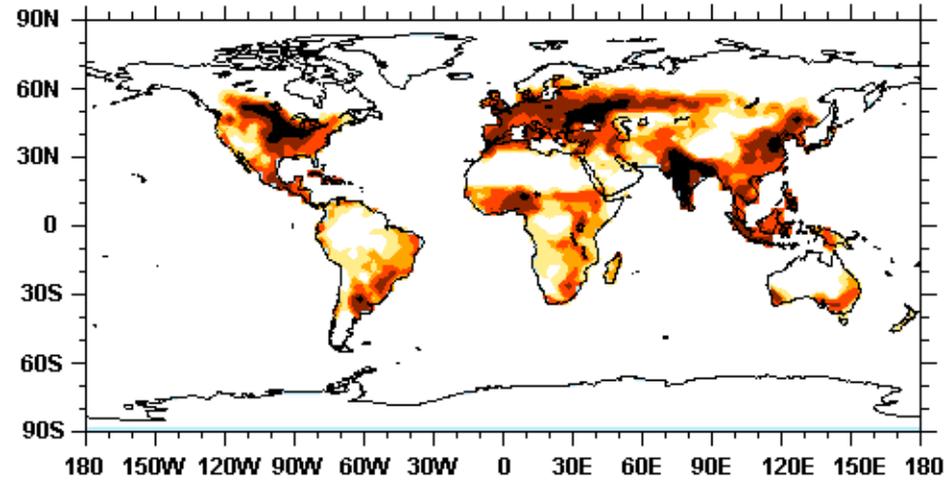
(c) Current Day - Potential Veg Shrub PFTs
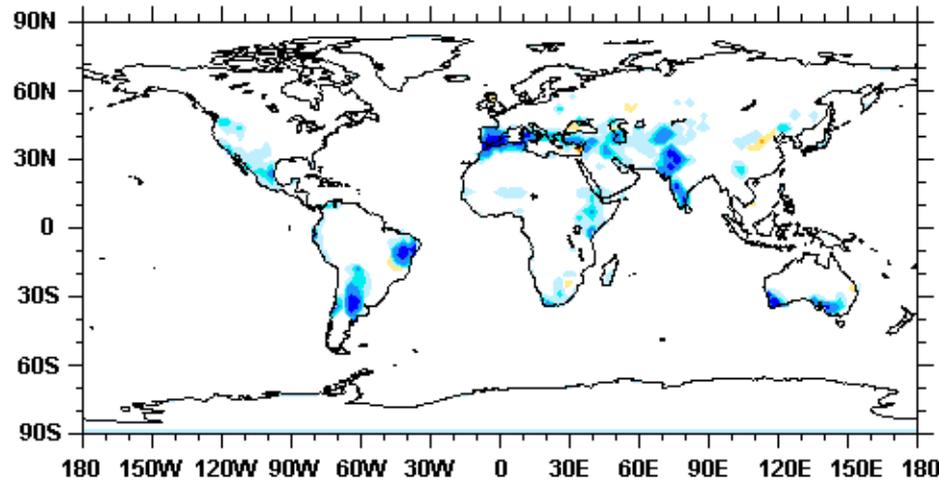
(d) Current Day - Potential Veg Grass PFTs

PFT (%)

-50 -25 -10 -5 -1   1   5   10 25 50
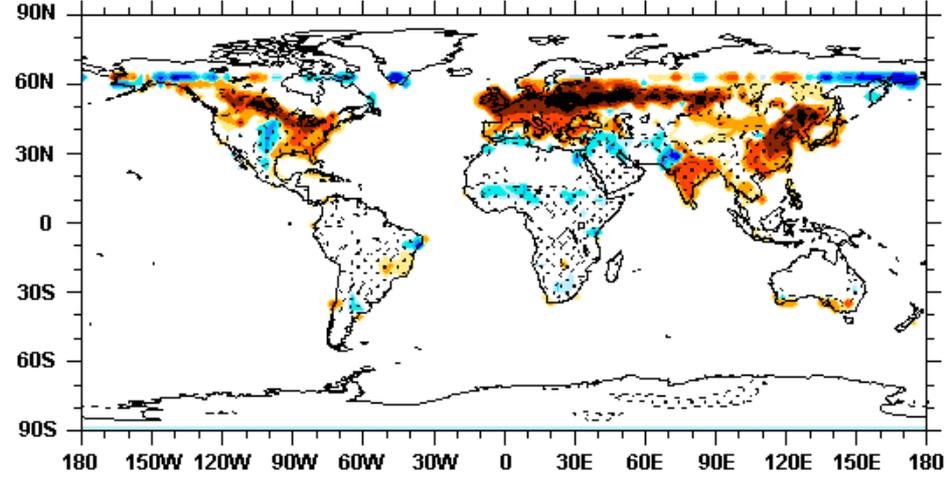
3. CCSM 3.0 Land Cover Change Climate Experiments

1. The biogeophysical climate impacts of changing land cover from potential vegetation to current day vegetation were investigated with the CCSM 3.0 model in *Lawrence and Chase* (2010)

2. The investigation compared six ensemble members of 30 years of current day equilibrium climate simulated in the fully coupled CCSM 3.0 model with Potential Vegetation land surface parameters, to the same climate simulated with Current Day land surface parameters

3. The Land Surface Hydrology representation in CLM 3.0 was modified as described in *Lawrence and Chase* (2009) to address modeling biases.

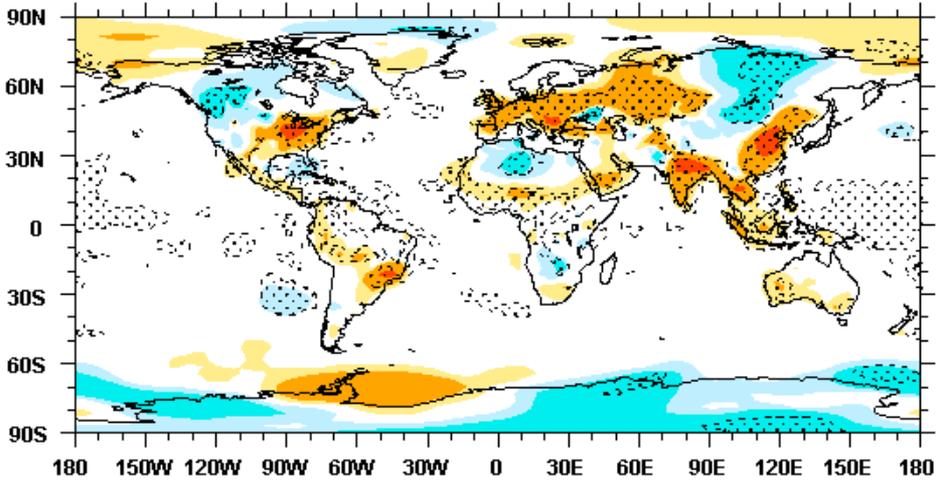# 3. Current Day – Potential Vegetation CCSM Climate-Albedo
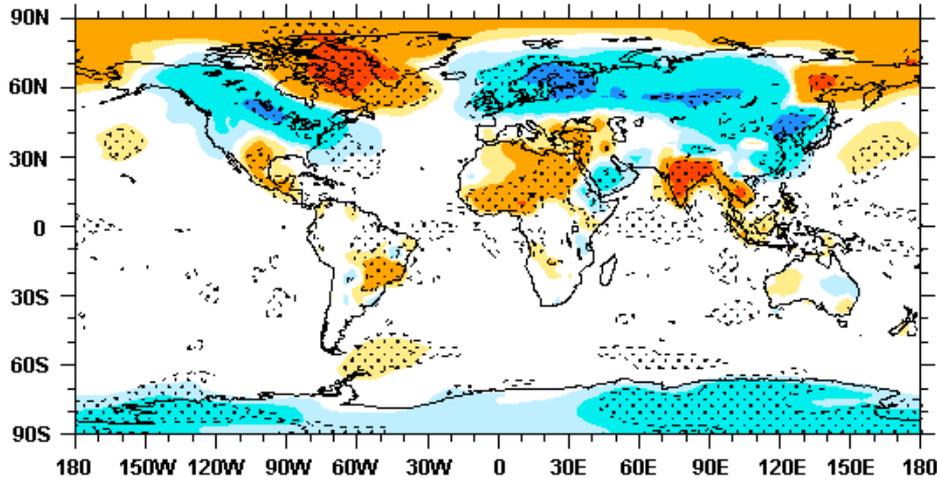
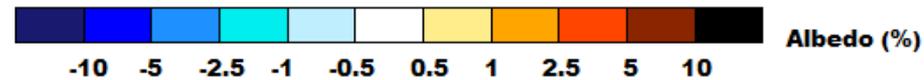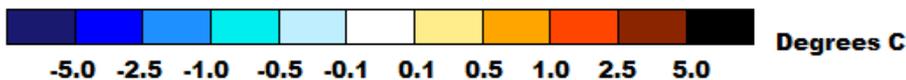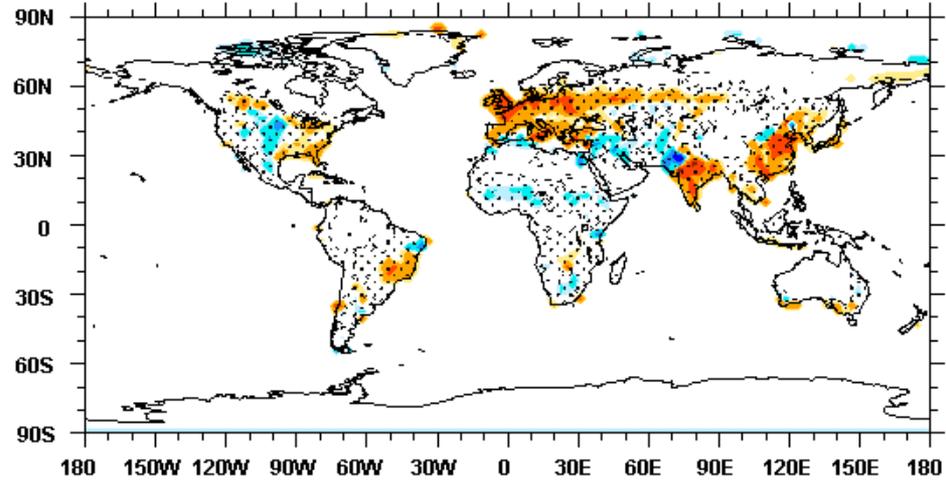
(a) Current Day - Potential Veg DJF 2m Temperature
(b) Current Day - Potential Veg DJF Land Albedo
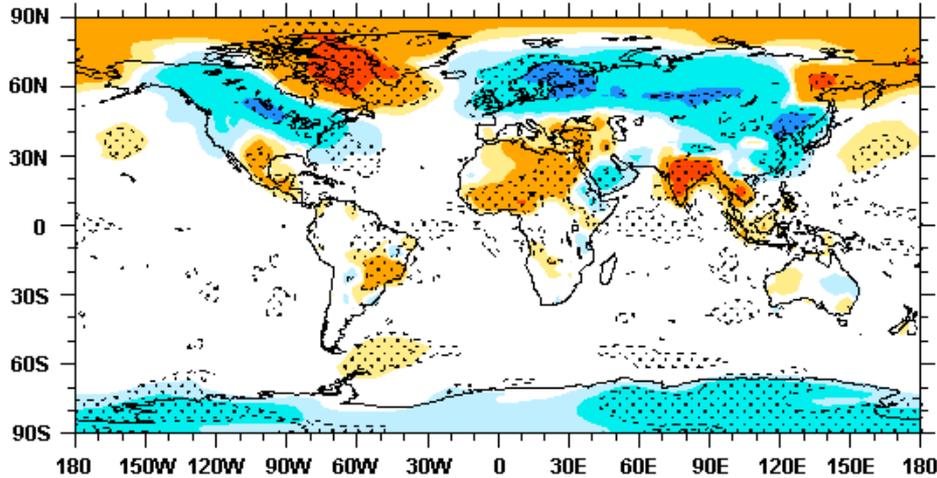(c) Current Day - Potential Veg JJA 2m Temperature
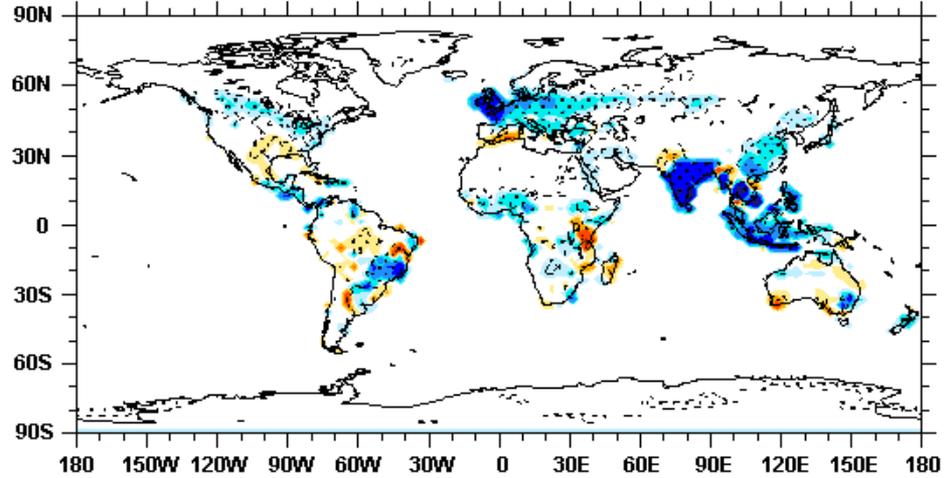(d) Current Day - Potential Veg JJA Land Albedo
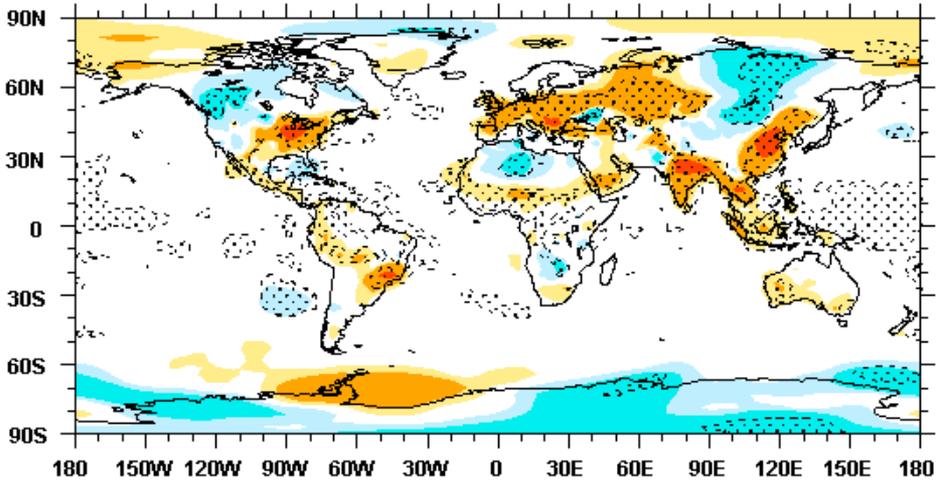
3. Current Day – Potential Vegetation CCSM Climate-Latent

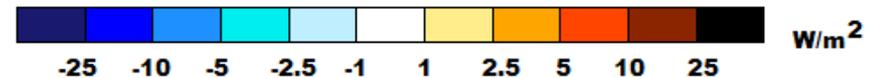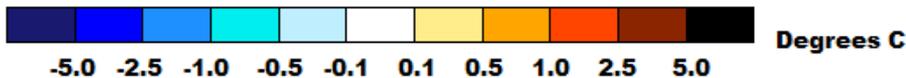(a) Current Day - Potential Veg DJF 2m Temperature

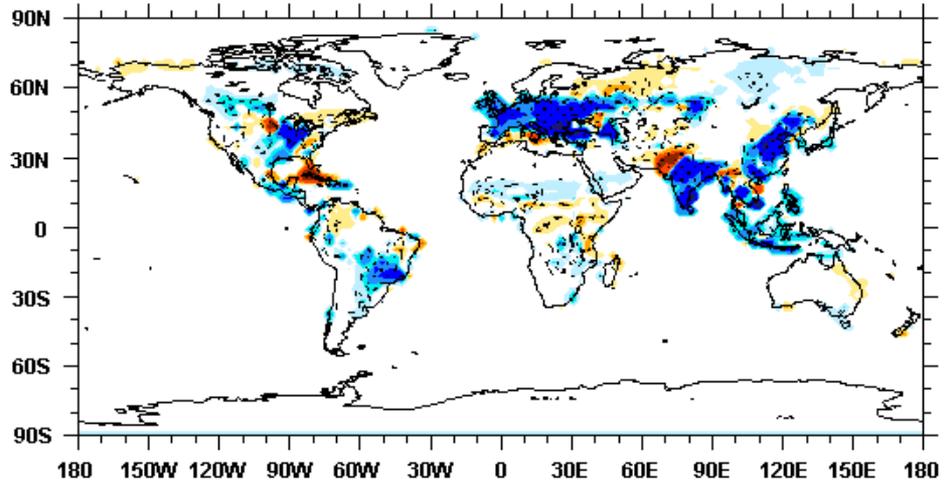(b) Current Day - Potential Veg DJF Land Latent Heat Flux

(c) Current Day - Potential Veg JJA 2m Temperature

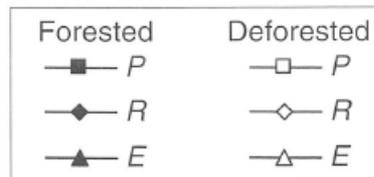(d) Current Day - Potential Veg JJA Land Latent Heat Flux

3. Human Land Cover Change Field Studies

Paired Catchment Hydrology Studies show Deforestation
can result in reduced Evapo-Transpiration and increased Runoff

Hubbard Brook Experimental Forest, New Hampshire Study (*Likens* 2004)
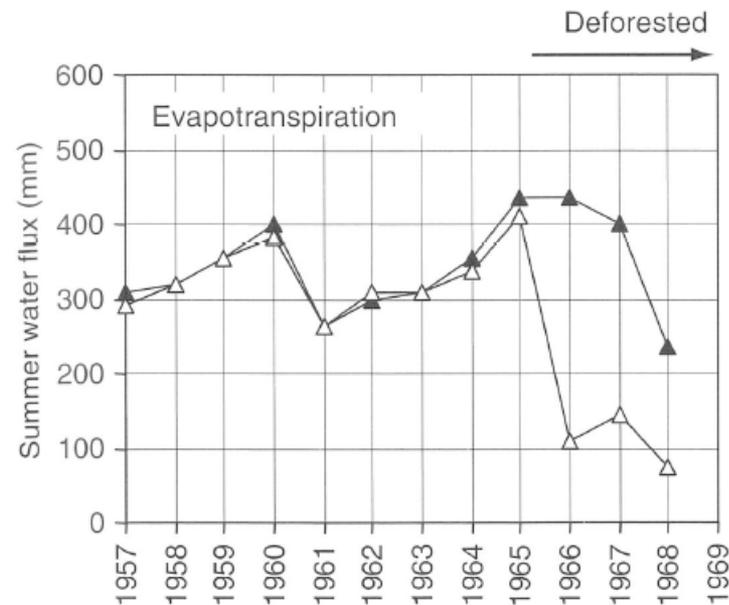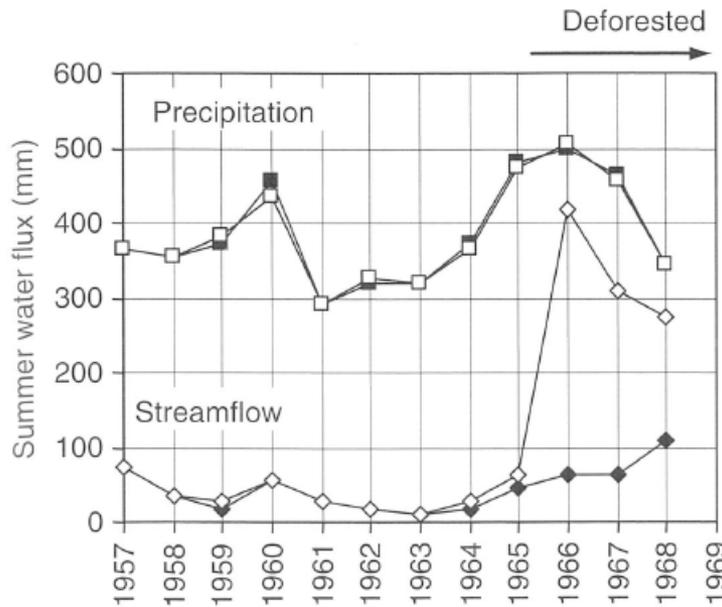
3. Human Land Cover Change Field Studies

Based on the relationship between Deforestation and Agriculture in 171 catchments, *Zhang et al.* (2001) developed a simplistic vegetation based relationship between Annual Precipitation and Evapo-Transpiration:

Figure 8. Comparison of equation (8) with the empirical relationships developed by *Holmes and Sinclair* [1986] and *Turner* [1991] for forested and grassed catchments.

3. Summary of CCSM 3.0 Land Cover Change Experiments

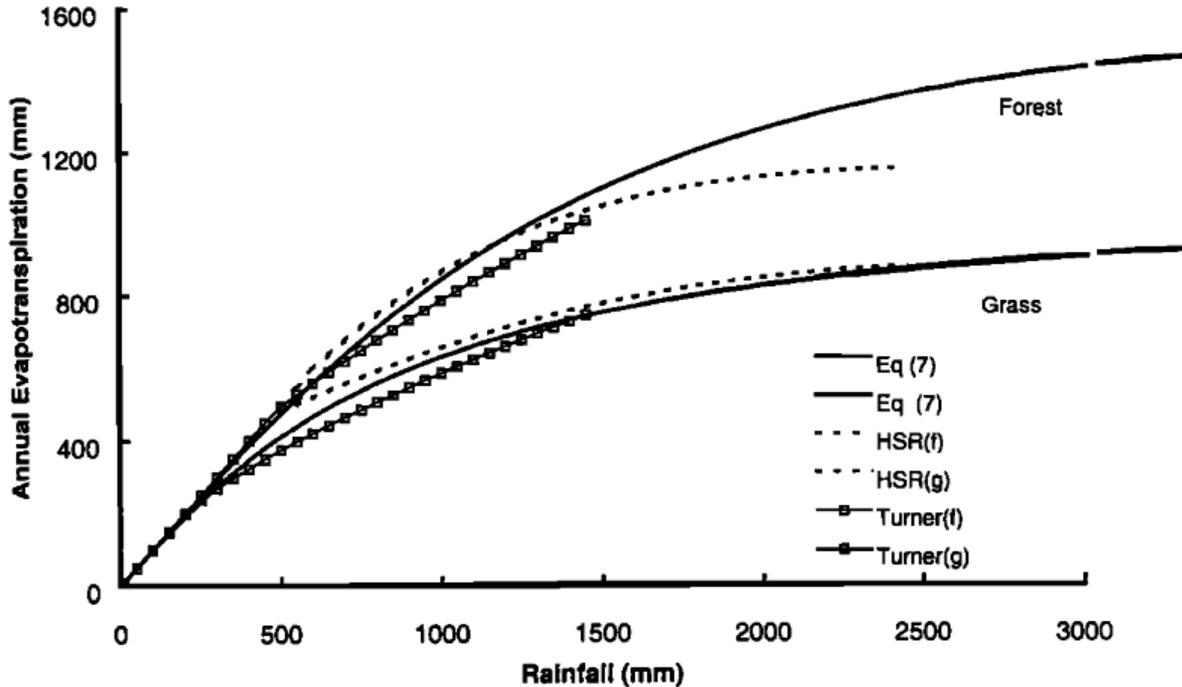1. The biogeophysical climate impacts of changing land cover from potential vegetation to current day vegetation were investigated with the CCSM 3.0 model in *Lawrence and Chase* (2010) and found:

2. High latitude winter cooling due increased albedo from current day crops and grasses which replace natural forests, savannas and shrublands. These changes were amplified by snow interactions

3. Tropical warming and summer higher latitude warming associated with reduced evapo-transpiration which left more of the surface energy budget available for sensible heating – despite higher albedo

4. CMIP5 – Land Cover Change and Wood Harvest

1. Land cover change is included in the CMIP5 protocol for the 1850 – 2005 Historical period and for each of the 2006 – 2100 Representative Concentration Pathway (RCP) periods

2. 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)

3. Harvesting of biomass is also prescribed for both primary and secondary vegetation land units

4. Methods for putting these trajectories into CCSM4 were discussed and finalized here at the 2009 Energy Modeling Forum

Intergovernmental Panel on
Climate Change

4. CMIP5 GLM Historical and RCP Land Cover Change

CMIP5 Land Cover Change for Historical and RCP Time Series (10^6 km^2). van Vuuren et al. (2011)

RCP Land Unit Vegetation Impact Scale: Best – 2nd Best – 2nd Worst – Worst

Time Series	Land Use Description	Primary	Secondary	Crop	Pasture
Historical 1850-2005	**Land use and land cover change is from the HYDE 3.0 database.**	**-48.98**	**13.71**	**9.81**	**25.47**
RCP 2.6 Image 2006 - 2100	**Largest increase in crops with smaller decrease in pasture. Biofuels included in croplands. Forest area declines.**	**-15.27**	**10.66**	**5.29**	**-0.67**
RCP 4.5 GCAM 2006 - 2100	**Only decrease in crops with a similar decrease in pasture. Biofuels included in croplands. Expansion of forested areas for carbon storage.**	**-12.05**	**20.71**	**-4.15**	**-4.52**
RCP 6.0 AIM 2006 - 2100	**Medium cropland increase with largest decrease in pasture. Biofuels included in croplands. Forested area remains constant.**	**-11.88**	**23.61**	**3.70**	**-15.42**
RCP 8.5 Message 2006 - 2100	**Medium increases in both cropland and pasture. Biofuels included in wood harvest. Largest decline in forest area.**	**-19.01**	**12.79**	**2.77**	**3.44**

4. CMIP5 Transient Land Cover in CLM 4 PFTs Method
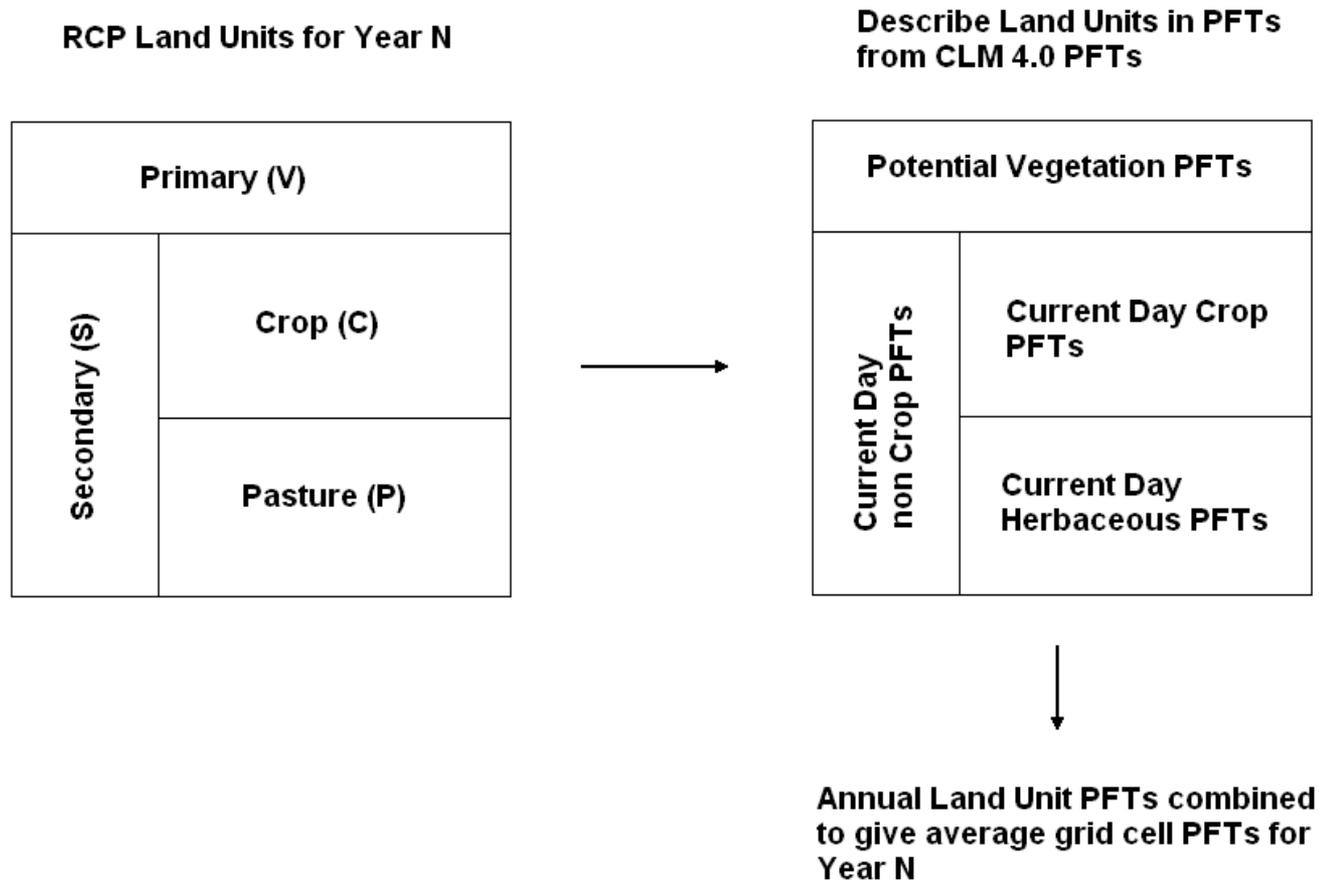
4. CMIP5 Transient Land Cover in CLM 4 1850 – 2100 Ex.

Example Transformation from Land Units to PFTs with wood harvest for a grid cell in Year 1850

GLM Year 2000 Land Units   Reference Data

Primary	- 10%
Secondary	- 20%
Crop	- 40%
Pasture	- 30%

CLM4 Year 2000 MODIS derived PFTs

Tropical Broadleaf Evergreen Tree	- 10%
Tropical Broadleaf Deciduous Tree	- 15%
Crop	- 40%
C4 Grass	- 35%

CLM4 Potential Veg PFTs

Tropical Broadleaf Evergreen Tree	- 70%
Tropical Broadleaf Deciduous Tree	- 20%
C4 Grass	- 10%

CLM4 Year 2000 calculated Secondary PFTs

Tropical Broadleaf Evergreen Tree	- 3%
Tropical Broadleaf Deciduous Tree	- 13%
C4 Grass	- 4%

4. CMIP5 Transient Land Cover in CLM 4 1850 – 2100 Ex.

Example Transformation from Land Units to PFTs with wood harvest for a grid cell in Year 1850

1. GLM Year 1850 Land Units   Transformation

Primary	- 100%	Primary Harvest - 0%
Secondary -	0%	Secondary Harvest - 0%
Crop -	0%	
Pasture -	0%	

GLM Year 2000 Land Units   Reference Data

Primary	- 10%
Secondary	- 20%
Crop	- 40%
Pasture	- 30%

2. CLM4 Year 1850 Final Aggregated PFTs

Tropical Broadleaf Evergreen Tree	-	70%
Tropical Broadleaf Deciduous Tree	-	20%
Crop	-	0%
C4 Grass	-	10%
Tree Harvest	-	0%

CLM4 Year 2000 MODIS derived PFTs

Tropical Broadleaf Evergreen Tree	- 10%
Tropical Broadleaf Deciduous Tree	- 15%
Crop	- 40%
C4 Grass	- 35%

CLM4 Potential Veg PFTs

Tropical Broadleaf Evergreen Tree	- 70%
Tropical Broadleaf Deciduous Tree	- 20%
C4 Grass	- 10%

CLM4 Year 2000 calculated Secondary PFTs

Tropical Broadleaf Evergreen Tree	- 3%
Tropical Broadleaf Deciduous Tree	- 13%
C4 Grass	- 4%

4. CMIP5 Transient Land Cover in CLM 4 1850 – 2100 Ex.

Example Transformation from Land Units to PFTs with wood harvest for a grid cell in Year 2000

1. GLM Year 2000 Land Units   **Transformation**

Primary	- 10%	Primary Harvest - 1%
Secondary	- 20%	Secondary Harvest - 4%
Crop	- 40%	
Pasture	- 30%	

GLM Year 2000 Land Units   **Reference Data**

Primary	- 10%
Secondary	- 20%
Crop	- 40%
Pasture	- 30%

2. CLM4 Year 2000 Final Aggregated PFTs

Tropical Broadleaf Evergreen Tree	- 10%
Tropical Broadleaf Deciduous Tree	- 15%
Crop	- 40%
C4 Grass	- 35%
Tree Harvest	- 4.1%

CLM4 Year 2000 MODIS derived PFTs

Tropical Broadleaf Evergreen Tree	- 10%
Tropical Broadleaf Deciduous Tree	- 15%
Crop	- 40%
C4 Grass	- 35%

CLM4 Potential Veg PFTs

Tropical Broadleaf Evergreen Tree	- 70%
Tropical Broadleaf Deciduous Tree	- 20%
C4 Grass	- 10%

CLM4 Year 2000 calculated Secondary PFTs

Tropical Broadleaf Evergreen Tree	- 3%
Tropical Broadleaf Deciduous Tree	- 13%
C4 Grass	- 4%

4. CMIP5 Transient Land Cover in CLM 4 1850 – 2100 Ex.

Example Transformation from Land Units to PFTs with wood harvest for a grid cell in Year 2100

1. GLM Year 2100 Land Units   **Transformation**

Primary	- 10%	Primary Harvest - 1%
Secondary	- 90%	Secondary Harvest - 4%
Crop	- 0%	
Pasture	- 0%	

GLM Year 2000 Land Units   **Reference Data**

Primary	- 10%
Secondary	- 20%
Crop	- 40%
Pasture	- 30%

2. CLM4 Year 2100 Final Aggregated PFTs

Tropical Broadleaf Evergreen Tree	- 20.5%
Tropical Broadleaf Deciduous Tree	- 60.5%
Crop	- 0%
C4 Grass	- 19%
Tree Harvest	- 4.1%

CLM4 Year 2000 MODIS derived PFTs

Tropical Broadleaf Evergreen Tree	- 10%
Tropical Broadleaf Deciduous Tree	- 15%
Crop	- 40%
C4 Grass	- 35%

CLM4 Potential Veg PFTs

Tropical Broadleaf Evergreen Tree	- 70%
Tropical Broadleaf Deciduous Tree	- 20%
C4 Grass	- 10%

CLM4 Year 2000 calculated Secondary PFTs

Tropical Broadleaf Evergreen Tree	- 3%
Tropical Broadleaf Deciduous Tree	- 13%
C4 Grass	- 4%

4. CMIP5 Historical and RCP Land Cover Change PFTs

CMIP5 Land Cover Change for Historical and RCP Time Series (10^6 km^2). van Vuuren et al. (2011)

RCP Land Unit Vegetation Impact Scale: Best – 2nd Best – 2nd Worst – Worst

Time Series	Land Use Description	Tree PFTs	Shrub PFTs	Crop PFTs	Grass PFTs
Historical 1850-2005	**Land use and land cover change is from the HYDE 3.0 database.**	**-5.53**	**-0.97**	**9.81**	**-3.25**
RCP 2.6 Image 2006 - 2100	**Largest increase in crops with smaller decrease in pasture. Biofuels included in croplands. Forest area declines.**	**-2.68**	**-0.41**	**5.29**	**-2.10**
RCP 4.5 GCAM 2006 - 2100	**Only decrease in crops with a similar decrease in pasture. Biofuels included in croplands. Expansion of forested areas for carbon storage.**	**2.96**	**0.19**	**-4.15**	**0.99**
RCP 6.0 AIM 2006 - 2100	**Medium cropland increase with largest decrease in pasture. Biofuels included in croplands. Forested area remains constant.**	**-0.33**	**-0.31**	**3.70**	**-2.95**
RCP 8.5 Message 2006 - 2100	**Medium increases in both cropland and pasture. Biofuels included in wood harvest. Largest decline in forest area.**	**-3.51**	**-0.10**	**2.77**	**0.85**

4. CMIP5 Transient Land Cover in CLM 4 PFTs

CMIP5 Total Global Tree PFT Area

Legend:
- Historical
- RCP 2.6 IMAGE
- RCP 4.5 MiniCAM
- RCP 6.0 AIM
- RCP 8.5 Message
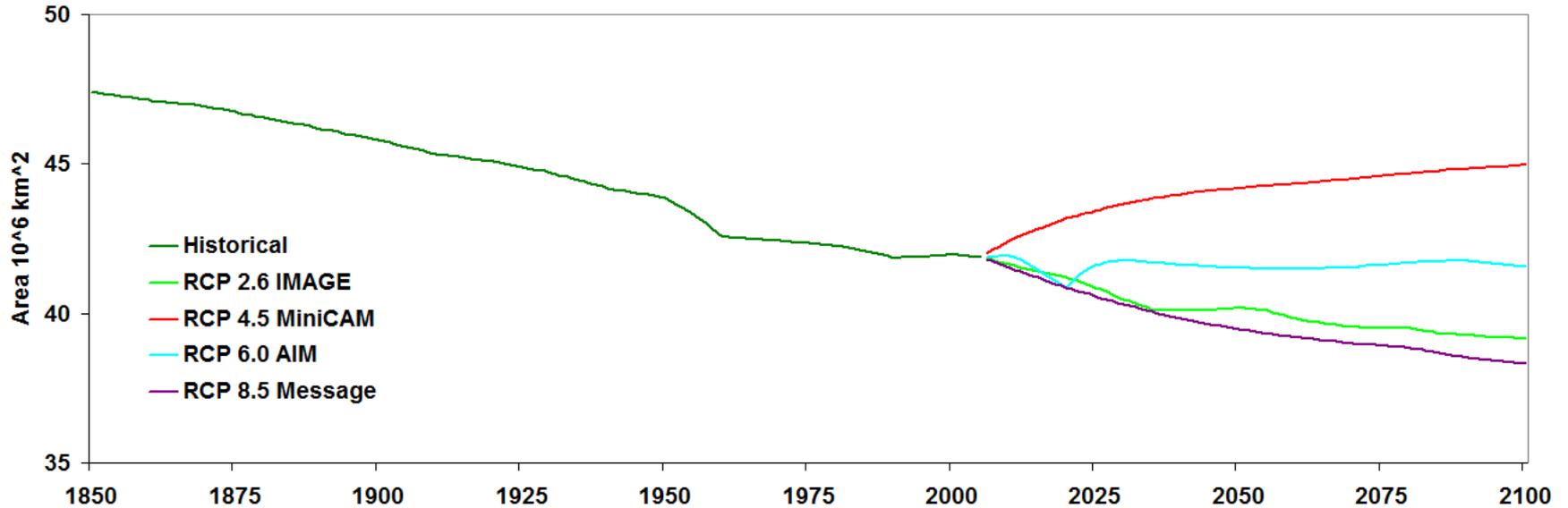
CMIP5 Total Global Crop PFT Area

Legend:
- Historical
- RCP 2.6 IMAGE
- RCP 4.5 MiniCAM
- RCP 6.0 AIM
- RCP 8.5 Message
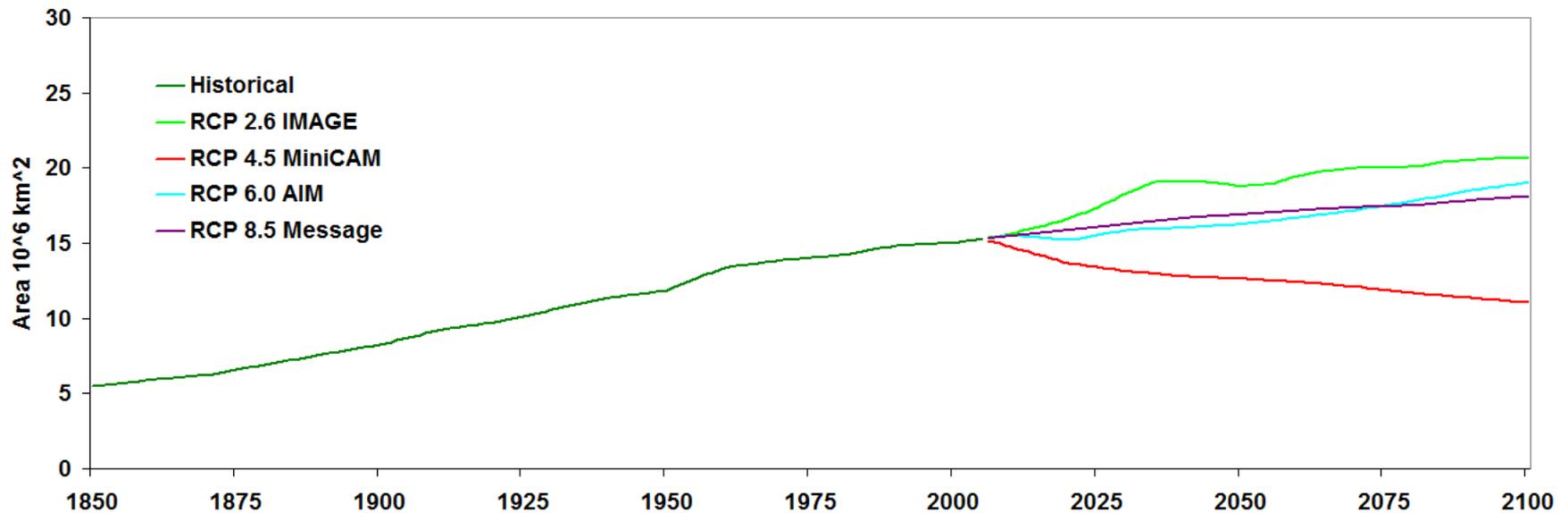
4. CMIP5 - Historical Land Cover Change – PFTs %area

4. CMIP5 - RCP Land Cover Change PFTs – Crop %area
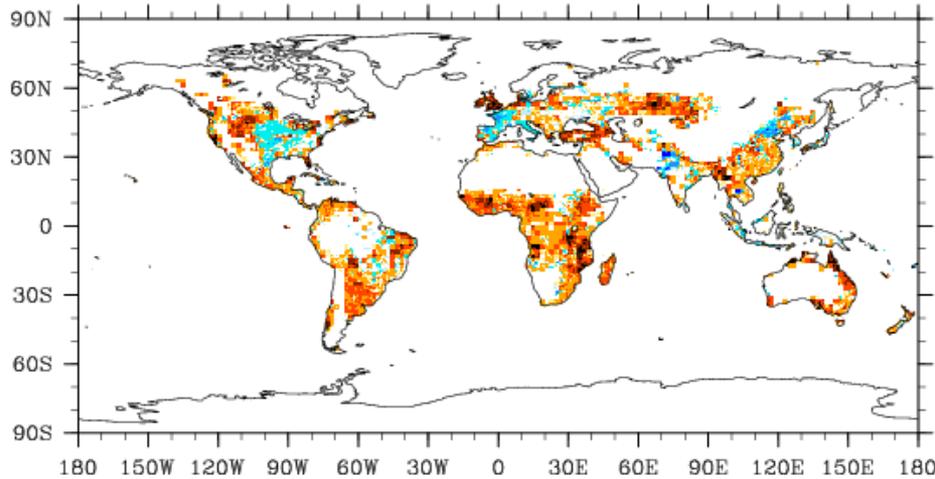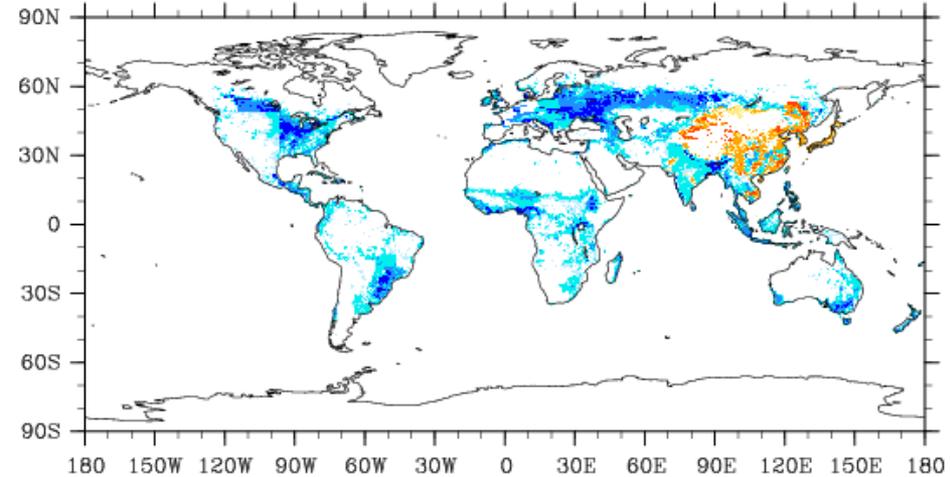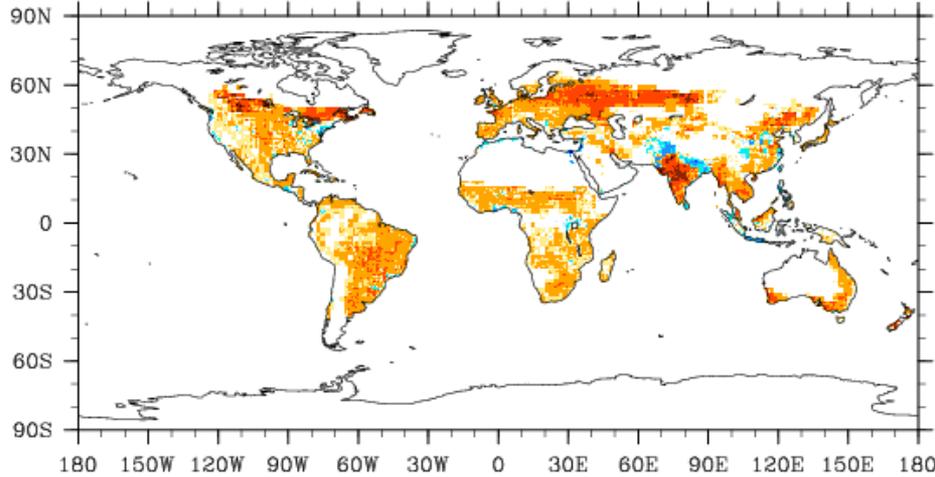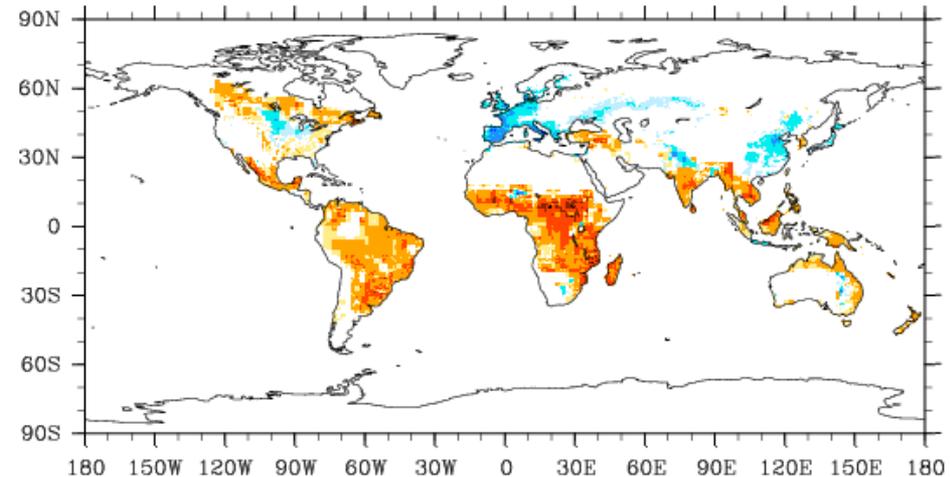
4. CMIP5 - RCP Land Cover Change PFTs – Trees %area

4. CMIP5 Wood Harvest in CLM 4 PFTs

1. Annual tree PFT harvest parameters are calculated for CLM4 based on the harvest area information of the CMIP5 time series

2. The area values are combined with the transient tree PFT values for each grid cell for each year giving a tree PFT harvest fraction

3. This means that the annual GLM harvest area is prescribed directly in CLM4 normalized to transient Tree PFT area.

4. CMIP5 Historical and RCP Tree PFT Harvest

CMIP5 Global Total Annual Tree PFT Harvest Area

Historical (2005-1850) Tree PFT Harvest
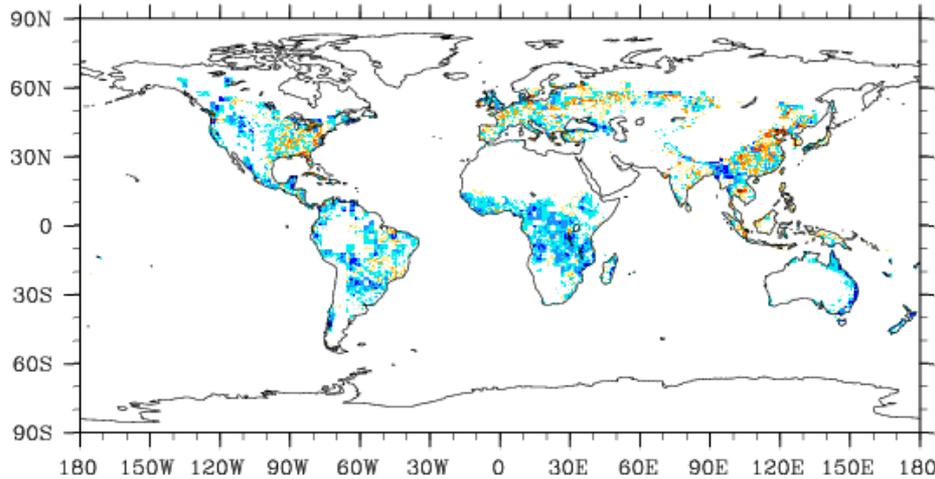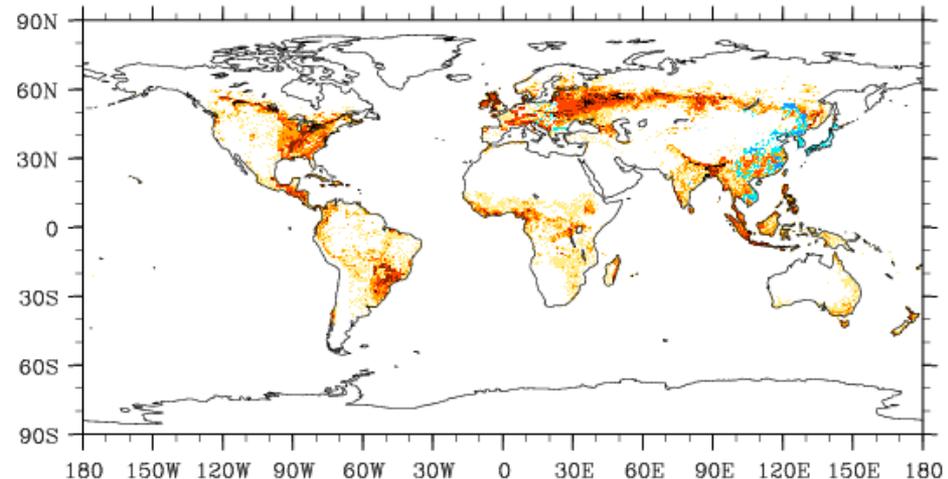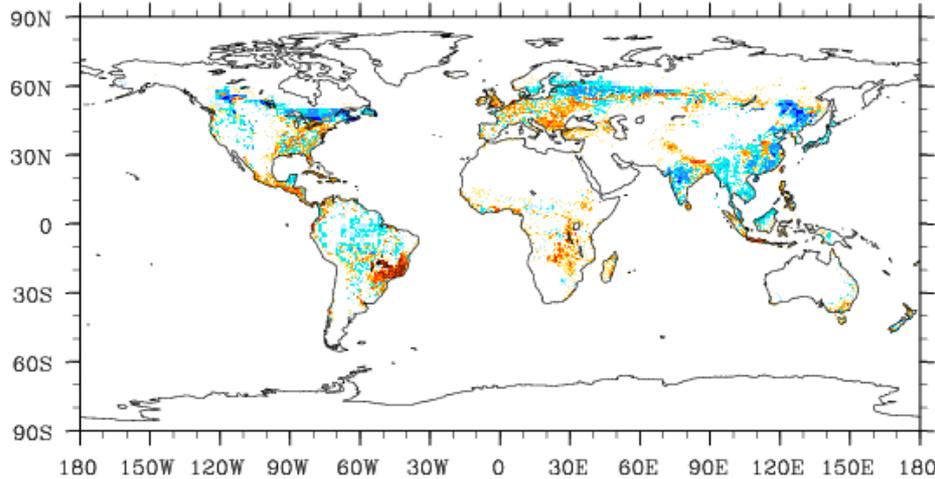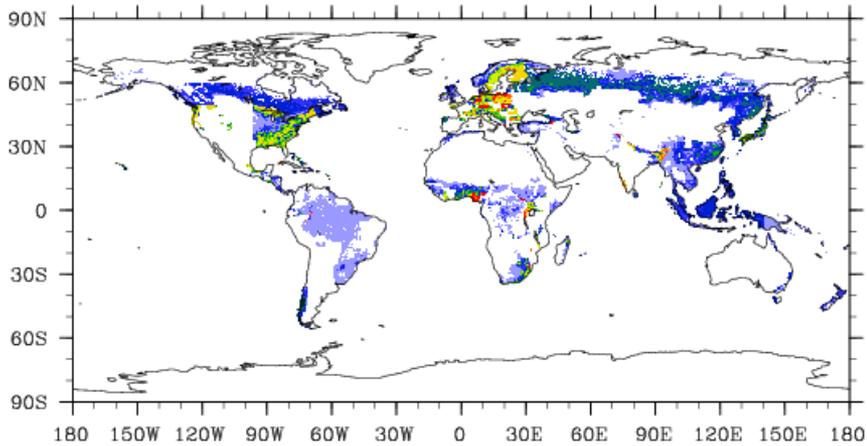
RCP 8.5 Message (2100-2006) Tree PFT Harvest %
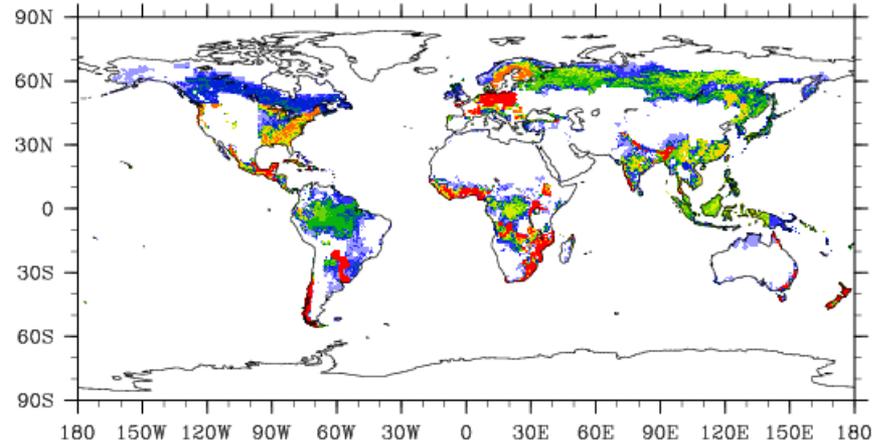
5. CCSM Historical and RCP Full Transient Climate Runs

1. Historical and RCP land surface biogeochemistry is analyzed for multiple realizations of each of the NCAR fully coupled CCSM4 CMIP5 experiments

2. All transient forcings and atmospheric forcings are prescribed through concentrations rather than emissions in these experiments

5. CCSM Historical and RCP Full Transient Climate Runs

CCSM 4.0 Global Averaged Land 2m Air Temperature - 10 year smoothed
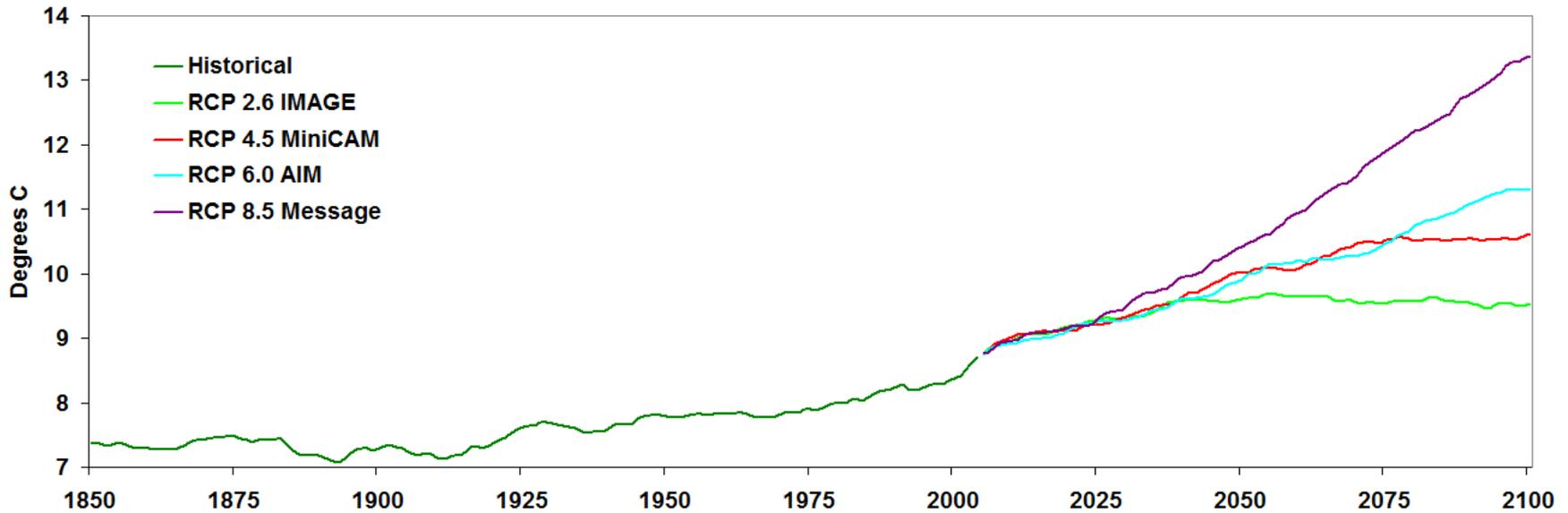
CCSM 4.0 Global Prescribed Surface CO2
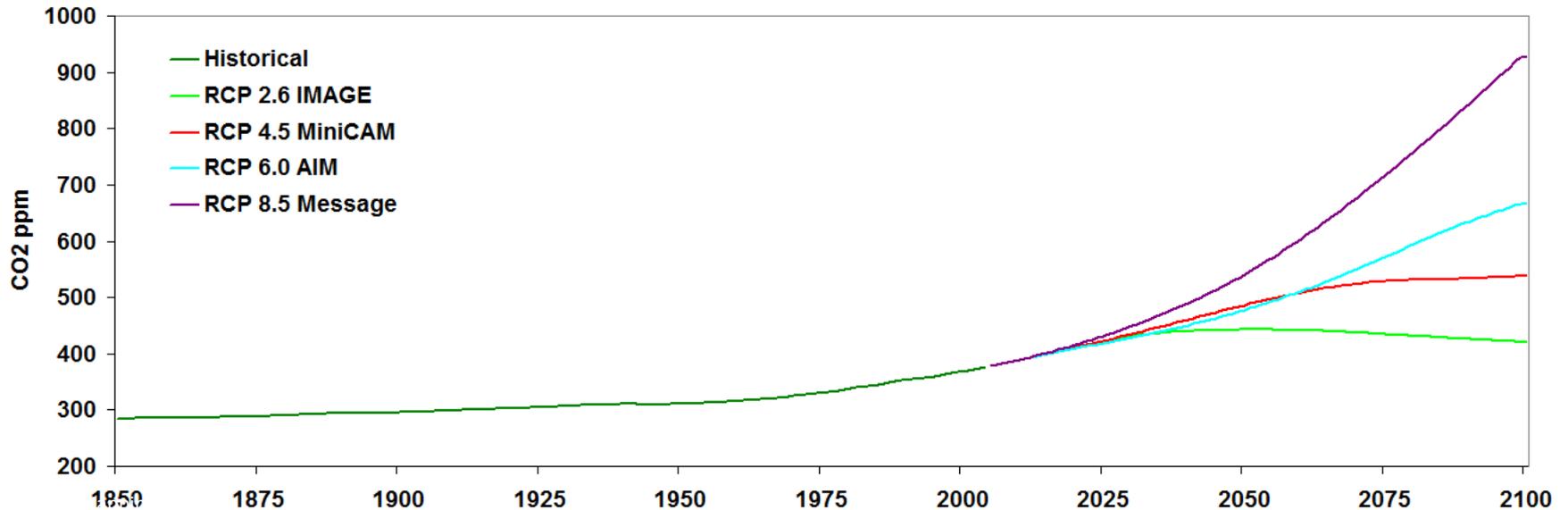
5. Land Cover Change in (CLM4 CN)

(a) Analyzed CLM4 CN Carbon Pools and Fluxes

Net Ecosystem Exchange (NEE)

(Land Use + Het. Resp.+ Fire - NPP)

Terrestrial Ecosystem Sink
(NPP - Het. Resp. - Fire)

Land Use Flux
(LCC + Prod Pool)

Net Primary
Production (NPP)

Heterotrophic
Respiration

Fire

Land Cover
Change Flux

Product Pool
Decay Flux

Leaf
Carbon

Storage
Carbon

Wood Harvest

Wood
Carbon

Litter

CWD

Snow

Soil
Carbon

Root Carbon

Soil

Product Pools
10 and 100 year

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

Aquifer

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

** CWD = Coarse Woody Debris

5. LCC in CCSM 4 – Coupled Climate & Prescribed CO_2

Global Land Use Carbon Fluxes

CCSM 4.0 — 120 Pg C 1850 - 2005 (Product Pool +8 Pg C)
Land Cover Canadell 2007 — 156 Pg C
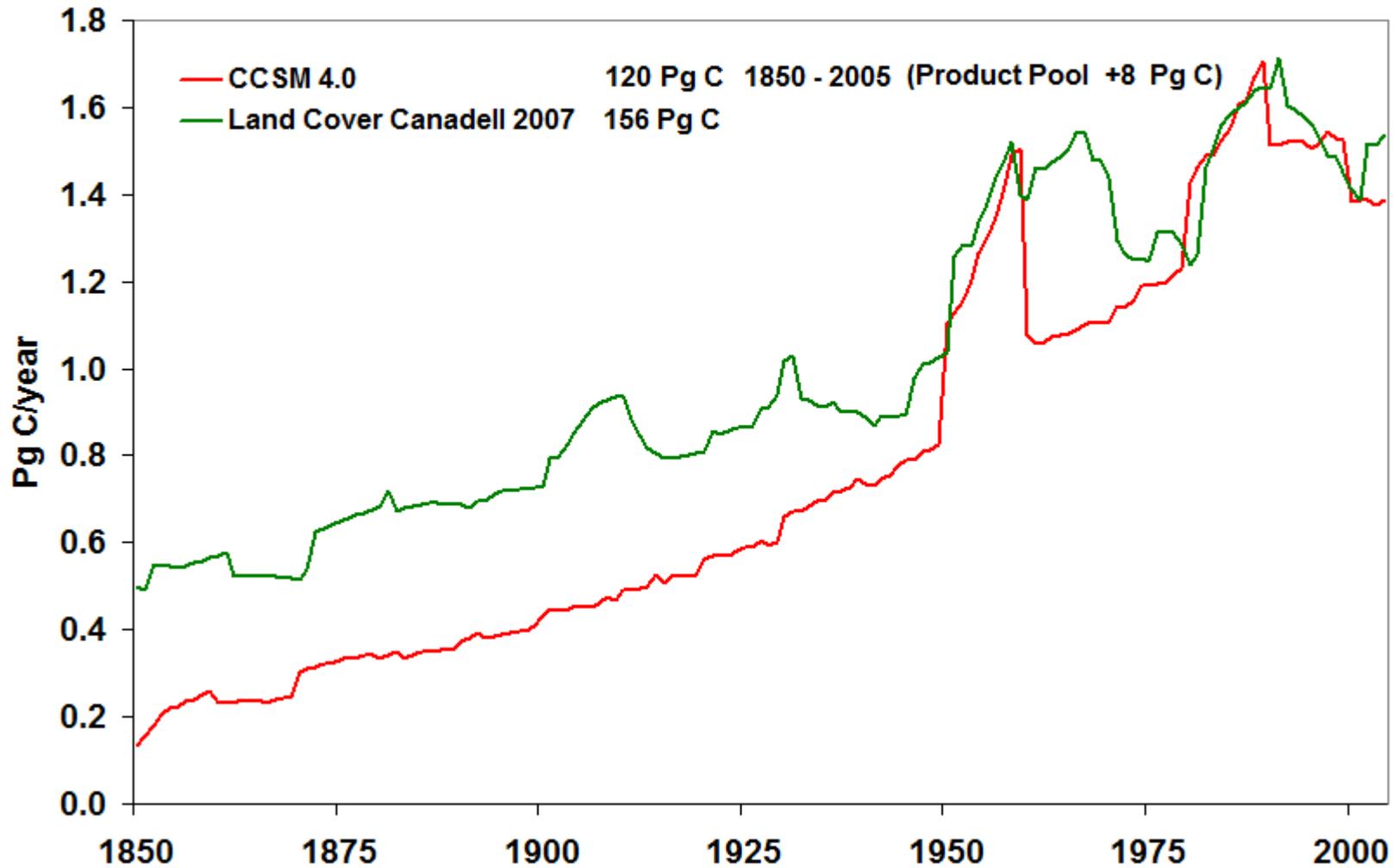
5. LCC in CCSM 4 – Coupled Climate & Prescribed CO2

CCSM 4.0 Global Total Land Use Carbon Flux to Atmosphere
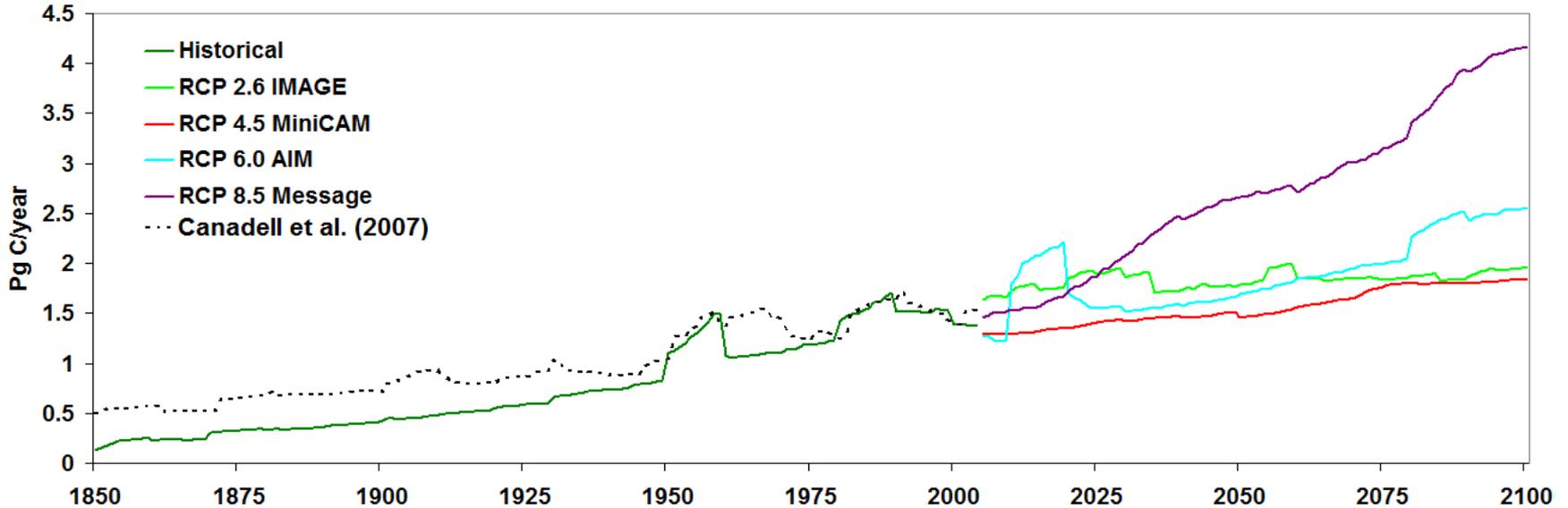
CCSM 4.0 Global Total Wood Harvest Carbon Flux compared to GLM Harvest Carbon Flux
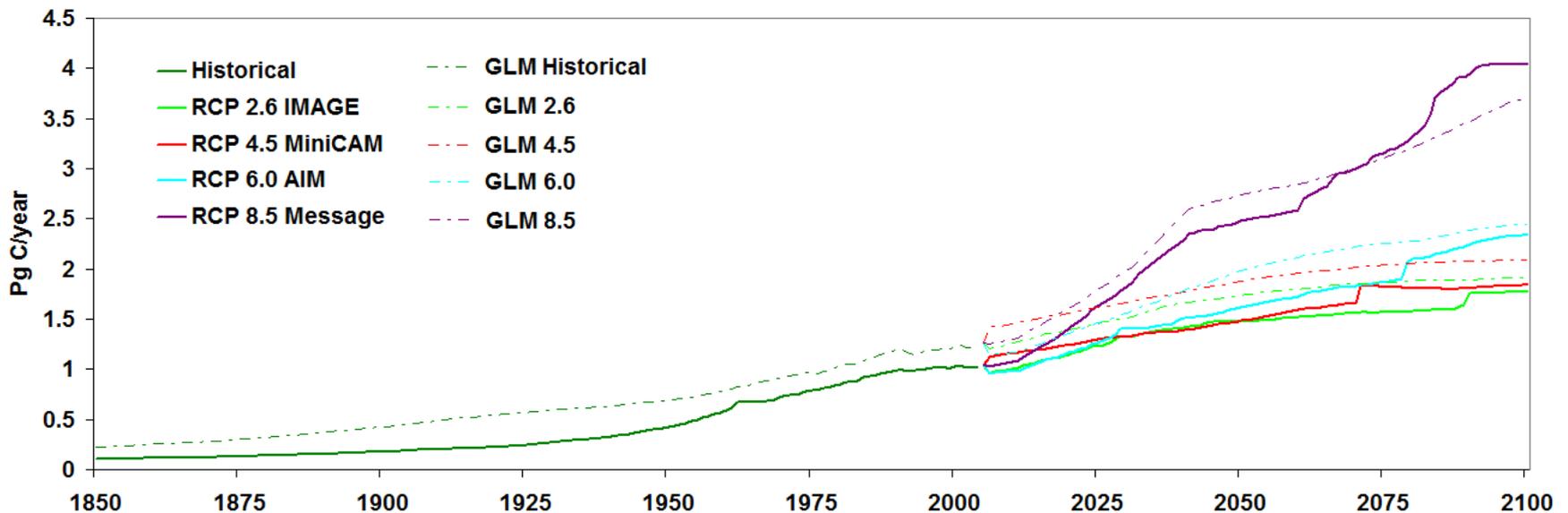
5. LCC in CCSM 4 – Coupled Climate & Prescribed CO2

CCSM 4.0 Global Total Net Ecosystem Exchange (NEE) - 10 year smoothed (Including Land Use Flux)
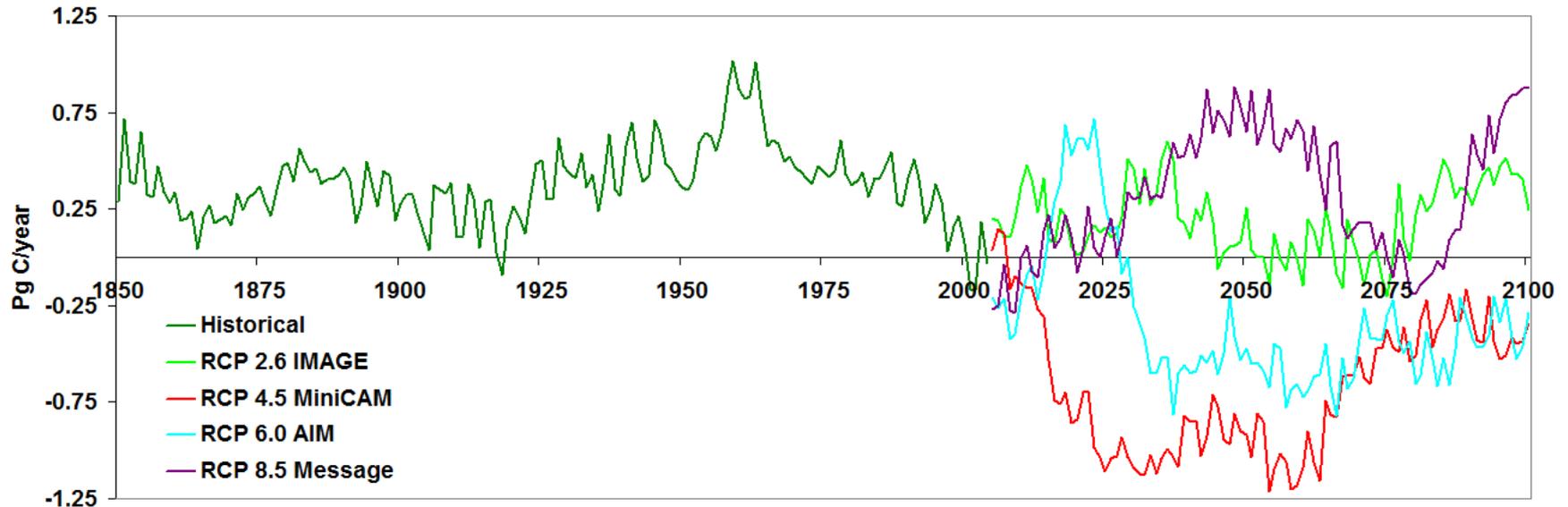
CCSM 4.0 Global Total Ecosystem Carbon (Excluding Product Pools)
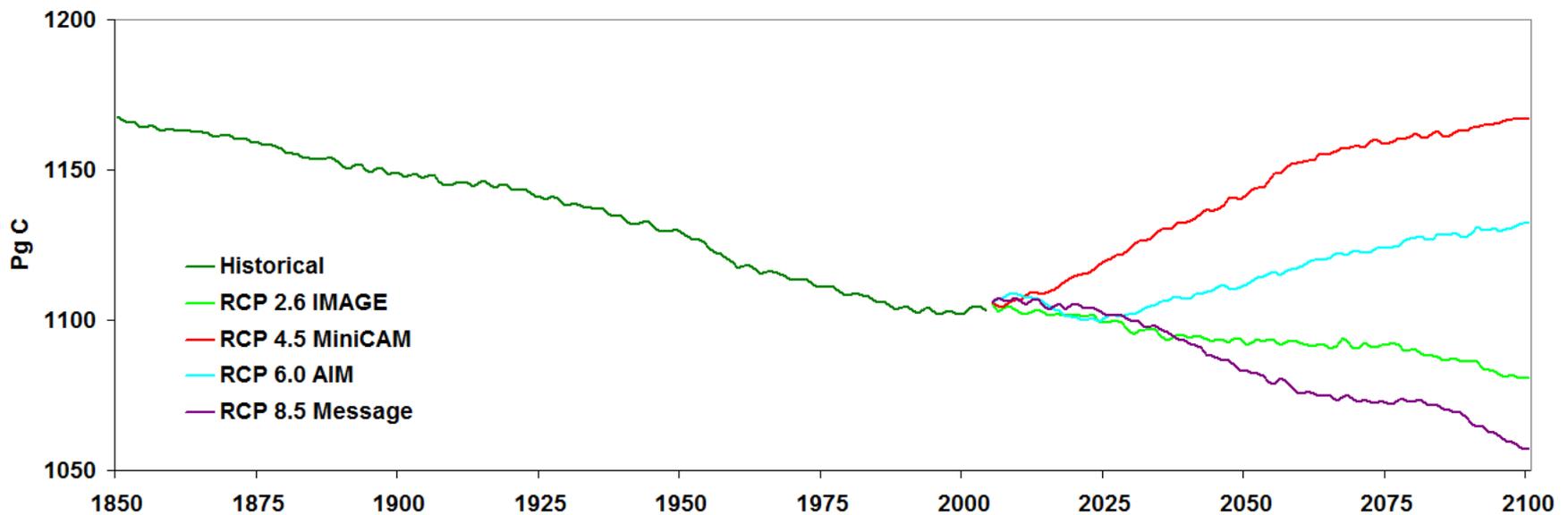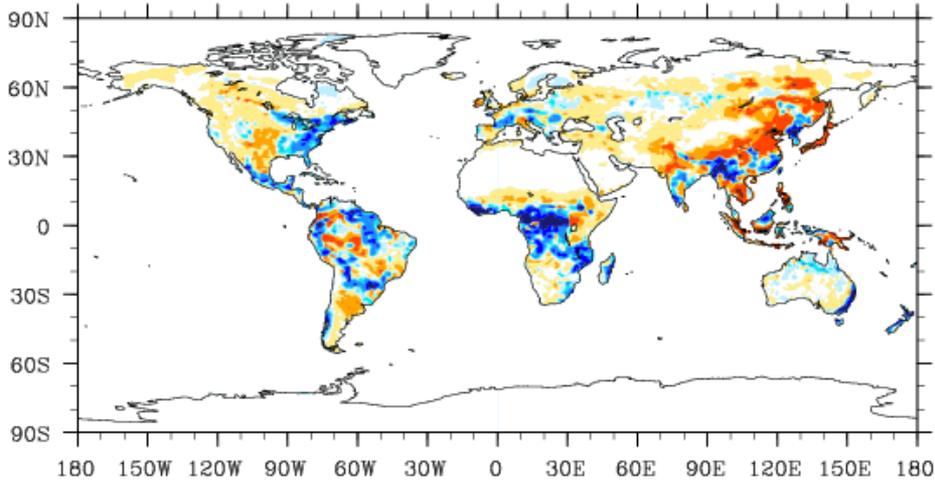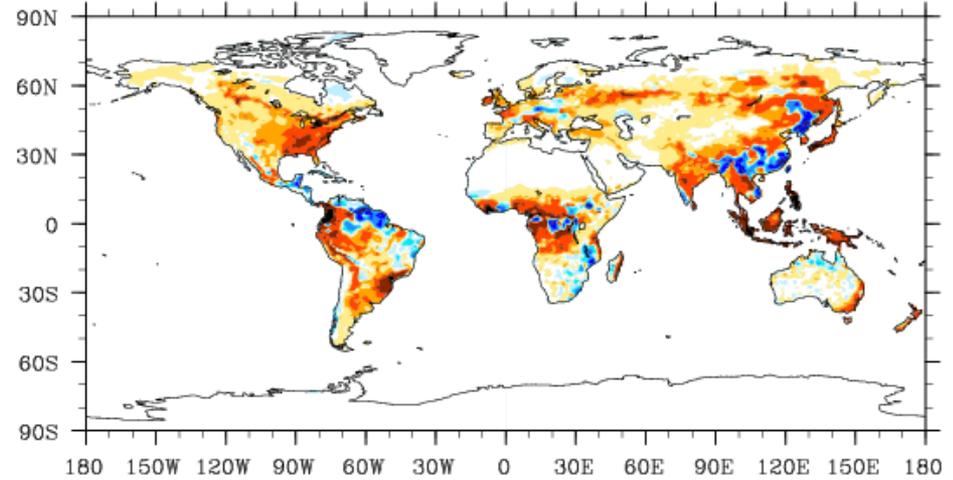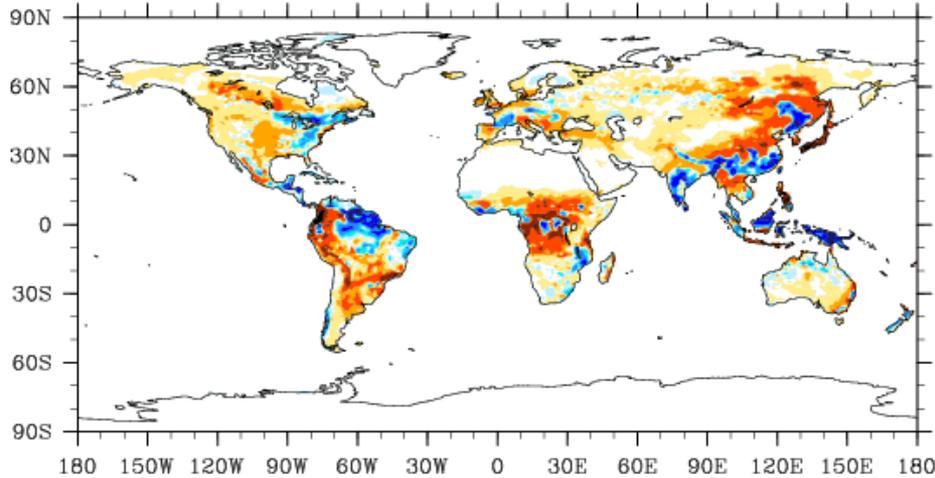
5. LCC in CCSM 4 – Coupled Climate & Prescribed CO2
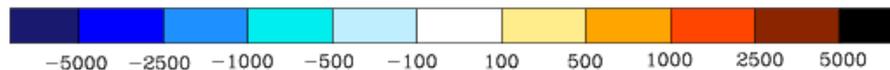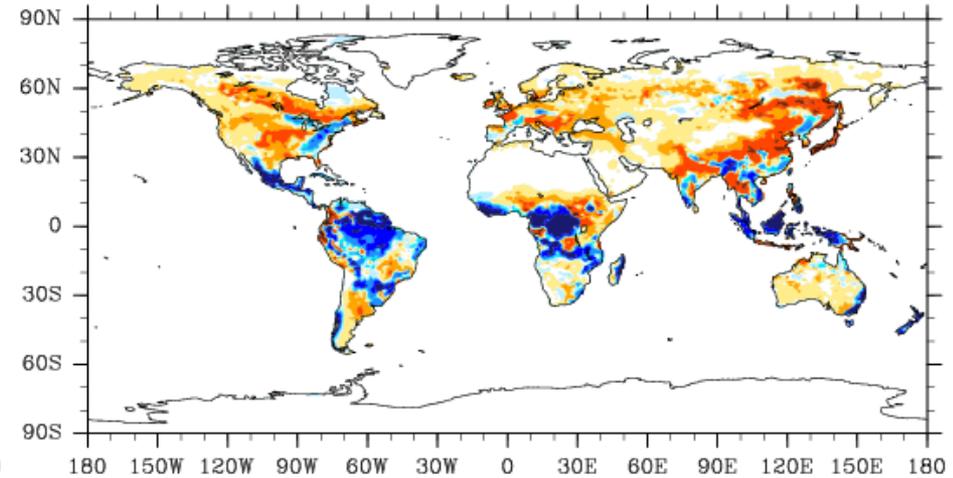
6. CCSM Historical Land Cover Change vs Full Transient

1. To investigate the biogeophysical impacts of transient land cover change in CCSM a Historical single forcing simulation was run where all forcings beside land cover change were held constant at 1850 values

2. Changes in a range of climate variables were analyzed from the single forcing experiment compared to the full transient experiment over two simulations periods

3. This allowed us to identify the biogeophysical impacts in isolation from and in combination with other transient forcings

6. Full Transient vs Land Cover Only (Last 30yr – First 30yr)
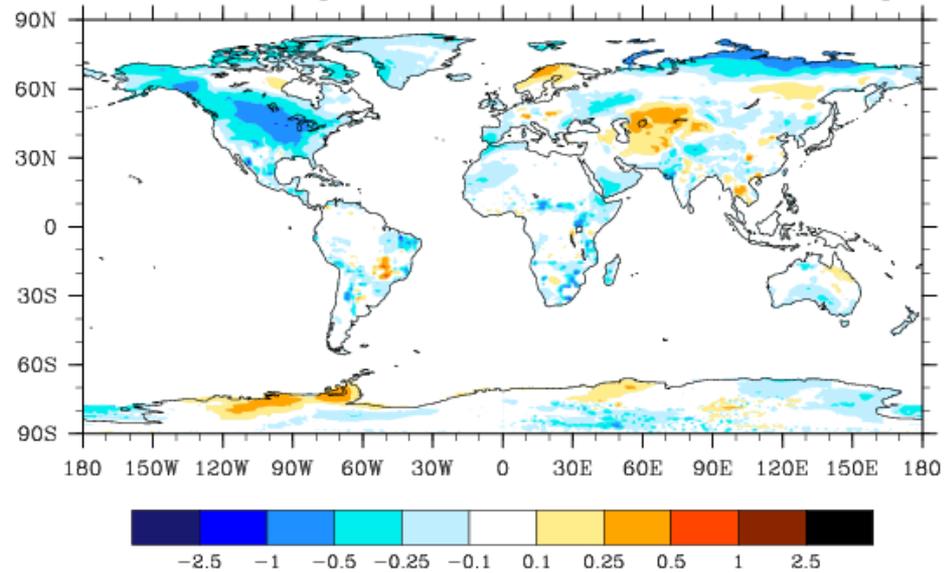

(a) Full Transient - Change in Albedo
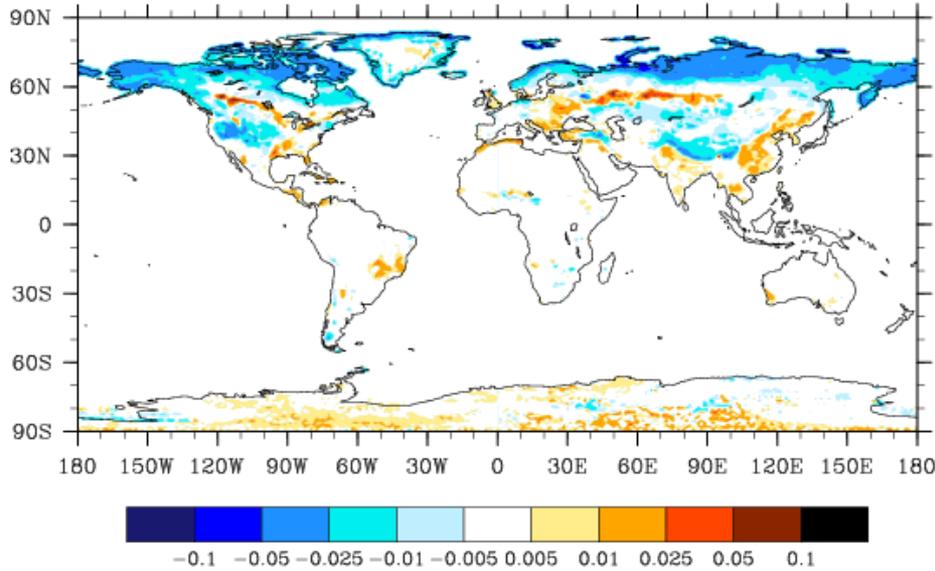
(b) Land Cover Change Only - Change in Albedo
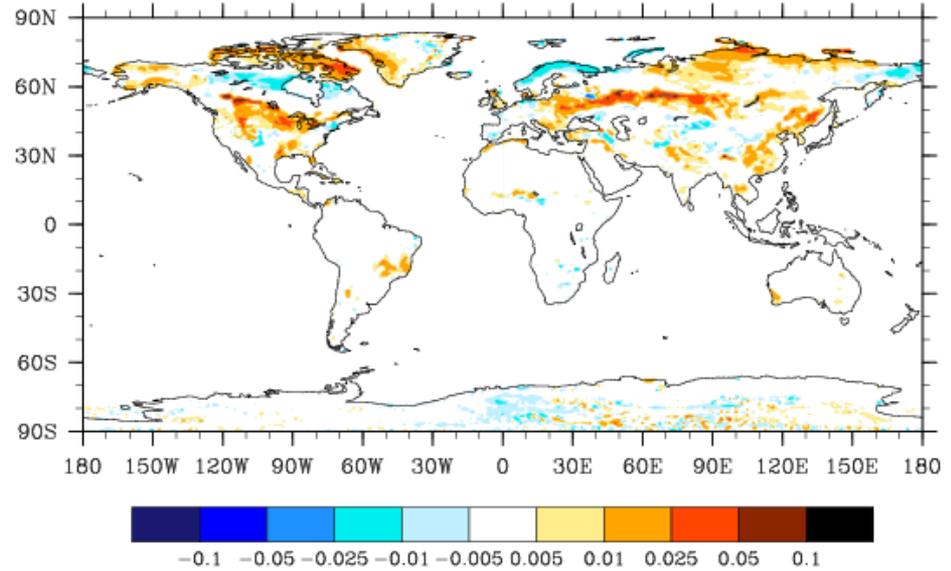
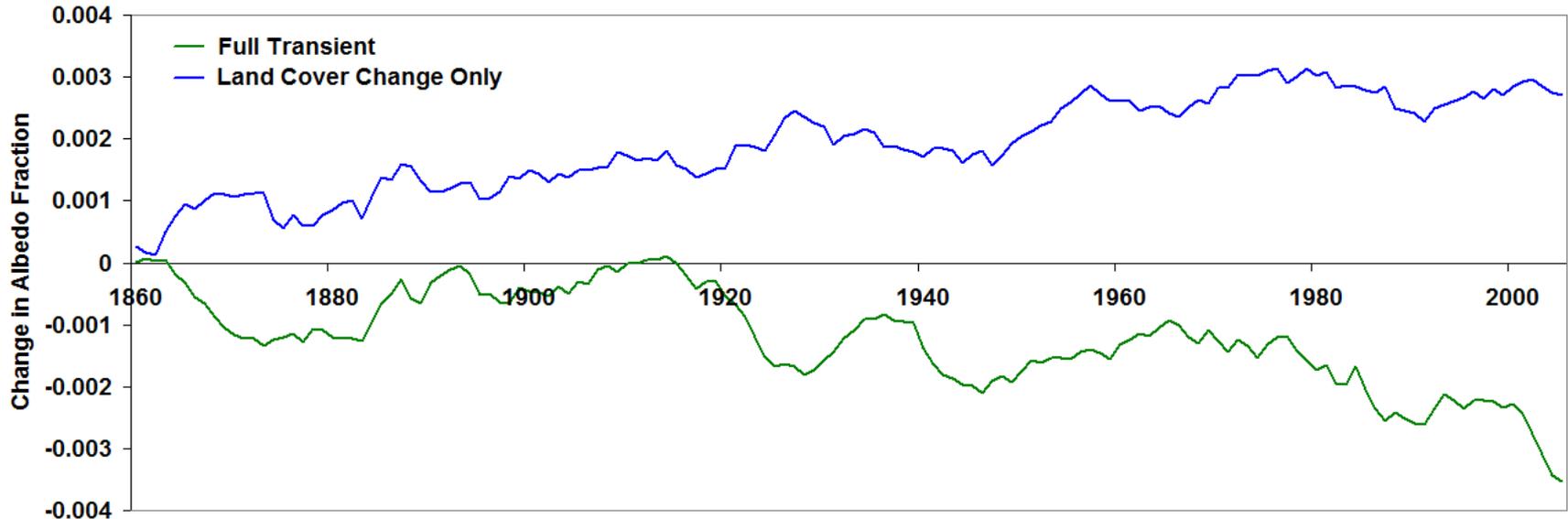(c) Full Transient - Change in 2m Temperature   Deg C
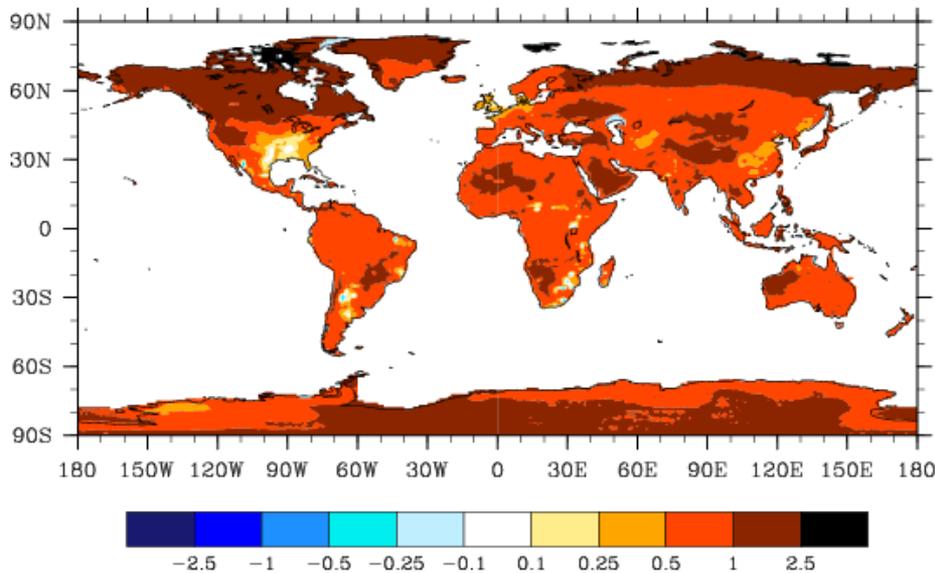
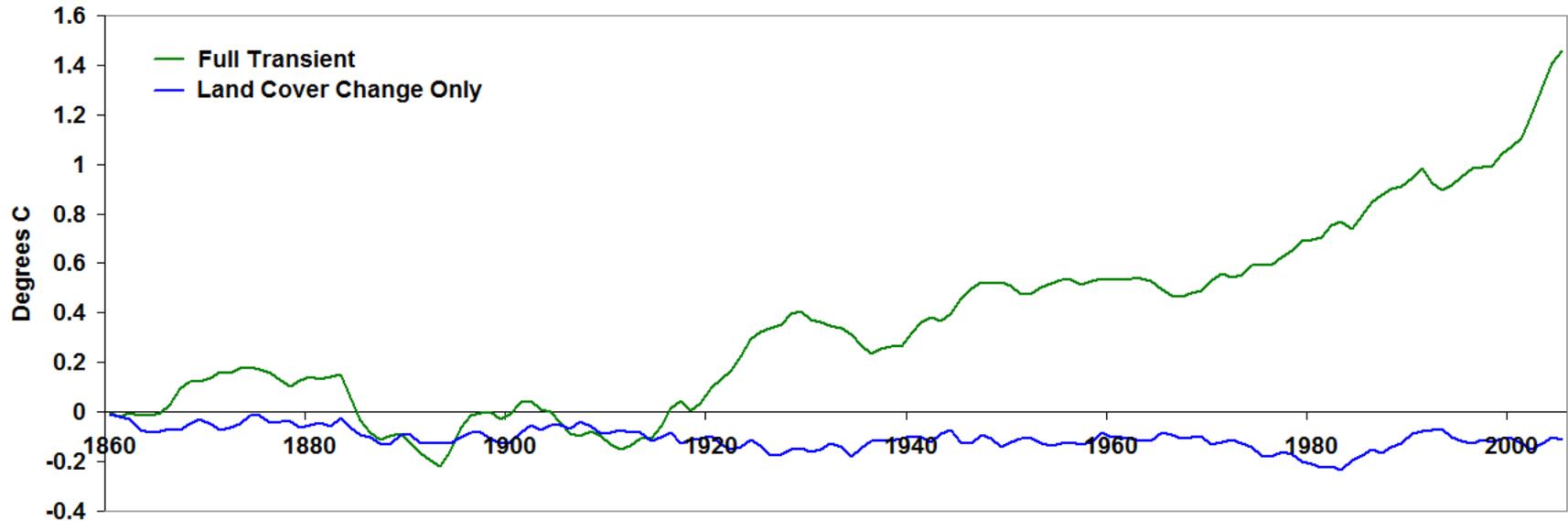(d) Land Cover Change Only - Change in 2m Temp Deg C

6. CCSM 4 – Full Transient vs Land Cover Change Only

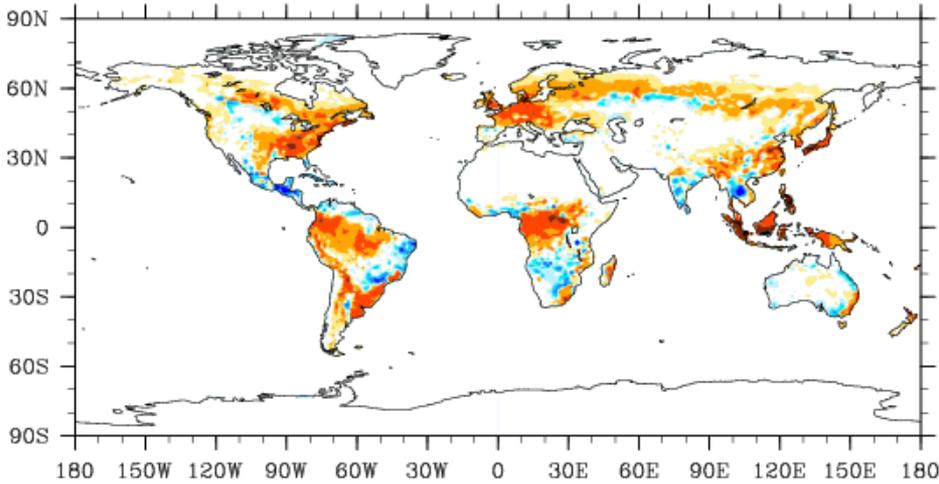CCSM 4.0 Change in Global Shortwave Land Surface Albedo - 10 year smoothed

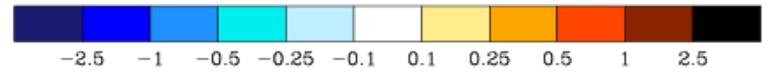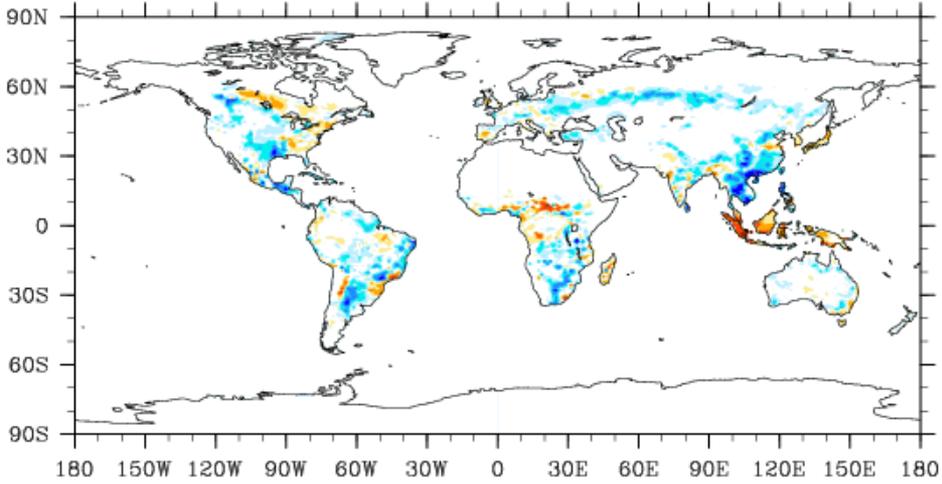CCSM 4.0 Change in Global Land Air Temperature - 10 year smoothed
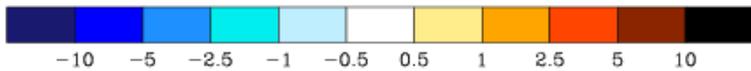
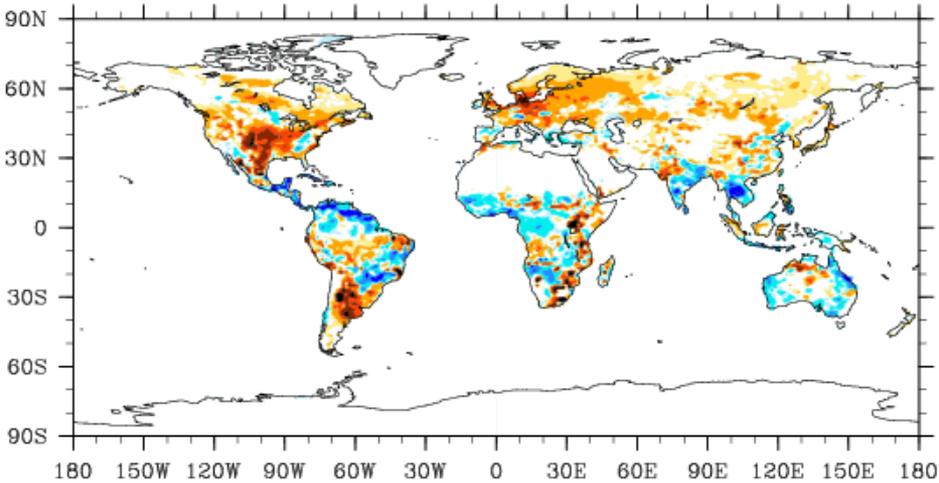# 6. Full Transient vs Land Cover Only (Last 30yr – First 30yr)

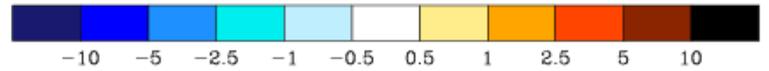(a) Full Transient - Change in Leaf Area Index   m²/m²
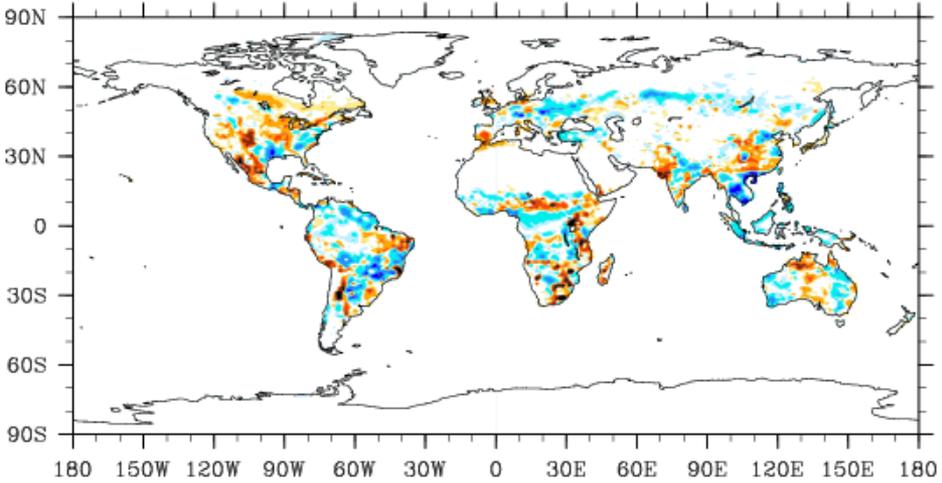
(b) Land Cover Change Only - Change in LAI   m²/m²

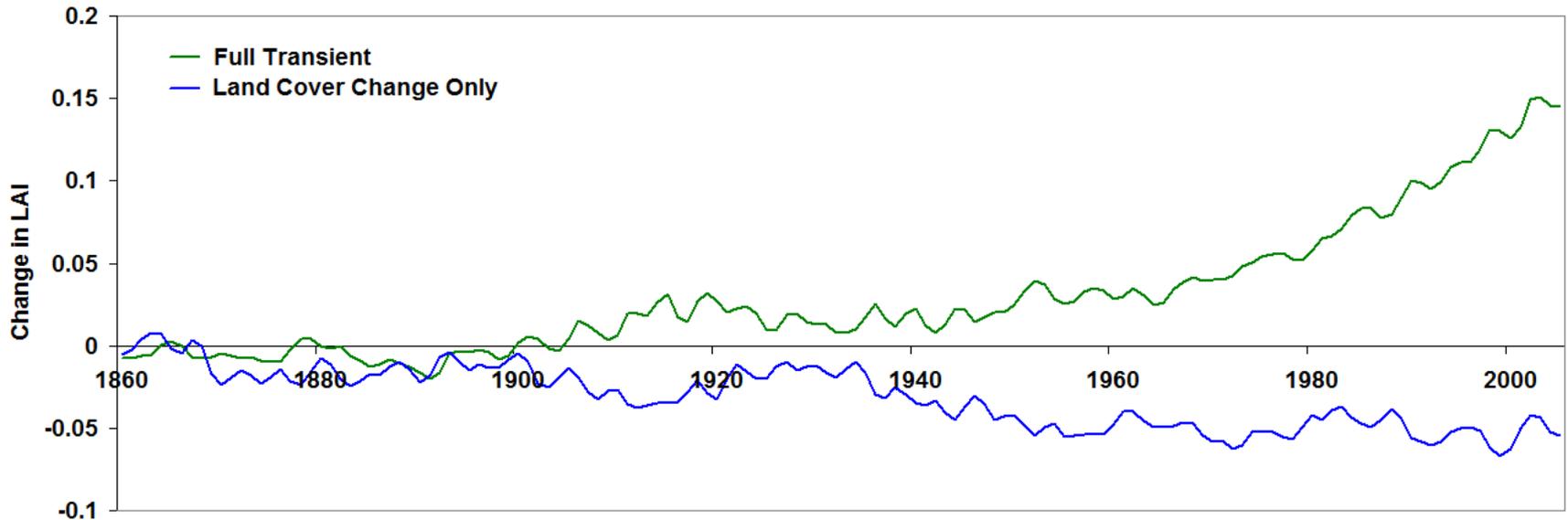(c) Full Transient - Change in Transpiration   W/m²

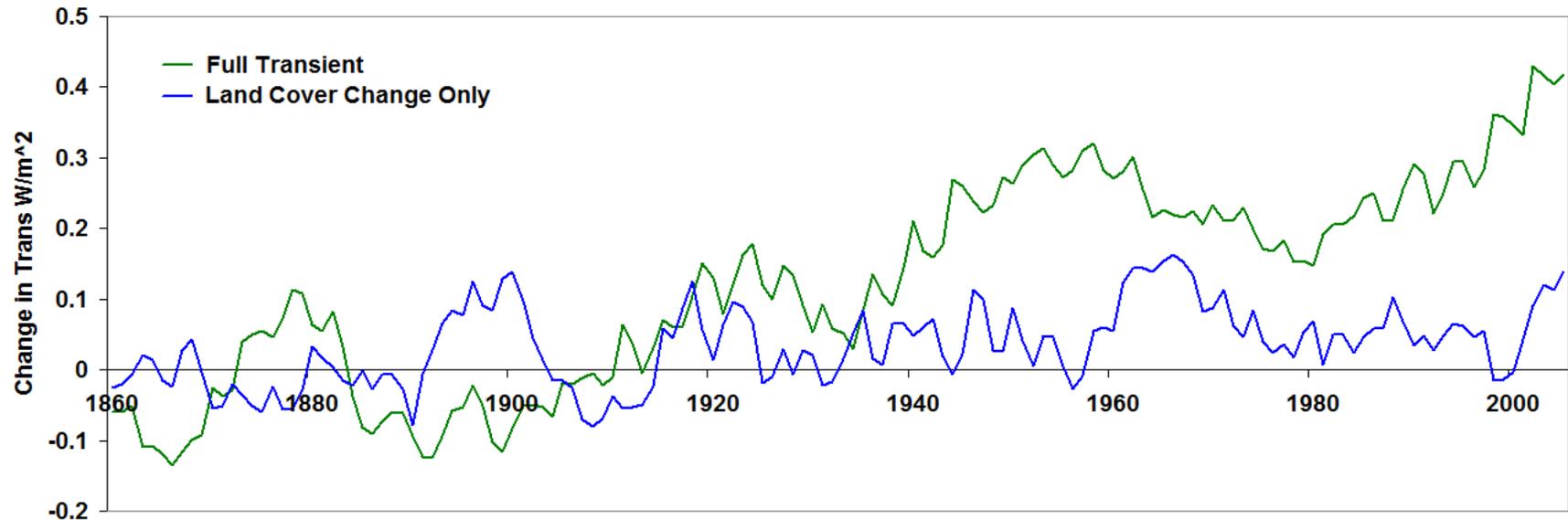(d) Land Cover Change Only - Change in Trans   W/m²

6. CCSM 4 – Full Transient vs Land Cover Change Only

CCSM 4.0 Change in Global Leaf Area Index (LAI) - 10 year smoothed

CCSM 4.0 Change in Global Transpiration - 10 year smoothed

7. Summary of Land Cover Change in CCSM4 CMIP5

1. Transient CLM4 Land Cover Change has been developed from current day MODIS vegetation and bioclimatically modeled potential vegetation which represents land cover change and wood harvest consistently with the CMIP5 historical and RCP trajectories.

2. The AR4 historical biogeochemical impacts of land cover change of 134 PgC and 0.5 W/m2 were similar to those simulated in CCSM4 with a global land use flux of 120 PgC.

5. The future RCP simulations demonstrated that land use is 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 land use fluxes.

6. RCP 8.5 on the other hand resulted in a loss of -49.0 PgC of ecosystem carbon and -30.3 PgC land carbon

7. Summary of Land Cover Change in CCSM4 CMIP5

5. The AR4 historical biogeophysical impacts of land cover change -0.2 W/m2 through increased albedo were also similar in CCSM4 with a global land surface decrease of -0.28 W/m2 in absorbed shortwave radiation and a decrease of -0.19 W/m2 in net radiation

6. The tropical warming and summer higher latitude warming of the CCSM 3.0 experiments and field studies was not present in the CCSM 4 and CESM1 experiments

7. The absence of reduced evapo-transpiration and warming is suspected to be due to significant biases in the representation of land surface hydrology in CLM4 which is an ongoing investigation.

7. Conclusions Land Cover Change in CCSM4 CMIP5

8. The biogeophysical impacts of land cover change are highly dependent the representation of the Terrestrial Carbon Cycle, Surface Albedo, Hydrology and Snow in CLM4.

9. Changes in these parameterizations may have impacts on the magnitude and possibly even the sign of the climate impacts simulated, such as through the inclusion of irrigated crops

10. The differences in the Historical Full Transient experiment compared to the Land Cover Change only experiment highlights how high latitude warming and black carbon deposition on snow significantly reduce the albedo impact of land cover change in full transient experiments.
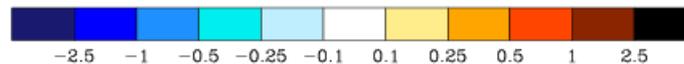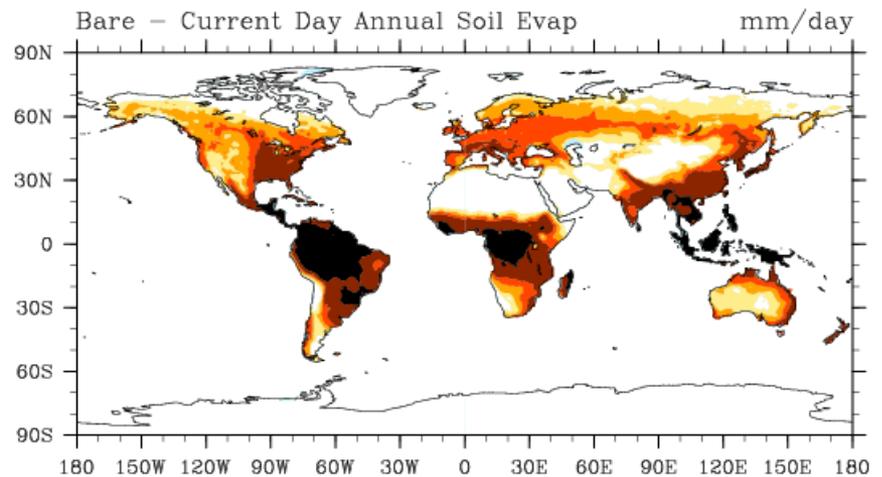
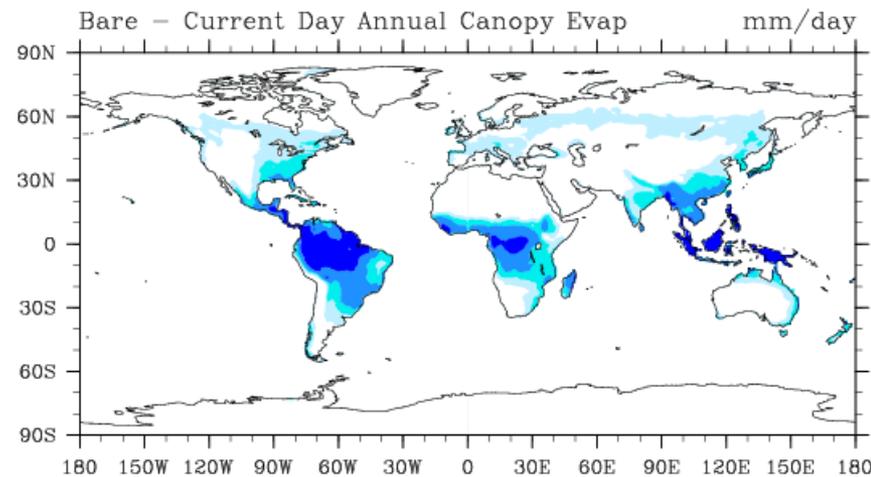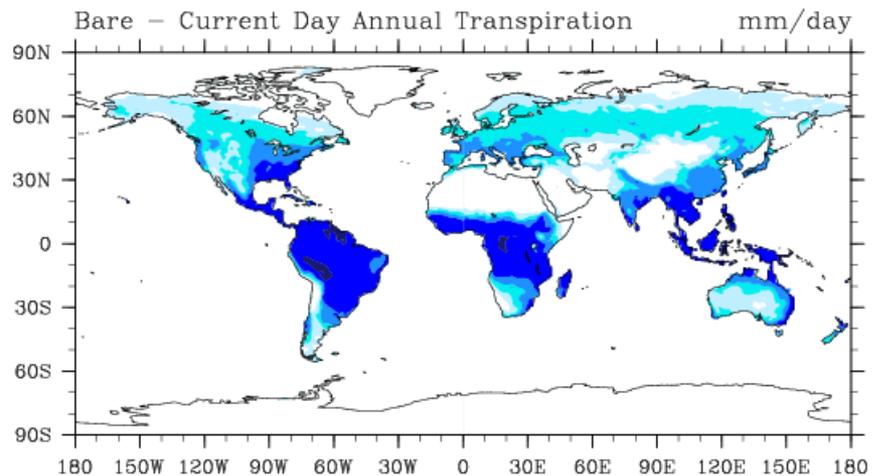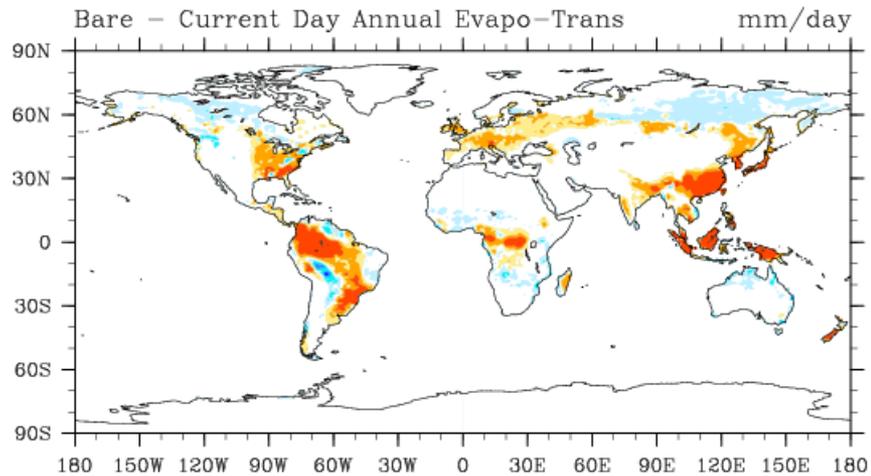## The End

8. Test CLM4 under extreme land cover change

1. Investigate changes in land surface climate of CLM4 with land cover change. All experiments are forced with Qian meteorology for 1970 – 1999 and have monthly satellite phenology (SP) Leaf Area Index.

2. Control: Current day vegetation

3. Vegetation Removal: Global bare soils

4. All Grass: All current day vegetation replaced with climate appropriate grass PFTs (Bare soil stays at Current Day values)

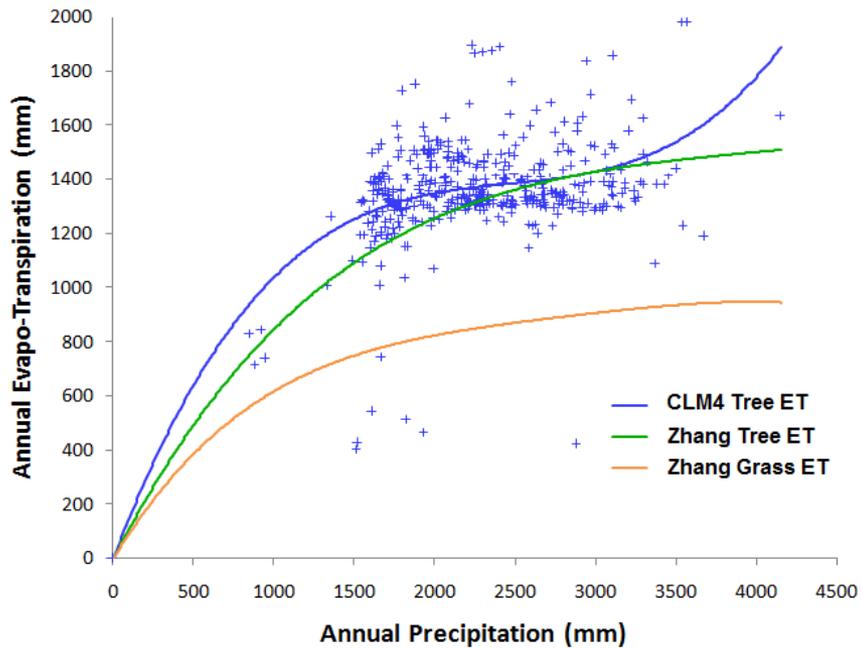# 8. Offline CLM4 – Vegetation Removal – Global Hydro

Global Hydrology (mm/day) Offline 1985 - 1999
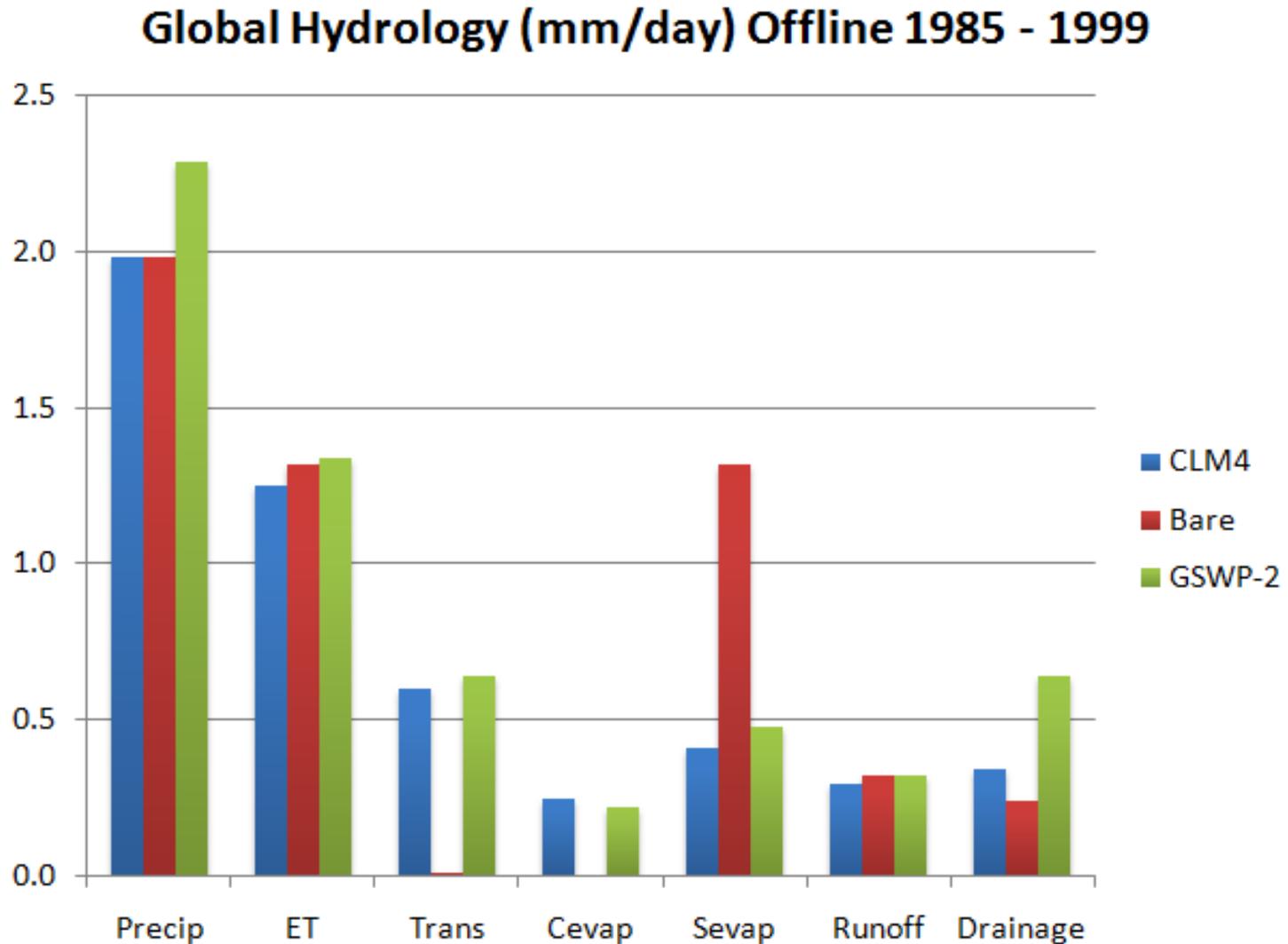
GSWP-2 is Global Soil Wetness Project 2 Global Hydrology used in *Lawrence et al.* (2007)
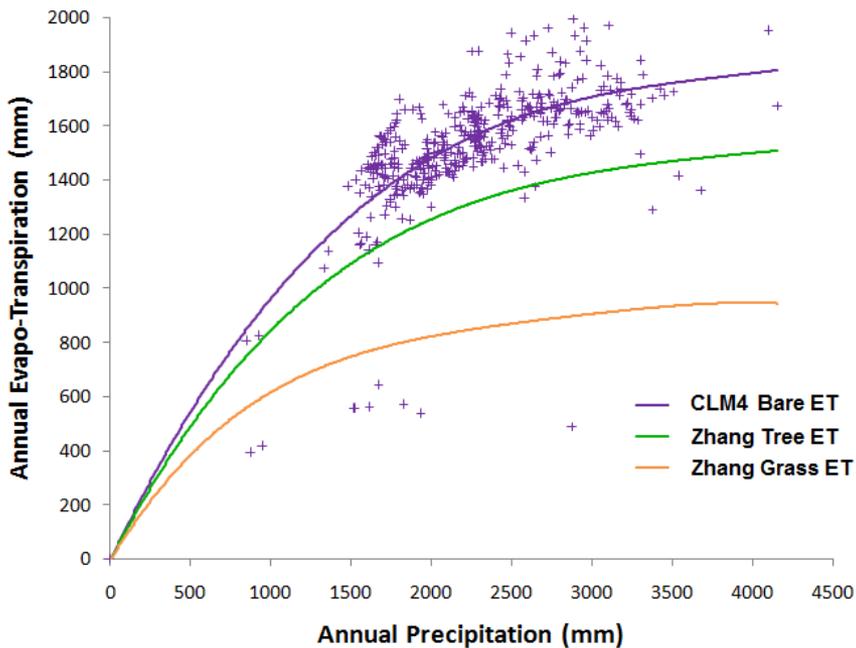
8. Offline CLM4 – Vegetation Removal – Annual ET

CLM4 Broadleaf Tree Precipitation - ET Curves

Annual Evapo-Transpiration (mm) vs Annual Precipitation (mm)
- CLM4 Tree ET
- Zhang Tree ET
- Zhang Grass ET

CLM4 Grass Precipitation - ET Curves

Annual Evapo-Transpiration (mm) vs Annual Precipitation (mm)
- CLM4 Grass ET
- Zhang Tree ET
- Zhang Grass ET
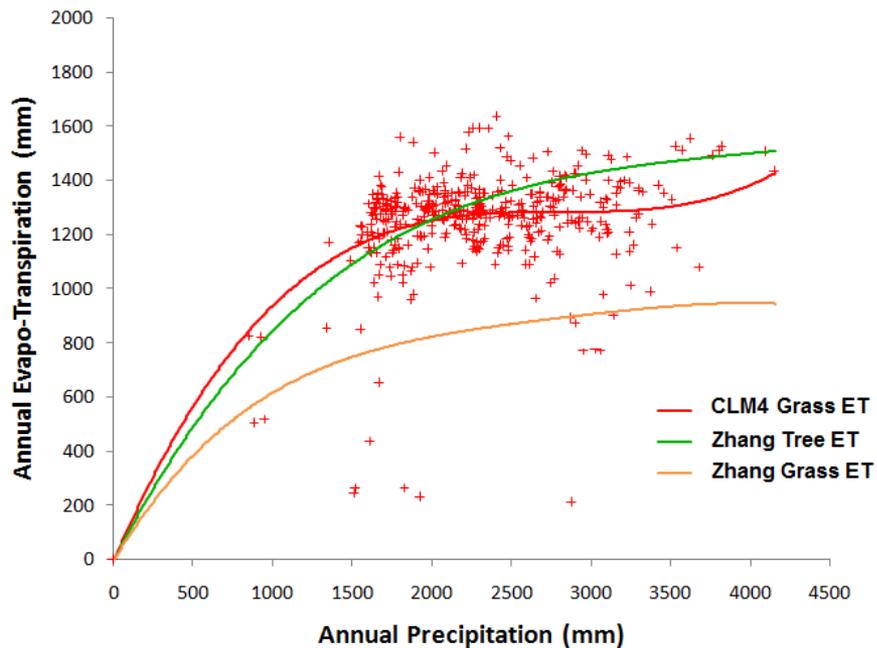
CLM4 Bare Soil Precipitation - ET Curves

Annual Evapo-Transpiration (mm) vs Annual Precipitation (mm)
- CLM4 Bare ET
- Zhang Tree ET
- Zhang Grass ET

CLM4 Broadleaf Tree - Grass Maximum LAI

Grass LAI vs Tree LAI

$y = 0.529x$
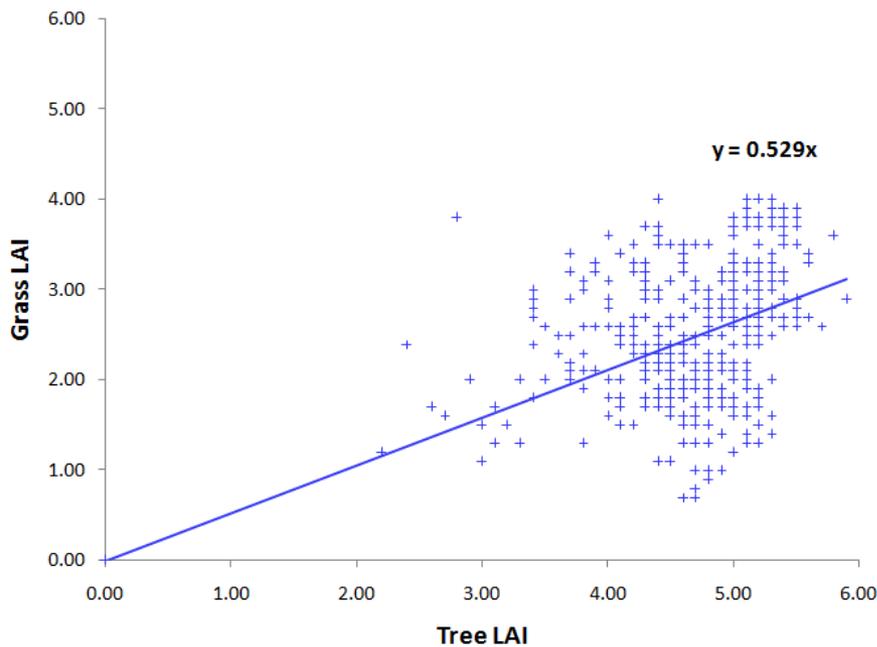
8. Conclusions

1. CLM 4 simulates higher Bare Soil evaporation than Forest evapo-transpiration

2. The high Bare Soil evaporation can be partially resolved through surface resistance

3. Tree and Grass PFT hydrology, and Bare Soil evaporation need further investigation

4. Need to look at Surface Hydrology through soil moisture profiles, runoff and drainage

5. Plant physiology through rooting depth and photosynthesis

6. This means that the biogeophysical impacts of land cover change in CLM 4 are uncertain in terms of hydrological response