Land Use and Land Cover Change Update for CTSM

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CLM5/CTSM Land Use and Land Cover Change

- New Raw Surface Datasets have been produced and will be released with an upcoming version of CTSM. New data is available on request.

- New Datasets are produced at 0.25 degrees for full time series data and 0.05 degrees for individual years. All include optional Shifting Cultivation

- Annual time series available for CMIP6 and CTSM versions at 0.25 degrees:
  - Potential Vegetation: no Anthropogenic compset includes no urban etc
  - Last Millennium: 850 – 1849
  - Historical (CMIP6): 1850 – 2015 (also low and high LULCC variants)
  - SSP1-RCP19: 2016 – 2100
  - SSP1-RCP26
  - SSP2-RCP45
  - SSP3-RCP70
  - SSP4-RCP34
  - SSP4-RCP60
  - SSP5-RCP34
  - SSP5-RCP85

- SSP extensions to 2300 are being finalized

CLM5/CTSM Land Use and Land Cover Change

- In addition the new time series have been updated or corrected to include:

- New high resolution data at 0.05 degrees for potential, 1850 and 2005 vegetation and crops, as well as monthly PFT lai, sai, height and soil color.

- New Cropping Data used from EARTHSTAT combined with UN FAOSTAT to provide better representation of changing crops from 1961 - 2015

- Cotton which was previously misrepresented as C3 perennial has now been represented as C3 annual with big impacts on distribution

- Methods for describing LUMIP c3/c4 annual, c3/c4 perennial and c3 nitrogen fixing crops updated for LUMIP – EARTHSTAT differences

- Small amounts of C3 Generic Crop (CFT 15/16) are present in the release datasets. This has been addressed in the new data

- Mksurfdata_map has been updated to address differences in land mask between land data, ice sheets and ocean in Antarctica.

CLM5 CMIP6 – New Land Surface Data Sets – Recap

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

2. The Global Land Model (GLM) describes land cover through 12 land units representing the dynamics of agriculture and forests. 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

CMIP6 LUMIP CLM5 Land Use Harmonization (LUH2)

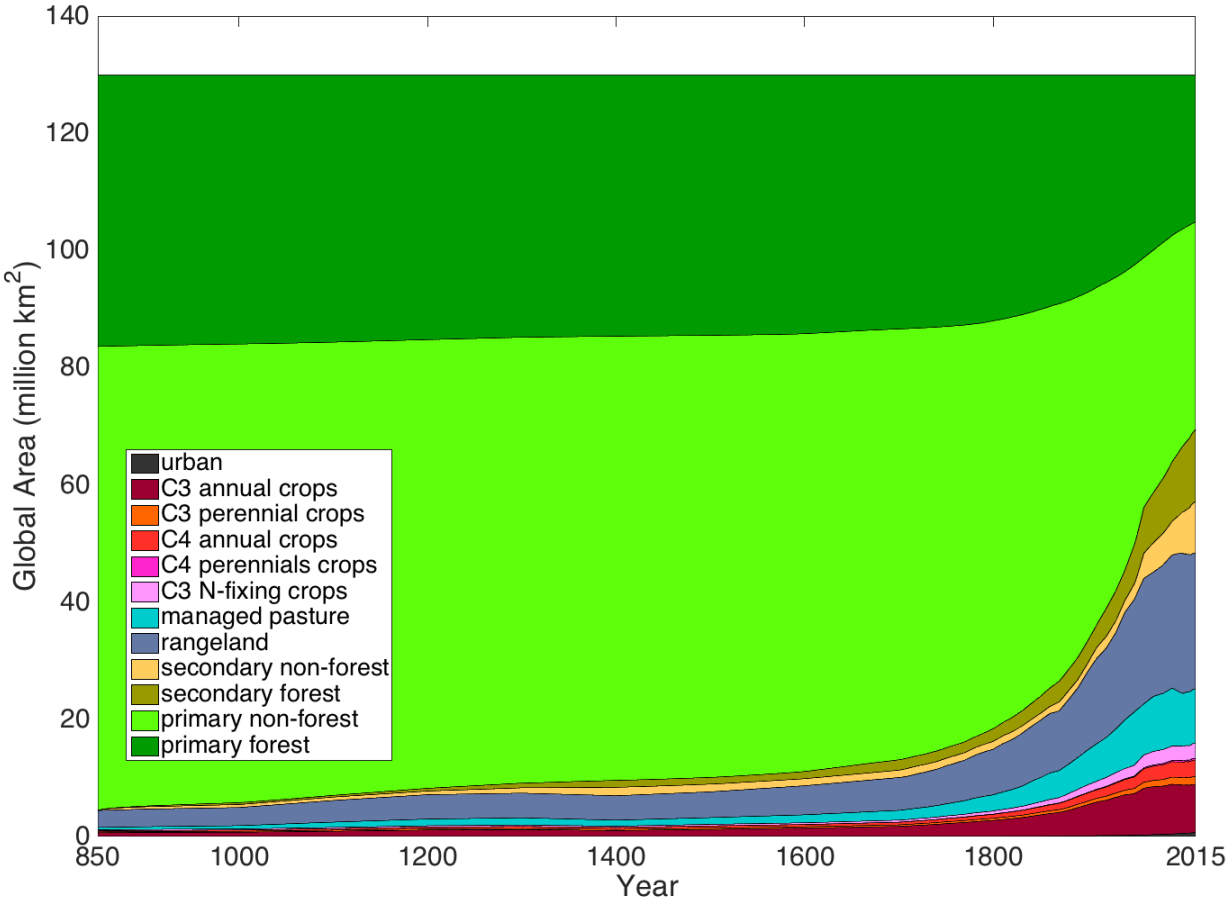
~ 50x information content of CMIP5!

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



CLM5 Human Land Management

CESM2 and CLM5 specify Land Use and Land Cover Change through annually prescribed natural vegetation and crop distributions that are combined with human management. The LUMIP/CMIP6 time series require that annual grid cell data is generated that represents:

- Changes in forest cover through time from the Forest / non forest information provided by the LUH2 time series through PFTs.

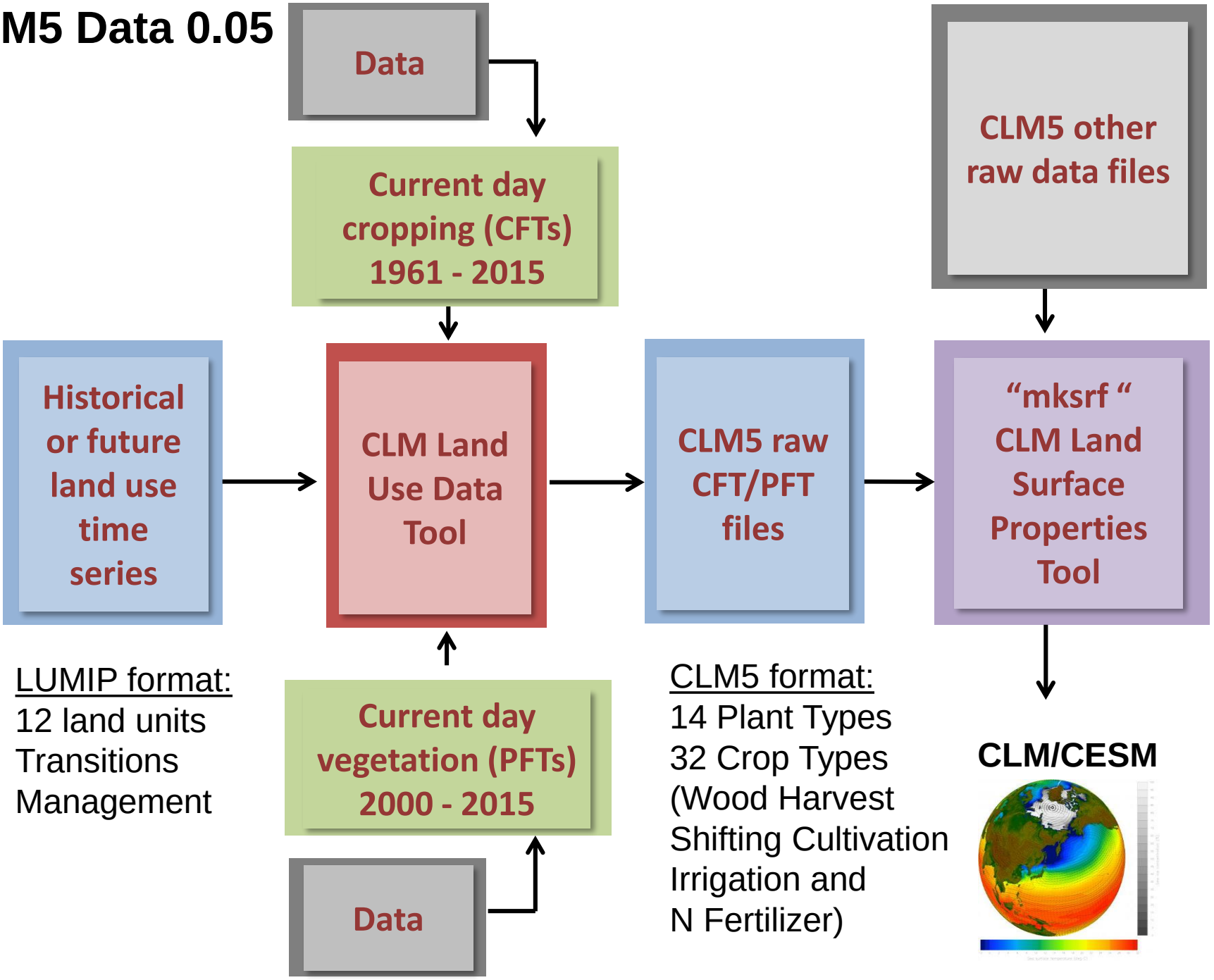
- Wood Harvest prescribed in a carbon amount to be extracted as biomass from trees PFTs

- Transient C3/C4 Crops of the LUMIP time series are modeled with the CLM5 Crop model which specifies planting dates, life histories and harvest rules for 32 individual crops for each grid cell and each year (only maize, cotton, rice, sugarcane, soybean, and wheat are currently parameterized)

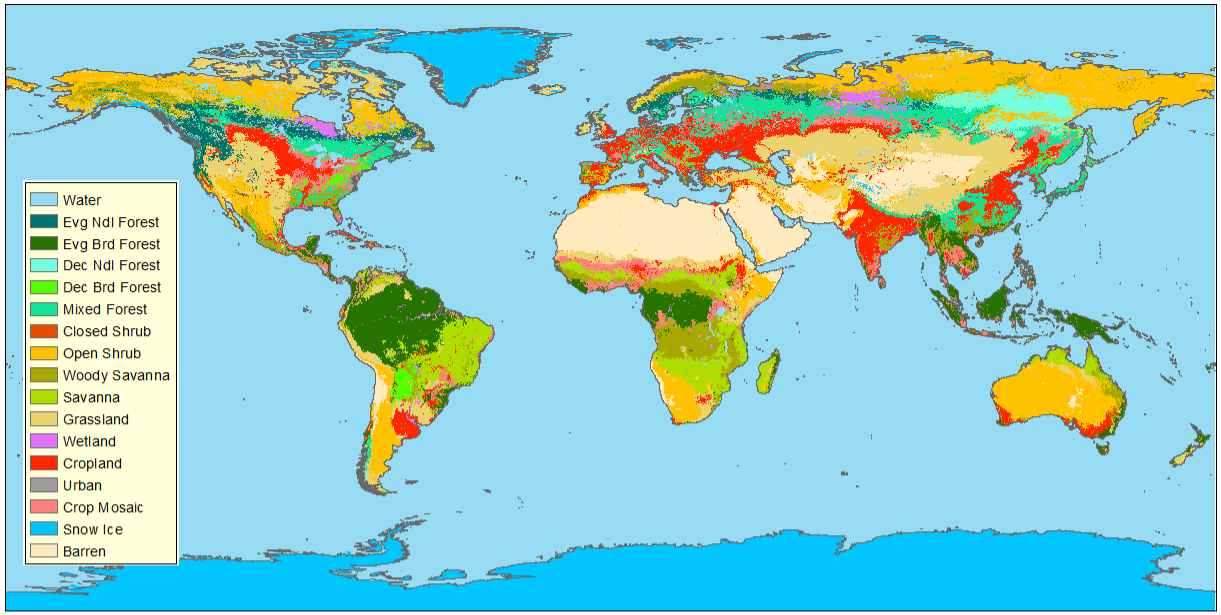
- Fertilizer and irrigation management are specified by crop and grid cell for every year of the time series

- CLM5 has optional Shifting Cultivation captured through Gross Transitions

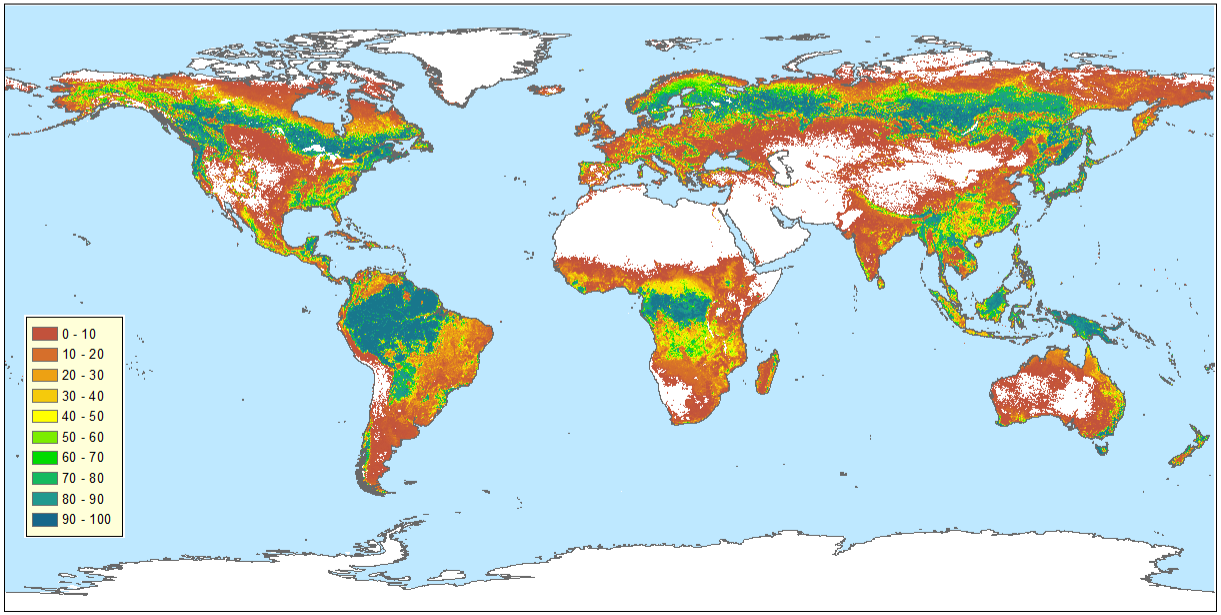
CLM5 Data 0.05



MODIS Land Cover - IGBP Classes (2003 - 2012)



CLM5 Percent Tree Cover 2005



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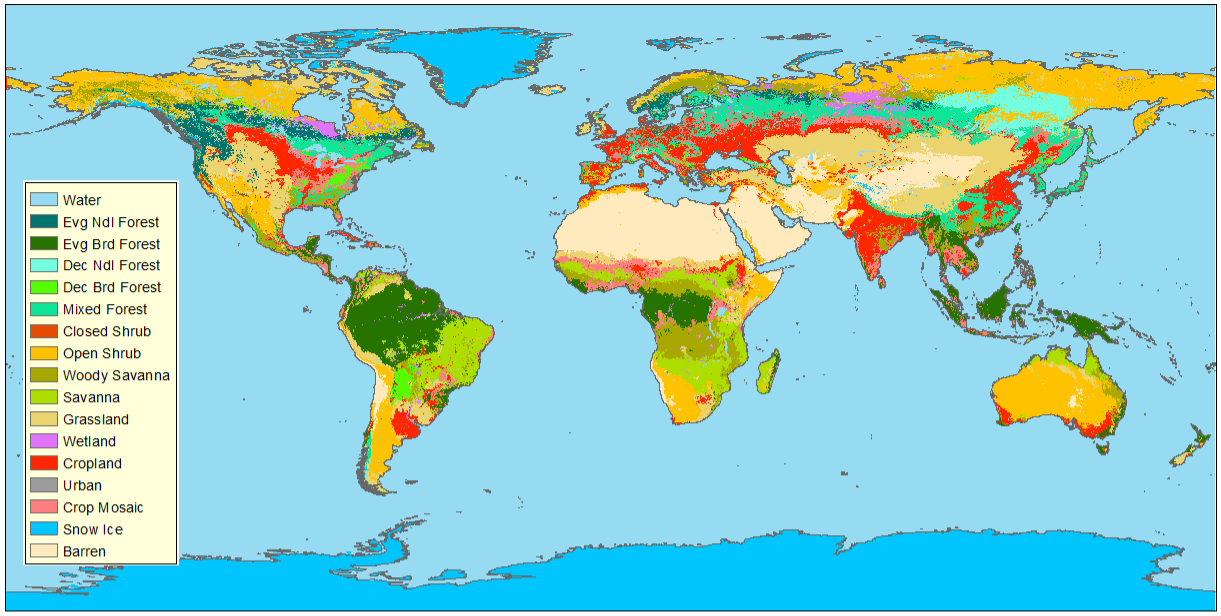
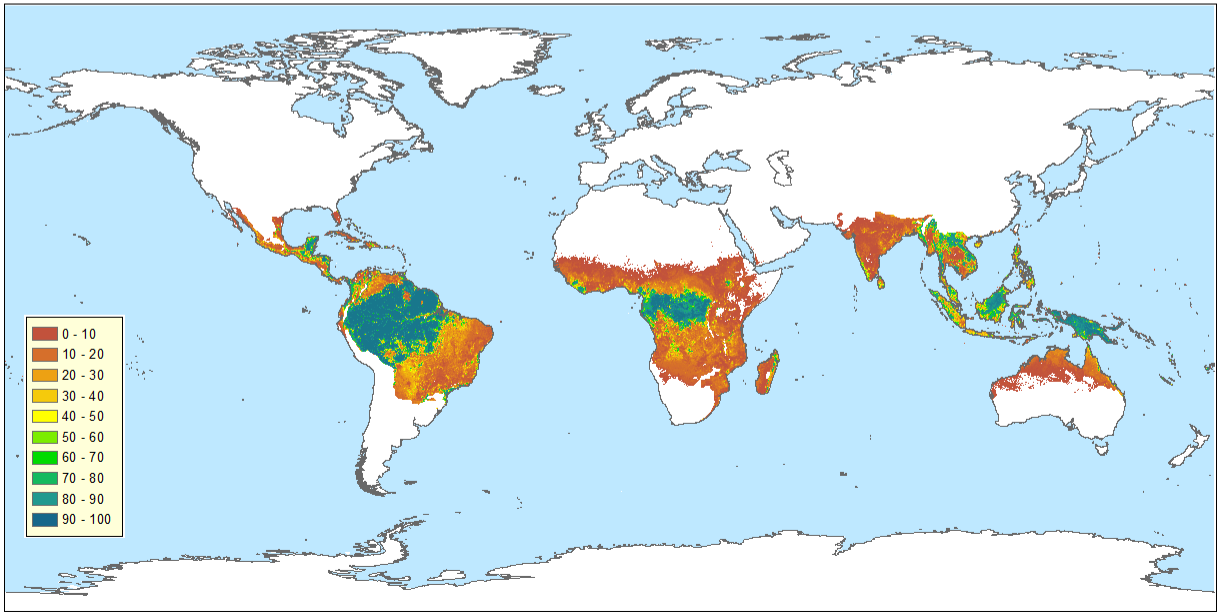


CLM5 Percent Broadleaf Evergreen Tropical Tree 2005



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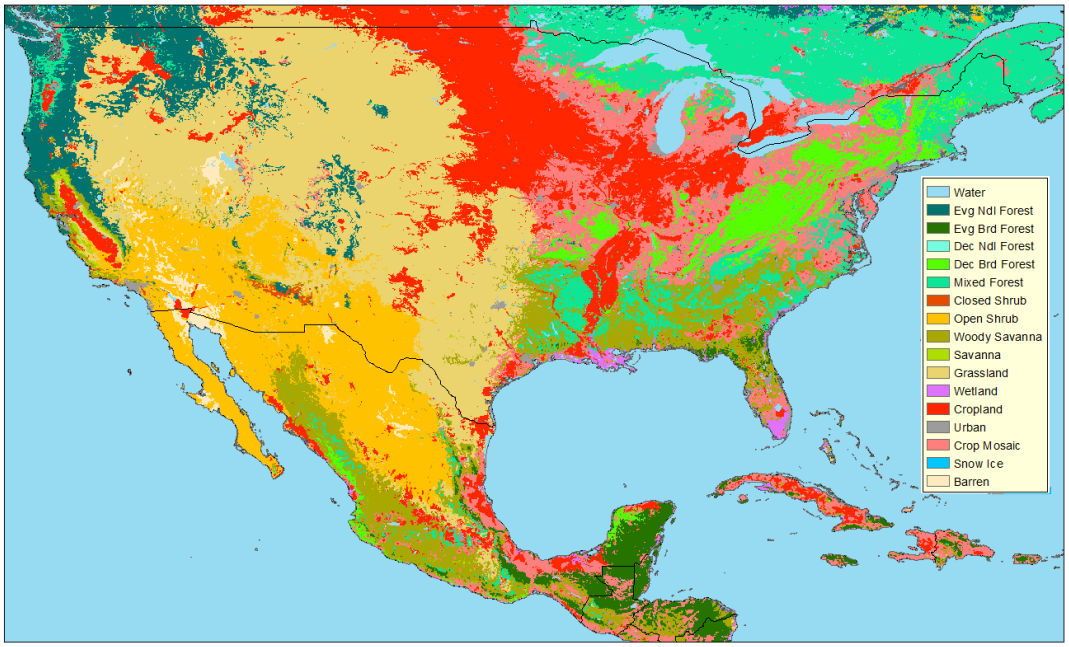

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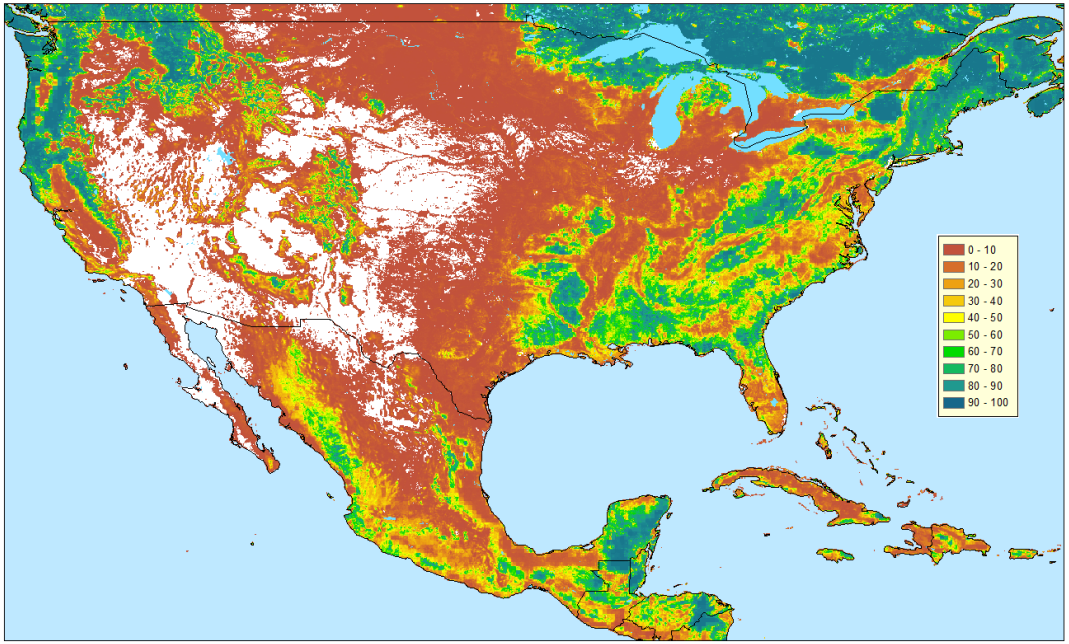
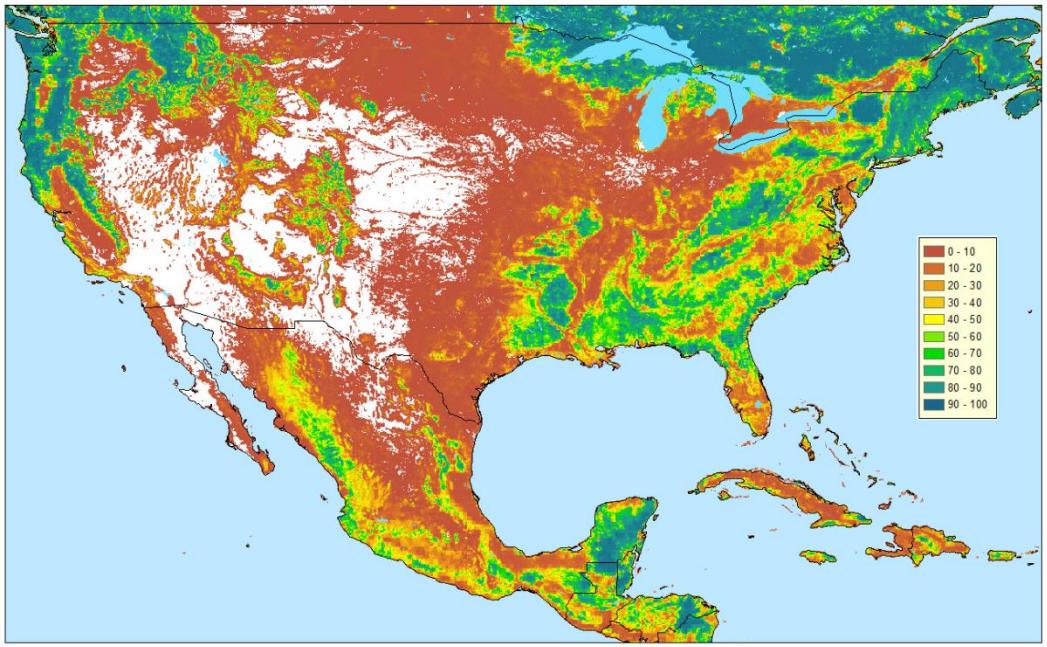


Google Earth - Quickbird 2015

CLM5 Percent Tree Cover 2005



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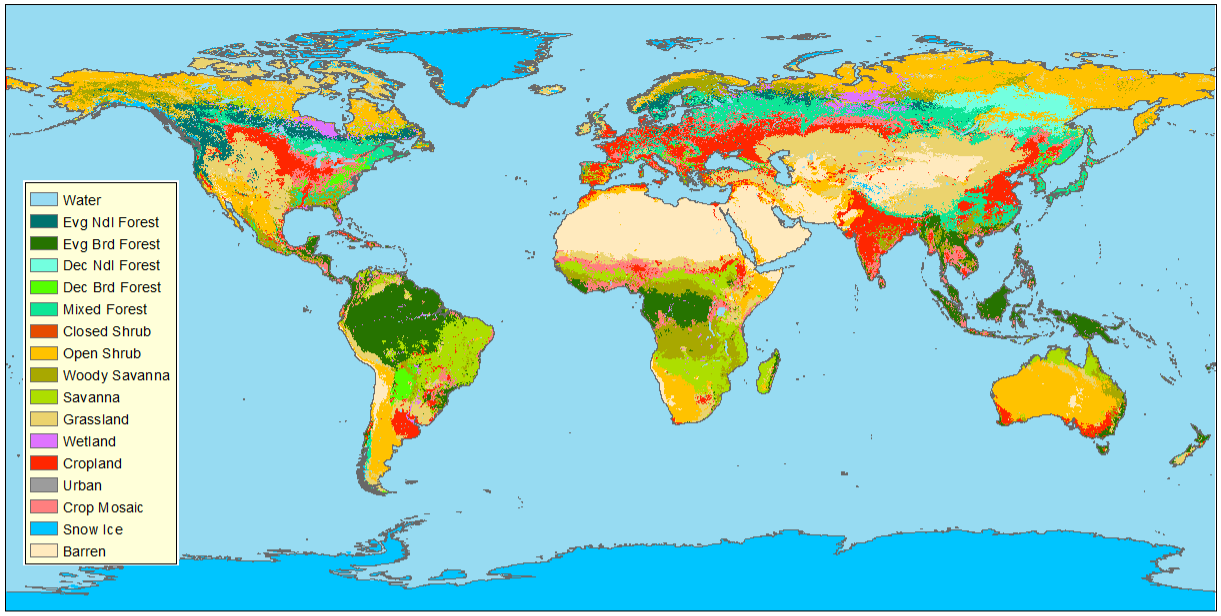
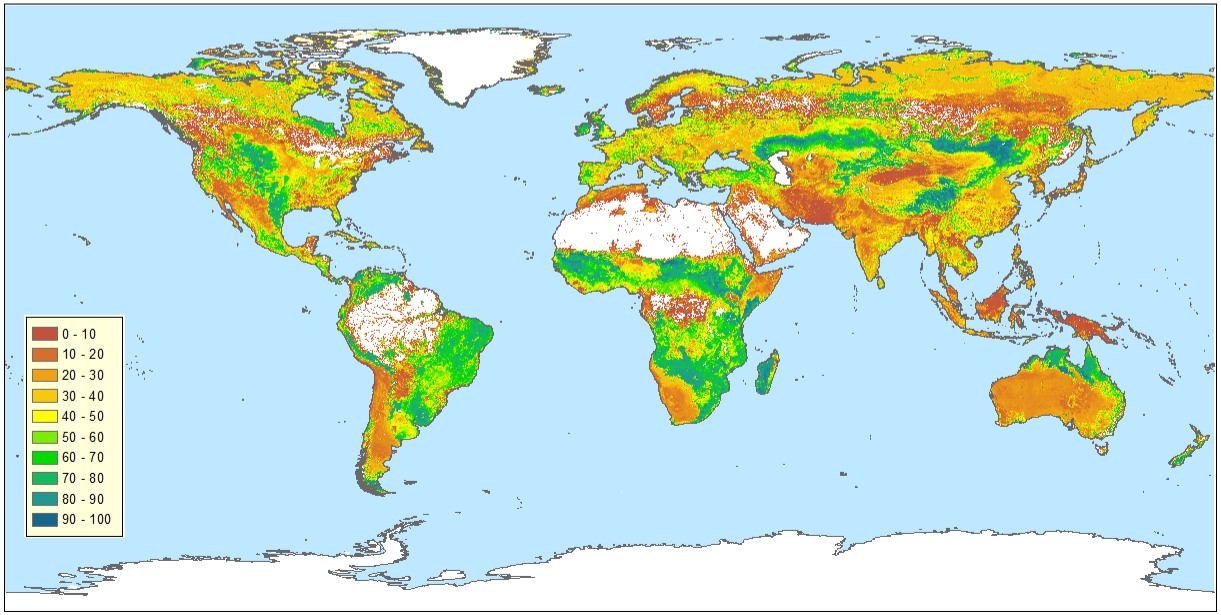


CLM5 Percent Grass 2005



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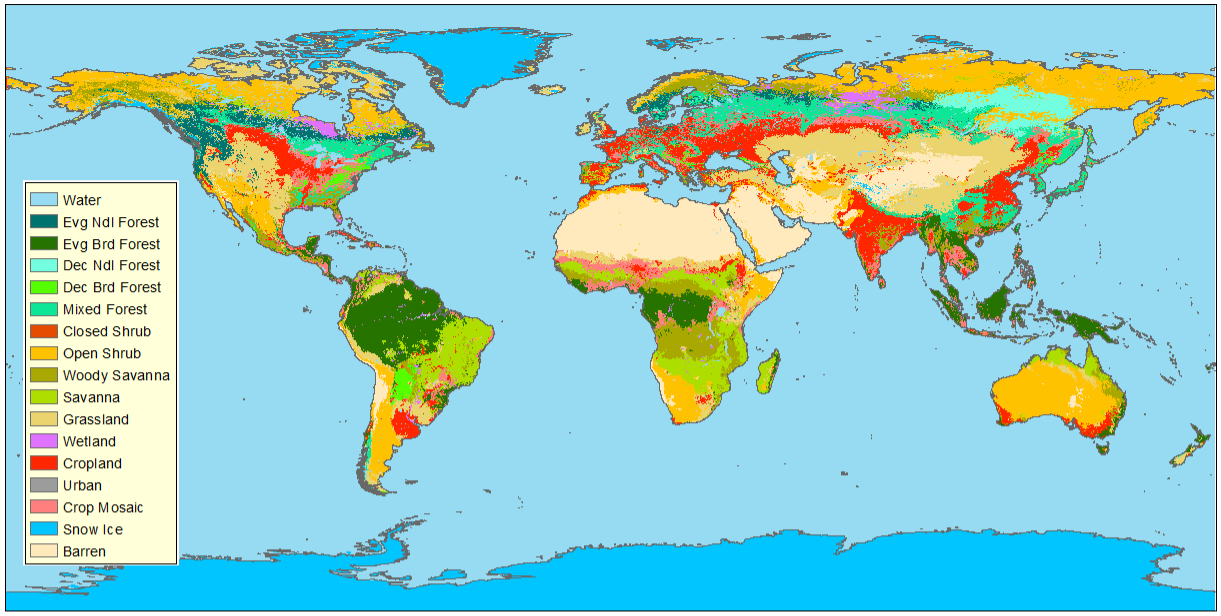
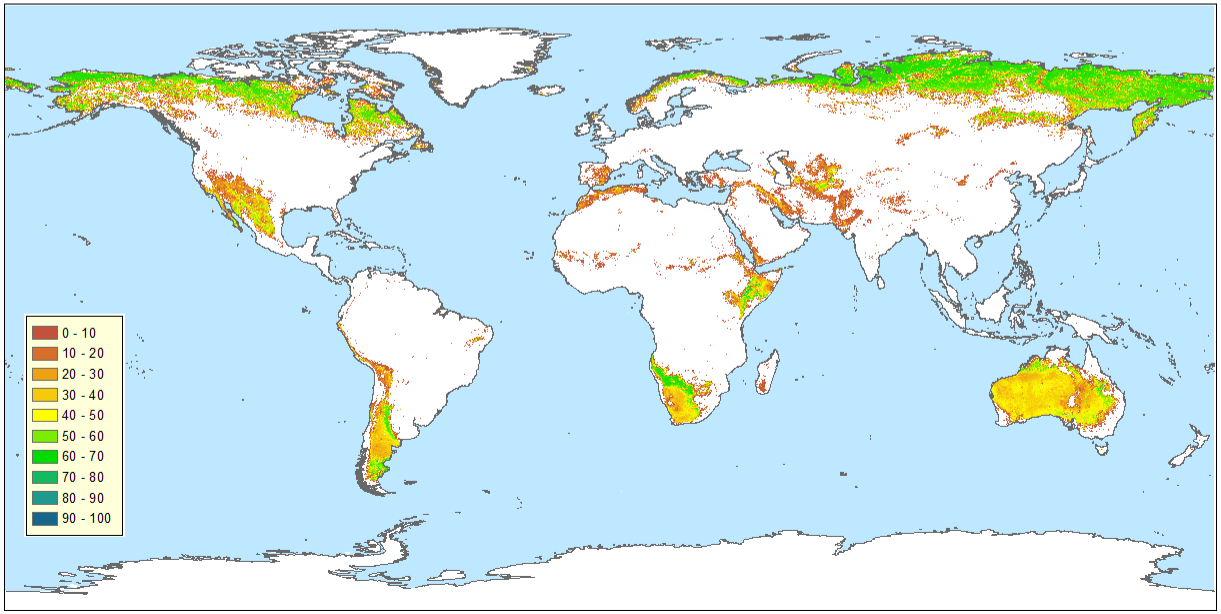
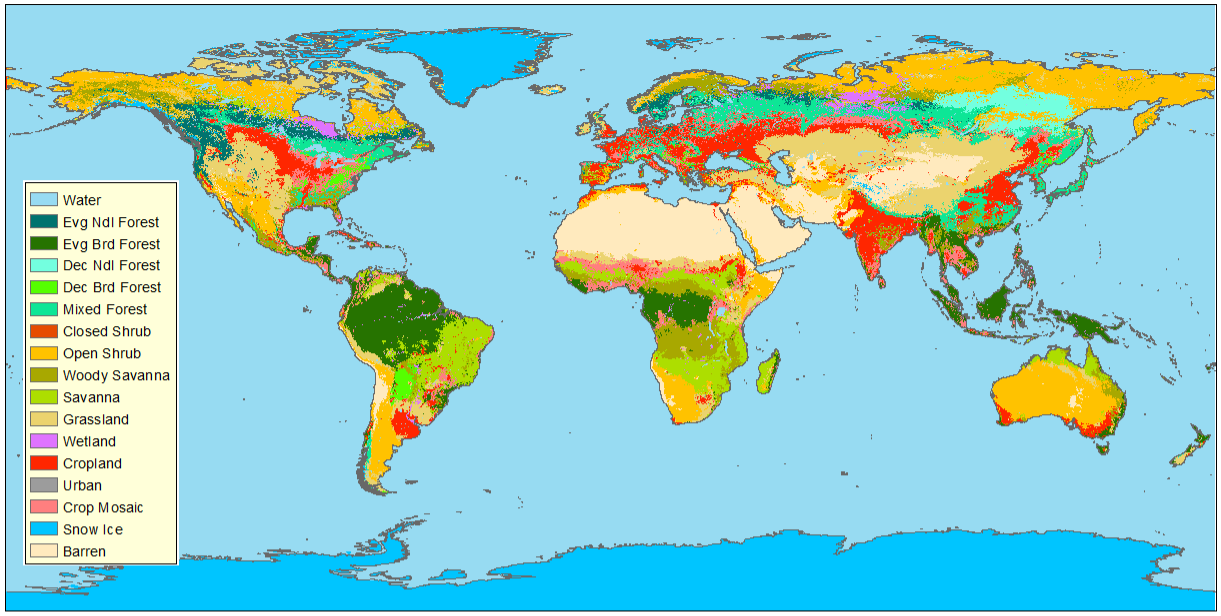


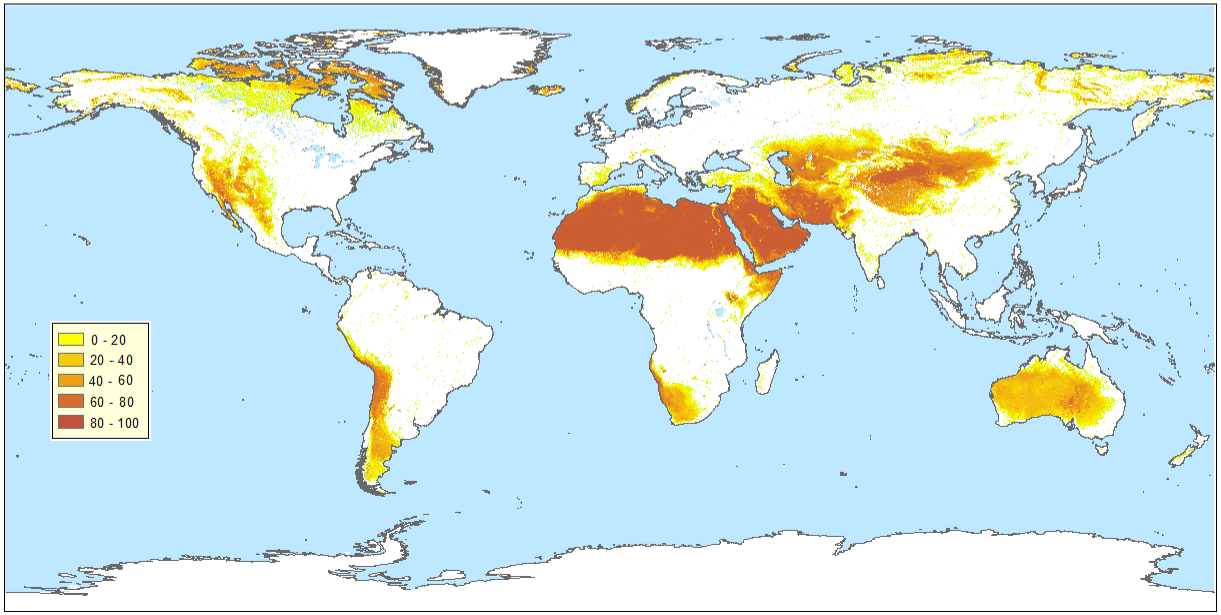
CLM5 Percent Shrub 2005

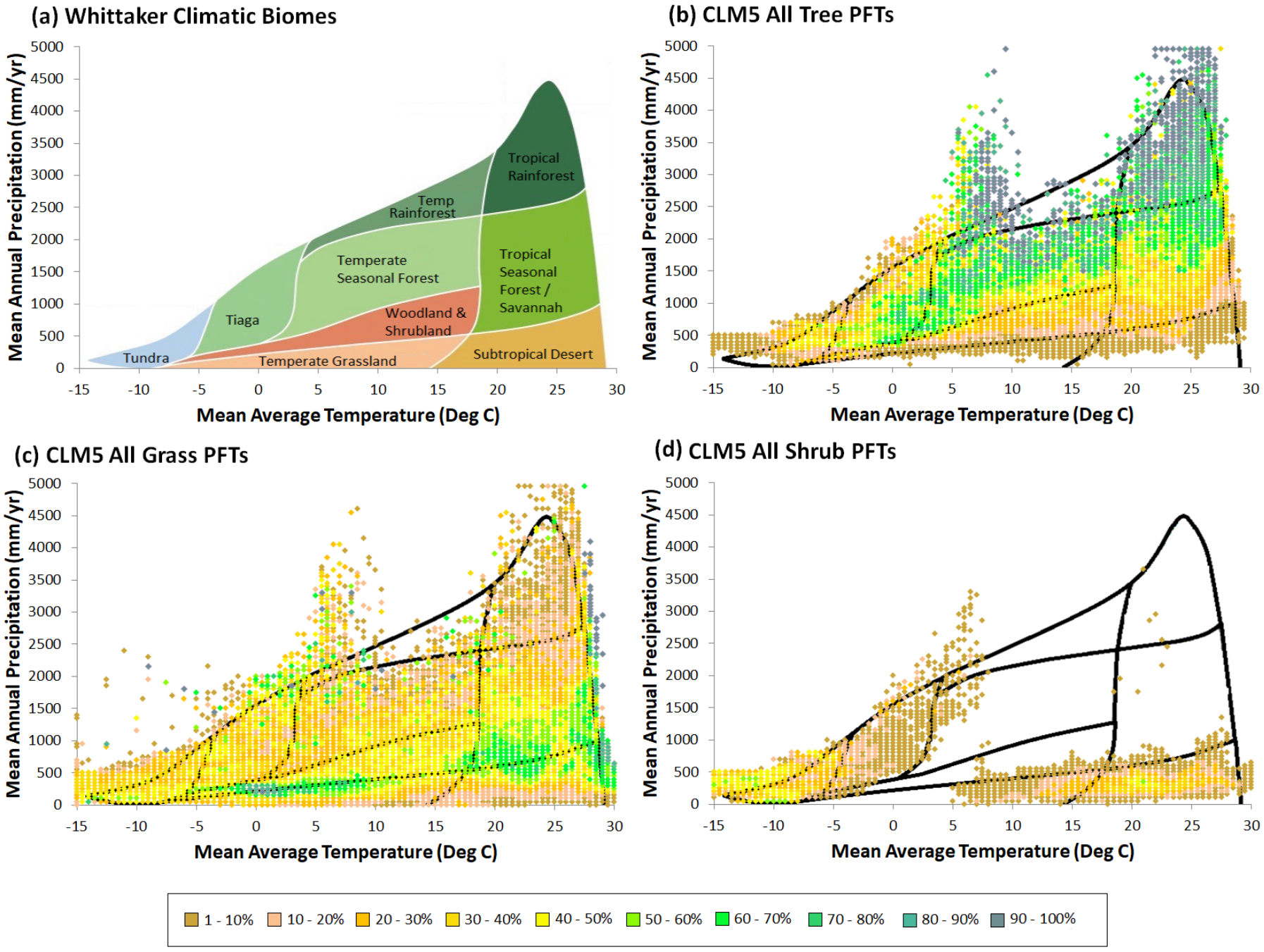


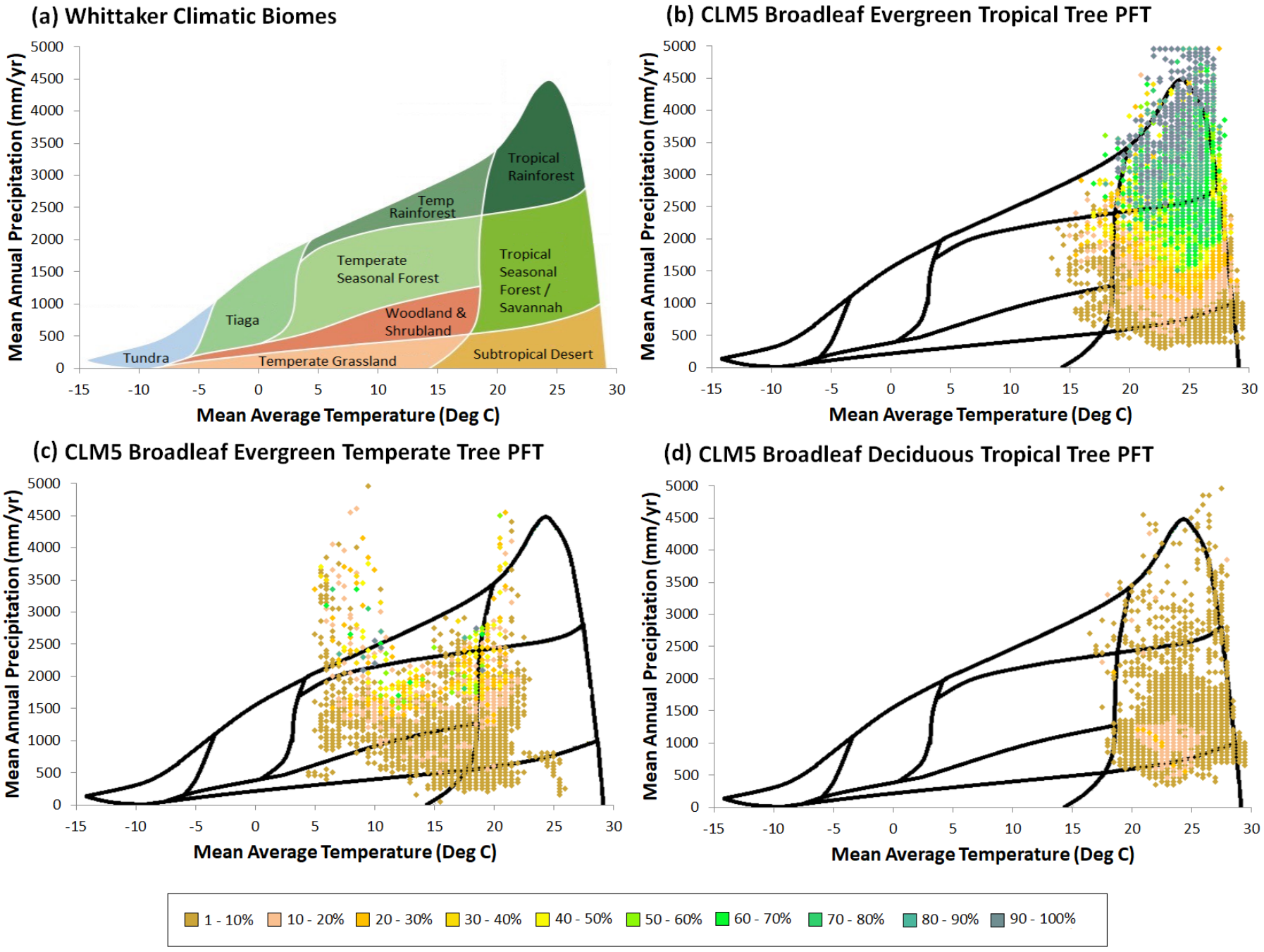
MODIS Land Cover - IGBP Classes (2003 - 2012)



CLM5 Percent Bare Soil 2005




(a) Whittaker Climatic Biomes
Mean Annual Precipitation (mm/yr)
Mean Average Temperature (Deg C)
Tundra
Tiaga
Temperate Seasonal Forest
Temp Rainforest
Tropical Rainforest
Woodland & Shrubland
Temperate Grassland
Tropical Seasonal Forest / Savannah
Subtropical Desert
(b) CLM5 All Tree PFTs
(c) CLM5 All Grass PFTs
(d) CLM5 All Shrub PFTs
1 - 10%
10 - 20%
20 - 30%
30 - 40%
40 - 50%
50 - 60%
60 - 70%
70 - 80%
80 - 90%
90 - 100%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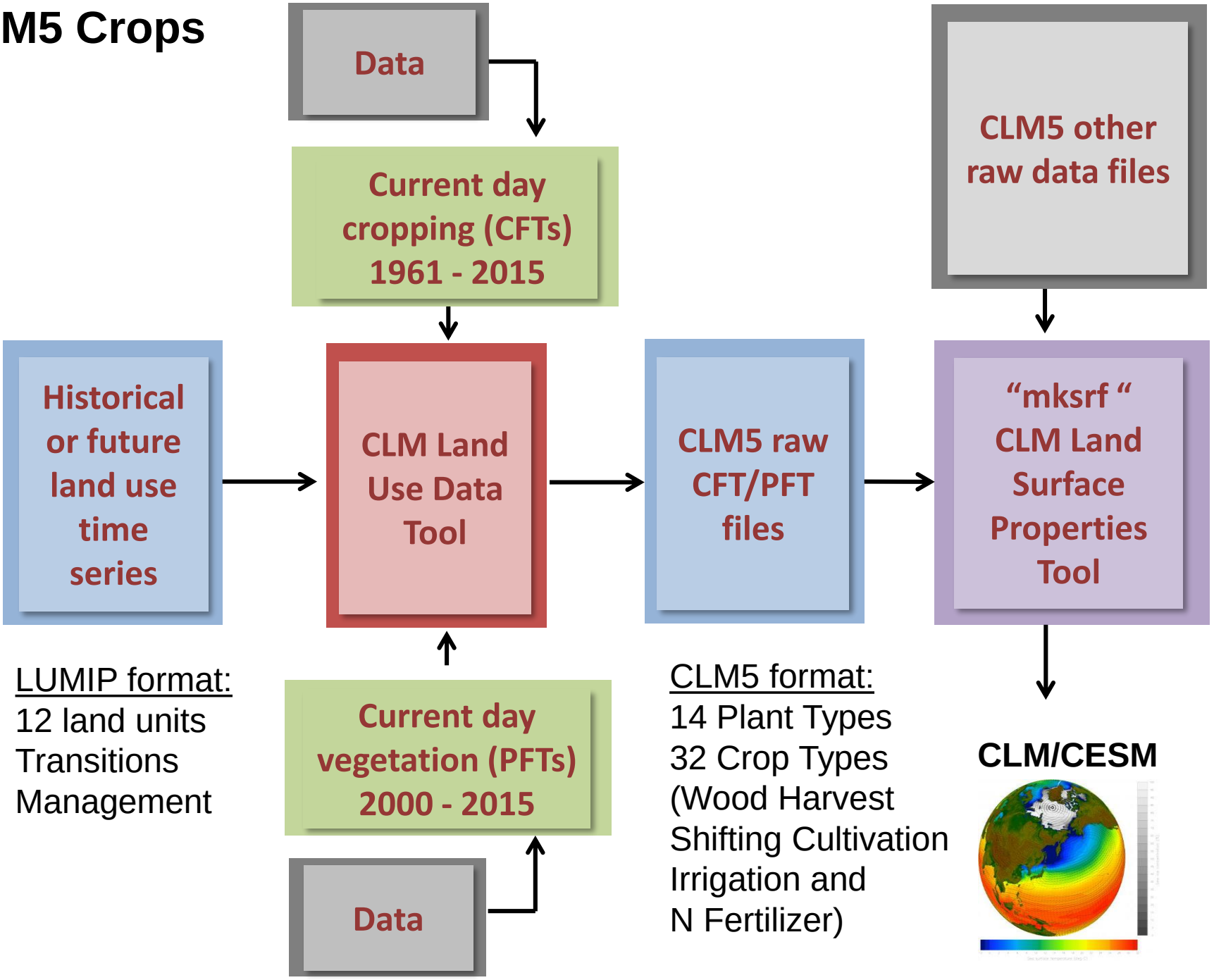
Subtropical Desert
(b) CLM5 Broadleaf Evergreen Tropical Tree PFT
(c) CLM5 Broadleaf Evergreen Temperate Tree PFT
(d) CLM5 Broadleaf Deciduous Tropical Tree PFT
1 - 10%
10 - 20%
20 - 30%
30 - 40%
40 - 50%
50 - 60%
60 - 70%
70 - 80%
80 - 90%
90 - 100%

CLM5 Crops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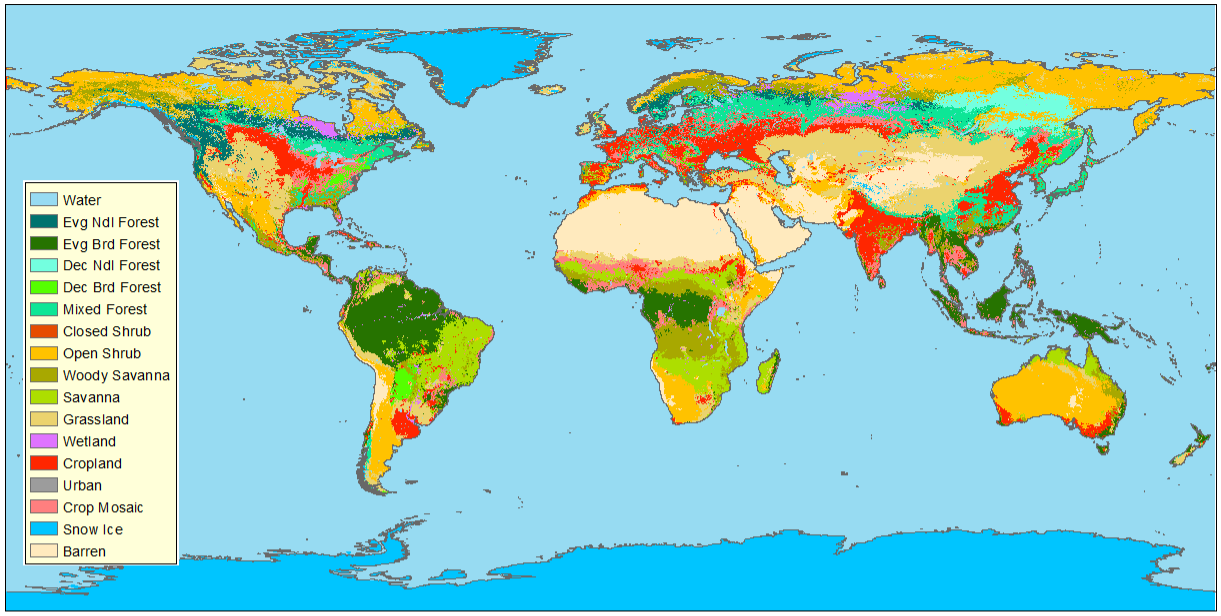
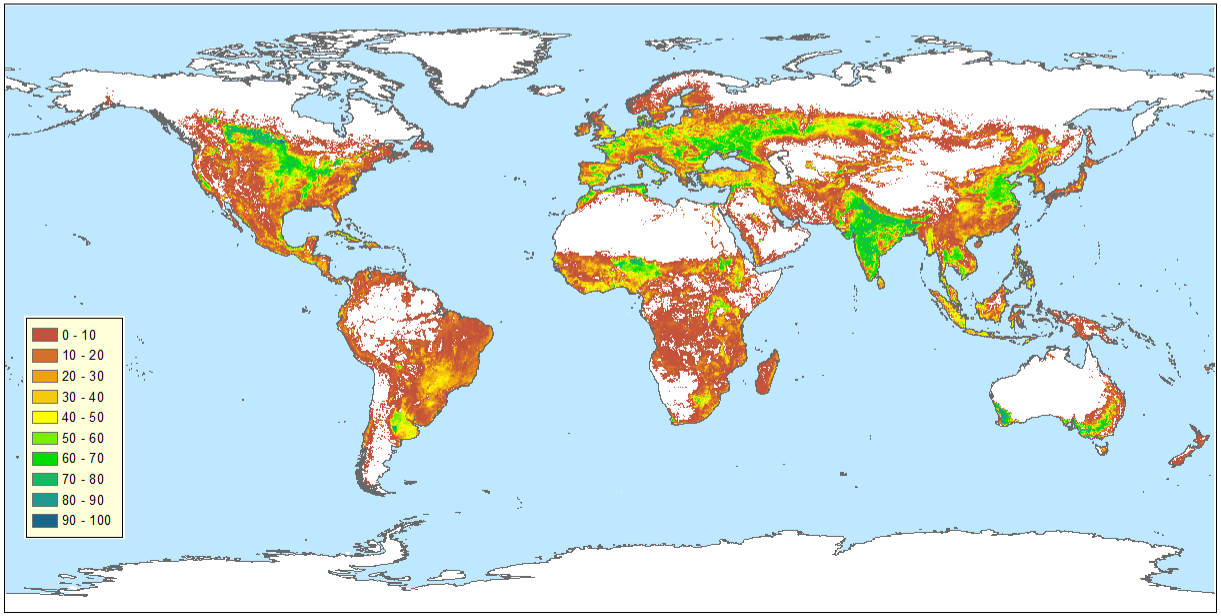
LUMIP format:
12 land units
Transitions
Management
Current day vegetation (PFTs) 2000 - 2015
Data
CLM5 format:
14 Plant Types
32 Crop Types
(Wood Harvest
Shifting Cultivation
Irrigation and
N Fertilizer)
CLM/CESM

MODIS Land Cover - IGBP Classes (2003 - 2012)



CLM5 Percent Crop 2005



LUMIP => 64 CLM5 Rainfed and Irrigated Crop Types Mapped using EARTHSTAT – UN FAOSTAT distributions

CFT	CFT	CFT	CFT	CFT
15. C3 Generic Crop	29. Rye	43. Datepalm	57. Pulses	71. Miscanthus
16. C3 Generic Crop Irrigated	30. Rye Irrigated	44. Datepalm Irrigated	58. Pulses Irrigated	72. Miscanthus Irrigated
17. Temperate Corn	31. Winter Rye	45. Foddergrass	59. Rapeseed	73. Switchgrass
18. Temperate Corn Irrigated	32. Winter Rye Irrigated	46. Foddergrass Irrigated	60. Rapeseed Irrigated	74. Switchgrass Irrigated
19. Spring Wheat	33. Cassava	47. Grapes	61. Rice	75. Tropical Corn
20. Spring Wheat Irrigated	34. Cassava Irrigated	48. Grapes Irrigated	62. Rice Irrigated	76. Tropical Corn Irrigated
21. Winter Wheat	35. Citrus	49. Groundnuts	63. Sorghum	77. Tropical Soybean
22. Winter Wheat Irrigated	36. Citrus Irrigated	50. Groundnuts Irrigated	64. Sorghum Irrigated	78. Tropical Soybean Irrigated
23. Temperate Soybean	37. Cocoa	51. Millet	65. Sugarbeet	
24. Temperate Soybean Irrigated	38. Cocoa Irrigated	52. Millet Irrigated	66. Sugarbeet Irrigated	
25. Barley	39. Coffee	53. Oilpalm	67. Sugarcane	
26. Barley Irrigated	40. Coffee Irrigated	54. Oilpalm Irrigated	68. Sugarcane Irrigated	
27. Winter Barley	41. Cotton	55. Potatoes	69. Sunflower	
28. Winter Barley Irrigated	42. Cotton Irrigated	56. Potatoes Irrigated	70. Sunflower Irrigated	

CLM5 Crop Distributions from LUMIP Crop Types

Remap Annual LUH2 Crop Land Units to 32 CLM5 Crop Functional Types using current day (1961 – 2015) crop distributions from EARTHSTAT and UN FAOSTAT:

- C3Ann -> Wheat, Rice, Cotton, Barley, Rye, Sunflower, Cassava, Potatoes, Sugar beet, Rape seed, Fodder grass

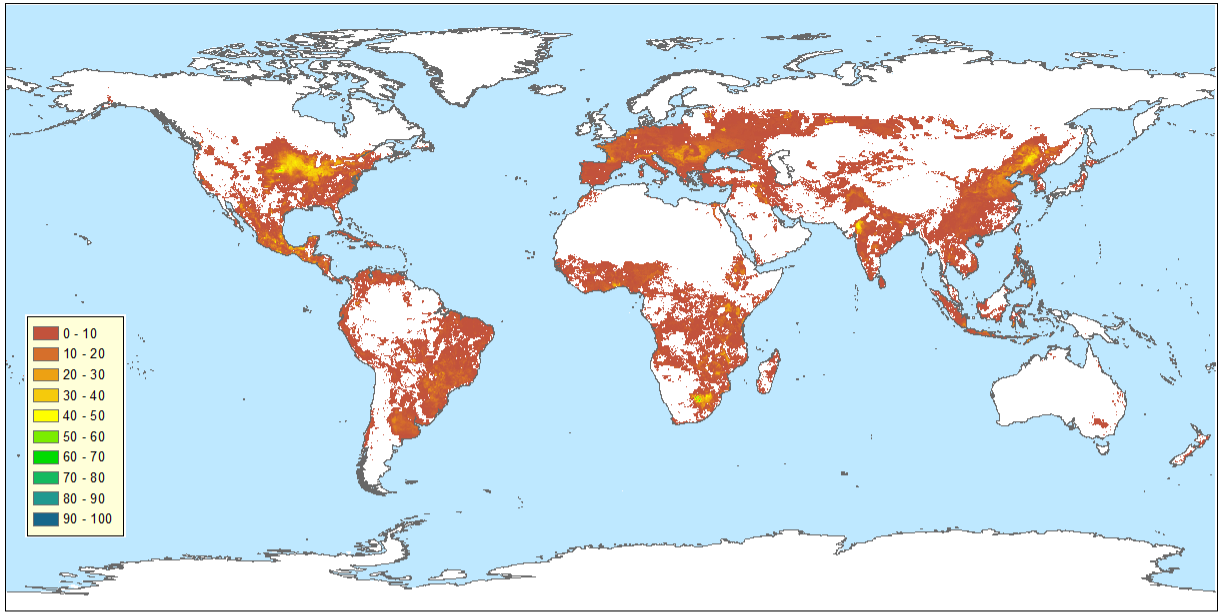
- C4Ann -> Maize, Millet, Sorghum

- C3Per -> Oil palm, Citrus, Date palm, Grapes, Cocoa, Coffee

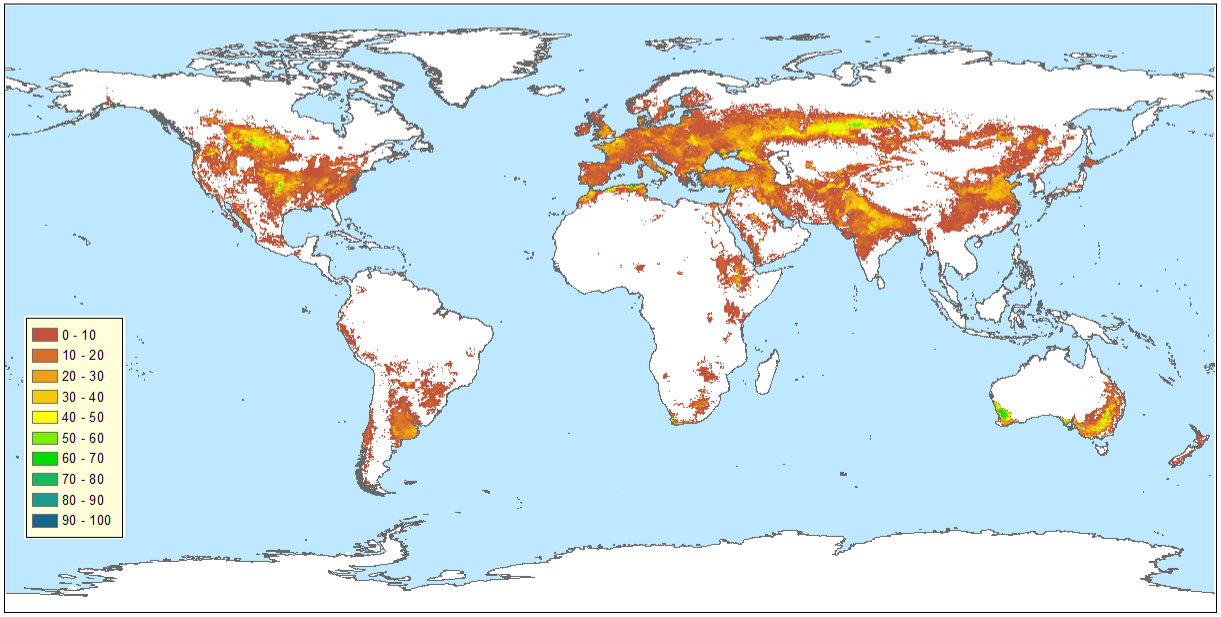
- C4Per -> Sugar cane

- C3Nfx -> Soybeans, Groundnuts, Pulses

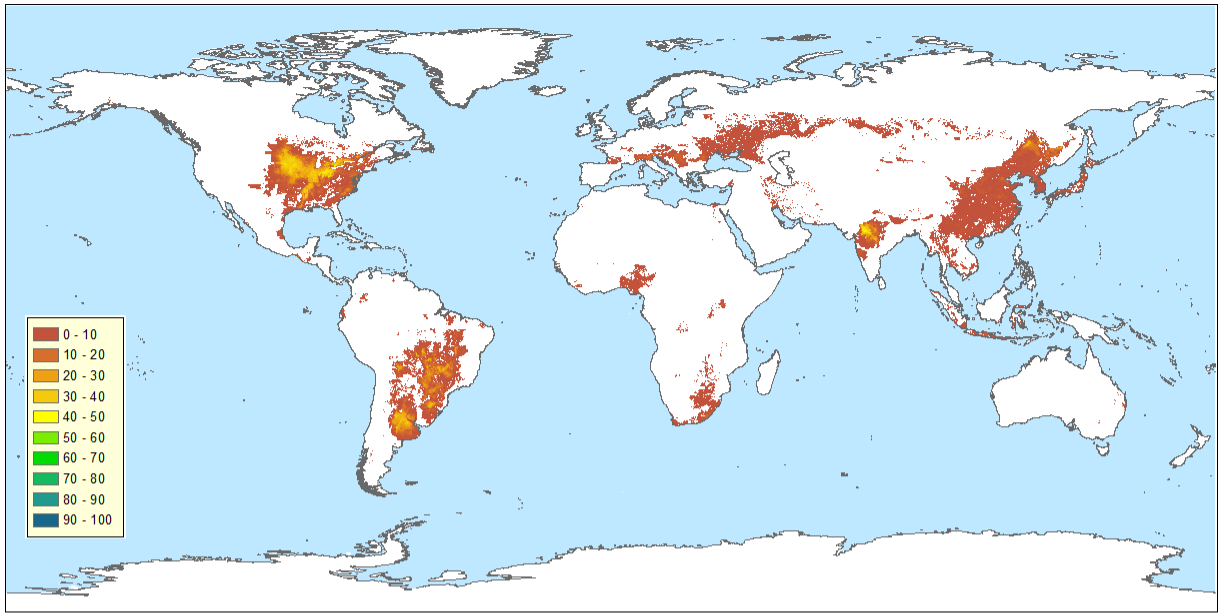
CLM5 Percent Corn 2005



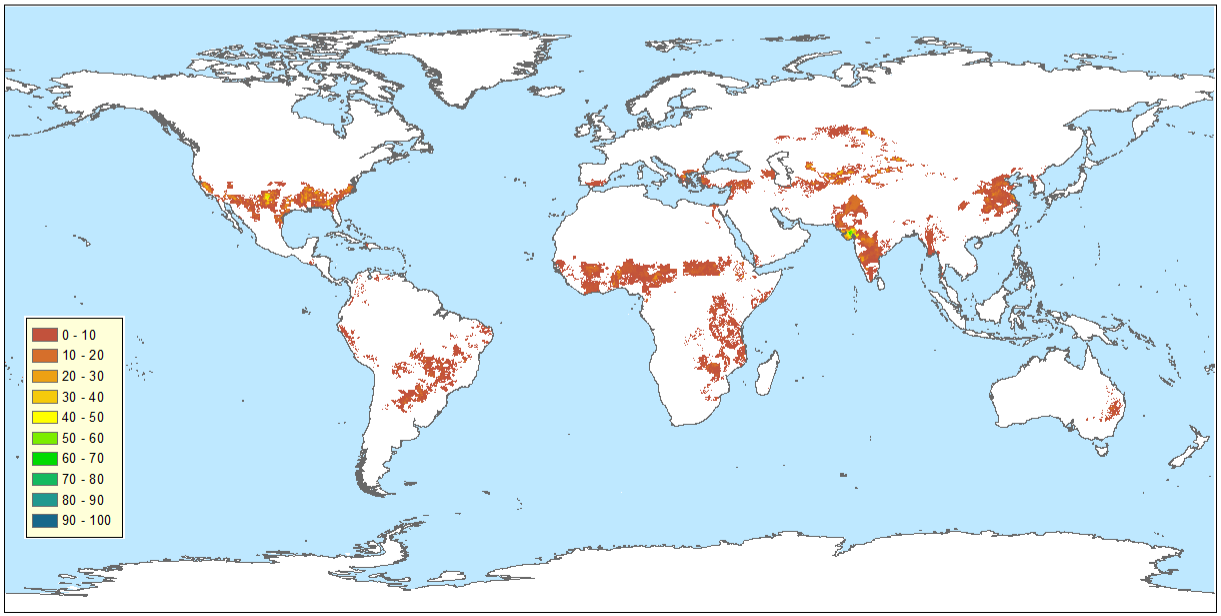
CLM5 Percent Wheat 2005



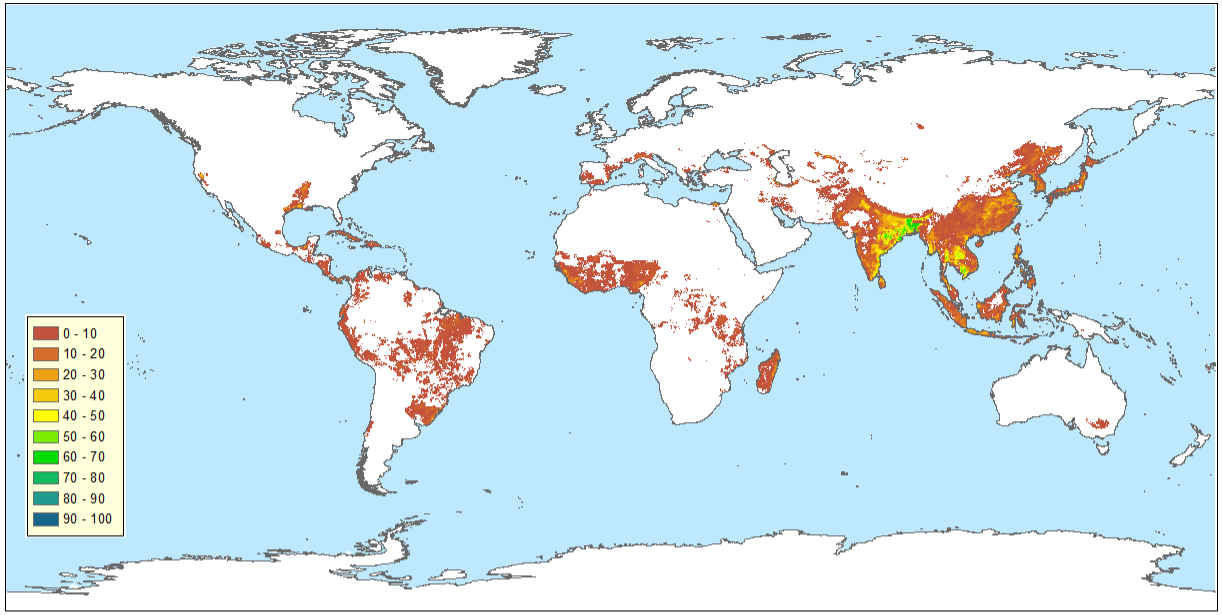
CLM5 Percent Soybean 2005



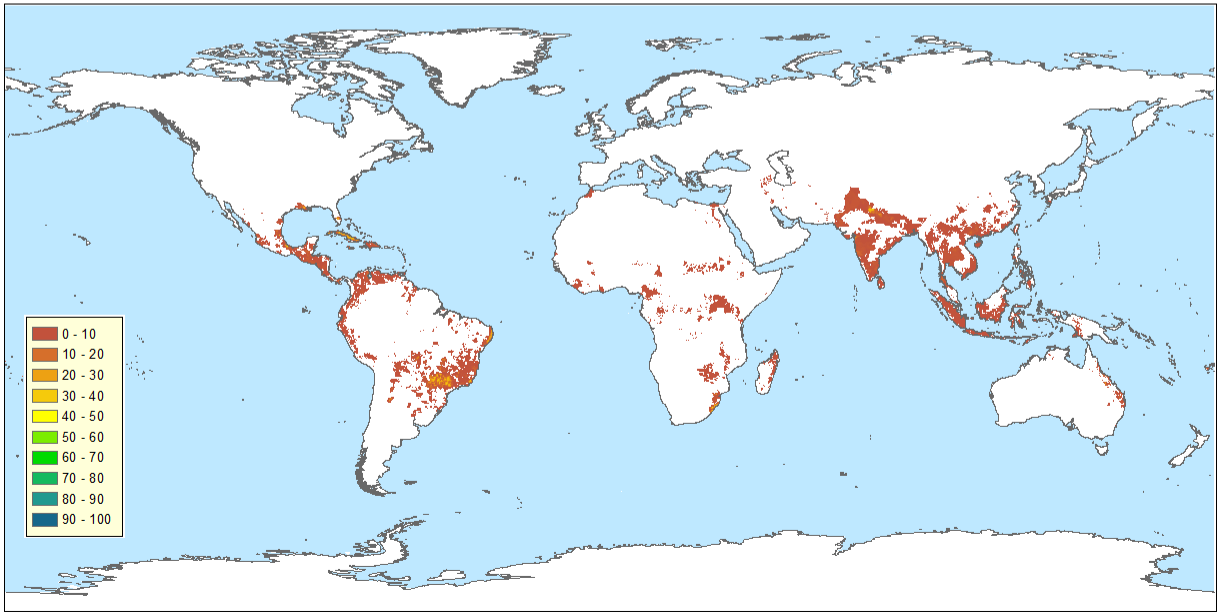
CLM5 Percent Cotton 2005



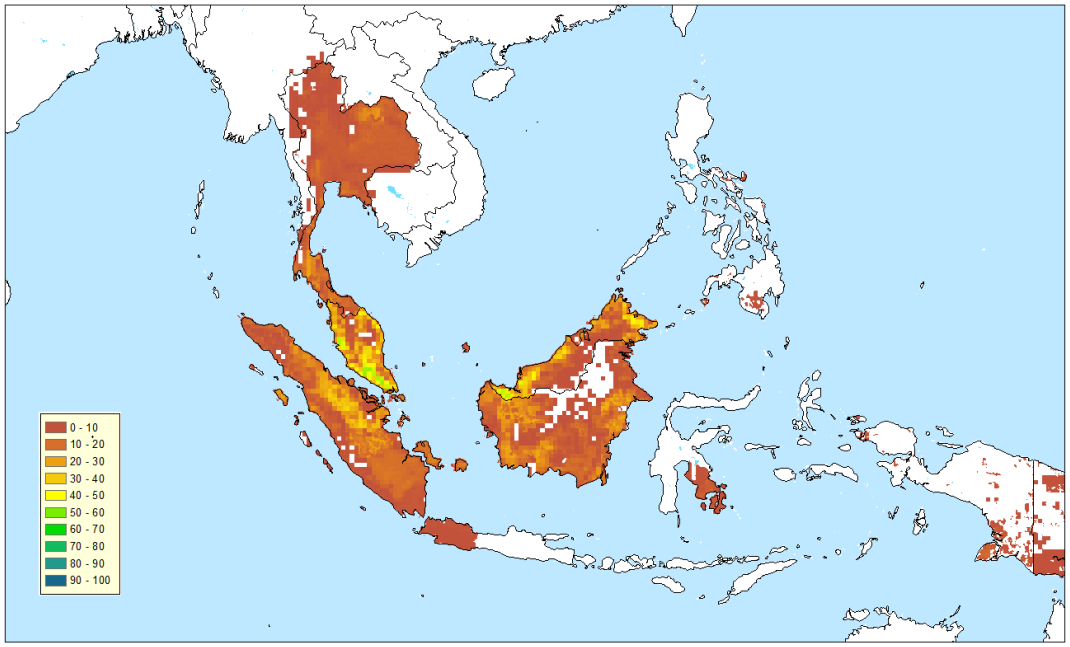
CLM5 Percent Rice 2005



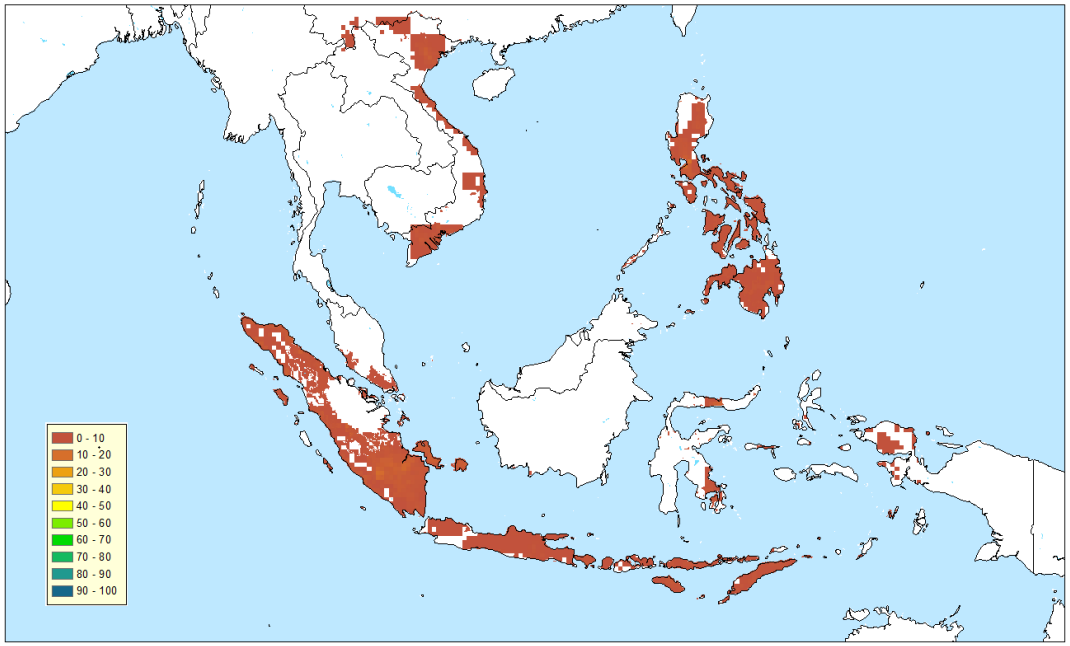
CLM5 Percent Sugarcane 2005



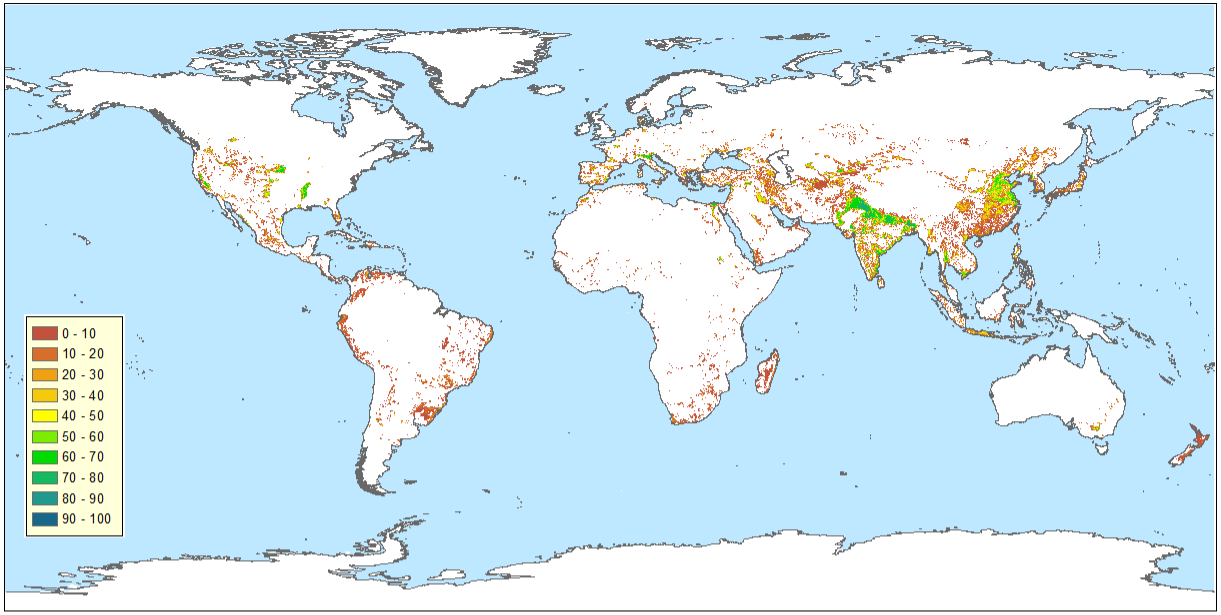
CLM5 Oil Palm 2005



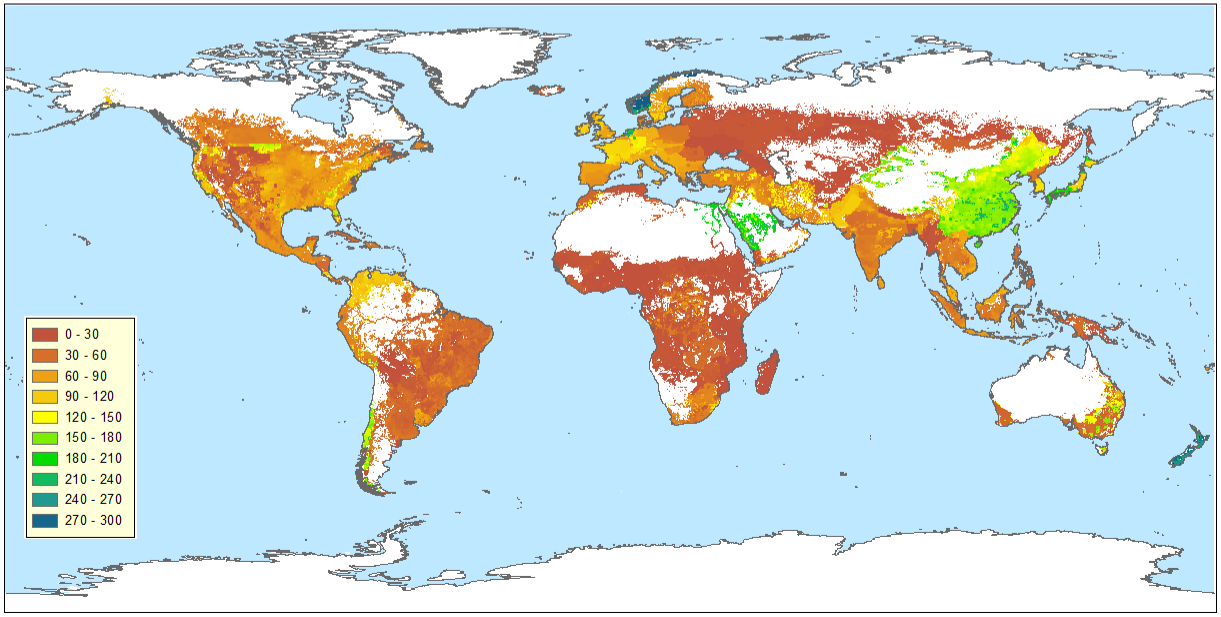
CLM5 Coffee 2005



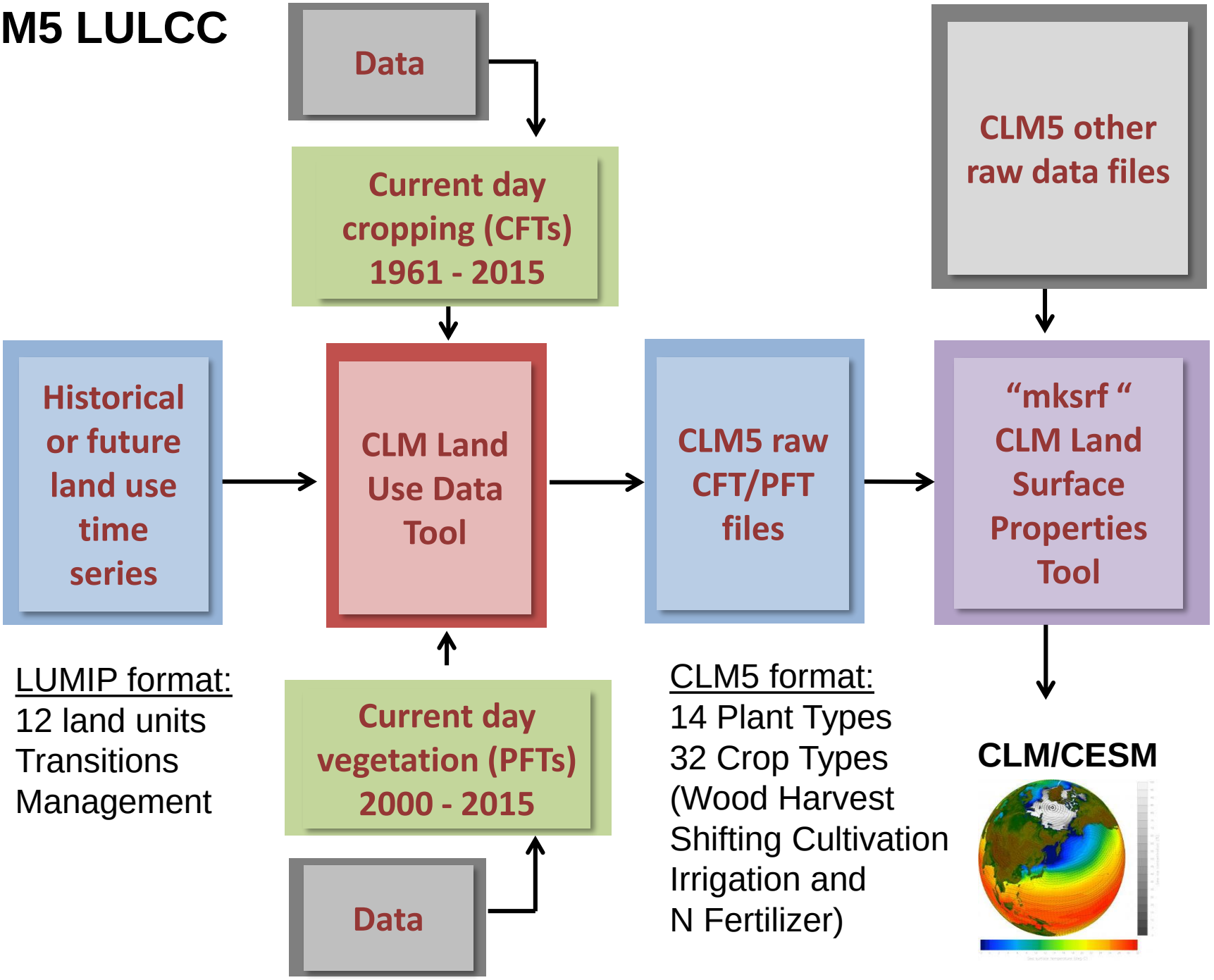
CLM5 Percent Crop Irrigated 2005



CLM5 Average Crop N Fertilizer kg/ha 2005



CLM5 LULCC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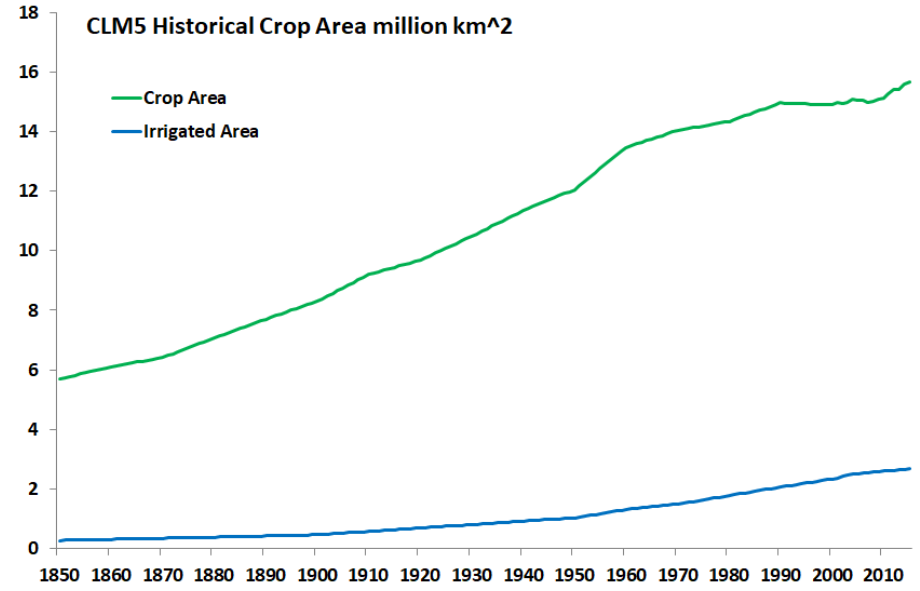
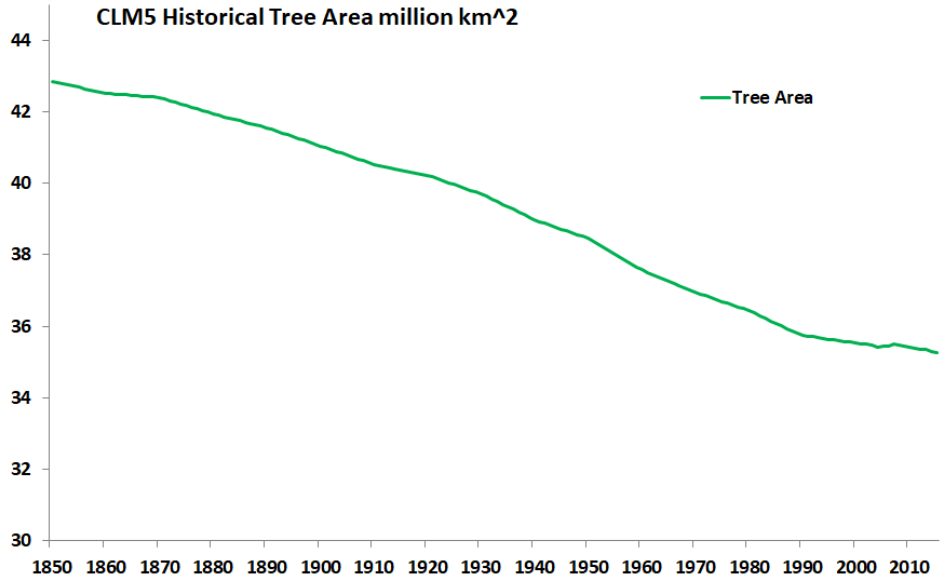
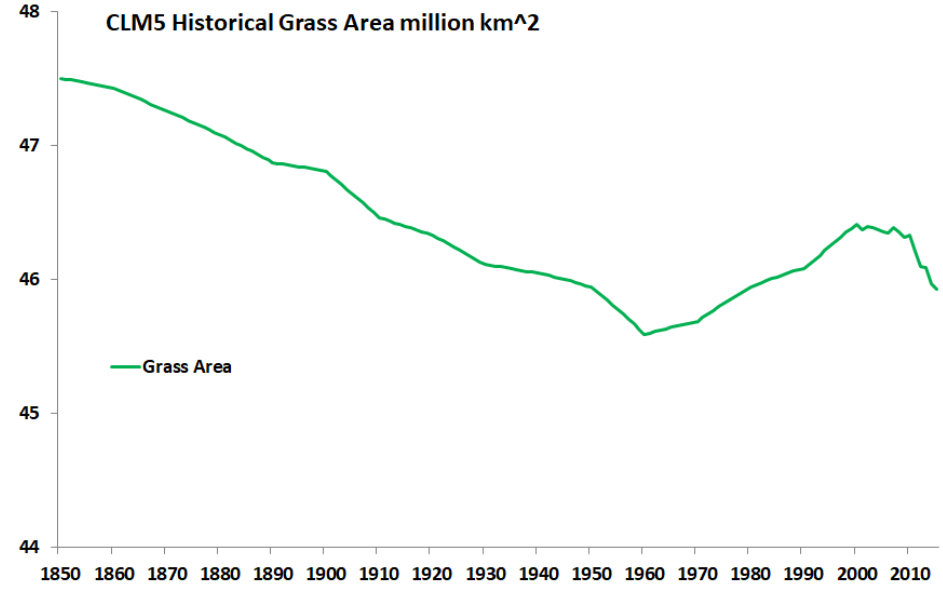
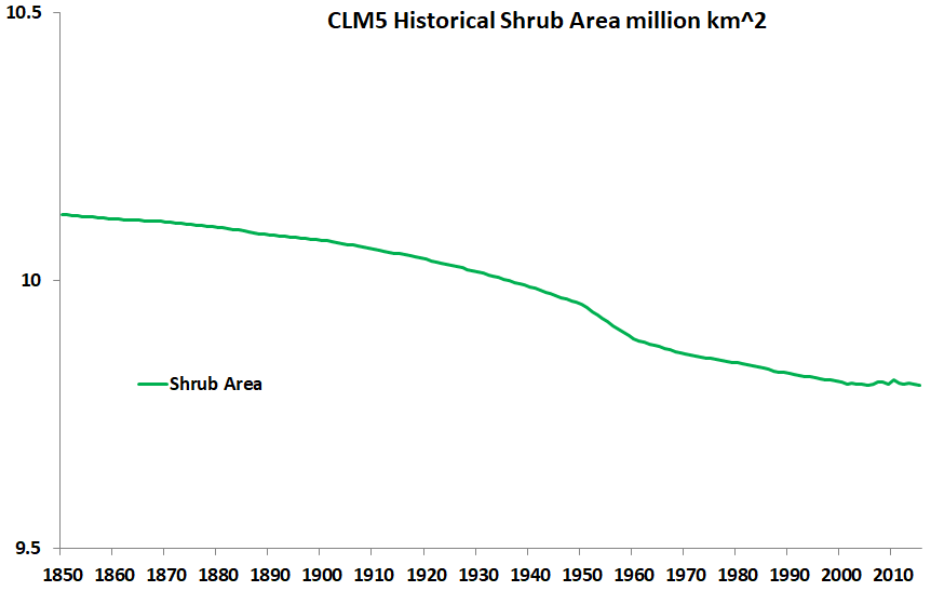
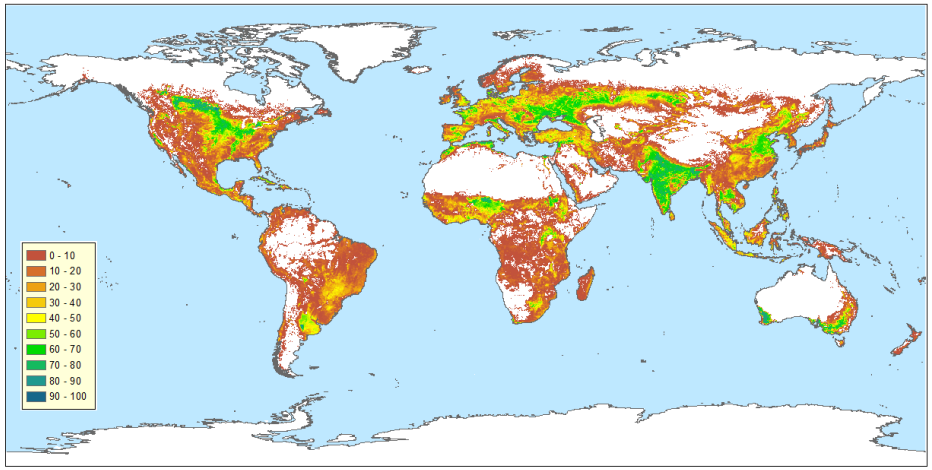

CLM5 Historical Crop Area million km^2
Crop Area
Irrigated Area
18
16
14
12
10
8
6
4
2
0
1850 1860 1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010


CLM5 Historical Tree Area million km^2
Tree Area
44
42
40
38
36
34
32
30
1850 1860 1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010

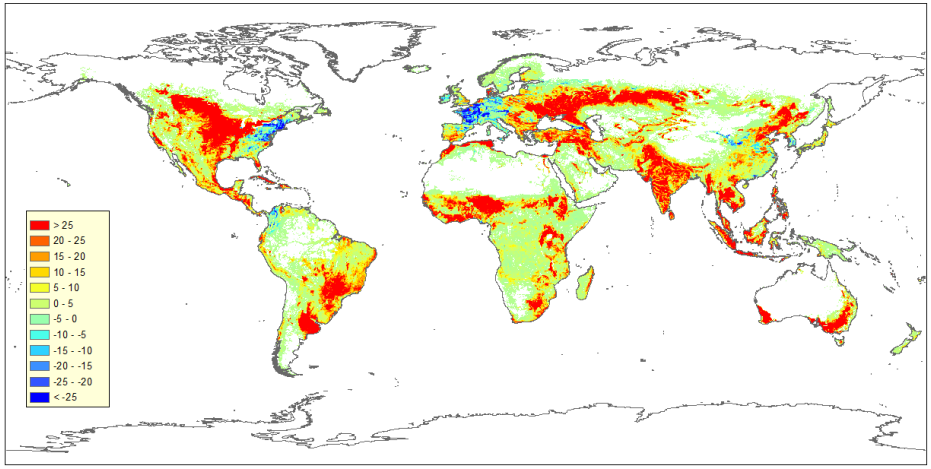

CLM5 Historical Grass Area million km^2
Grass Area
48
47
46
45
44
1850 1860 1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010


CLM5 Historical Shrub Area million km^2
Shrub Area
10.5
10
9.5
1850 1860 1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010

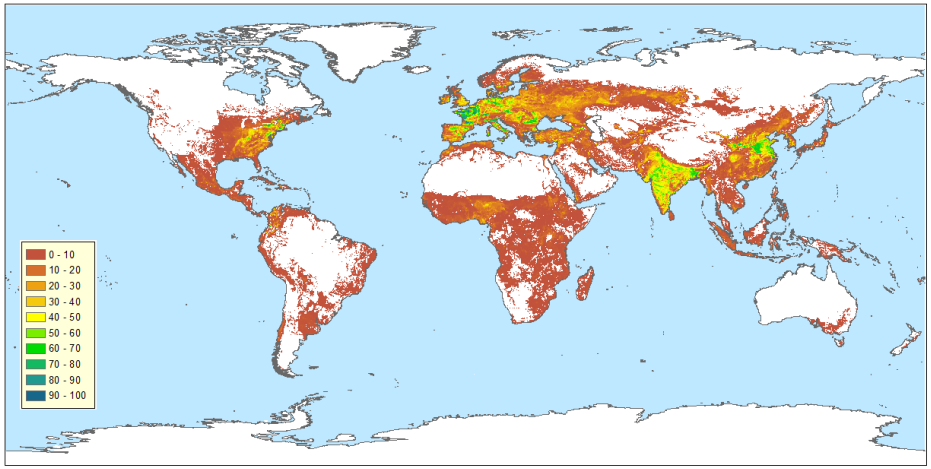
CLM5 Percent Crop 2005

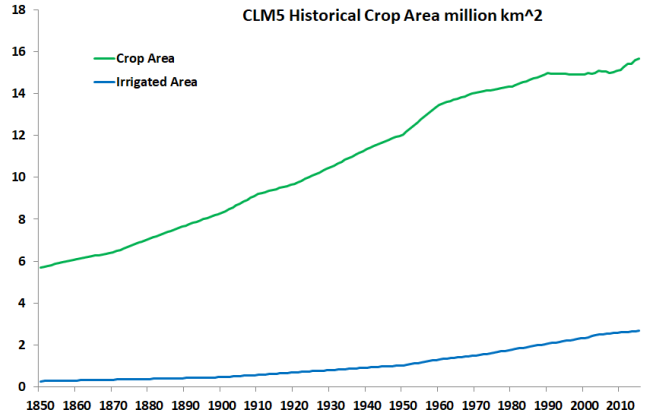


CLM5 Percent Crop Difference 2005 - 1850

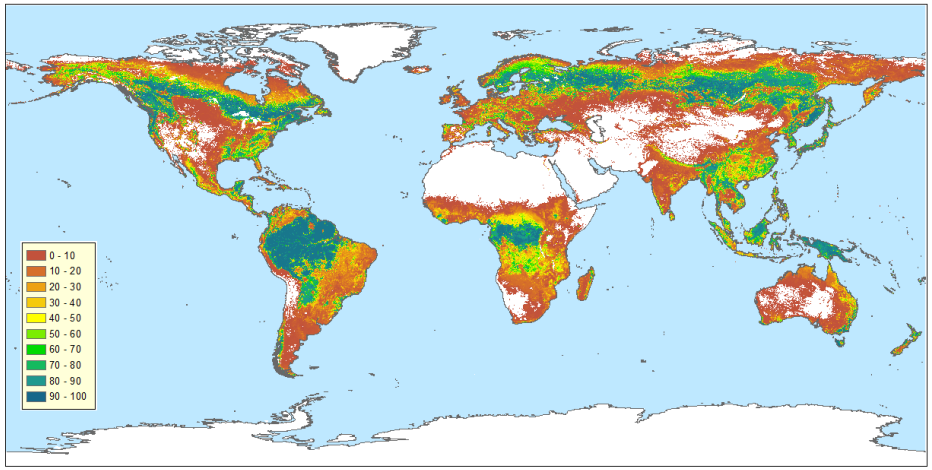


CLM5 Percent Crop 1850

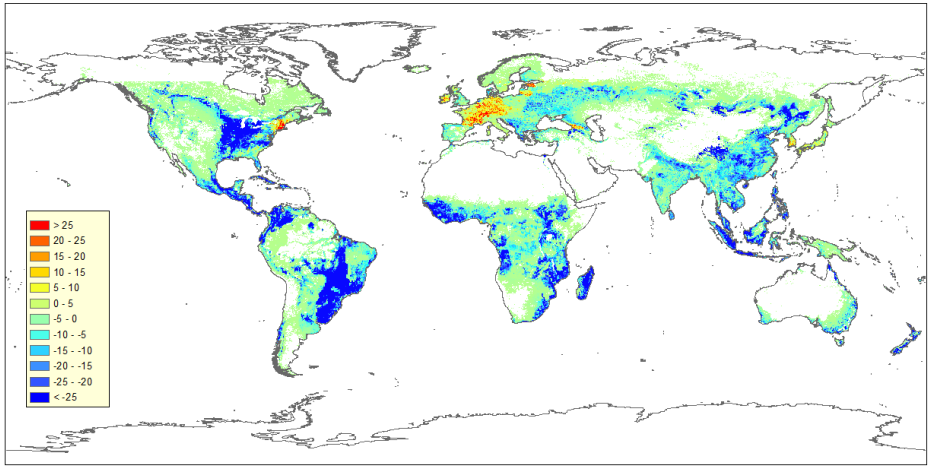




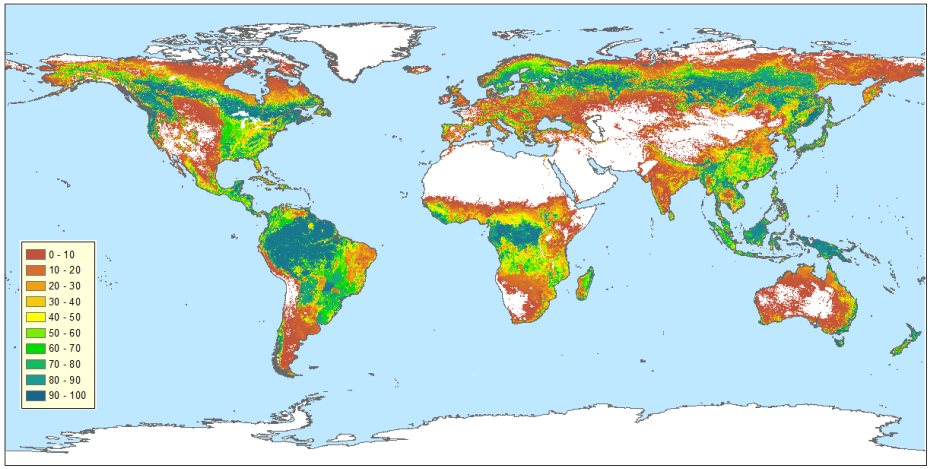
CLM5 Percent Tree 2005

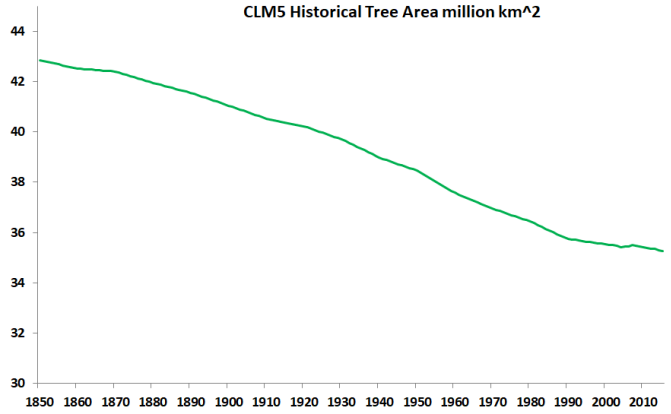


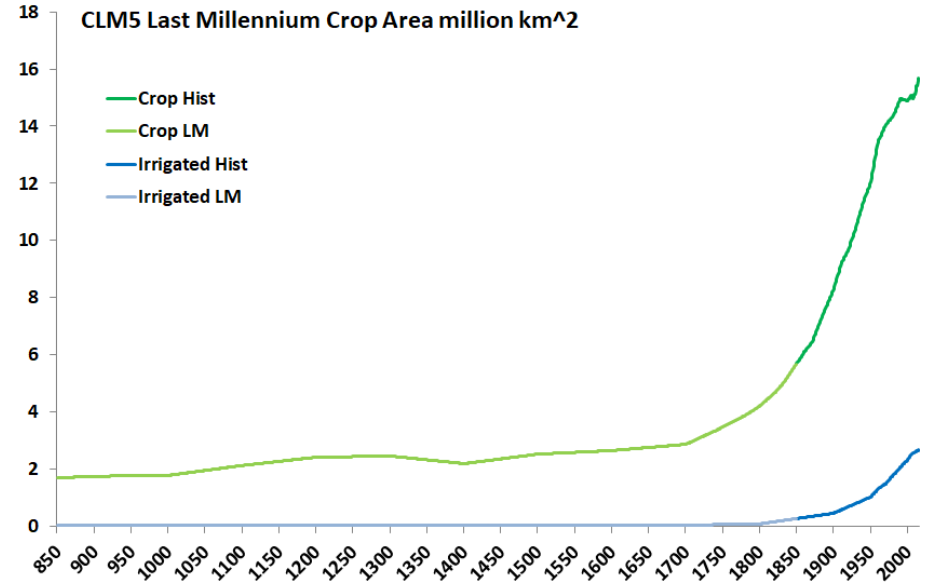
CLM5 Percent Tree Difference 2005 - 1850

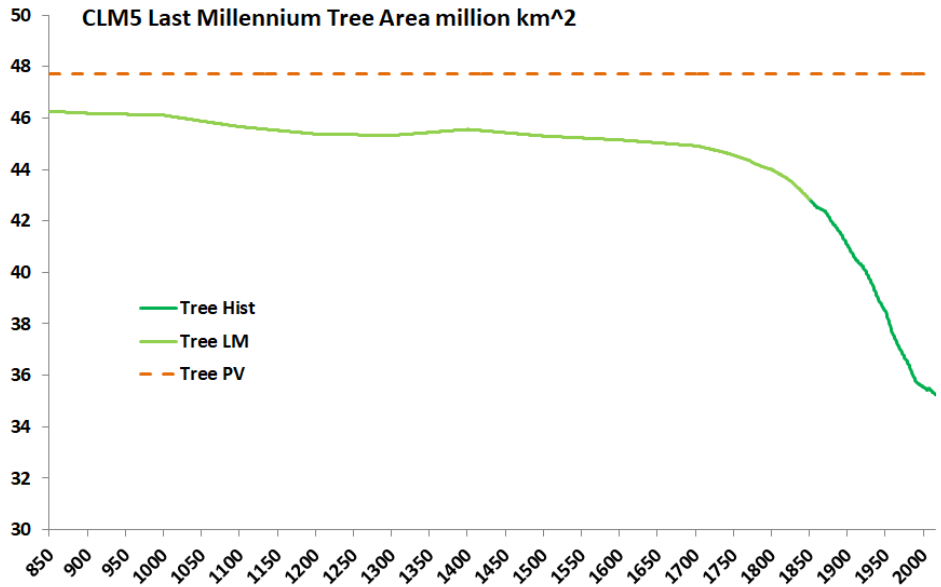


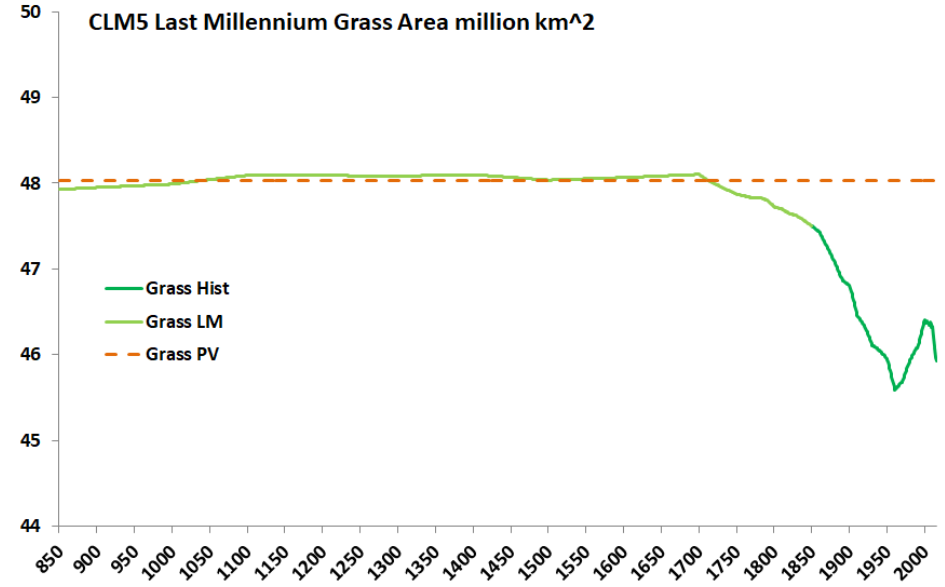
CLM5 Percent Tree 1850

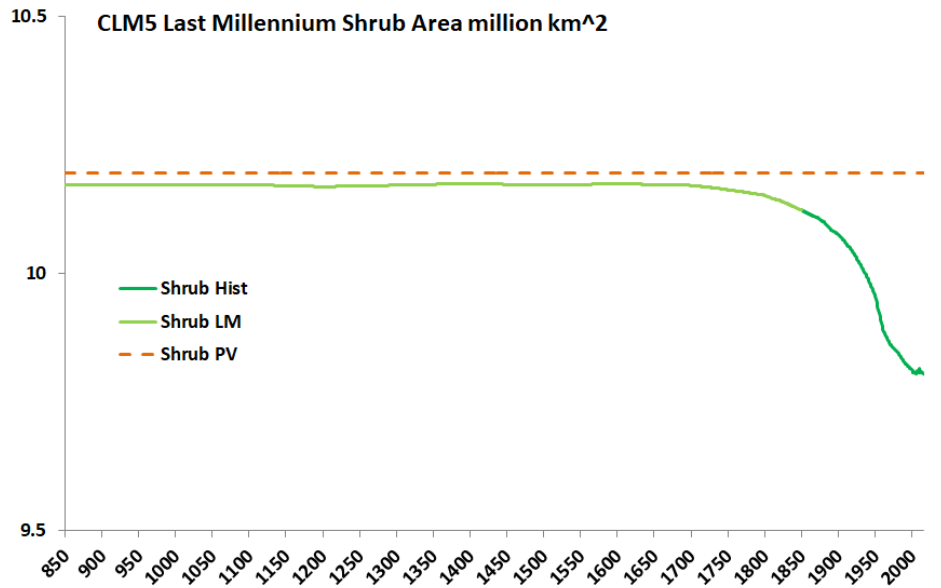




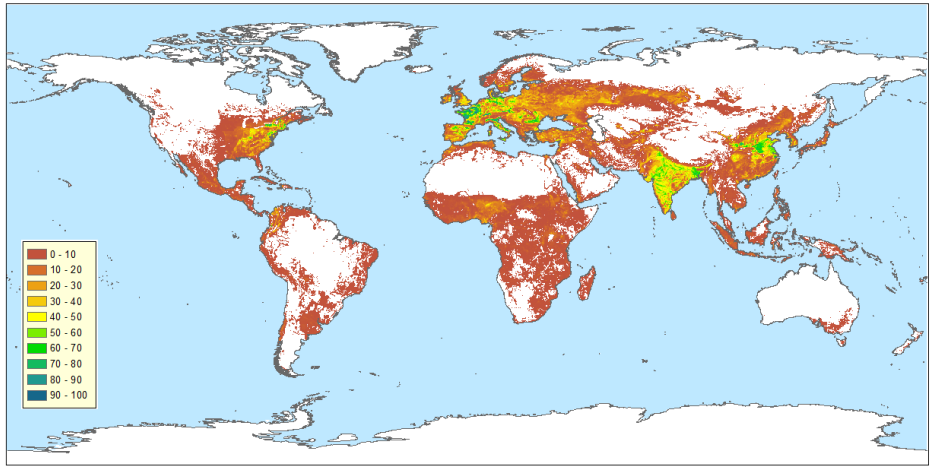

CLM5 Last Millennium Crop Area million km^2
Crop Hist
Crop LM
Irrigated Hist
Irrigated LM
18
16
14
12
10
8
6
4
2
0
850 900 950 1000 1050 1100 1150 1200 1250 1300 1350 1400 1450 1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000


CLM5 Last Millennium Tree Area million km^2
Tree Hist
Tree LM
Tree PV
50
48
46
44
42
40
38
36
34
32
30
850 900 950 1000 1050 1100 1150 1200 1250 1300 1350 1400 1450 1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000

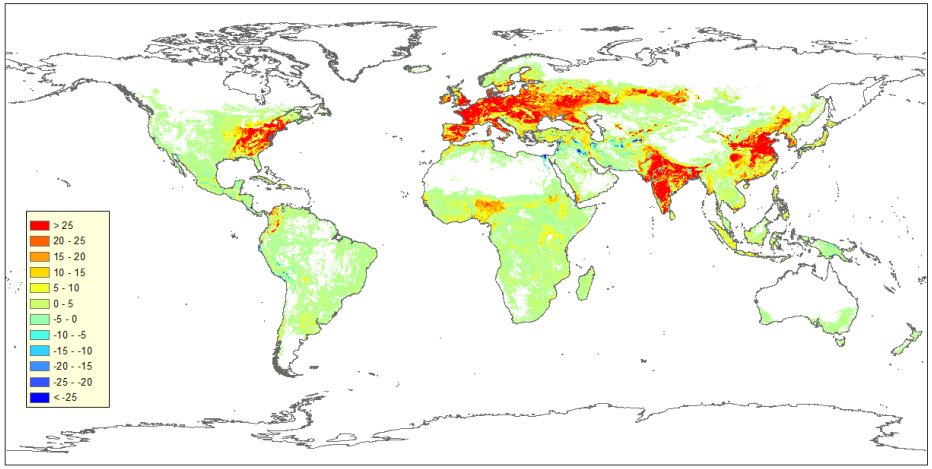

CLM5 Last Millennium Grass Area million km^2
Grass Hist
Grass LM
Grass PV
50
49
48
47
46
45
44
850 900 950 1000 1050 1100 1150 1200 1250 1300 1350 1400 1450 1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000


CLM5 Last Millennium Shrub Area million km^2
Shrub Hist
Shrub LM
Shrub PV
10.5
10
9.5
850 900 950 1000 1050 1100 1150 1200 1250 1300 1350 1400 1450 1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000

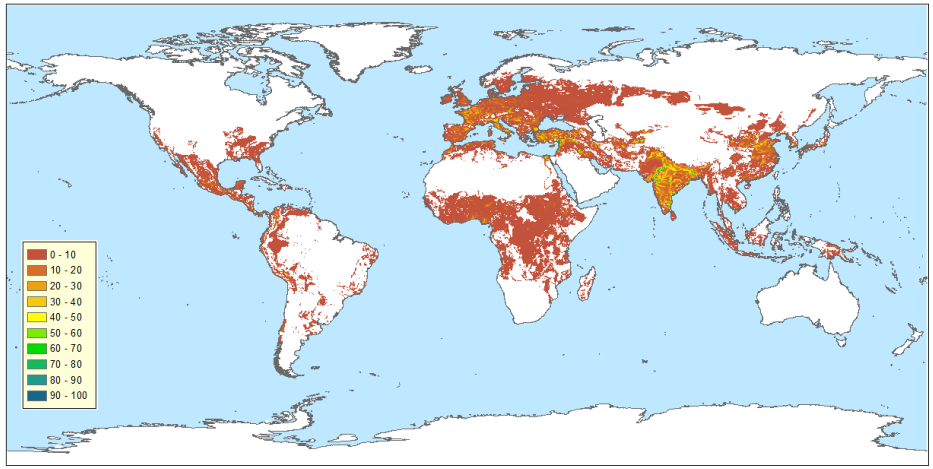
CLM5 Percent Crop 1850

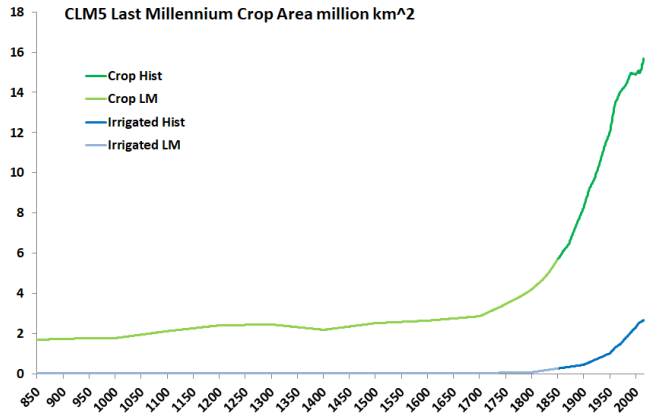


CLM5 Percent Crop Difference 1850 - 850

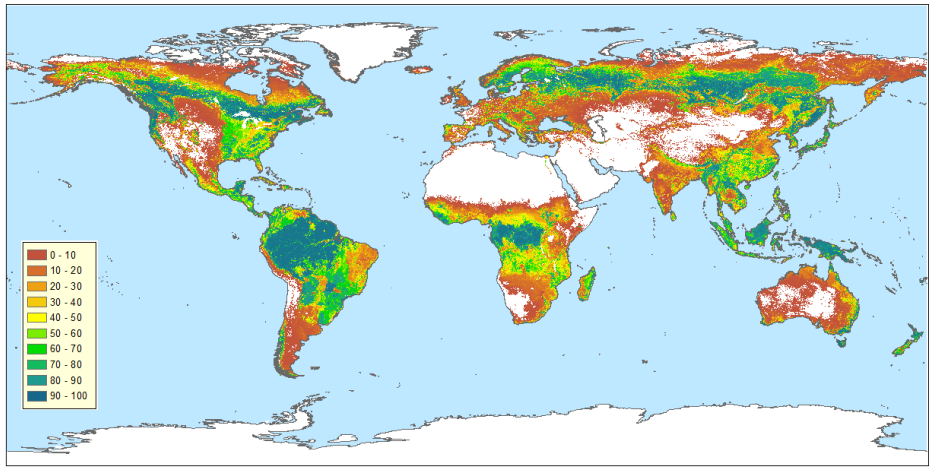


CLM5 Percent Crop 850

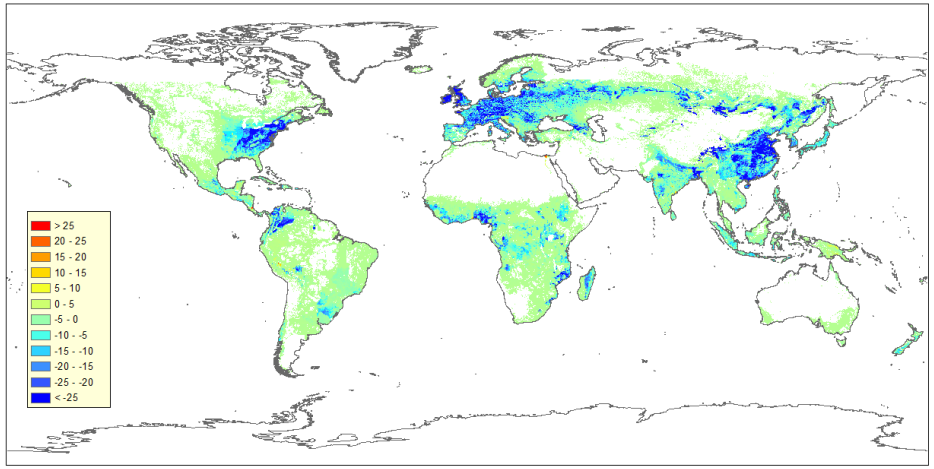




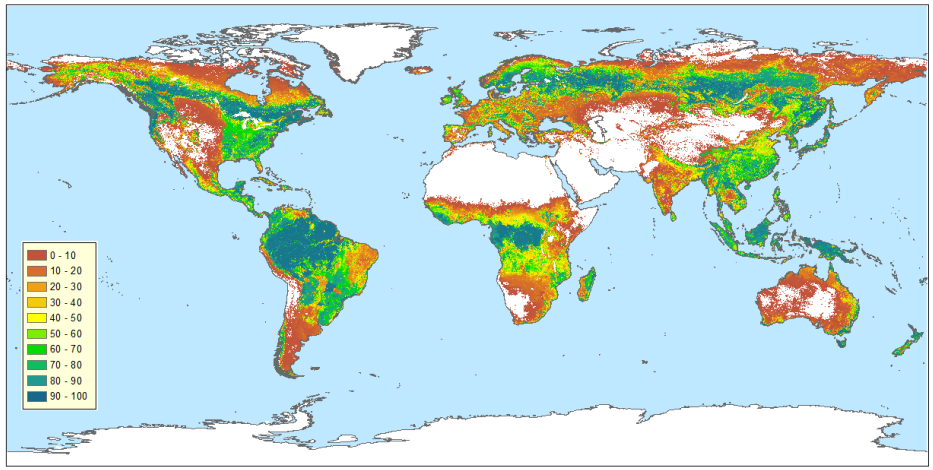
CLM5 Percent Tree 1850

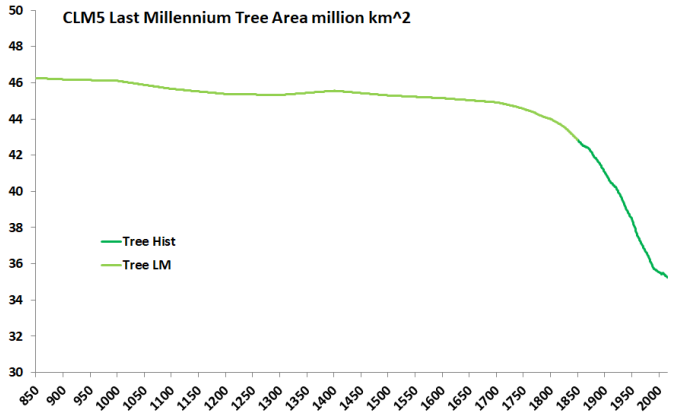


CLM5 Percent Tree Difference 1850 - 850

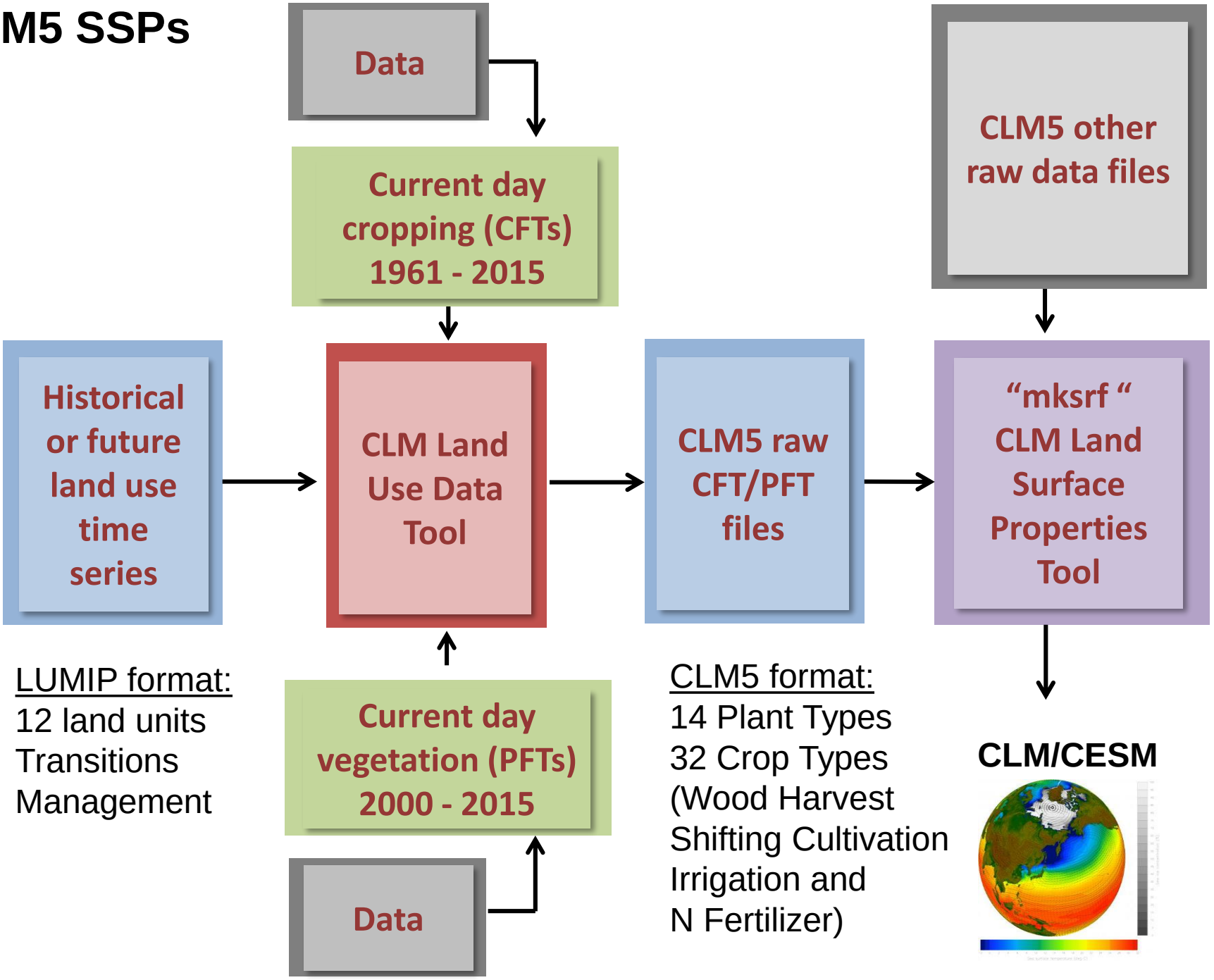


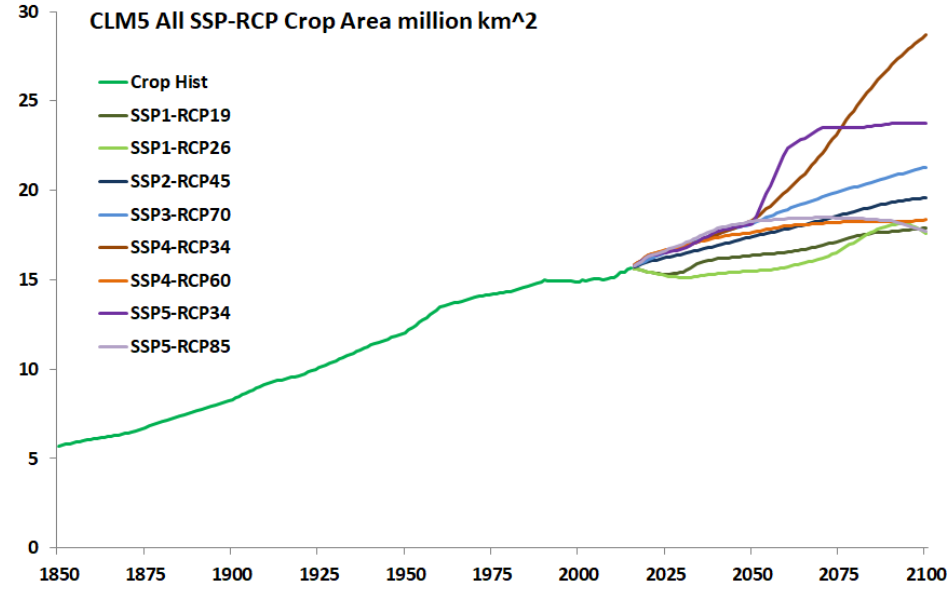
CLM5 Percent Tree 850

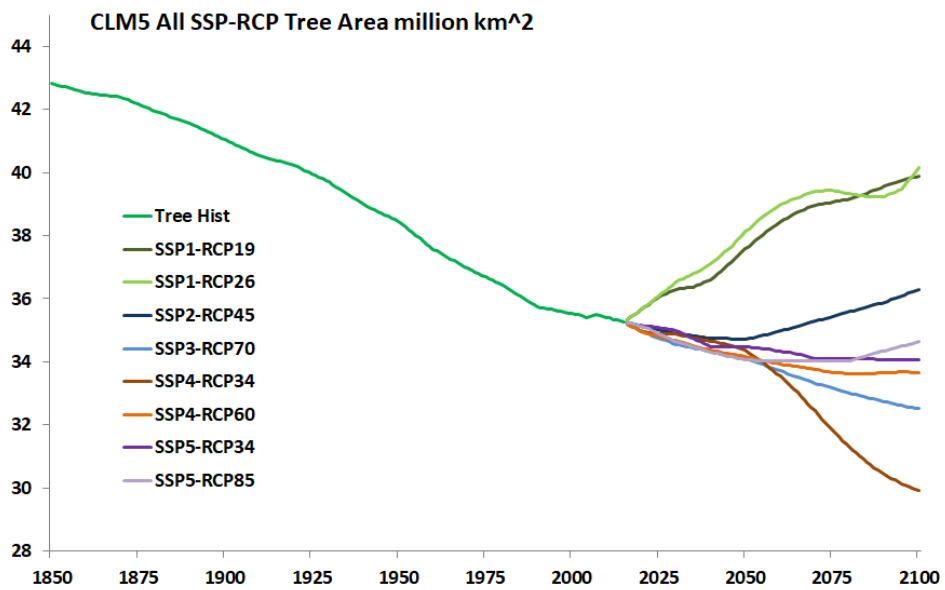


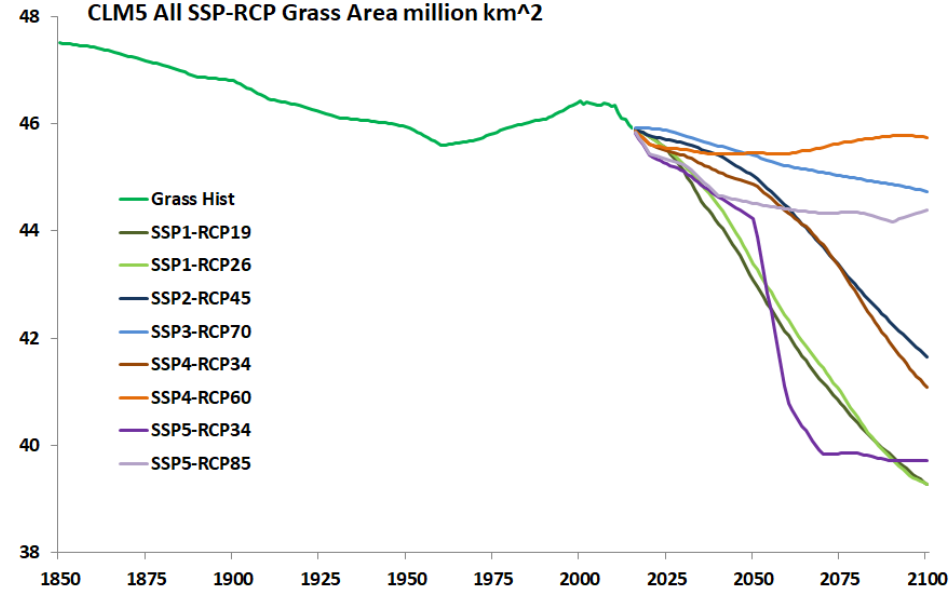


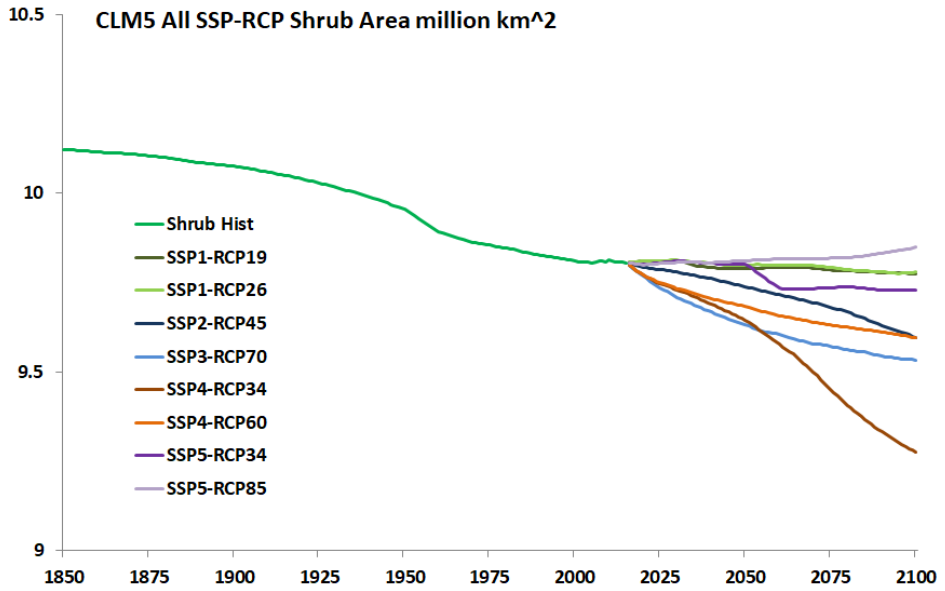
CLM5 SSPs

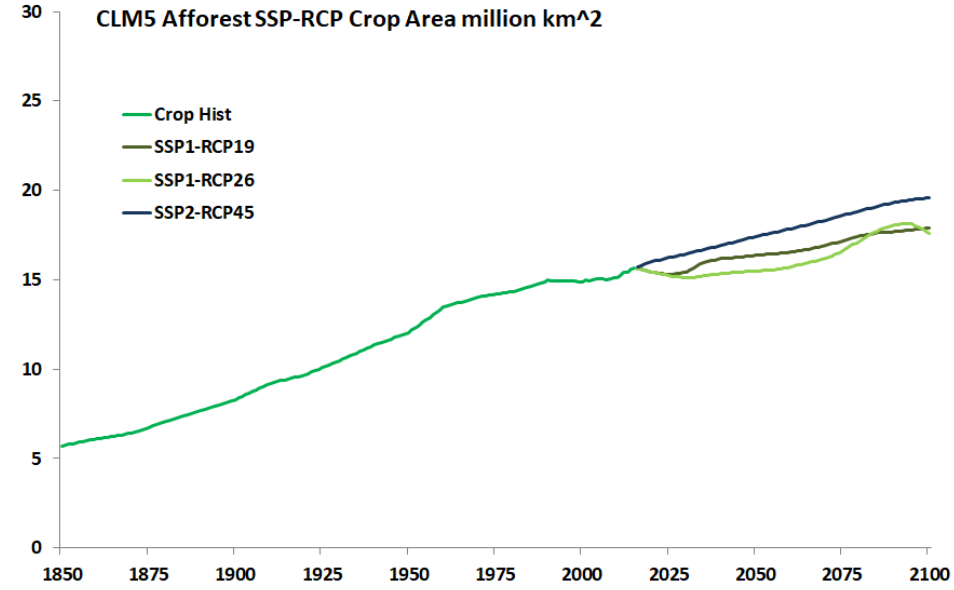

Data
Current day cropping (CFTs) 1961 - 2015
CLM5 other raw data files
Historical or future land use time series
CLM Land Use Data Tool
CLM5 raw CFT/PFT files
"mksrf " CLM Land Surface Properties Tool
LUMIP format:
12 land units
Transitions
Management
Current day vegetation (PFTs) 2000 - 2015
Data
CLM5 format:
14 Plant Types
32 Crop Types
(Wood Harvest
Shifting Cultivation
Irrigation and
N Fertilizer)
CLM/CESM

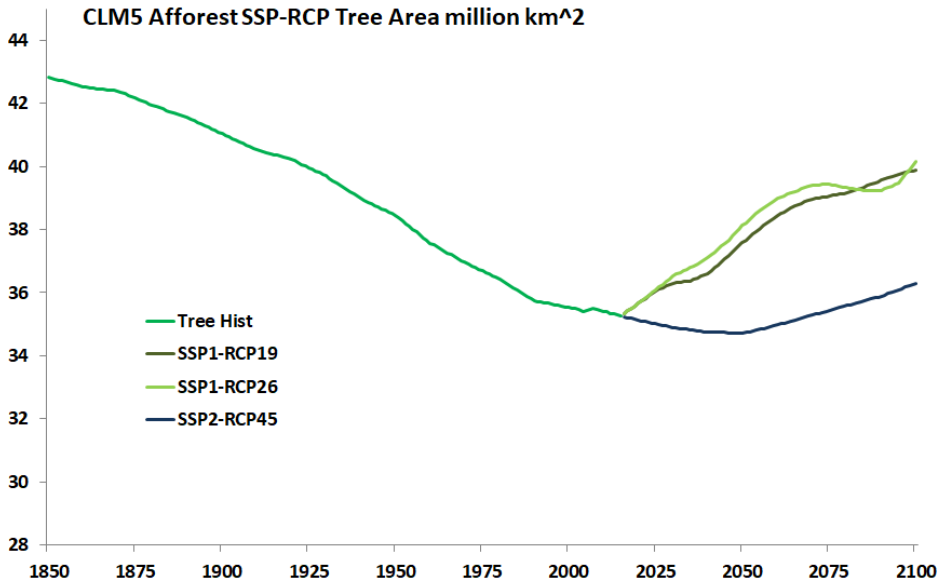

CLM5 All SSP-RCP Crop Area million km^2
Crop Hist
SSP1-RCP19
SSP1-RCP26
SSP2-RCP45
SSP3-RCP70
SSP4-RCP34
SSP4-RCP60
SSP5-RCP34
SSP5-RCP85
30
25
20
15
10
5
0
1850
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100

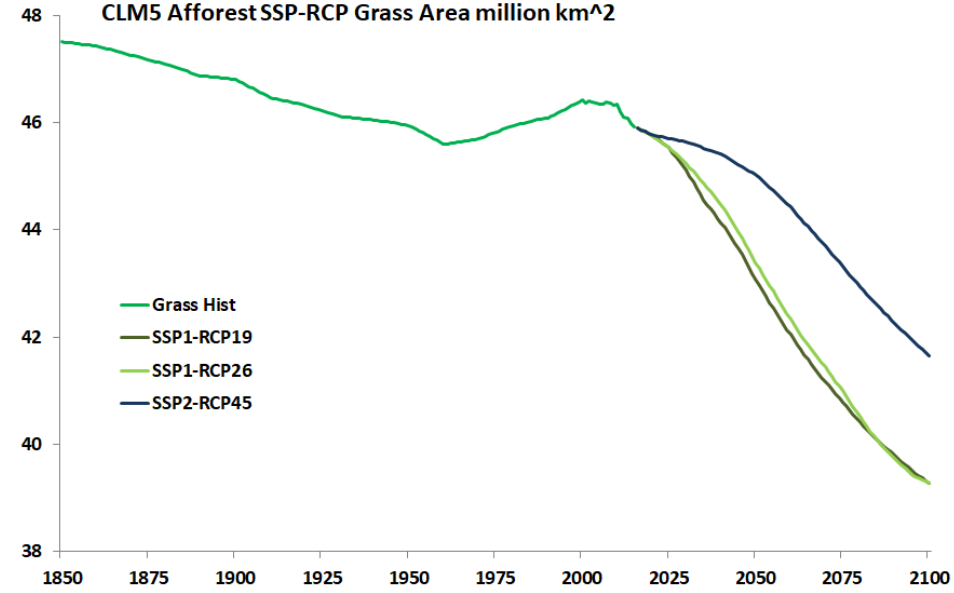

CLM5 All SSP-RCP Tree Area million km^2
Tree Hist
SSP1-RCP19
SSP1-RCP26
SSP2-RCP45
SSP3-RCP70
SSP4-RCP34
SSP4-RCP60
SSP5-RCP34
SSP5-RCP85
44
42
40
38
36
34
32
30
28
1850
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100

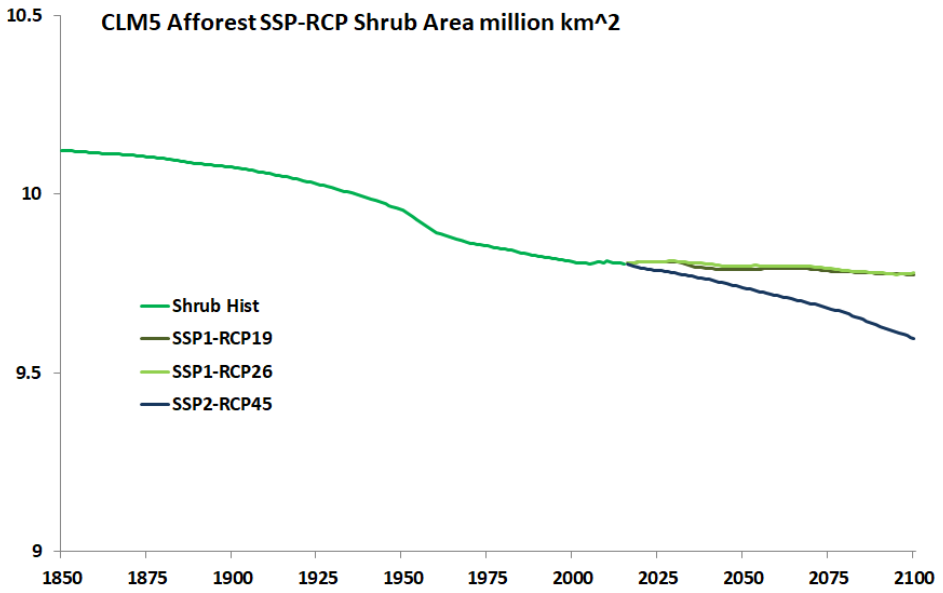

CLM5 All SSP-RCP Grass Area million km^2
Grass Hist
SSP1-RCP19
SSP1-RCP26
SSP2-RCP45
SSP3-RCP70
SSP4-RCP34
SSP4-RCP60
SSP5-RCP34
SSP5-RCP85
48
46
44
42
40
38
1850
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100


CLM5 All SSP-RCP Shrub Area million km^2
Shrub Hist
SSP1-RCP19
SSP1-RCP26
SSP2-RCP45
SSP3-RCP70
SSP4-RCP34
SSP4-RCP60
SSP5-RCP34
SSP5-RCP85
10.5
10
9.5
9
1850
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100

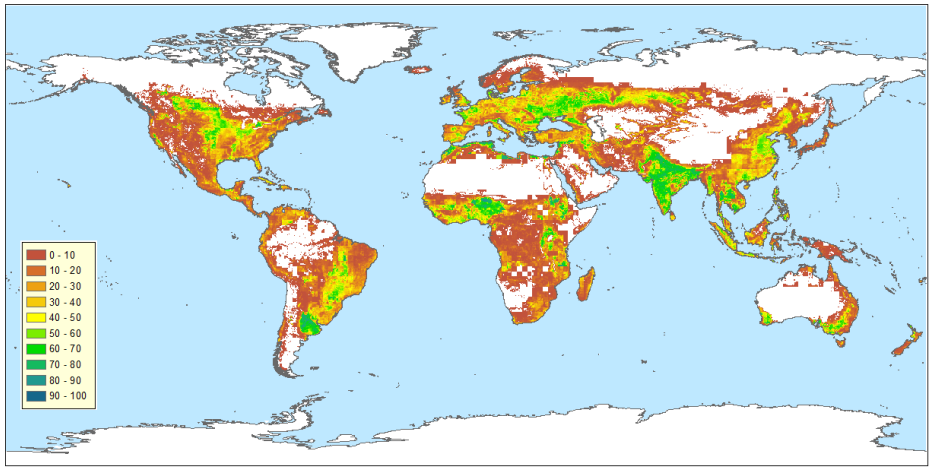

CLM5 Afforest SSP-RCP Crop Area million km^2
Crop Hist
SSP1-RCP19
SSP1-RCP26
SSP2-RCP45
30
25
20
15
10
5
0
1850
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100


CLM5 Afforest SSP-RCP Tree Area million km^2
Tree Hist
SSP1-RCP19
SSP1-RCP26
SSP2-RCP45
44
42
40
38
36
34
32
30
28
1850
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100

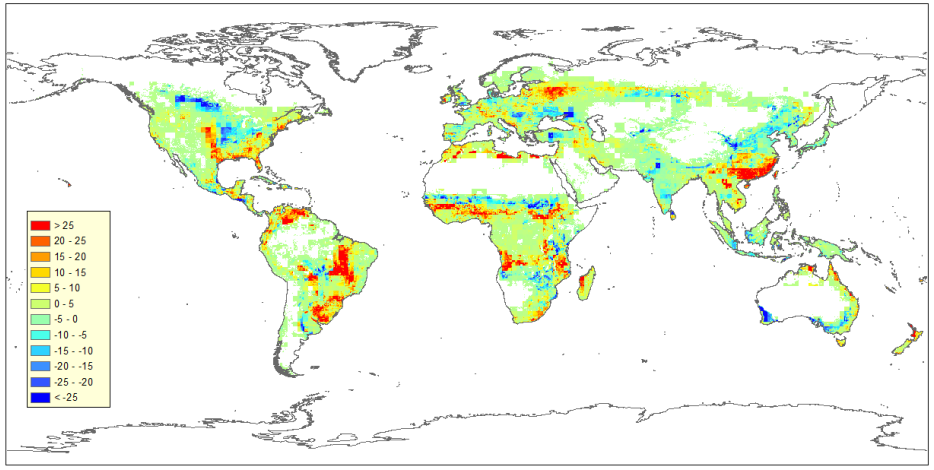

CLM5 Afforest SSP-RCP Grass Area million km^2
Grass Hist
SSP1-RCP19
SSP1-RCP26
SSP2-RCP45
48
46
44
42
40
38
1850
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100


CLM5 Afforest SSP-RCP Shrub Area million km^2
Shrub Hist
SSP1-RCP19
SSP1-RCP26
SSP2-RCP45
10.5
10
9.5
9
1850
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100

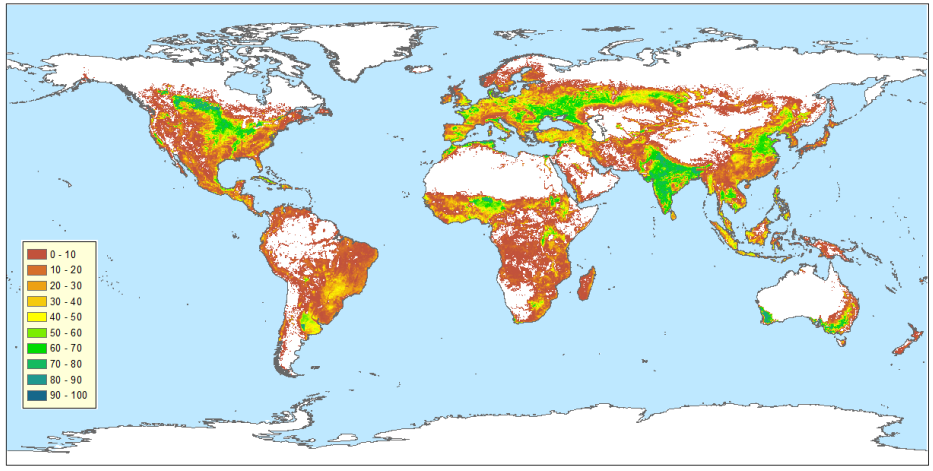
CLM5 Percent Crop SSP1-RCP26 2100

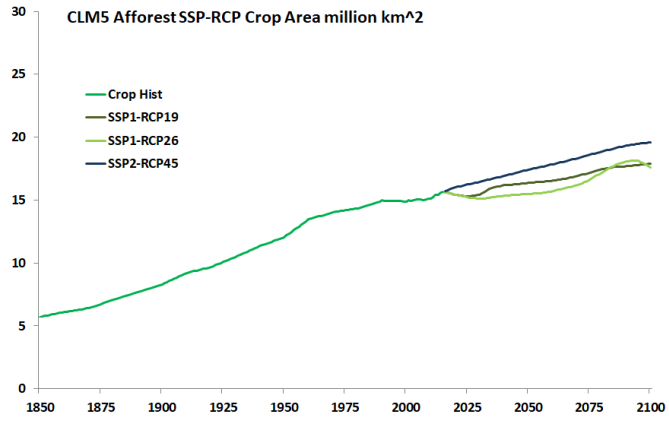


CLM5 Percent Crop Difference SSP1-RCP26 2100 - 2015

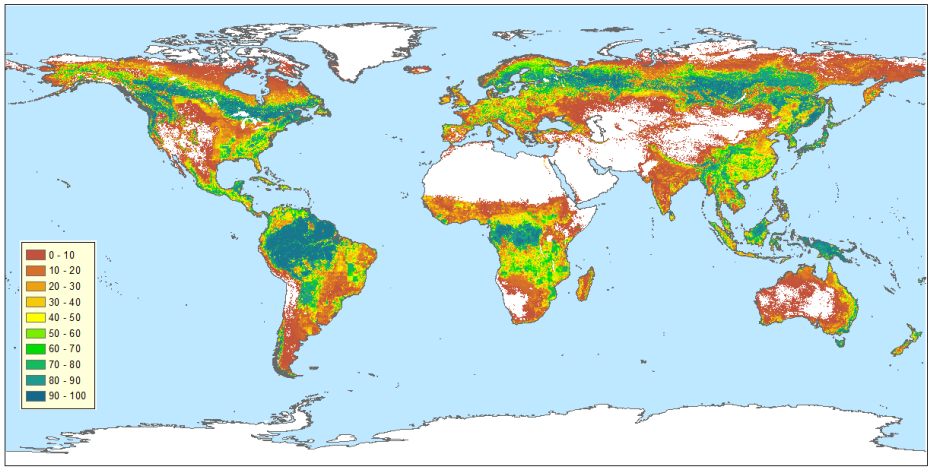


CLM5 Percent Crop 2015

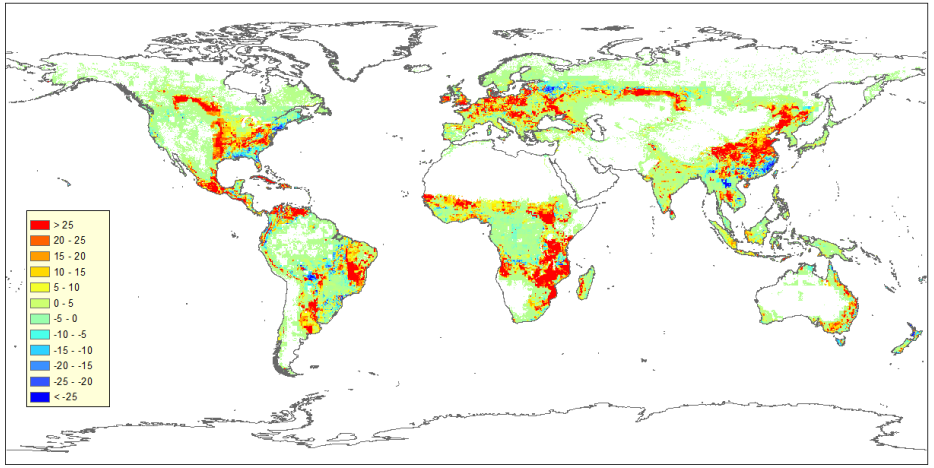




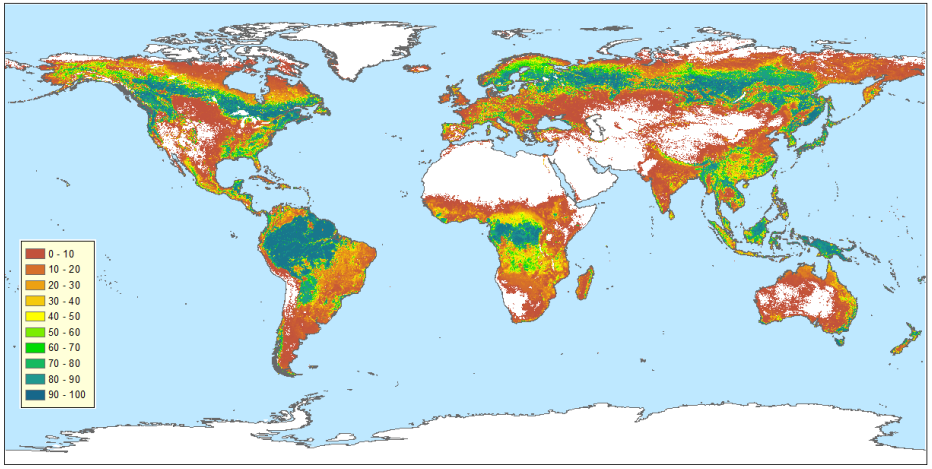
CLM5 Percent Tree SSP1-RCP26 2100

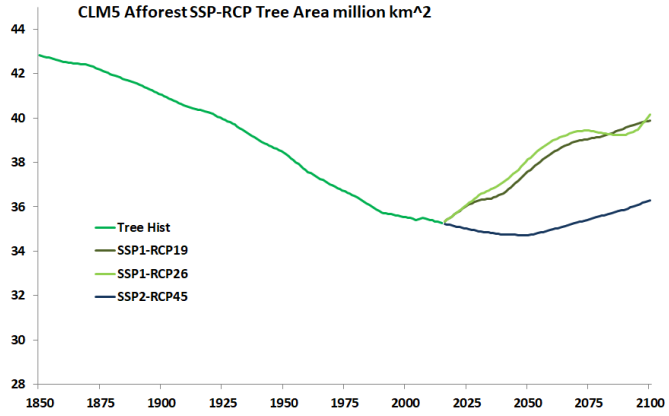


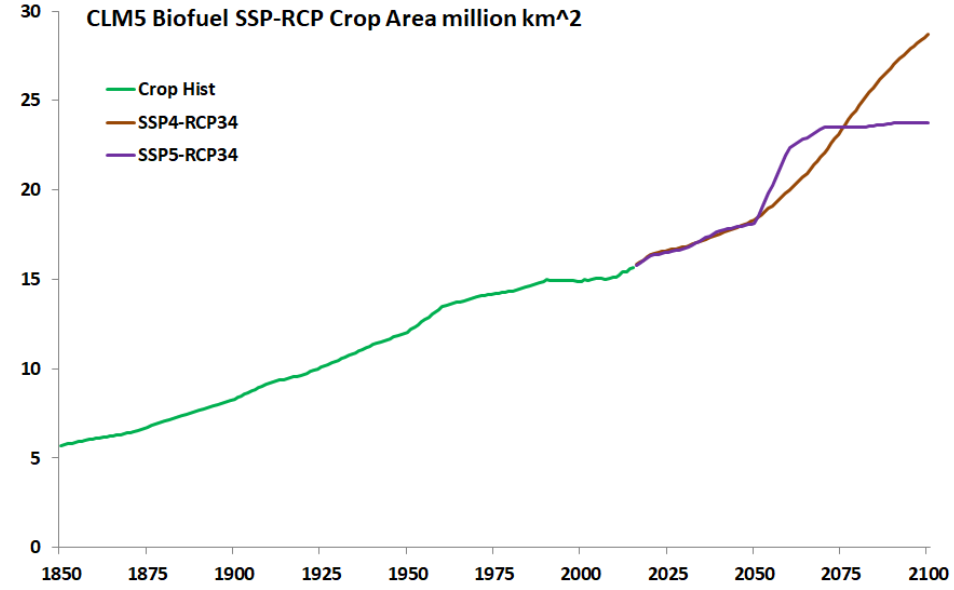
CLM5 Percent Tree Difference SSP1-RCP26 2100 - 2015

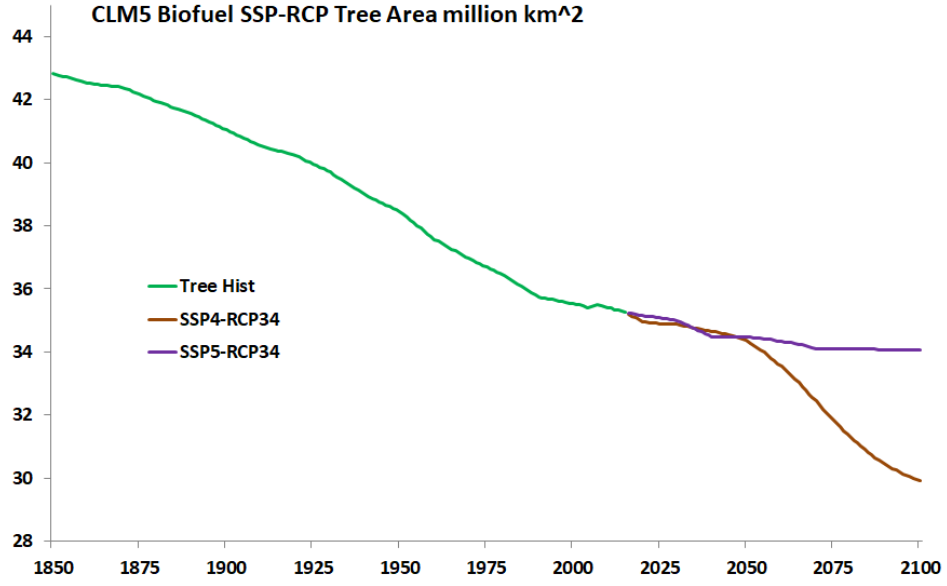


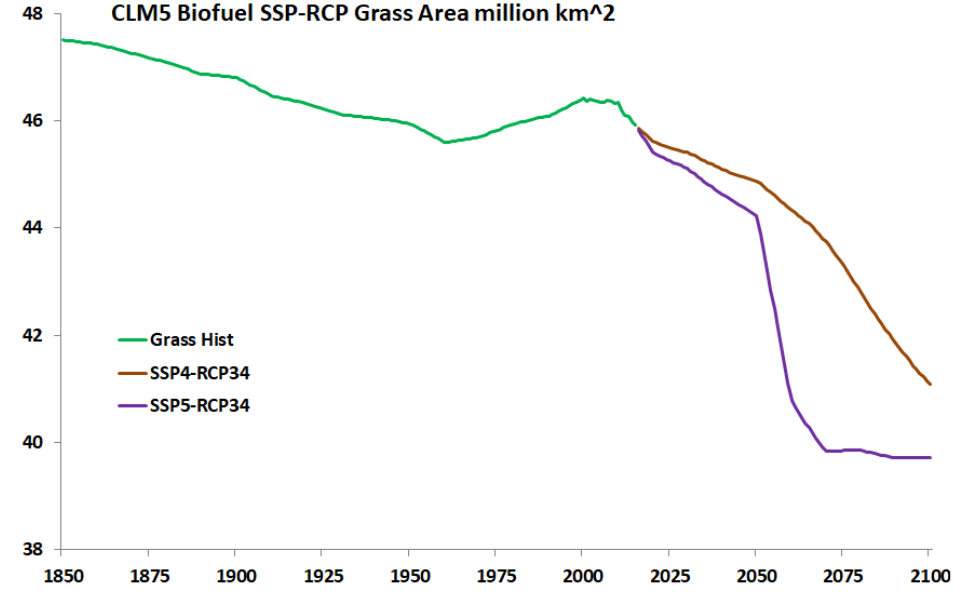
CLM5 Percent Tree 2015

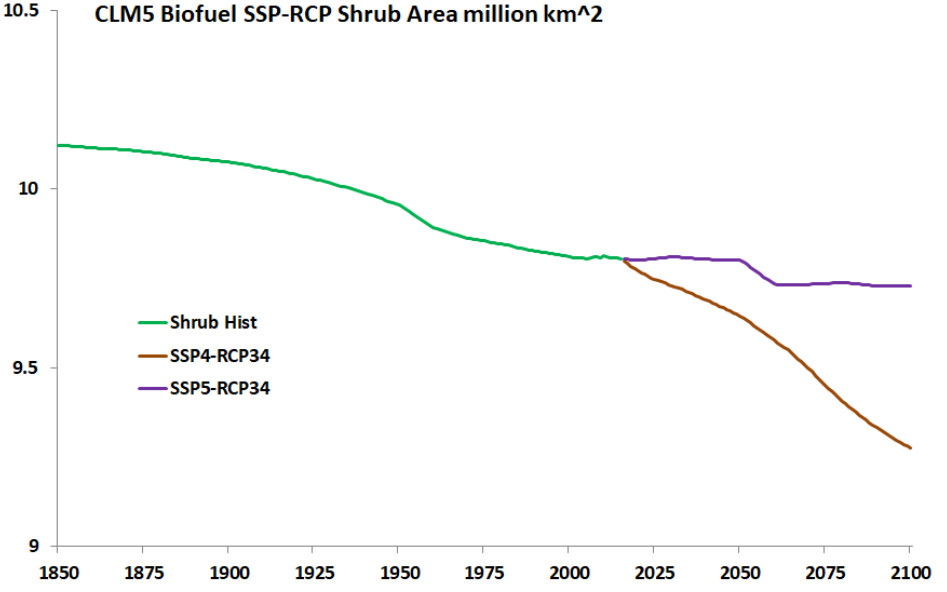




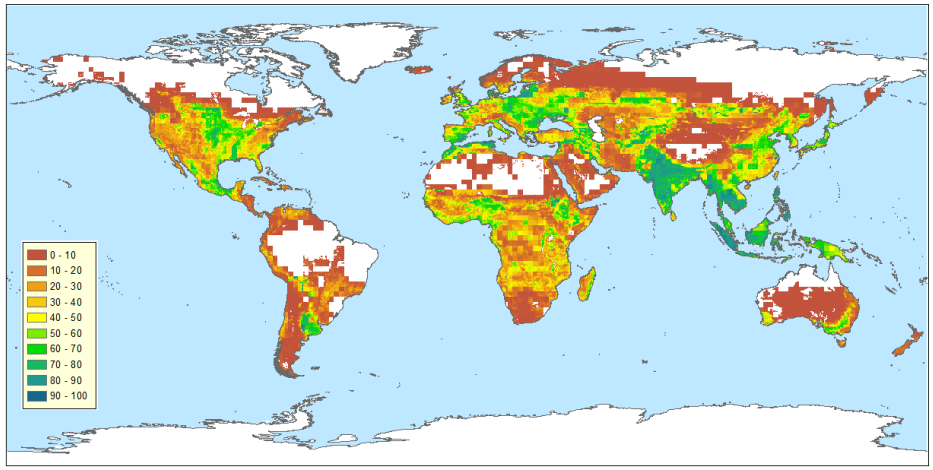

CLM5 Biofuel SSP-RCP Crop Area million km^2
Crop Hist
SSP4-RCP34
SSP5-RCP34
30
25
20
15
10
5
0
1850
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100


CLM5 Biofuel SSP-RCP Tree Area million km^2
Tree Hist
SSP4-RCP34
SSP5-RCP34
44
42
40
38
36
34
32
30
28
1850
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100

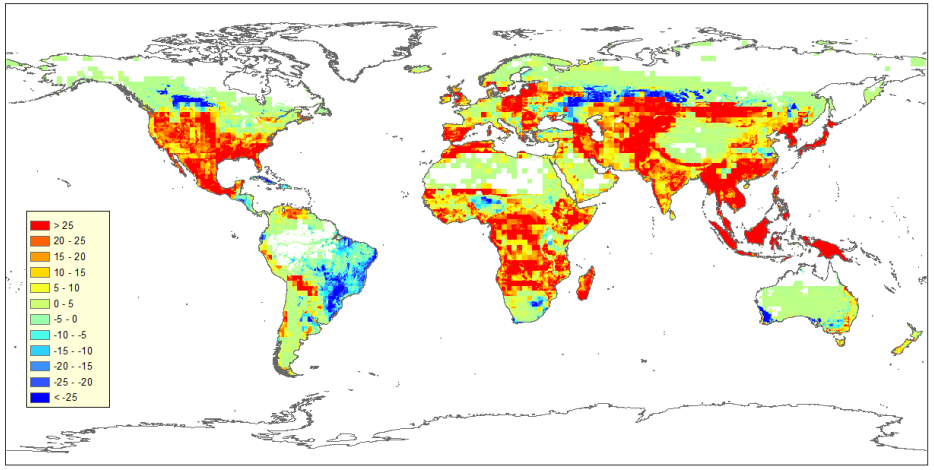

CLM5 Biofuel SSP-RCP Grass Area million km^2
Grass Hist
SSP4-RCP34
SSP5-RCP34
48
46
44
42
40
38
1850
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100


CLM5 Biofuel SSP-RCP Shrub Area million km^2
Shrub Hist
SSP4-RCP34
SSP5-RCP34
10.5
10
9.5
9
1850
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100

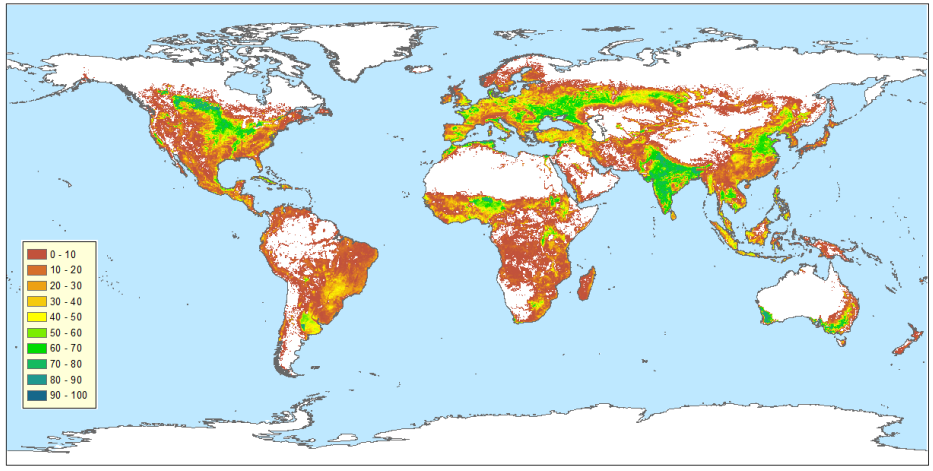
CLM5 Percent Crop SSP4-RCP34 2100

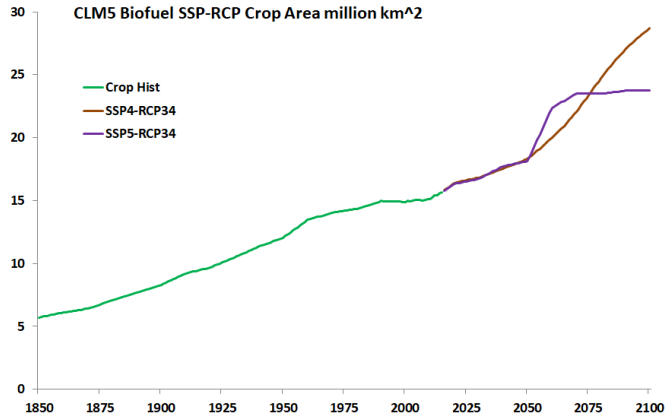


CLM5 Percent Crop Difference SSP4-RCP34 2100 - 2015

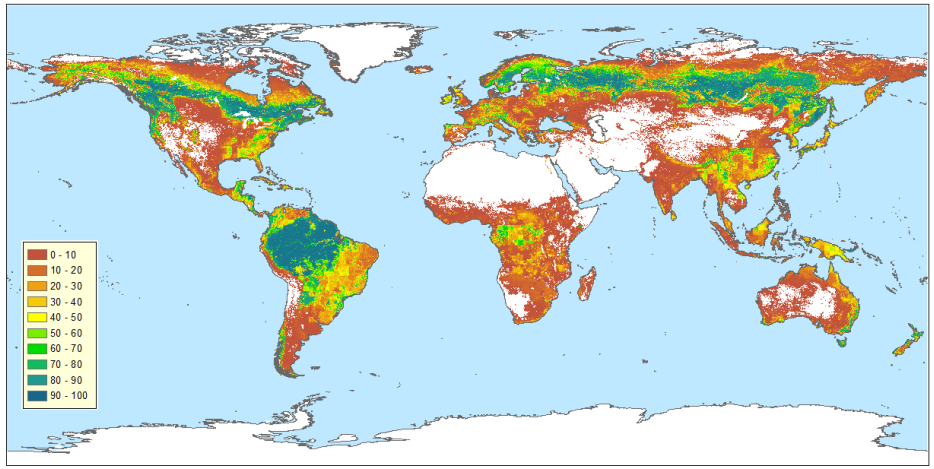


CLM5 Percent Crop 2015

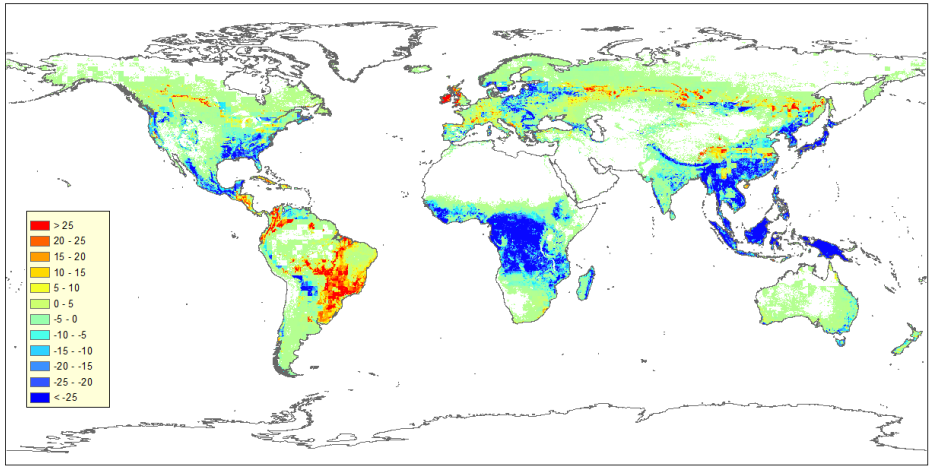




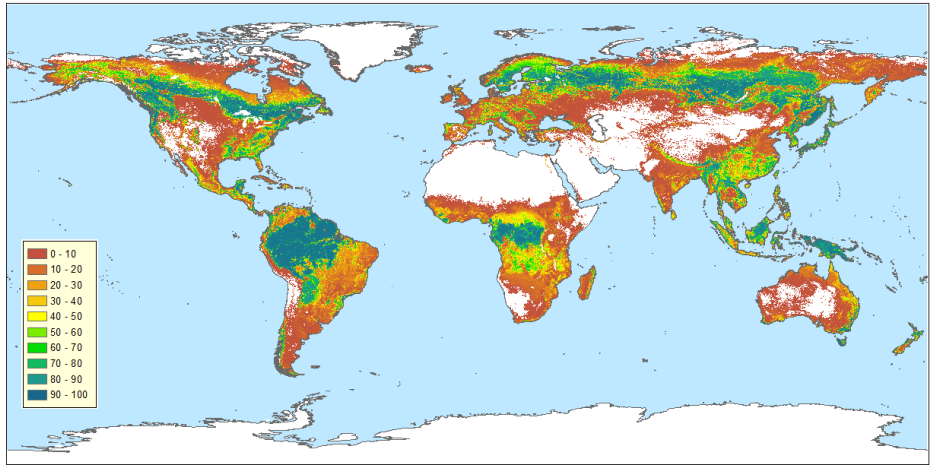
CLM5 Percent Tree SSP4-RCP34 2100

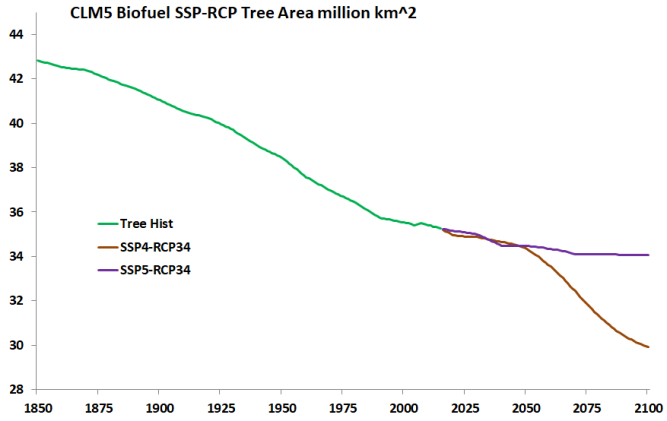


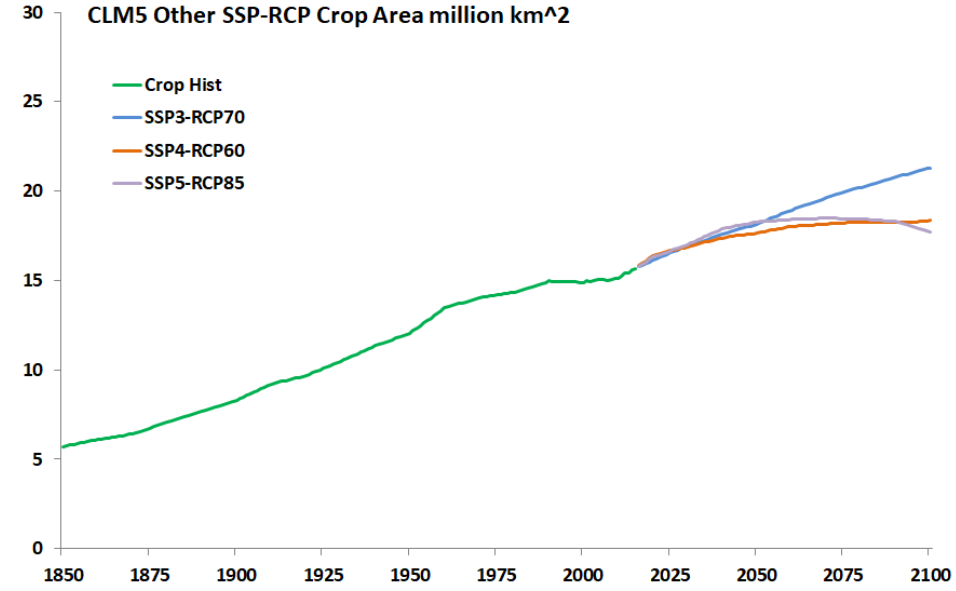
CLM5 Percent Tree Difference SSP4-RCP34 2100 - 2015

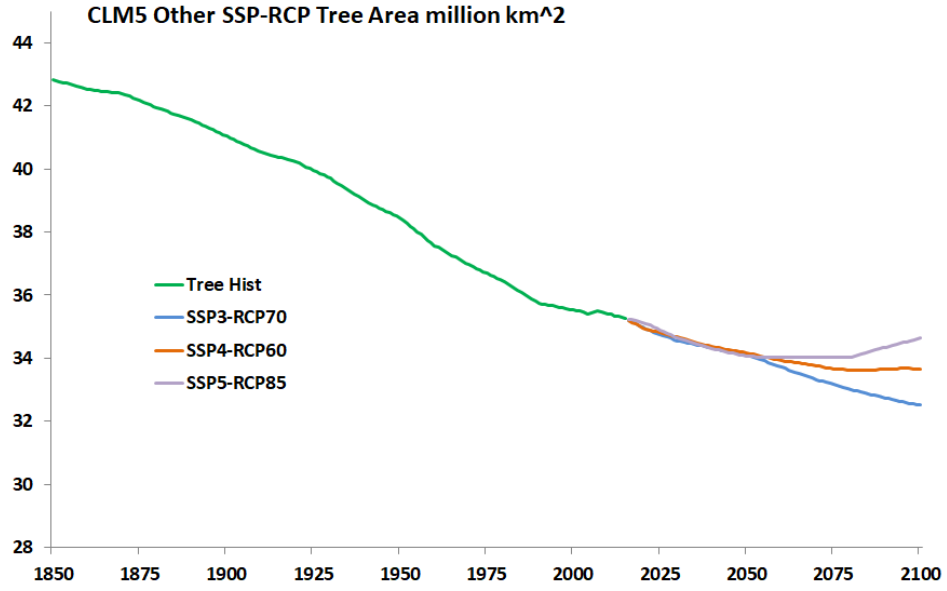


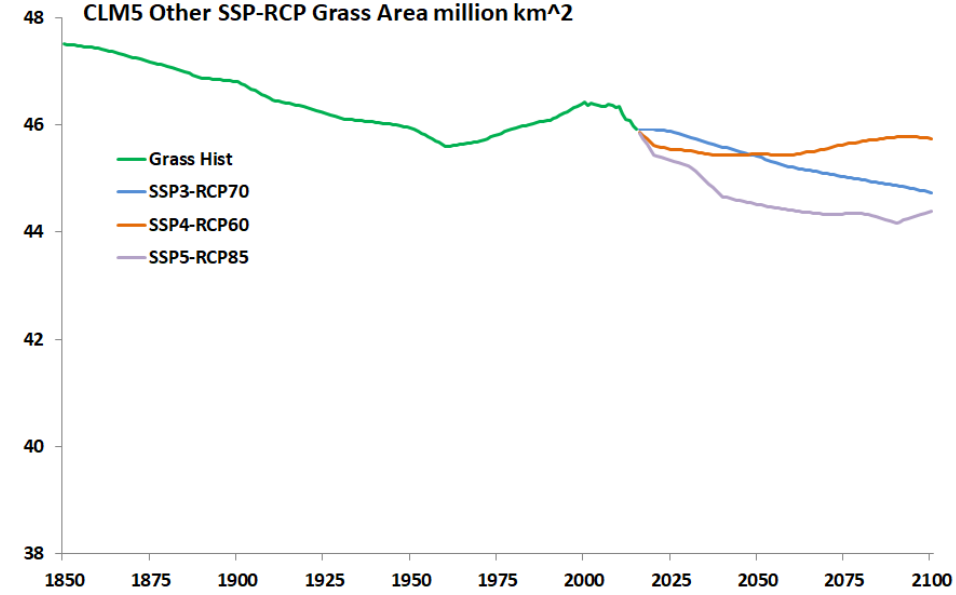
CLM5 Percent Tree 2015

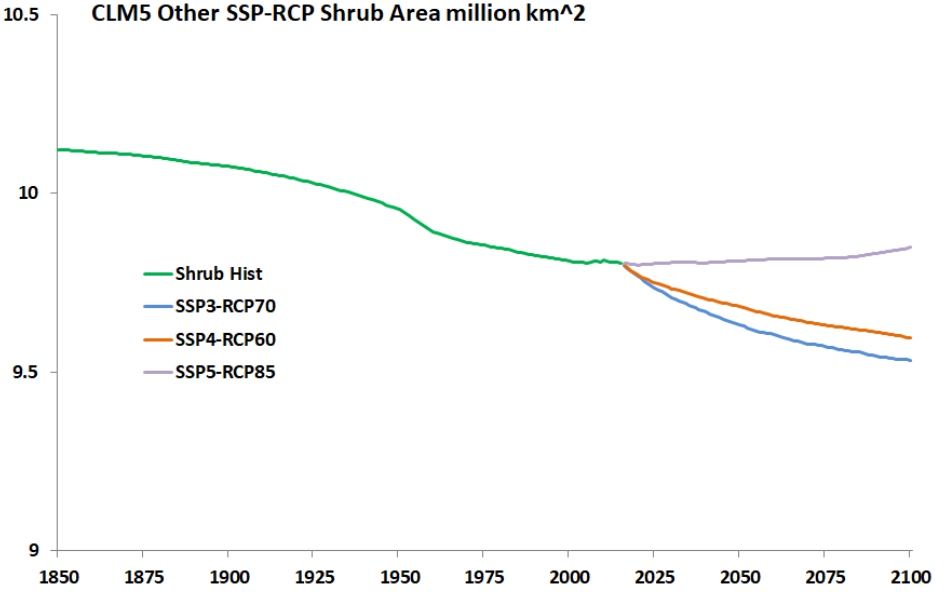




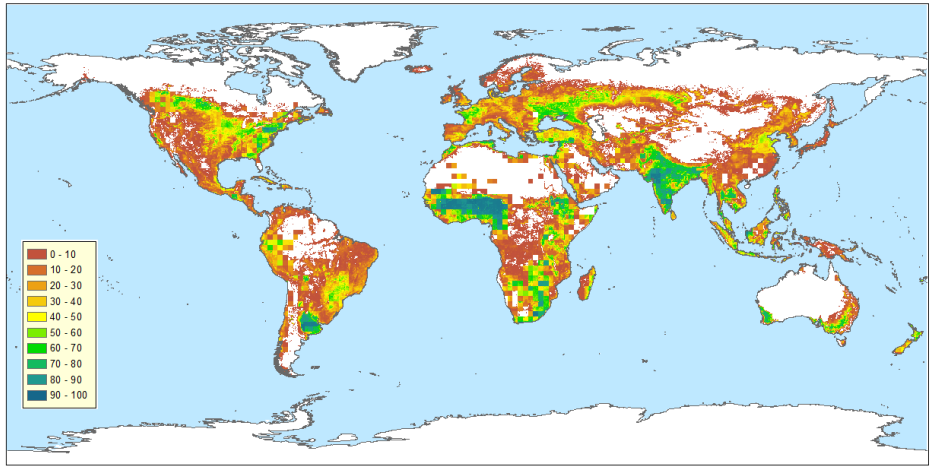

CLM5 Other SSP-RCP Crop Area million km^2
Crop Hist
SSP3-RCP70
SSP4-RCP60
SSP5-RCP85
30
25
20
15
10
5
0
1850
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100


CLM5 Other SSP-RCP Tree Area million km^2
Tree Hist
SSP3-RCP70
SSP4-RCP60
SSP5-RCP85
44
42
40
38
36
34
32
30
28
1850
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100

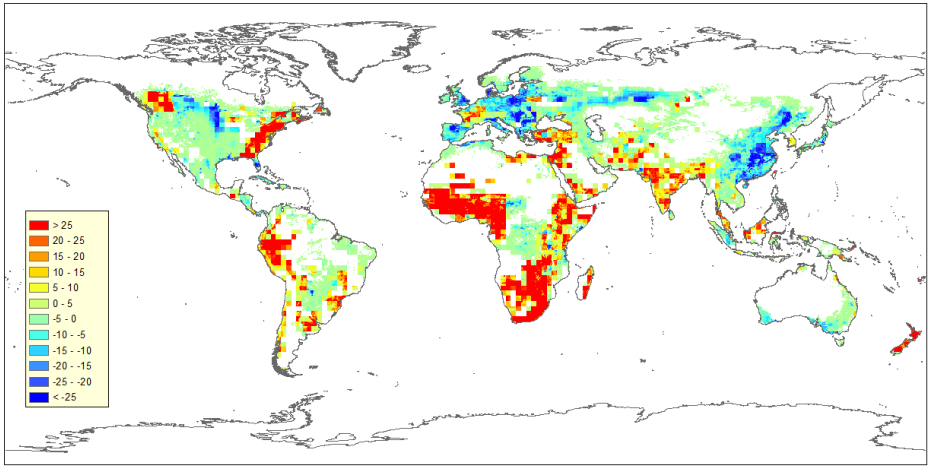

CLM5 Other SSP-RCP Grass Area million km^2
Grass Hist
SSP3-RCP70
SSP4-RCP60
SSP5-RCP85
48
46
44
42
40
38
1850
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100


CLM5 Other SSP-RCP Shrub Area million km^2
Shrub Hist
SSP3-RCP70
SSP4-RCP60
SSP5-RCP85
10.5
10
9.5
9
1850
1875
1900
1925
1950
1975
2000
2025
2050
2075
2100

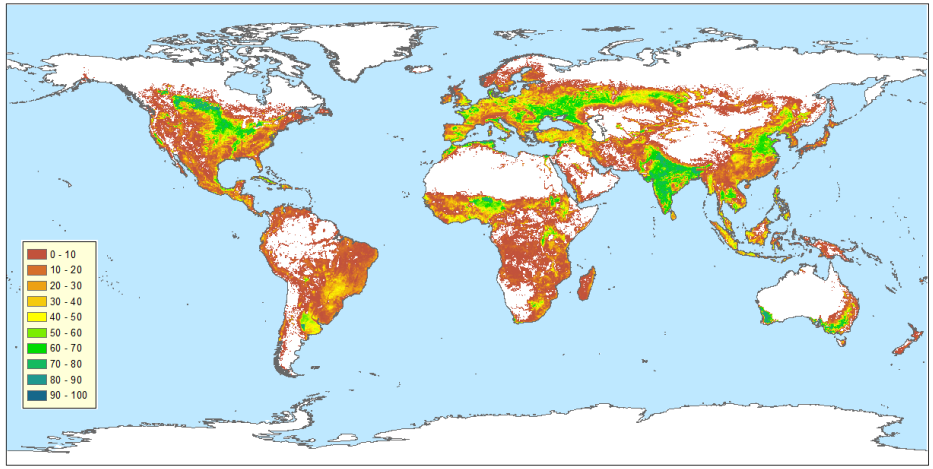
CLM5 Percent Crop SSP3-RCP70 2100

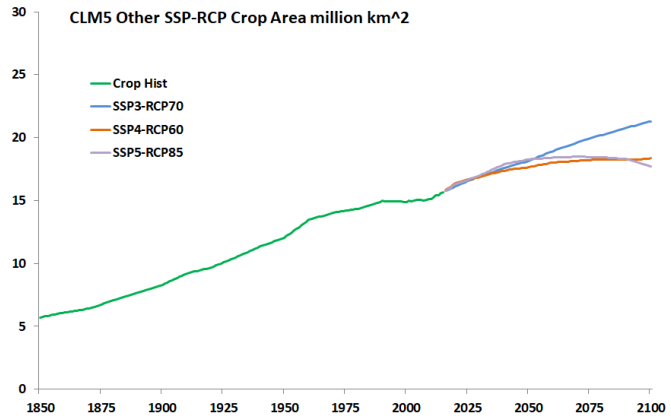


CLM5 Percent Crop Difference SSP3-RCP70 2100 - 2015

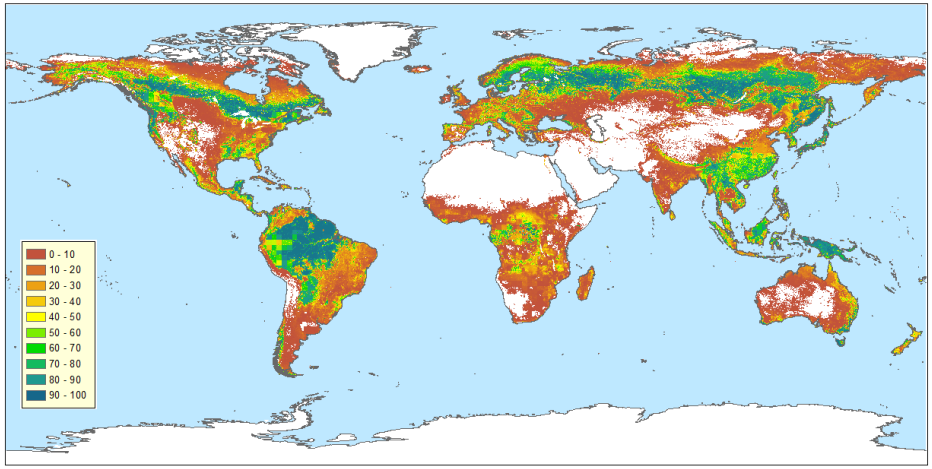


CLM5 Percent Crop 2015

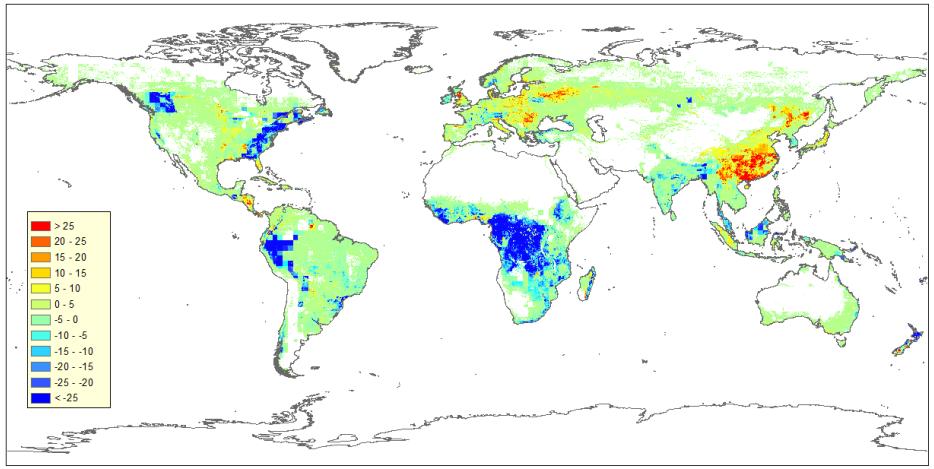




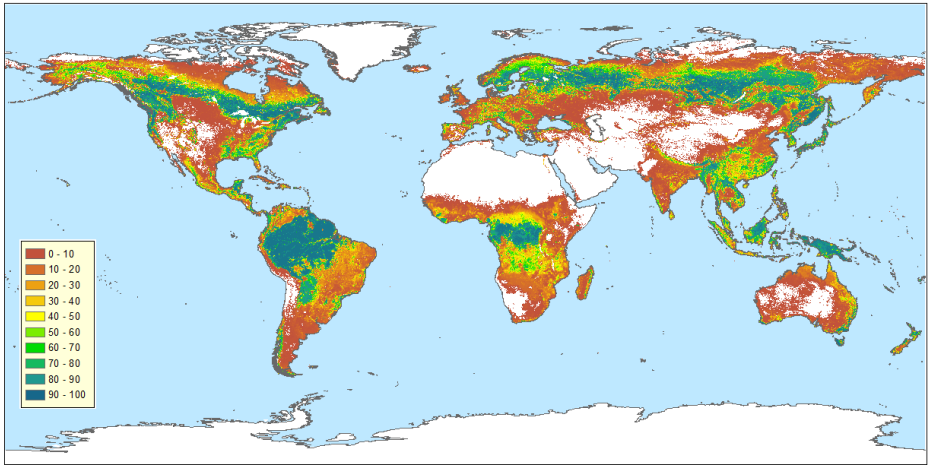
CLM5 Percent Tree SSP3-RCP70 2100

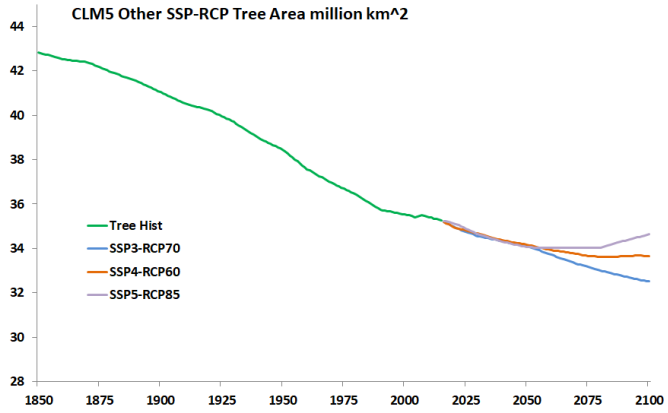


CLM5 Percent Tree Difference SSP3-RCP70 2100 - 2015



CLM5 Percent Tree 2015





CLM5/CTSM Land Use and Land Cover Change Status

- CMIP6 – CESM2/WACCM simulations running with LULCC

- DECK – Pre Industrial Control – Historical – SSP-RCP Scenarios

- LUMIP Land only simulations – C4MIP – LS3MIP – CDRMIP

- NCAR project to look at the potential for Land Management as a means of Carbon Dioxide Removal in part of a larger Geoengineering Research Initiative to achieve 1.5^{o} or 2.0^{o} C climate targets

- Future projects will look at increasing Land Units to include Primary and Secondary vegetated land as well as Pasture explicitly

- Integrating LULCC into FATES for future CLM6 / CTSM2