

Using the CESM to Evaluate Global Carbon Dioxide Removal Potentials

Peter Lawrence – Project Scientist - CGD

CESM Land Use and Land Cover Change



CESM Tutorial - July 2021



CESM Tutorial – Carbon Dioxide Removal through Land Management

The carbon dioxide removal potential for large scale Reforestation and Afforestation has been receiving much attention in both the literature and the press.

nature
climate change


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International journal of science

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Letter | Published: 27 May 2019

Potential for low-cost carbon dioxide removal through tropical reforestation

Jonah Busch , Jens Engelmann, Susan C. Cook-Patton, Bronson W. Griscom, Timm Kroeger, Hugh Possingham & Priya Shyamsundar

NEWS FEATURE • 15 JANUARY 2019

How much can forests fight climate change?

Trees are supposed to slow global warming, but growing evidence suggests they might not always be climate saviours.

Gabriel Popkin

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The New York Times

Restoring Forests Could Help Put a Brake on Global Warming, Study Finds

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The global tree restoration potential



Jean-Francois Bastin^{1,*}, Yelena Finegold², Claude Garcia^{3,4}, Danilo Mollicone², Marcelo Rezende², Devin Routh¹, Constantin...

+ See all authors and affiliations



Science 05 Jul 2019:
Vol. 365, Issue 6448, pp. 76-79
DOI: 10.1126/science.aax0848

Natural climate solutions

Bronson W. Griscom, Justin Adams, Peter W. Ellis, Richard A. Houghton, Guy Lomax, Daniela A. Miteva, William H. Schlesinger, David Shoch, Juha V. Siikamäki, Pete Smith, Peter Woodbury, Chris Zganjar, Allen Blackman, João Campari, Richard T. Conant, Christopher Delgado, Patricia Elias, Trisha Gopalakrishna, Marisa R. Hamsik, Mario Herr Joseph Kiesecker, Emily Landis, Lars Laestadius, Sara M. Leavitt, Susan Minnemeyer, Stephen Polasky, Peter Potapov, Francis E. Putz, Jonathan Sanderman, Marcel Silvius, Eva Wollenberg, and Joseph Fargione

PNAS October 31, 2017 114 (44) 11645-11650; first published October 16, 2017 <https://doi.org/10.1073/pnas.1701164114>

**Range of results upper end has:
Re/Afforestation of 9 million km²
With 205 PgC additional storage
(Cumulative emissions ~500 PgC)**

CESM Tutorial – Carbon Dioxide Removal through Land Management

CESM Provides Methods for Investigating Carbon Dioxide Removal through Land Management in a Fully Coupled Carbon Climate Model

- The Community Land Model (CLM5) provides functionality provides multiple ways to represent Carbon Dioxide Removal and Management.
- Re/Afforestation is represented through the Land Use and Land Cover Change by prescribing annually changing plant and crop functional types (PFTs and CFTs). Forest biomass extraction can be represented with the prescription of annual wood harvest to capture forest management.
- Biofuels production is represented through the CLM5 Crop Model for conventional ethanol and biomass fuels such as Corn, Soybean, Wheat and Sugarcane. There is a new Miscanthus and Switchgrass crop representations are now available for cellulosic ethanol production.
- Other agricultural management for Carbon Dioxide Removal can be represented in the CLM5 Crop Model with options for various rates of residue and tilling.

*Community Terrestrial Systems Model (CTSM5.2) going forward

CLM5 Land Cover Change – Prescribed Re/Afforestation

Gridcell



CLM 5 LULCC for
Natural PFTs and
Crop CFTs

Landunit



Vegetated



Lake



Urban



Glacier



Crop



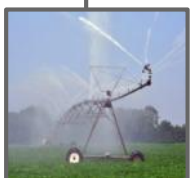
Column



Unirrig



Unirrig



Irrig



Unirrig



Irrig



Crop1



Crop1



Crop2



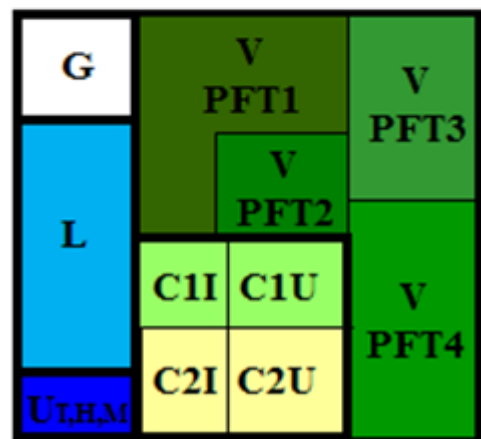
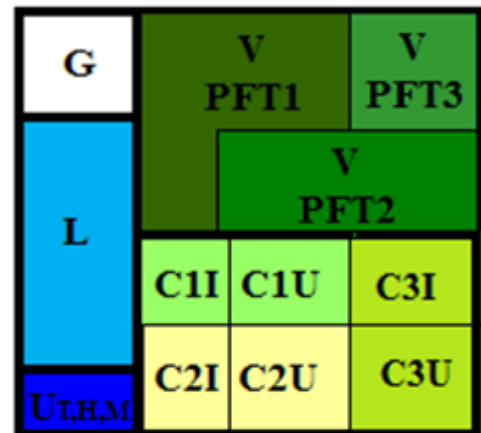
Crop2 ...



PFT1



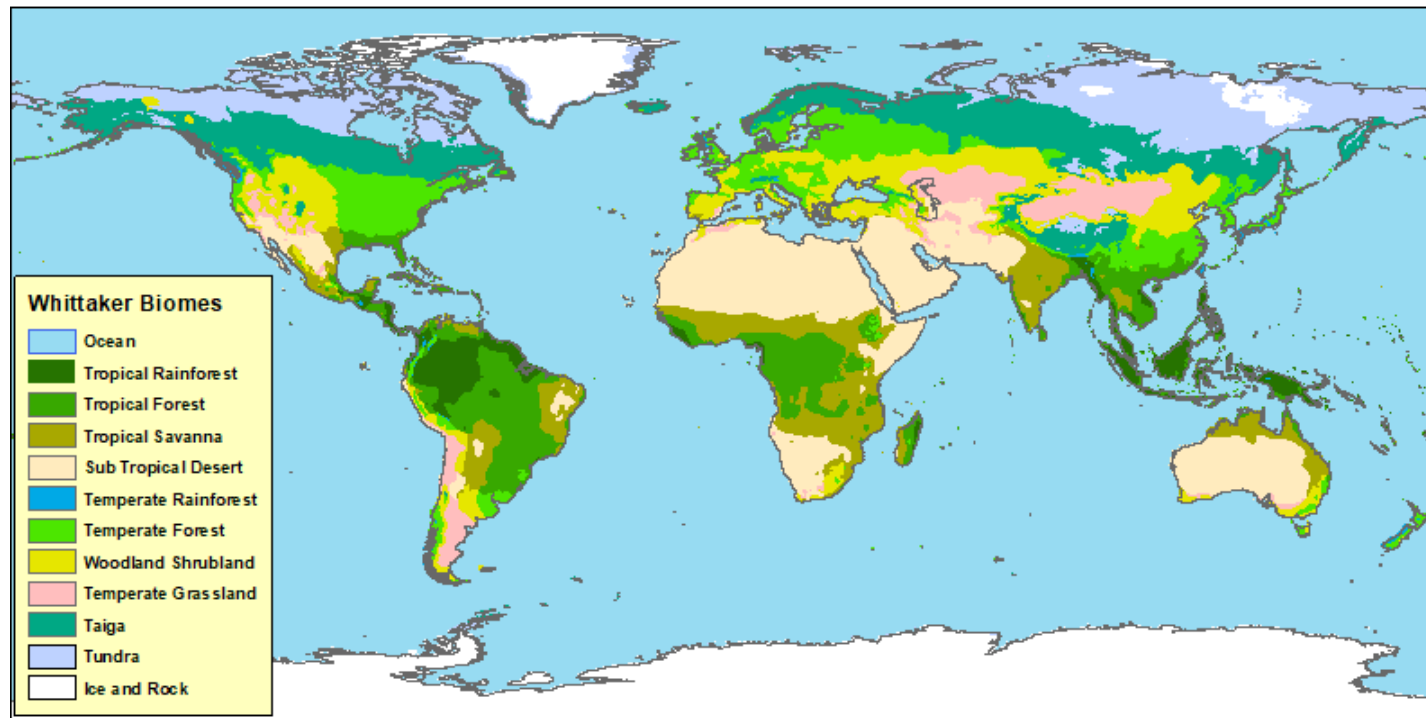
PFT2



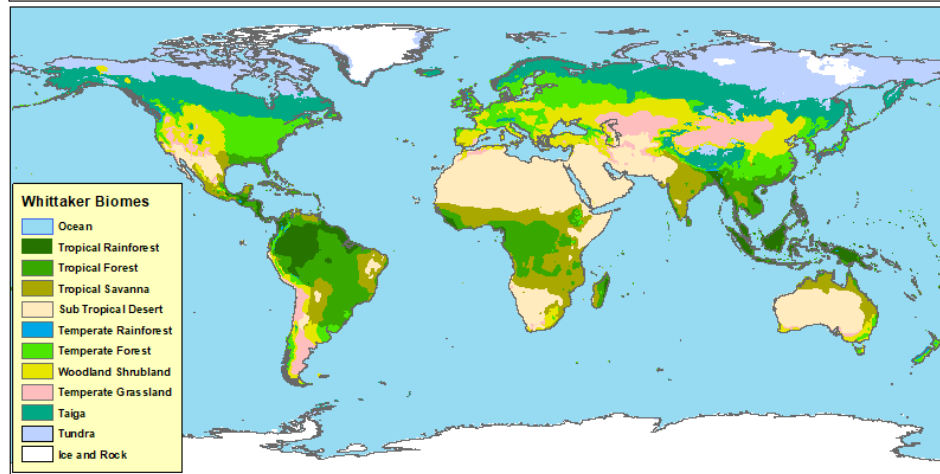
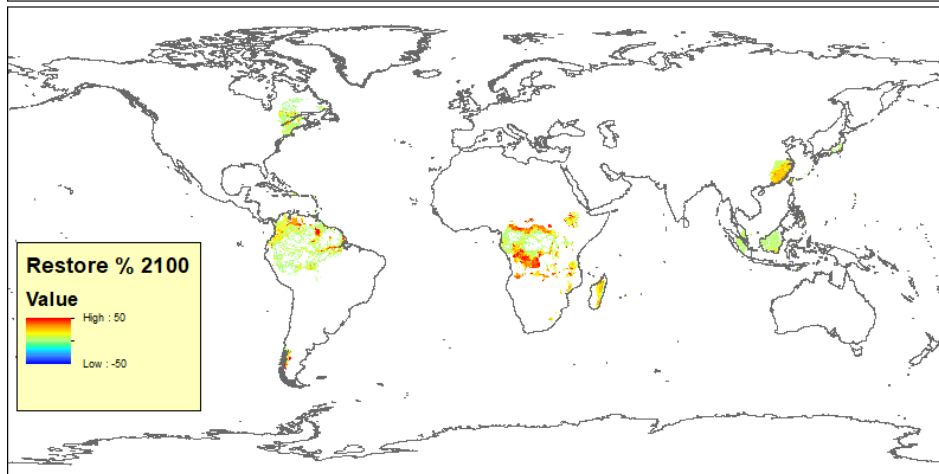
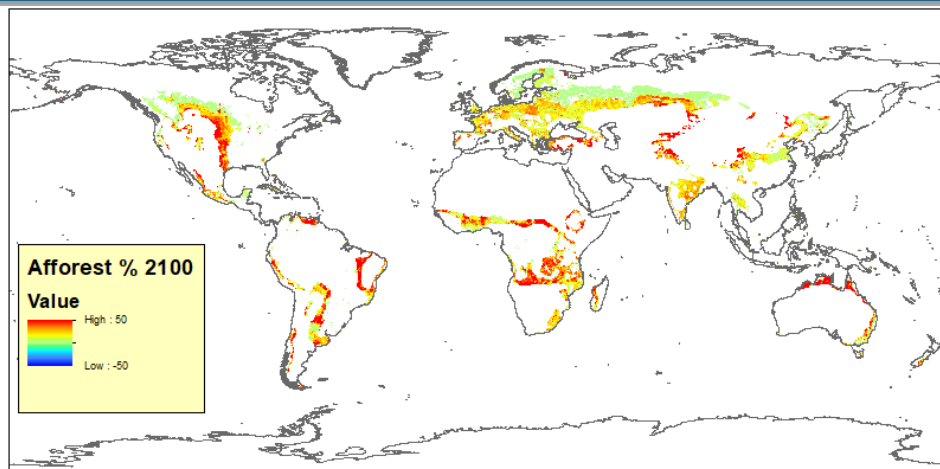
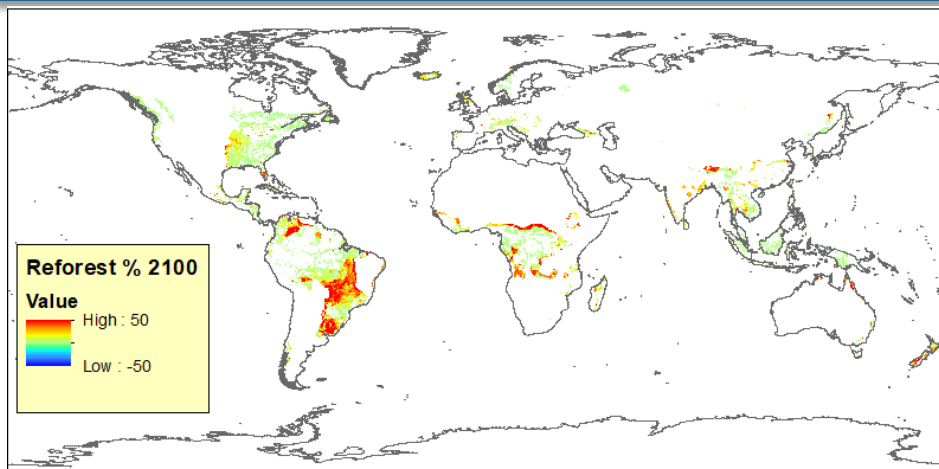
CLM5 Land Cover Change – Prescribed Re/Afforestation

Generated Maximum Plausible Reforestation, Afforestation and Restoration Scenarios compared with CMIP6 Baseline Scenarios 2015 – 2100 at 0.25 degrees resolution within agricultural limits:

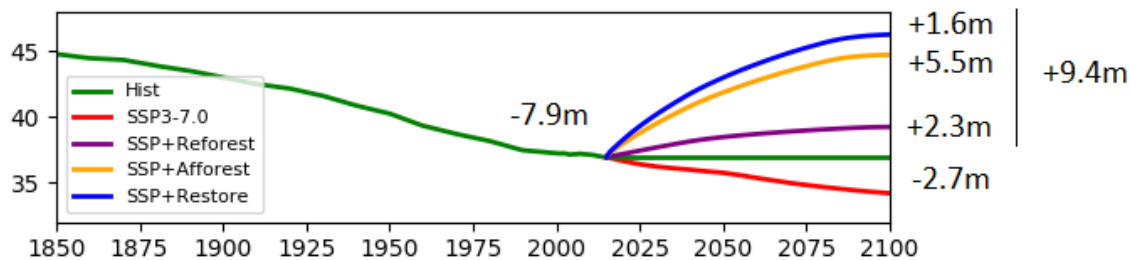
- **Reforestation** is performed on land where current day climate Whittaker Biomes would allow for Tropical, Temperate or Boreal Forests and the land is not used for cropping, pasture or urban
- **Afforestation** is performed where current day climate does not represent a Whittaker Forest Biome but tree cover currently or historically was over 10% and land is not used for crop, pasture or urban
- **Restoration** occurs on land which is considered forest in the CMIP6 scenarios but CLM5 tree cover is less than the potential tree cover for the current day Whittaker Biome



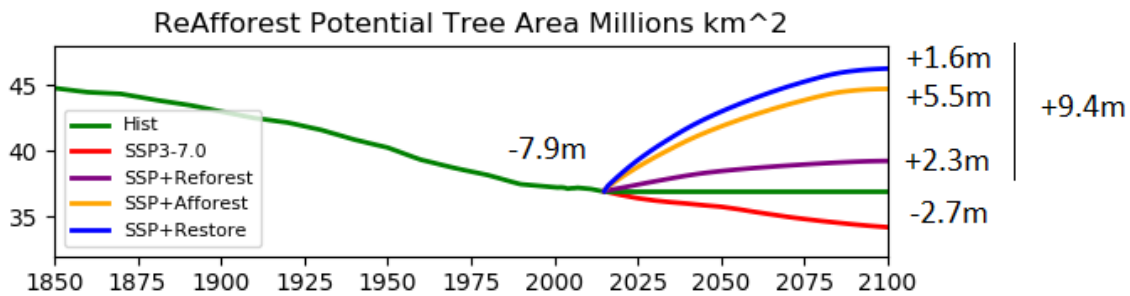
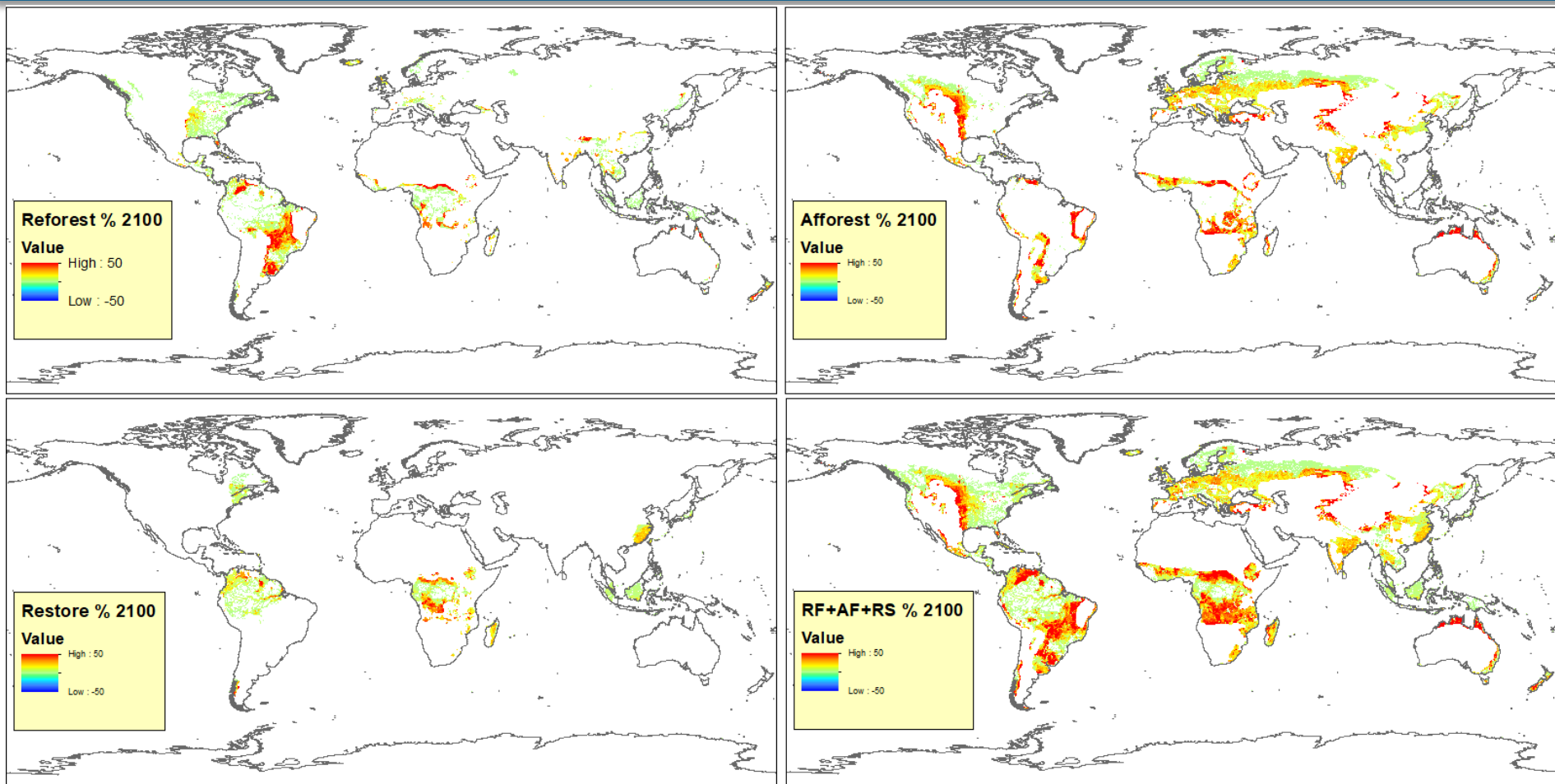
CLM5 LULCC – Prescribed Re/Afforestation Tree PFTs



ReAfforest Potential Tree Area Millions km²



CLM5 LULCC – Prescribed Re/Afforestation Tree PFTs



CESM Afforestation and Reforestation Potentials

New CMIP6 Reforestation / Afforestation Land Use Land Cover Change Scenarios

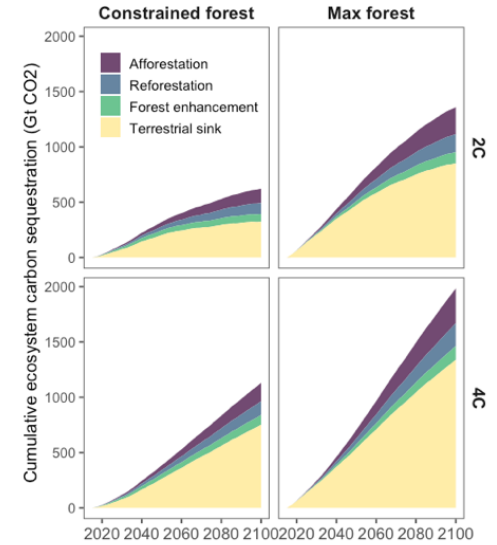
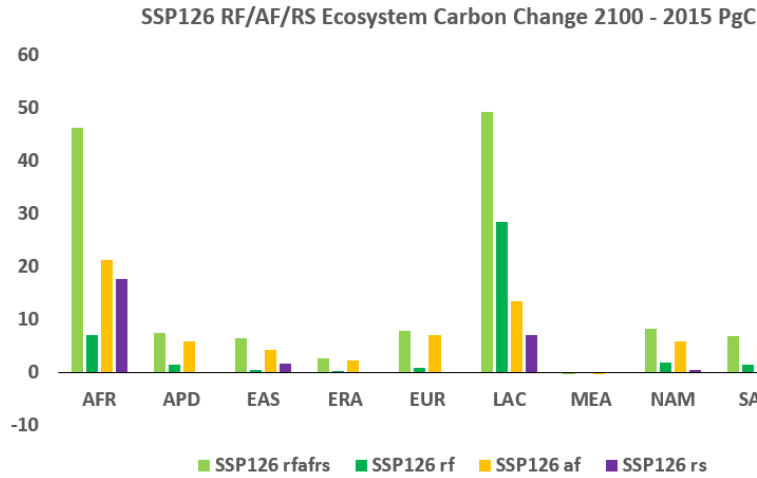
- Current Land Use (NoLULCC 2015)
- SSP1-2.6 Sustainable World Baseline (SSP126Base)
- SSP3-70 High Population and Agriculture Baseline (SSP370Base)

Two Climate Scenarios (Land Only and Coupled Concentration CESM2)

- SSP1-2.6 Reduced emissions and CO₂ concentrations
- SSP3-7.0 High emissions and CO₂ concentrations

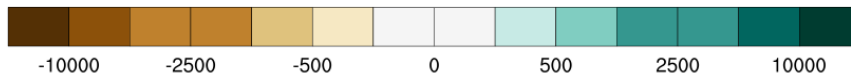
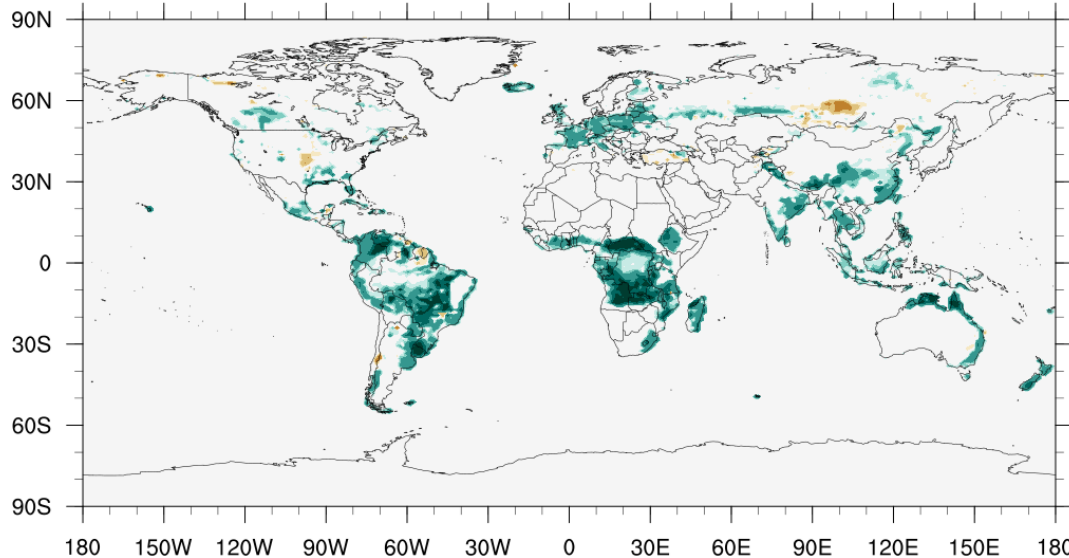
		Climate			
		2.6 (2C)		7.0 (4C)	
Land used for agriculture (Food security)	SSP3 (High agriculture)	I.	1. Baseline (BAU)	IV.	10. Baseline (BAU)
			2. Reforestation		11. Reforestation
			3. Reforestation + Afforestation		12. Reforestation + Afforestation
	Current 2015 (Static land use)	II.	4. Baseline	V.	13. Baseline
			5. Reforestation		14. Reforestation
			6. Reforestation + Afforestation		15. Reforestation + Afforestation
	SSP1 (Low agriculture)	III.	7. Baseline	VI.	16. Baseline
			8. Reforestation		17. Reforestation
			9. Reforestation + Afforestation		18. Reforestation + Afforestation

CLM5 RCP 2.6 Re/Afforestation – Total Eco Carbon 139 PgC



SSP126 rfafrs - noLU Total Ecosystem C (2091 - 2100)

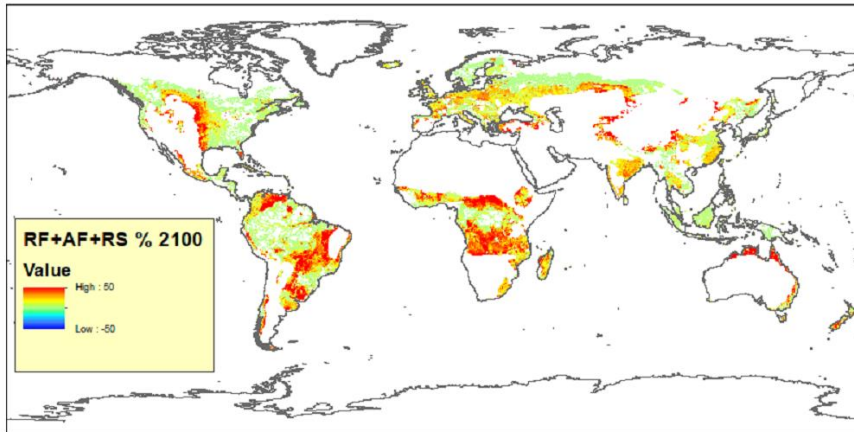
[gC/m²]



Terrestrial Sink Carbon Enhancement SSP1-2.6 Max Forest

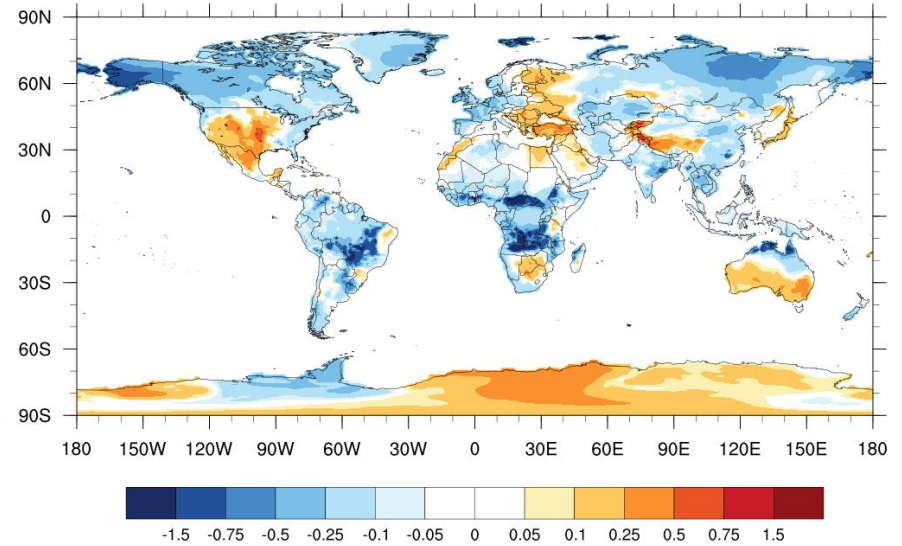
Reforestation	44 PgC
Afforestation	67 PgC
Restoration	28 PgC
Total	139 PgC

CLM5 RCP 2.6 Re/Afforestation – Air Temp / Evapotrans



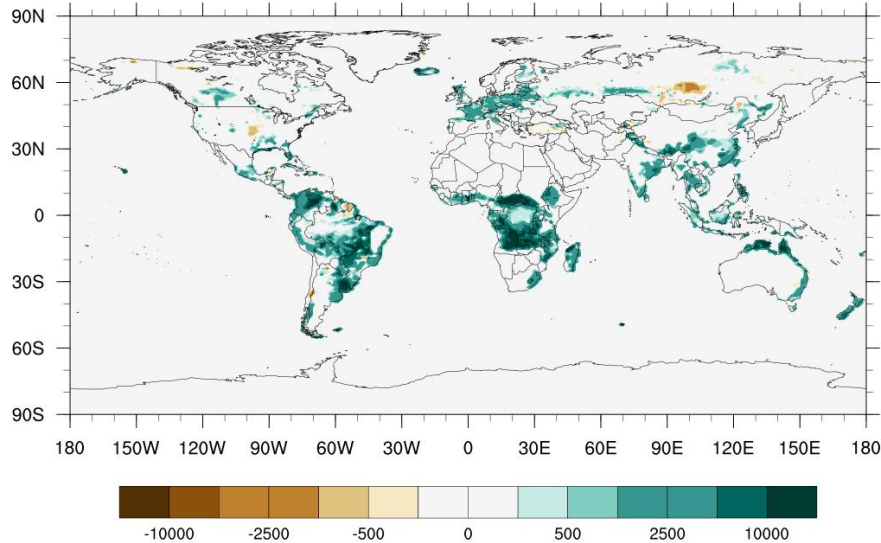
SSP126 rfafrs - noLU 2m Ref Temperature (2091 - 2100)

[DegC]



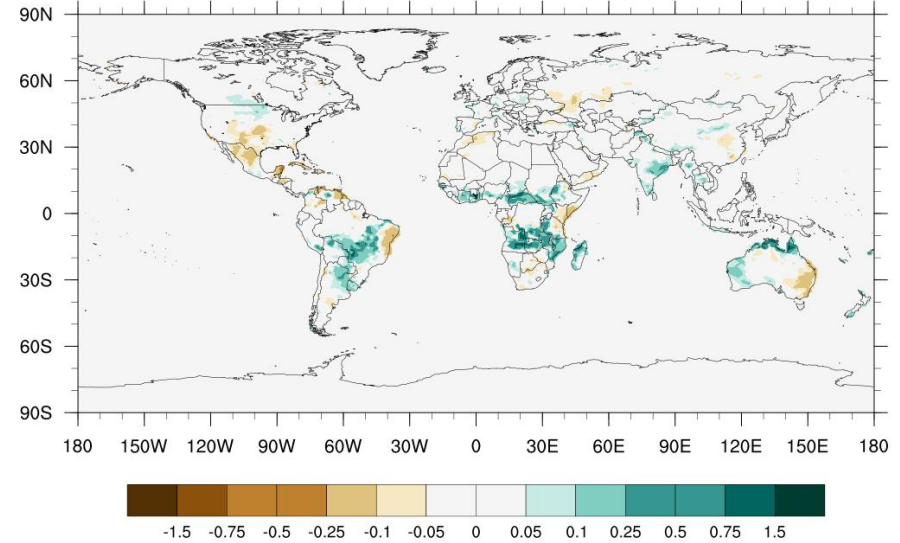
SSP126 rfafrs - noLU Total Ecosystem C (2091 - 2100)

[gC/m2]



SSP126 rfafrs - noLU Evapotranspiration (2091 - 2100)

[mm/d]



CESM Tutorial – Carbon Dioxide Removal through Land Management

The carbon dioxide removal potential for large scale Bioenergy with Carbon Capture and Storage (BECCS).

Science

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REVIEW



Cellulosic biofuel contributions to a sustainable energy future: Choices and outcomes

G. Philip Robertson^{1,2,3,*}, Stephen K. Hamilton^{1,3,4}, Bradford L. Barham^{5,6}, Bruce E. Dale^{3,7}, R. Cesar Izaurralde^{3,8,9}, Randall ...

+ See all authors and affiliations

Science 30 Jun 2017:
1197-1210



ELSEVIER

Journal of Integrative Agriculture

Volume 16, Issue 6, June 2017, Pages 1197-1210



ELSEVIER

Global Environmental Change

Volume 42, January 2017, Pages 153-168



REVIEW

Modeling the biomass of energy crops: Descriptions, strengths and prospective

Rui JIANG ^{a, b} ✉, Tong-tong WANG ^a ✉, Jin SHAO ^c, Sheng GUO ^a, Wei ZHU ^a, Ya-jun YU ^d, Rysuke HATANNO ^e

The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview

Keywan Riahi ^a ✉, Detlef P. van Vuuren ^b, Elmar Kriegler ^c, Jae Edmonds ^d, Brian C. O'Neill ^e, Shinichiro Fujimori ^f,

All CMIP6 SSP Mitigation Scenarios use Bioenergy with Carbon Capture and Storage in some form to provide renewable liquid fuels to reduce fossil fuel emissions

CLM5 Land Cover Change – Crop Management

Gridcell



CLM 5 LULCC for Natural PFT and Crop



Vegetated



Lake



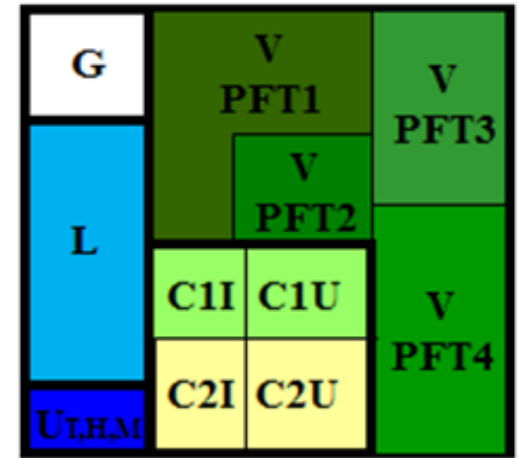
Urban



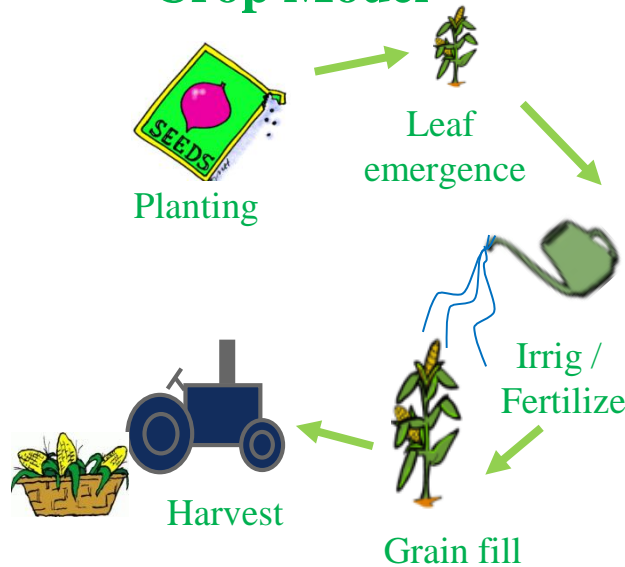
Glacier



Crop



Crop Model



Unirrig



Irrig



Unirrig



Irrig



Crop1



Crop1



Crop2



Crop2 ...

CESM Tutorial – Carbon Dioxide Removal through Land Management

JAMES

Journal of Advances in
Modeling Earth Systems



RESEARCH ARTICLE

10.1029/2019MS001719

Special Section:

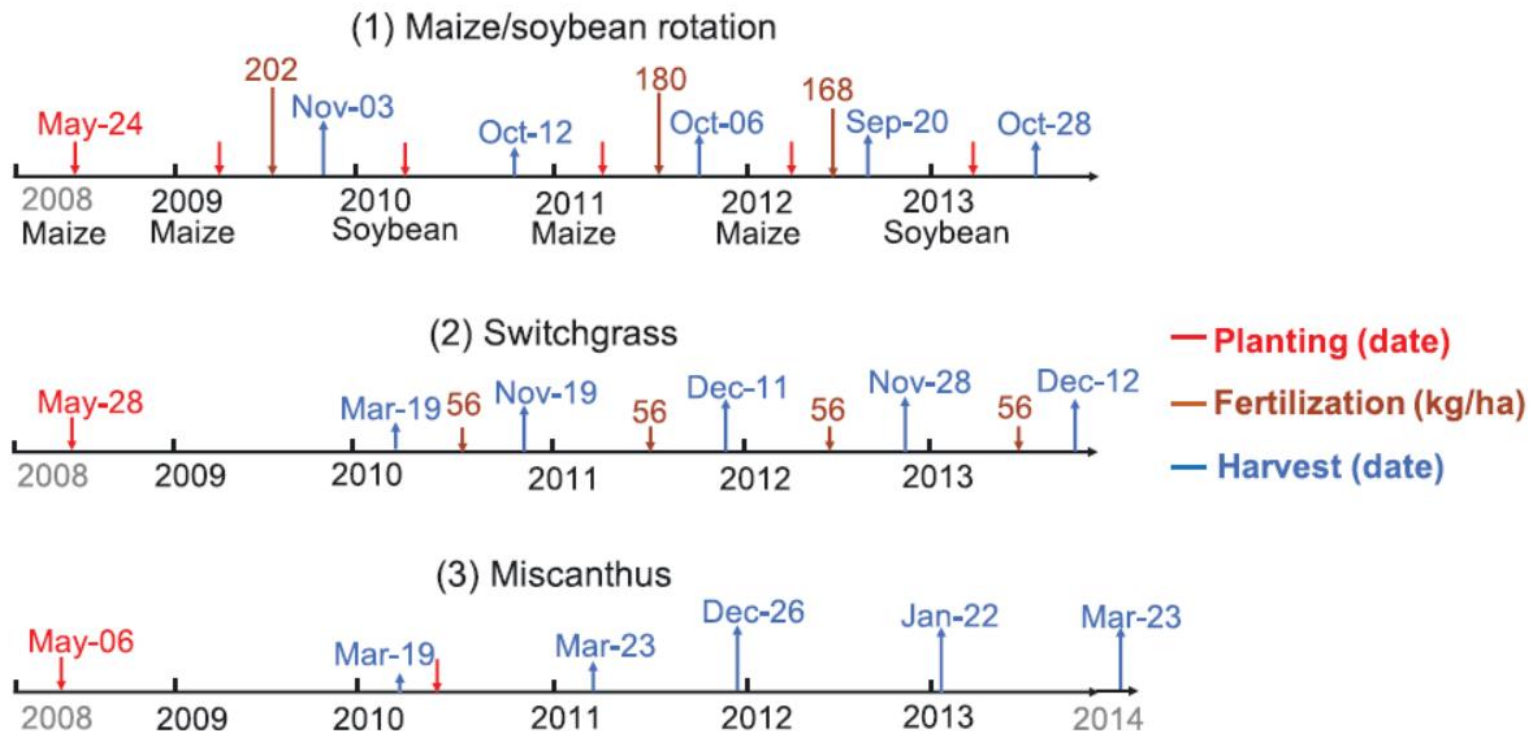
Community Earth System
Model version 2 (CESM2)
Special Collection

Parameterizing Perennial Bioenergy Crops in Version 5 of the Community Land Model Based on Site-Level Observations in the Central Midwestern United States

Yanyan Cheng¹, Maoyi Huang¹, Min Chen², Kaiyu Guan^{3,4}, Carl Bernacchi^{5,6,7}, Bin Peng^{3,4}, and Zeli Tan¹

Key Points:

(b)



CESM/CLM5 Carbon Dioxide Removal Summary

Evaluating Plausible Reforestation, Afforestation and Restoration Scenarios compared with CMIP6 Baseline Scenarios 2015 – 2100 with agricultural and climate limits:

- **Global Reforestation** 2.3m km² **Afforestation** 5.5m km² **Restoration** 1.5m km² **Total** 9.4m km²
- **Carbon Reforestation** 44 PgC **Afforestation** 67 PgC **Restoration** 28 PgC **Total** 139 PgC
- **South America** has large reforestation but smaller afforestation and restoration potential
- **Central Africa** has large afforestation and restoration and smaller reforestation potential due to agriculture
- **Tropical Forests** have large carbon uptake with increased evapotranspiration and cooling
- **Mid and High Latitude Forest** result in low carbon uptake with lower albedo and warming

Investigating Biofuel and Other Agricultural Practices for Carbon Management:

- **CLM5 Crop Model** provides basis for existing conventional biofuel production through Corn, Soybean, Wheat and Sugarcane.
- **New Miscanthus and Switchgrass** crop representations are available for cellulosic ethanol production.
- **Other Agricultural Management** for Carbon Dioxide Removal can be represented in the CLM5 Crop Model with options for various rates of residue and tilling.