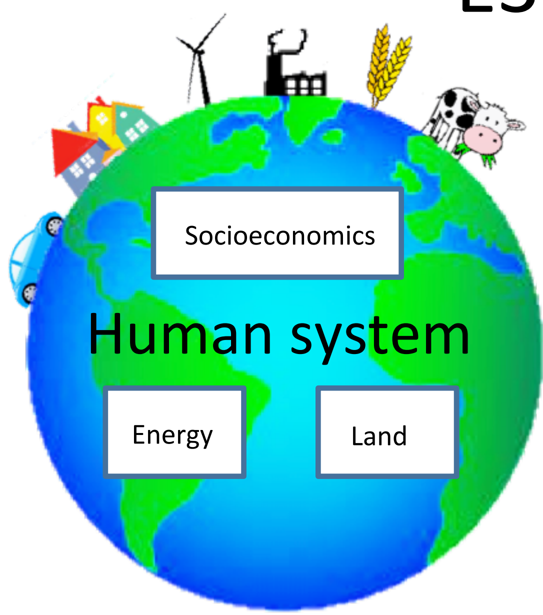
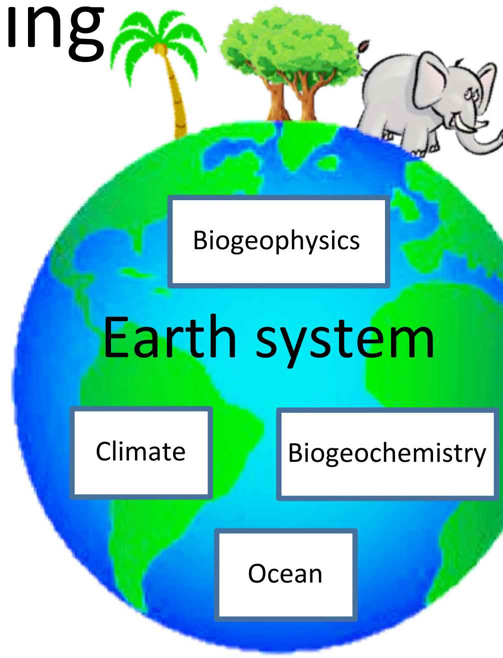
Modeling Human-Earth feedbacks: GCAM-E3SM coupling



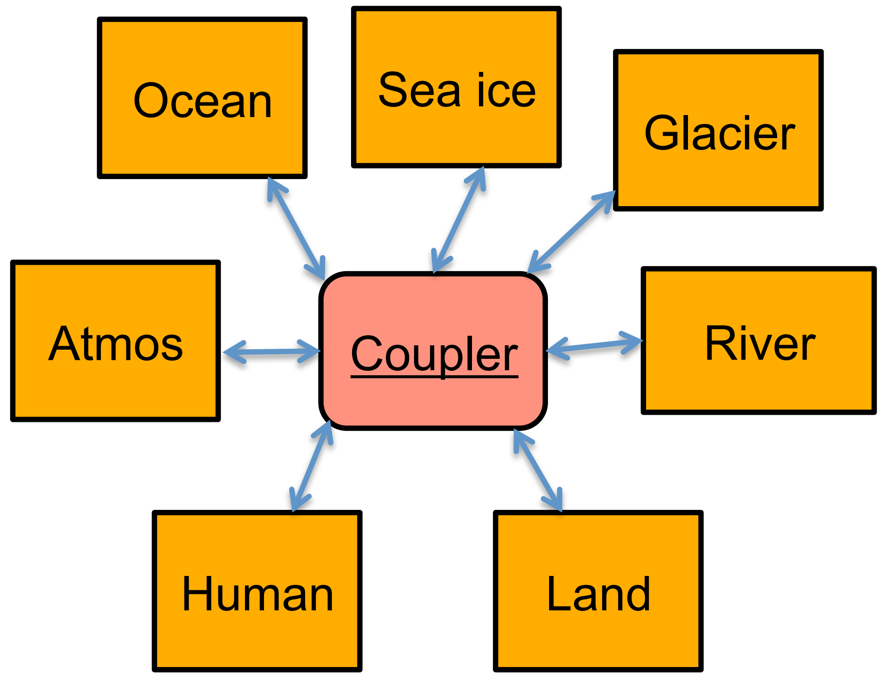


Alan Di Vittorio, Kate Calvin, Tim Shippert, Ben Bond-Lamberty

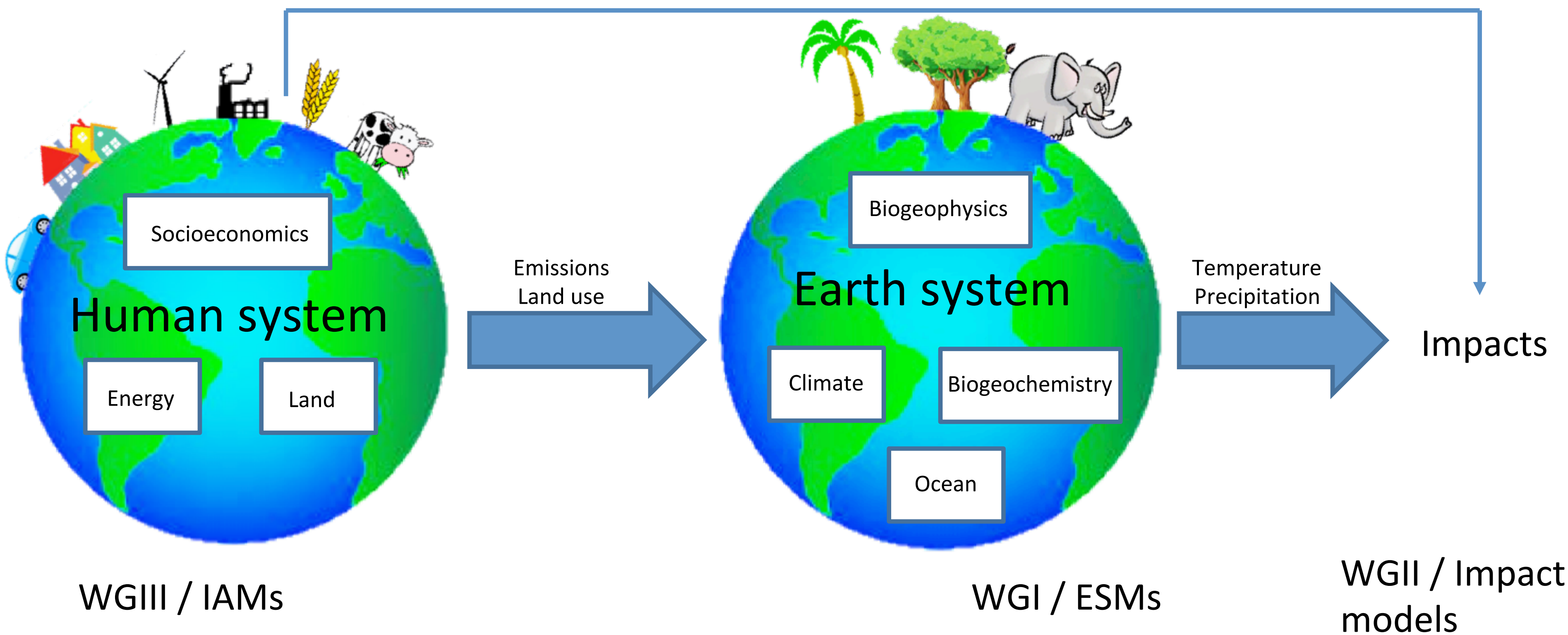
Overview

- Scenario-based modeling
- Consequences of Human-Earth feedbacks
- State of Human-Earth research
- E3SM-GCAM

E3SM-GCAM

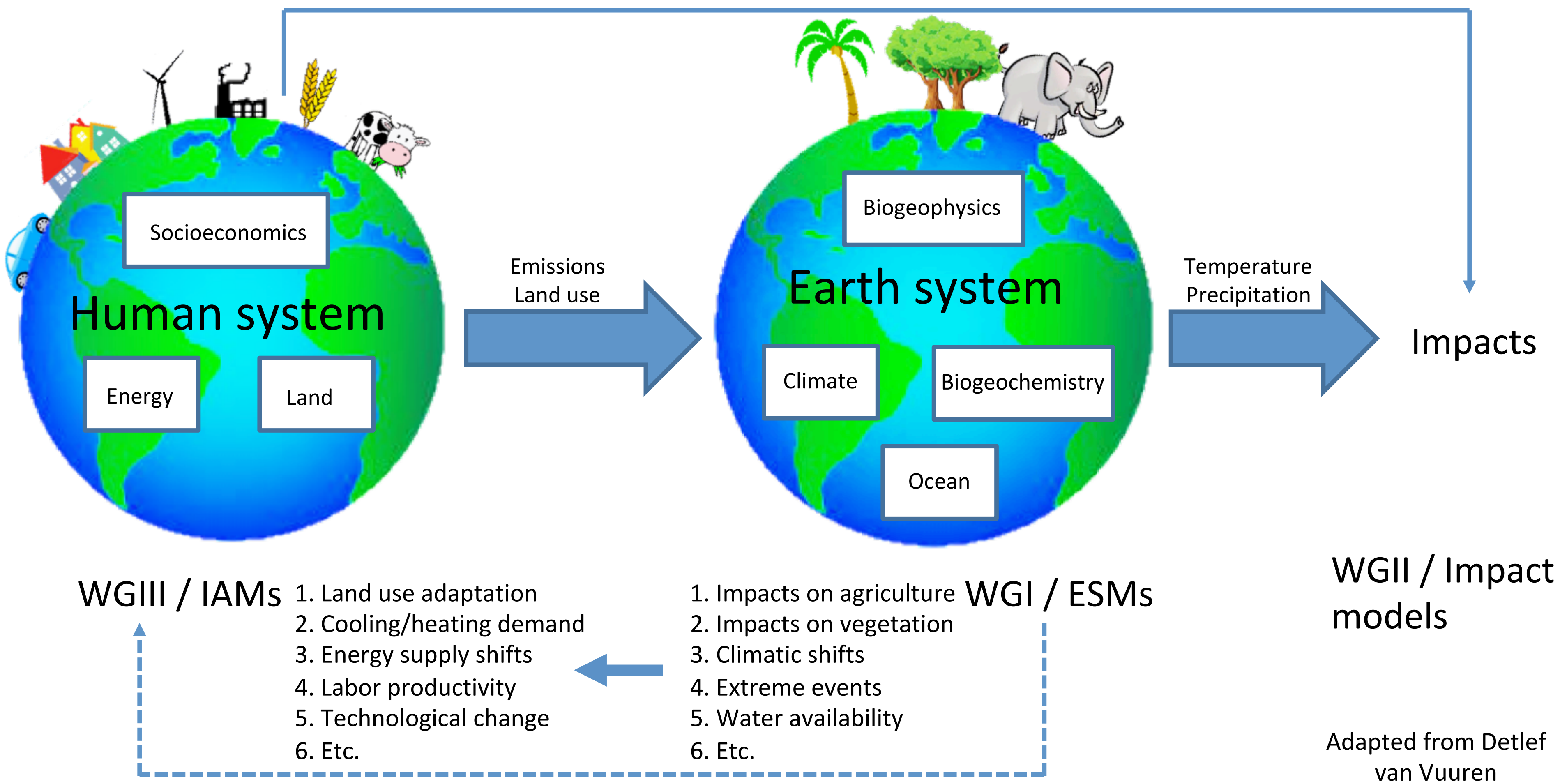


Current state of scenario-based modeling



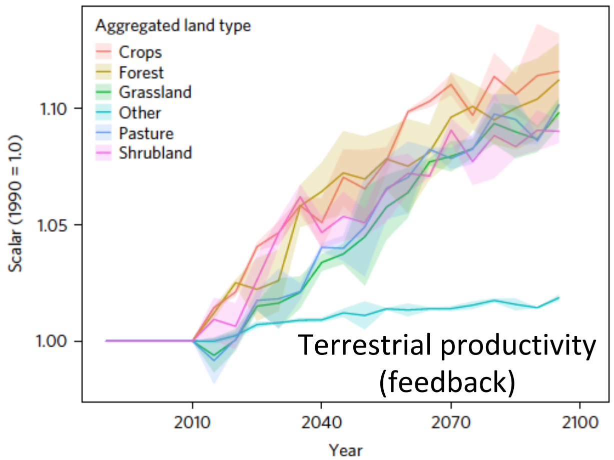
Adapted from Detlef van Vuuren

How do feedbacks disrupt the linear system?

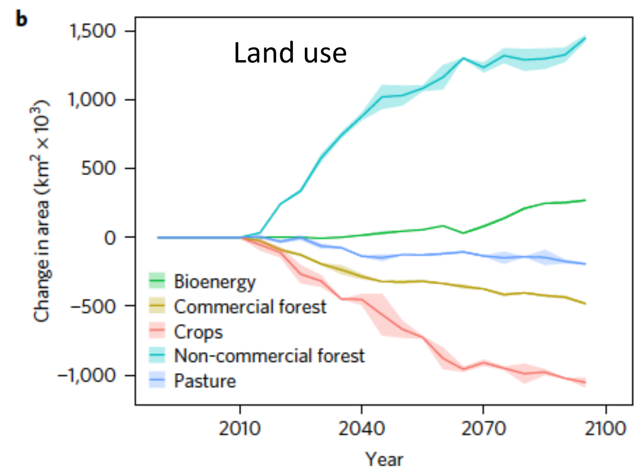


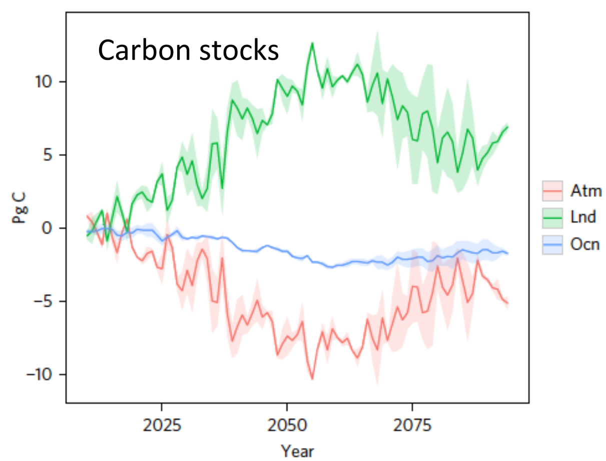
Adapted from Detlef van Vuuren

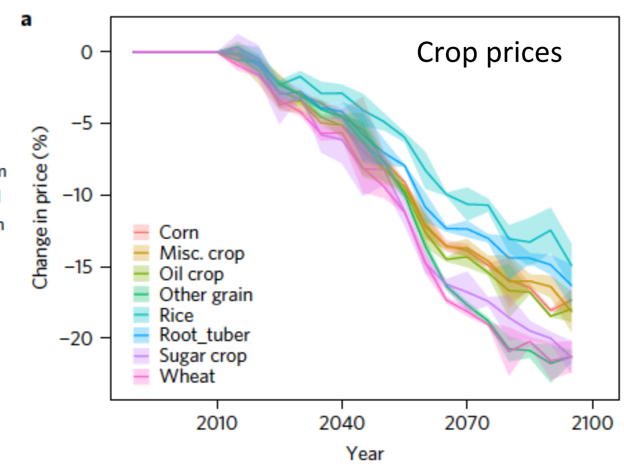
Human-Earth feedbacks alter the scenario



Effects of RCP 4.5
terrestrial feedbacks

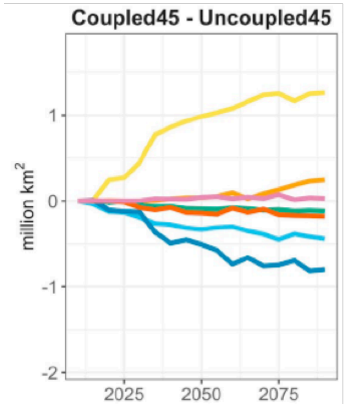


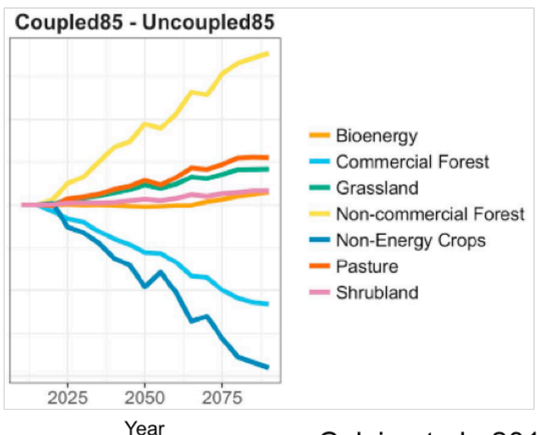




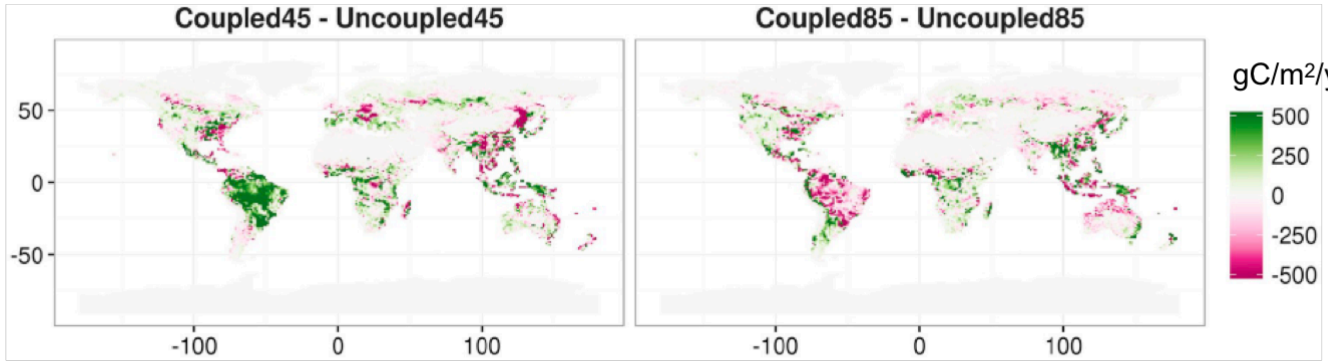
Thornton et al., 2017

Human-Earth feedbacks also affect carbon and temperature

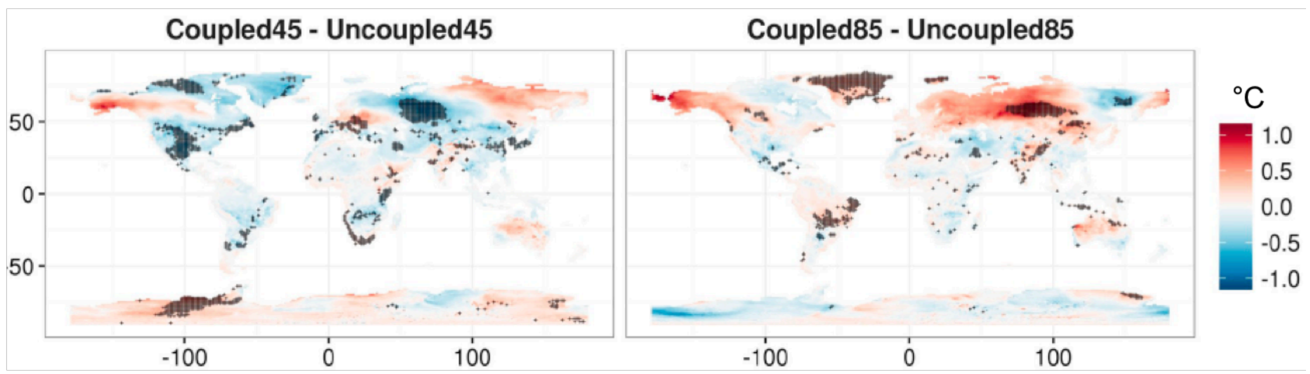




Changes in land carbon uptake (2071-2090)



Significant changes in local temperature

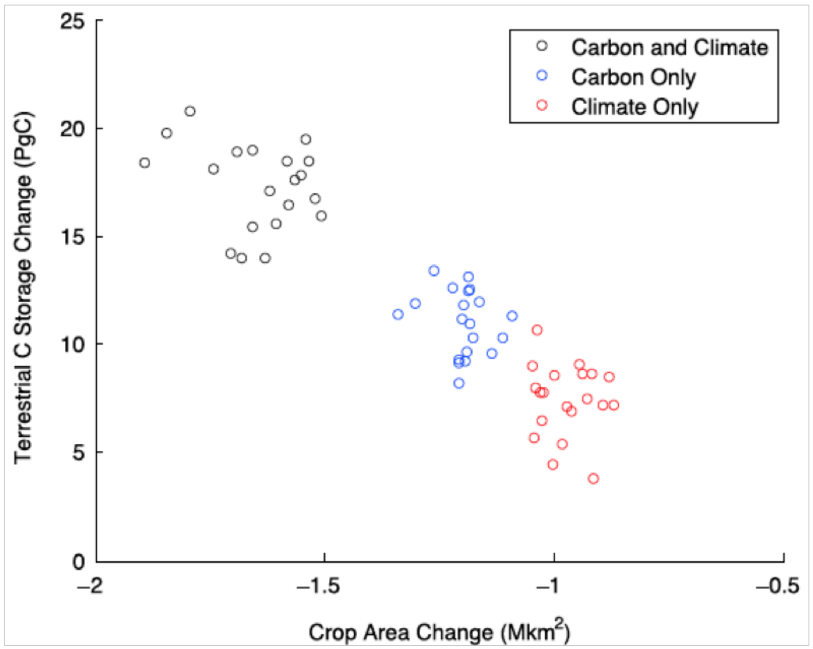


Calvin et al., 2019

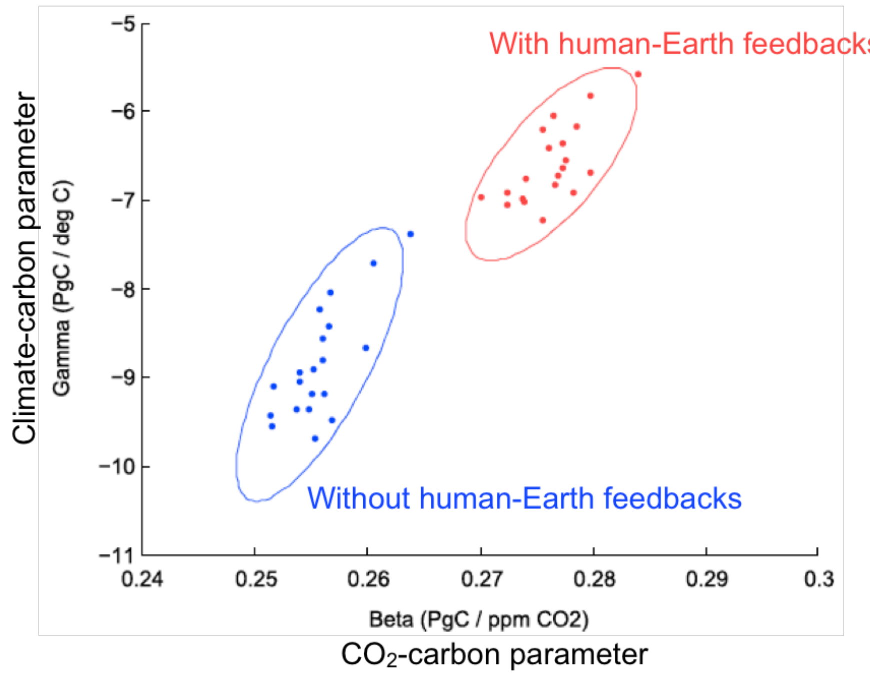
Human-Earth feedbacks also affect land carbon feedbacks

RCP 8.5

Changes in land C and crop area (2070-2089)



Changes in land C feedbacks (2070-2089)



Jones et al., 2018

Growing area of research

Environ. Res. Lett. 7 (2012) 024012 (10pp) doi:10.1088/1748-9326/7/2/024012

A comprehensive view on climate change: coupling of earth system and integrated assessment models

Detlef P van Vuuren[1,2], Laura Batlle Bayer[3], Clifford Chuwah[4], Laurens Ganzeveld[5], Wilco Hazeleger[4,5], Bart van den Hurk[3,4], Twan van Noije[4], Brian O'Neill[6] and Bart J Strengers[1]

Received: 8 December 2017 | Revised: 28 December 2018 | Accepted: 18 January 2019
DOI: 10.1002/wcc.582

WIREs CLIMATE CHANGE WILEY

ADVANCED REVIEW

The use of the Community Earth System Model in human dimensions climate research and applications

Emily K. Laidlaw[1,2*] | Brian C. O'Neill[1,3*] | Ryan D. Harp[4,5]

Modeling sustainability: population, inequality, consumption, and bidirectional coupling of the Earth and Human Systems

Safa Motesharrei[1,*,†], Jorge Rivas[2,†], Eugenia Kalnay[1,†], Ghassem R. Asrar[3], Antonio J. Busalacchi[4], Robert F. Cahalan[5,6], Mark A. Cane[7], Rita R. Colwell[1], Kuishuang Feng[1], Rachel S. Franklin[8], Klaus Hubacek[1], Fernando Miralles-Wilhelm[1,3], Takemasa Miyoshi[1,9], Matthias Ruth[10], Roald Sagdeev[1], Adel Shirmohammadi[1], Jagadish Shukla[11], Jelena Srebric[1], Victor M. Yakovenko[1], and Ning Zeng[1]

Methods and approaches to modelling the Anthropocene

Peter H. Verburg[a,*], John A. Dearing[b], James G. Dyke[b], Sander van der Leeuw[c,h], Sybil Seitzinger[d], Will Steffen[e,f], James Syvitski[g]

Growing area of research

Modelling feedbacks between human and natural processes in the land system

Derek T. Robinson[1], Alan Di Vittorio[2], Peter Alexander[3,4], Almut Arneth[5], C. Michael Barton[6], Daniel G. Brown[7], Albert Kettner[8], Carsten Lemmen[9], Brian C. O'Neill[10], Marco Janssen[11], Thomas A. M. Pugh[12,13], Sam S. Rabin[5], Mark Rounsevell[3,5], James P. Syvitski[14], Isaac Ullah[15], and Peter H. Verburg[16]

Grand Challenges in Understanding the Interplay of Climate and Land Changes

Shuguang Liu,[a,b] Ben Bond-Lamberty,[c] Lena R. Boysen,[d] James D. Ford,[e] Andrew Fox,[f] Kevin Gallo,[g] Jerry Hatfield,[h] Geoffrey M. Henebry,[i] Thomas G. Huntington,[j] Zhihua Liu,[k] Thomas R. Loveland,[b] Richard J. Norby,[l] Terry Sohl,[b] Allison L. Steiner,[m] Wenping Yuan,[n] Zhao Zhang,[n] and Shuqing Zhao[o]

Environ. Res. Lett. 13 (2018) 063006

https://doi.org/10.1088/1748-9326/aac642

Environmental Research Letters

8) land-use modeling frameworks with uncertainty measures that capture all major biogeophysical, climatic, and socioeconomic forces of LCLUC and address feedbacks between processes operating at scales from local to global;

TOPICAL REVIEW

Integrated human-earth system modeling—state of the science and future directions

Katherine Calvin[1,2] and Ben Bond-Lamberty[1]

New organizations focused on Human-Earth modeling

AIMES
analysis, integration, and modeling of the earth system

The AIMES Modeling Earth System and Human interactions (MESH) Working Group

https://aimesproject.org/mesh/

Linking Human and Earth System Models for Global Change Analysis

JULY 19, 2021 TO JULY 21, 2021 Virtual Workshop

This workshop will bring together researchers working on a range of strategies to better understand the interactions and feedbacks between human and earth systems through improved linkages and coupled modeling of human and earth systems. Workshop themes include:

https://www.agci.org/event/21s2

The Open Modeling Foundation

Enabling next generation modeling of human and natural systems

About | Organization & Governance | Standards

https://openmodelingfoundation.github.io

Highlights of MESH workshop on linking Human and Earth system models for global change analysis

- Feedbacks are important, but not well understood
  - Some climate-sectoral relationships are better understood
    - Crops, energy, forest

- Critical development needs
  - Extreme events, biodiversity,
  - human behavior, bioenergy,
  - policy conditions and response
  - Multiple feedback approaches:
    - E.g., soft vs hard coupling

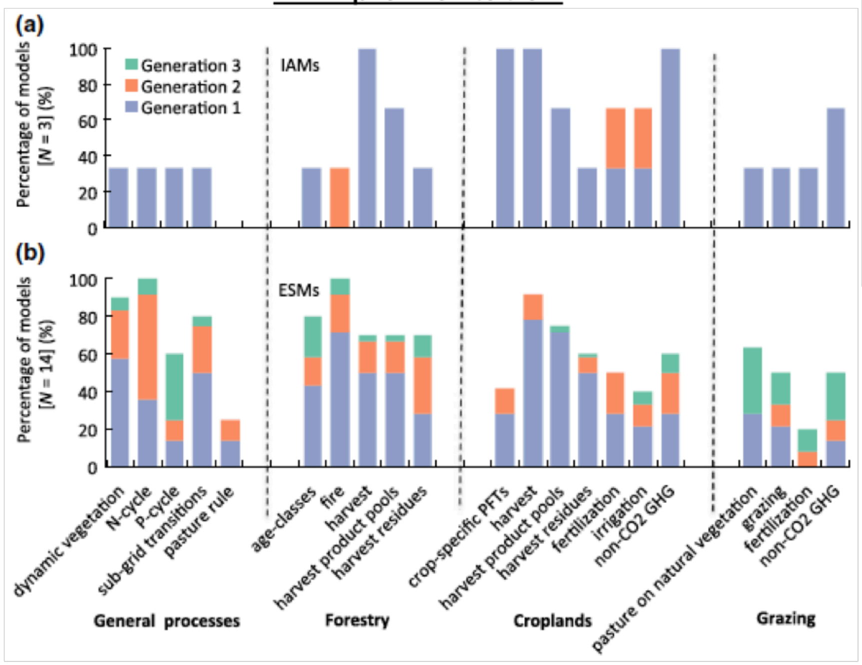
- Scenarios need expansion
  - Additional factors such as SDGs
  - Pathways vs targets
  - Shocks/disruptions
  - More scenarios

- Must reduce inconsistencies across models
  - Land use/cover
  - Agricultural practices
  - Forestry practices
  - Biogeophysics
  - Baselines and Definitions

Highly abstracted and condensed

IAM-ESM inconsistencies pose challenges

Basic land management is increasing in implementation



Pongratz et al., 2018

Carbon management is limited (and is only in IAMs)

Levels of Inclusion

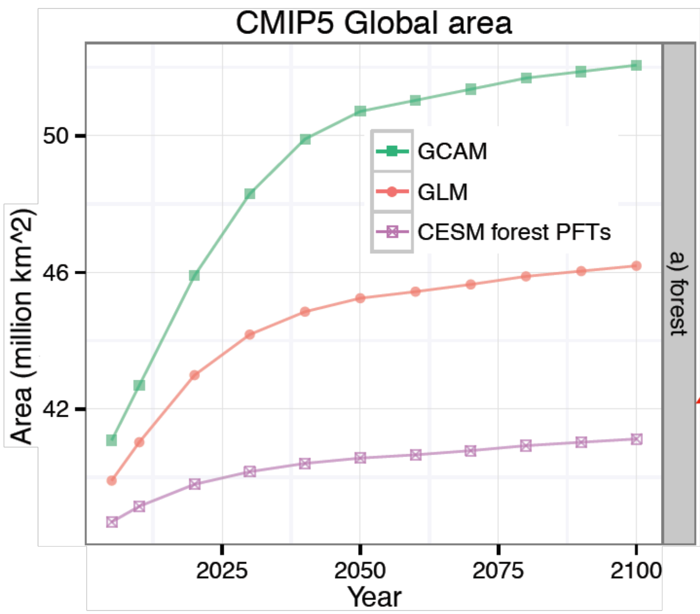
	Explicit	Implicit
Endogenous	A	C
Exogenous	B	D
E	Not represented by model	

	AIM	BET	COPPE-COFFEE	C-ROADS	DNE21+	GCAM 4.2	GEM-E3 3.0	GENESYSmod 1.0	GRAPE 1.0	IEA ETP	IEA WEM	IMACLIM 1.1	IMACLIM NL	IMAGE 3.0	MERGE-ETL 6.0	MESSAGE-GLOBIOM	MESSAGEix-GLOBIOM	POLES	REMIND-MAgPIE	Shell WEM v1	WITCH
Carbon Dioxide (Greenhouse Gas) Removal																					
BECCS	A	A	A	D	A	A	E	E	A	A	A	A	A	A	A	A	E	A	A	B	A
Direct air capture and sequestration (DACS) of CO_2 using chemical solvents and solid absorbents, with subsequent storage	E	E	E	D	E	E	E	E	E	E	E	E	E	E	A	E	E	E	A	E	E
Mineralization of atmospheric CO_2 through enhanced weathering of rocks	E	E	E	D	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Forest expansion	A	E	A	C	A	A	E	E	A	E	E	E	B	B	E	A	A	B	A	D	A
Restoration of wetlands (e.g., coastal and peat-land restoration, blue carbon)	E	E	E	D	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Biochar	E	E	E	D	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Soil carbon enhancement, enhancing carbon sequestration in biota and soils, e.g. with plants with high carbon sequestration potential (also AFOLU measure)	E	E	E	D	E	E	E	E	E	E	E	E	D	E	E	A	A	B	C	E	E
AFOLU Measures																					
Reduced deforestation	A	E	A	D	B	A	E	E	B	D	D	E	B	B	E	A	A	B	A	D	C
Forest management	C	E	E	D	E	C	E	E	C	D	D	E	B	B	E	A	A	B	E	D	C
Reduced land degradation, and forest restoration	C	E	D	D	E	E	E	E	C	D	D	E	E	B	E	E	E	B	E	D	E
Agroforestry and silviculture	E	E	D	D	E	E	E	E	E	D	D	E	E	E	E	E	E	E	E	E	E
Urban and peri-urban agriculture and forestry	E	E	E	D	E	E	E	E	E	D	D	E	E	E	E	E	E	E	E	E	E
Fire management and (ecological) pest control	C	E	D	D	E	C	E	E	E	D	D	E	E	E	E	E	E	E	E	E	E
Changing agricultural practices that enhance soil carbon	C	E	E	D	E	E	E	E	E	D	D	E	E	E	E	E	E	B	E	D	E
Conservation agriculture	E	E	E	D	E	E	E	E	E	D	D	E	E	E	E	A	A	E	E	E	C
Increased ag productivity	A	E	A	D	A	B	E	E	B	D	D	E	A	B	E	A	A	E	A	D	C
Methane reductions in rice paddies	C	E	C	D	C	C	C	E	C	D	D	E	C	C	E	A	A	B	C	D	C
Nitrogen pollution reductions (e.g., by fertilizer reduction, increasing nitrogen fertilizer efficiency, sustainable fertilizers)	C	E	C	D	C	C	C	E	E	D	D	E	A	C	E	A	A	B	C	D	C
Livestock and grazing management, for example, methane and ammonia reductions in ruminants through feeding management or feed additives, or manure management for local biogas production to replace traditional biomass use	C	E	C	D	C	C	C	E	C	D	D	E	A	C	E	A	A	B	C	D	C
Manure management	C	E	C	D	C	C	C	E	C	D	D	E	C	C	E	A	A	E	C	E	C
Biophysical effects	E	E	E	D	E	E	E	E	E	D	D	E	E	E	E	E	E	E	D	D	E

Forster et al., 2018

IAM-ESM inconsistencies pose challenges

But existing processes are not yet consistent across human-Earth modeling



Di Vittorio et al., 2014

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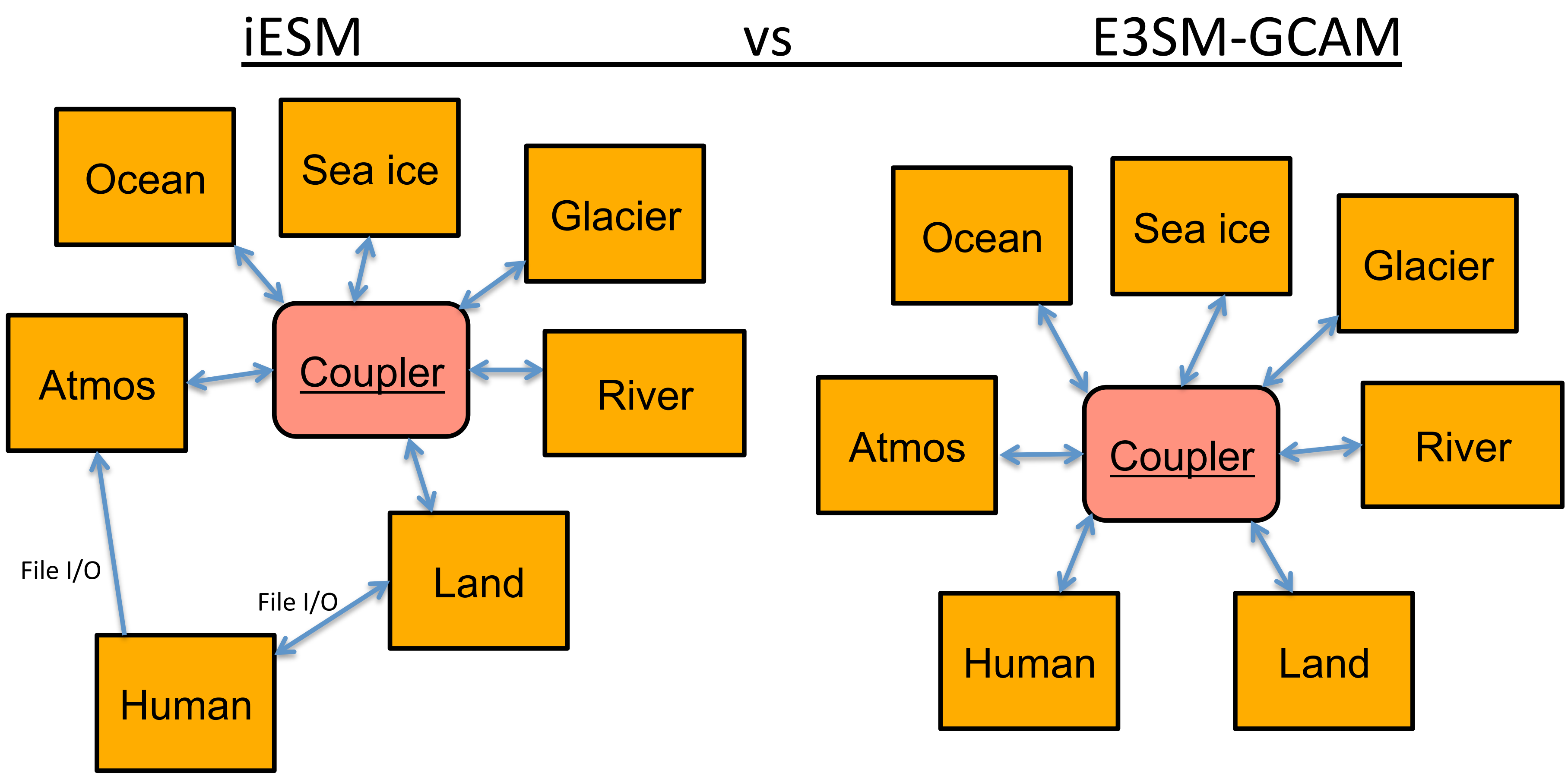
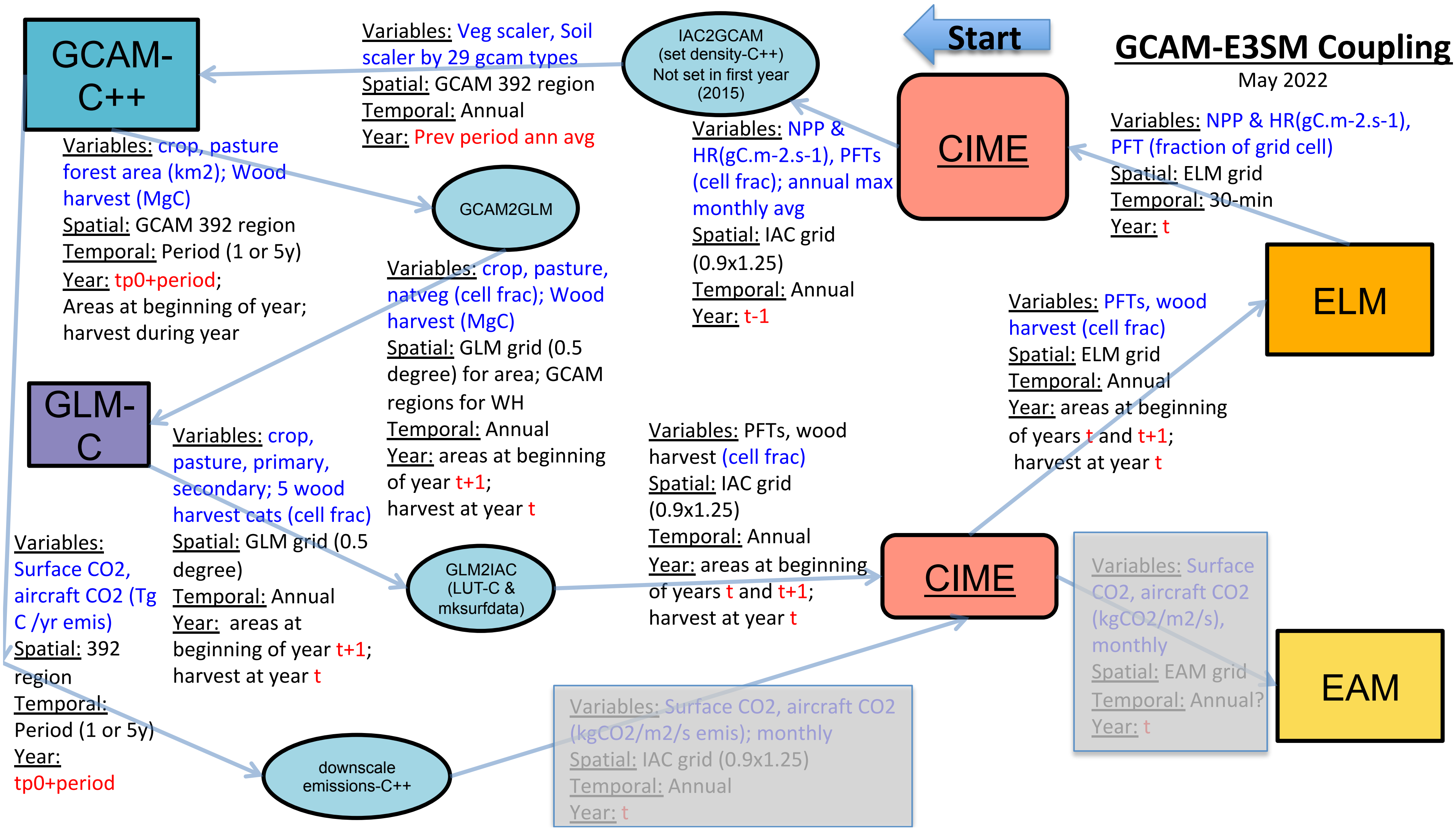
Carbon Dioxide (Greenhouse Gas) Removal																					
B (t … BECCS	A	A	A	D	A	A	E	E	A	A	A	A	A	A	A	A	E	A	A	B	A
Direct air capture and sequestration (DACS) of CO_2 using chemical solvents and solid absorbents, with subsequent storage	E	E	E	D	E	E	E	E	E	E	E	E	E	E	A	E	E	E	A	E	E
Mineralization of atmospheric CO_2 through enhanced weathering of rocks	E	E	E	D	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
A … Forest expansion	A	E	A	C	A	A	E	E	A	E	E	E	B	B	E	A	A	B	A	D	A
Restoration of wetlands (e.g., coastal and peat-land restoration, blue carbon)	E	E	E	D	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Biochar	E	E	E	D	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Soil carbon enhancement, enhancing carbon sequestration in biota and soils, e.g. with plants with high carbon sequestration potential (also AFOLU measure)	E	E	E	D	E	E	E	E	E	E	E	E	D	E	E	A	A	B	C	E	E
AFOLU Measures																					
R … Reduced deforestation	A	E	A	D	B	A	E	E	B	D	D	E	B	B	E	A	A	B	A	D	C
Forest management	C	E	E	D	E	C	E	E	C	D	D	E	B	B	E	A	A	B	E	D	C
Reduced land degradation, and forest restoration	C	E	D	D	E	E	E	E	C	D	D	E	E	B	E	E	E	B	E	D	E
Agroforestry and silviculture	E	E	D	D	E	E	E	E	E	D	D	E	E	E	E	E	E	E	E	E	E
Urban and peri-urban agriculture and forestry	E	E	E	D	E	E	E	E	E	D	D	E	E	E	E	E	E	E	E	E	E
Fire management and (ecological) pest control	C	E	D	D	E	C	E	E	E	D	D	E	E	E	E	E	E	E	E	E	E
Changing agricultural practices that enhance soil carbon	C	E	E	D	E	E	E	E	E	D	D	E	E	E	E	E	E	B	E	D	E
Conservation agriculture	E	E	E	D	E	E	E	E	E	D	D	E	E	E	E	A	A	E	E	E	C
I … Increased ag productivity	A	E	A	D	A	B	E	E	B	D	D	E	A	B	E	A	A	E	A	D	C
Methane reductions in rice paddies	C	E	C	D	C	C	C	E	C	D	D	E	C	C	E	A	A	B	C	D	C
Nitrogen pollution reductions (e.g., by fertilizer reduction, increasing nitrogen fertilizer efficiency, sustainable fertilizers)	C	E	C	D	C	C	C	E	E	D	D	E	A	C	E	A	A	B	C	D	C
Livestock and grazing management, for example, methane and ammonia reductions in ruminants through feeding management or feed additives, or manure management for local biogas production to replace traditional biomass use	C	E	C	D	C	C	C	E	C	D	D	E	A	C	E	A	A	B	C	D	C
Manure management	C	E	C	D	C	C	C	E	C	D	D	E	C	C	E	A	A	E	C	E	C
I … Biophysical effects	E	E	E	D	E	E	E	E	E	D	D	E	E	E	E	E	E	E	D	D	E

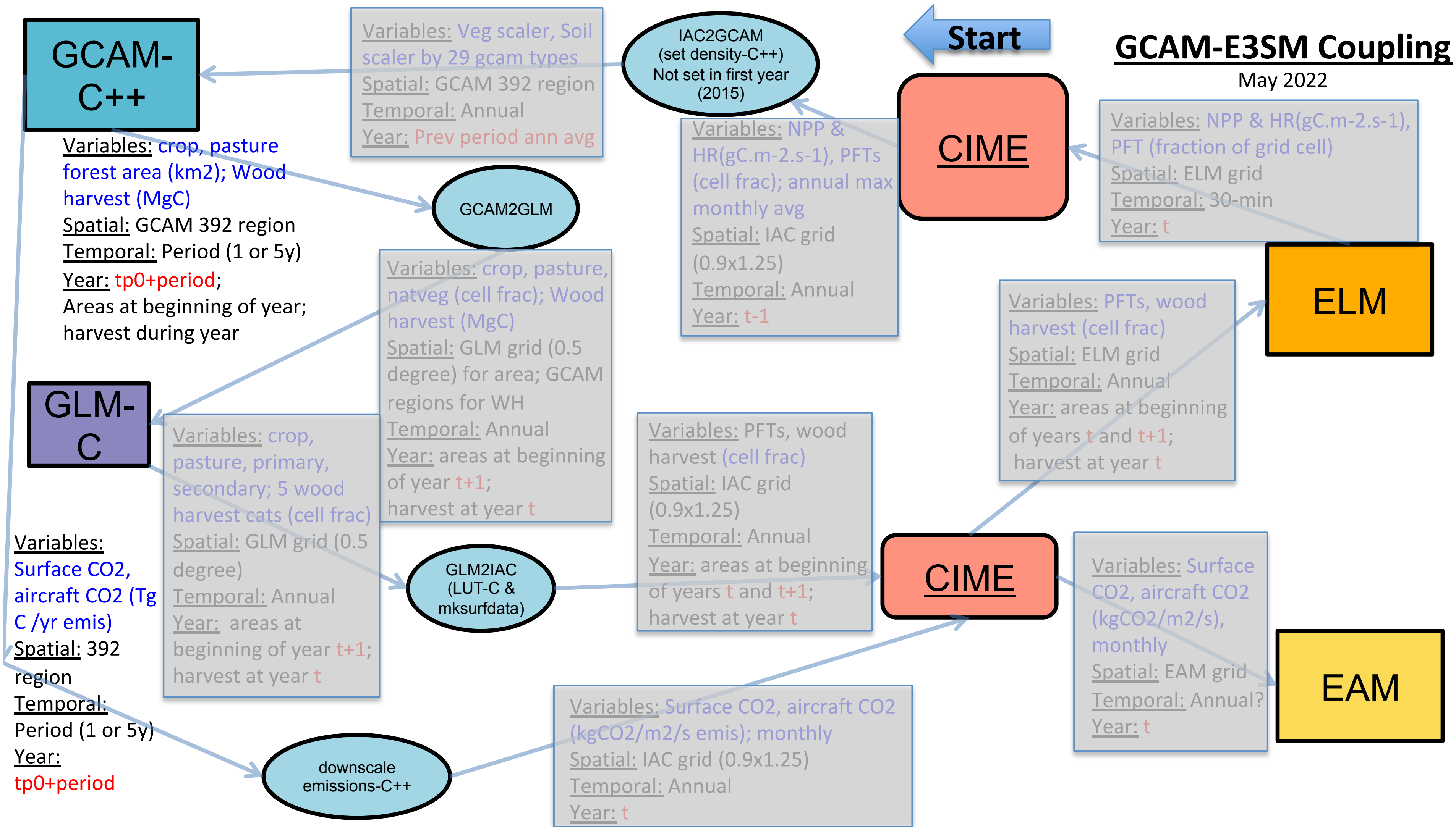
Forster et al., 2018



iESM
vs
E3SM-GCAM
Ocean
Sea ice
Glacier
Atmos
Coupler
River
Land
Human
File I/O
File I/O
Ocean
Sea ice
Glacier
Atmos
Coupler
River
Human
Land



GCAM-E3SM Coupling
May 2022
Start
CIME
ELM
Variables: NPP & HR(gC.m-2.s-1), PFT (fraction of grid cell)
Spatial: ELM grid
Temporal: 30-min
Year: t
Variables: NPP & HR(gC.m-2.s-1), PFTs (cell frac); annual max monthly avg
Spatial: IAC grid (0.9x1.25)
Temporal: Annual
Year: t-1
IAC2GCAM (set density-C++) Not set in first year (2015)
Variables: Veg scaler, Soil scaler by 29 gcam types
Spatial: GCAM 392 region
Temporal: Annual
Year: Prev period ann avg
GCAM-C++
Variables: crop, pasture forest area (km2); Wood harvest (MgC)
Spatial: GCAM 392 region
Temporal: Period (1 or 5y)
Year: tp0+period;
Areas at beginning of year; harvest during year
GCAM2GLM
Variables: crop, pasture, natveg (cell frac); Wood harvest (MgC)
Spatial: GLM grid (0.5 degree) for area; GCAM regions for WH
Temporal: Annual
Year: areas at beginning of year t+1;
harvest at year t
GLM-C
Variables: crop, pasture, primary, secondary; 5 wood harvest cats (cell frac)
Spatial: GLM grid (0.5 degree)
Temporal: Annual
Year: areas at beginning of year t+1;
harvest at year t
GLM2IAC (LUT-C & mksurfdata)
Variables: PFTs, wood harvest (cell frac)
Spatial: IAC grid (0.9x1.25)
Temporal: Annual
Year: areas at beginning of years t and t+1;
harvest at year t
CIME
Variables: PFTs, wood harvest (cell frac)
Spatial: ELM grid
Temporal: Annual
Year: areas at beginning of years t and t+1;
harvest at year t
Variables: Surface CO2, aircraft CO2 (Tg C /yr emis)
Spatial: 392 region
Temporal: Period (1 or 5y)
Year: tp0+period
downscale emissions-C++
Variables: Surface CO2, aircraft CO2 (kgCO2/m2/s emis); monthly
Spatial: IAC grid (0.9x1.25)
Temporal: Annual
Year: t
Variables: Surface CO2, aircraft CO2 (kgCO2/m2/s), monthly
Spatial: EAM grid
Temporal: Annual?
Year: t
EAM



GCAM-E3SM Coupling
May 2022
Start
GCAM-C++
Variables: crop, pasture forest area (km2); Wood harvest (MgC)
Spatial: GCAM 392 region
Temporal: Period (1 or 5y)
Year: tp0+period;
Areas at beginning of year; harvest during year
Variables: Veg scaler, Soil scaler by 29 gcam types
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Temporal: Annual
Year: Prev period ann avg
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Spatial: ELM grid
Temporal: 30-min
Year: t
ELM
GCAM2GLM
Variables: crop, pasture, natveg (cell frac); Wood harvest (MgC)
Spatial: GLM grid (0.5 degree) for area; GCAM regions for WH
Temporal: Annual
Year: areas at beginning of year t+1; harvest at year t
Variables: PFTs, wood harvest (cell frac)
Spatial: ELM grid
Temporal: Annual
Year: areas at beginning of years t and t+1; harvest at year t
GLM-C
Variables: crop, pasture, primary, secondary; 5 wood harvest cats (cell frac)
Spatial: GLM grid (0.5 degree)
Temporal: Annual
Year: areas at beginning of year t+1; harvest at year t
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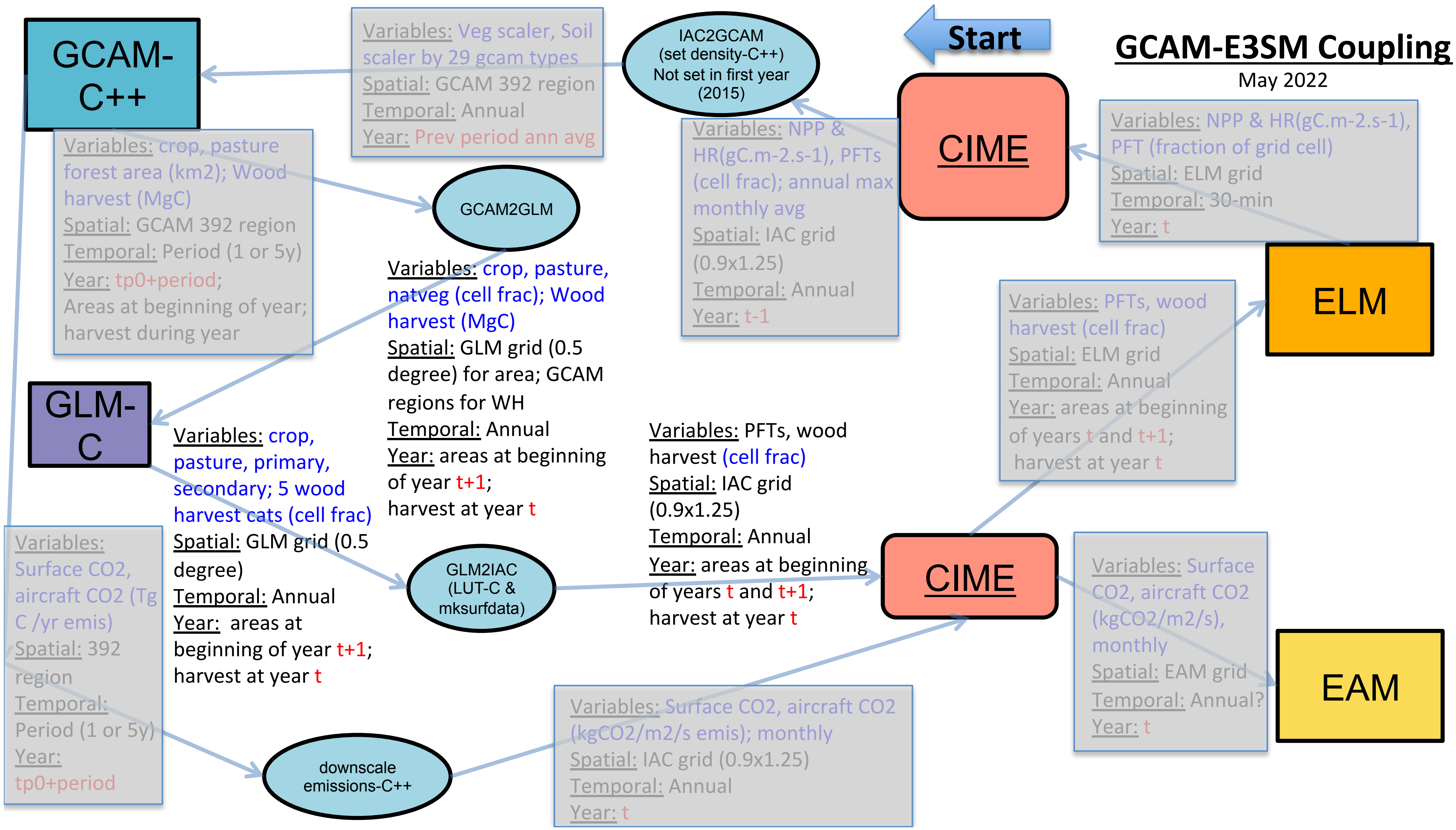
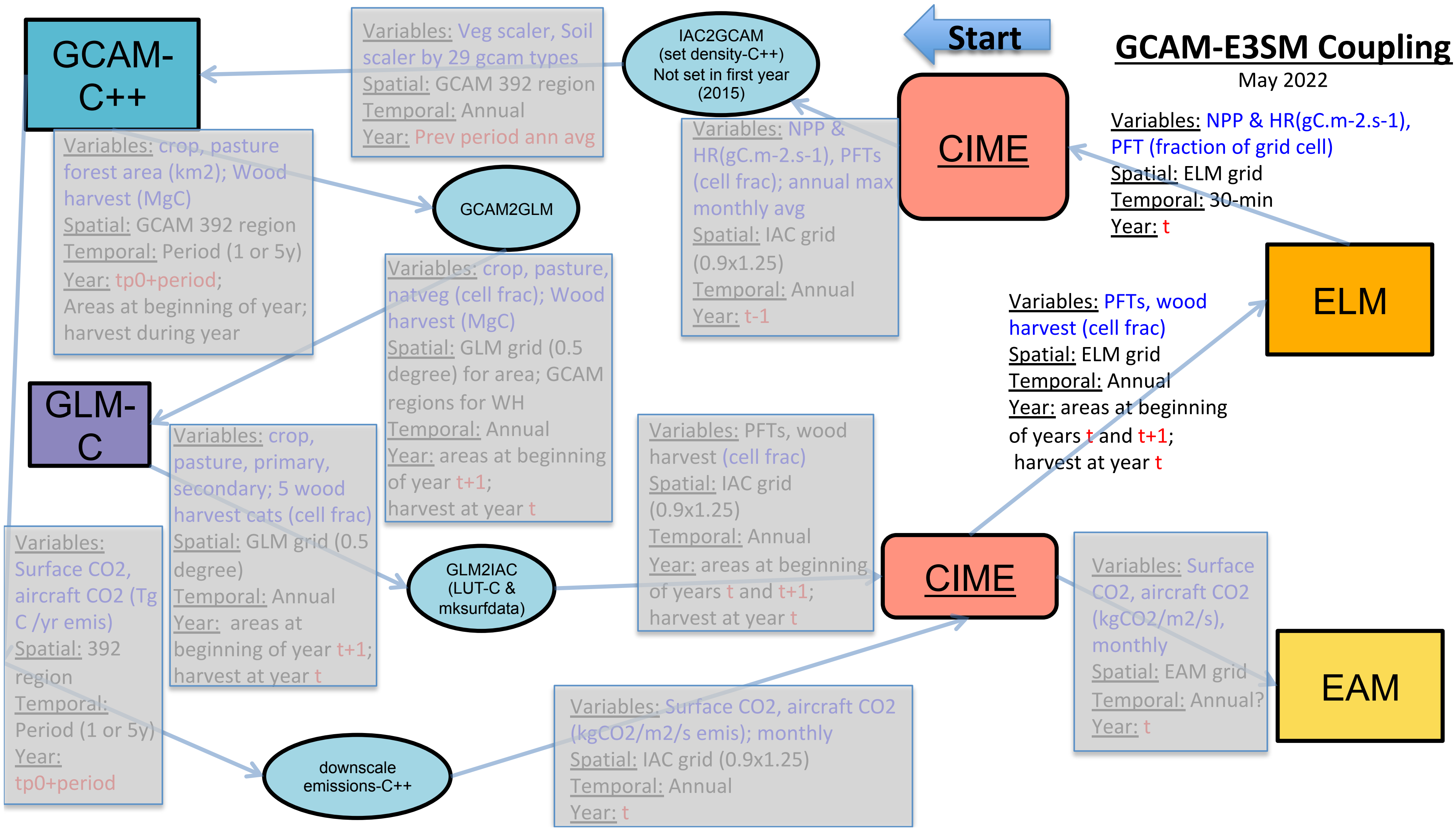
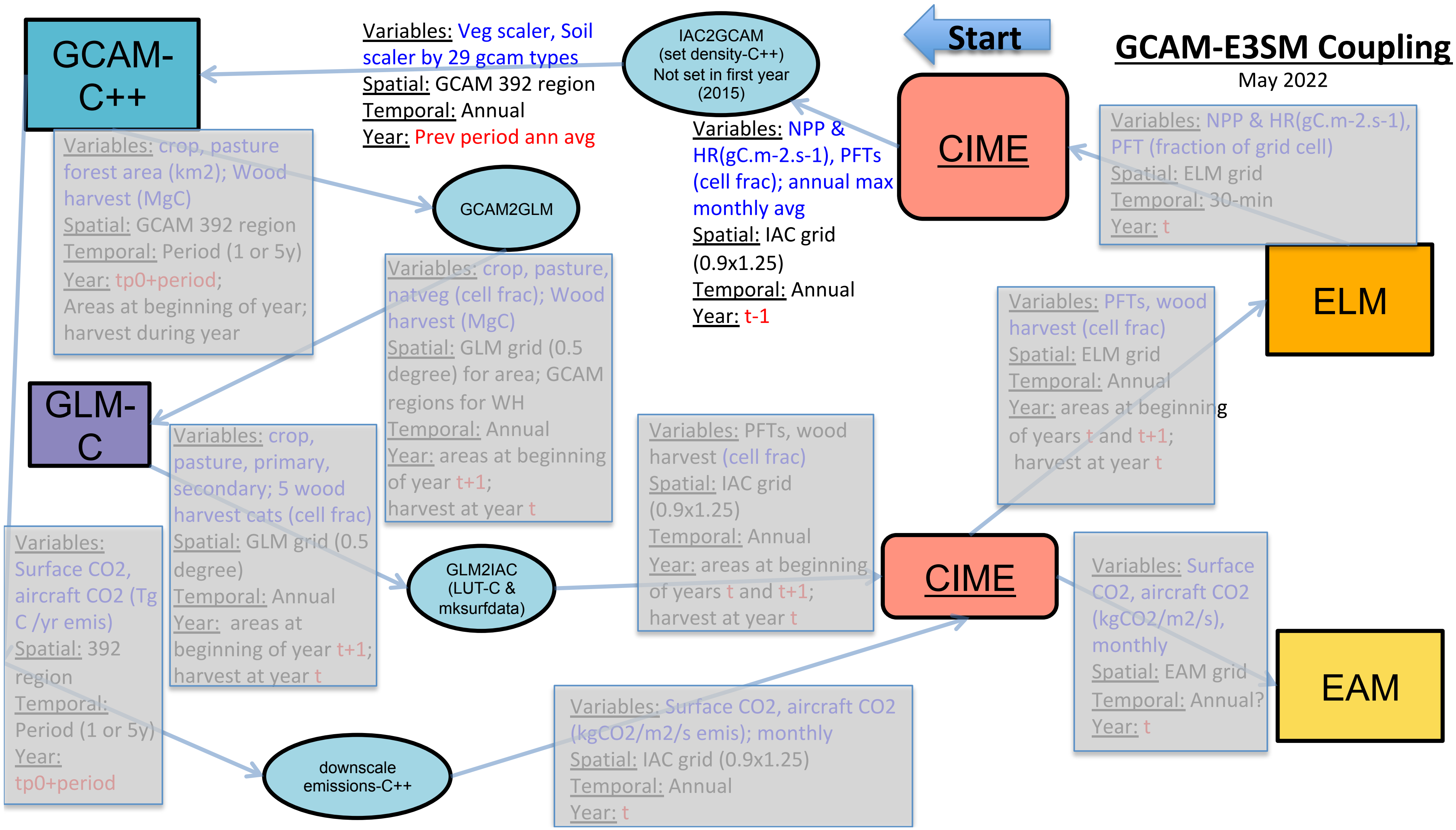
Spatial: IAC grid (0.9x1.25)
Temporal: Annual
Year: areas at beginning of years t and t+1; harvest at year t
GLM2IAC (LUT-C & mksurfdata)
CIME
Variables: Surface CO2, aircraft CO2 (kgCO2/m2/s), monthly
Spatial: EAM grid
Temporal: Annual?
Year: t
EAM
Variables: Surface CO2, aircraft CO2 (Tg C /yr emis)
Spatial: 392 region
Temporal: Period (1 or 5y)
Year: tp0+period
downscale emissions-C++
Variables: Surface CO2, aircraft CO2 (kgCO2/m2/s emis); monthly
Spatial: IAC grid (0.9x1.25)
Temporal: Annual
Year: t


GCAM-E3SM Coupling
May 2022
Start
CIME
Variables: NPP & HR(gC.m-2.s-1), PFT (fraction of grid cell)
Spatial: ELM grid
Temporal: 30-min
Year: t
ELM
Variables: NPP & HR(gC.m-2.s-1), PFTs (cell frac); annual max monthly avg
Spatial: IAC grid (0.9x1.25)
Temporal: Annual
Year: t-1
IAC2GCAM
(set density-C++)
Not set in first year
(2015)
Variables: Veg scaler, Soil scaler by 29 gcam types
Spatial: GCAM 392 region
Temporal: Annual
Year: Prev period ann avg
GCAM-
C++
Variables: crop, pasture forest area (km2); Wood harvest (MgC)
Spatial: GCAM 392 region
Temporal: Period (1 or 5y)
Year: tp0+period;
Areas at beginning of year;
harvest during year
GCAM2GLM
Variables: crop, pasture, natveg (cell frac); Wood harvest (MgC)
Spatial: GLM grid (0.5 degree) for area; GCAM regions for WH
Temporal: Annual
Year: areas at beginning of year t+1;
harvest at year t
GLM-
C
Variables: crop, pasture, primary, secondary; 5 wood harvest cats (cell frac)
Spatial: GLM grid (0.5 degree)
Temporal: Annual
Year: areas at beginning of year t+1;
harvest at year t
GLM2IAC
(LUT-C &
mksurfdata)
Variables: PFTs, wood harvest (cell frac)
Spatial: IAC grid (0.9x1.25)
Temporal: Annual
Year: areas at beginning of years t and t+1;
harvest at year t
CIME
Variables: PFTs, wood harvest (cell frac)
Spatial: ELM grid
Temporal: Annual
Year: areas at beginning of years t and t+1;
harvest at year t
Variables: Surface CO2, aircraft CO2 (kgCO2/m2/s), monthly
Spatial: EAM grid
Temporal: Annual?
Year: t
EAM
Variables: Surface CO2, aircraft CO2 (Tg C /yr emis)
Spatial: 392 region
Temporal: Period (1 or 5y)
Year: tp0+period
downscale
emissions-C++
Variables: Surface CO2, aircraft CO2 (kgCO2/m2/s emis); monthly
Spatial: IAC grid (0.9x1.25)
Temporal: Annual
Year: t

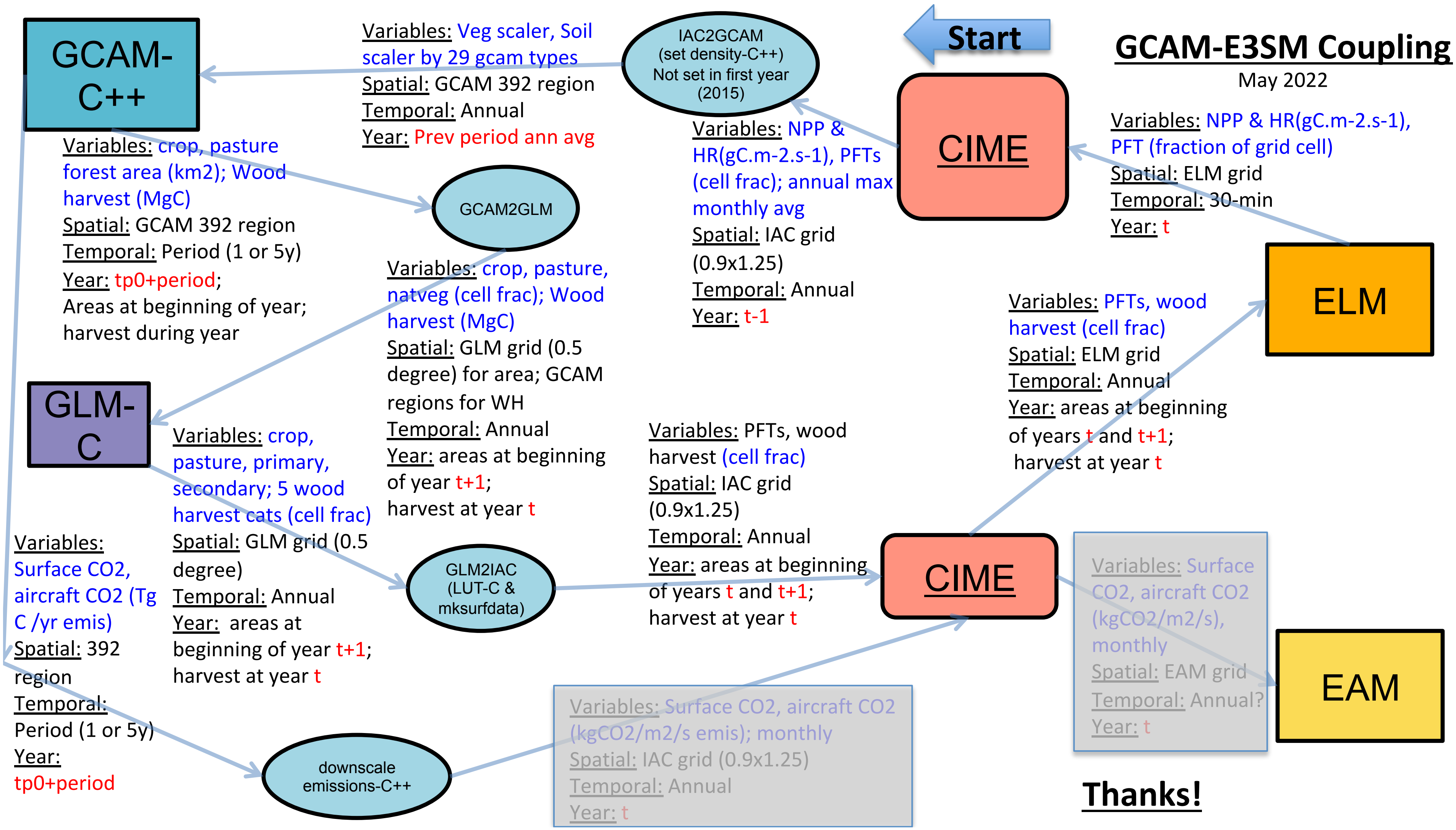

GCAM-E3SM Coupling
May 2022
Start
GCAM-C++
Variables: Veg scaler, Soil scaler by 29 gcam types
Spatial: GCAM 392 region
Temporal: Annual
Year: Prev period ann avg
IAC2GCAM
(set density-C++)
Not set in first year
(2015)
CIME
Variables: NPP & HR(gC.m-2.s-1), PFT (fraction of grid cell)
Spatial: ELM grid
Temporal: 30-min
Year: t
Variables: crop, pasture forest area (km2); Wood harvest (MgC)
Spatial: GCAM 392 region
Temporal: Period (1 or 5y)
Year: tp0+period;
Areas at beginning of year; harvest during year
GCAM2GLM
Variables: NPP & HR(gC.m-2.s-1), PFTs (cell frac); annual max monthly avg
Spatial: IAC grid (0.9x1.25)
Temporal: Annual
Year: t-1
ELM
Variables: crop, pasture, natveg (cell frac); Wood harvest (MgC)
Spatial: GLM grid (0.5 degree) for area; GCAM regions for WH
Temporal: Annual
Year: areas at beginning of year t+1;
harvest at year t
Variables: PFTs, wood harvest (cell frac)
Spatial: ELM grid
Temporal: Annual
Year: areas at beginning of years t and t+1;
harvest at year t
GLM-C
Variables: crop, pasture, primary, secondary; 5 wood harvest cats (cell frac)
Spatial: GLM grid (0.5 degree)
Temporal: Annual
Year: areas at beginning of year t+1;
harvest at year t
Variables: PFTs, wood harvest (cell frac)
Spatial: IAC grid (0.9x1.25)
Temporal: Annual
Year: areas at beginning of years t and t+1;
harvest at year t
CIME
Variables: Surface CO2, aircraft CO2 (Tg C /yr emis)
Spatial: 392 region
Temporal: Period (1 or 5y)
Year: tp0+period
GLM2IAC
(LUT-C &
mksurfdata)
Variables: Surface CO2, aircraft CO2 (kgCO2/m2/s), monthly
Spatial: EAM grid
Temporal: Annual?
Year: t
EAM
downscale
emissions-C++
Variables: Surface CO2, aircraft CO2 (kgCO2/m2/s emis); monthly
Spatial: IAC grid (0.9x1.25)
Temporal: Annual
Year: t



GCAM-E3SM Coupling
May 2022
Start
CIME
IAC2GCAM (set density-C++) Not set in first year (2015)
GCAM-C++
GCAM2GLM
GLM-C
GLM2IAC (LUT-C & mksurfdata)
downscale emissions-C++
CIME
ELM
EAM
Variables: Veg scaler, Soil scaler by 29 gcam types
Spatial: GCAM 392 region
Temporal: Annual
Year: Prev period ann avg
Variables: NPP & HR(gC.m-2.s-1), PFTs (cell frac); annual max monthly avg
Spatial: IAC grid (0.9x1.25)
Temporal: Annual
Year: t-1
Variables: NPP & HR(gC.m-2.s-1), PFT (fraction of grid cell)
Spatial: ELM grid
Temporal: 30-min
Year: t
Variables: crop, pasture forest area (km2); Wood harvest (MgC)
Spatial: GCAM 392 region
Temporal: Period (1 or 5y)
Year: tp0+period;
Areas at beginning of year; harvest during year
Variables: crop, pasture, natveg (cell frac); Wood harvest (MgC)
Spatial: GLM grid (0.5 degree) for area; GCAM regions for WH
Temporal: Annual
Year: areas at beginning of year t+1;
harvest at year t
Variables: crop, pasture, primary, secondary; 5 wood harvest cats (cell frac)
Spatial: GLM grid (0.5 degree)
Temporal: Annual
Year: areas at beginning of year t+1;
harvest at year t
Variables: PFTs, wood harvest (cell frac)
Spatial: IAC grid (0.9x1.25)
Temporal: Annual
Year: areas at beginning of years t and t+1;
harvest at year t
Variables: PFTs, wood harvest (cell frac)
Spatial: ELM grid
Temporal: Annual
Year: areas at beginning of years t and t+1;
harvest at year t
Variables: Surface CO2, aircraft CO2 (Tg C /yr emis)
Spatial: 392 region
Temporal: Period (1 or 5y)
Year: tp0+period
Variables: Surface CO2, aircraft CO2 (kgCO2/m2/s emis); monthly
Spatial: IAC grid (0.9x1.25)
Temporal: Annual
Year: t
Variables: Surface CO2, aircraft CO2 (kgCO2/m2/s), monthly
Spatial: EAM grid
Temporal: Annual?
Year: t

GCAM-E3SM Coupling

May 2022



Thanks!