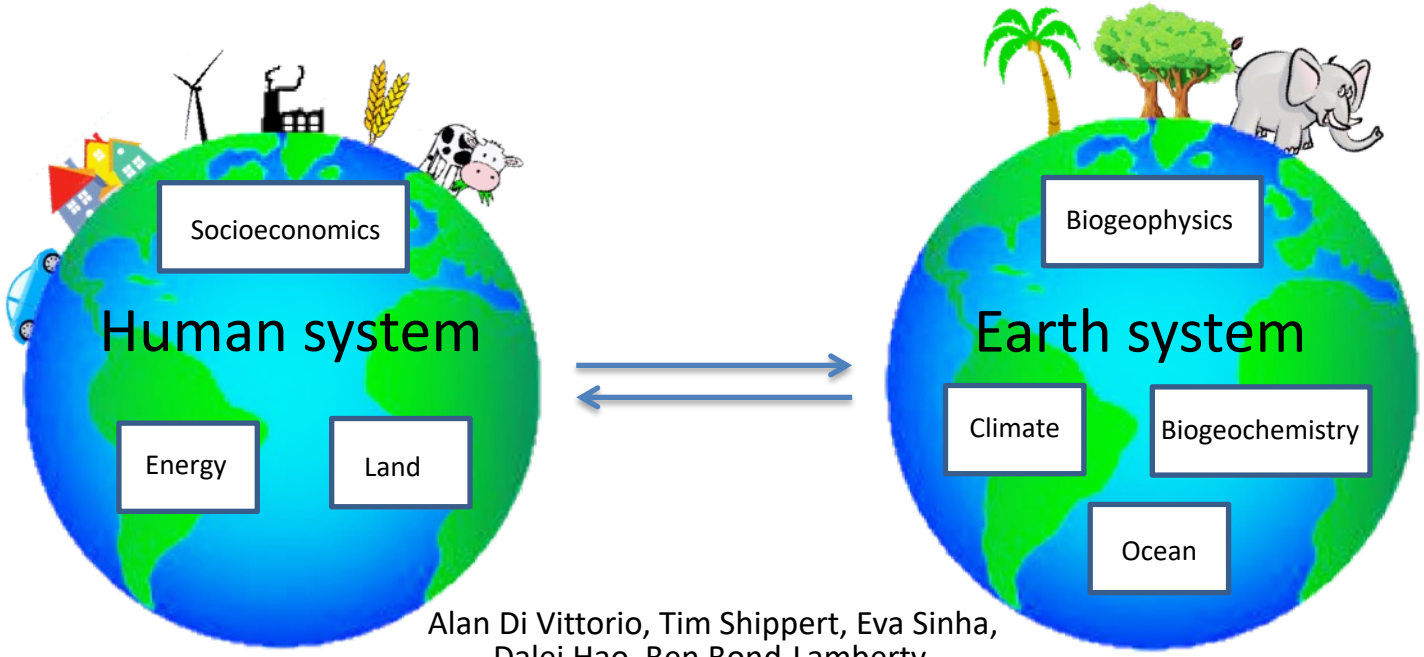
Human-Earth feedbacks with E3SM-GCAM



Alan Di Vittorio, Tim Shippert, Eva Sinha,
Dalei Hao, Ben Bond-Lamberty,
Balwinder Singh

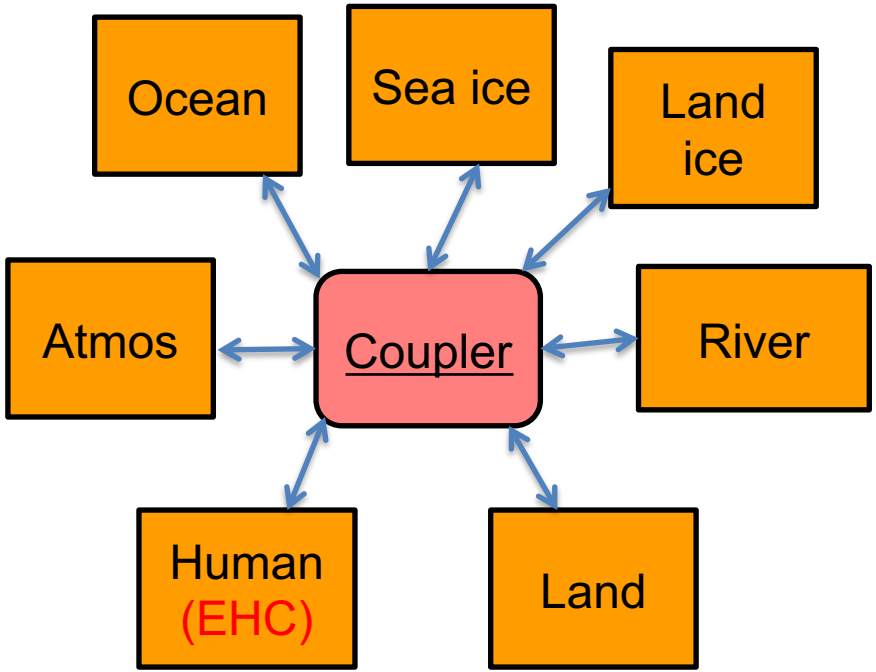
Oct 2023

E3SM-GCAM is a novel system

- More efficient updating of code
- Easier addition of passed variables
- Easier integration with multiple components

Current state:

- Rebased to E3SMv2 (May 2022 master)
  - Considering rebasing to E3SMv2.1 release
- Updated to GCAM 6
- Documentation on confluence (HES)



EHC: E3SM Human Component/Coupler

GCAM: Global Change Analysis Model, US Department of Energy

E3SM: Energy Exascale Earth System Model, US Department of Energy

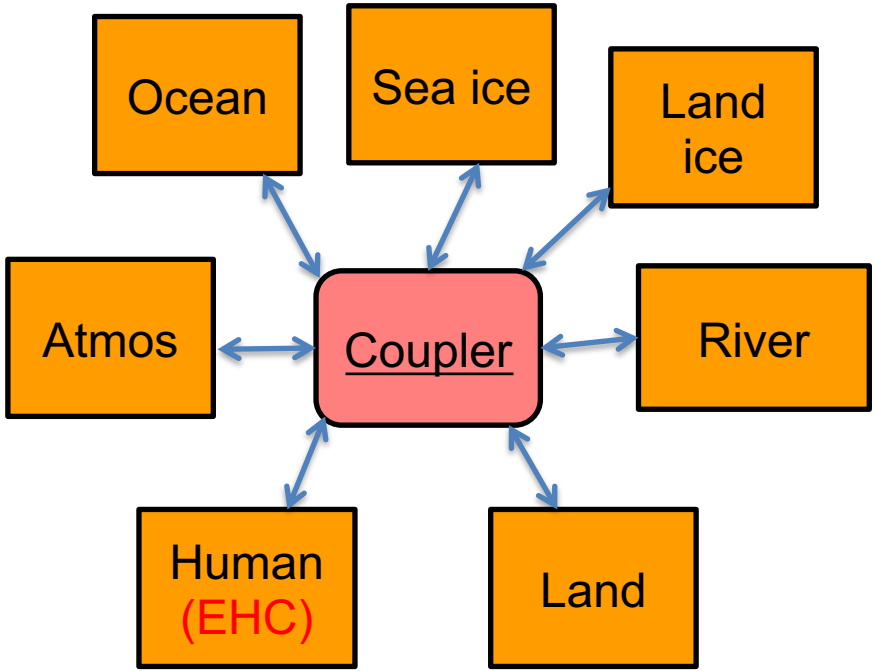
Current status

Land feedbacks are working correctly!

- Both agriculture yield and potential carbon density are scaled in GCAM (5-year intervals)

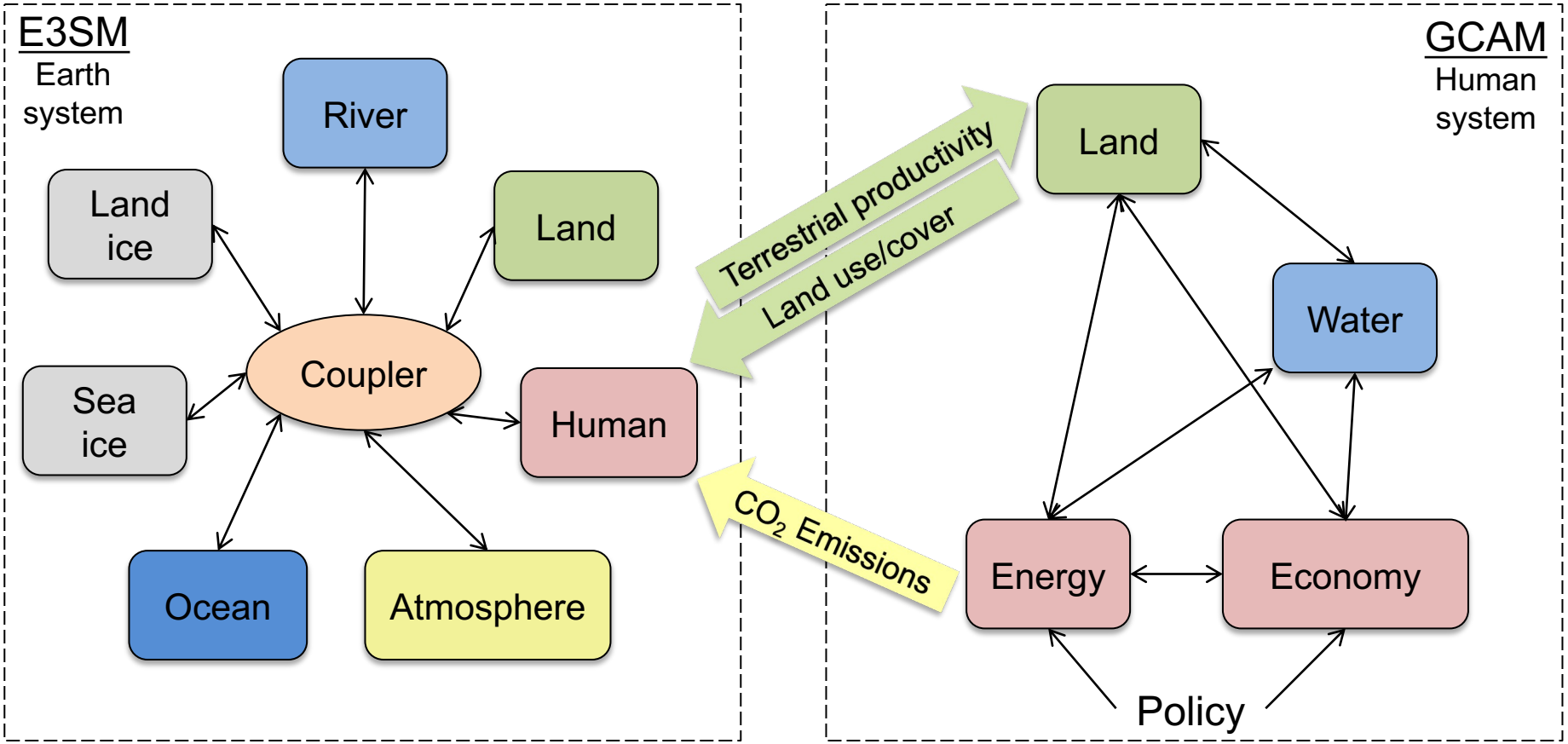
Ongoing development:

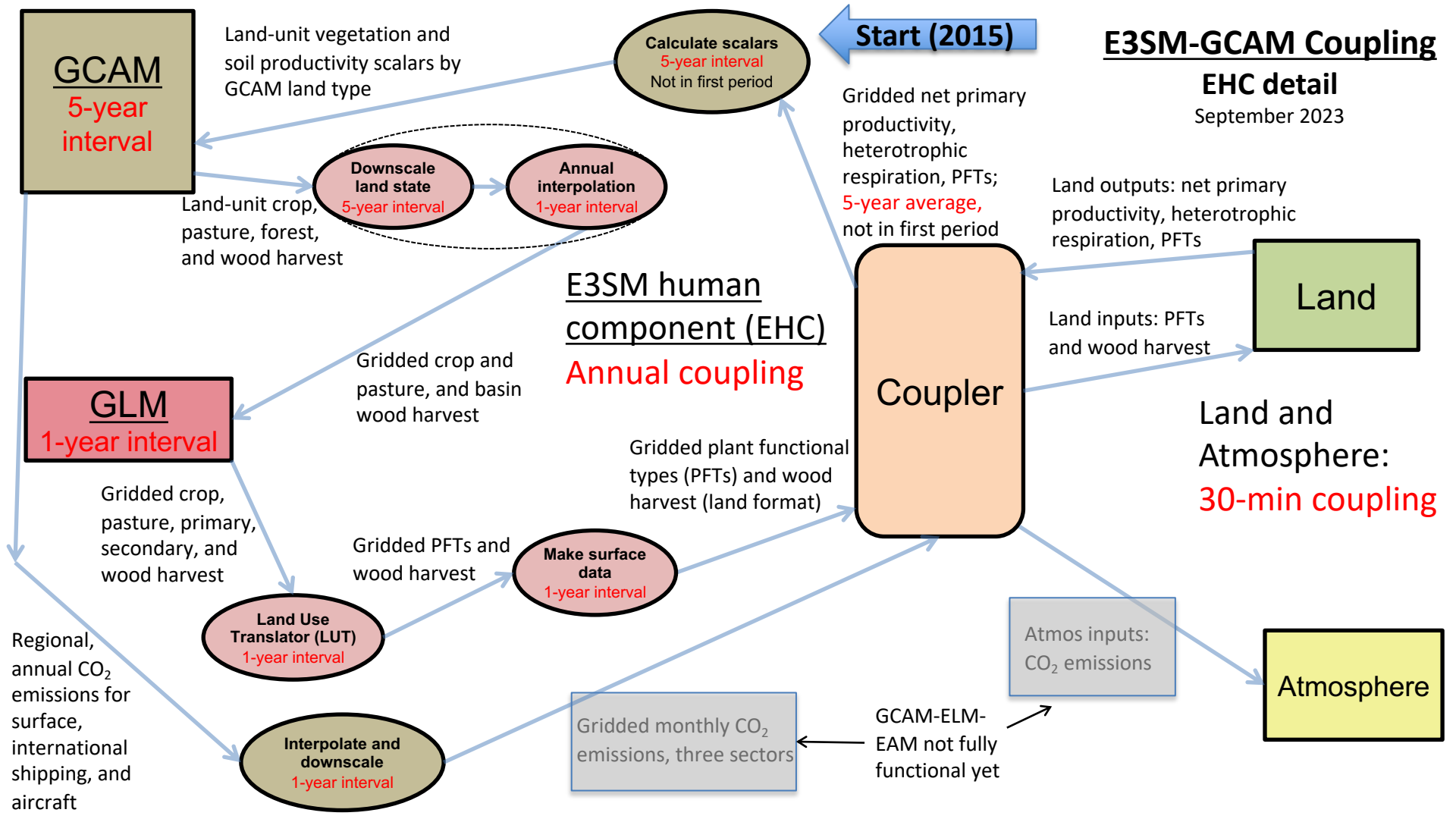
- CO_2 coupling
  - Updating atmosphere configuration
  - Distributing CO_2 to atmosphere
  - Separating surface, international shipping, and aircraft sectors for downscaling
- ELM – EHC resolution mismatch
  - No mismatch with 0.9x1.25 land



EHC: E3SM Human Component/Coupler

The E3SM human component is the EHC

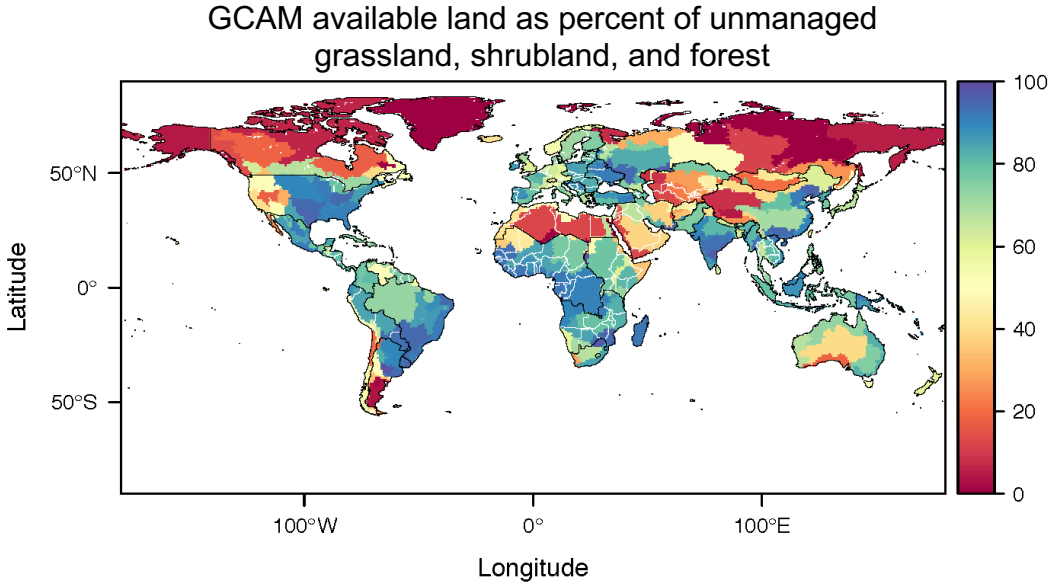



GCAM
5-year interval
Land-unit vegetation and soil productivity scalars by GCAM land type
Calculate scalars
5-year interval
Not in first period
Start (2015)
E3SM-GCAM Coupling
EHC detail
September 2023
Gridded net primary productivity, heterotrophic respiration, PFTs;
5-year average,
not in first period
Downscale land state
5-year interval
Annual interpolation
1-year interval
Land-unit crop, pasture, forest, and wood harvest
Land outputs: net primary productivity, heterotrophic respiration, PFTs
Land
E3SM human component (EHC)
Annual coupling
Coupler
Land inputs: PFTs and wood harvest
Gridded crop and pasture, and basin wood harvest
GLM
1-year interval
Land and Atmosphere:
30-min coupling
Gridded plant functional types (PFTs) and wood harvest (land format)
Gridded crop, pasture, primary, secondary, and wood harvest
Gridded PFTs and wood harvest
Make surface data
1-year interval
Land Use Translator (LUT)
1-year interval
Atmos inputs: CO_2 emissions
Atmosphere
Regional, annual CO_2 emissions for surface, international shipping, and aircraft
Interpolate and downscale
1-year interval
Gridded monthly CO_2 emissions, three sectors
GCAM-ELM-EAM not fully functional yet

Configuring/running E3SM-GCAM

Workflow

1. Determine scenario
    a. SSP-RCP
    b. Emissions (net-zero, NDCs)
        a. Needs Bioenergy with CCS
    c. Land carbon value (net-zero?)
2. Configure and run GCAM
3. Process GCAM outputs
    a. Downscale emissions
    b. Get carbon price path (RCP only)
4. Specify scenario in E3SM
    a. GCAM configuration
    b. Non-CO_2 emissions (and CO_2?)
    c. Carbon price path (RCP only)
5. Run E3SM-GCAM



GCAM land units (shading) are the intersection of 235 water basins and 32 regions (black lines)

Configuring/running E3SM-GCAM

Boolean EHC namelist items

- run_gcam – should always be true
- gcam_spinup
- ehc_elm_co2_emissions
- elm_ehc_agyield_scaling
- elm_ehc_carbon_scaling
- read_scalars – no calculation if true
- write_scalars – disabled if read_scalars is true
- write_co2 - diagnostic

Key E3SM-GCAM run options

- Terrestrial productivity feedbacks
  - Agricultural yield scaling
  - Potential carbon density scaling
    - Matters only for scenarios where carbon is valued in the landscape
  - Feedbacks can be calculated and written to a file even if GCAM is not using them
  - Feedbacks can be read from a file generated by a previous run
- CO_2 emissions feed-forward

ELM-GCAM Example

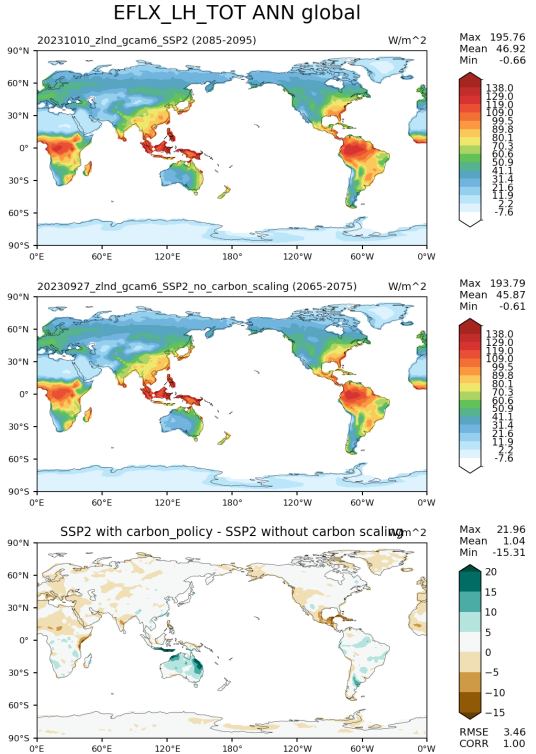
This is not a scientifically valid configuration; it is just to test functionality

GCAM

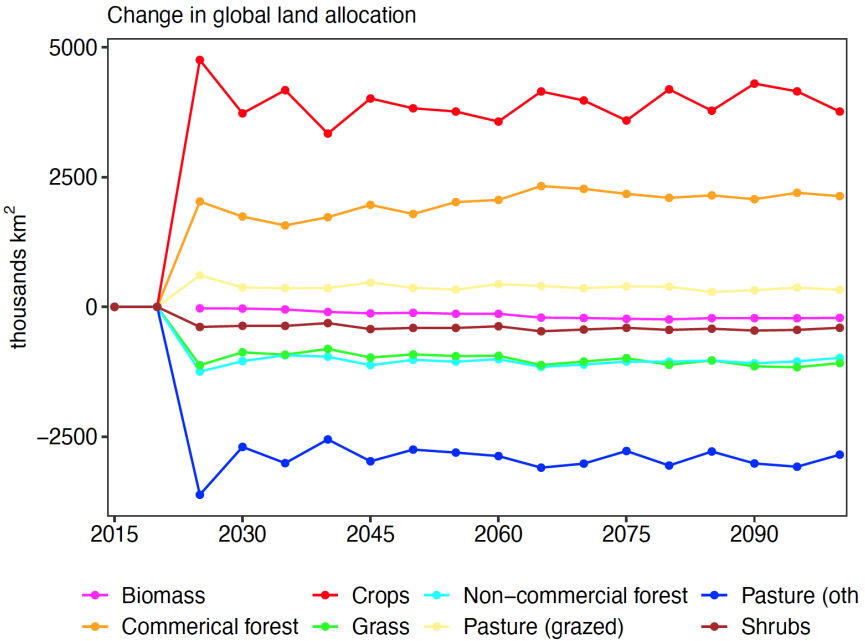
- SSP2 socio-economics
- RCP2.6 carbon price path
- Full carbon price applies to land

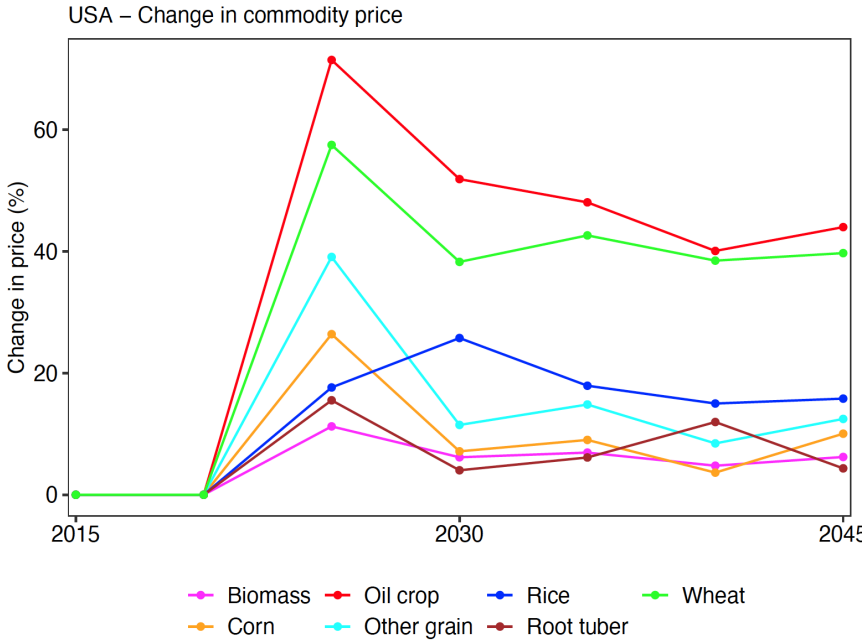
ELM-EHC

- RCP4.5 data atmosphere
- Ag yield and carbon scaling on
- ELM grid: 1.9x2.5
- EHC grid: 0.9x1.25
- ELM initial conditions generated by ELM-GCAM run with 1948-1972 atmosphere

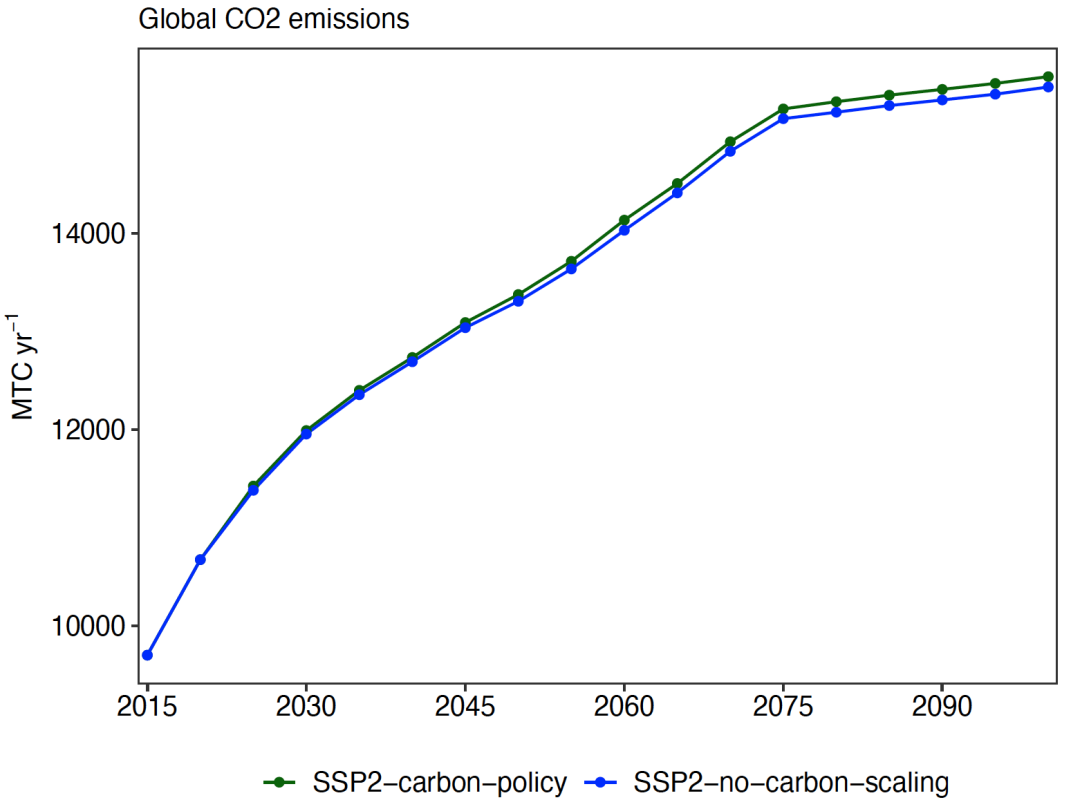


Terrestrial feedbacks generate a different scenario

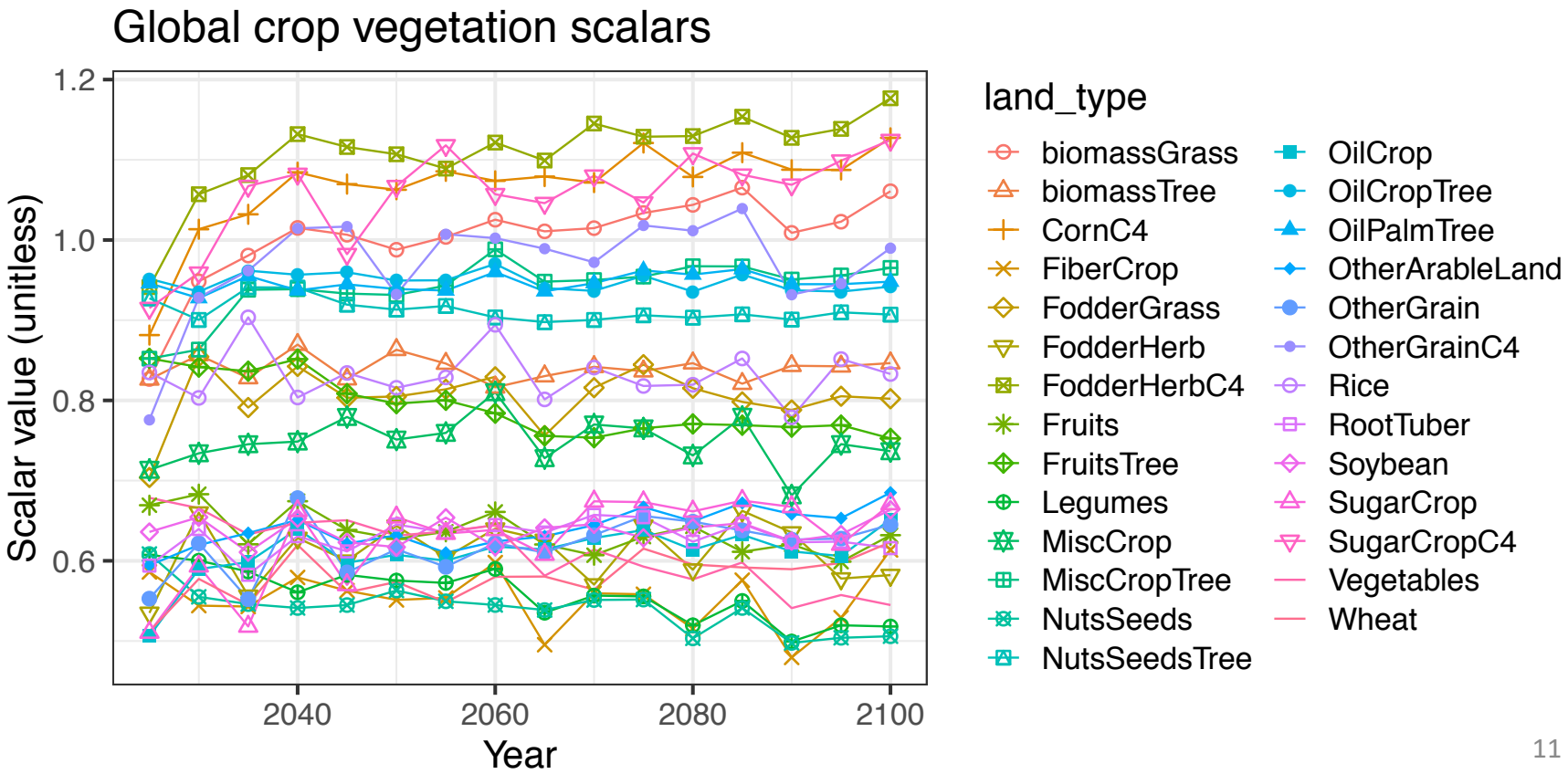




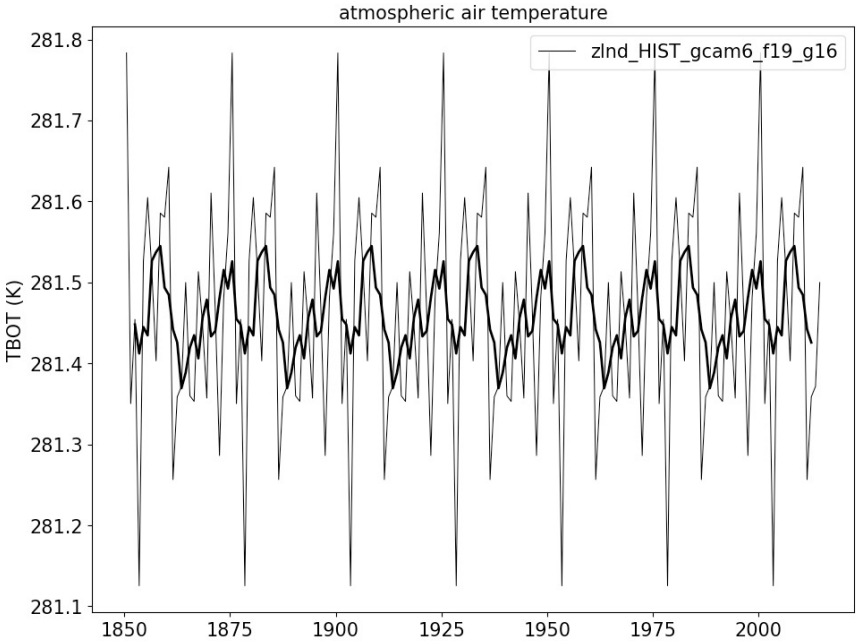
Terrestrial feedbacks generate a different scenario, but global CO_2 emissions change little

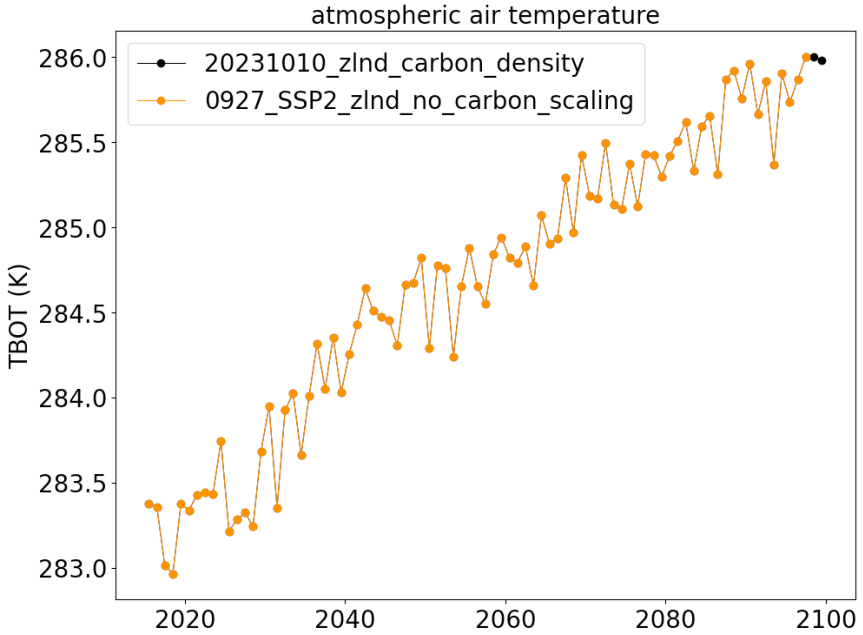


More cropland is needed with feedbacks because crops are less productive with feedbacks

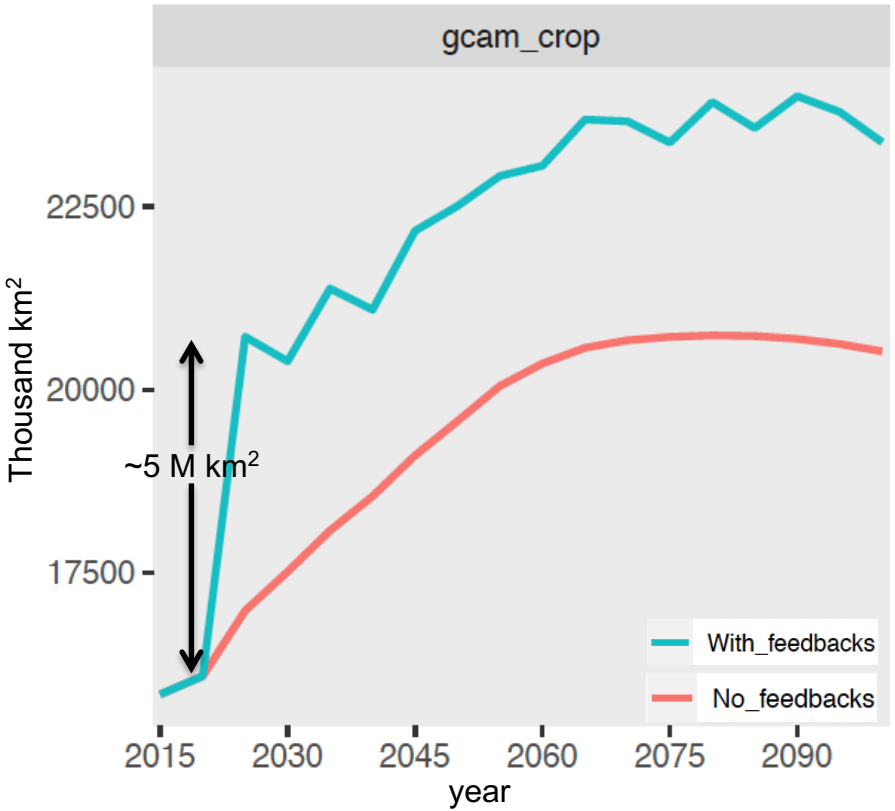


2015 is 2 degrees warmer than 2014

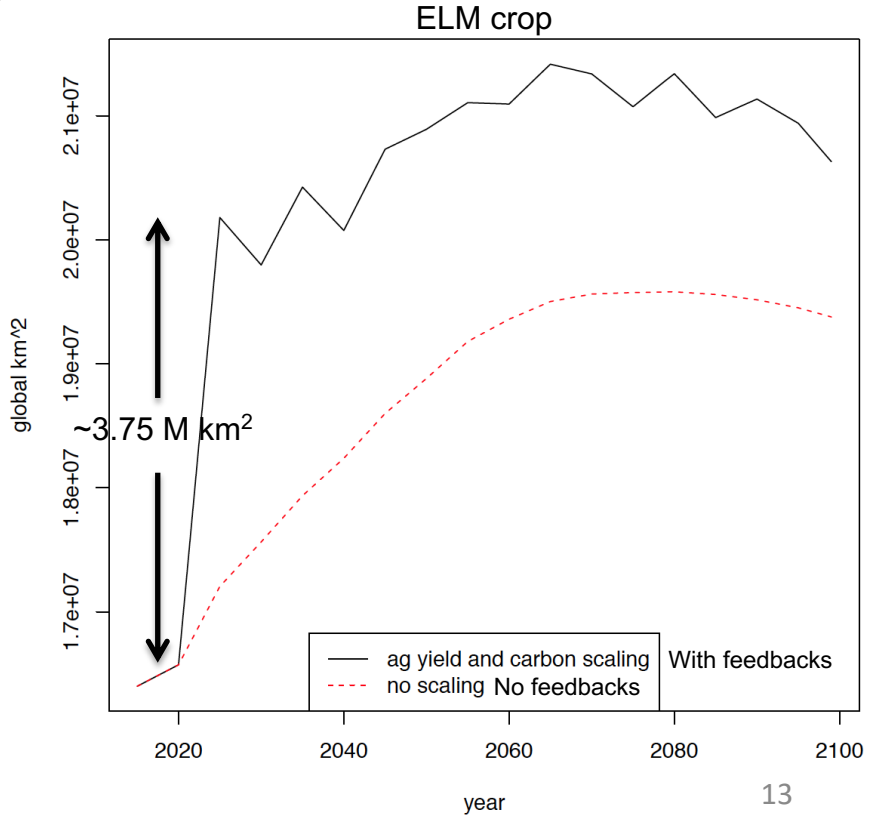




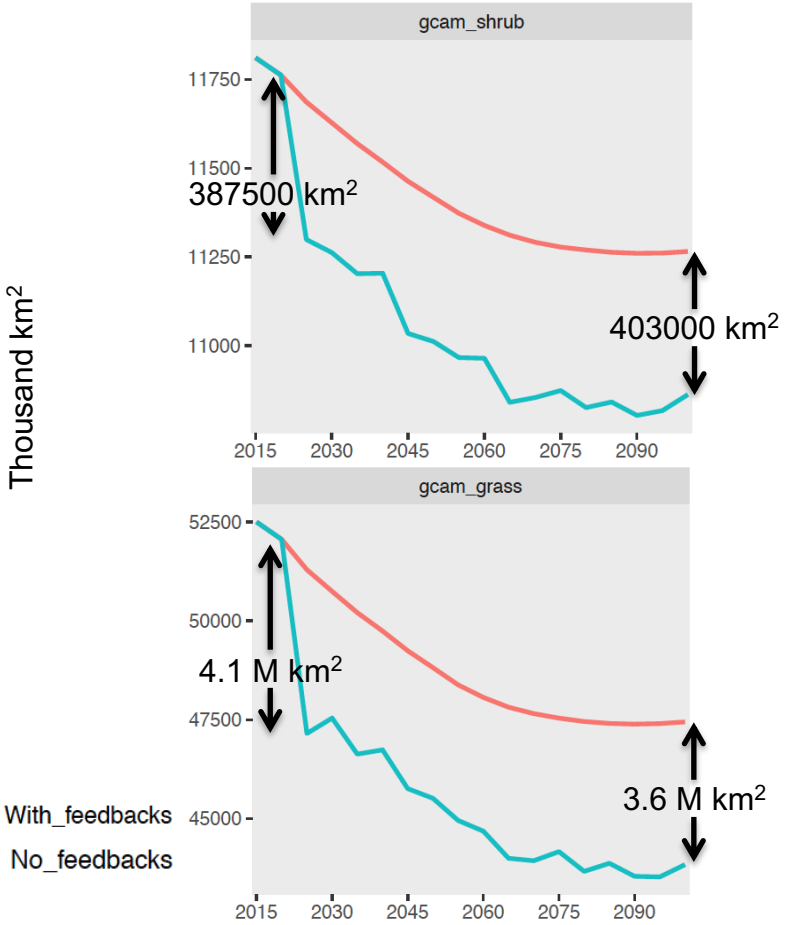
Good cropland fidelity between GCAM and ELM

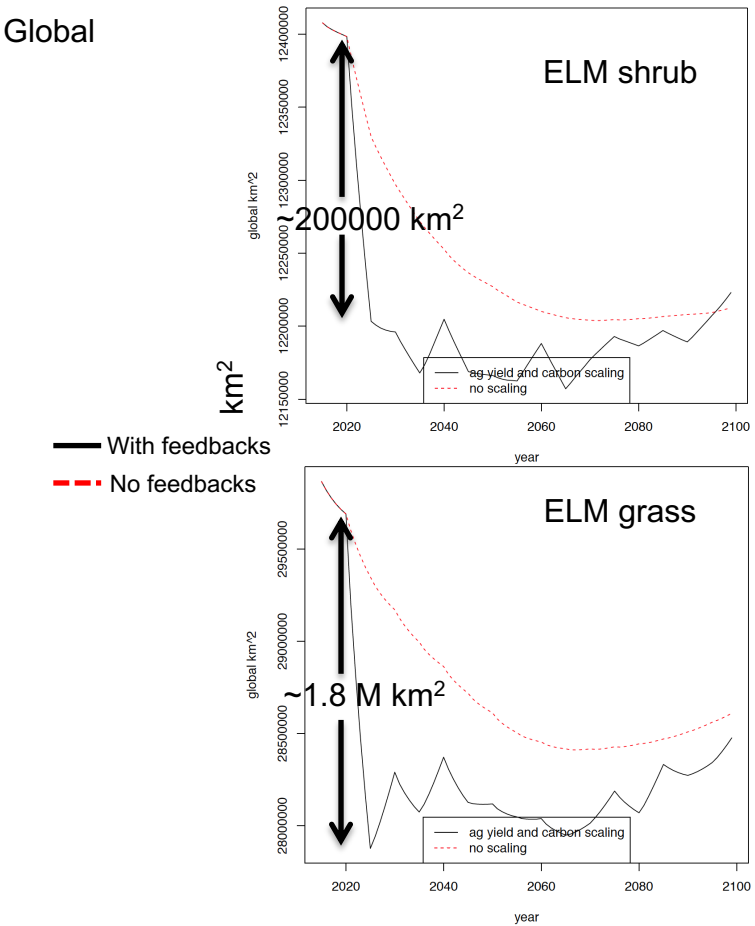


Global

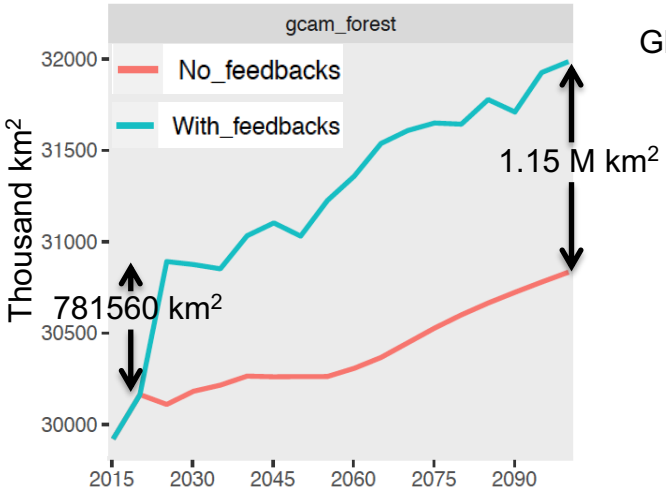


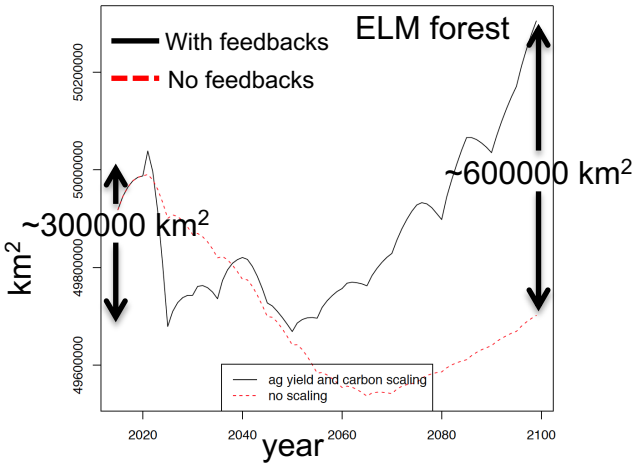
Land cover change is not consistent across models





Land cover change is not consistent across models





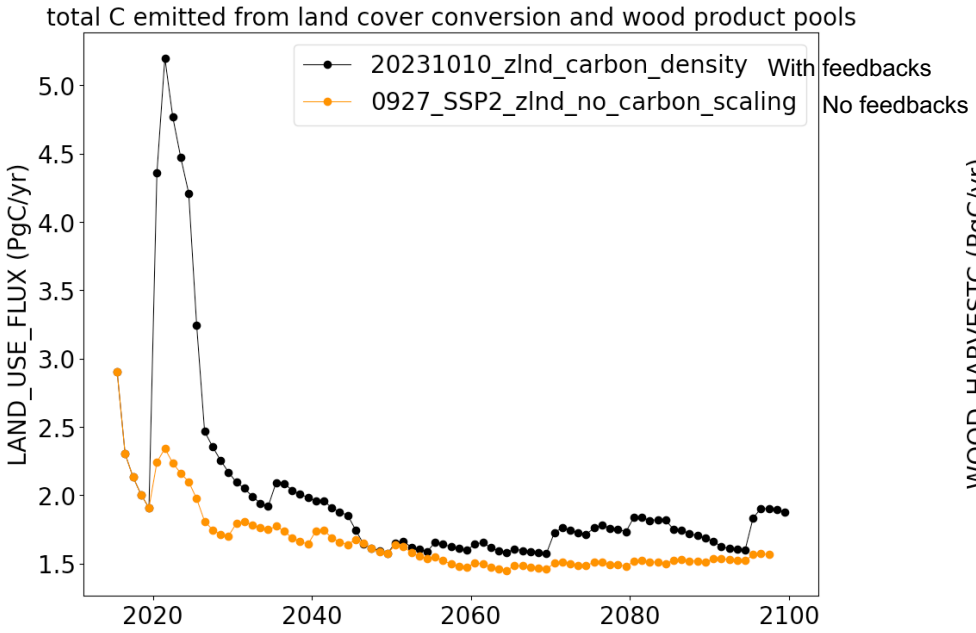
- Not a new problem
- Directly influences carbon results

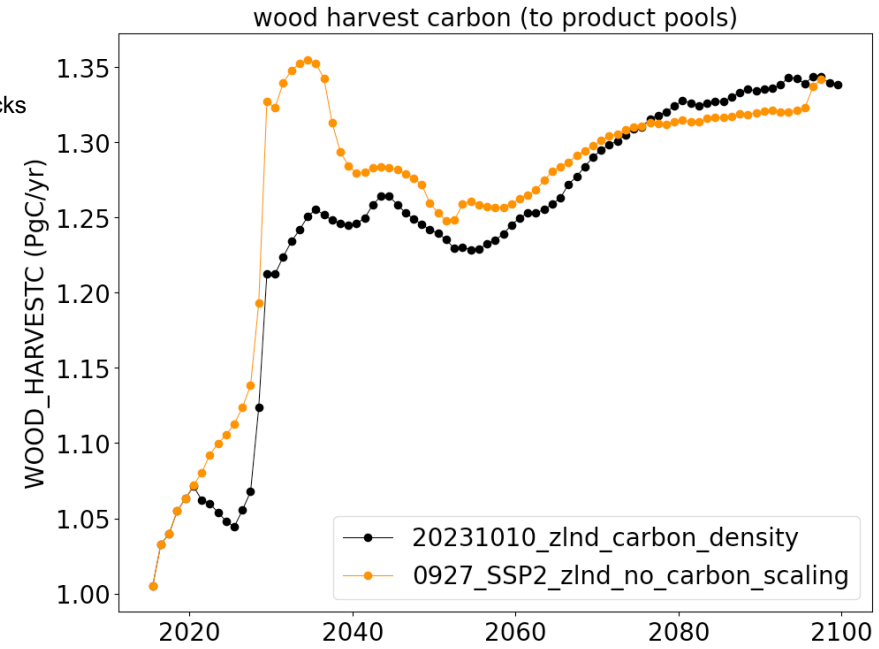
GCAM6

- Much less reliance on afforestation
- More reliance on other technologies

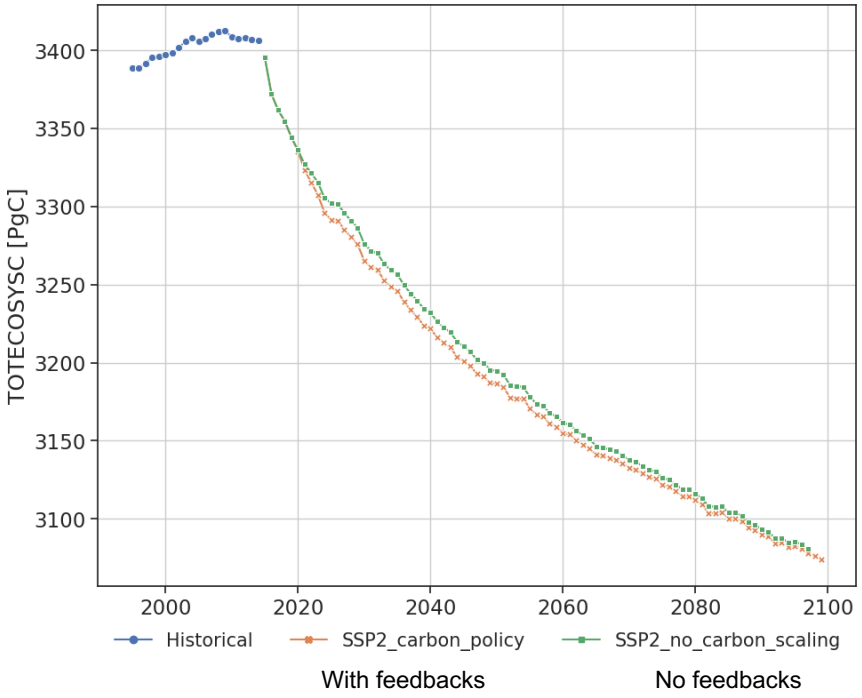
- Adjusting land conversion assumptions to better match GCAM requires:
  - Running with valid scenario
  - Running with different scenarios
  - Assuming similar conversion will apply to other scenario sources

Shift due to feedbacks is apparent in land use outputs

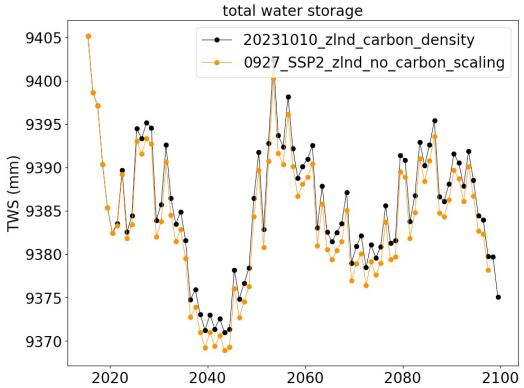




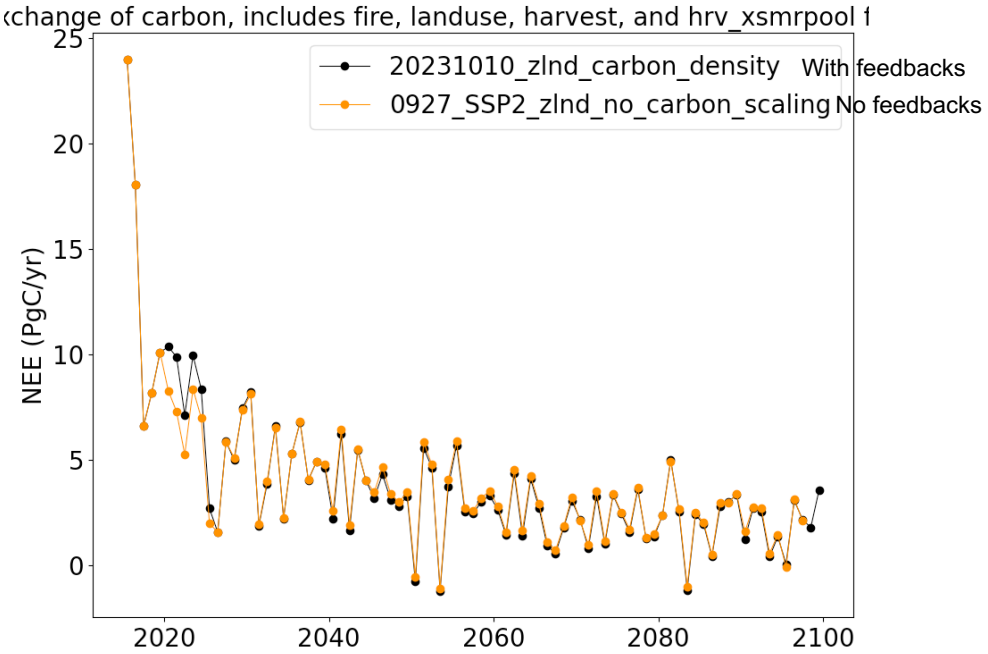
Global terrestrial ecosystem responds to the altered scenario – but there is a 2015 singularity due to climate

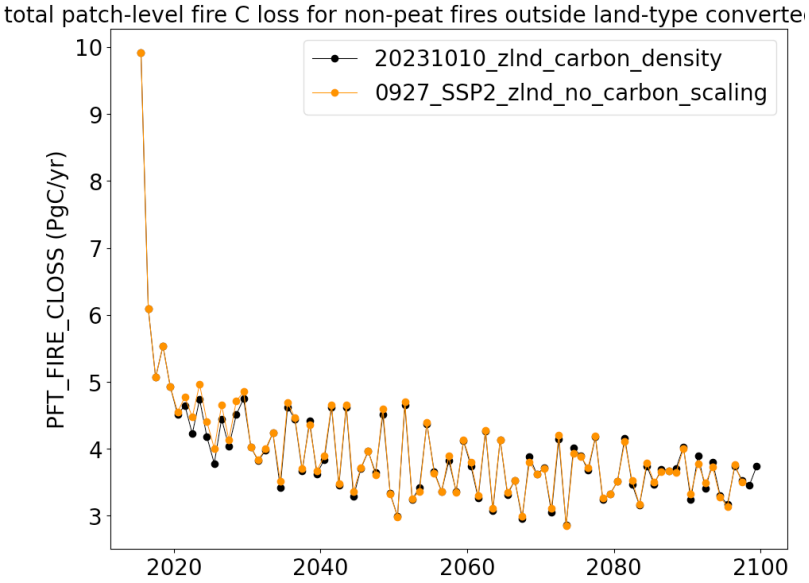


- Long-term convergence is due to veg C, likely due to forest (and shrub) area inconsistencies with GCAM
- Other variables (e.g., nutrients, water, ET) are also affected



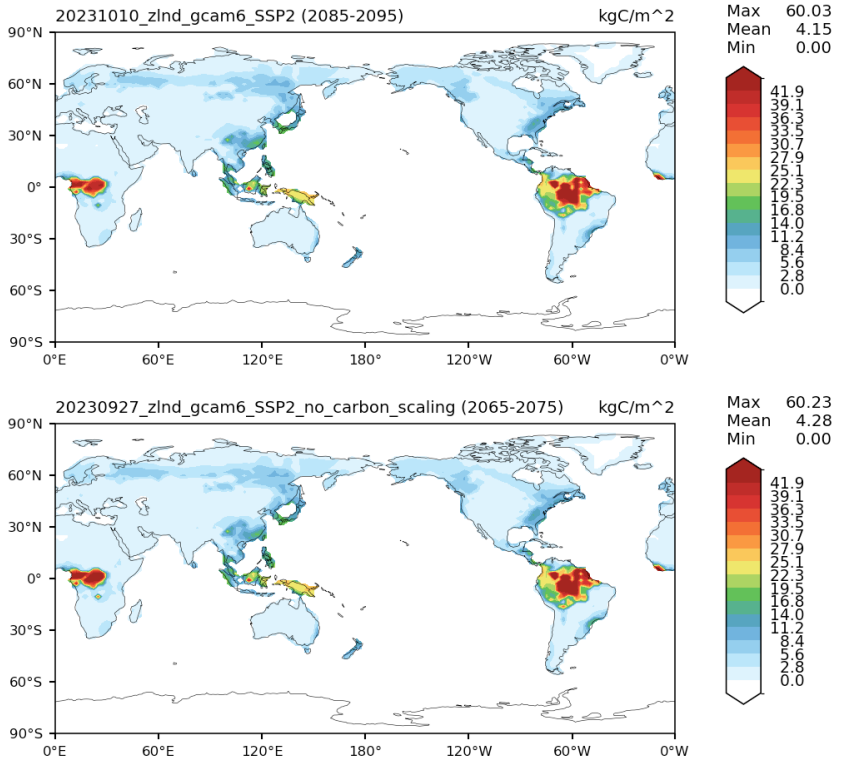
High fire loss contributes to the rapid carbon loss due to climate singularity



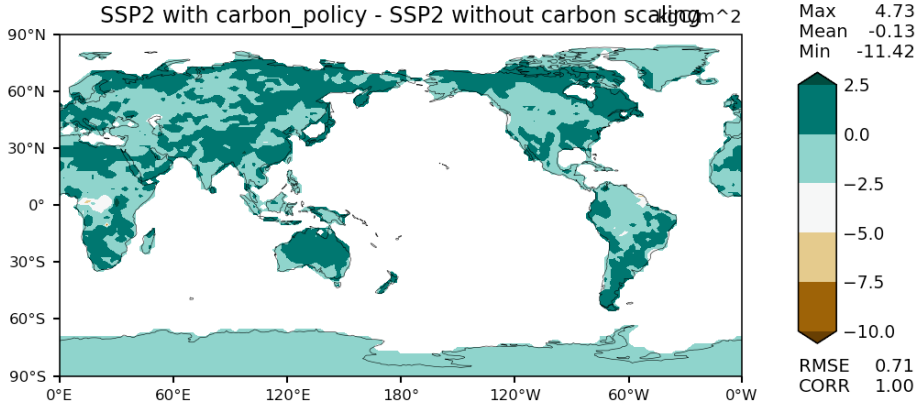


Regional differences are more pronounced than global

TOTVEGC ANN global

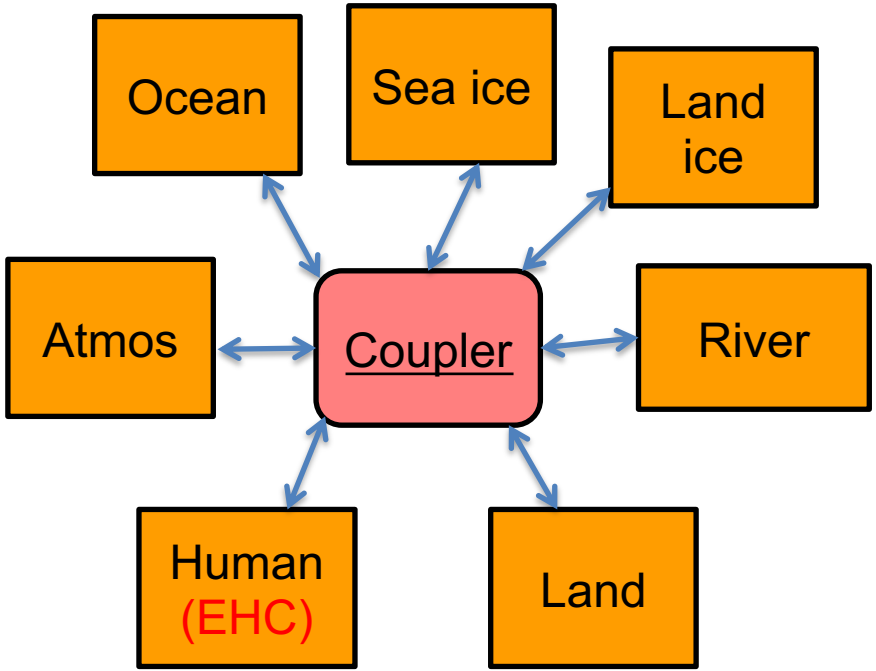


This is likely to hold for atmospheric variables also



Summary

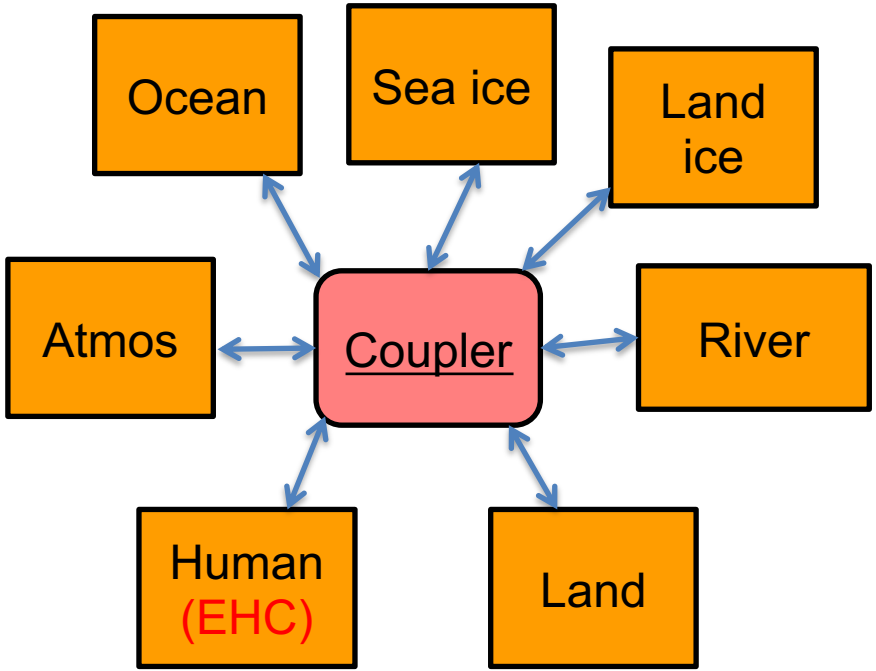
- E3SM-GCAM is unique
- ELM-GCAM land coupling is complete
  - Both ag yield and potential carbon density are scaled in GCAM
- Both models are responding as expected given the configuration
- Land cover inconsistencies across models are affecting terrestrial carbon impacts of terrestrial feedback



EHC: E3SM Human Component/Coupler

Next steps

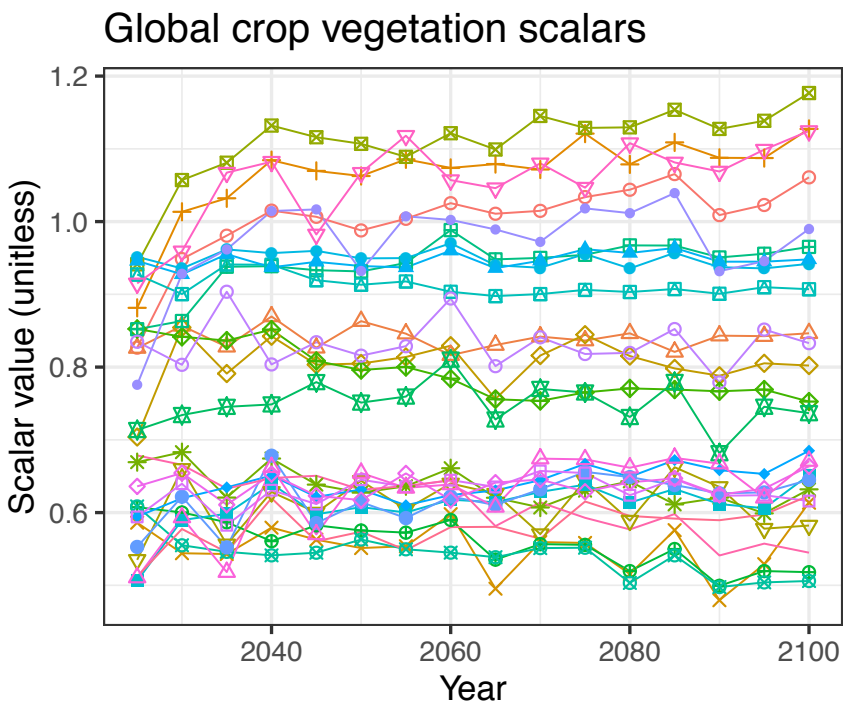
- Working on GCAM scenario configurations
- Working on overall E3SM-GCAM configuration (EAM-ELM-EHC)
  - Including grids and new spinup with prognostic atmosphere
- GMD paper
  - Defining configuration and simulations (E3SMv2.1?)
    - Obtaining existing SSP2-RCP4.5 configuration files
  - Completing atmosphere coupling
- Incorporate into E3SMv3!

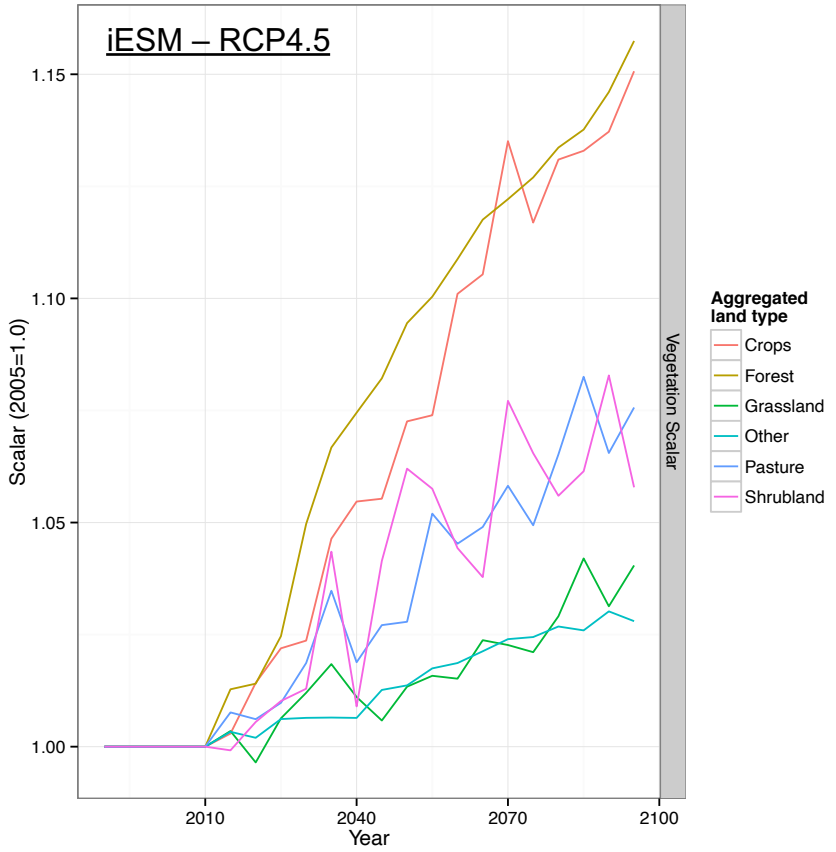


EHC: E3SM Human Component/Coupler

Expect initial scaling values to be near 1

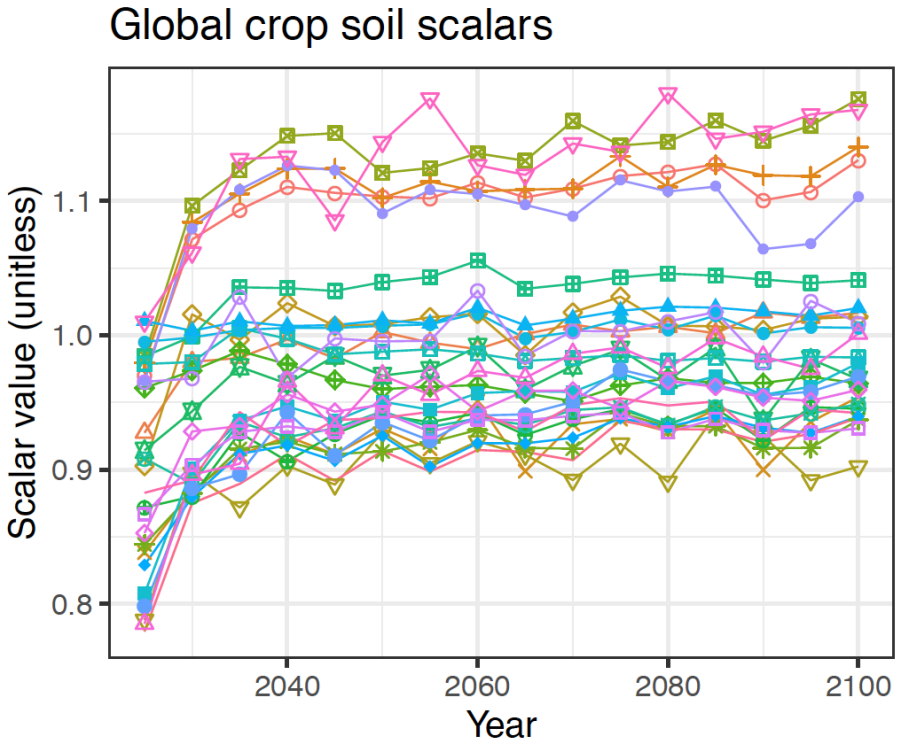
E3SM

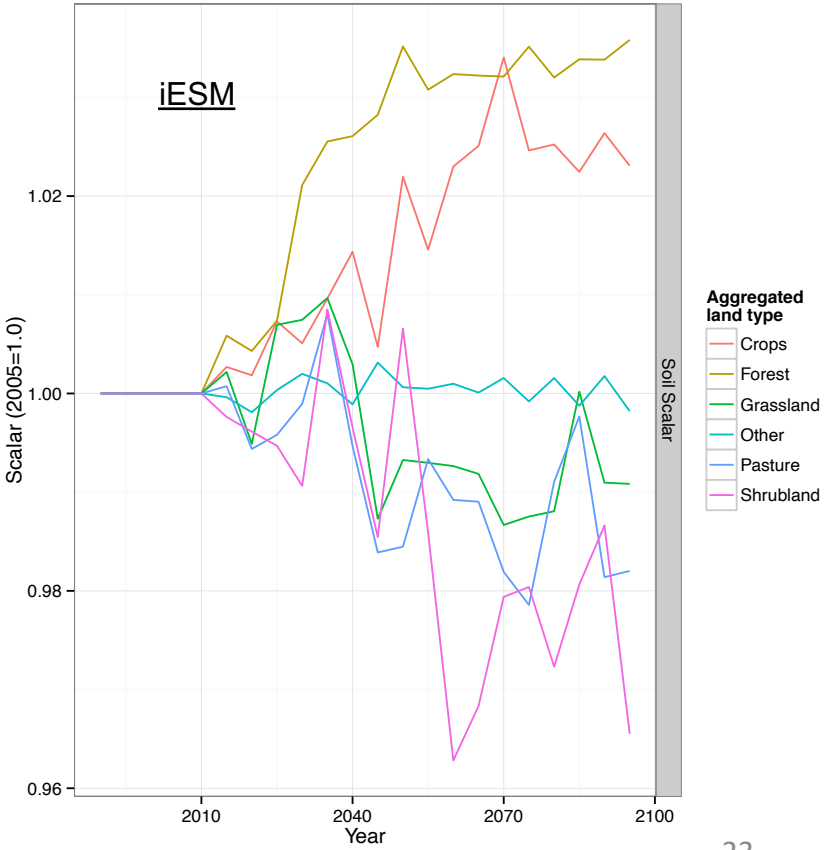




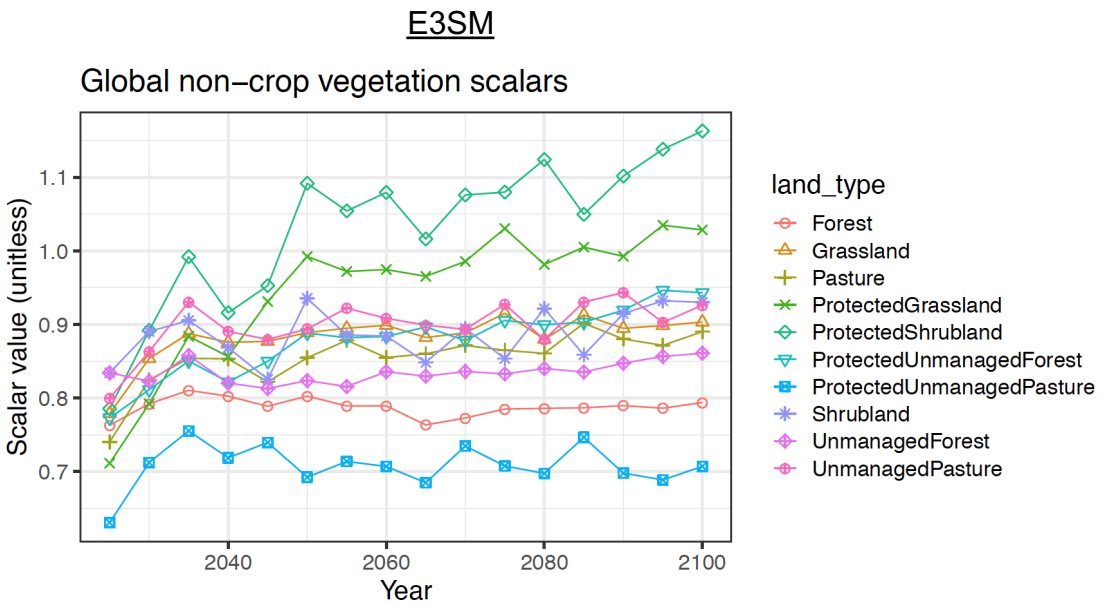
Expect initial scaling values to be near 1

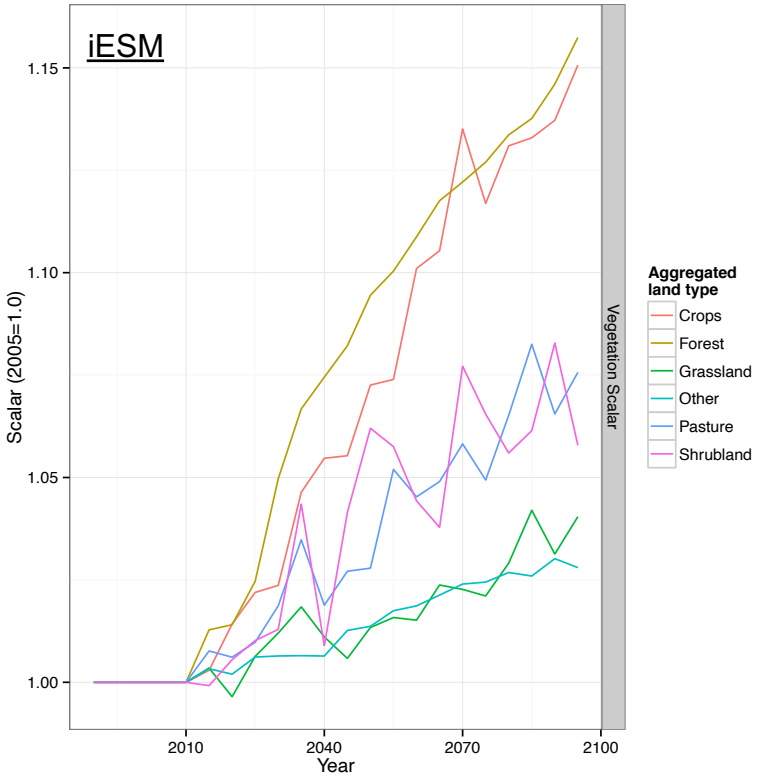
E3SM





Expect initial scaling values to be near 1





Land cover is consistent across 2015