E3SMv1.1 Biogeochemistry simulation campaign – overview of configuration and historical simulations (JAMES, 2020)

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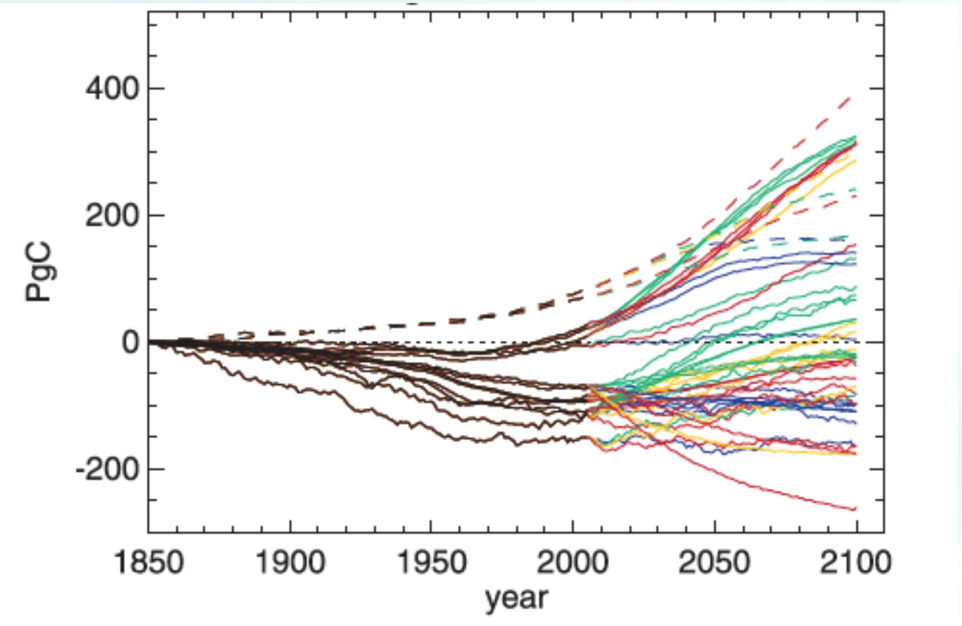
Motivation: There is large uncertainty in future changes in terrestrial and ocean carbon.

- Changes in carbon varied dramatically across models in CMIP5.
- Land models that included nitrogen limitations tended to have weaker terrestrial carbon uptake.
- These results suggest that model structure and nutrient limits matter for prediction of future climate.

Change in Vegetation Carbon



Source: Jones et al. (2013)

Two pathways for carbon cycle-climate feedbacks

Concentration-carbon feedback

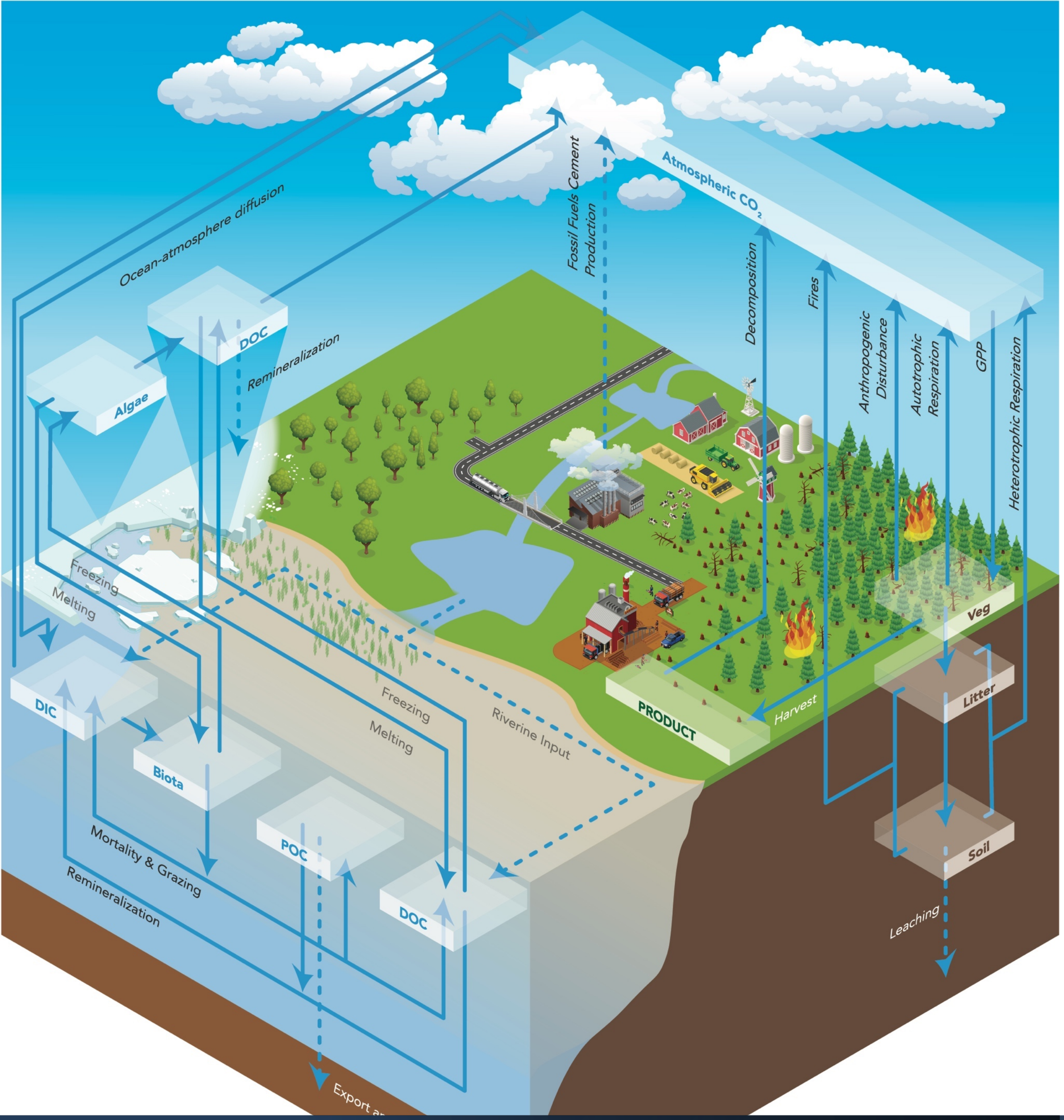
Climate-carbon feedback

Progressive nutrient limitation hypothesis:

Nutrient limitations reduce the response of ecosystem growth and carbon uptake to increases in atmospheric CO_2 (Luo et al., 2003)

Simulation Plan

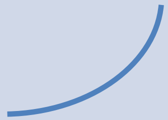
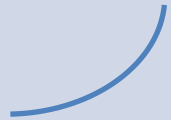
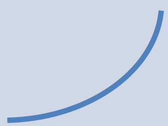
- V1 Science Question: What are the effects of **nitrogen and phosphorous** on climate-biogeochemistry interactions, and how sensitive are these interactions to **model structural uncertainty**?



The E3SMv1.1 BGC model configuration

- Terrestrial:
  - Two approaches to soil biogeochemistry (CTC and ECA), both including N and P limits on C uptake
- Ocean/ice:
  - Based on the Biogeochemical Elemental Cycling model (BEC), including N, P, Si, Fe
  - Includes ocean-ice biogeochemical interactions

Simulation plan

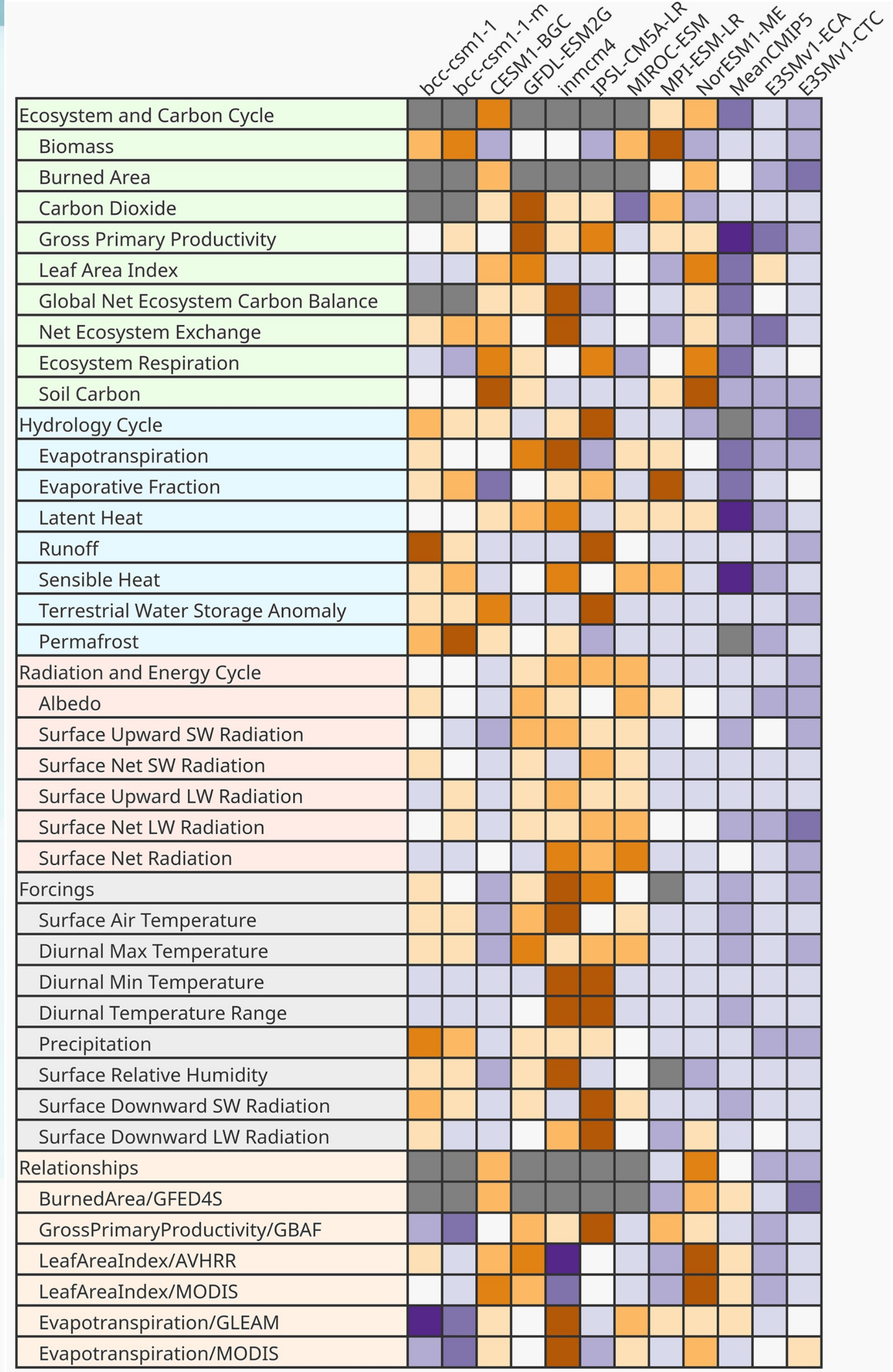
	CO_2 input to radiation (greenhouse effect)	CO_2 input to carbon cycle (fertilization effects)	Non-CO_2 climate forcings (LULCC, aerosols…)	Reason
Fully-coupled ***(BDRD-hist)***			historical	Simulates the fully-coupled system
Biogeochemically-coupled ***(BDRC-hist)***	—		historical	Isolates the carbon-cycle response to CO_2 (ferlizization)
Radiatively-coupled ***(BCRD-hist)***		—	historical	Isolates carbon-cycle response to climate change
CO_2 constant ***(BCRC-hist)***	—	—	historical	Isolates effect of non-CO_2 historical forcings
All forcings constant ***(CNST-forcing)***	—	—	constant	Control for model drift in absence of forcings

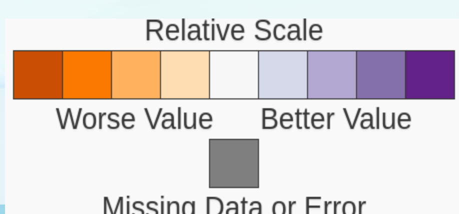
Land biogeochemistry: high-level results

ILAMB global benchmarking for land model

- Overall, both CTC and ECA simulations perform better than most CMIP5 models across a range of metrics.
- Link to interactive output:

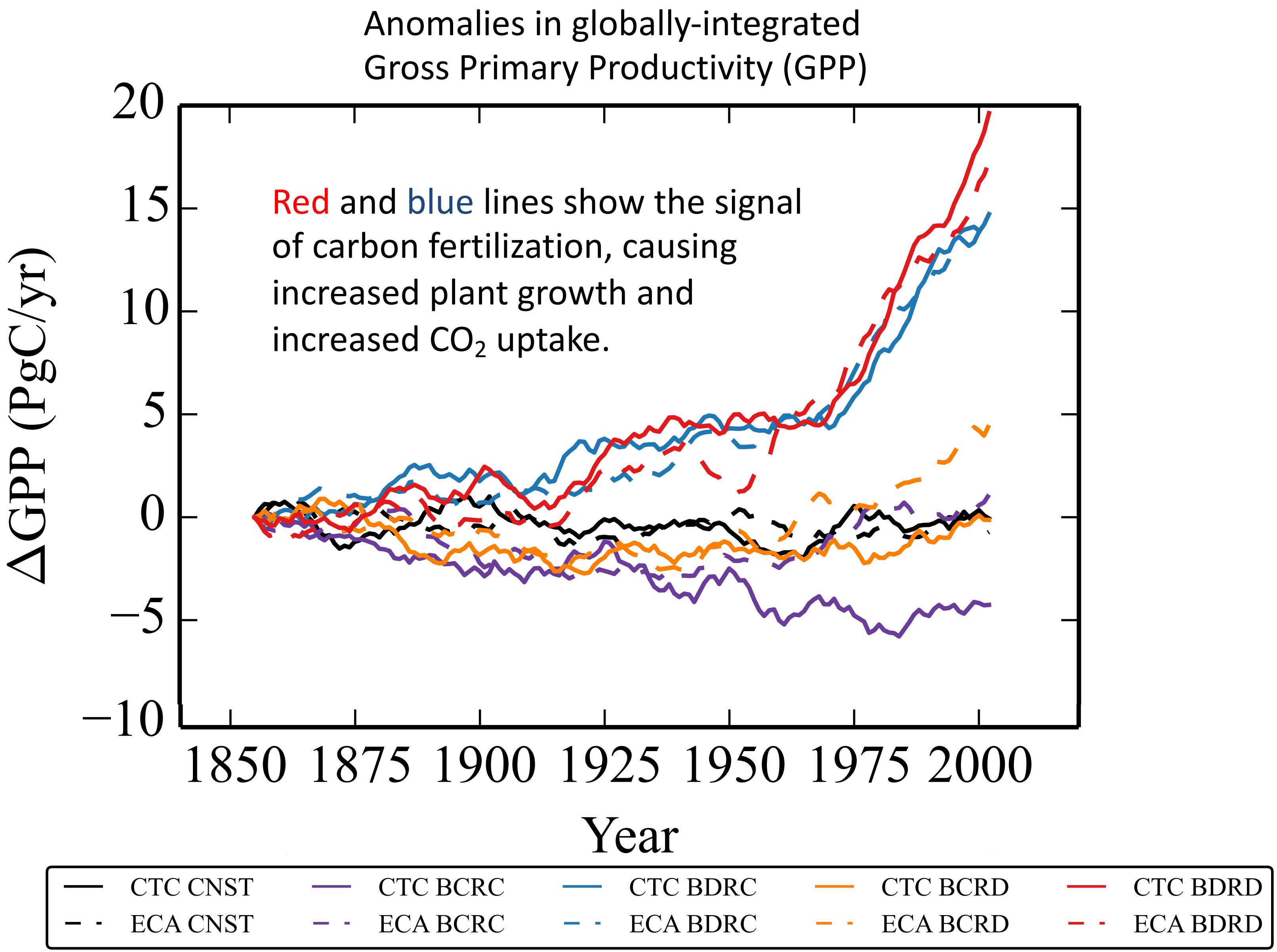
https://doi.org/10.6084/m9.figshare.11097356.v2





E3SM Energy Exascale Earth System Model

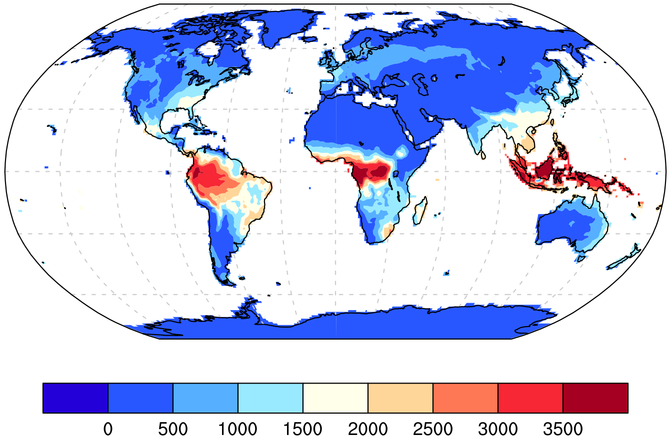
Response of plant growth (GPP) to carbon fertilization effect is similar in CTC and ECA



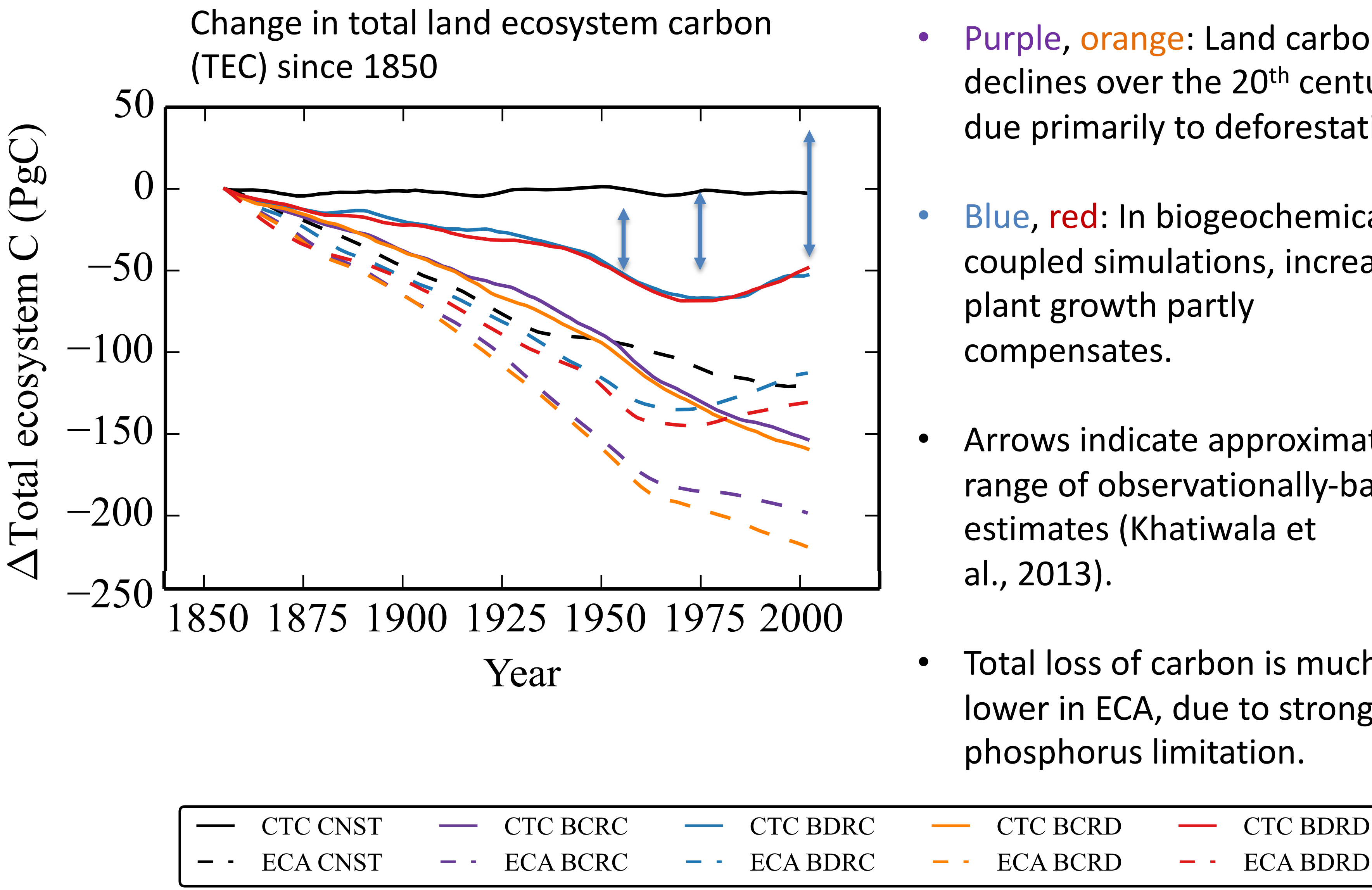
Impacts of CO_2 increase on GPP

- GPP is highest in tropical forest ecosystems (as expected)

Constant CO_2 (BCRC-hist)



Total loss of carbon from land since 1850 is comparable to observational estimates in default (CTC) configuration

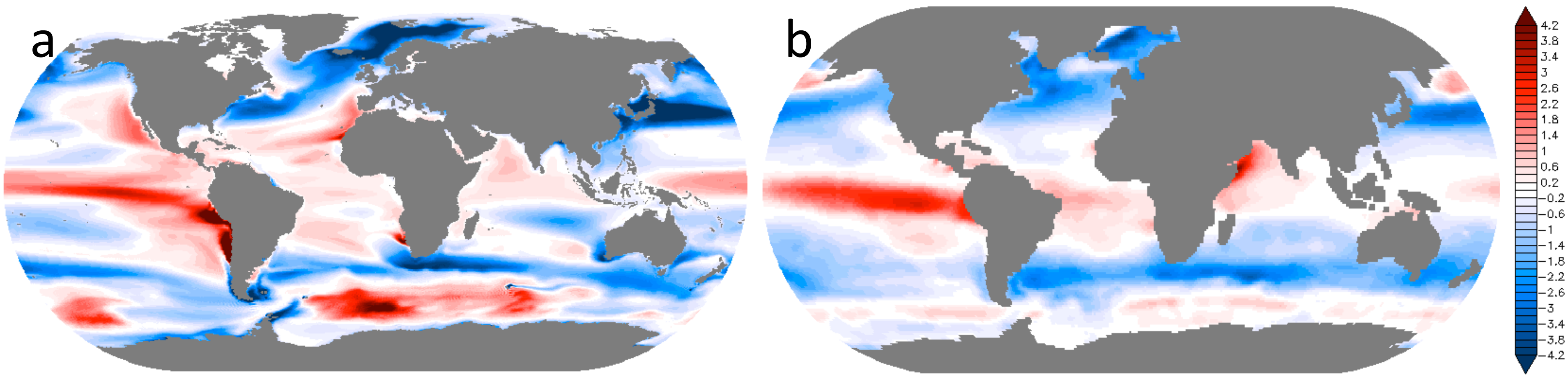


- Purple, orange: Land carbon declines over the 20th century due primarily to deforestation.
- Blue, red: In biogeochemically-coupled simulations, increased plant growth partly compensates.
- Arrows indicate approximate range of observationally-based estimates (Khatiwala et al., 2013).
- Total loss of carbon is much lower in ECA, due to stronger phosphorus limitation.

Ocean / sea ice BGC: high-level results

Net CO_2 flux from ocean to atmosphere (mmol/m^2/yr), present-day

MODEL (BDRD-hist, 1977-2006) | OBS (World Ocean Atlas)



- Red colors are fluxes out of ocean (outgassing)
- Blue colors are fluxes into ocean (uptake / sink)

Total ocean carbon uptake since 1850:

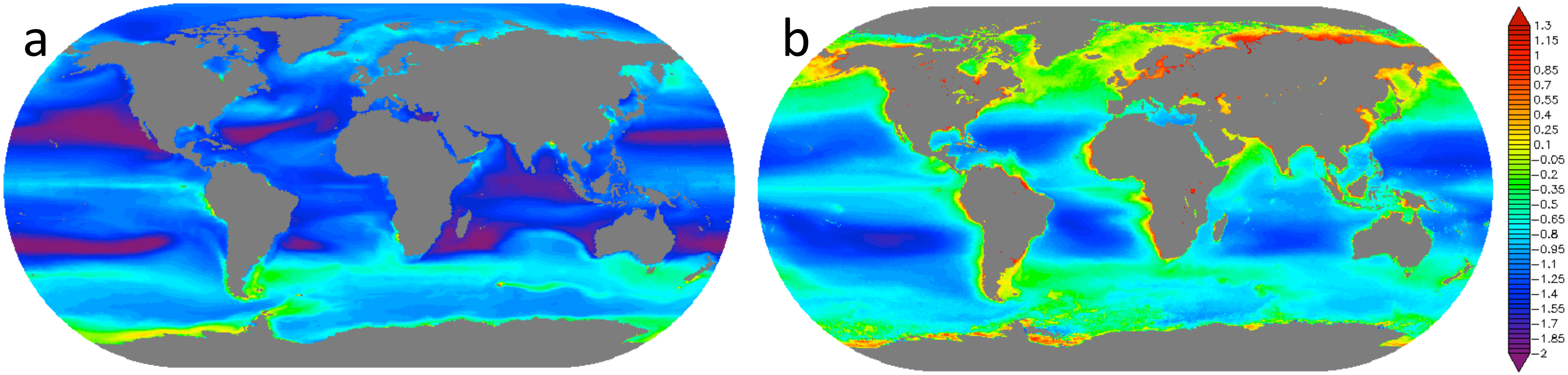
- Benchmark: 150 ± 20 PgC/yr (Le Quéré et al., 2018)
- E3SMv1.1-BGC: ~93 PgC/yr

E3SM Energy Exascale Earth System Model

U.S. DEPARTMENT OF ENERGY

Ocean surface Chl-a – too little biomass

MODEL (BDRD-hist, 1977-2006) OBS (SeaWIFS satellite, 1997-2010)



Log(ocean surface Chl-a) (mg/m^3)

Possible sources of bias:

- Lack of parameterized lateral mixing along isopycnal surfaces (Redi mixing).
- Biases in riverine nutrient inputs.
- Ocean mixed-layer depth biases, which lead to too-little overturning of nutrients in regions like the North Atlantic.
- Coastal underprediction is partly a resolution issue.

These issues are being addressed in v2 developments.

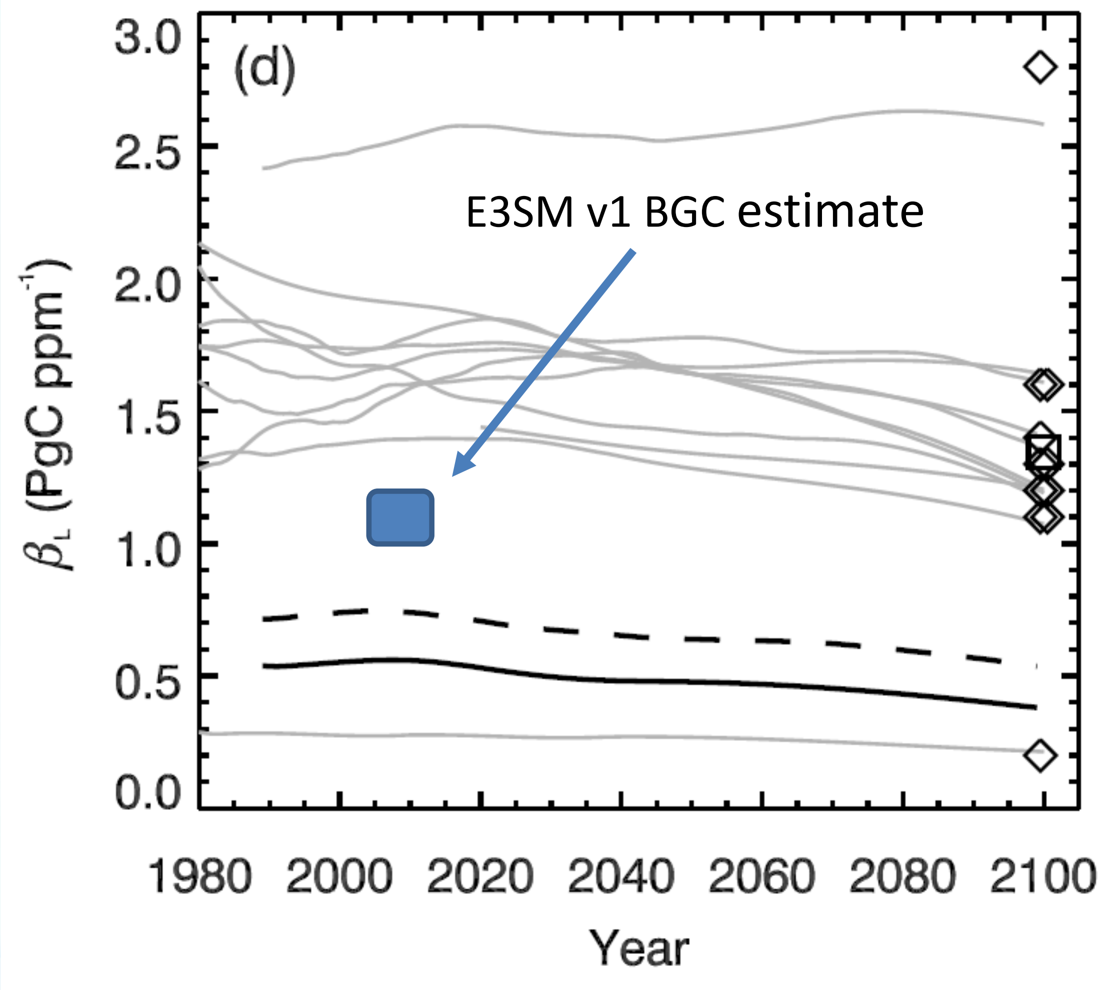
Carbon cycle – Climate feedback analysis

E3SM land CO_2 – climate feedbacks are comparatively weak (~expected)

Beta (Response of CO_2 uptake to CO_2 concentration, PgC/ppmv)

Differences:

- Different physical climate
- Different land model
  - Physics and BGC
- Active P cycle
- E3SM is using dynamic LULCC



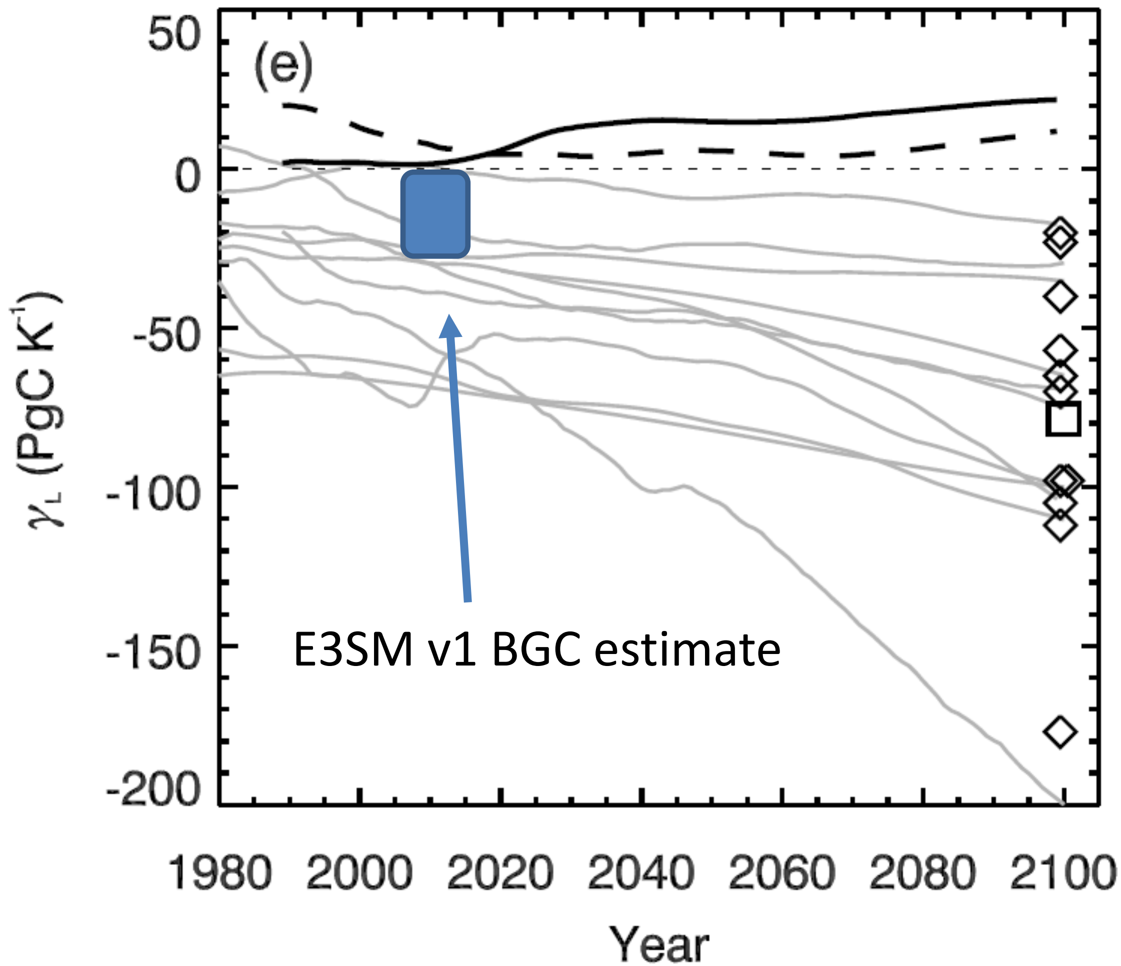
Plotted on data from Thornton et al. 2009

E3SM land CO_2 – climate feedbacks are comparatively weak (~expected)

Gamma (Response of CO_2 uptake to temperature, PgC/K)

Differences:

- Different physical climate
- Different land model
    - Physics and BGC
- Active P cycle
- E3SM is using dynamic LULCC



Plotted on data from Thornton et al. 2009

Summary / Outlook

- Conducted E3SMv1.1-BGC historical simulations with two land model configurations.
  - Both perform well on ILAMB land model observational benchmarks
  - Structural differences occur in nutrient limitation and nutrient pools
  - Both configurations have comparatively weak carbon-climate feedbacks, supporting the hypothesis that such feedbacks are weaker in models where nutrient limitations are represented
- Ocean carbon cycle: several sources of bias were identified, which are being addressed for v2.
- Additional papers published / in progress will describe responses to future scenarios, land nutrient limitations and structural uncertainties, sea ice biogeochemistry, and feedbacks on atmospheric dynamics

Thank you!