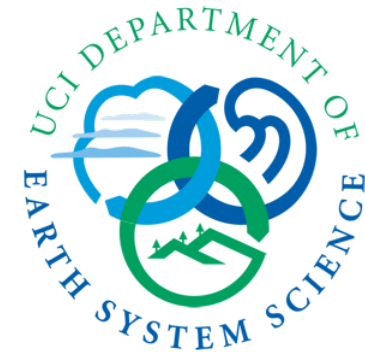


Grand Challenges in Carbon Cycle Modeling ILAMB and new opportunities

J.T. Randerson, J.K. Moore, F. M. Hoffman, A.L.S. Swann, F. Primeau,
N. Collier, K. Lindsay, C. D. Koven, and D. Lawrence

March 26, 2018



Caltech

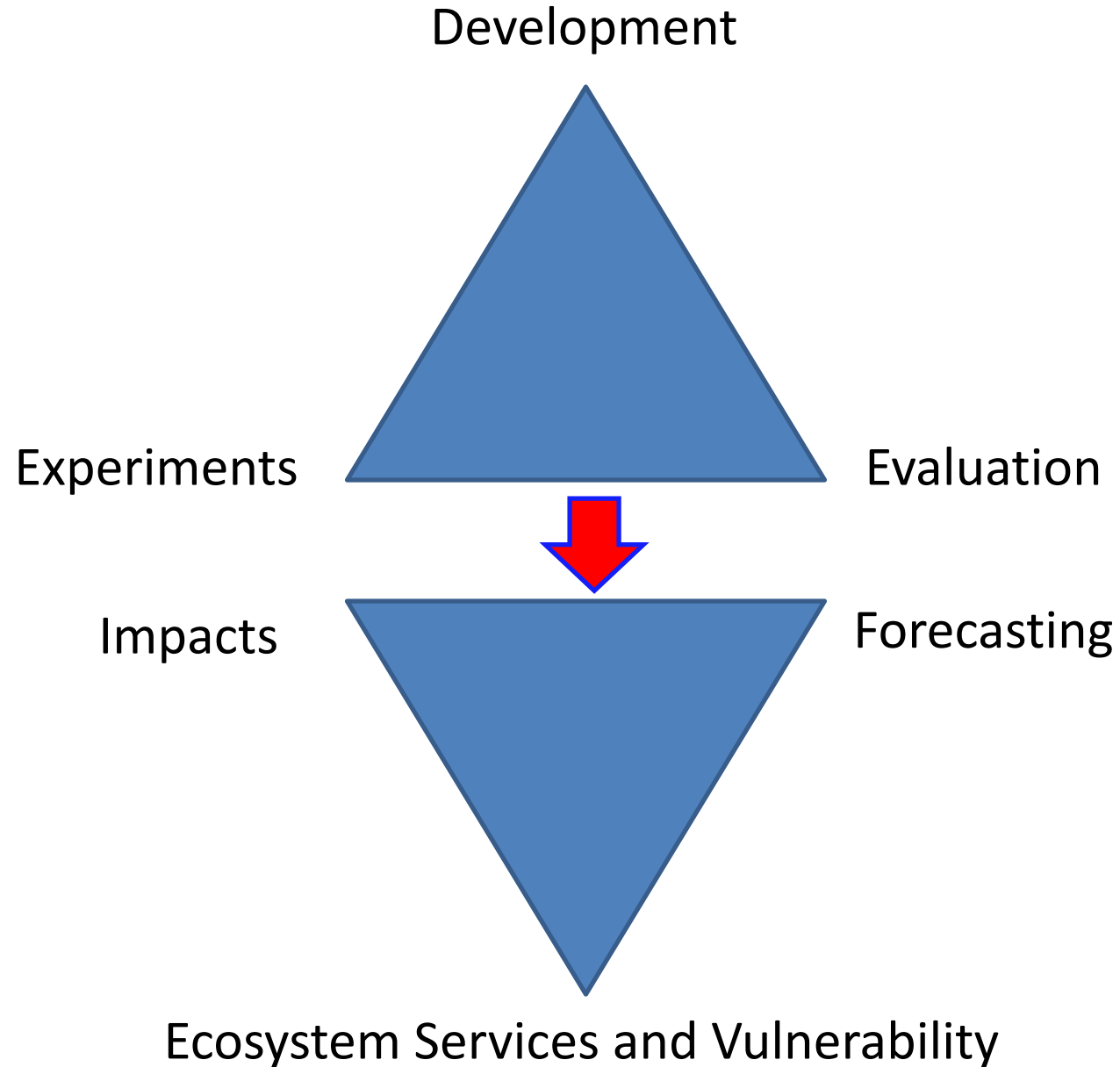
Keck Institute for Space Studies



Frontiers in Modeling the Earth System

- Imagining and articulating different futures beyond the year 2100
 - What are the tipping points we want to avoid?
 - Are targets to stabilize climate by 2100 really stable?
- Coupling between land and oceans driven by sea level rise, nutrient flows, changes in the hydrological cycle
- Dynamic vegetation – the movement of species driven by all forms of global change
- Integrating ecosystem services with models (Bonan and Doney, 2018)

A Healthy Model Ecosystem



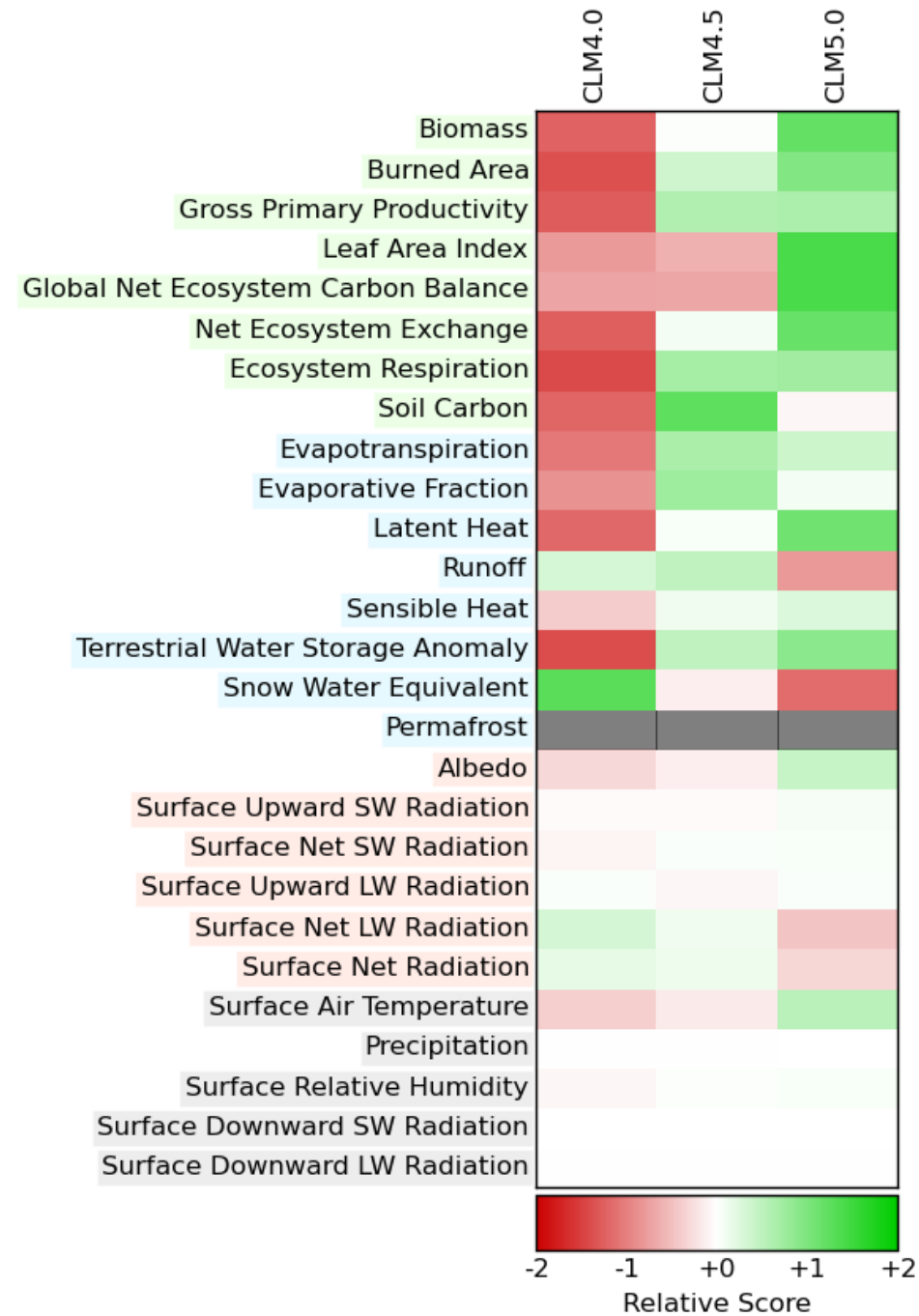
Threats to a Healthy Model Ecosystem

- Development
 - Stress from lack of long-term funding at modeling centers and no clear home for coupled modeling at NSF
 - Increasing model complexity limits cost-effective use and access
 - Lack of a systematic hierarchal approach that recognizes different needs as a function of time and space scape
- Evaluation – data integration
 - Significant barriers remain wrt allowing experimental community to explore model behavior
 - Data assimilation approaches for ESMs are nascent
 - Importance of systematic data evaluation for development may be underappreciated
 - Land surface forcing conditions are
- Experiments:
 - For most ESM Centers, IPCC/CMIP has co-opted PI-driven experiments – this needs discussion
 - There is very little time in dev. cycle or funding support for model experiments
 - Weakest link in ecosystem, huge bottleneck for wider impact

International Land Model Benchmarking (ILAMB) System

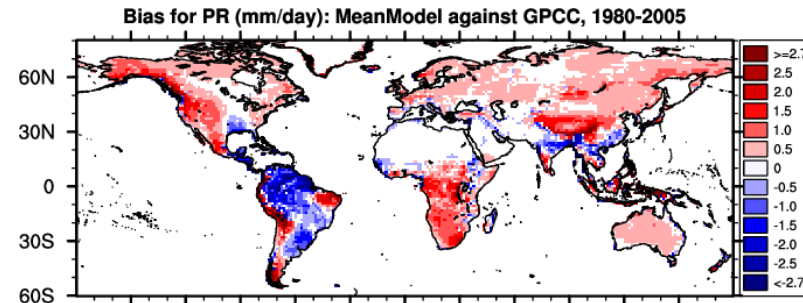
- <http://ilamb.ornl.gov/CMIP5/>
- <http://ilamb.ornl.gov/CLM/>
- Collier, N., F.M. Hoffman, D.M. Lawrence, G. Keppel-Aleks, C.D. Koven, W.J. Riley, M. Mu, J.T. Randerson. International Land Model Benchmarking (ILAMB) System: Design, Theory, and Implementation. JAMES, in prep.

ILAMB v2

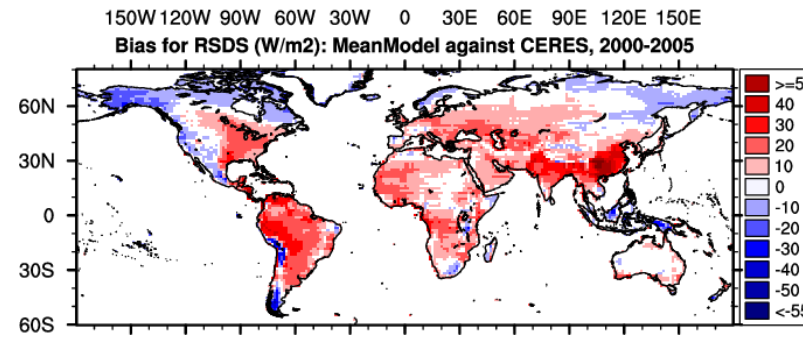


Systematic biases in
CMIP5 ESMs illustrated
in ILAMBv1:

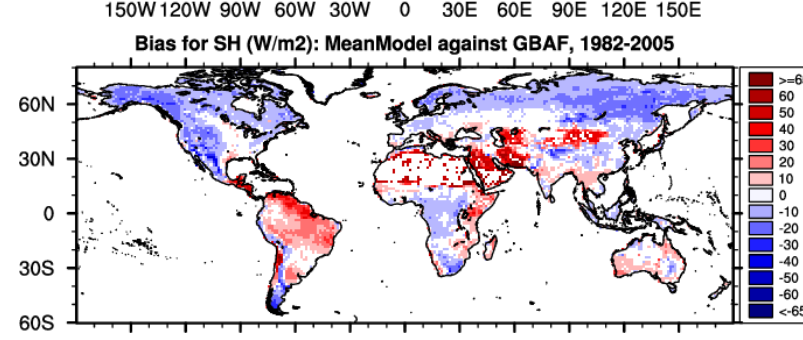
The Amazon dry bias
cascade



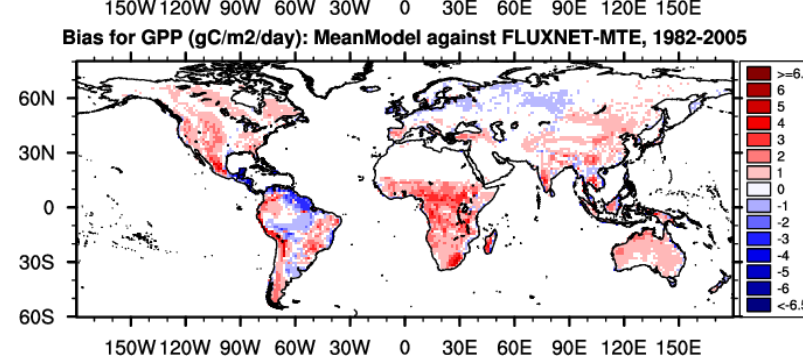
PPT



Sin

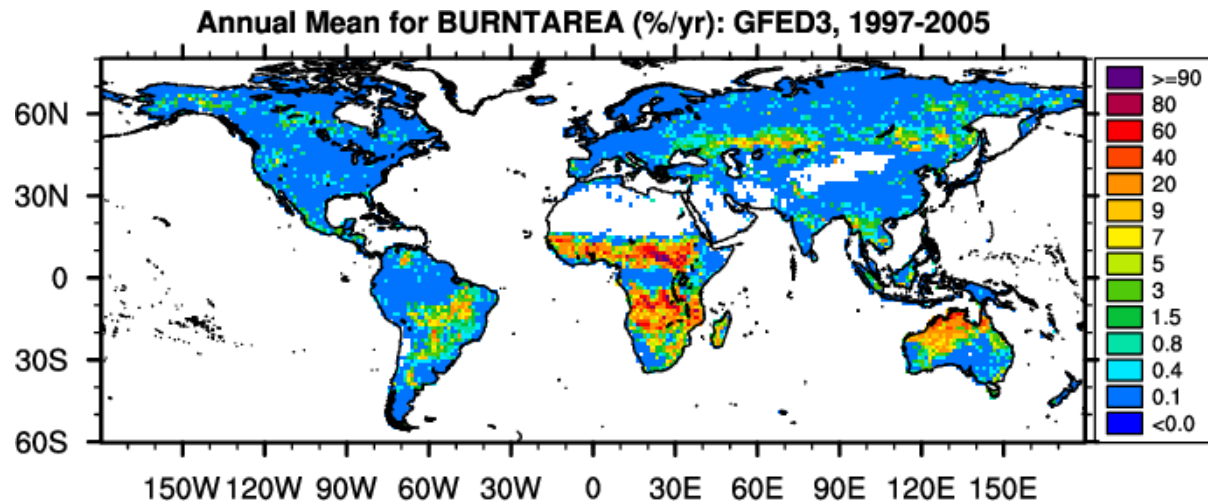


Sensible Heat

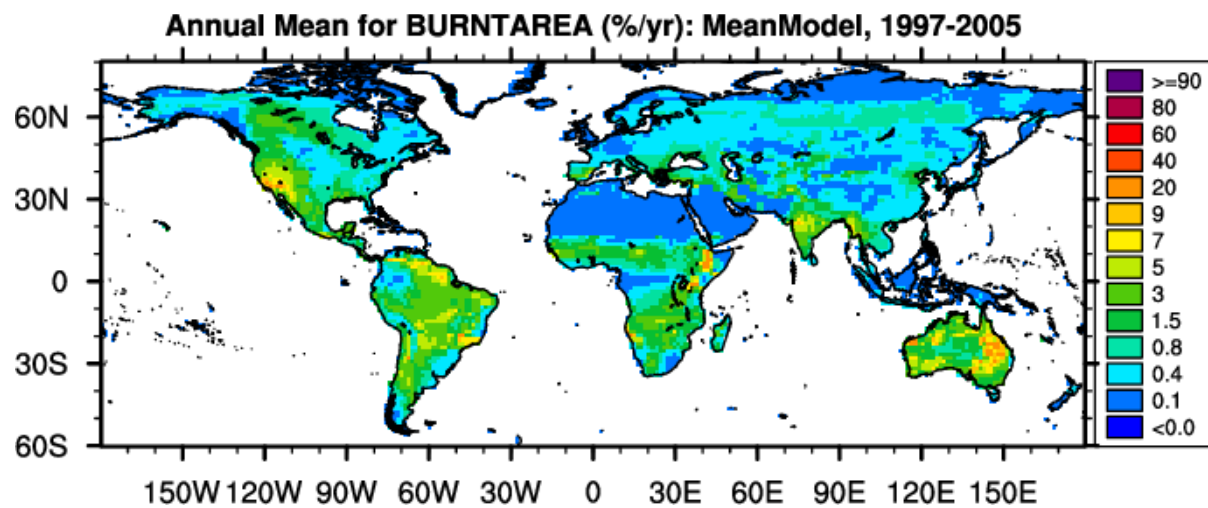


GPP

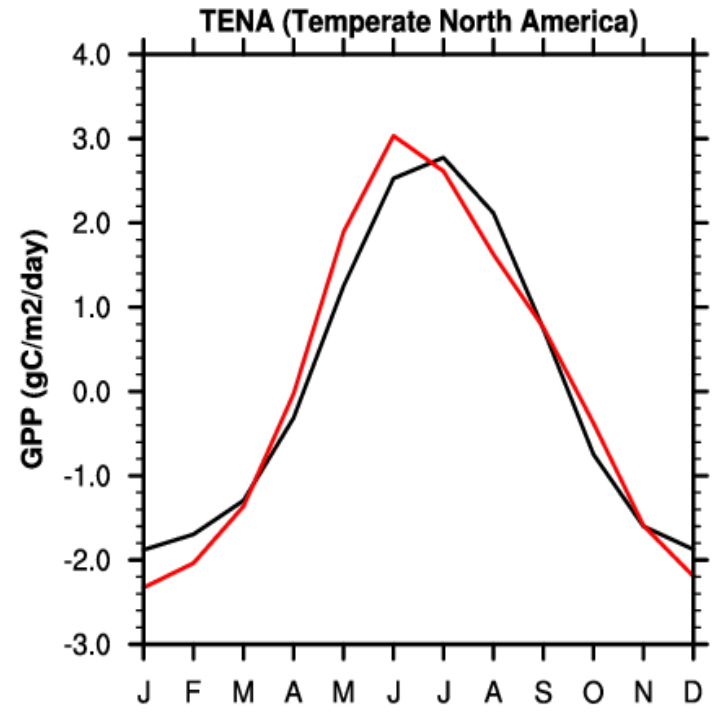
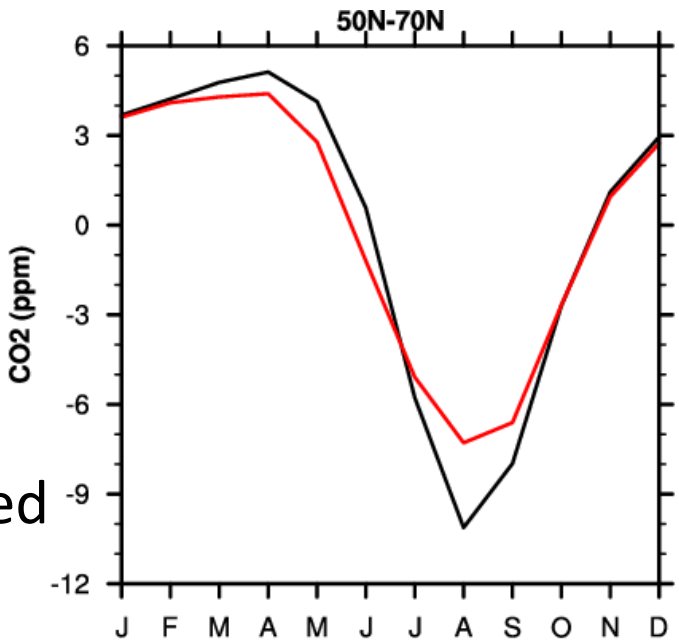
Systematic biases in
CMIP5 ESMs illustrated
in ILAMBv1:



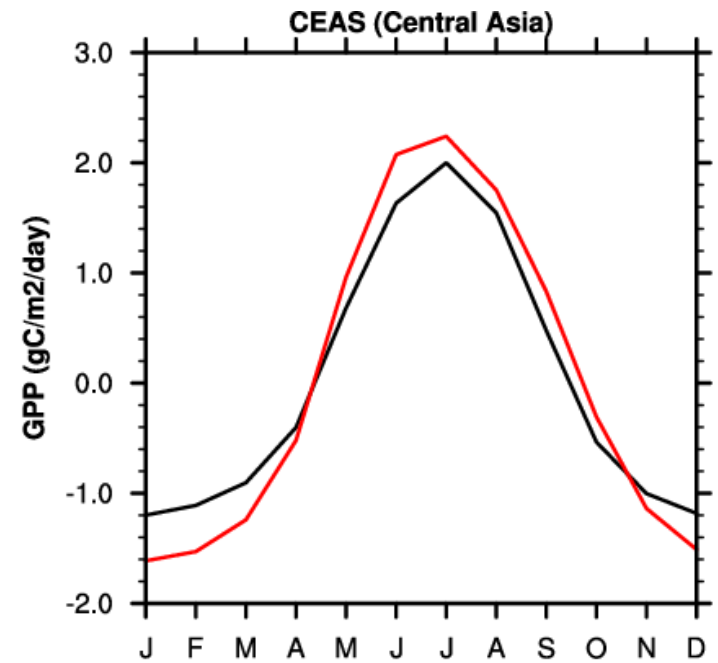
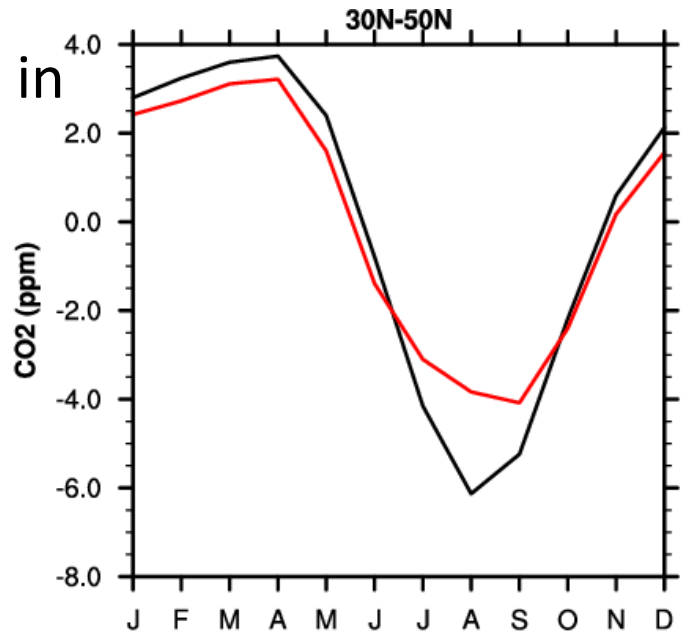
Fires across the
western US



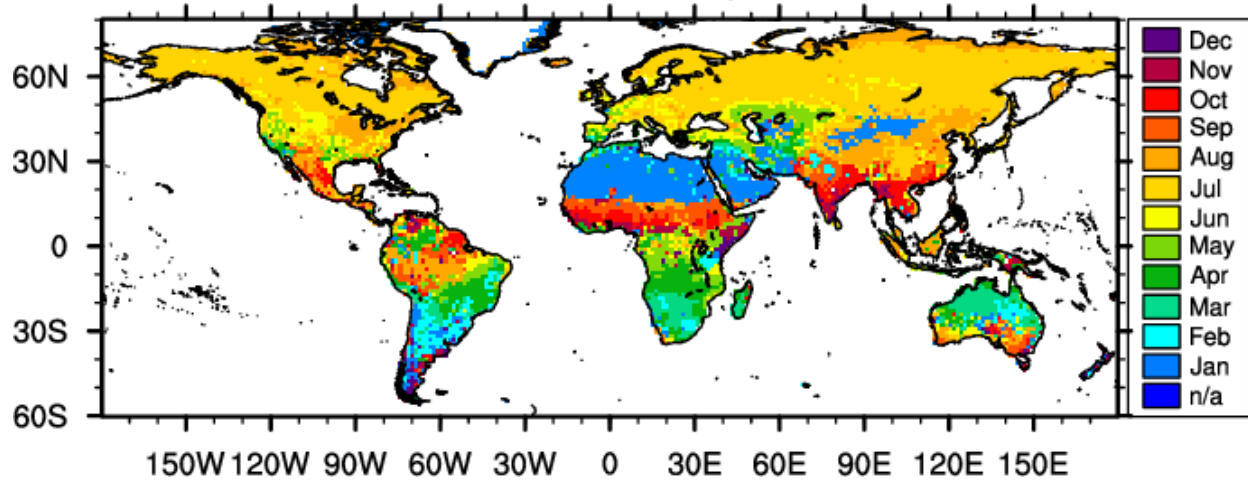
Systematic biases in CMIP5 ESMs illustrated in ILAMBv1:



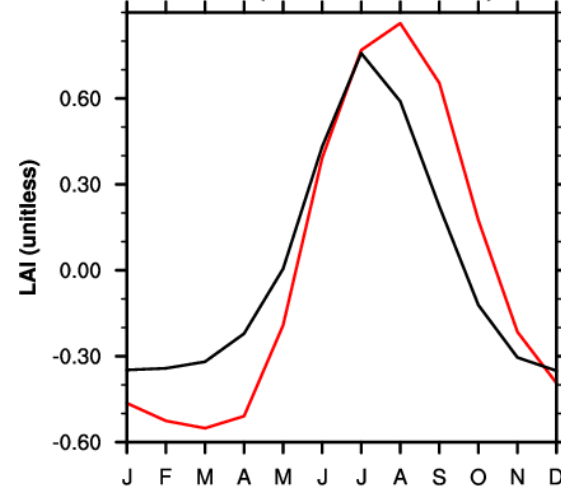
Carbon uptake onset in GPP and NEE is too early



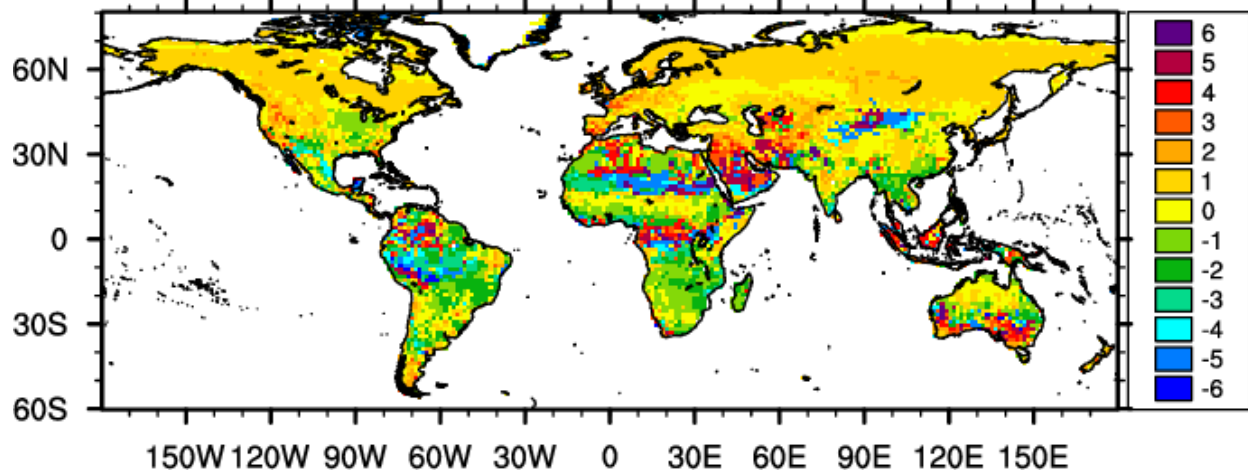
Peak month for LAI: MODIS, 2000-2005



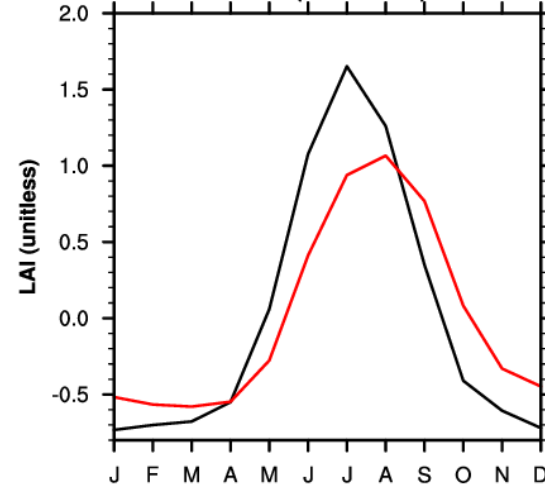
BONA (Boreal North America)



Difference of peak month for LAI: MeanModel against MODIS, 2000-2005

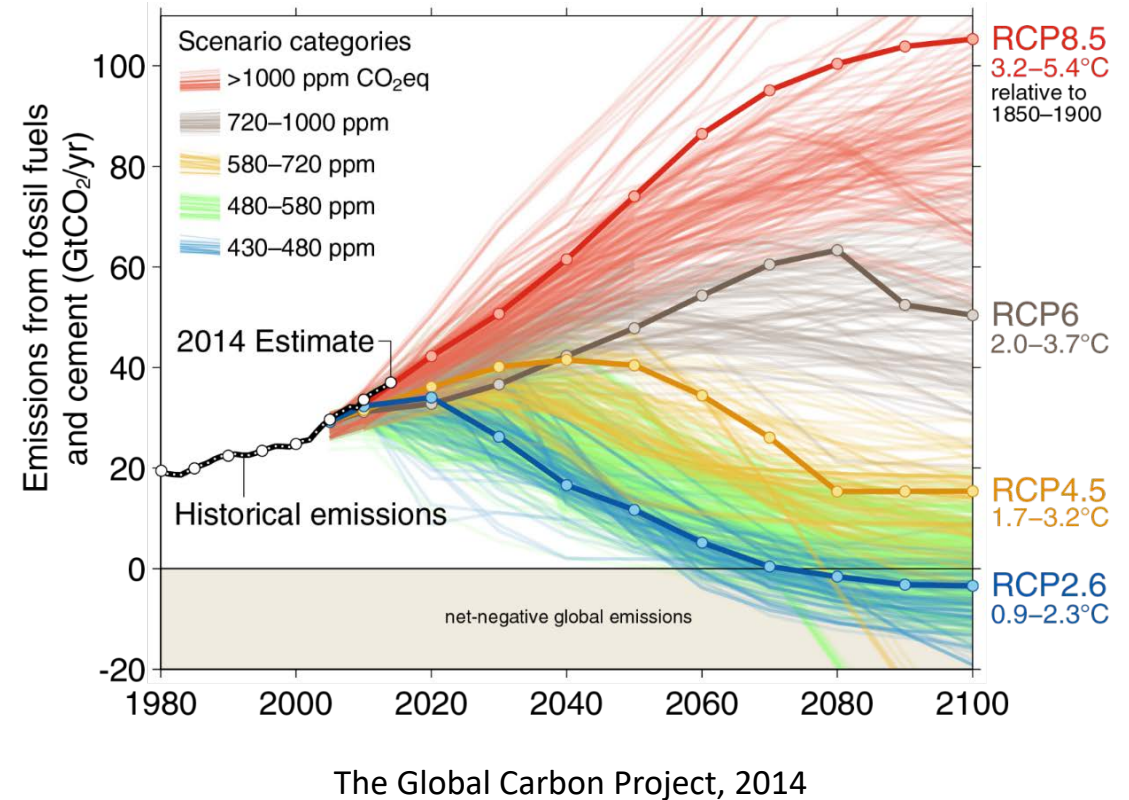


BOAS (Boreal Asia)



What will the world look like after 2100 and why should we care?

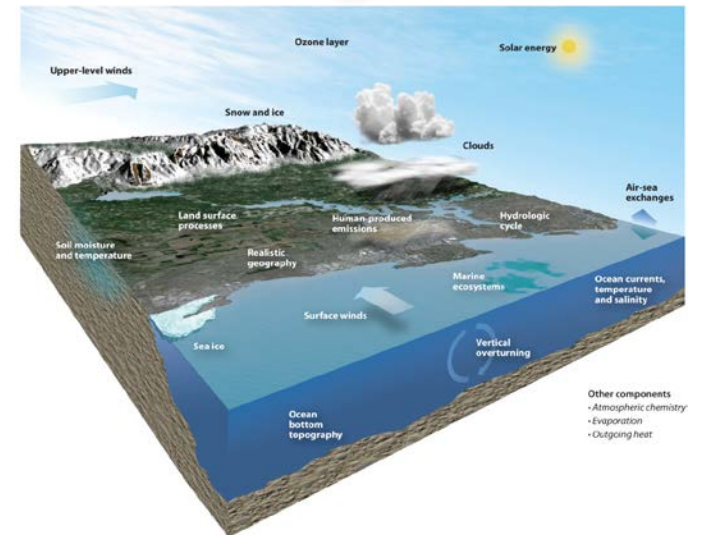
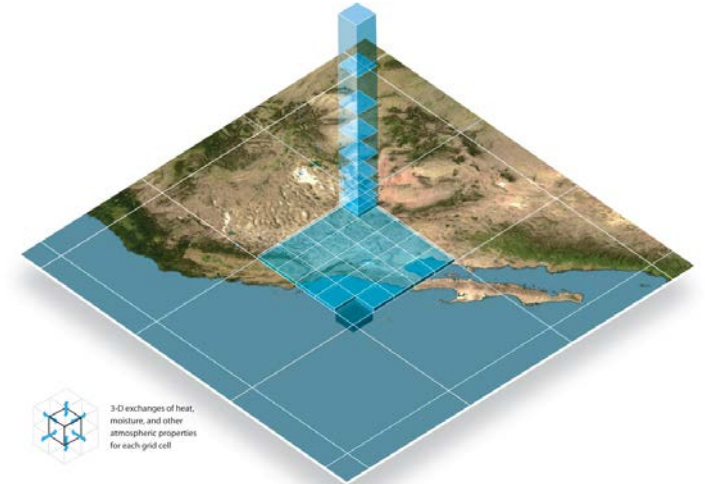
- Most model simulations stop by the year 2100
- Exploration of climate-biogeochemical feedbacks beyond this time often relies on EMICs
- Many processes will unfold over much longer time scales, for example, ice sheet degradation, sea level rise, and permafrost melt.
- If we discover unavoidable catastrophic changes in the biosphere, perhaps it will provide stronger motivation for emissions reductions in the next few decades



Science question

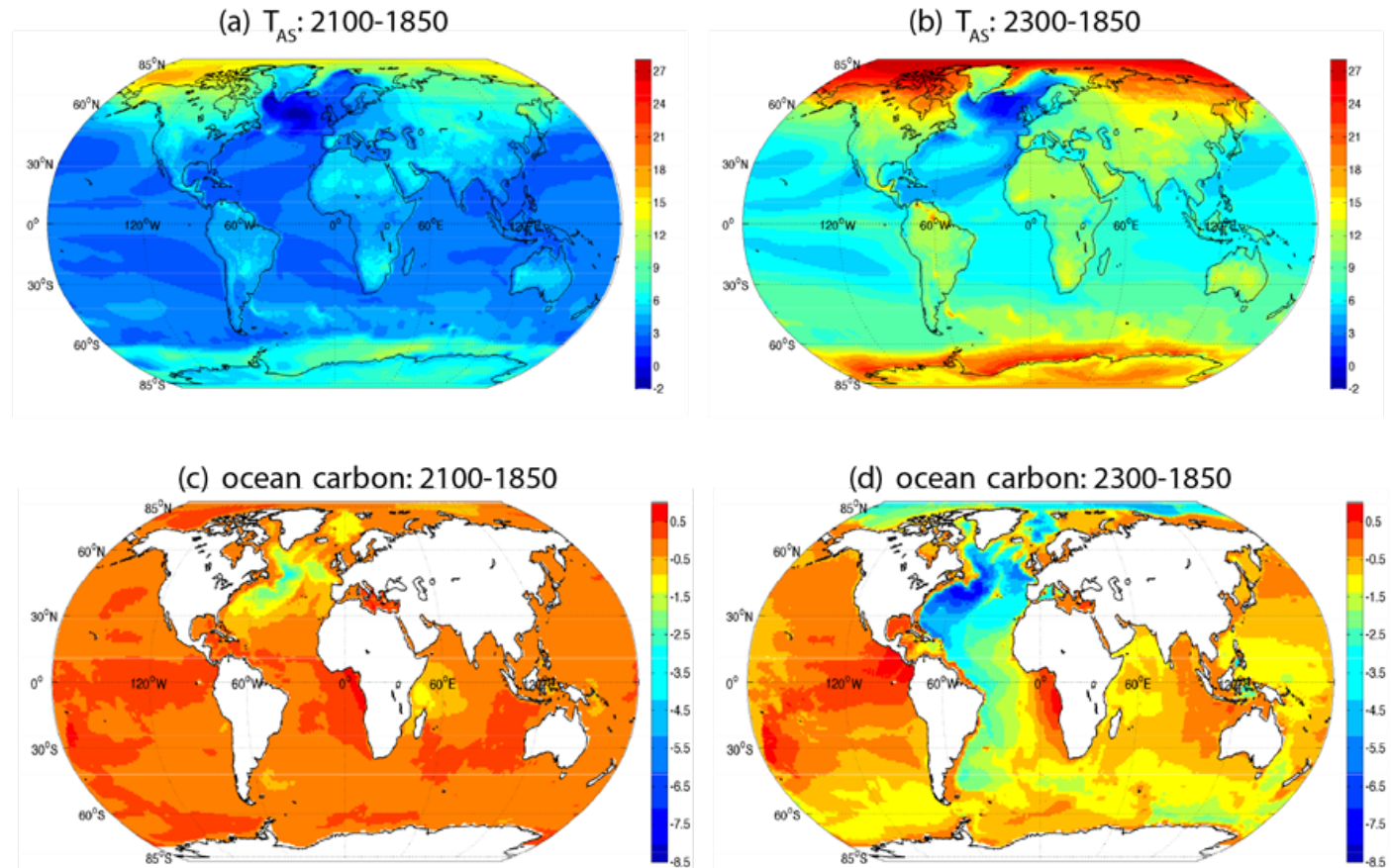
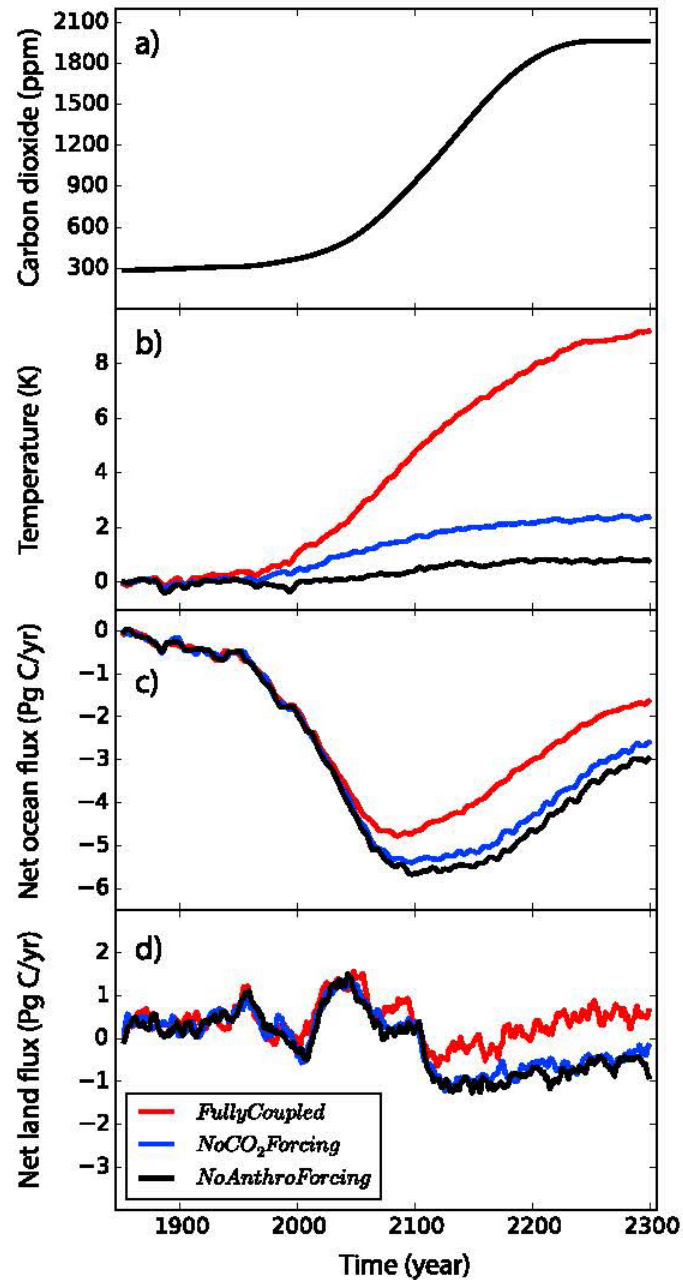
- How will changes in winds and ocean dynamics influence biology and fisheries?

The Community Earth System Model



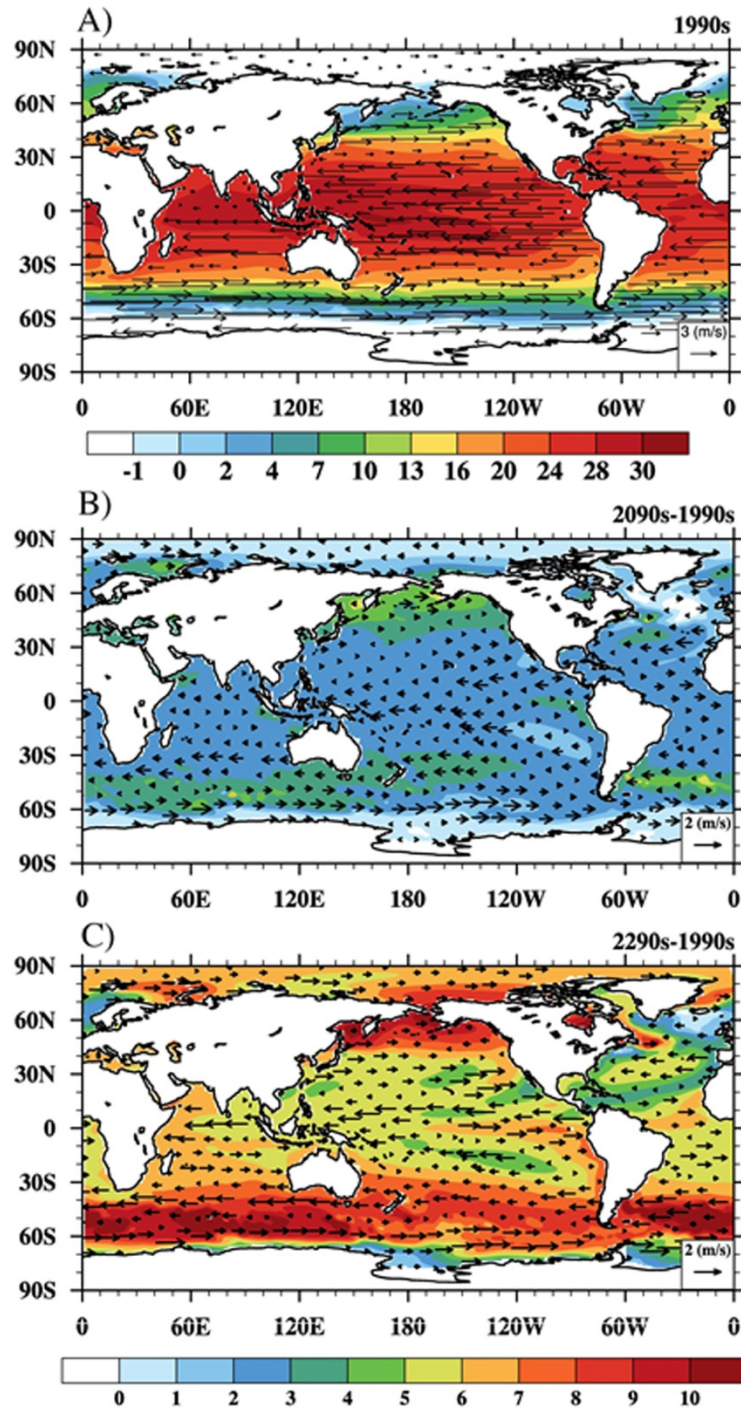
Graphic credit: UCAR

CESM Extended Climate Simulation to Year 2300



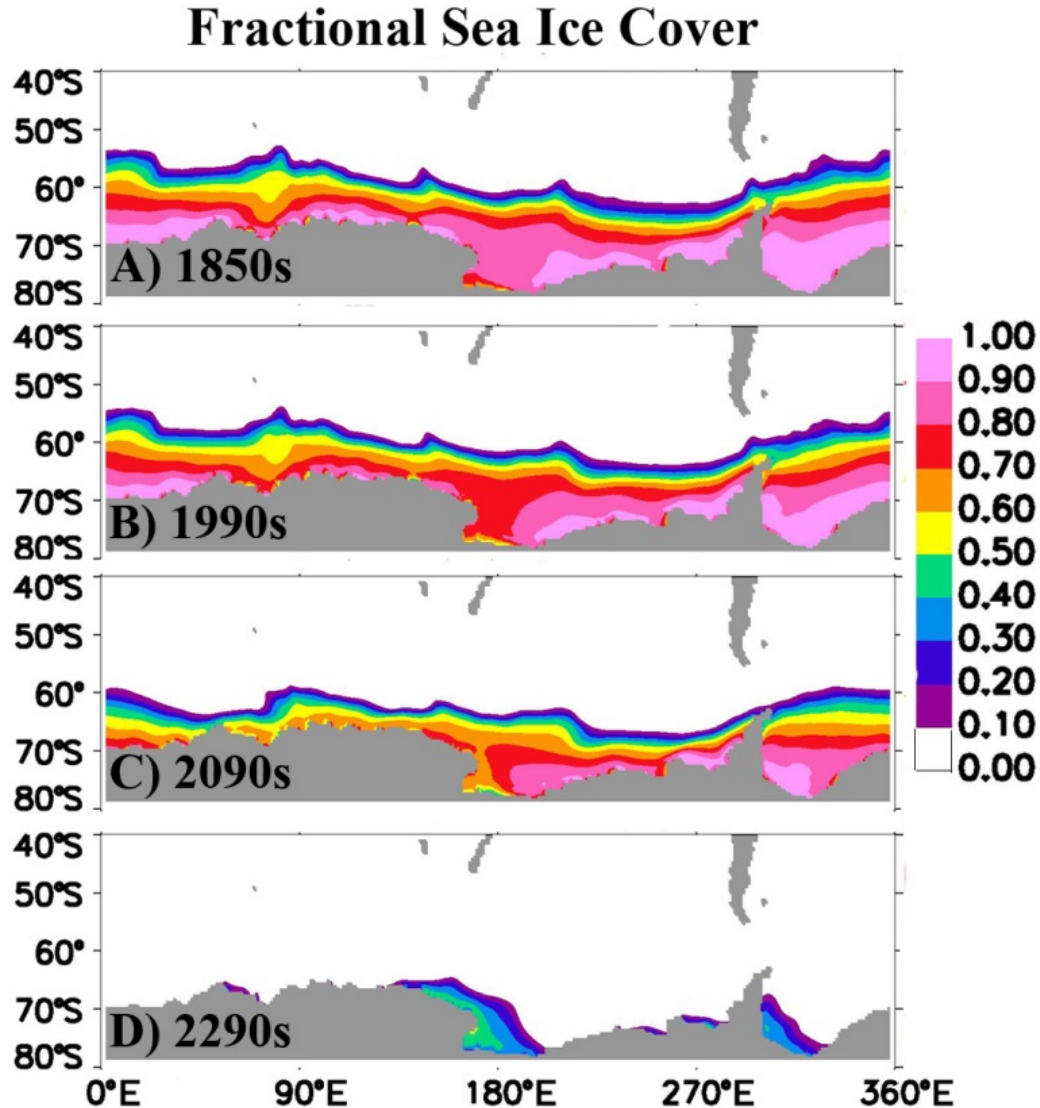
kg C per m²

The multicentury warming in RCP8.5-ECP8.5 drives big changes in ocean circulation and biogeochemistry.



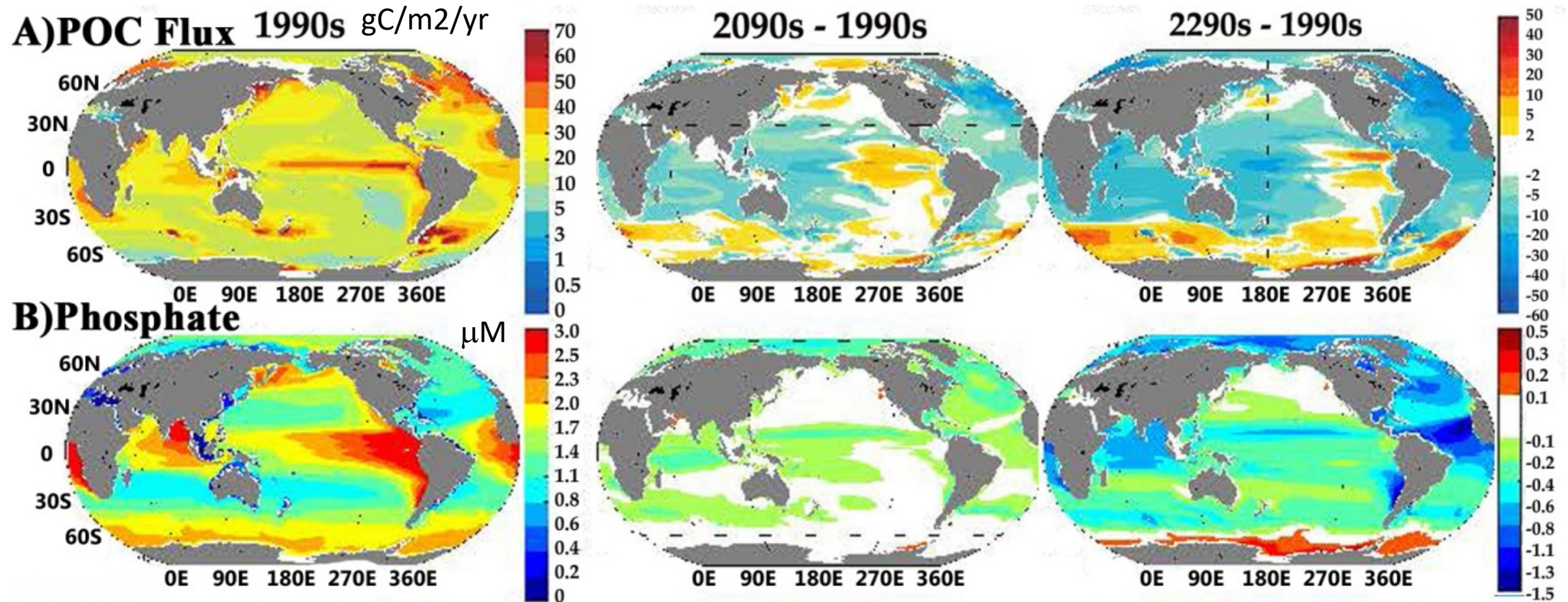
Ocean warming is stronger at high latitudes, and the southern hemisphere Westerlies shift south, strengthening near the coast of Antarctica

Ocean Warming Around Antarctica Decreases Sea Ice

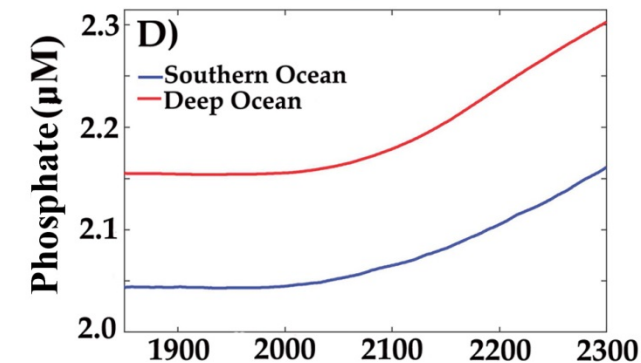
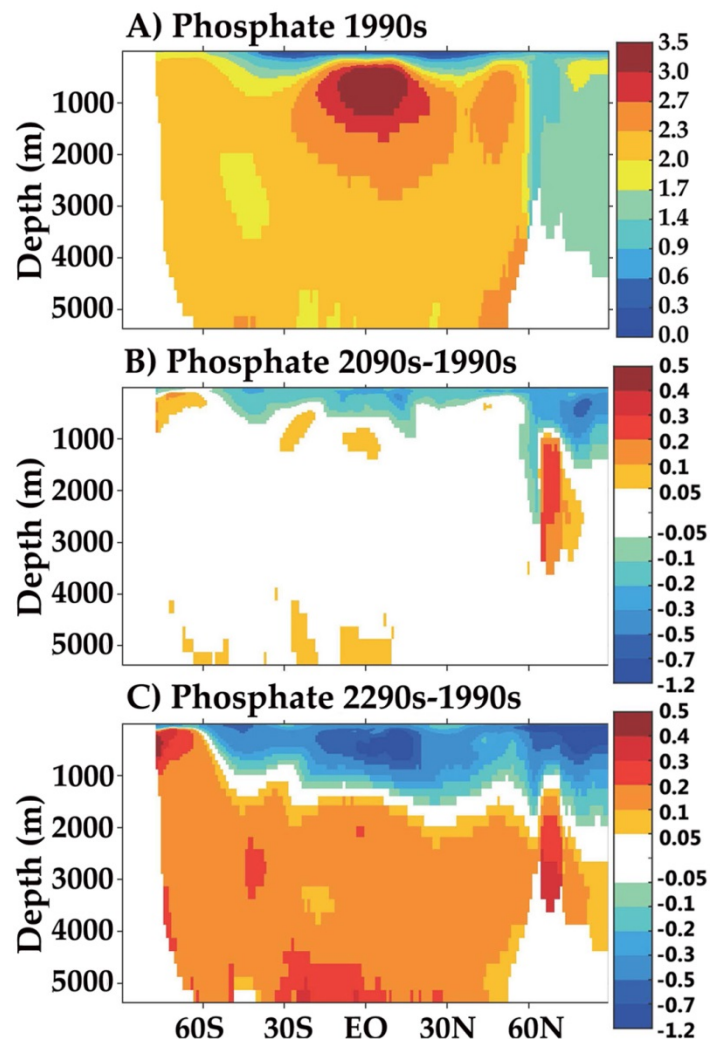


- Factors Boosting SO Productivity:**
- 1) Reduction in ice increases light**
 - 2) Warming surface waters increase growth rates, and shallow mixed layer depths, improving light regime.**
 - 3) Shifting Westerlies increase upwelling rate, and incorporates more margin, high-iron waters.**

The changing climate stimulates a massive phytoplankton bloom around Antarctica



Moore et al. (2018)



The nutrient trapping in the Southern Ocean decreases the northward flux of nutrients, within Antarctic Intermediate Water (AAIW) and Subantarctic Mode Waters, into the low-latitude mid-depth waters.

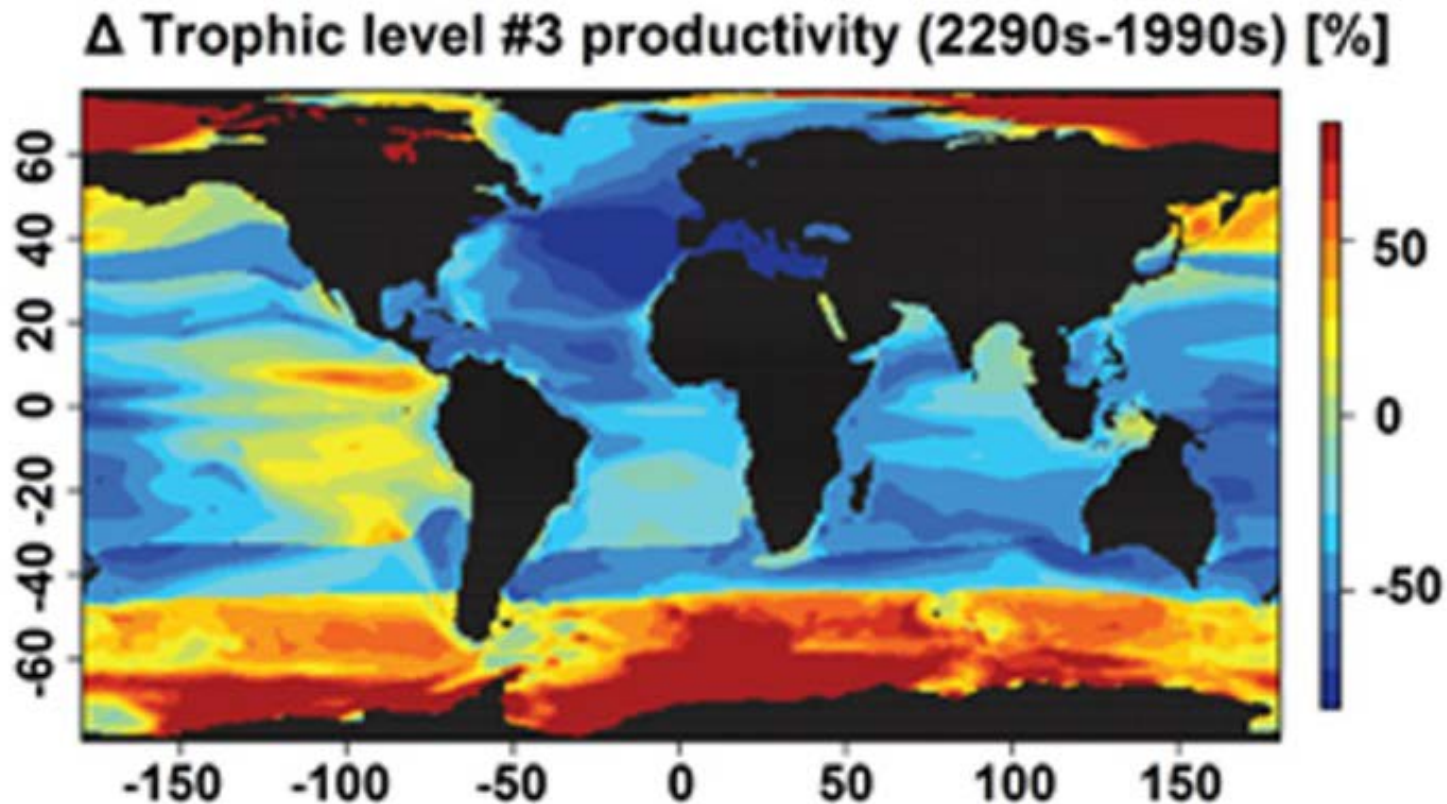
Some of the trapped nutrients are moved back into the deep ocean by circulation and mixing.

Thus, there is a net transfer of nutrients to the deep ocean and a large decrease in phosphate concentrations in the upper ocean, everywhere to the north of the Southern Ocean (A-C).

The collapse of deep winter mixing in the high latitude North Atlantic, also acts to deplete upper ocean nutrients and increase deep ocean nutrient concentrations (C).

Note that the buildup of nutrient concentrations in the Southern Ocean (all depths) and global deep ocean are still steadily increasing at 2300.

Warming around Antarctica may trigger a biogeochemical tipping point



- Ocean fisheries decrease more than 20% globally, and by nearly 60% in the North Atlantic
- Southern Ocean nutrient trapping may suppress global ocean productivity for a millennium
- There may be value in illuminating a future path we don't want to take
- An important next step is to assess how much emissions will trigger An

Wish list for starting over

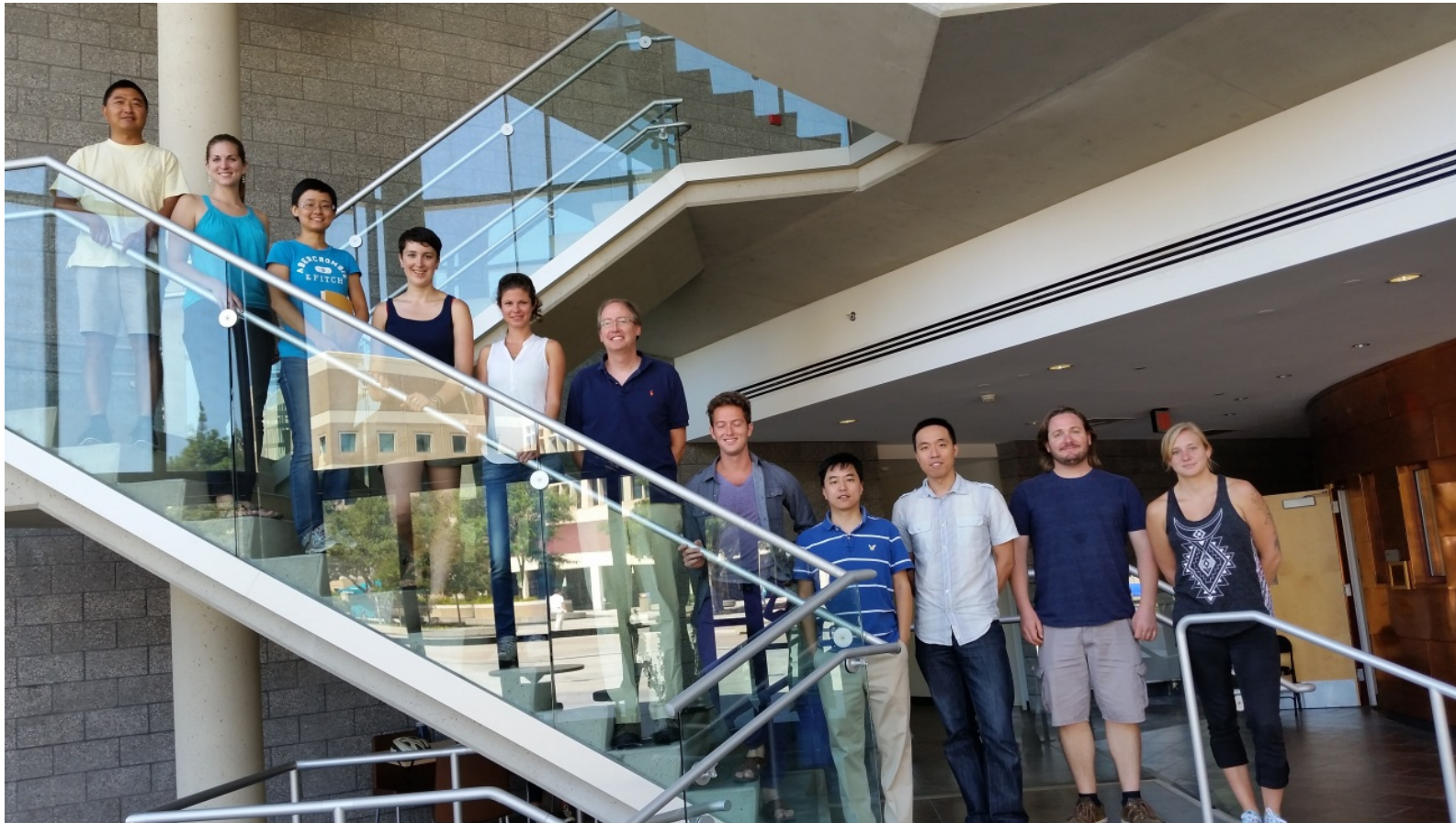
- Get rid of FORTRAN
- Take a hierarchal and modular approach
 - Support 2-3 models with different levels of complexity in key processes (not clear one-size fits all will continue to work)
 - Consider interface carefully – could a simple/modular scripting language help with model access and model-data comparisons
- Carefully consider public access! What would it take to allow undergraduates to perform fully coupled experiments in a cloud environment?
- Converse: is fully coupled modeling becoming increasingly sequestered with our monasteries?
- Line up a consortium of private and public partners (foundations, IT companies, and several US funding agencies)

James Randerson

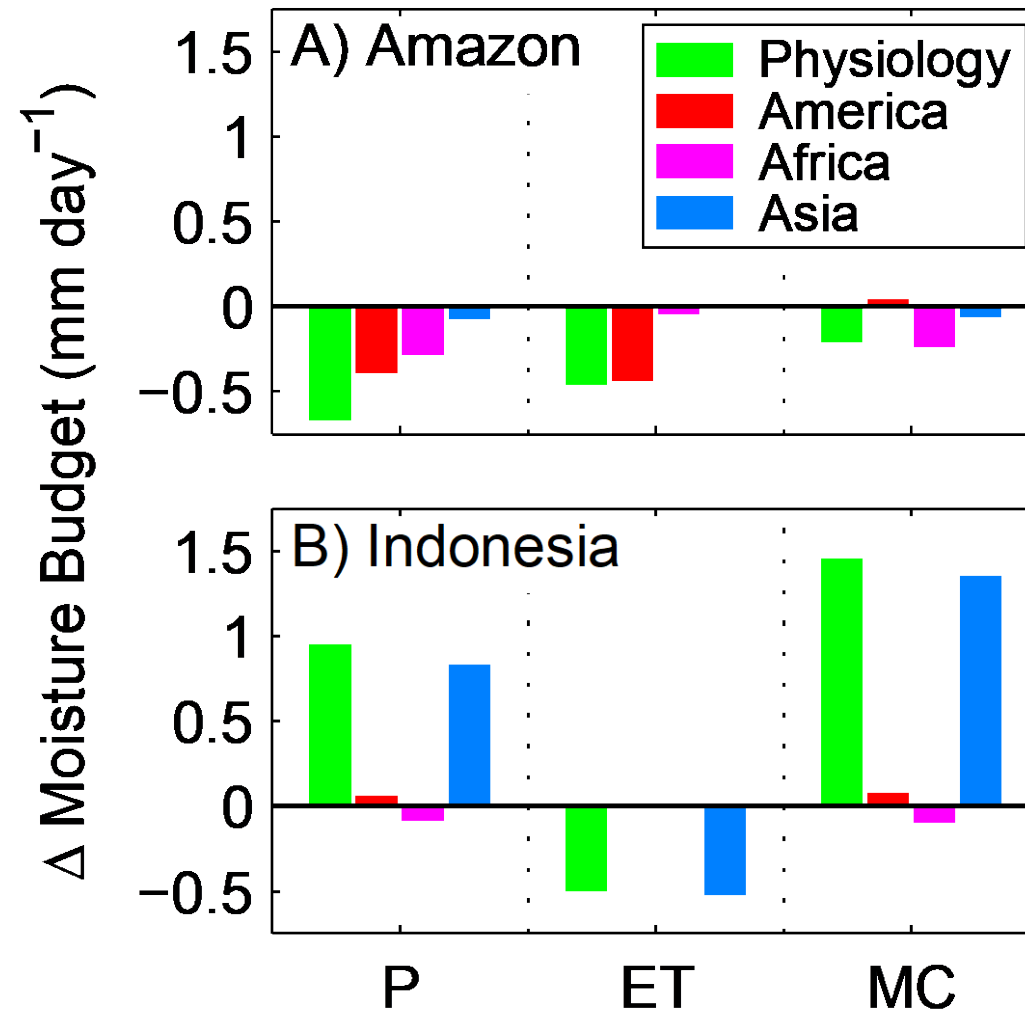
Department of Earth System Science, UC Irvine

jranders@uci.edu

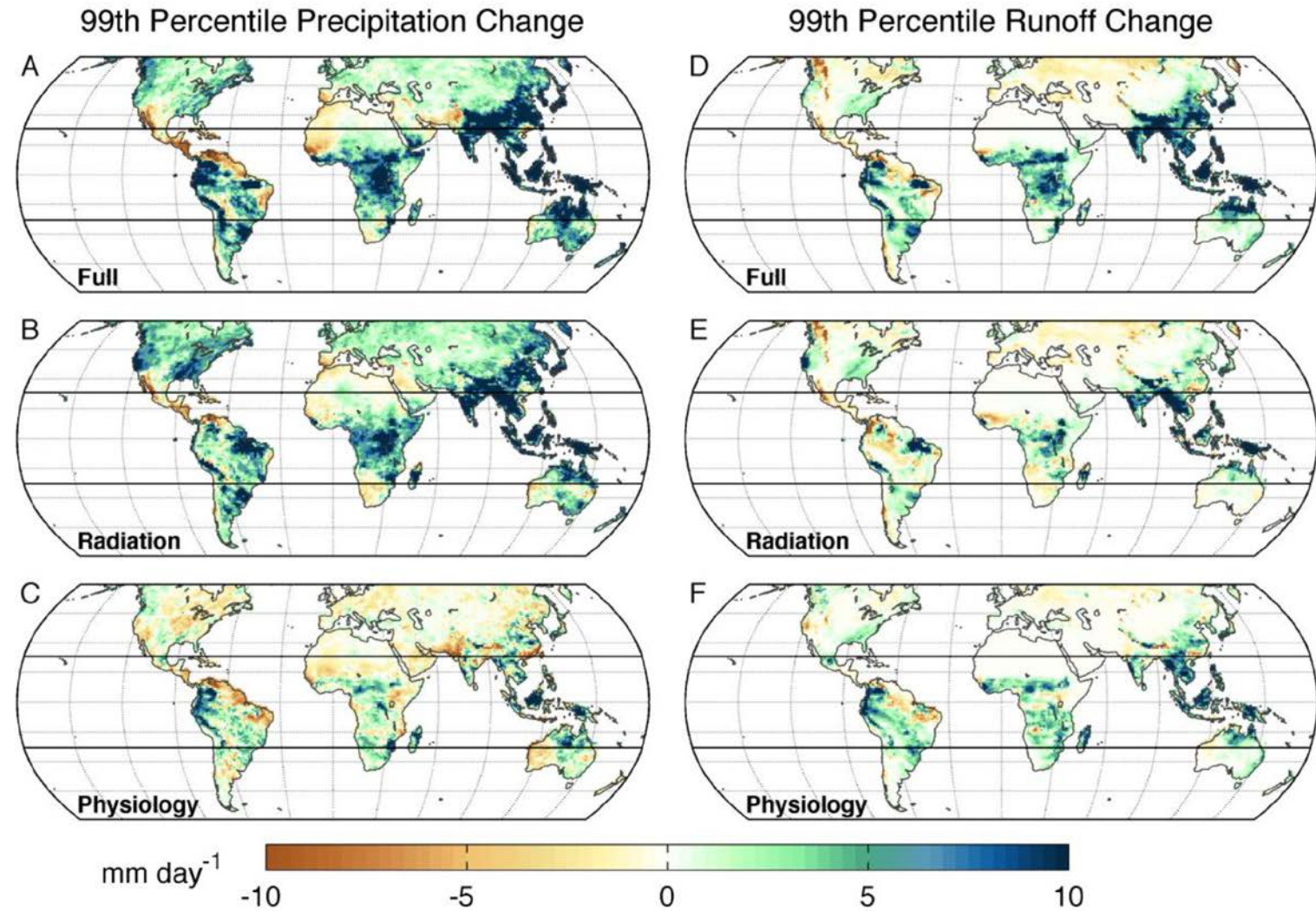
<http://sites.uci.edu/randersonlab/>



Rising CO₂ causes increases in moisture convergence in Indonesia but not the Amazon



Increasing runoff extremes caused in part by the physiological effects of CO₂ raising the water table

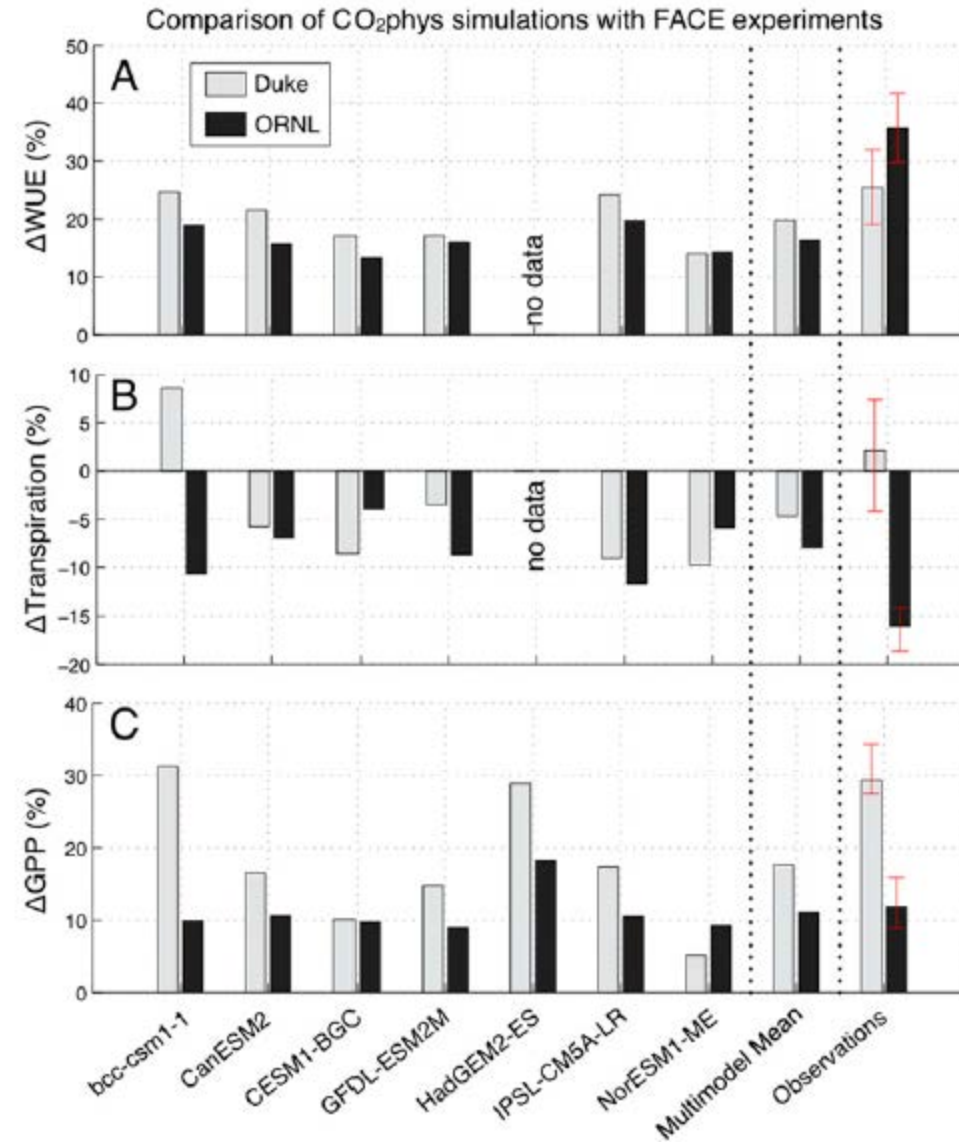


Conclusions

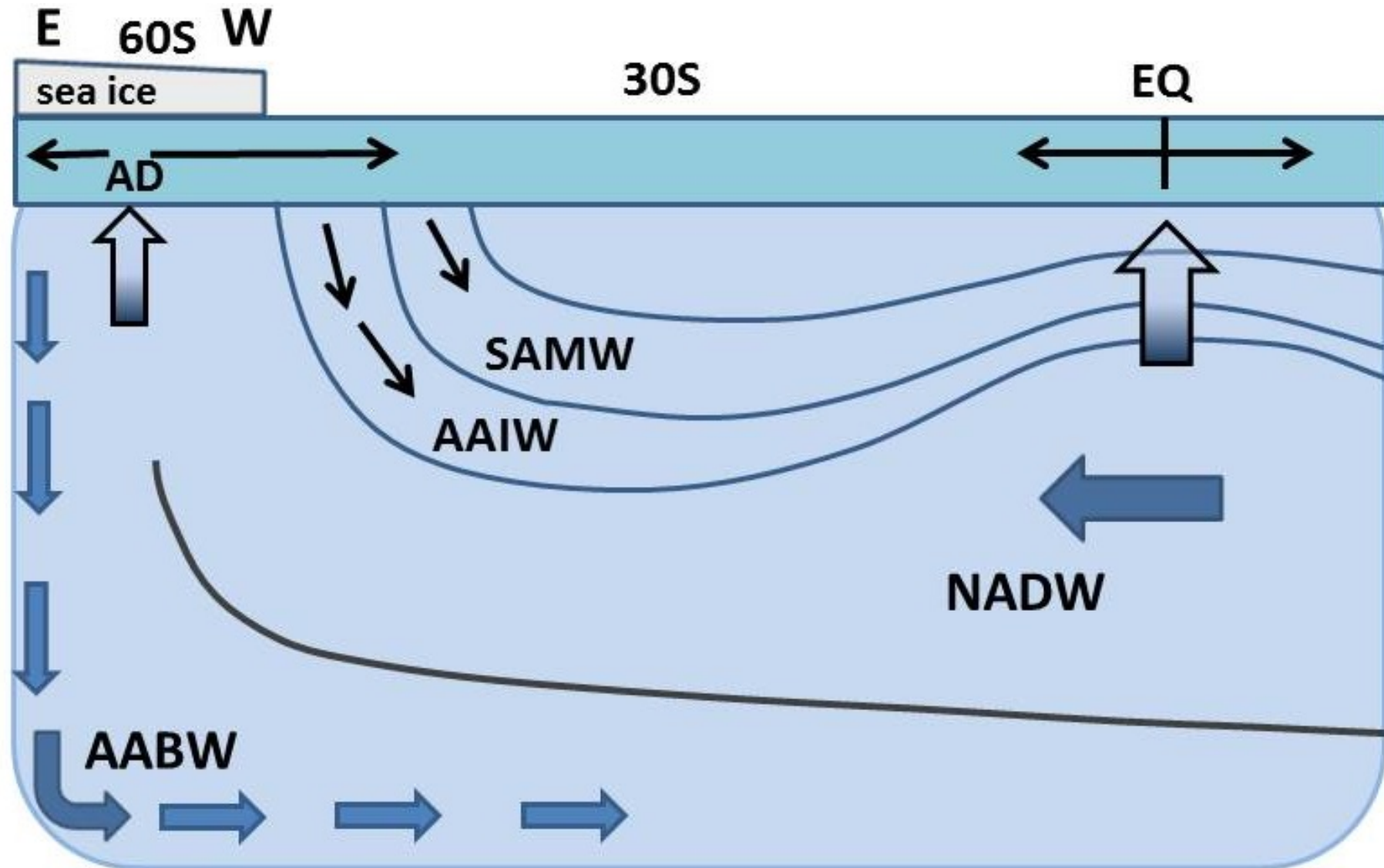
- A growing tropical precipitation asymmetry across different tropical continents is ubiquitous and robust in CMIP5 earth system models
- Analysis of C4MIP simulations indicates that significant driver of the growing asymmetry is plant physiological responses to rising CO₂
- New fully coupled simulations with CESM indicates that plant responses to rising CO₂ induce contrasting circulation changes in the Amazon and Indonesia
- ***Tropical forests in Central and South America may be more vulnerable to future drought stress than forests in Africa and Asia***

Challenges

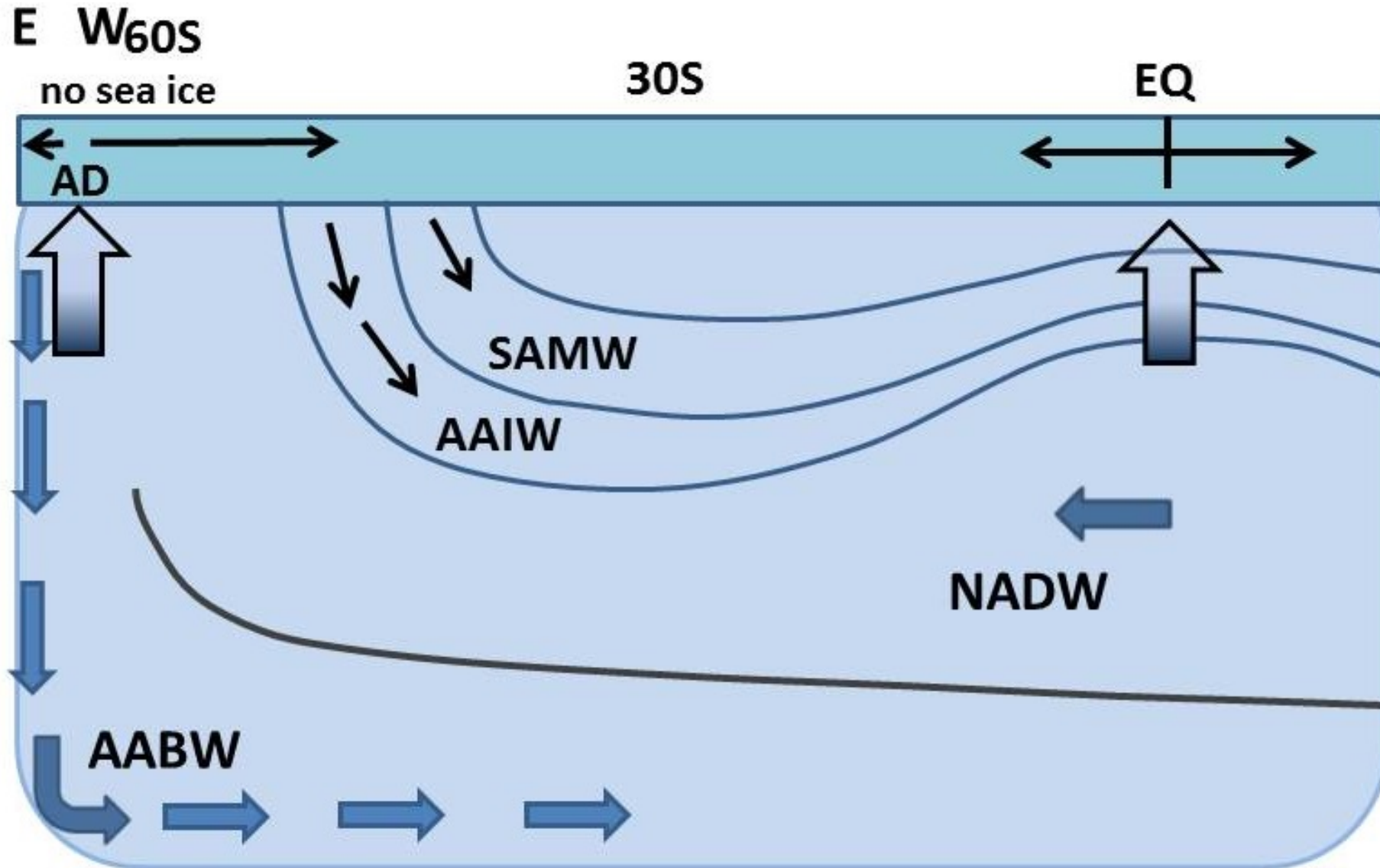
- Our understanding of the influence of CO₂ on water use efficiency and conductance is rapidly evolving; it is possible that sensitivity of transpiration to rising CO₂ has been systematically overestimated
- Do land use change and rising CO₂ reinforce each other on the different continents?



Mean Zonal Overturning Circulation - 2000 Climate



Mean Zonal Overturning Circulation - 2300 Climate



Amazon broadleaf forest burned area from the fully coupled CESM simulation

