Using large ensembles to study changes in terrestrial ecosystems

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Large Ensembles Workshop
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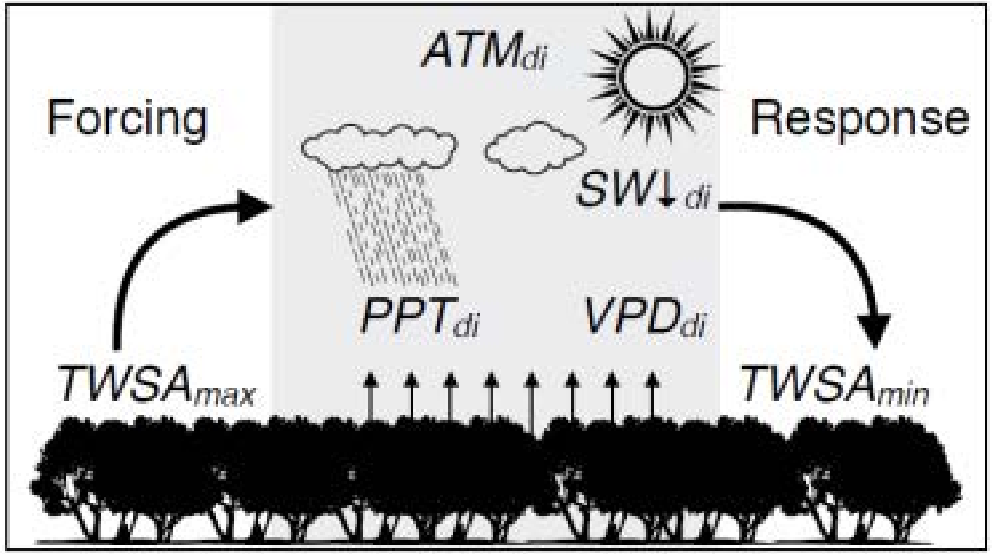
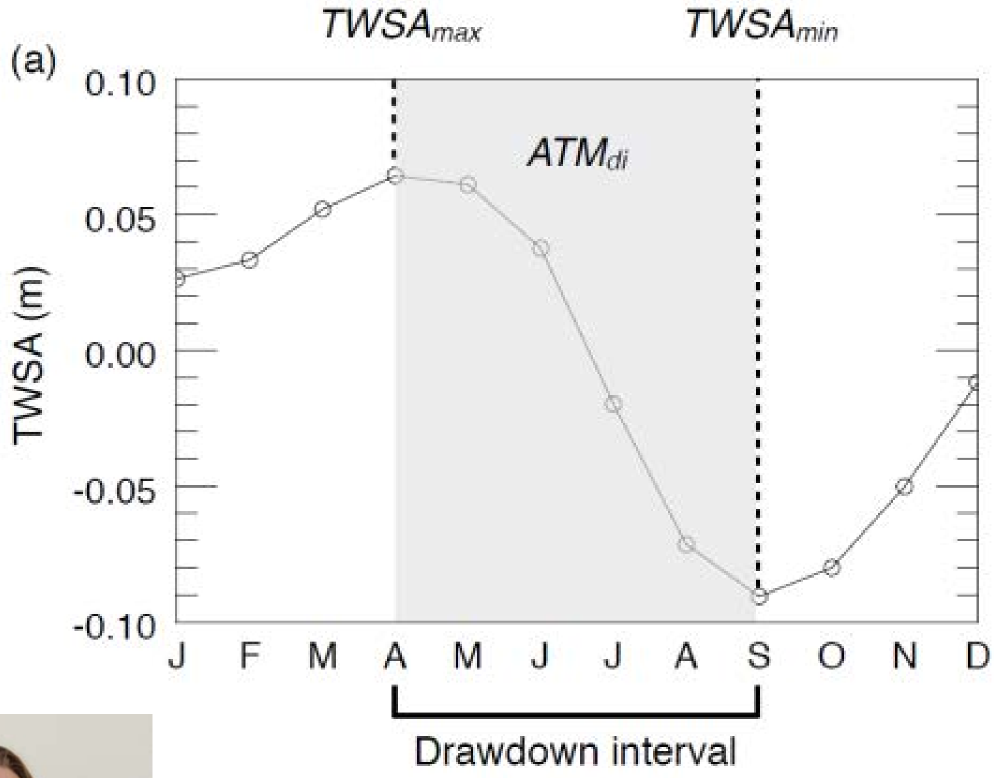
Are land surface models getting better over time?

- Assessment of model performance using ILAMB
- CMIP6 models perform better than CMIP5 models
- Why?
  - Driver variables look to have smaller biases (air temperature, precip.)
  - Improvements in model mechanism (permafrost, nitrogen cycle, fires)

Hoffman et al. (in prep)

Do ESMs accurately represent the strength of land-atmosphere coupling?





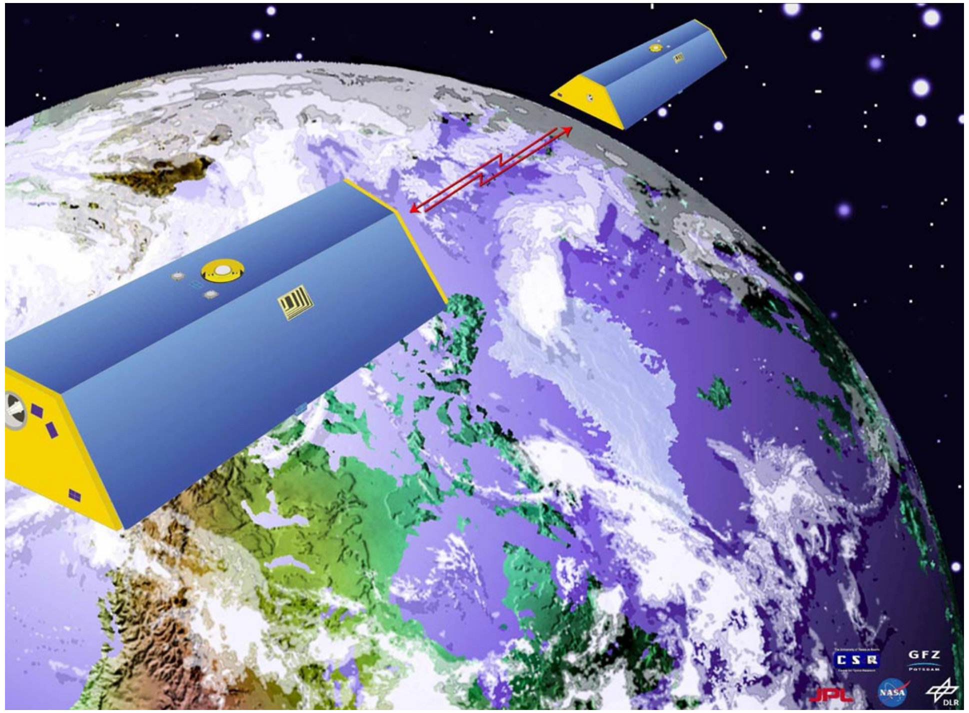
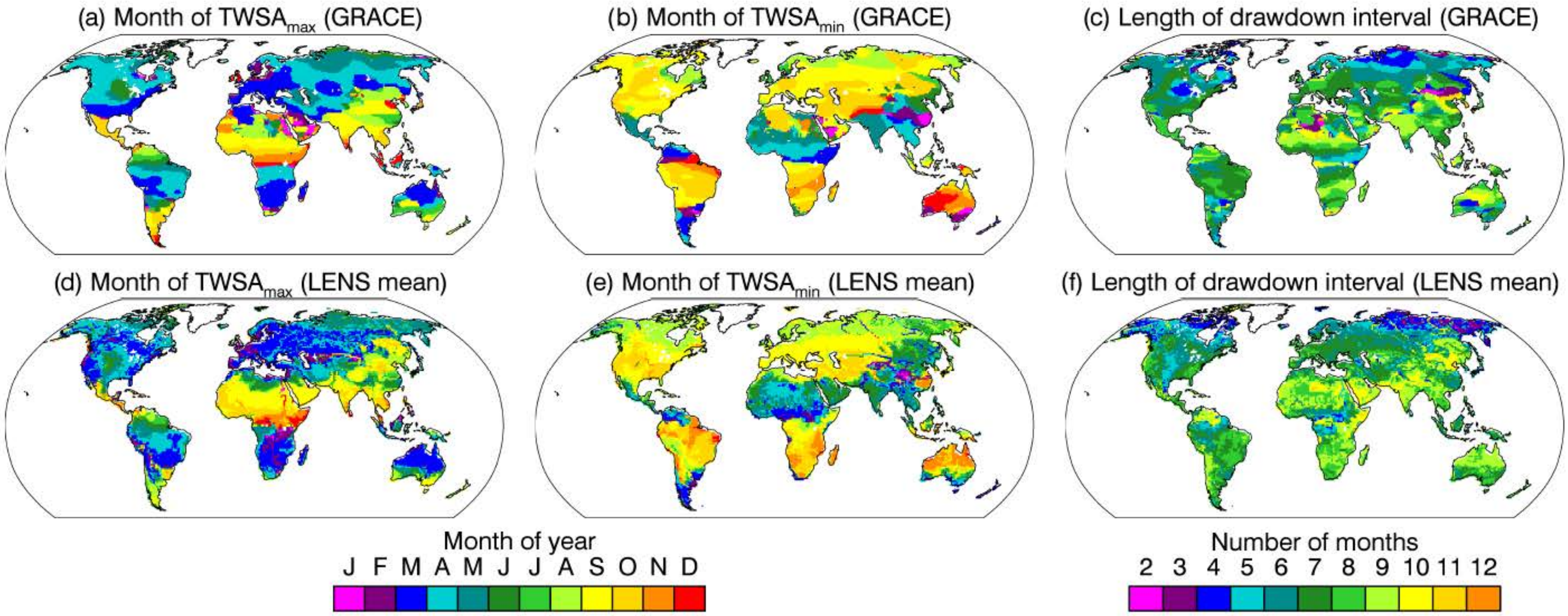


Table 1. Remote sensing products used for analysis.

Variable	Abbr.	Data product	Spatial resolution	Temporal resolution	Reference
Terrestrial water storage	TWS	GRACE Tellus RL05.1	1°	monthly	Landerer and Swenson (2012)
Vapor pressure deficit	VPD	AIRS AIRX3STM v6	1°	monthly	Susskind et al. (2014)
Precipitation	PPT	GPCP 1DD v1.2	1°	daily	Huffman et al. (2009)
Downwelling shortwave radiation	SW↓	CERES EBAF Ed2.8	1°	monthly	Loeb et al. (2009)

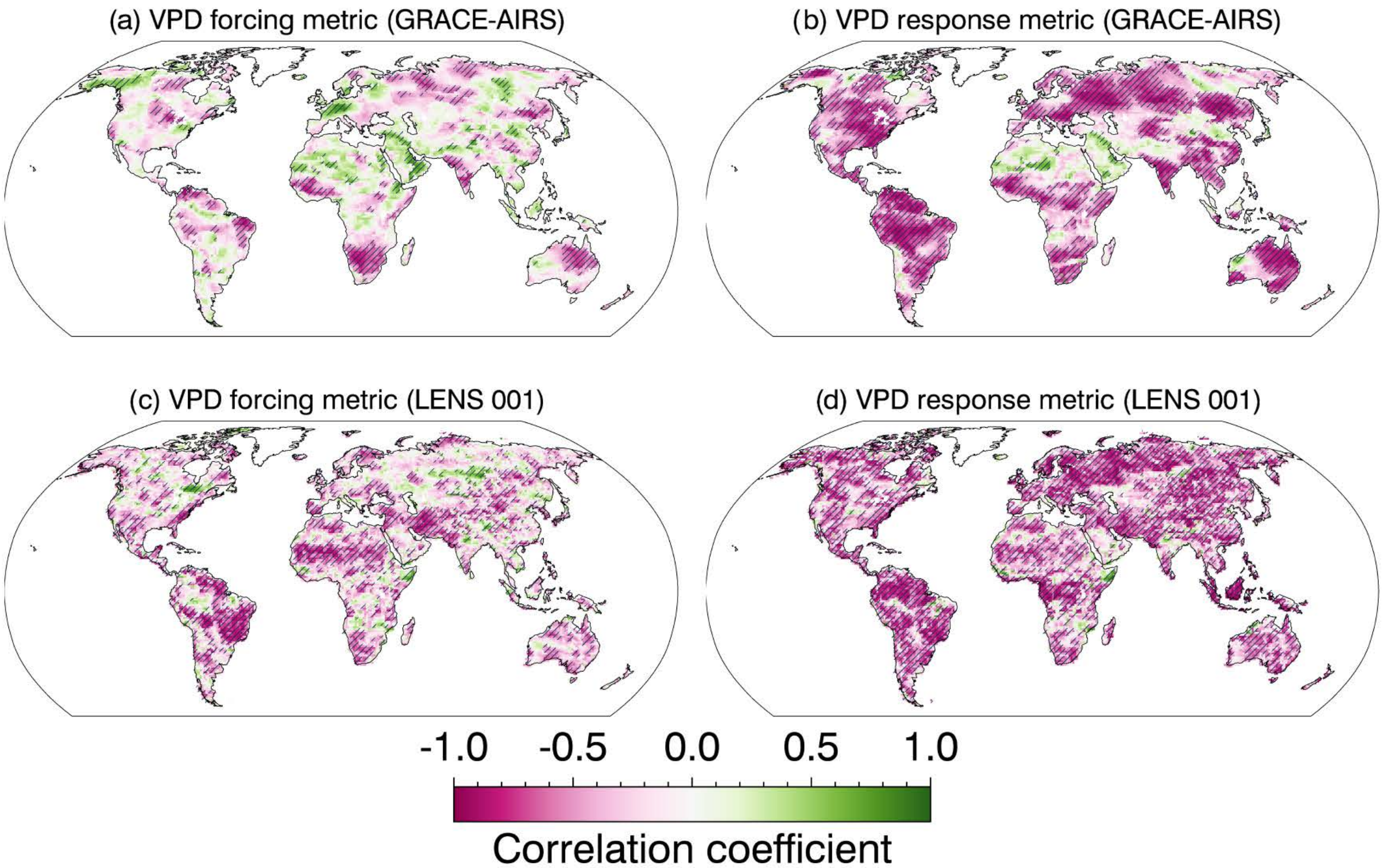
Timing of onset, termination, and duration of drawdown interval (dry season)



Example relationships between soil moisture and atmospheric state variables

Forcing metric

Response metric



In tropical and temperate regions, the forcing branch of land-atmosphere coupling in CESM1-LENS looks to be too strong

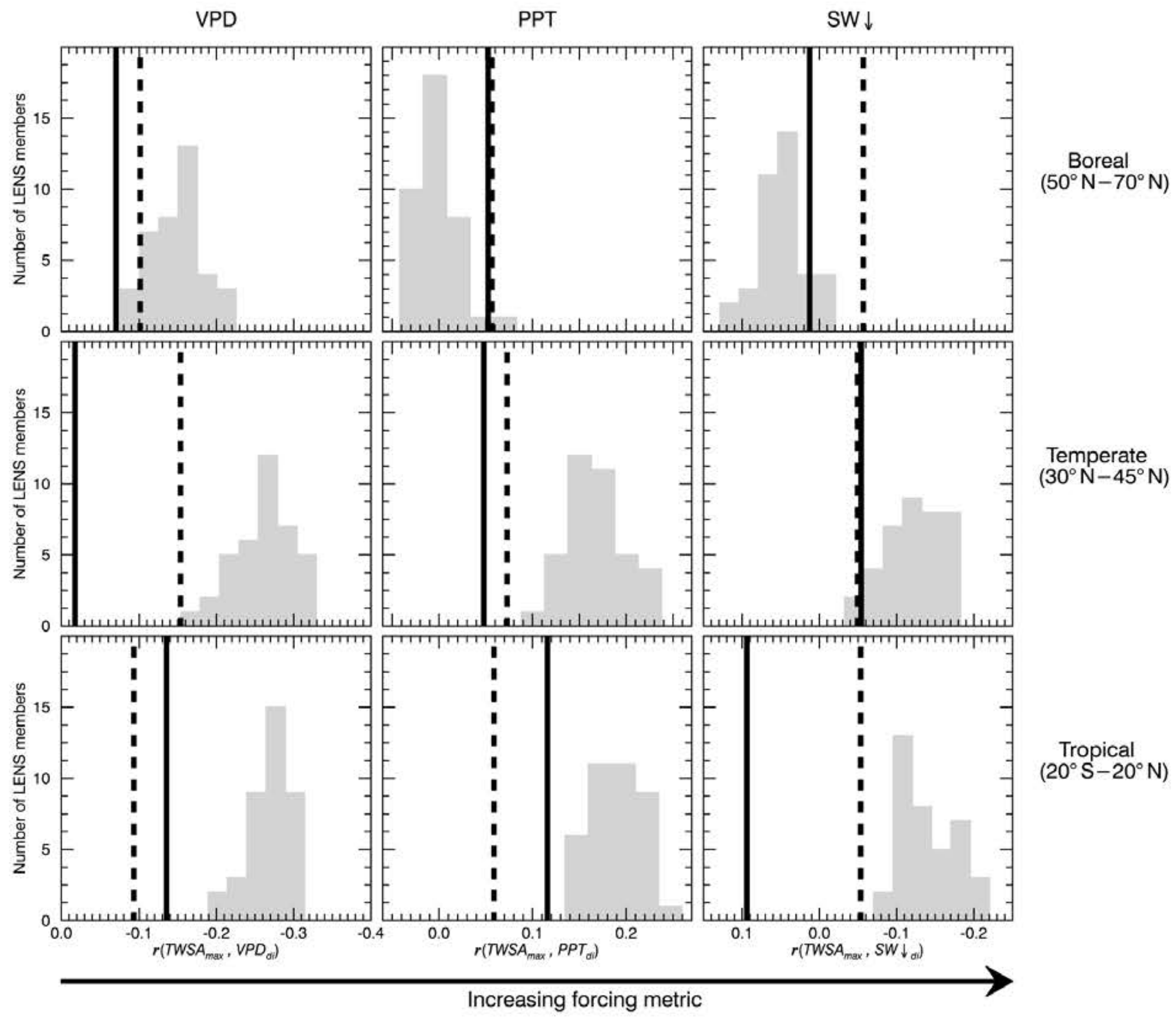
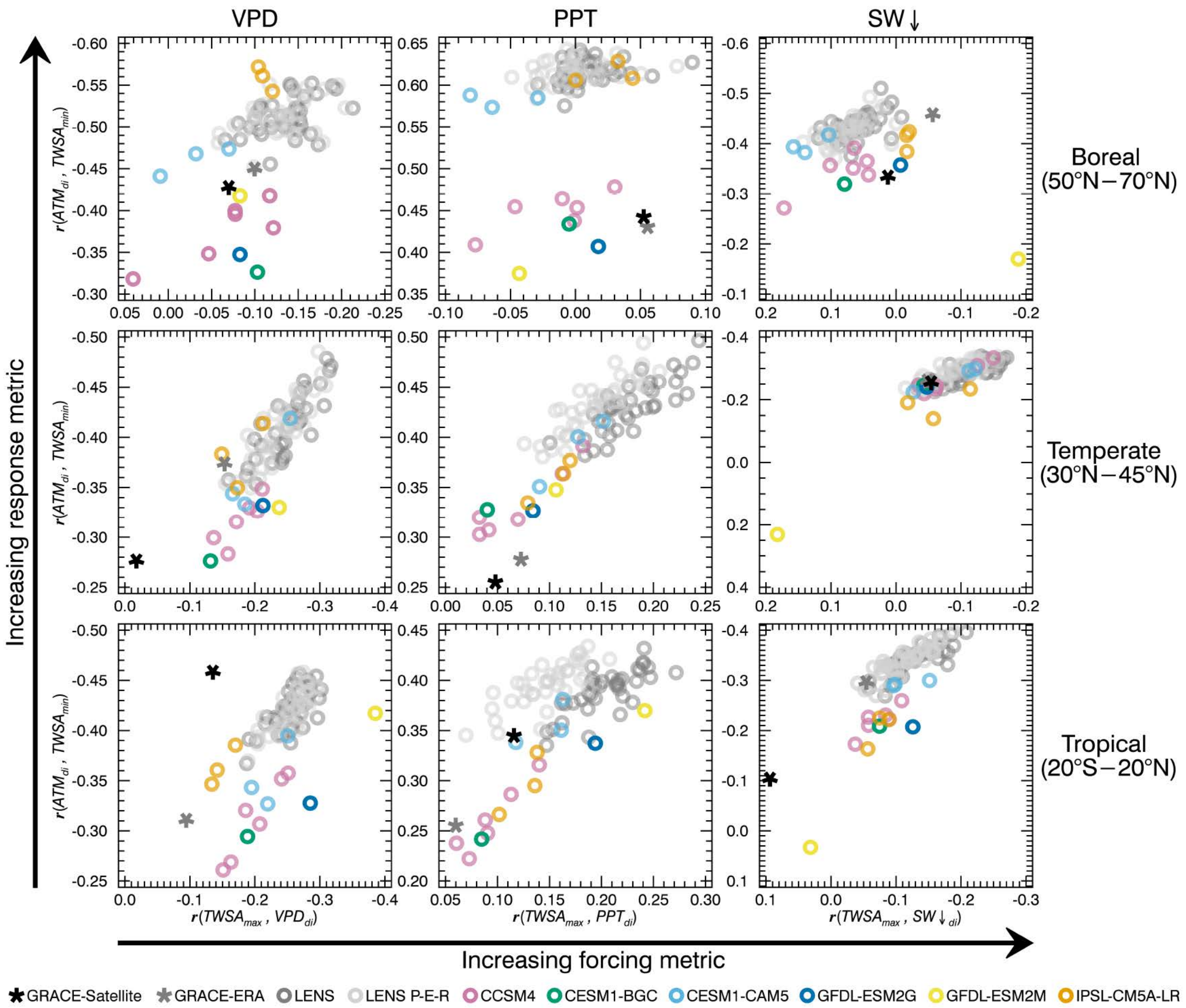


Figure 8. Ensemble histogram of forcing metrics from the 38 simulations in LENS (gray bars) compared to satellite observations from GRACE/AIRS/GPCP/CERES (solid black line) and the alternate set of observations from GRACE and ERA-Interim (dashed black line), averaged across land regions within different latitude bands.



VPD
PPT
SW↓
Boreal (50°N–70°N)
Temperate (30°N–45°N)
Tropical (20°S–20°N)
Increasing response metric
Increasing forcing metric
r(ATM_di , TWSA_min)
r(TWSA_max , VPD_di)
r(TWSA_max , PPT_di)
r(TWSA_max , SW↓_di)
GRACE-Satellite
GRACE-ERA
LENS
LENS P-E-R
CCSM4
CESM1-BGC
CESM1-CAM5
GFDL-ESM2G
GFDL-ESM2M
IPSL-CM5A-LR

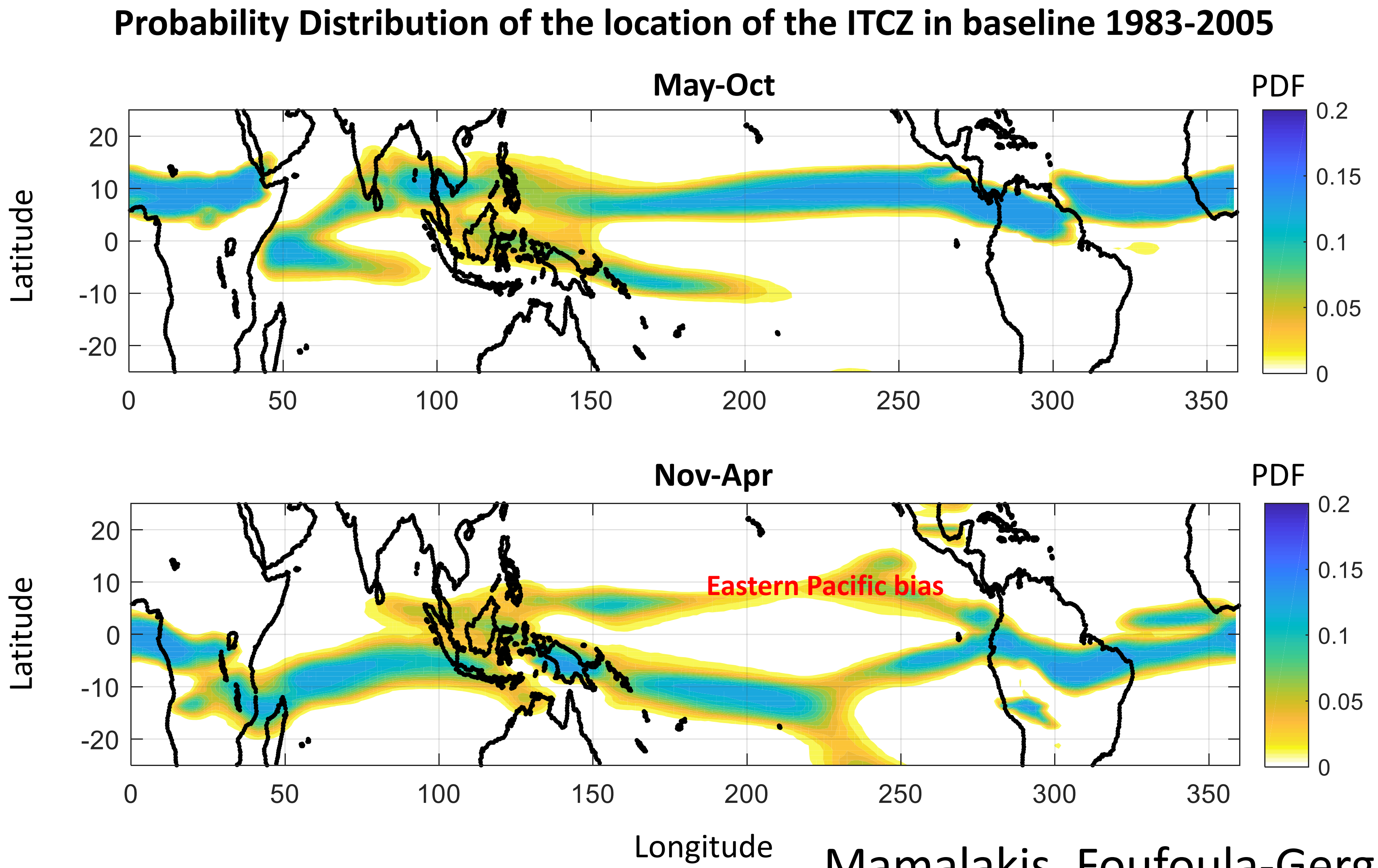
Land-atmosphere coupling findings

- To evaluate the land-atmosphere moisture feedback, its important conceptually to consider both soil moisture forcing of the atmosphere, but also the response of soil moisture to atmospheric forcing
- Biases in either branch can affect the strength of the land-atmosphere moisture feedback
- CESM1 and many other CMIP5 models appear to exhibit too strong a land-atmosphere moisture feedback
- Land-atmosphere coupling likely amplifies and extends terrestrial carbon cycle responses to ENSO forcing in the Amazon and elsewhere

Levine, P.A., J.T. Randerson, S.C. Swenson, and D.M. Lawrence. 2016. Evaluating the strength of the land-atmosphere moisture feedback in earth system models using satellite observations. *Hydrology and Earth System Sciences*. 20: 4837-4856.

Levine, P.A., M. Xu, F.M. Hoffman, Y. Chen, M. S. Pritchard, and J.T. Randerson. 2019. Soil moisture variability intensifies and prolongs eastern Amazon temperature and carbon cycle response to El Niño-Southern Oscillation. *Journal of Climate*. 32: 1273–1292. doi: 10.1175/JCLI-D-18-0150.1.

Climate change impacts on the position of the ITCZ and patterns of tropical precipitation in CESM1-LENS

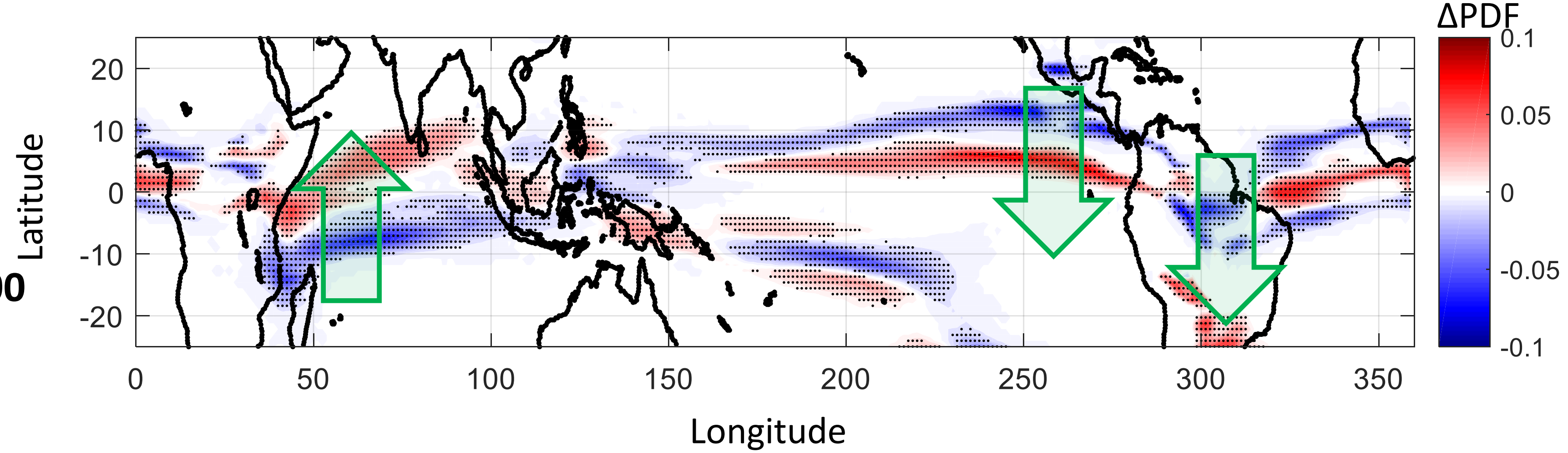


Mamalakis, Foufoula-Gergiou et al., In prep.

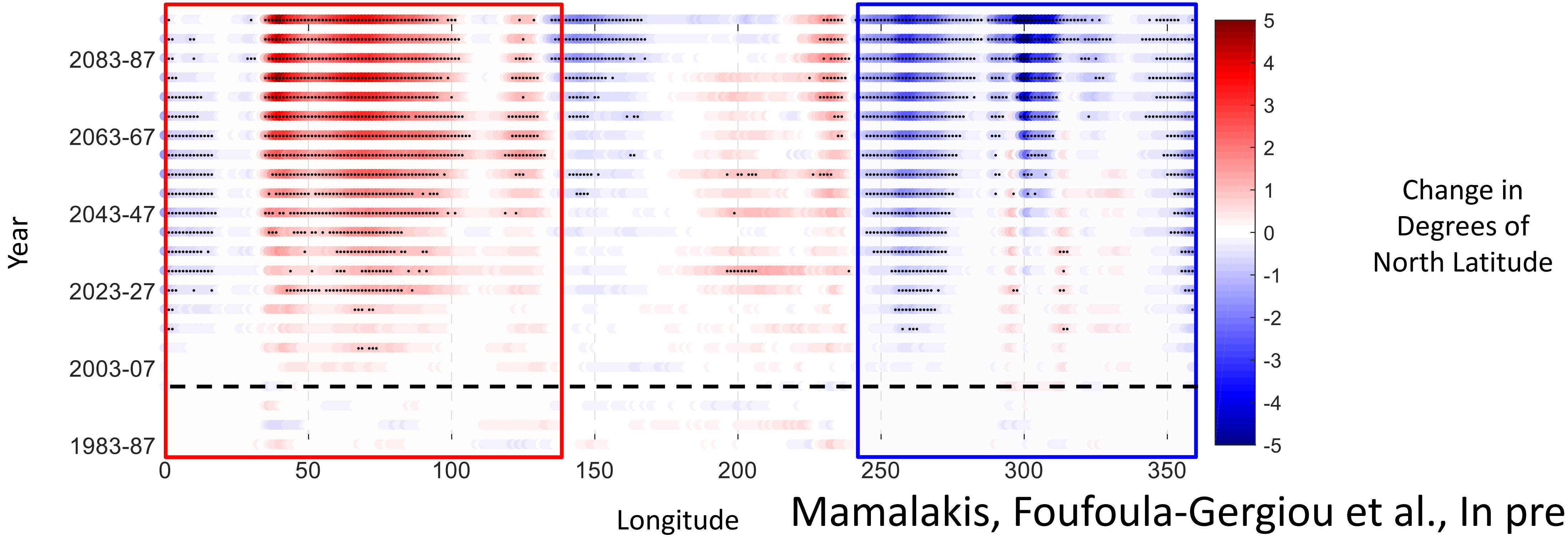
Changes in the ITCZ show a diverging pattern across Eastern and Western Hemispheres

CESM-LENS

Difference in the distribution of the ITCZ location between 2075-2100 and 1983-2005



Future trends in the location of the ITCZ



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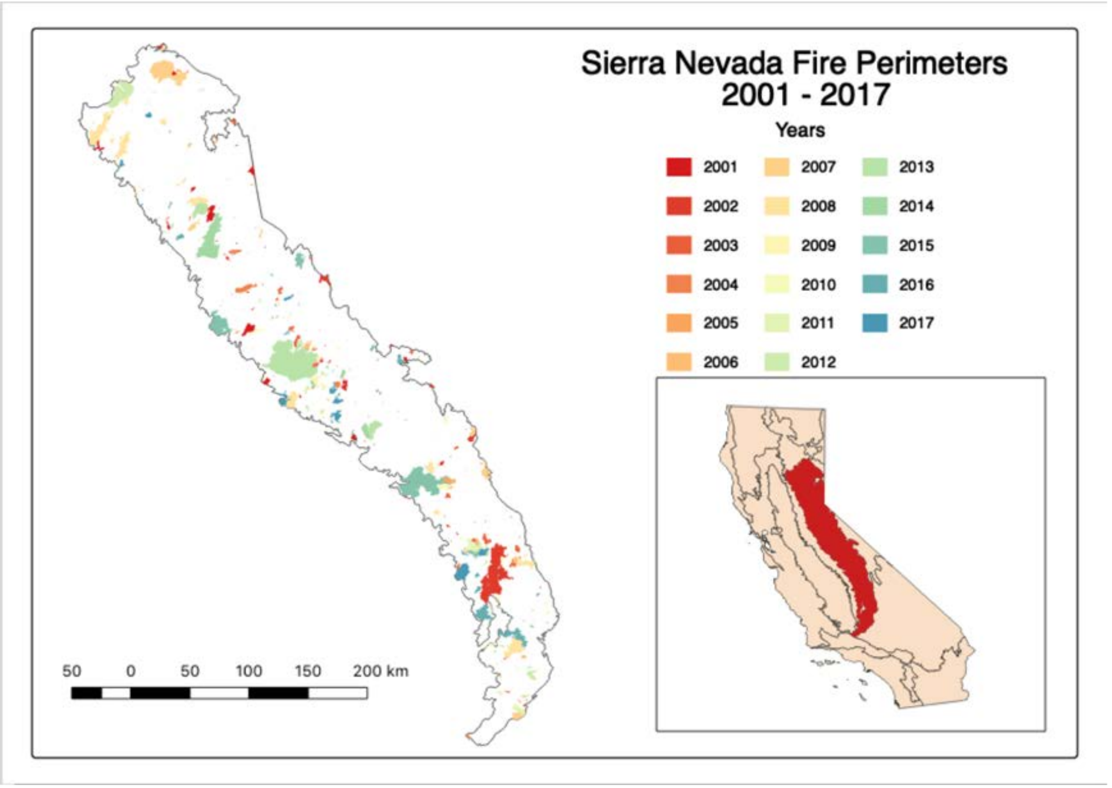
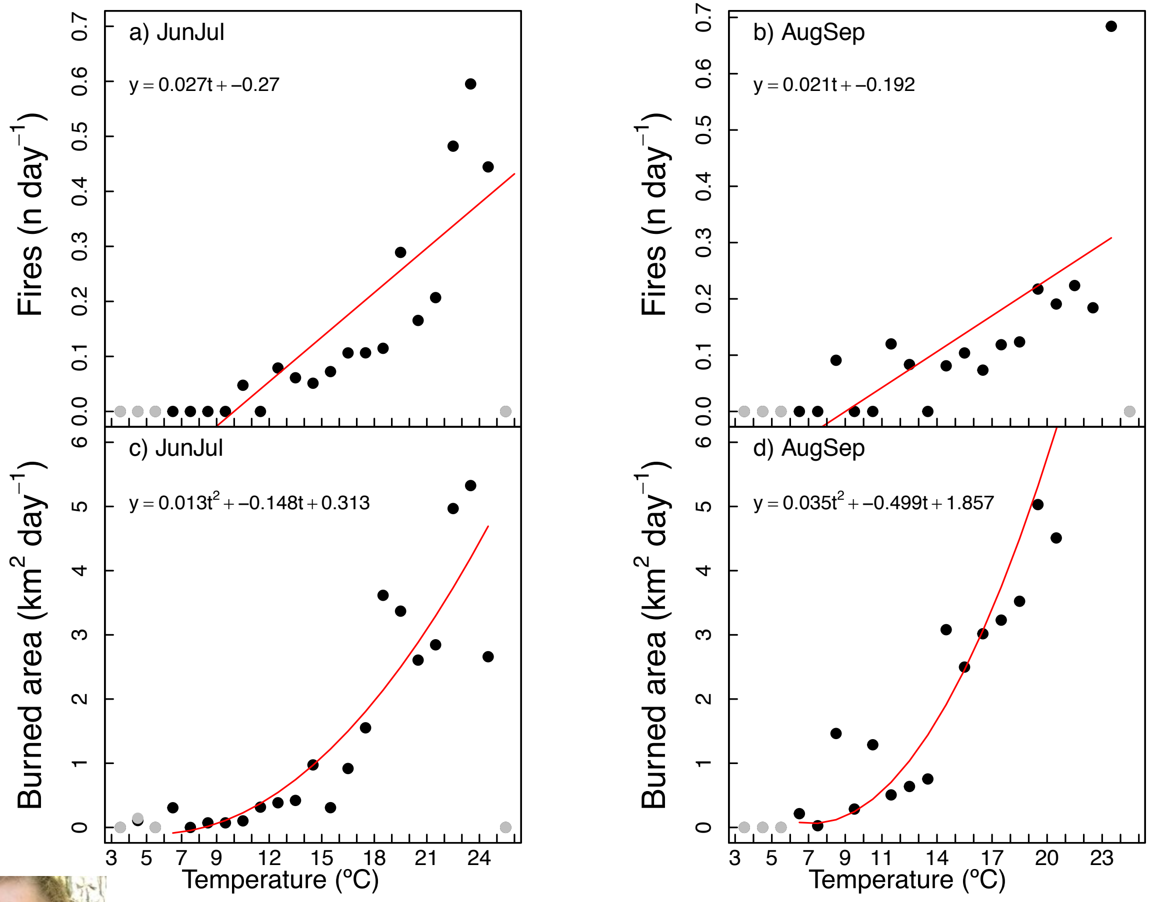
The effect of daily climate extremes on California wildfires

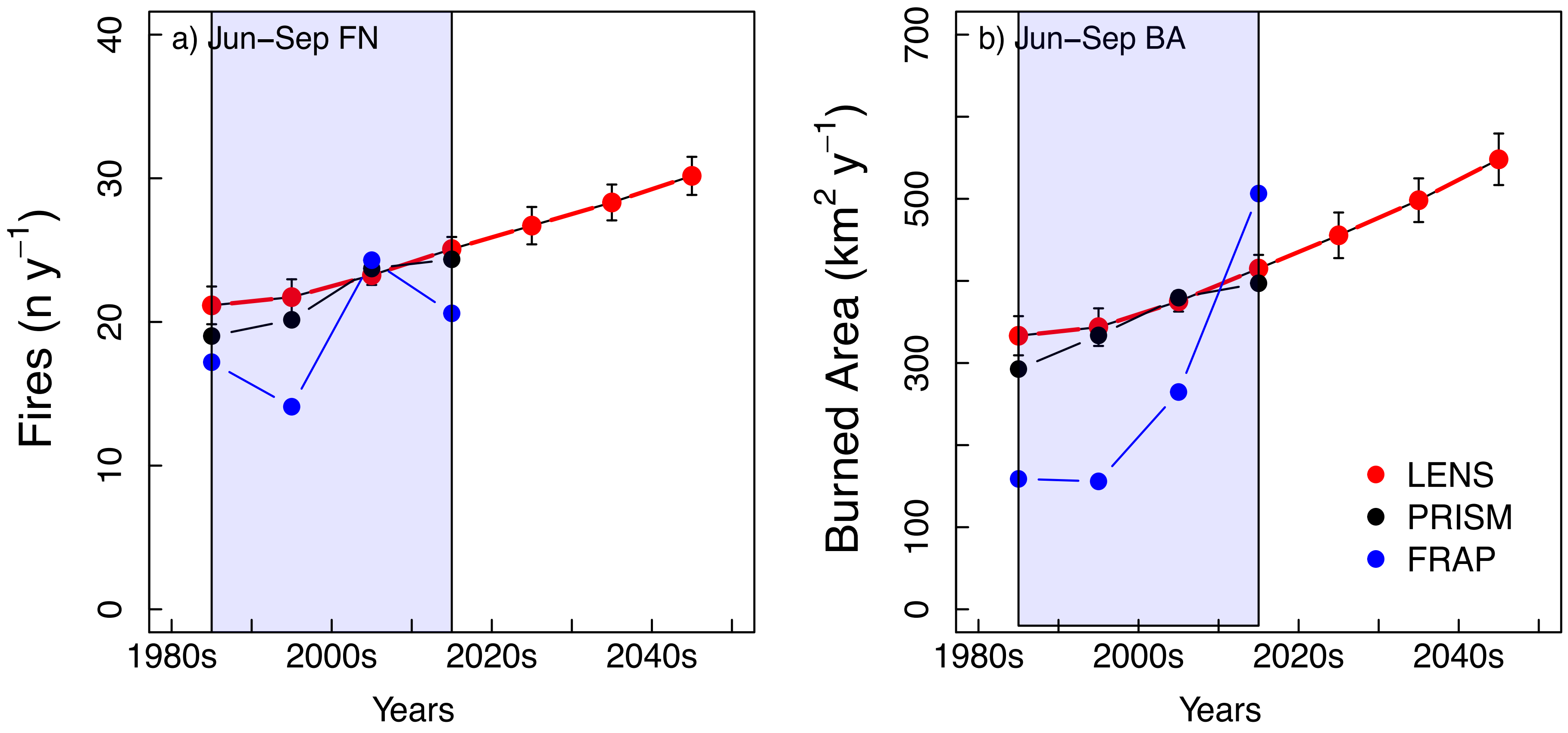




Data sources: Daily MODIS burned area and daily PRISM

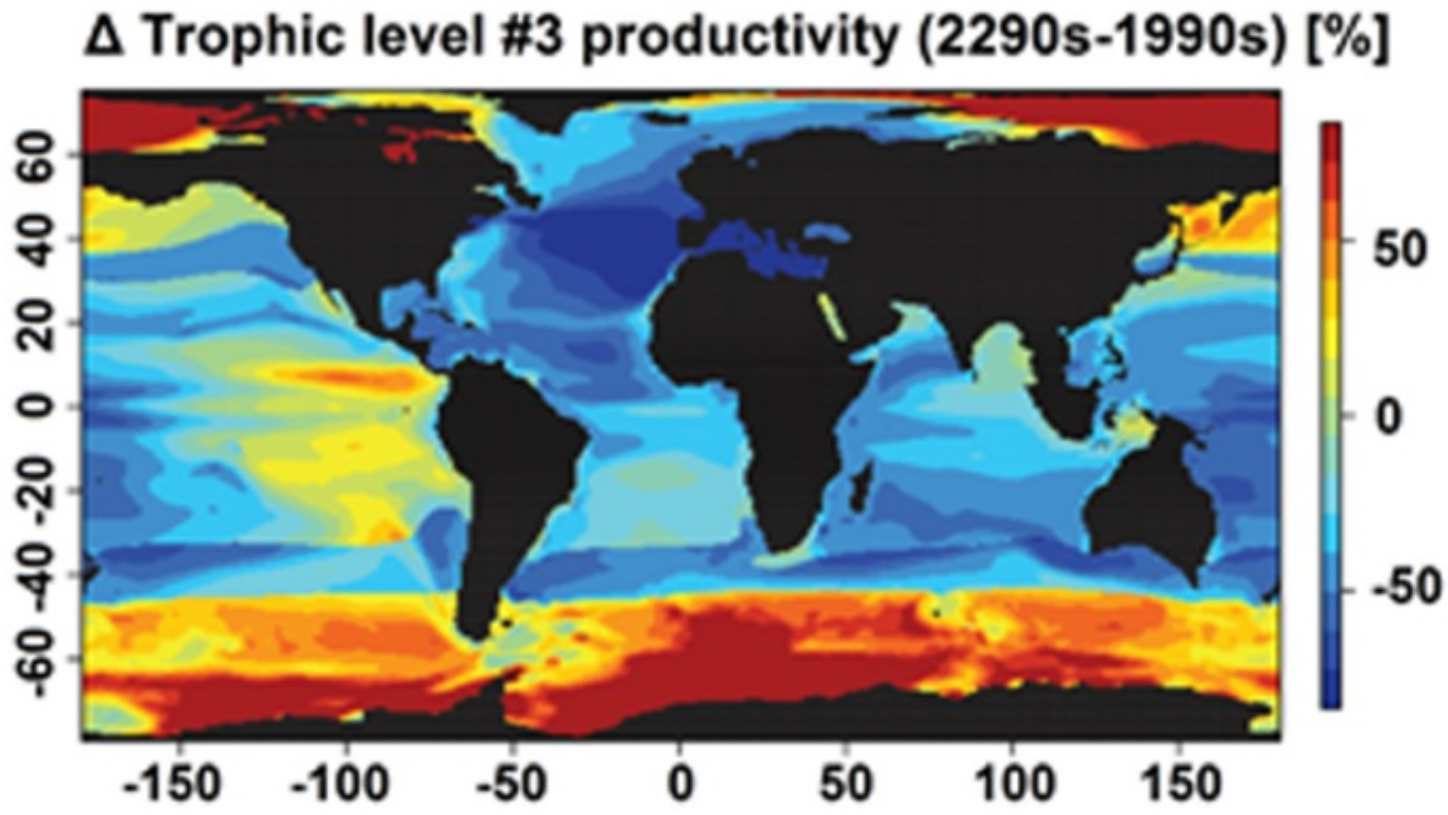
Gutierrez et al.

The effect of daily climate extremes on California wildfires



Gutierrez et al.

Longer term ensembles to 2300 and beyond are needed to quantify the robustness of new climate-driven ecological teleconnections



- Loss of sea ice around Antarctica stimulates a massive phytoplankton bloom after 2100 for RCP8.5
- Nutrients are trapped in the deep Southern Ocean
- Northward water flows into Atlantic and Pacific are depleted in N, P, Si
- Ocean fisheries decrease more than 30% globally north of 40°S, and by nearly 60% in the North Atlantic

Moore et al. (2018) *Science*

Conclusions

- Variability in comparison to benchmarks is much larger across different land surface models than among ensemble members of a single model
- Better metrics are needed for evaluating large ensembles
- More work is needed integrating large ensembles into BGC and land benchmarking systems (and into CMIP7 and beyond)
- Using GRACE observations, there is some evidence that CESM1 (LENS) and many CMIP5 models overestimate the strength of land-atmosphere moisture feedback
- A new frontier is to use large ensembles to explore the robustness of climate-driven ecological teleconnections on longer timescales

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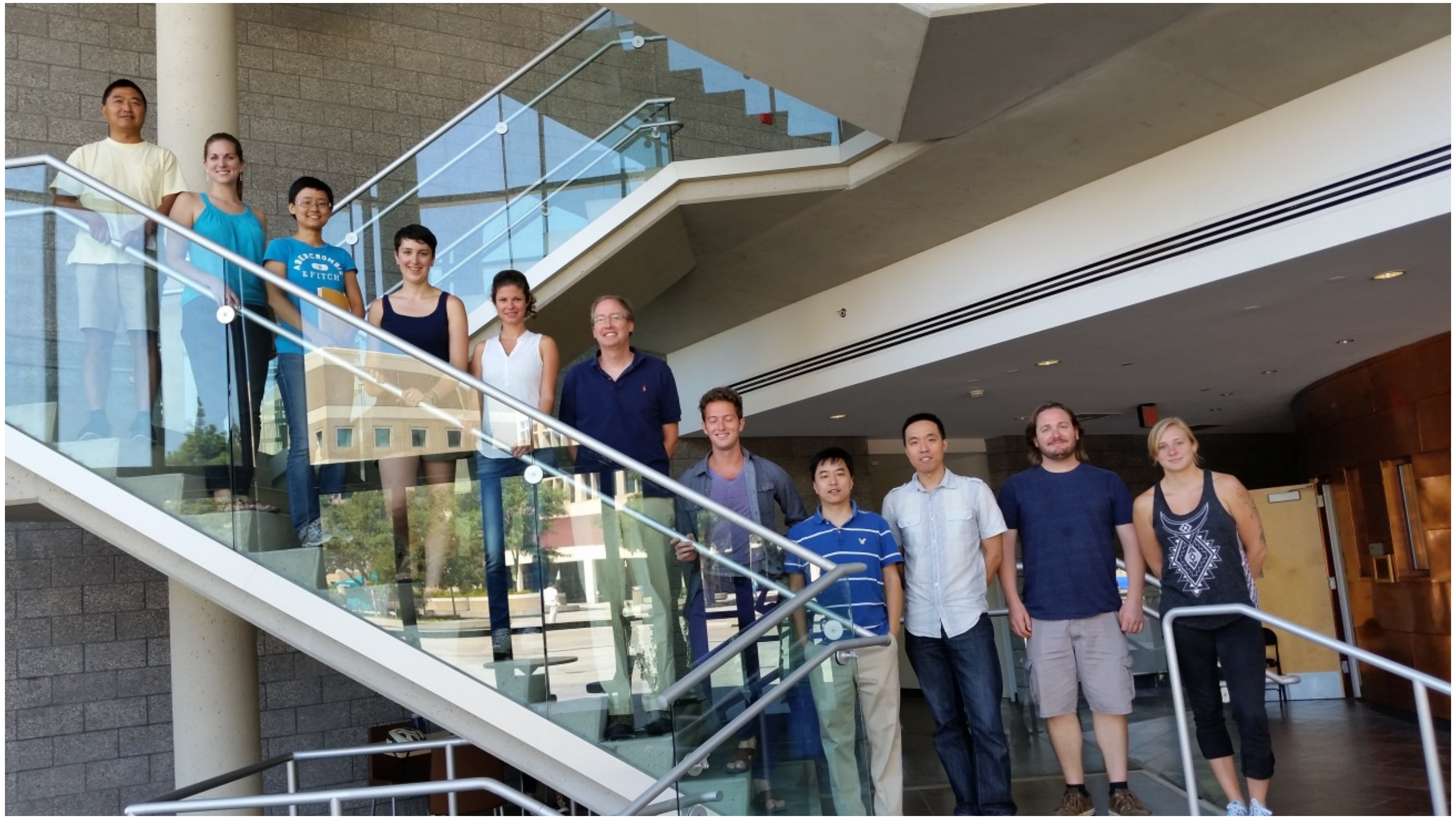
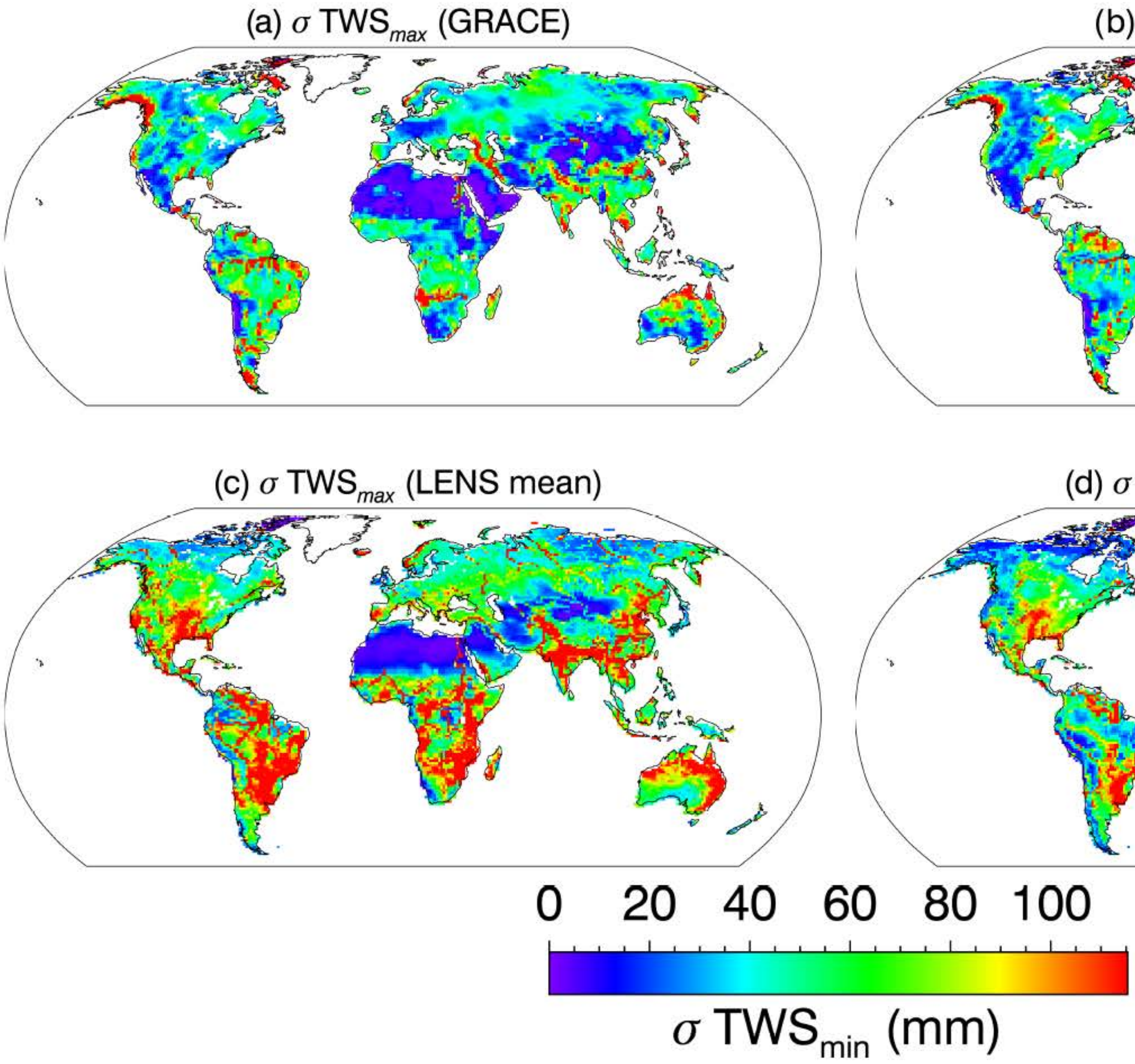




Levine et al. (2016) HESS

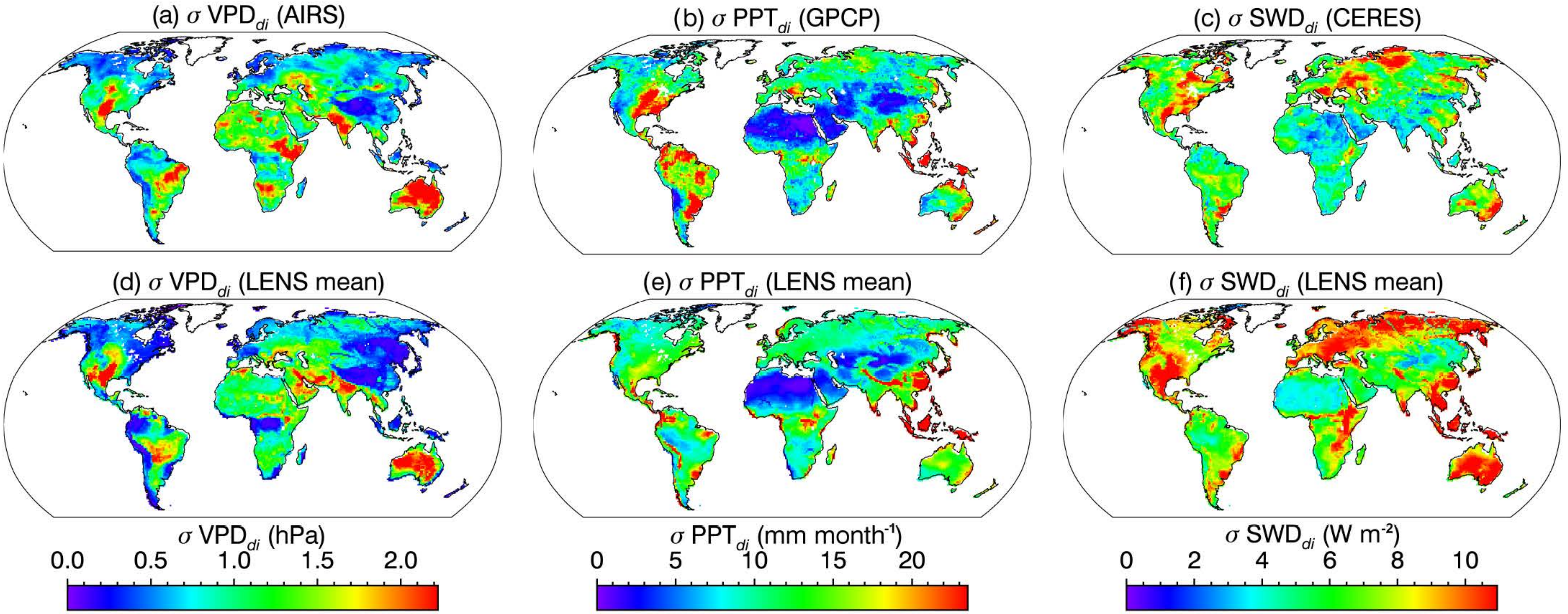
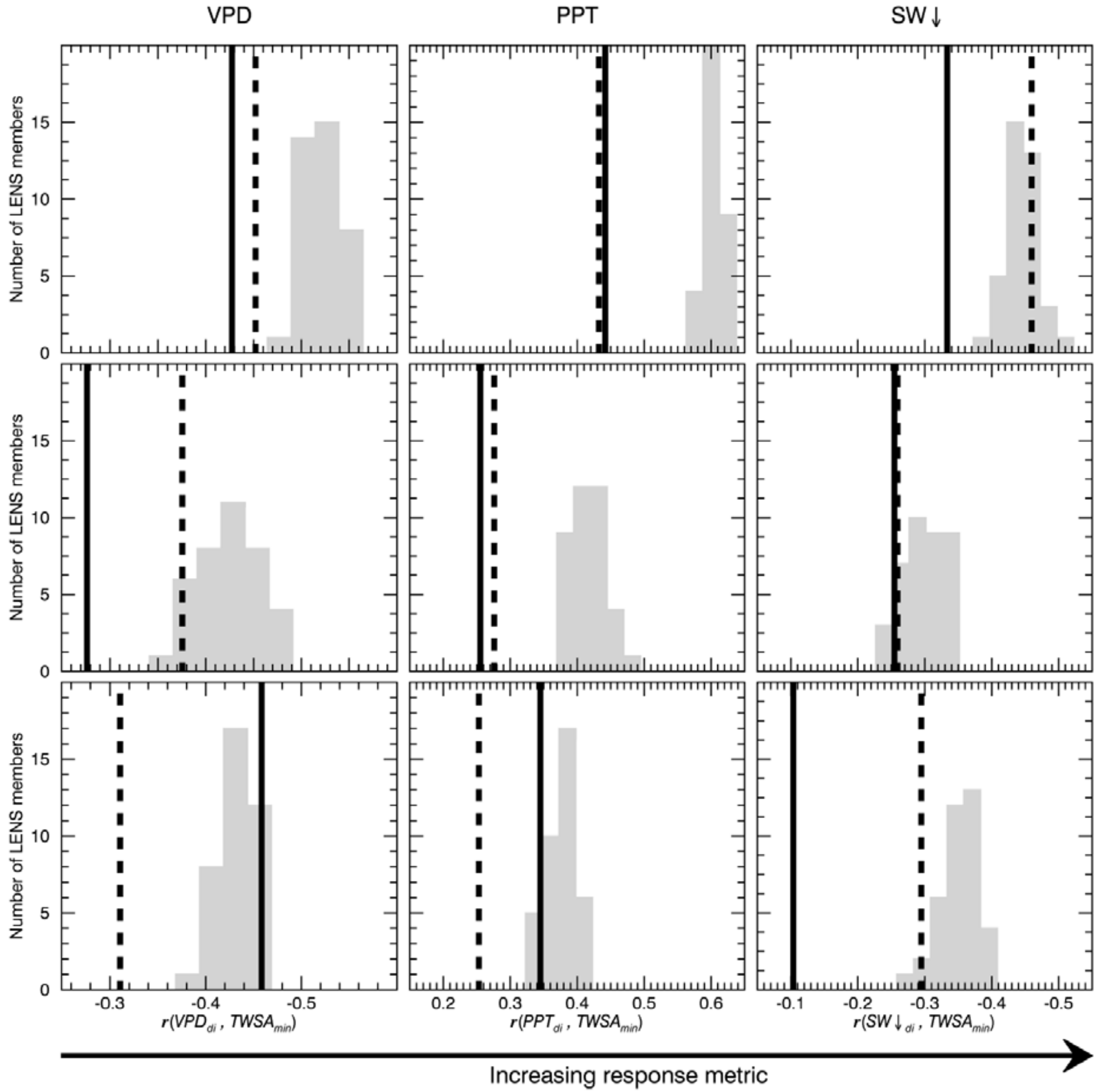


Figure 4. Interannual variability (standard deviation) of VPD_{di} from AIRS **(a)**, PPT_{di} from GPCP **(b)**, $SW{\downarrow}_{di}$ from CERES **(c)** and the equivalent quantities from the LENS ensemble mean **(d–f)**.

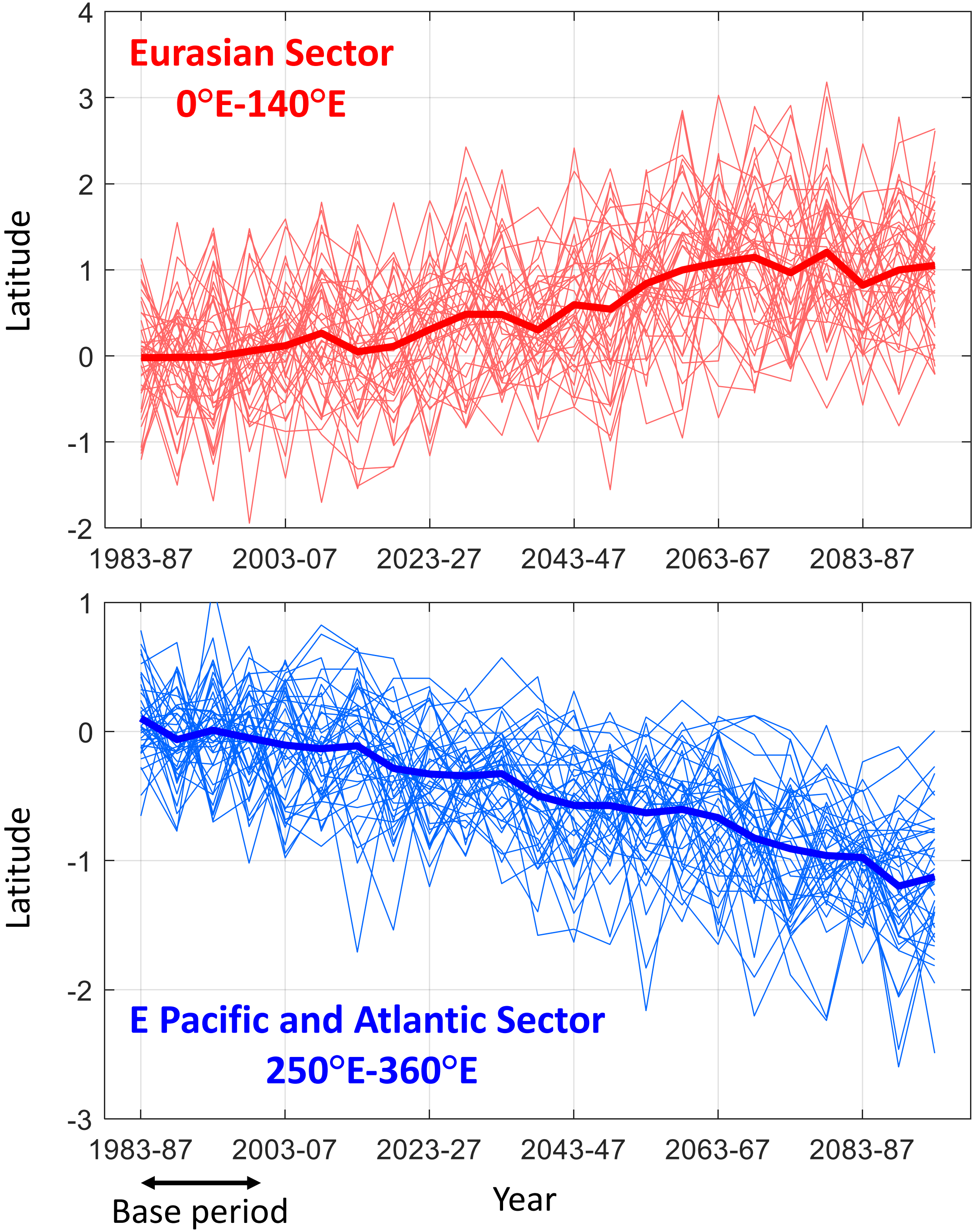
Levine et al. (2016) HESS

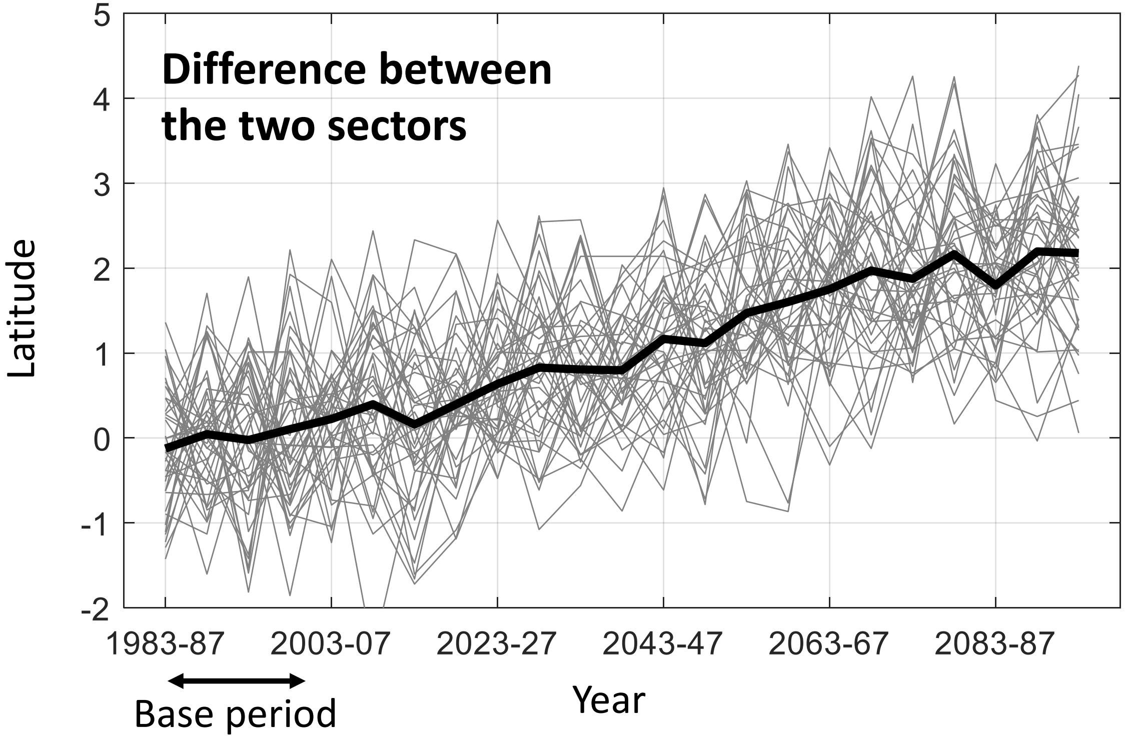
In tropical and temperate regions, the response branch of land-atmosphere coupling in CESM1-LENS looks to be somewhat stronger than observations



Levine et al. (2016) HESS

Future trends in the location of the ITCZ

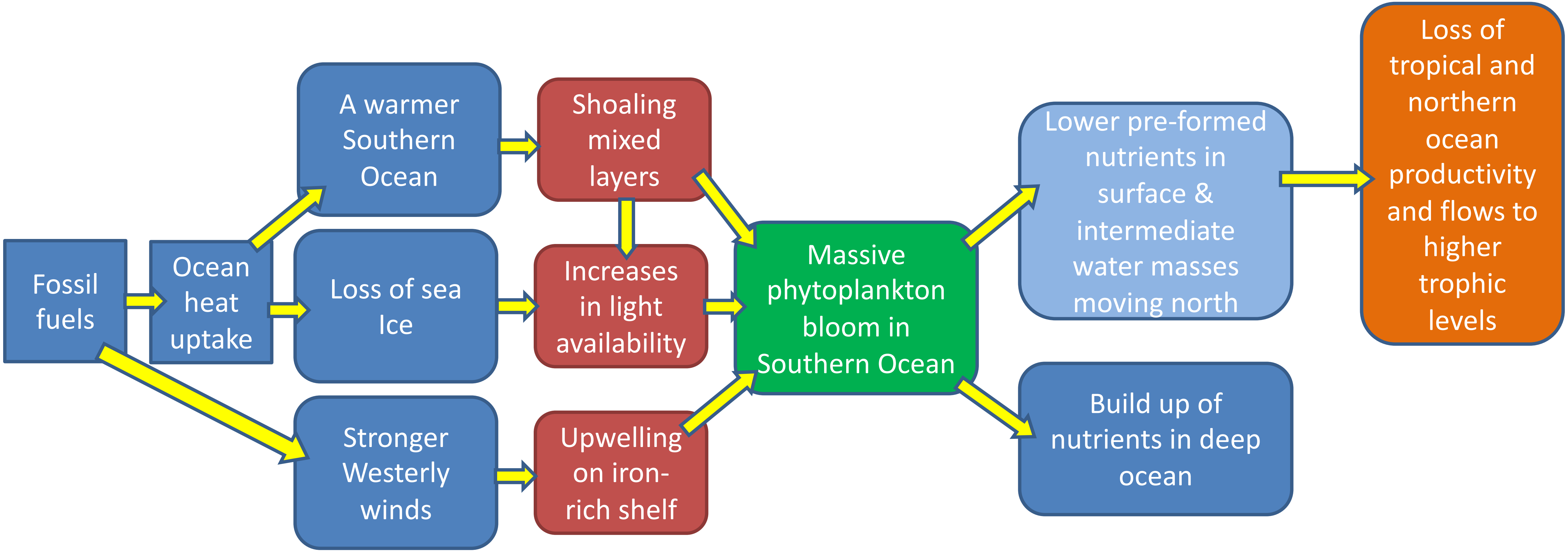


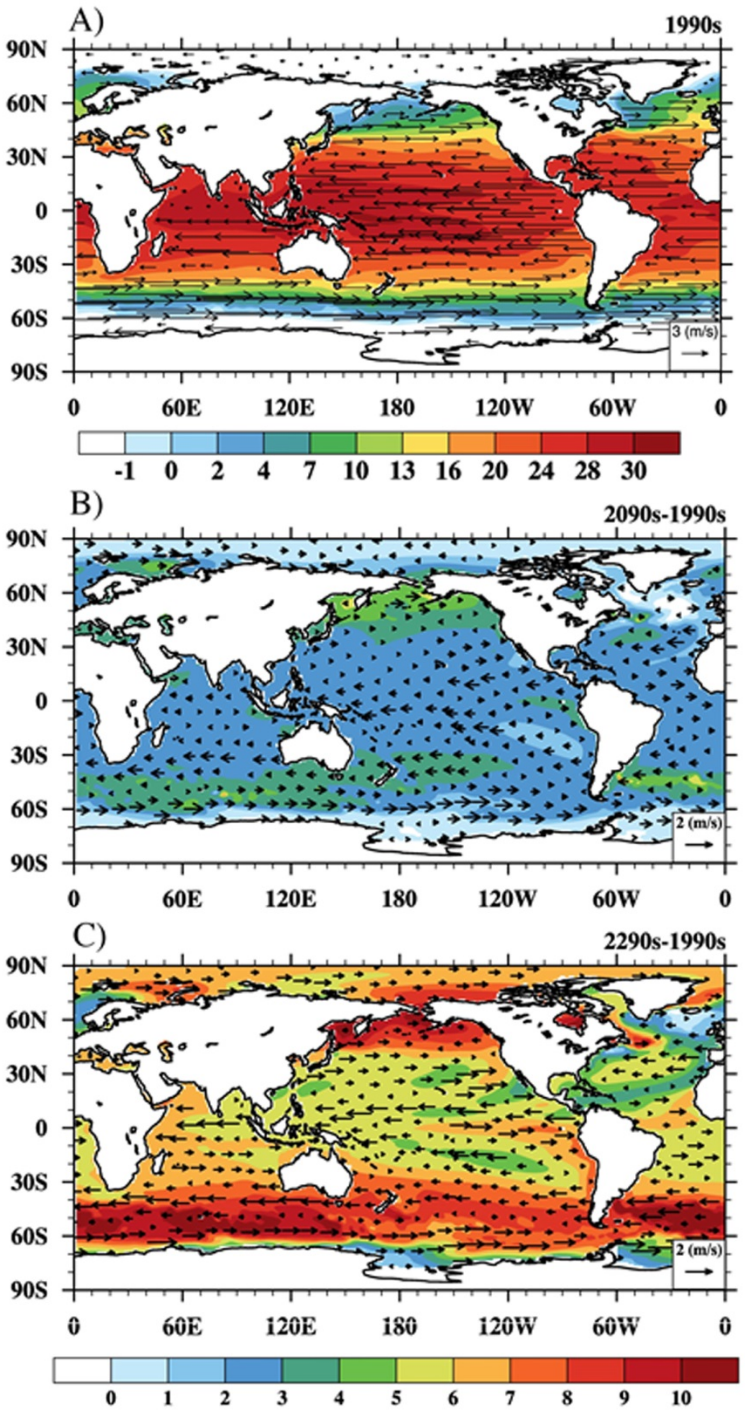


Mamalakis, Foufoula-Gergiou et al., In prep.

A Global Ecological Teleconnection Driven By Nutrient Trapping

Definition: Global change impact on the biosphere in one region generates a large-scale change in another remote region, as a consequence of changes in transport of energy, water, nutrients, or information

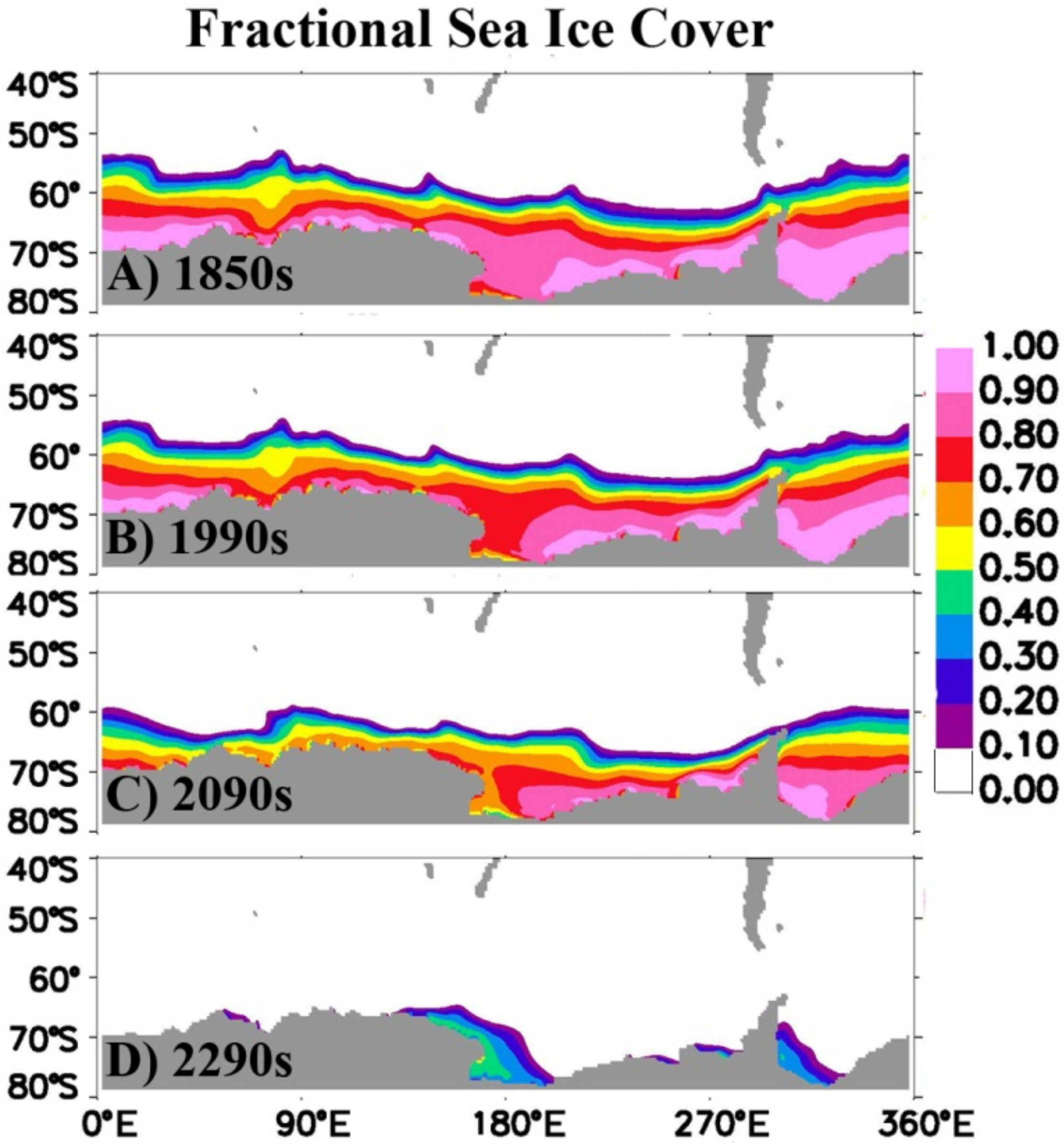




Ocean warming is stronger at high latitudes, and the southern hemisphere Westerlies shift south, strengthening near the coast of Antarctica

Moore et al. (2018) Science

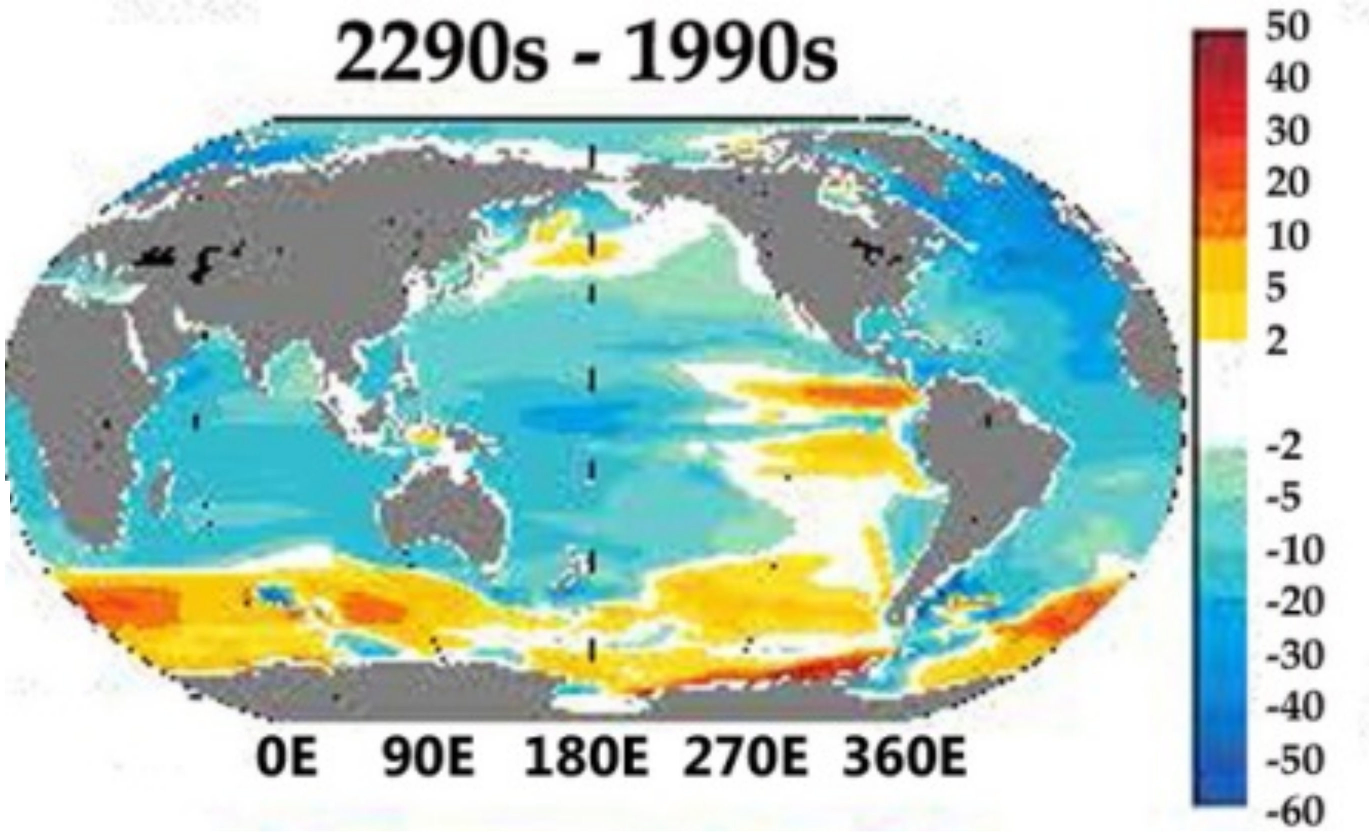
Ocean Warming Around Antarctica Decreases Sea Ice



Moore et al. (2018)

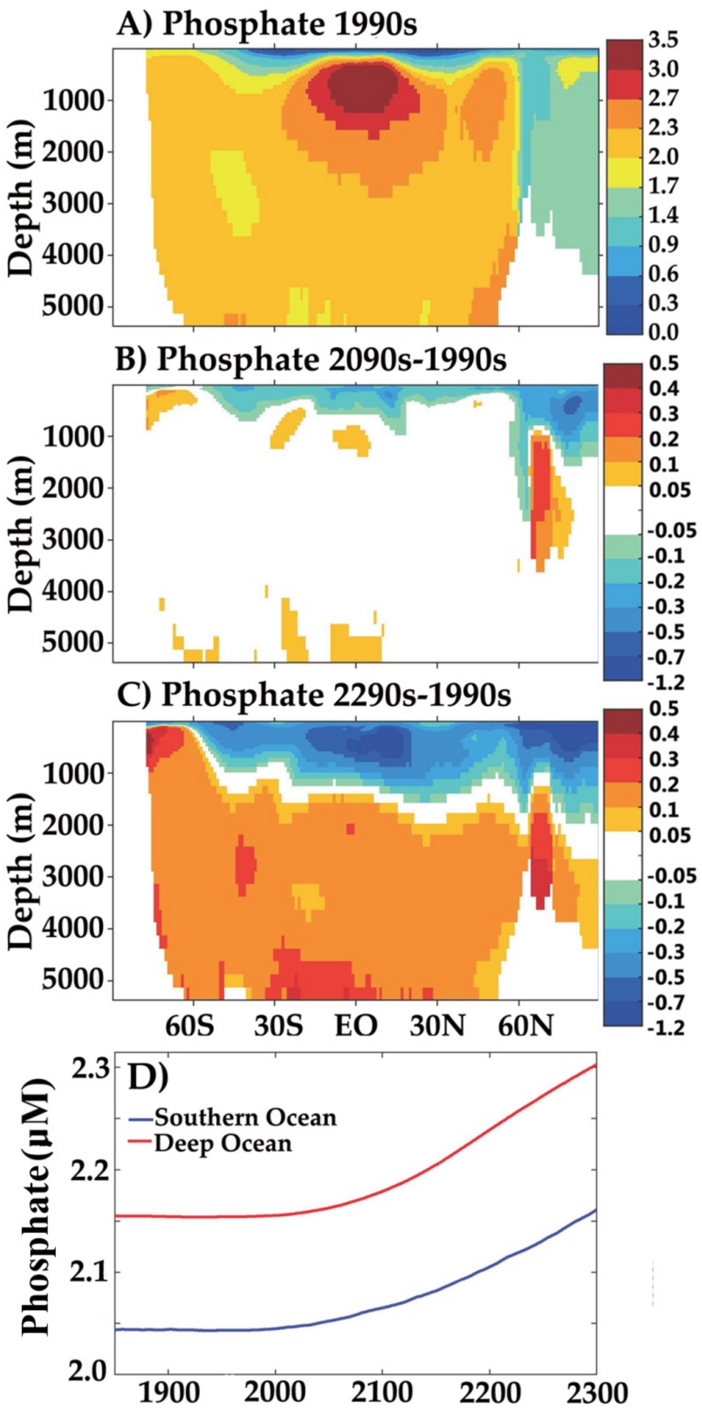
The changing climate stimulates a phytoplankton bloom around Antarctica

Particulate sinking carbon flux



gC/m2/yr

Moore et al. (2018) *Science*



Sinking biological particles in the Southern Ocean carry nutrients with them

This traps phosphorus and other nutrients in the deep ocean

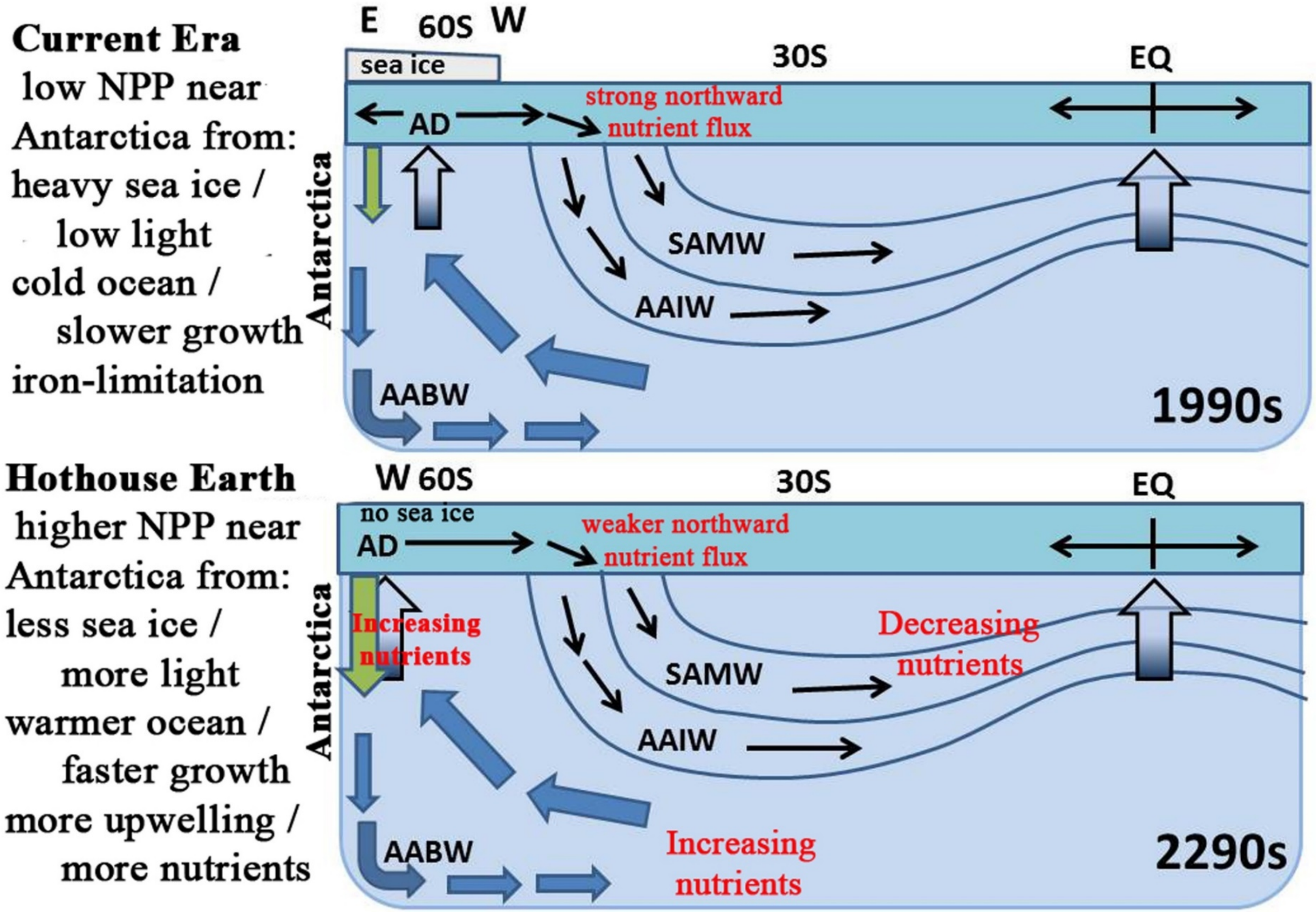
Currents that flow into the Pacific and Atlantic Oceans have much lower nutrients than normal (these are Antarctic Intermediate Water (AAIW) and SubAntarctic Mode Waters)

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).

Moore et al. (2018) *Science*

Nutrient Transfer to Deep Ocean Via the Southern Ocean

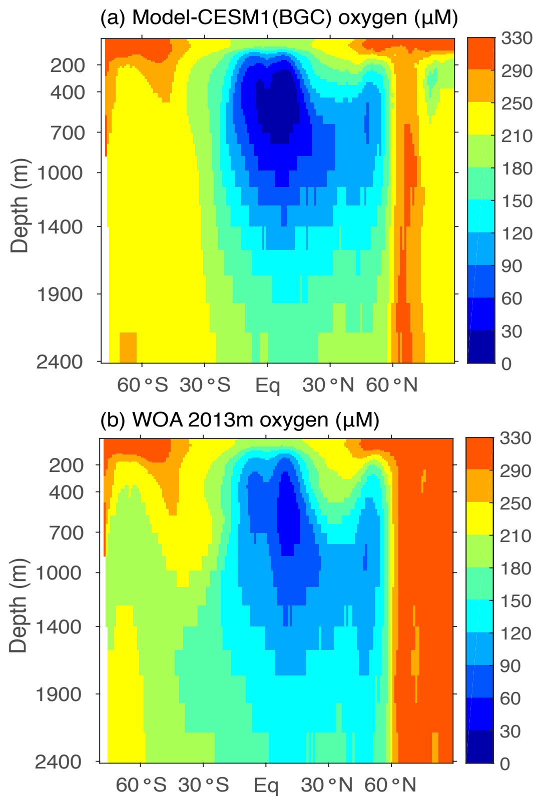


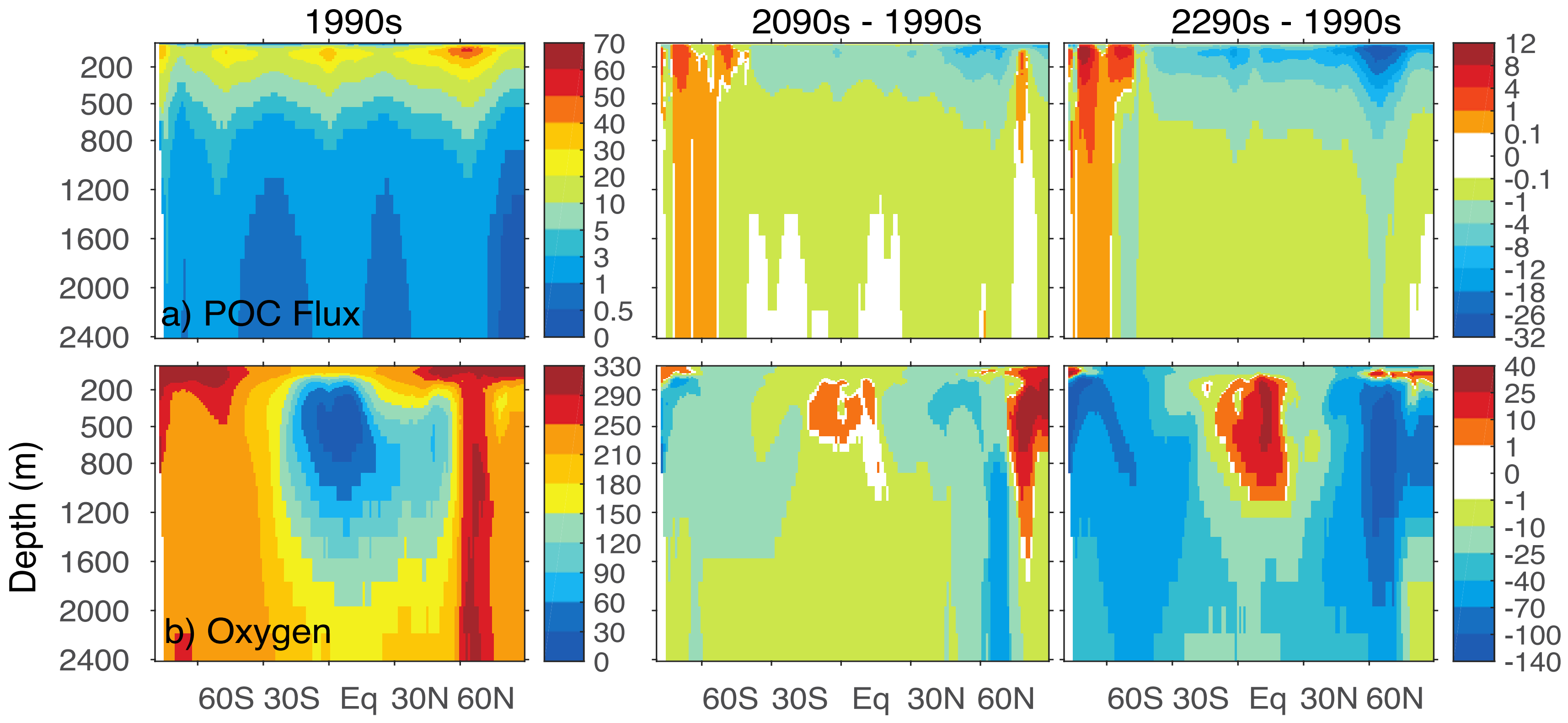
SAMW: Subantarctic Mode Waters

AAIW: Antarctic Intermediate Water

Moore et al. (2018) *Science*

Tropical ocean hypoxic zones contract from loss of productivity in ocean surface waters





Fu et al. (2018) GBC

Salinity in Arctic Ocean declines by nearly 10% by 2300