Drought in the Western US:

How can the paleoclimate record help us to understand the climate system & our future?

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Jackson School of Geosciences

Atmospheric and Oceanic Sciences

DEPARTMENT OF EARTH & PLANETARY SCIENCES

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COLUMBIA CLIMATE SCHOOL
Climate, Earth, and Society

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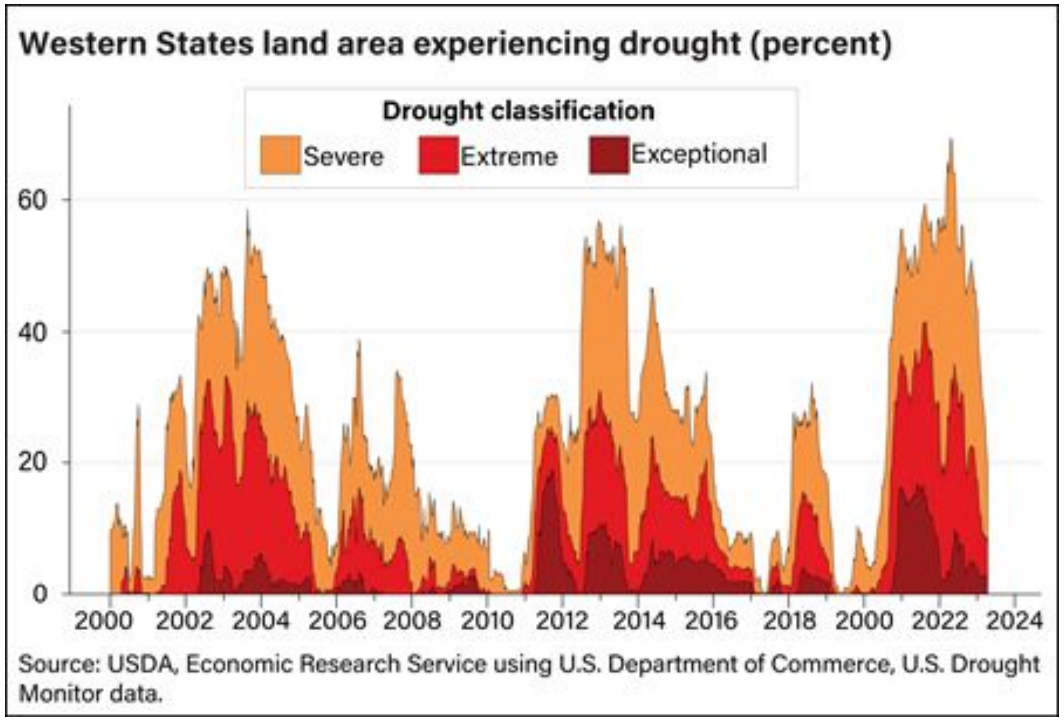
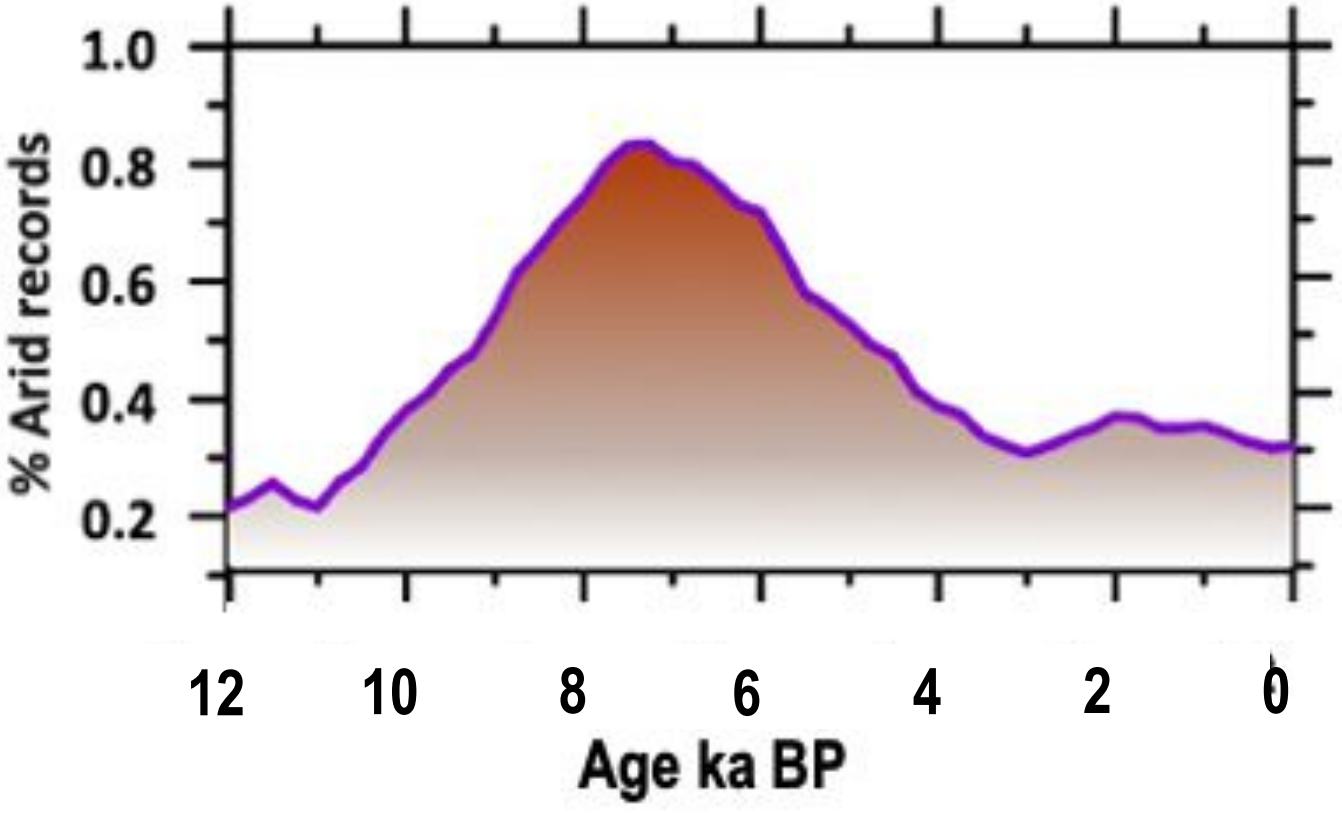
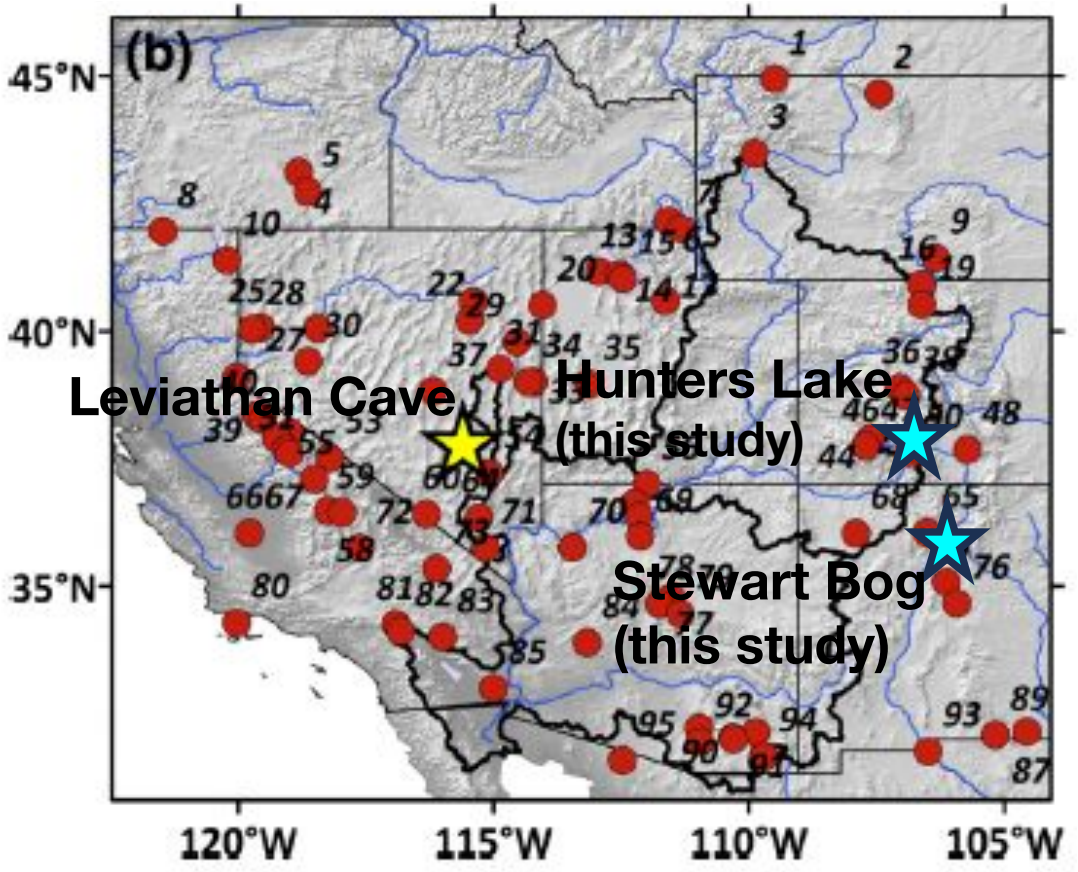


NSF National Science Foundation

EARLY TO MID-HOLOCENE DROUGHT

… but quantitative estimates are scarce



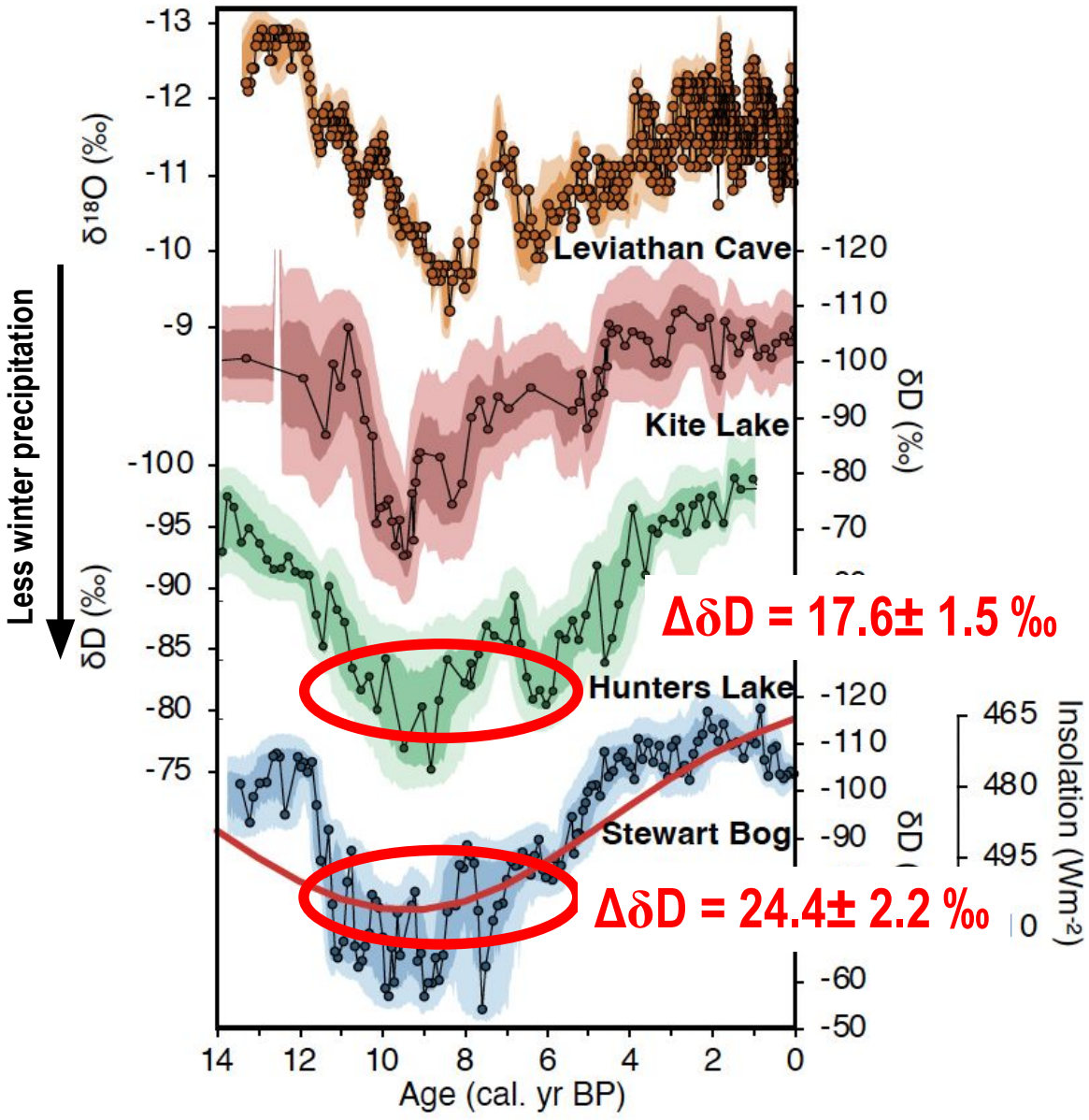


Lachniet et al., 2020

HYDROCLIMATE RECONSTRUCTIONS

Lachniet et al., 2016
Nevada speleothem

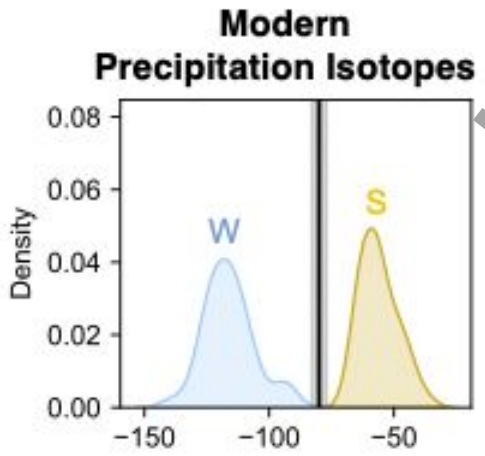
$\delta D_{precipitation}$ reconstructions (NEW RECORDS!)

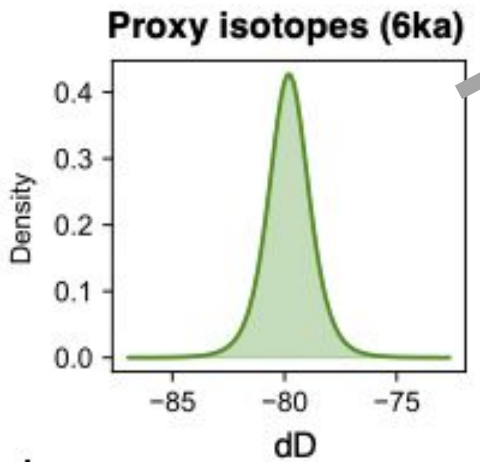


Coherent insolation-driven large-scale changes in hydroclimate

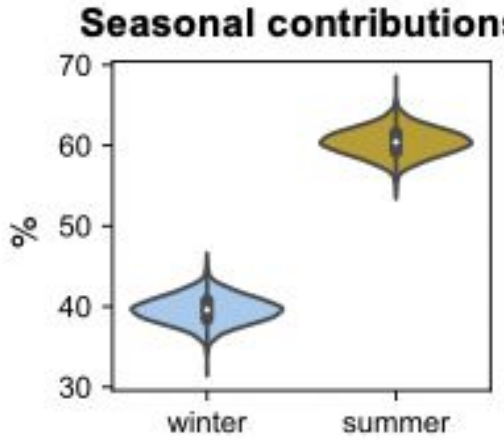
BAYESIAN MIXING MODEL

INPUT



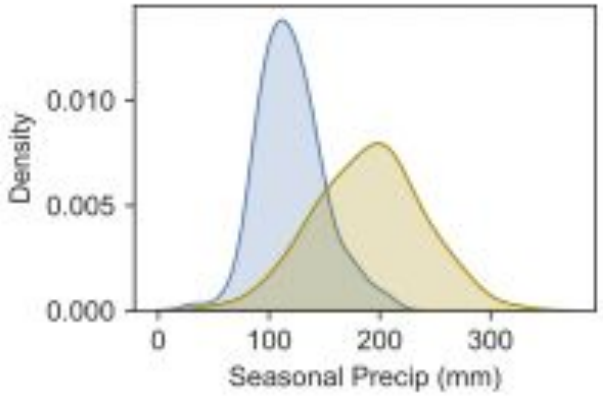


SIMULATED



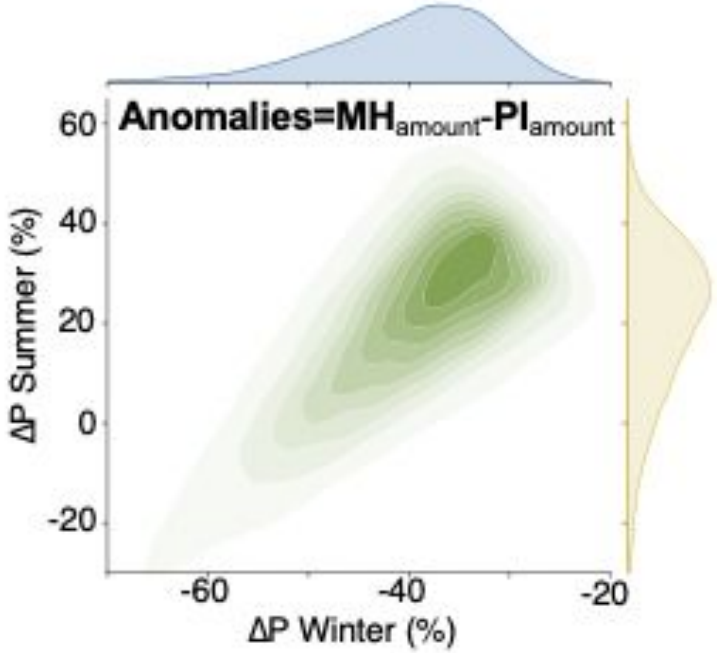
$P_{Holocene} < P_{modern}$

INPUT

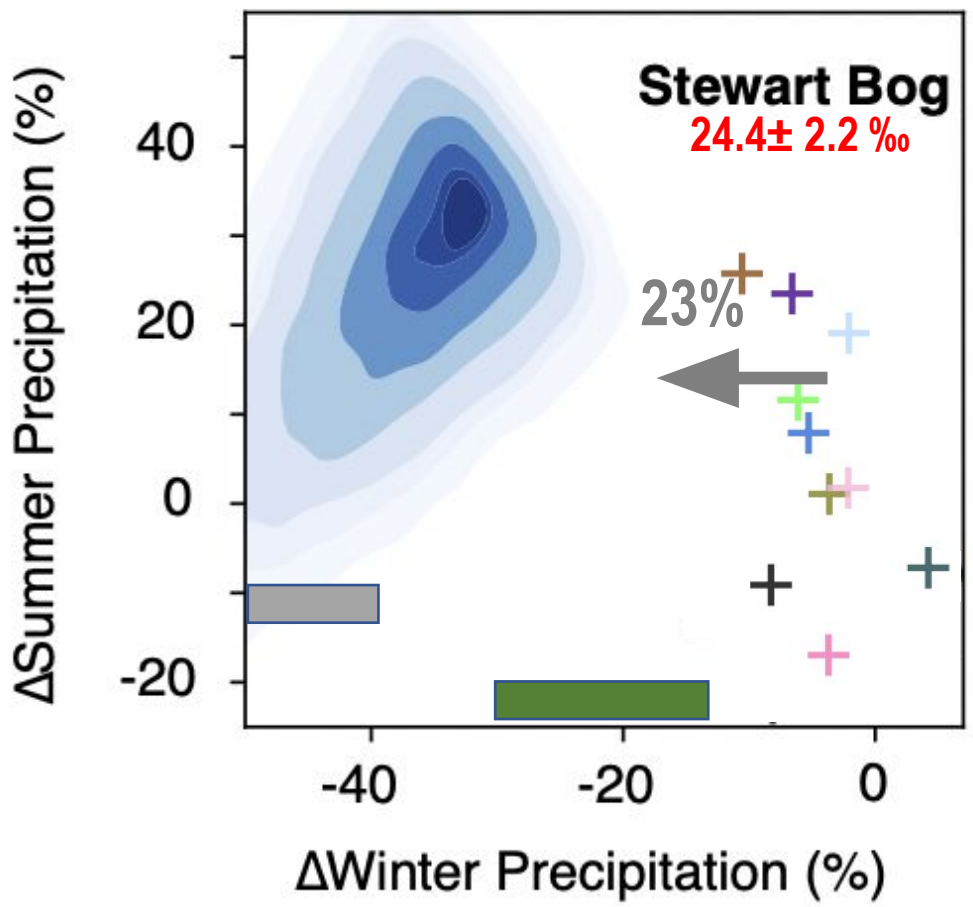


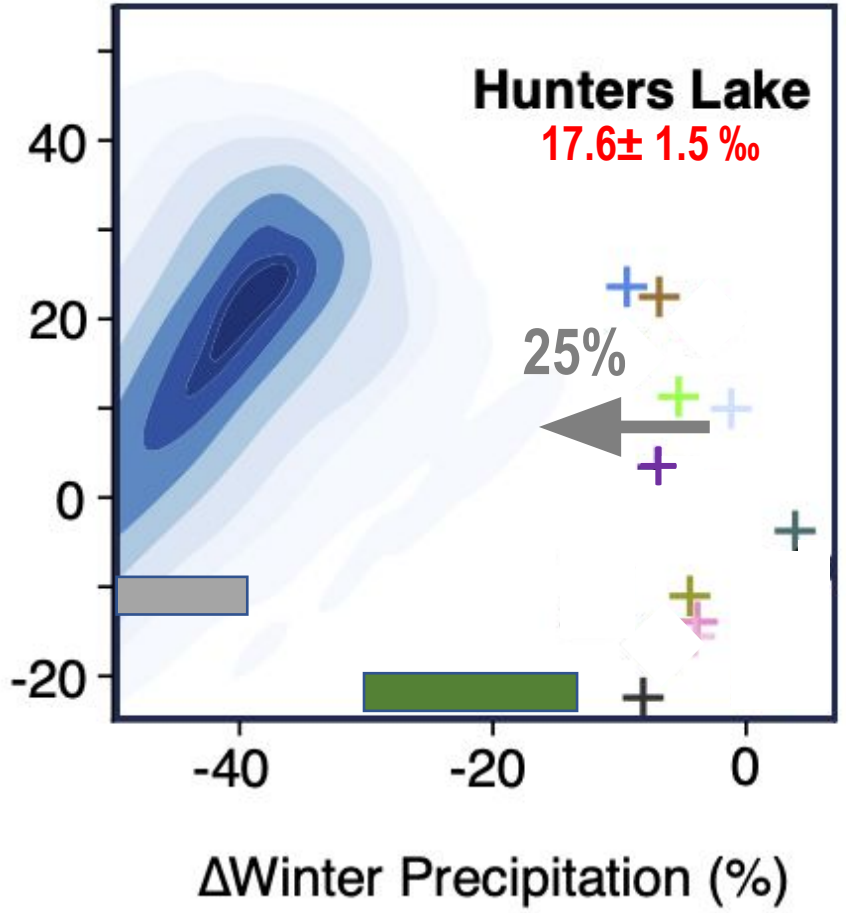
RESULT

Precipitation changes



MODELS UNDERESTIMATE WINTER PRECIP. DECLINE

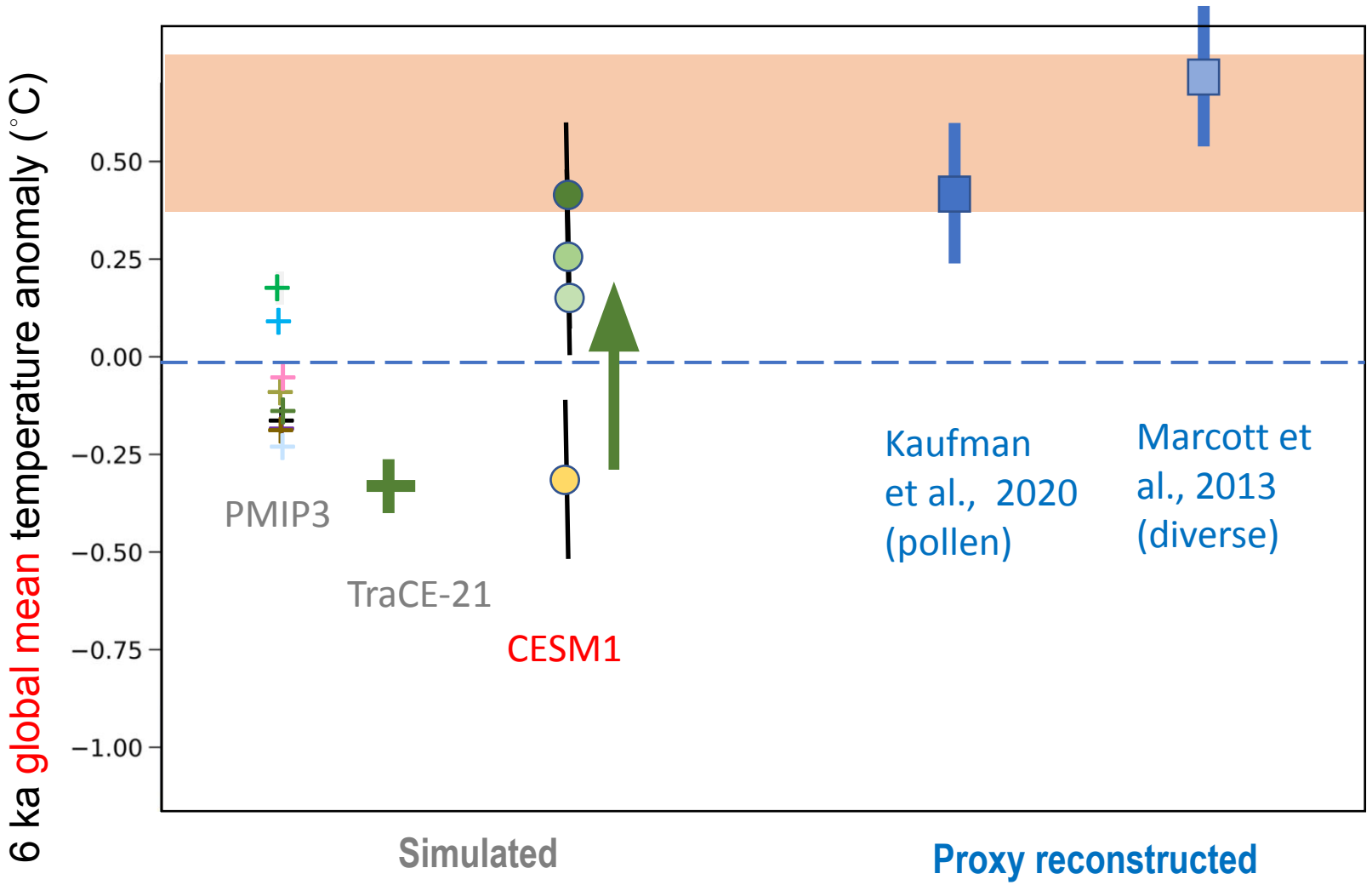


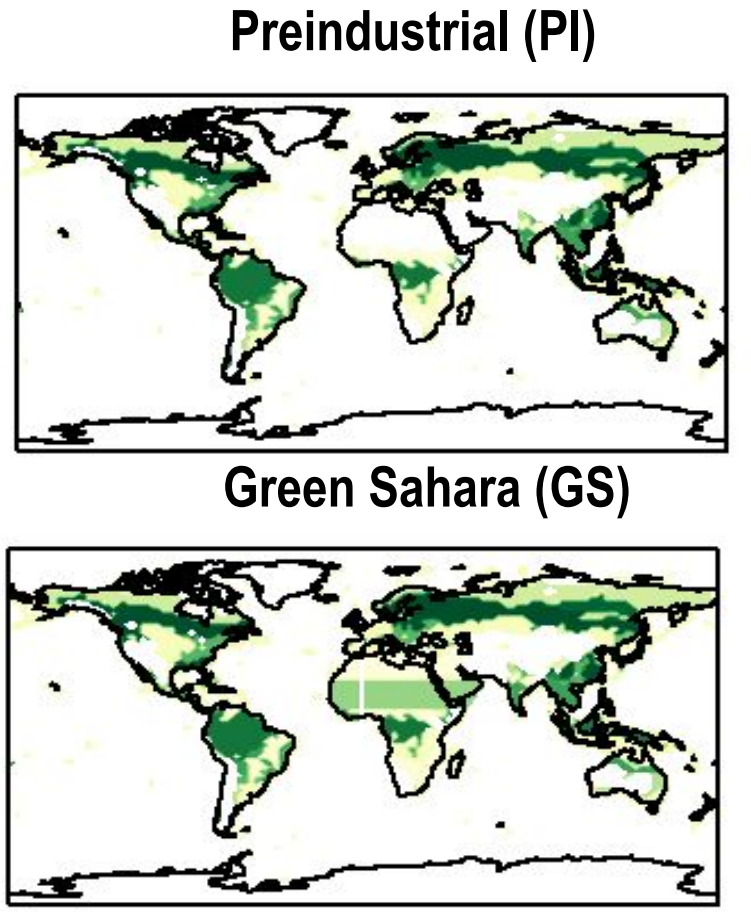


PMIP3 models
Morrill et al., 2019
Routson et al., 2019

Water balance model
Pollen

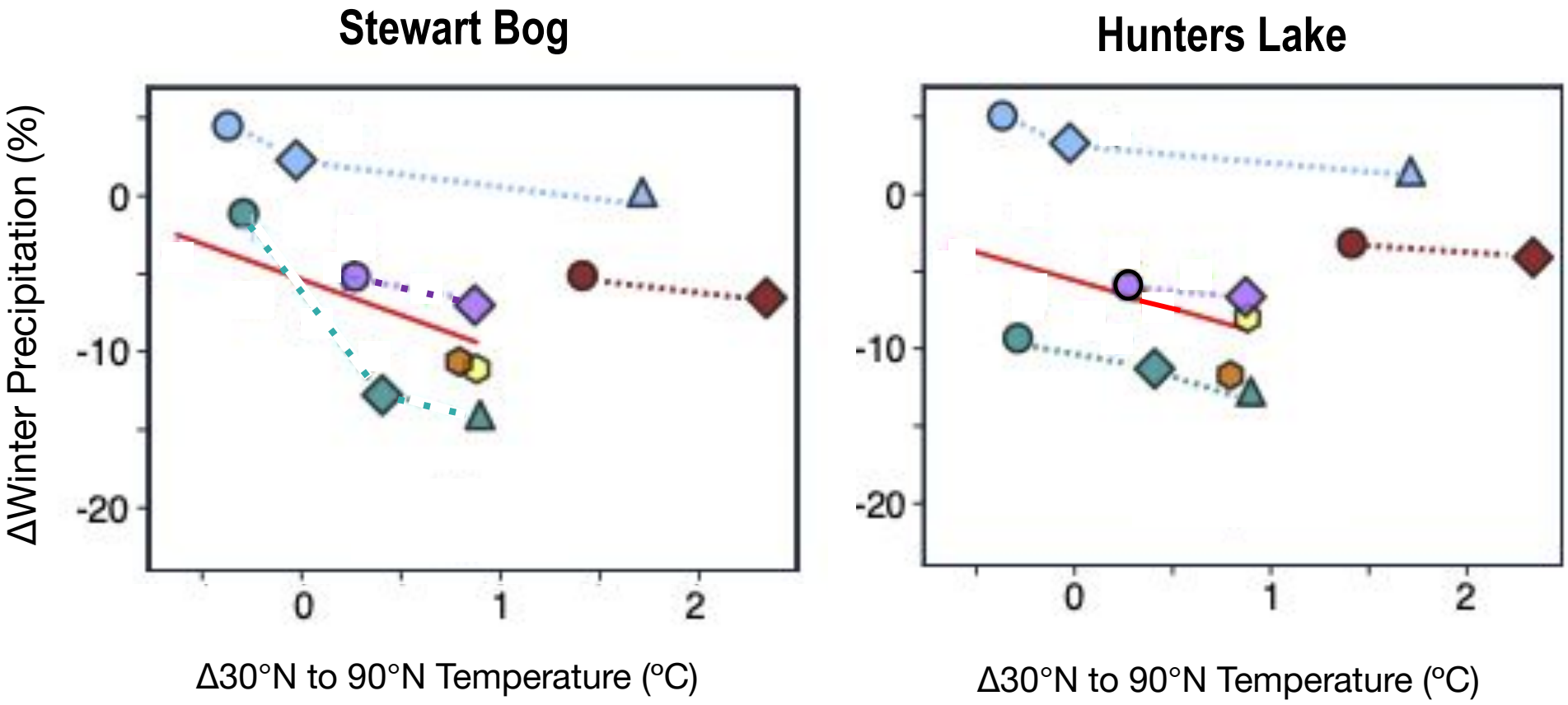
PRESCRIBED VEGETATION DRIVES WARMING



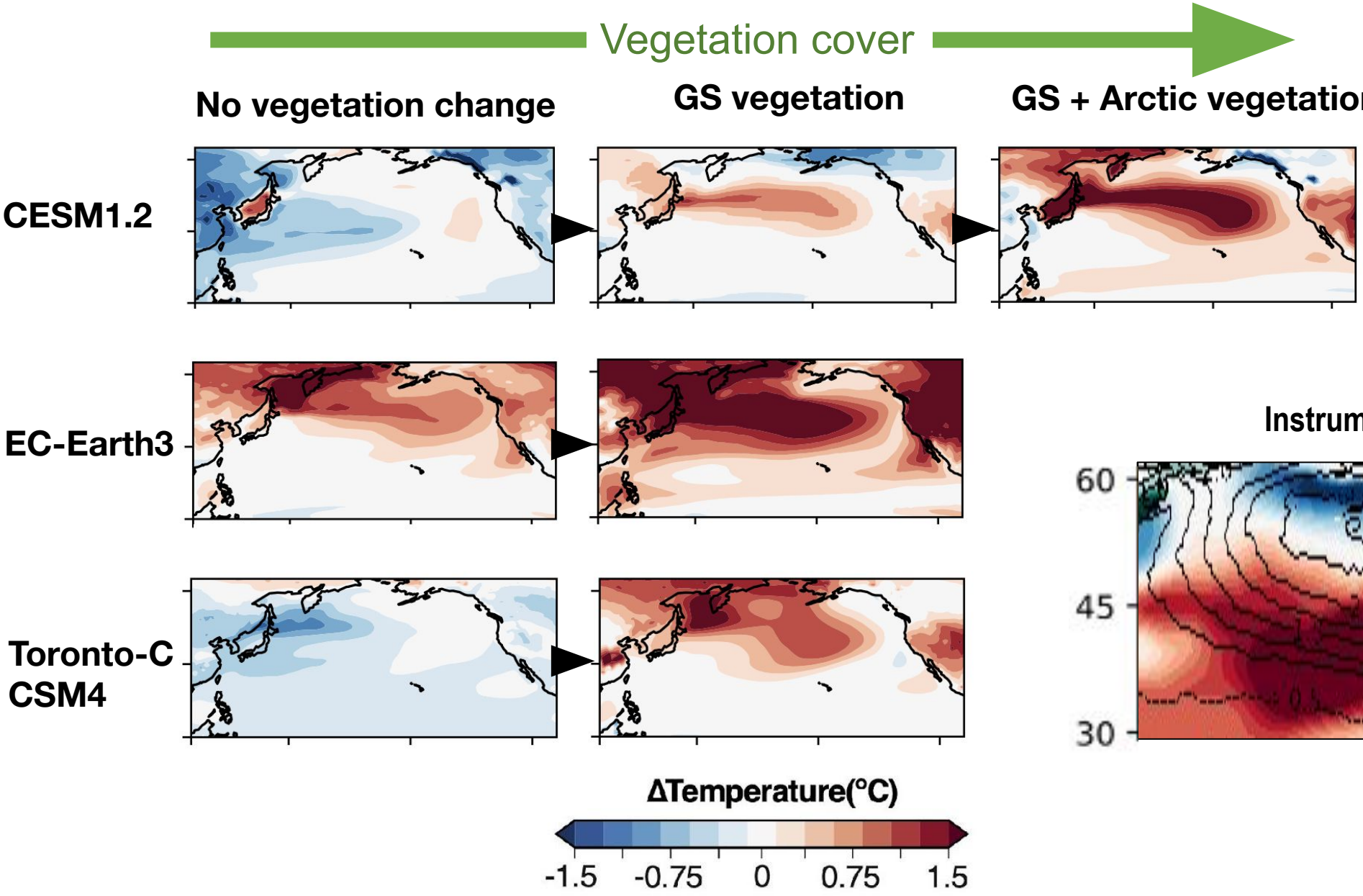


CESM1 Holocene time slice experiments Thompson *et al.*, 2020

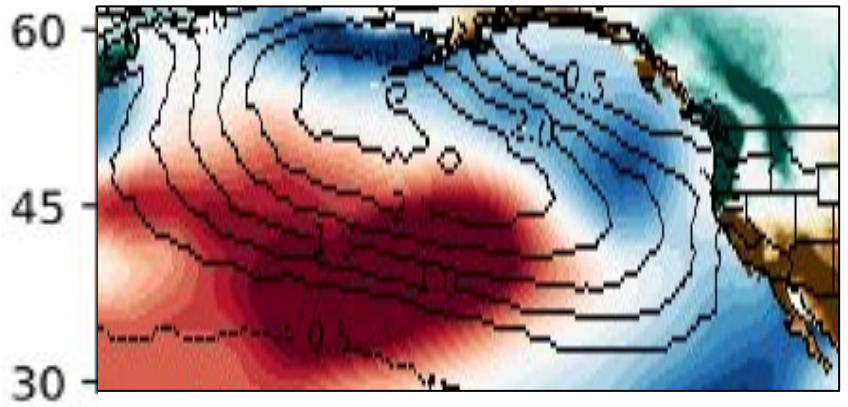
SIMULATED WINTER PRECIPITATION DECLINES WITH INCREASING TEMPERATURE



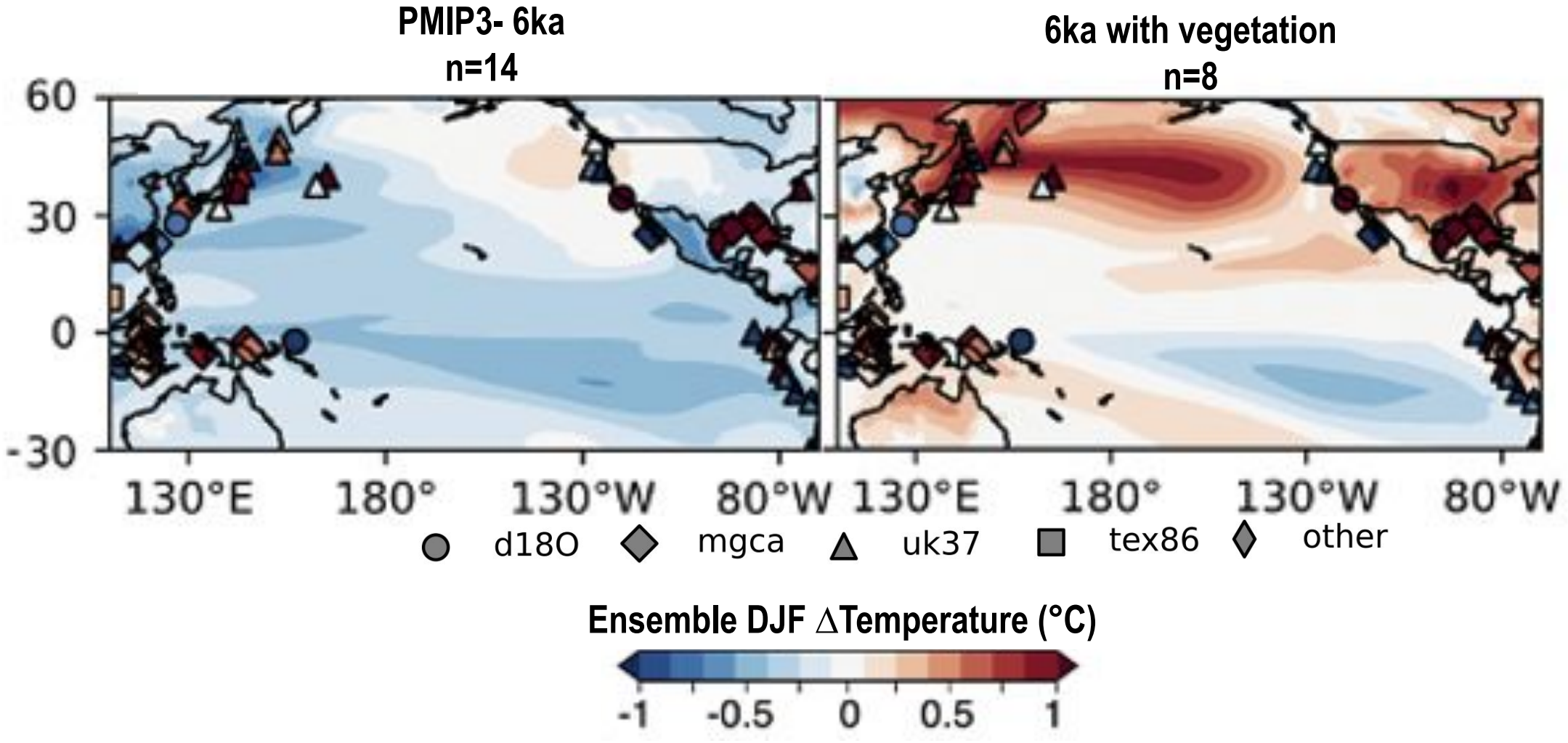
PATTERNS OF NORTH PACIFIC WARMING



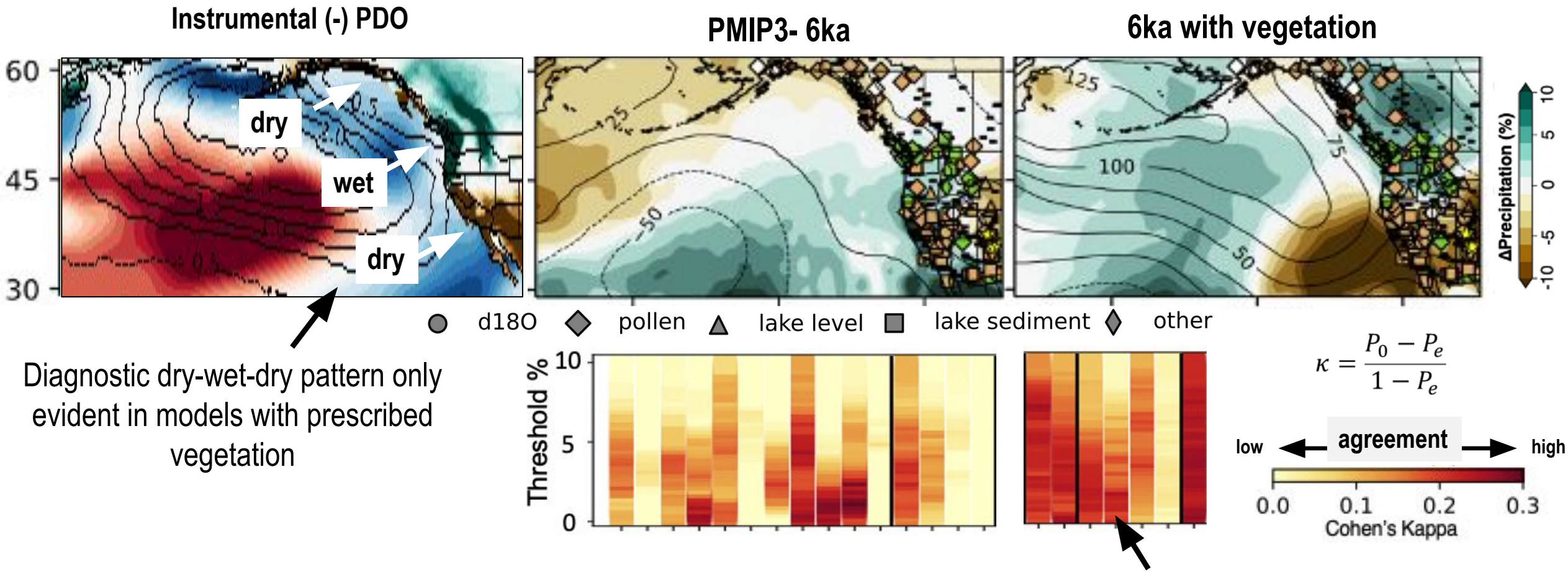
Instrumental (-) PDO



PROXY-MODEL TEMPERATURE COMPARISON SUPPORTS PDO-LIKE WARMING PATTERN



PROXY-MODEL PRECIPITATION COMPARISON SUPPORTS PDO-LIKE PRECIPITATION RESPONSE



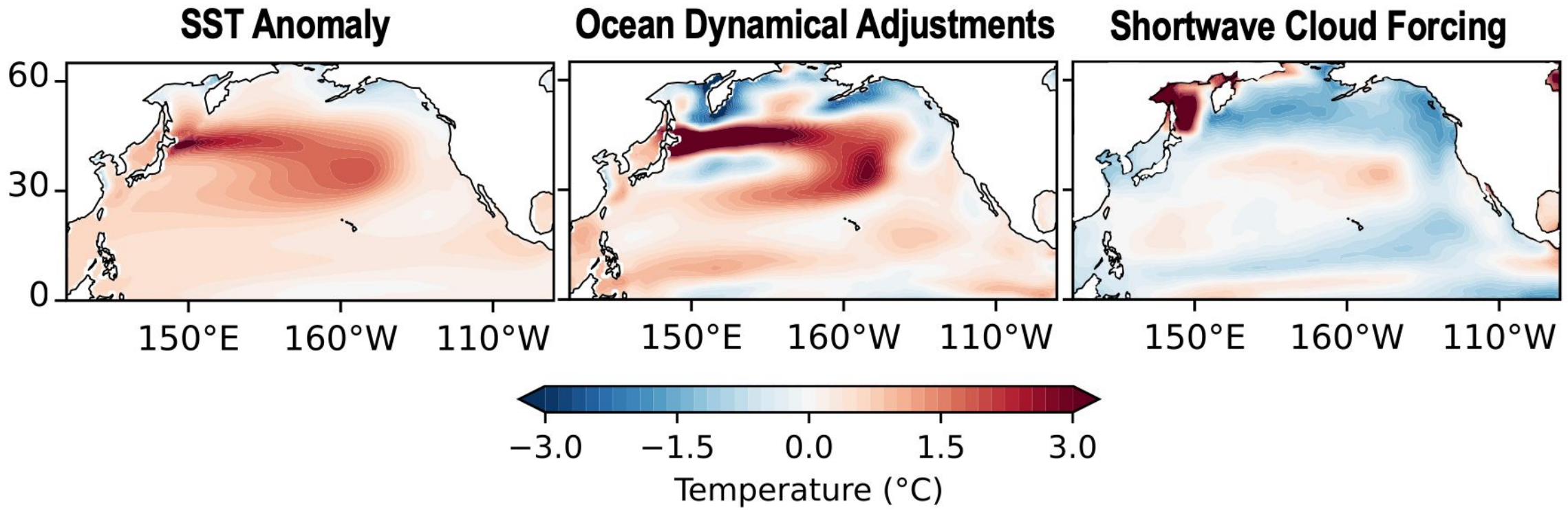
$$\kappa = \frac{P_0 - P_e}{1 - P_e}$$

Diagnostic dry-wet-dry pattern only evident in models with prescribed vegetation

Higher kappa agreement in vegetation models

MECHANISM DRIVING PDO-LIKE RESPONSE

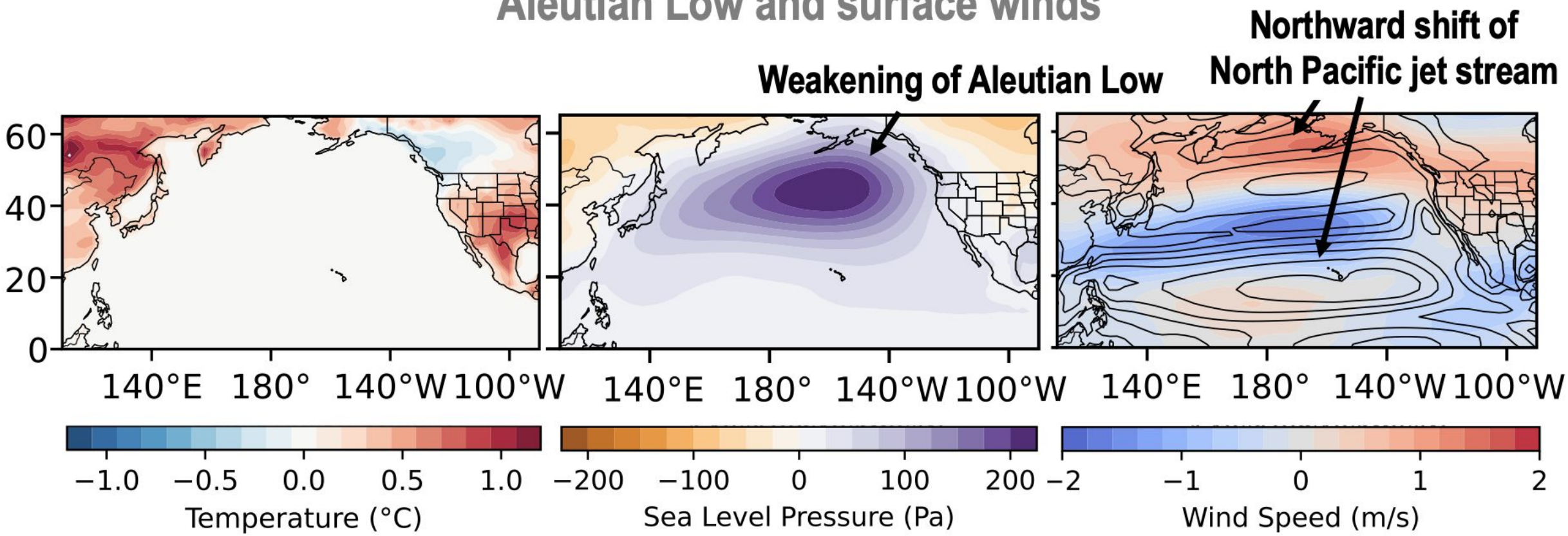
Heat budget analysis shows this SST pattern persists due to ocean dynamical adjustments and low cloud feedbacks



Annual anomalies CESM $6ka_{GS+NHveg}$ - PI

MECHANISM DRIVING PDO-LIKE RESPONSE

6ka simulation with prescribed vegetation and fixed SSTs and sea ice show that solely land surface warming can initiate the atmospheric response in the Aleutian Low and surface winds



Annual anomalies from CESM 6ka control

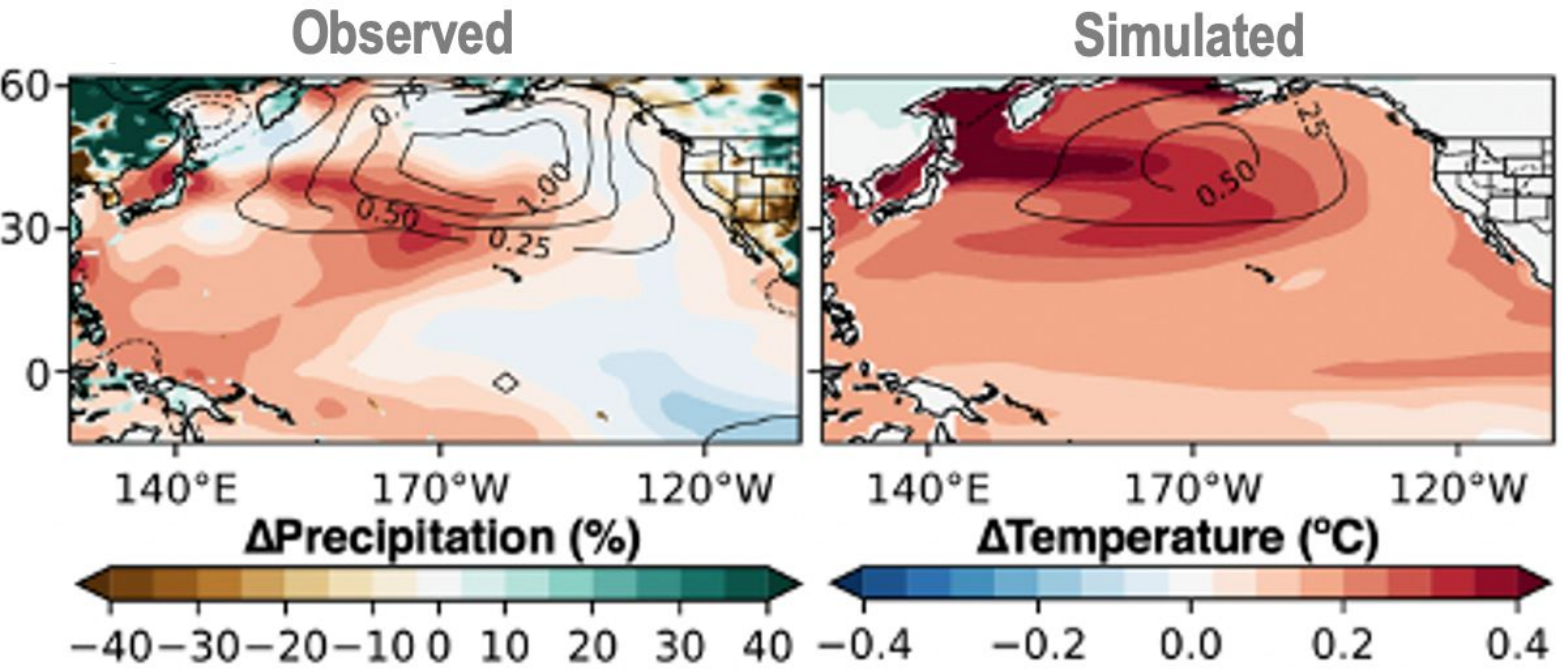
II. IMPLICATIONS

1. Models underestimate the winter precipitation changes during the mid-Holocene
2. Proxy-model agreement is higher in simulations with mid-Holocene warming
3. Across multiple models, warming is associated with the emergence of a PDO-like state
4. This emergent PDO-like state appears to be initiated by an atmospheric response and is magnified by ocean-atmosphere interactions
5. Hemispheric warming may induce a (-) PDO like state, contributing to persistent drought in the Southwest. Could the PDO be forced?

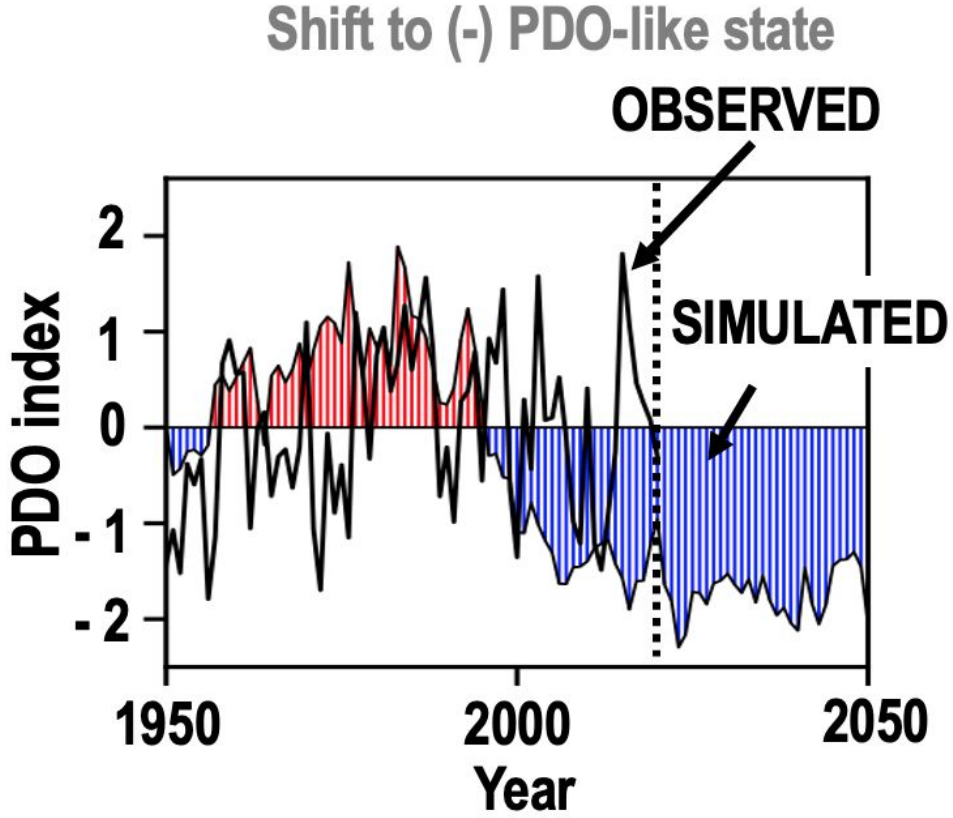
Thanks for listening!
Please reach out:
victoria.todd@austin.utexas.edu

FUTURE, WARMING DRIVEN SHIFT TO A PERMANENT (-) PDO-LIKE STATE?

From 1982 to 2019

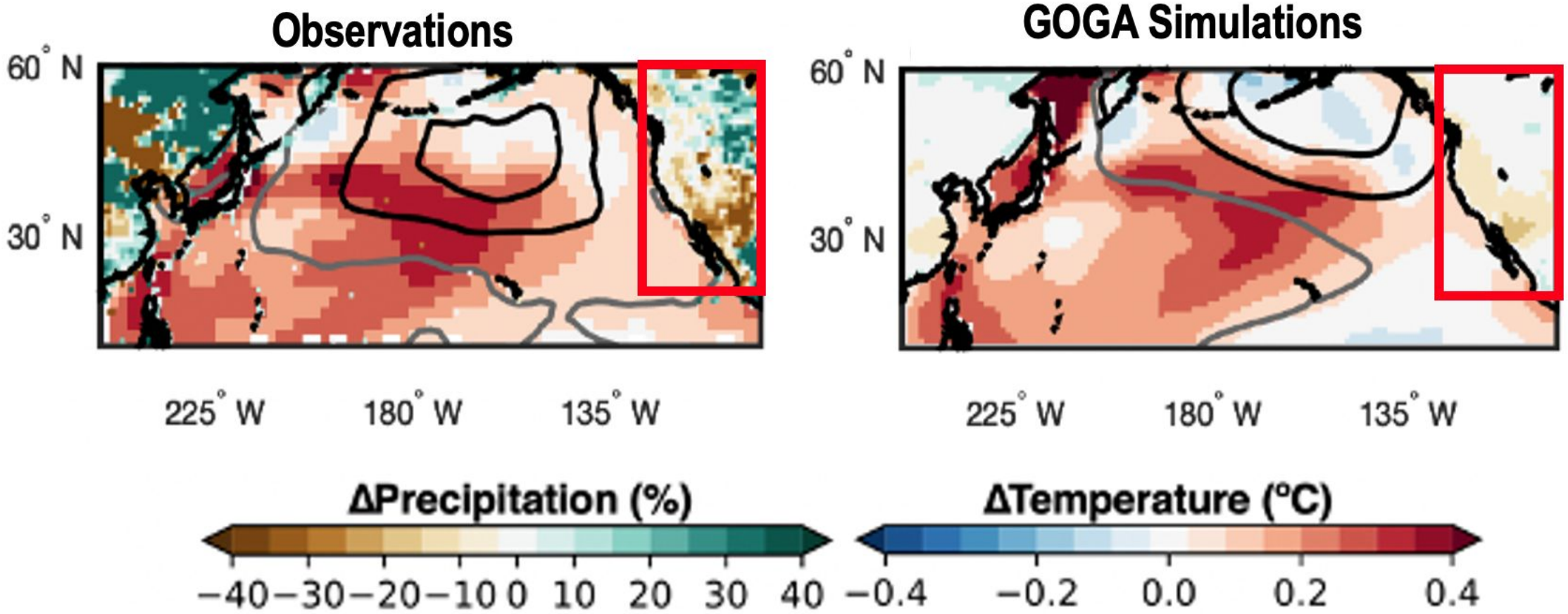


Large (100 member) CESM2 ensemble (Rodgers et al., 2021)



MODELS UNDERESTIMATE RESPONSE TO OBSERVED PDO

...and could explain why they underestimate precipitation changes in the Holocene as well

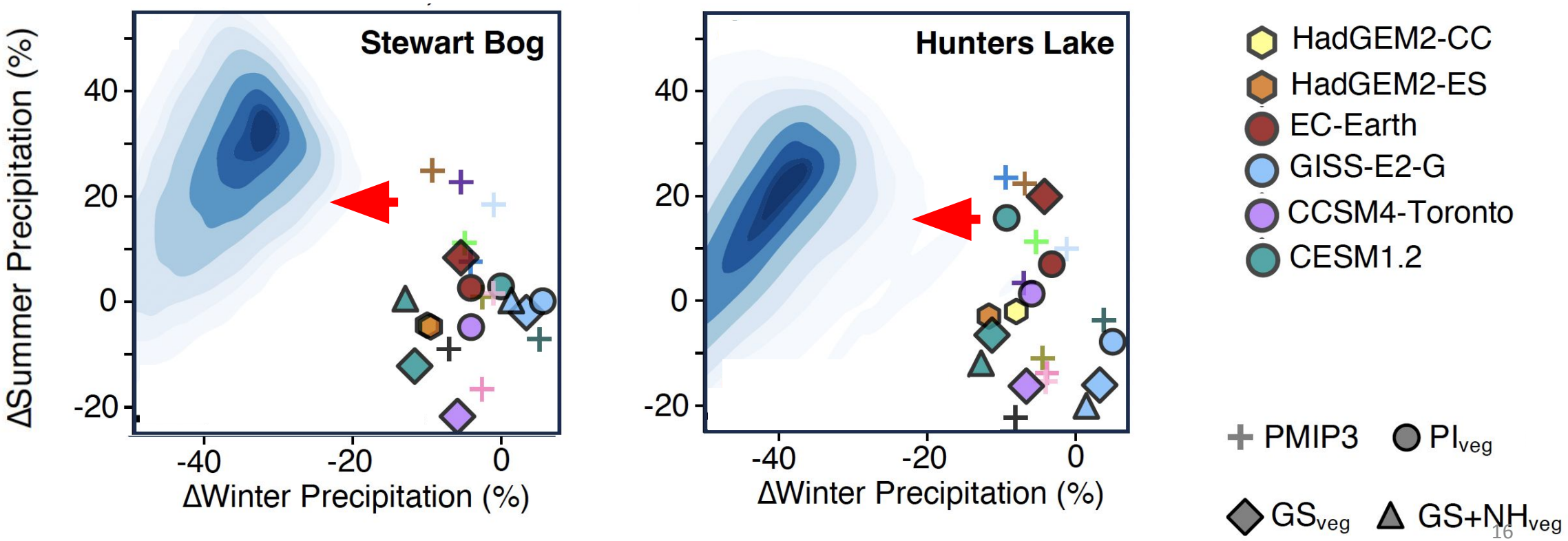


Observed SST (ERSST), SLP (NCEP) and precipitation (GPCC) trends 1982-2019

Simulated trends in SST, SLP and precipitation forced with observed SSTs

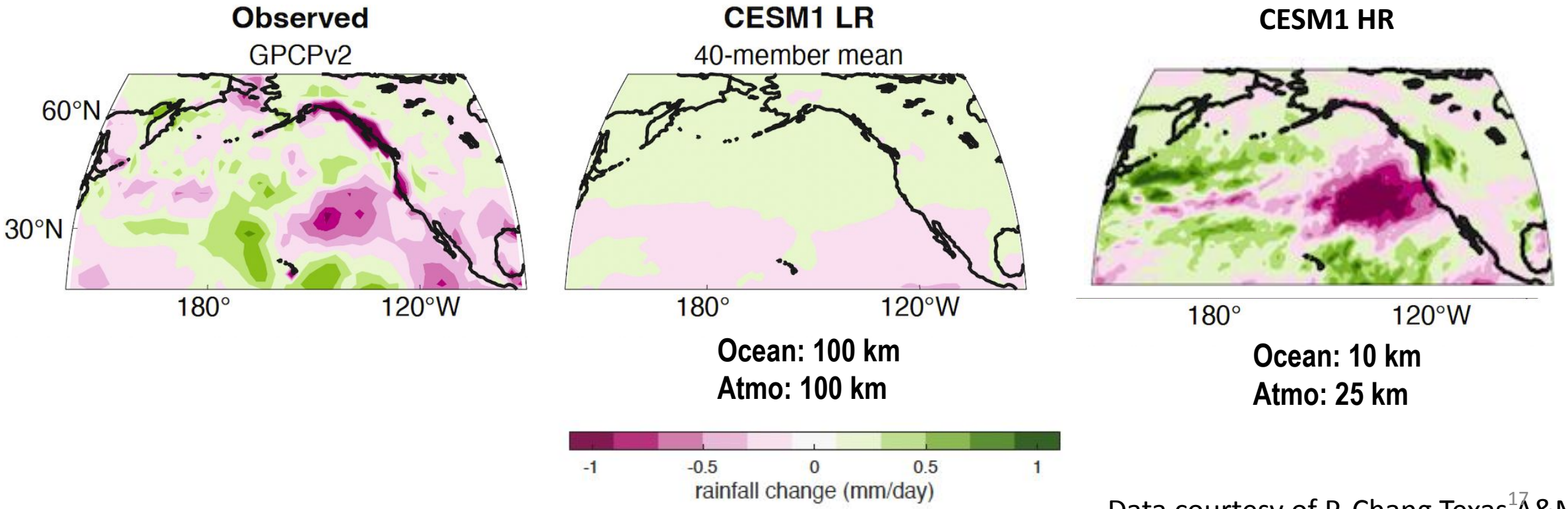
…BUT THE MAGNITUDE OF MID-HOLOCENE DROUGHT IS UNDERESTIMATED

Models with prescribed vegetation show shifts to lower winter (and summer) precipitation, but the changes are insufficient in comparison with proxy estimates.



BONUS: WHY DO MODELS UNDERESTIMATE THE IMPACT OF A NEGATIVE PDO?

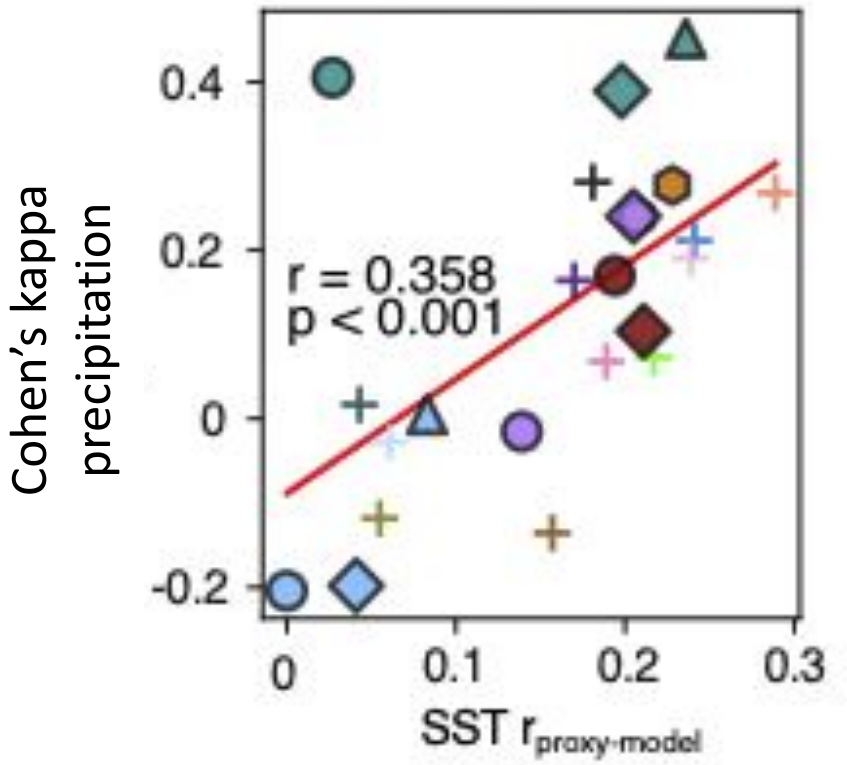
RESOLUTION?



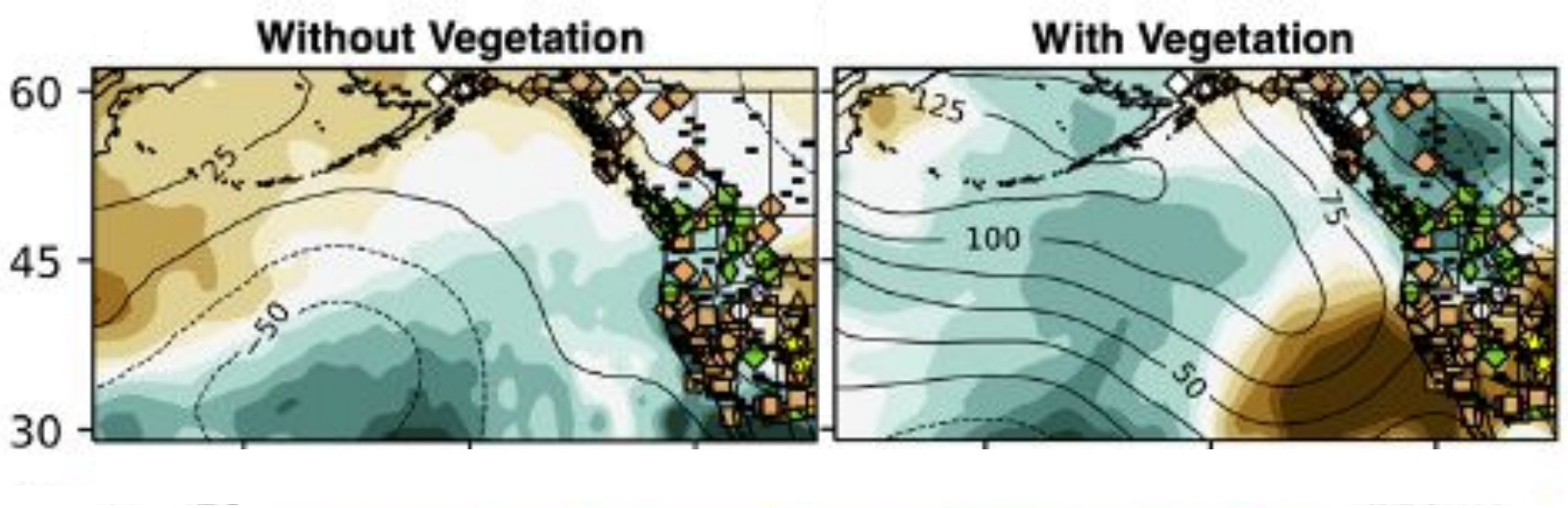
Data courtesy of P. Chang Texas A&M

PROXY-MODEL COMPARISON SUPPORTS SPATIAL SIGNATURE OF NORTH PACIFIC WARMING

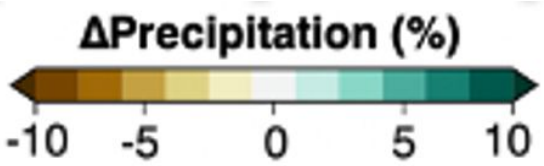
When proxy-model SST correlation is stronger – the precipitation kappa agreement is as well

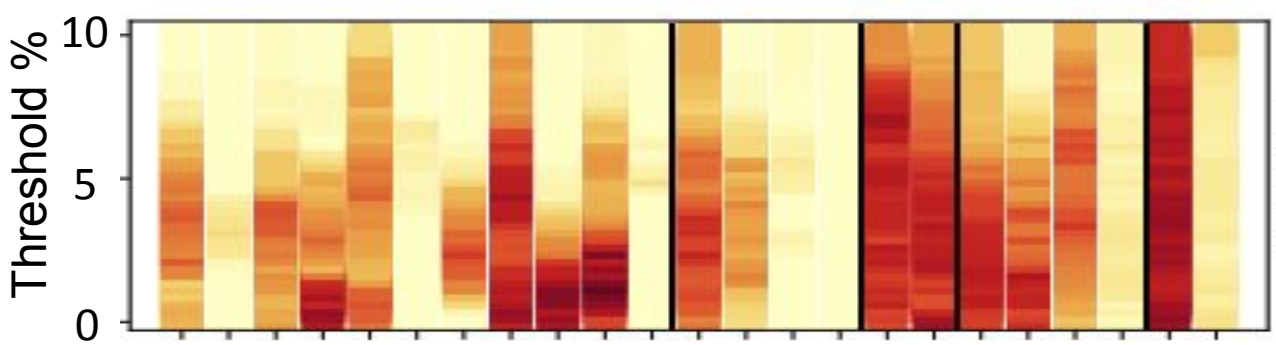


PROXY-MODEL COMPARISON SUPPORTS SPATIAL SIGNATURE OF PRECIPITATION



Plotted: ensemble means





PMIP3 unchanged vegetation

Dyn. Prescribed MH vegetation

$$\kappa = \frac{P_0 - P_e}{1 - P_e}$$