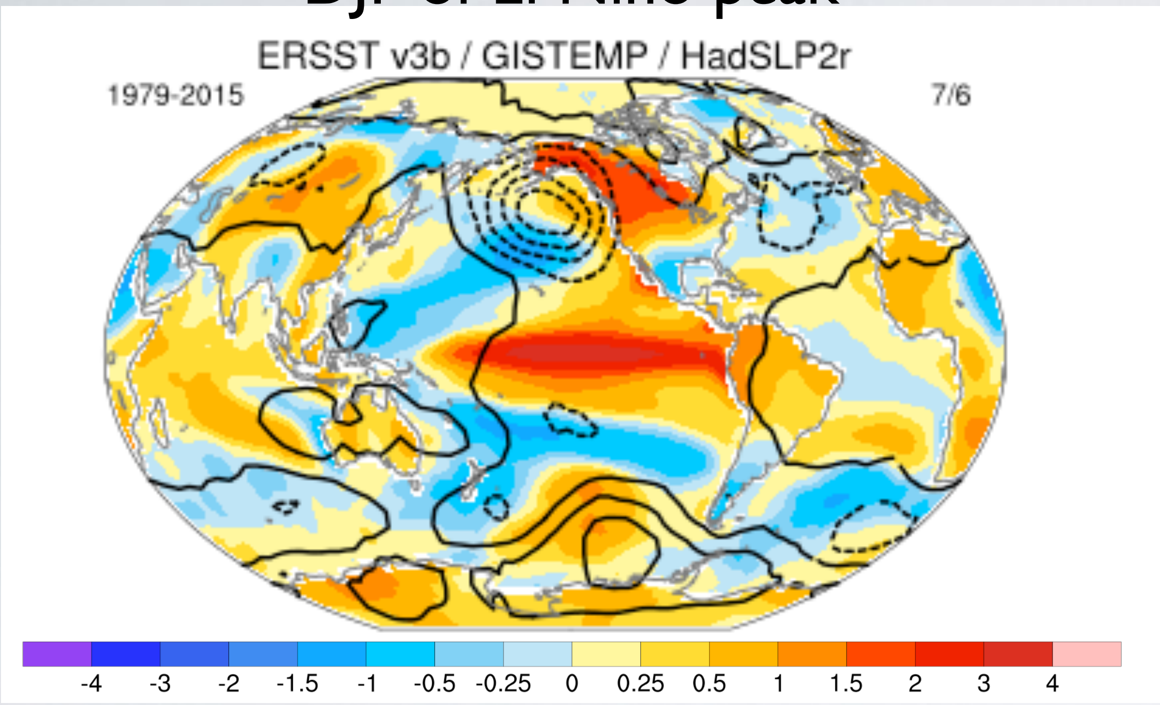
Quantifying Uncertainty in Teleconnections Simulated by Climate Models

Samantha Stevenson

National Center for Atmospheric Research, University of California at Santa Barbara

“Teleconnections” come in many varieties

SST/air temp/SLP composite:
DJF of El Nino peak



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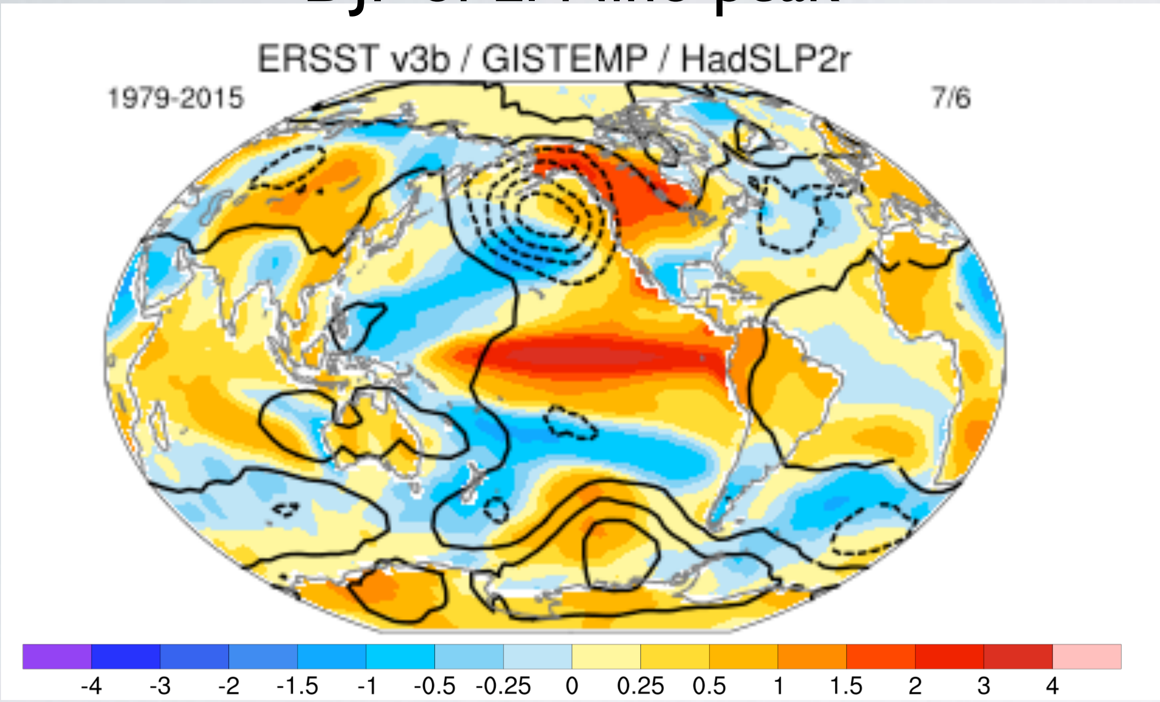
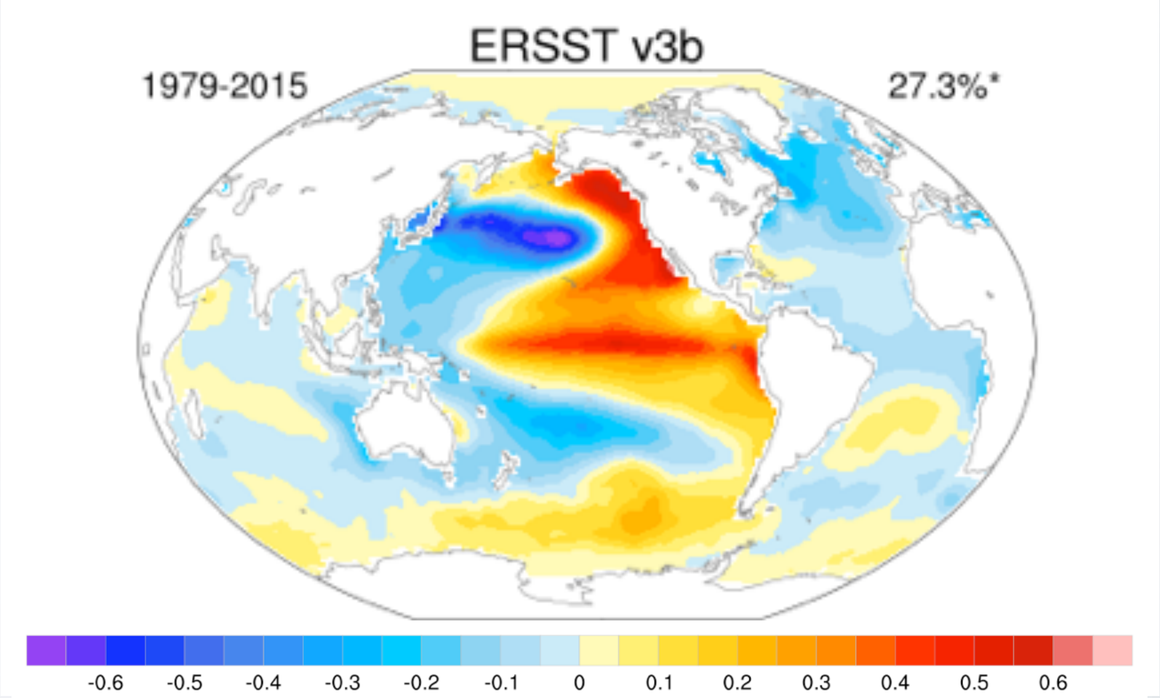


Spatial pattern of SST associated with the PDO



NCAR Climate Variability Diagnostics Package

"Teleconnections" come in many varieties

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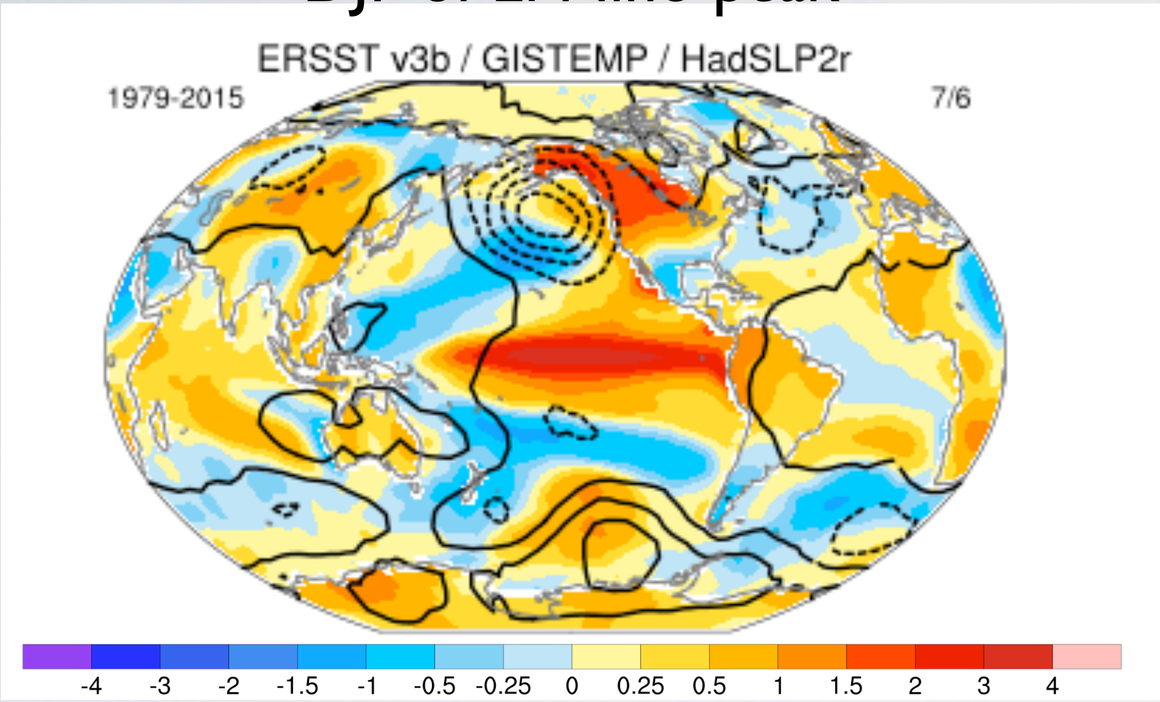

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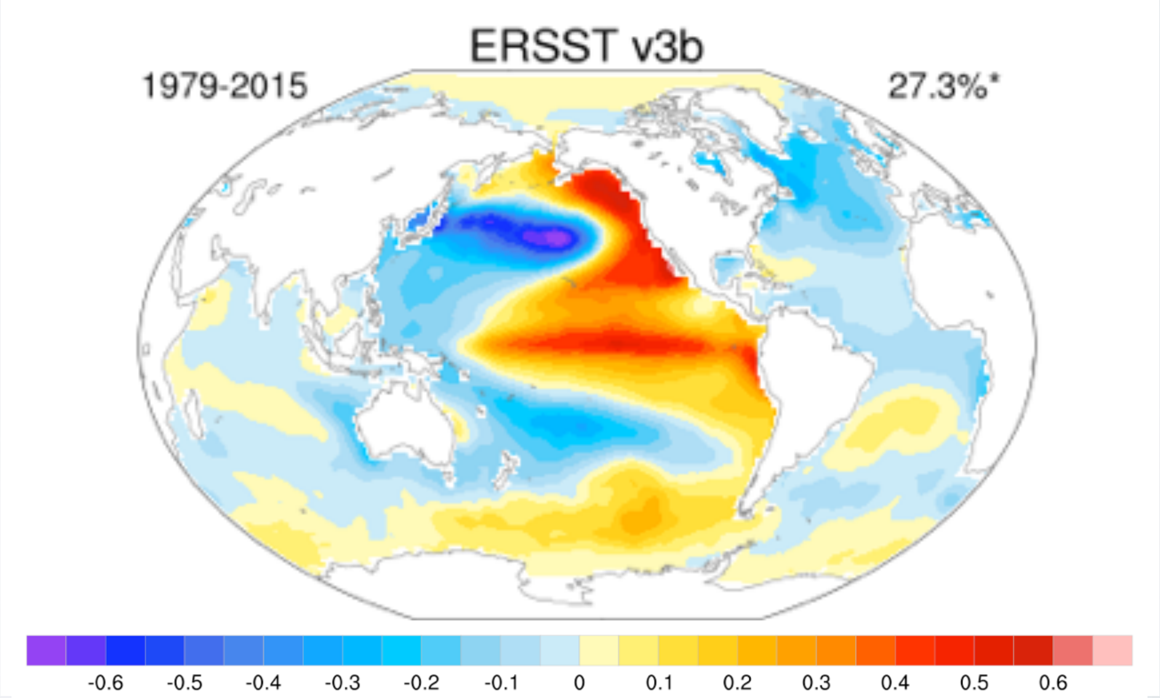
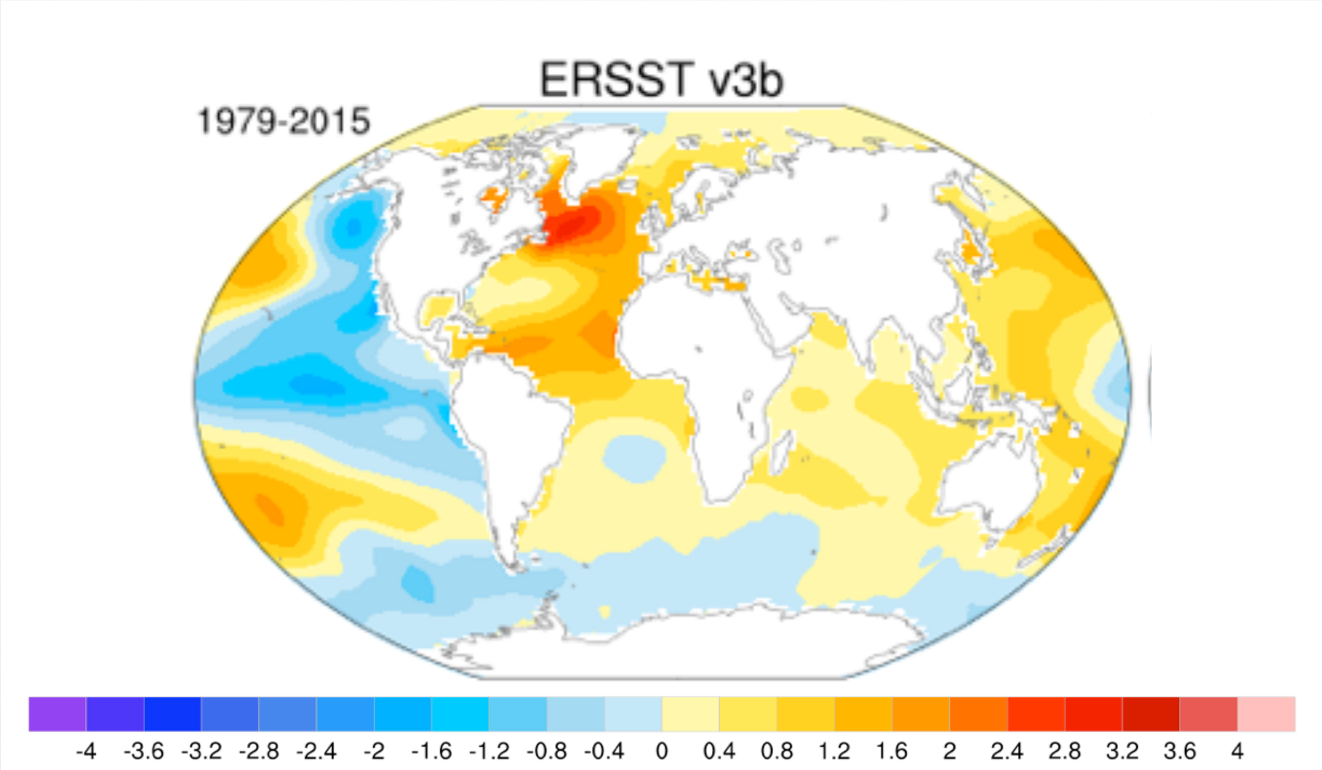


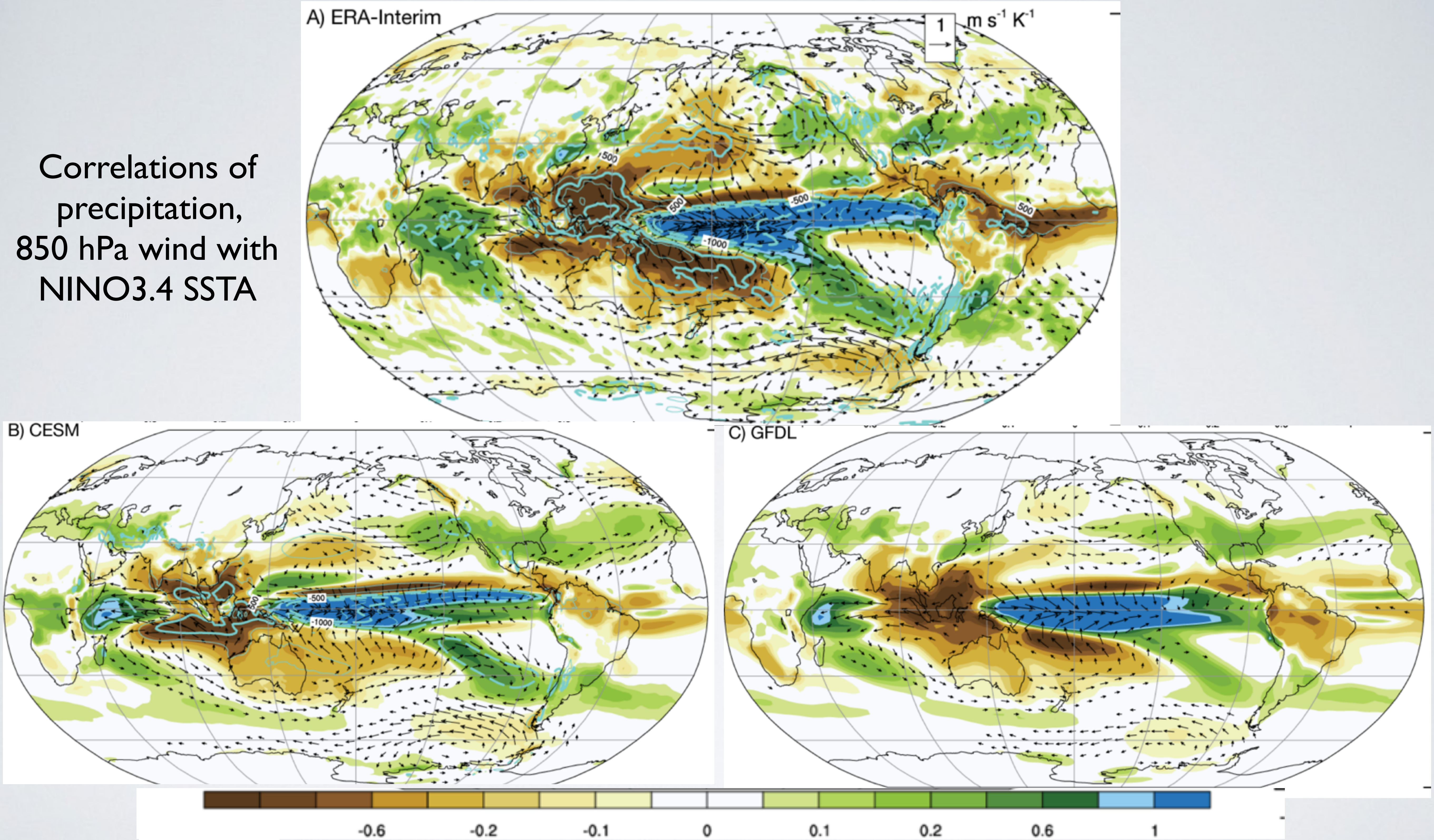
Spatial pattern of SST associated with the AMO



NCAR Climate Variability Diagnostics Package

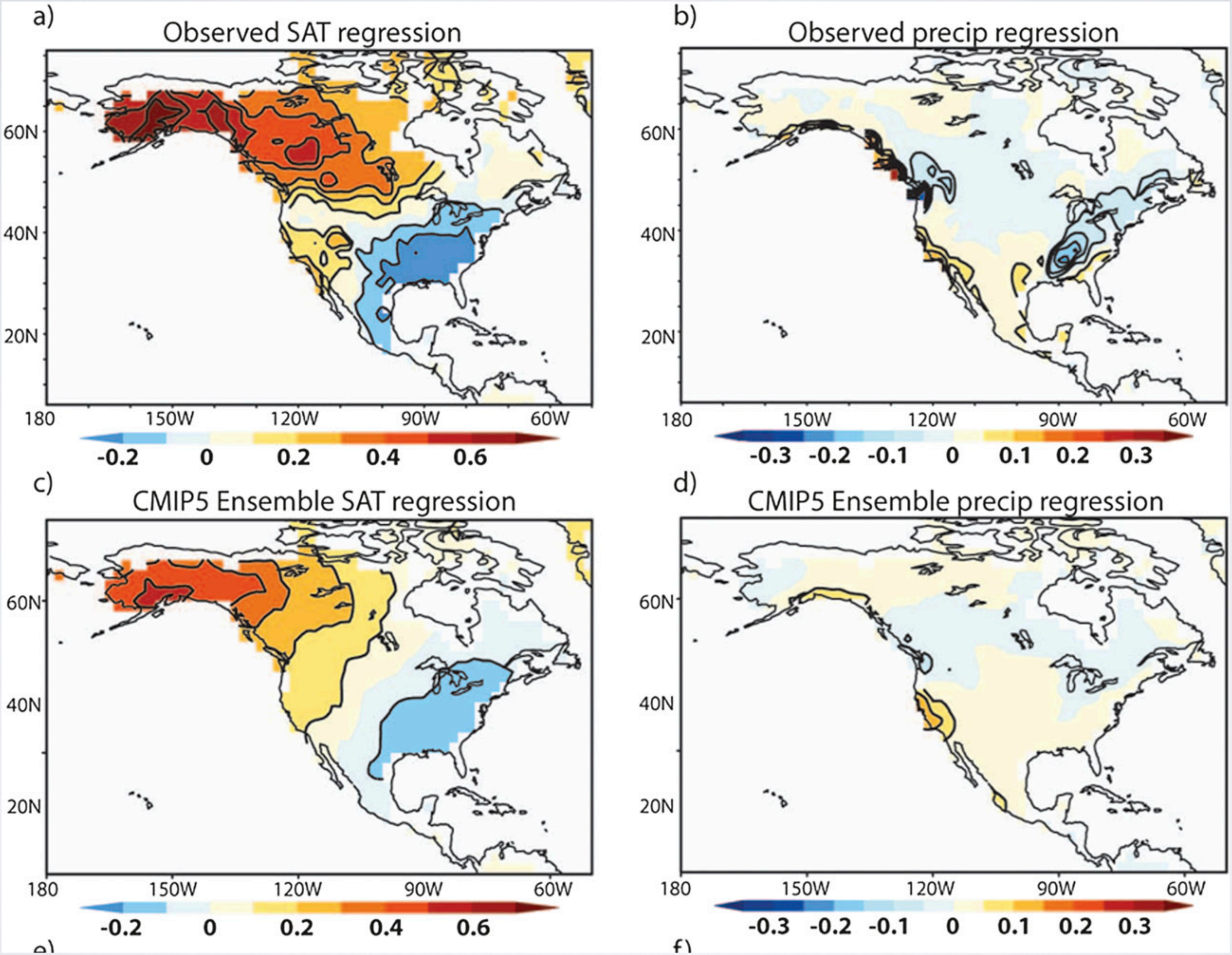
Models simulate broad features of ENSO teleconnections

Correlations of precipitation, 850 hPa wind with NINO3.4 SSTA



Fasullo, Otto-Bliesner & Stevenson (2017), Nature Climate Change, in revision

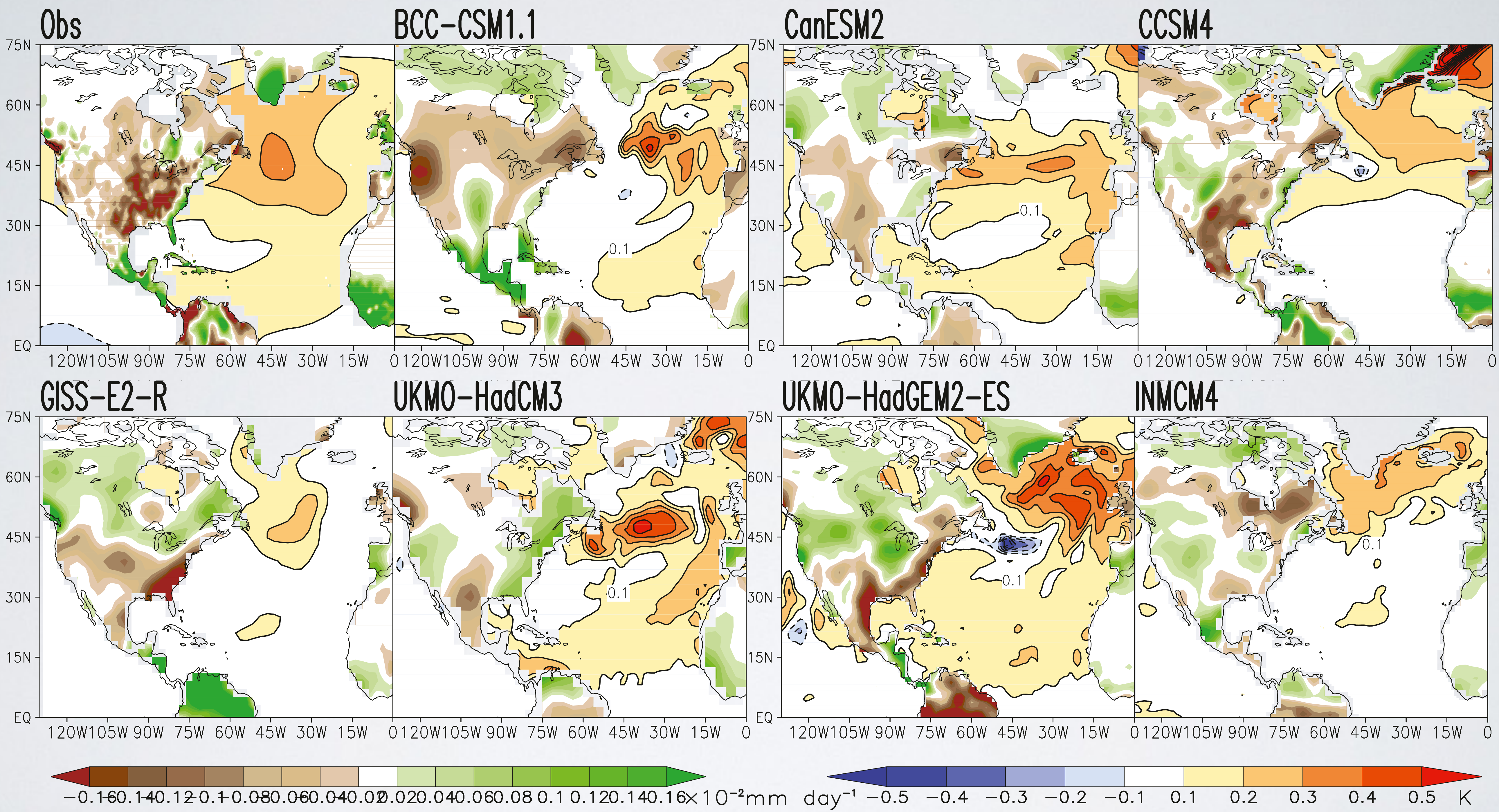
Models capture broad features of PDO teleconnections as well



DJF regressions on PDO index
Obs: CRU TS3.1

Sheffield et al. (2013)

AMO teleconnections not well represented

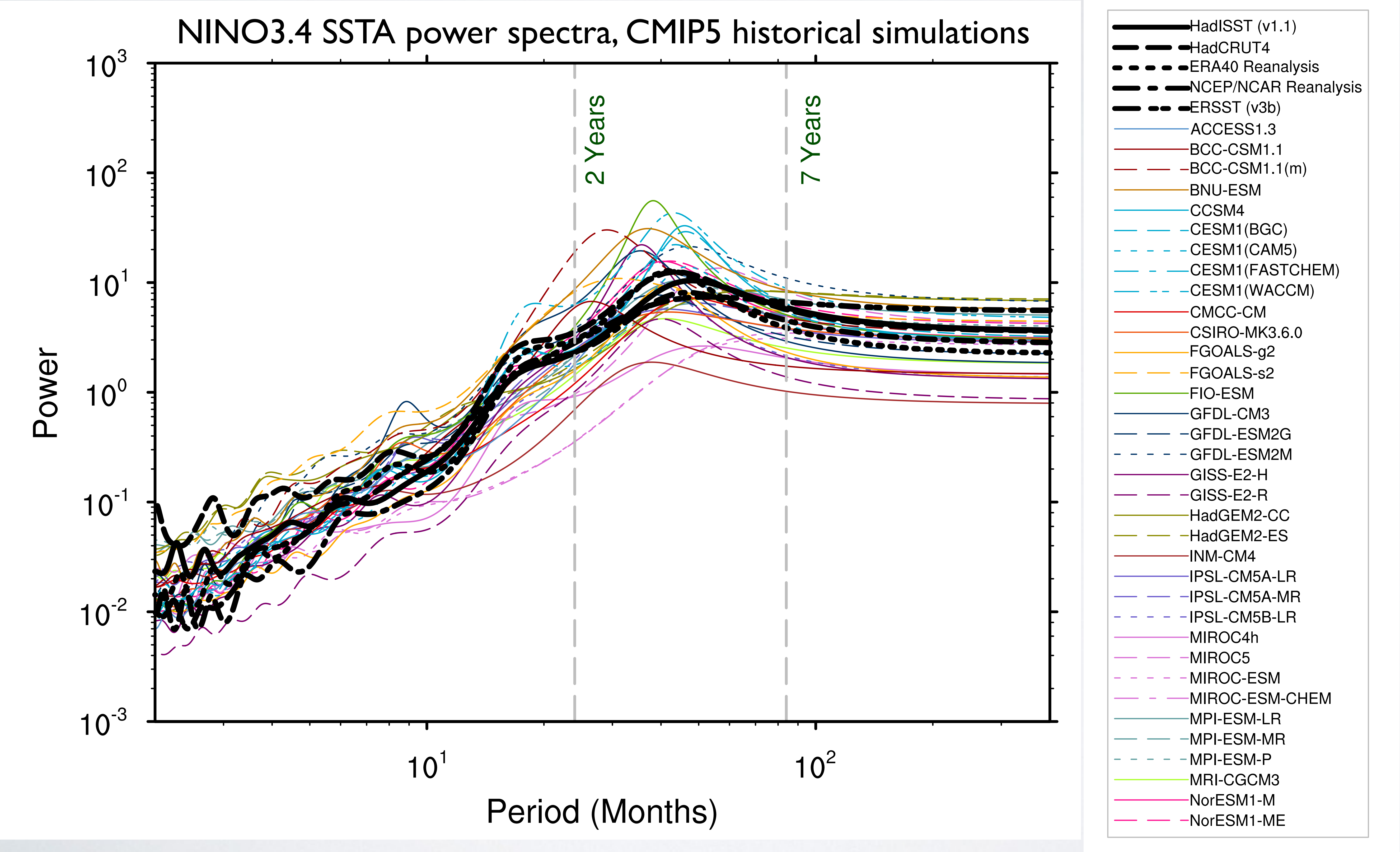


SON regressions on AMO index, 1900-1999

Obs: HadISST1.1, CRU TS3.1

Sheffield et al. (2013)

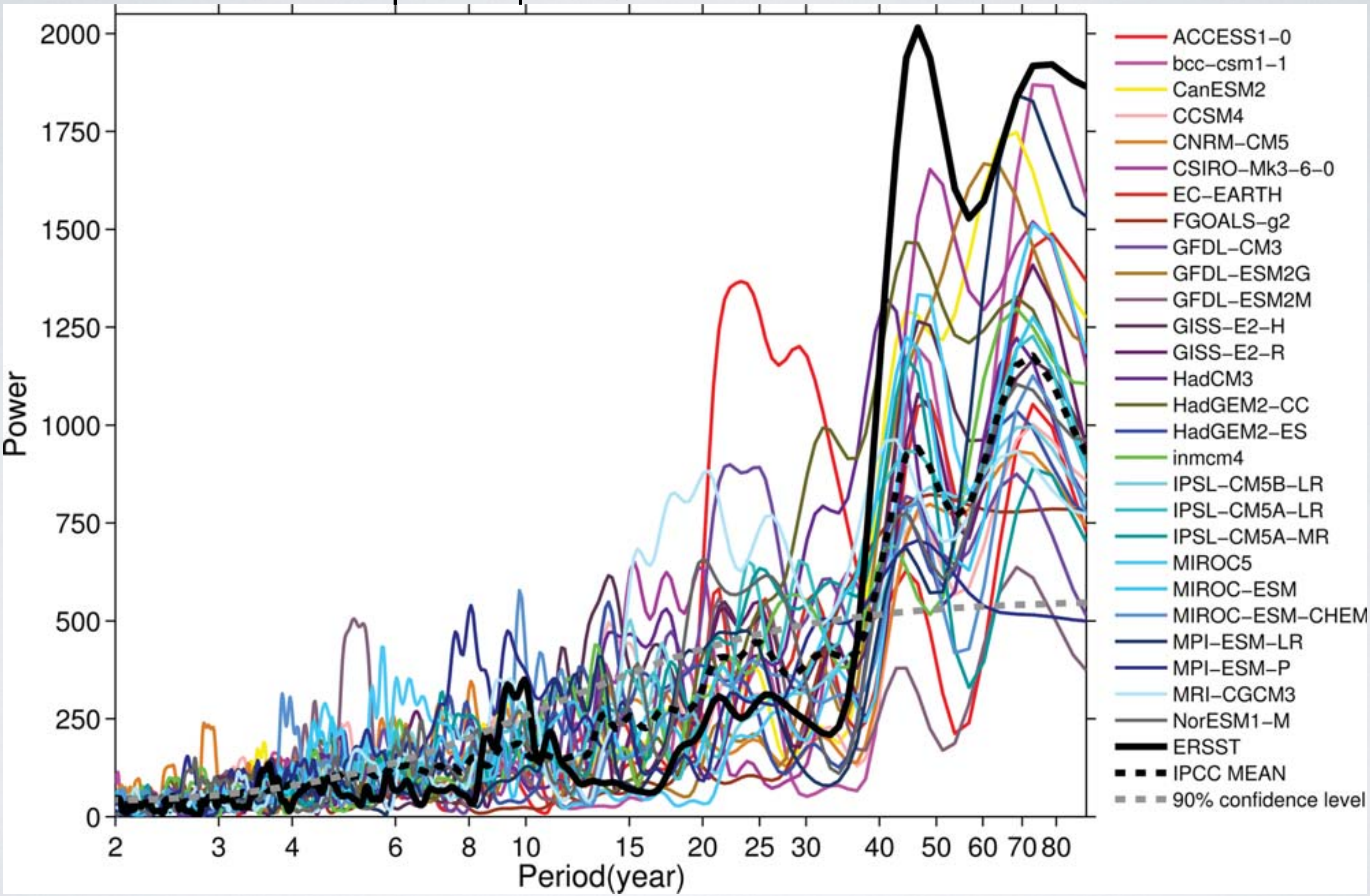
Amplitude of climate modes not always well simulated



IPCC AR5 WG1

Amplitude of climate modes not always well simulated

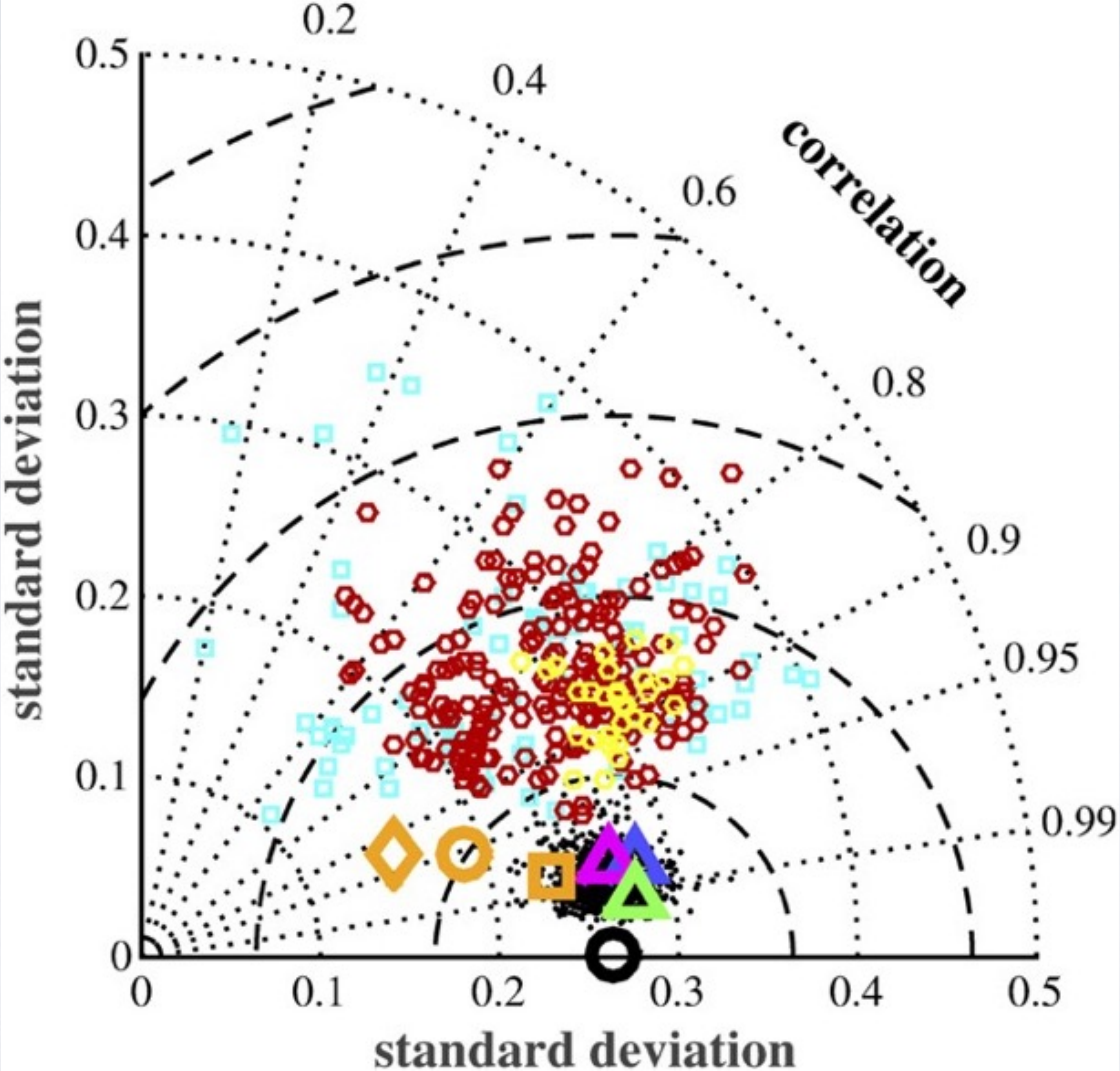
AMO power spectra, CMIP5 historical simulations



Zhang & Wang (2013)

Amplitude of climate modes not always well simulated

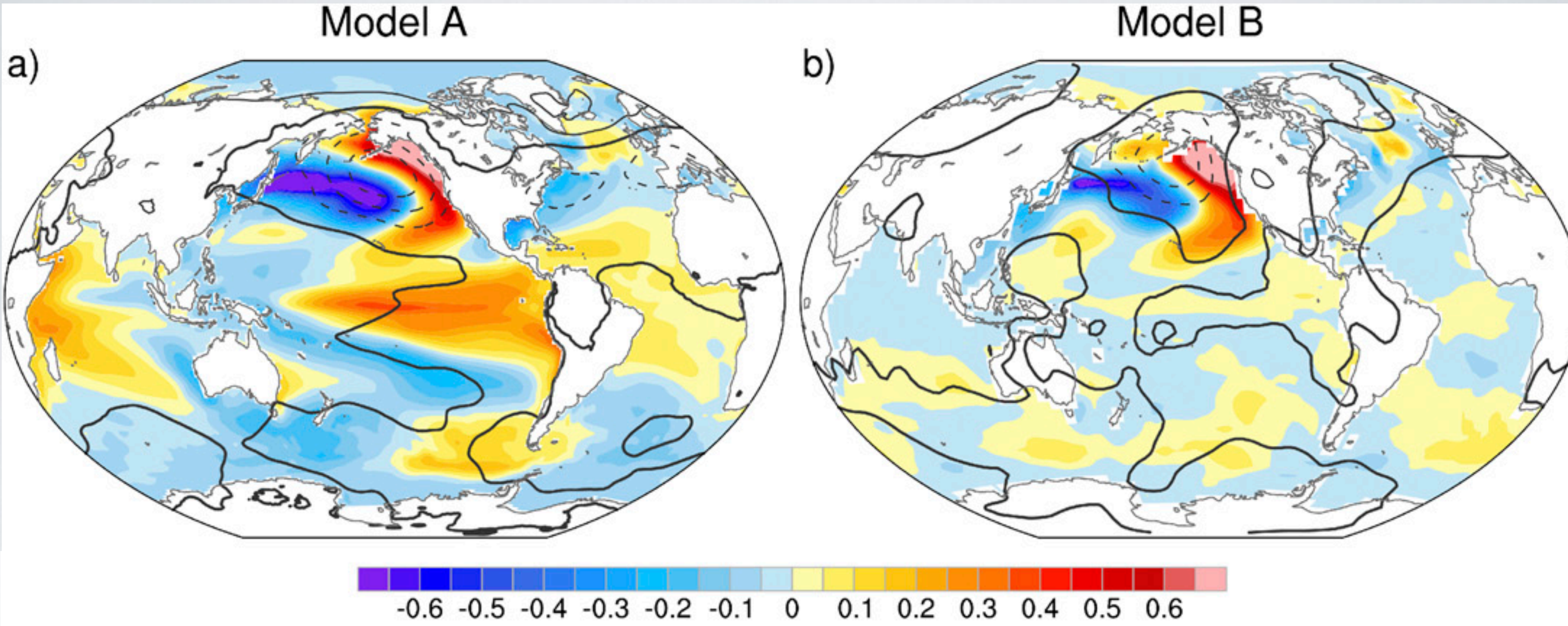
PDO Taylor diagram, CMIP3/CMIP5 historical simulations and CESM Large Ensemble



Newman et al. (2016)

Sources of uncertainty: structural differences among models

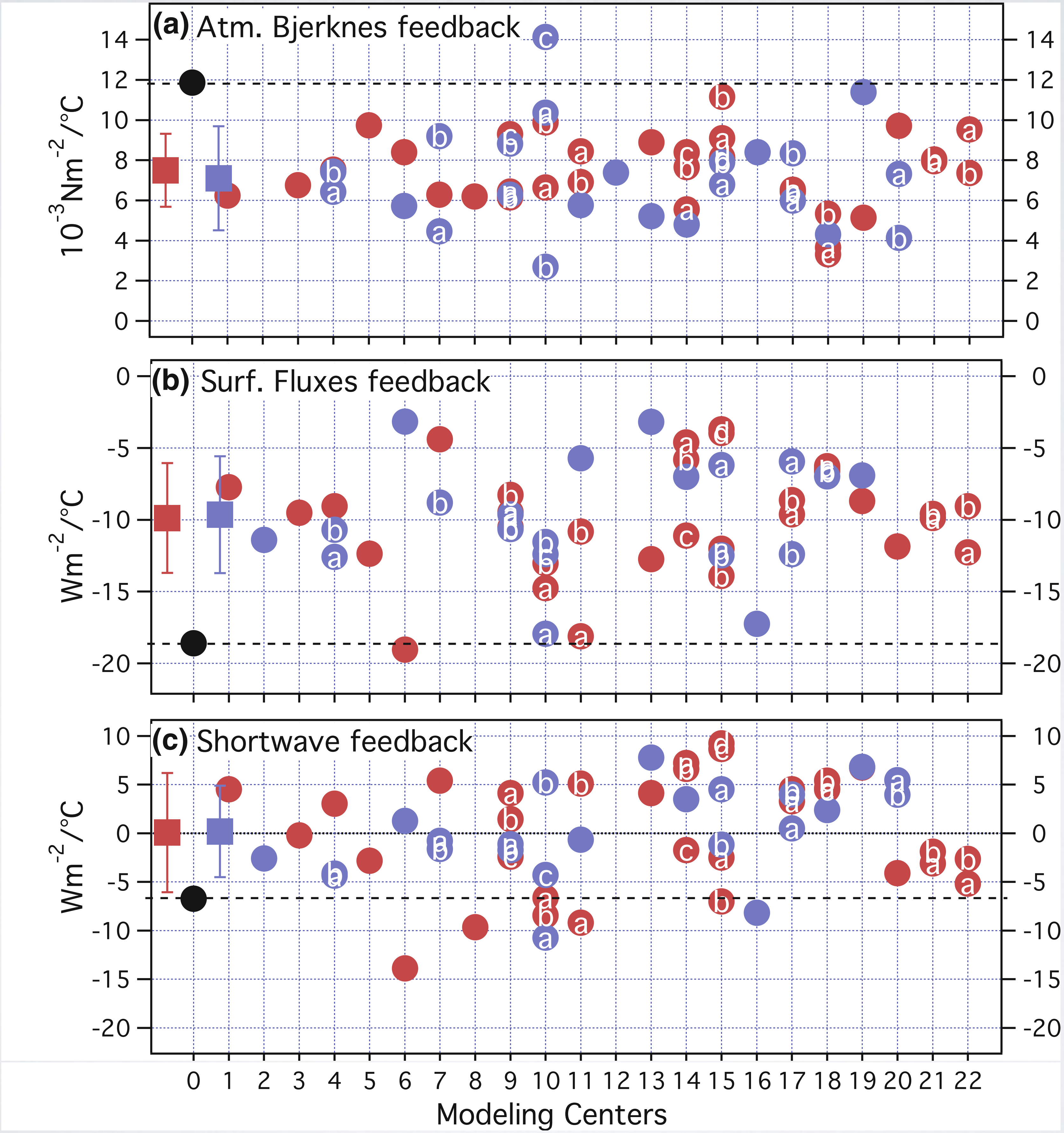
a), b): PDO spatial structure in CMIP5 models closest to, farthest from observations



Newman et al. (2016)

Understanding structural differences: process-level diagnostics

Major feedbacks relevant to the ENSO cycle



Bjerknes: sensitivity of SST to wind stress

Surf. fluxes: damping of SST by latent heat flux

Shortwave feedback: damping of SST by shortwave fluxes

Bellenger et al. (2014)

Understanding internal variability: large model ensembles

CESM Last Millennium Ensemble (CESM LME): Otto-Bliesner et al. (2016)
Multiple ensembles, varying sizes: different combinations of climate forcings 850-2005
(Orbital, solar, volcanic, GHG, ozone/aerosol, land use/land cover, all of the above)

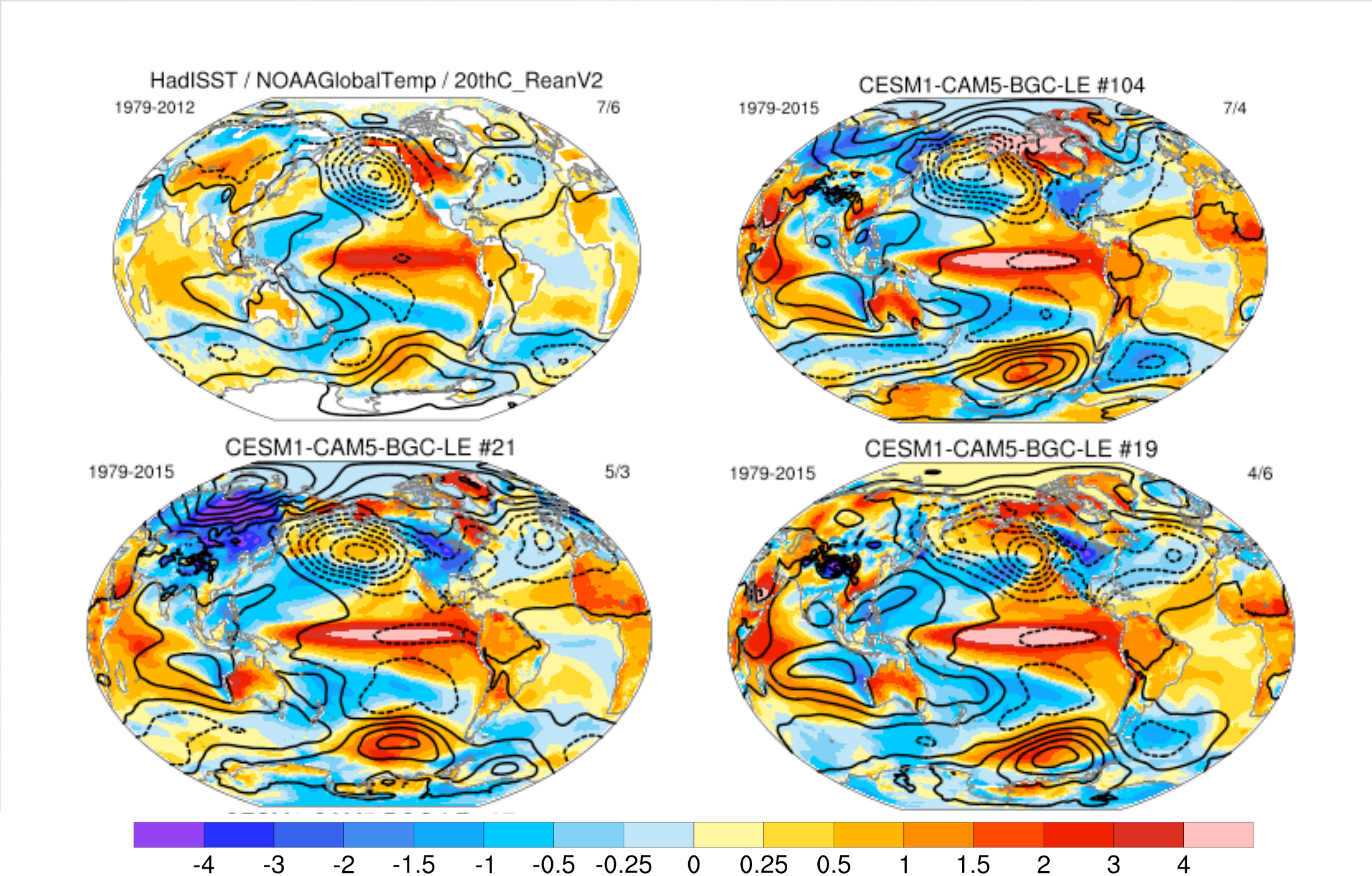
CESM Large Ensemble: Kay et al. (2016)
30+ members, 20th century: 1920-2005; 21st century: 2006-2100 (RCP8.5)

CESM Medium Ensemble: Sanderson et al. (2016)
15 members, 20th century: 1920-2005; 21st century: 2006-2100 (RCP4.5)

GFDL ESM2M: Rodgers et al. (2015)
30 members, 20th century: 1950-2005; 21st century: 2006-2100 (RCP8.5)

Internal variability affects ENSO teleconnections

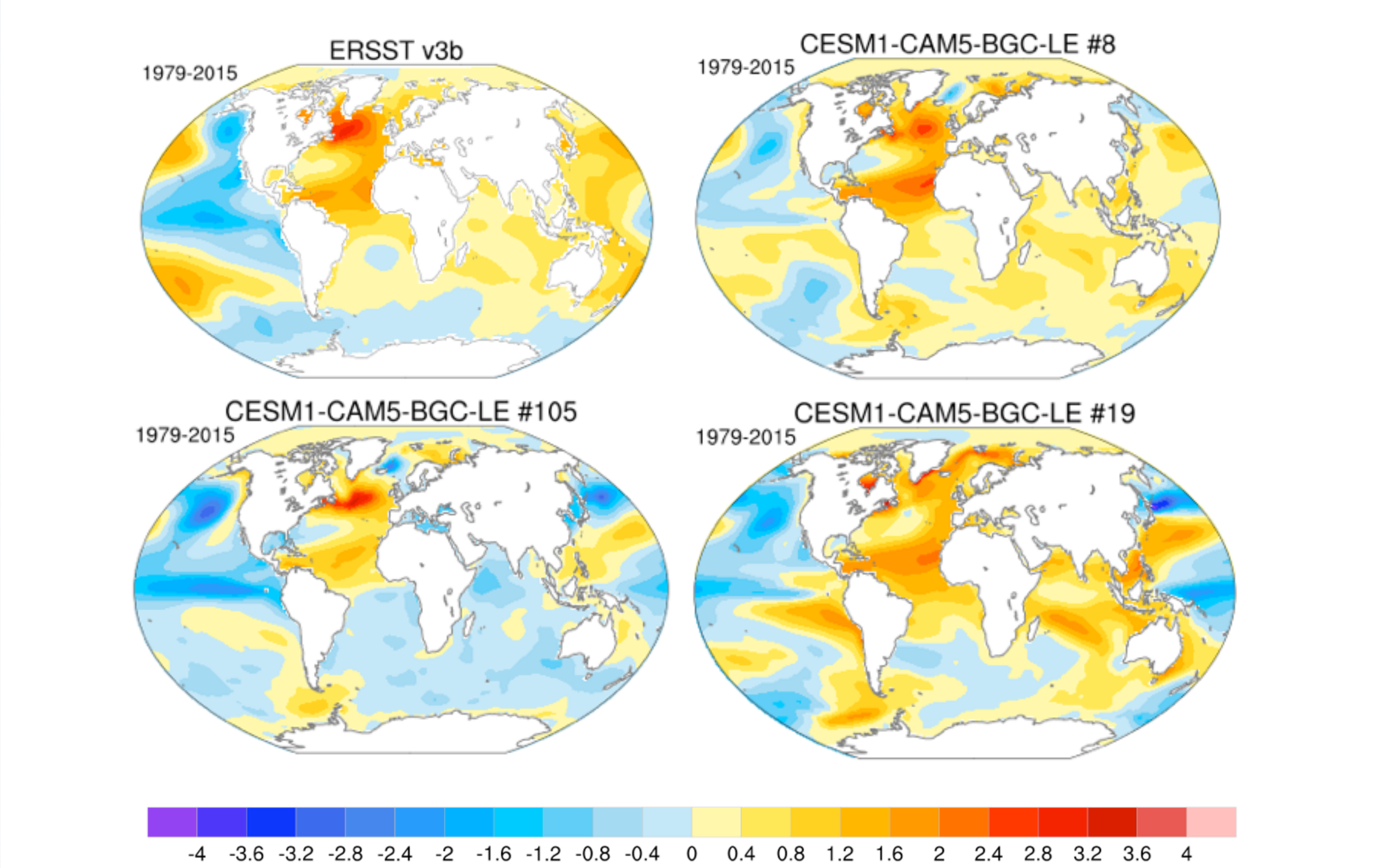
Composite SST/surface air temperature (colors), SLP (contours) during DJF of El Nino peak



NCAR Climate Variability Diagnostics Package

Internal variability affects AMO teleconnections

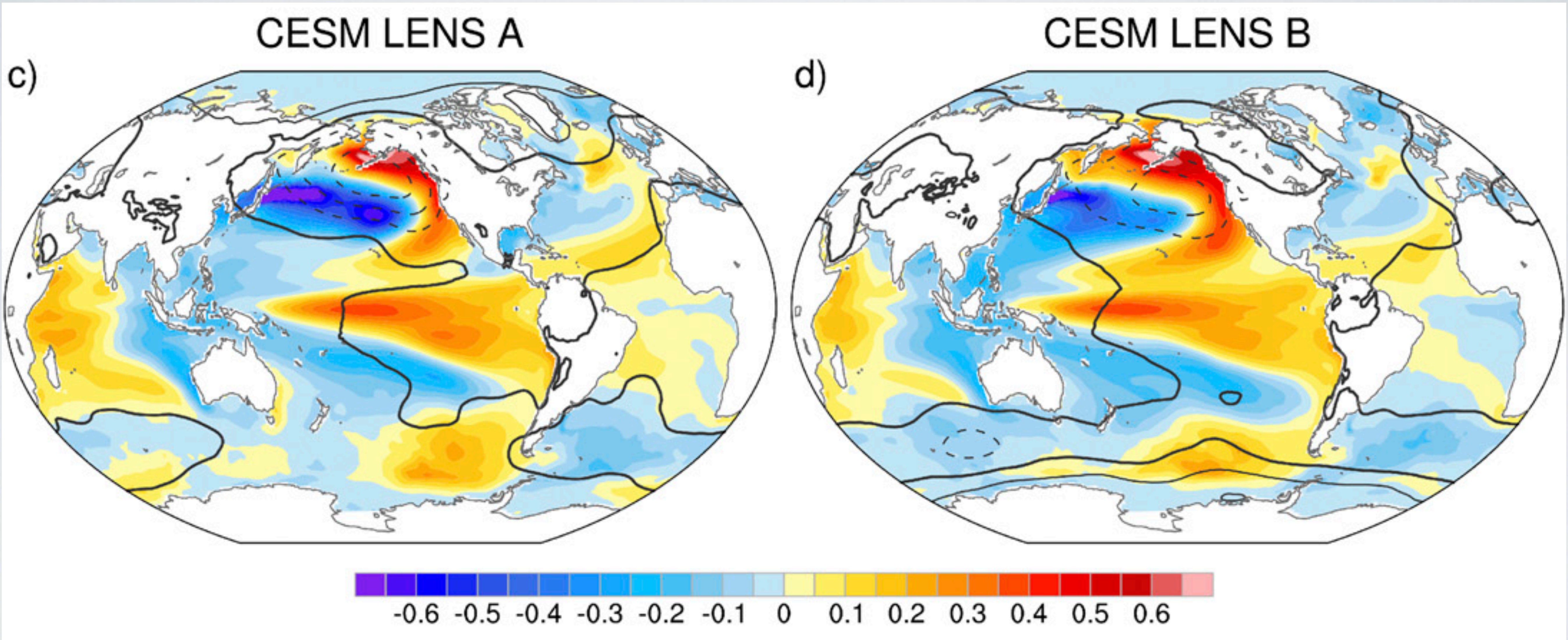
SST anomaly pattern associated with AMO: observations, CESM Large Ensemble



NCAR Climate Variability Diagnostics Package

Internal variability affects PDO teleconnections

PDO spatial structure in members of the CESM Large Ensemble closest to, farthest from observations

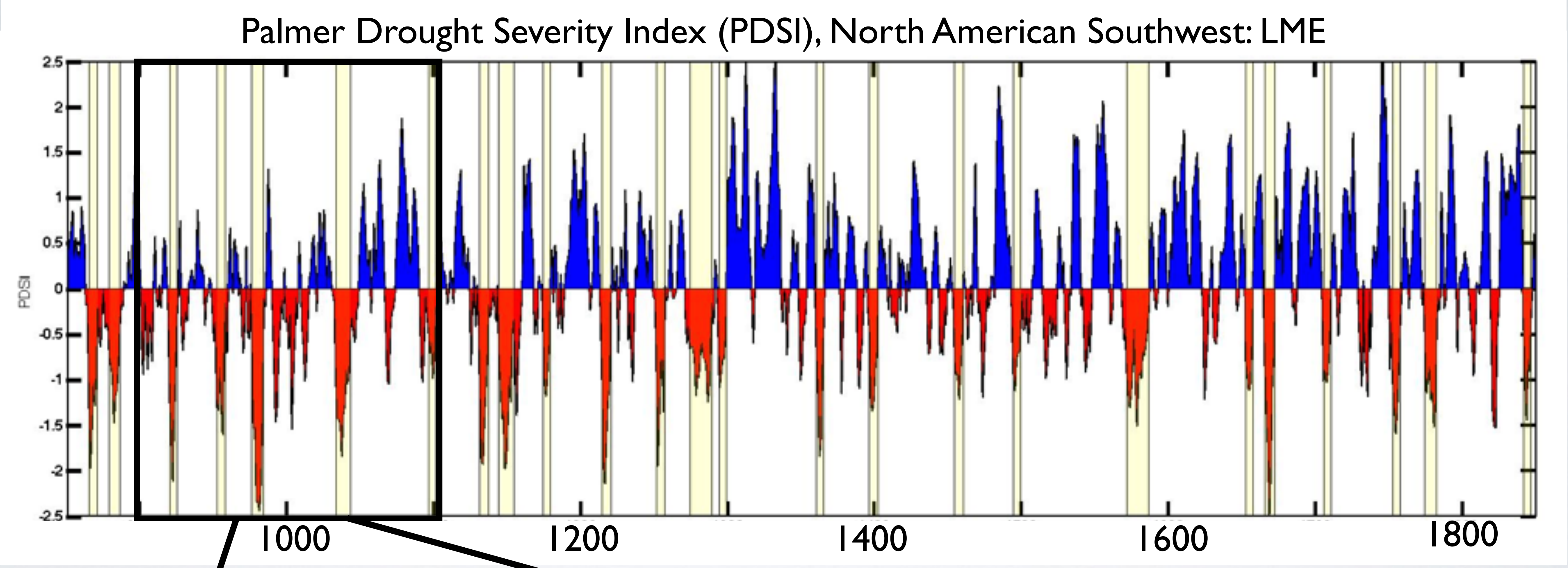


Newman et al. (2016)

What portion of long-term variability in teleconnected regions is driven by changes to major climate modes?

Large ensemble application: multidecadal "megadrought"

200-year moving window



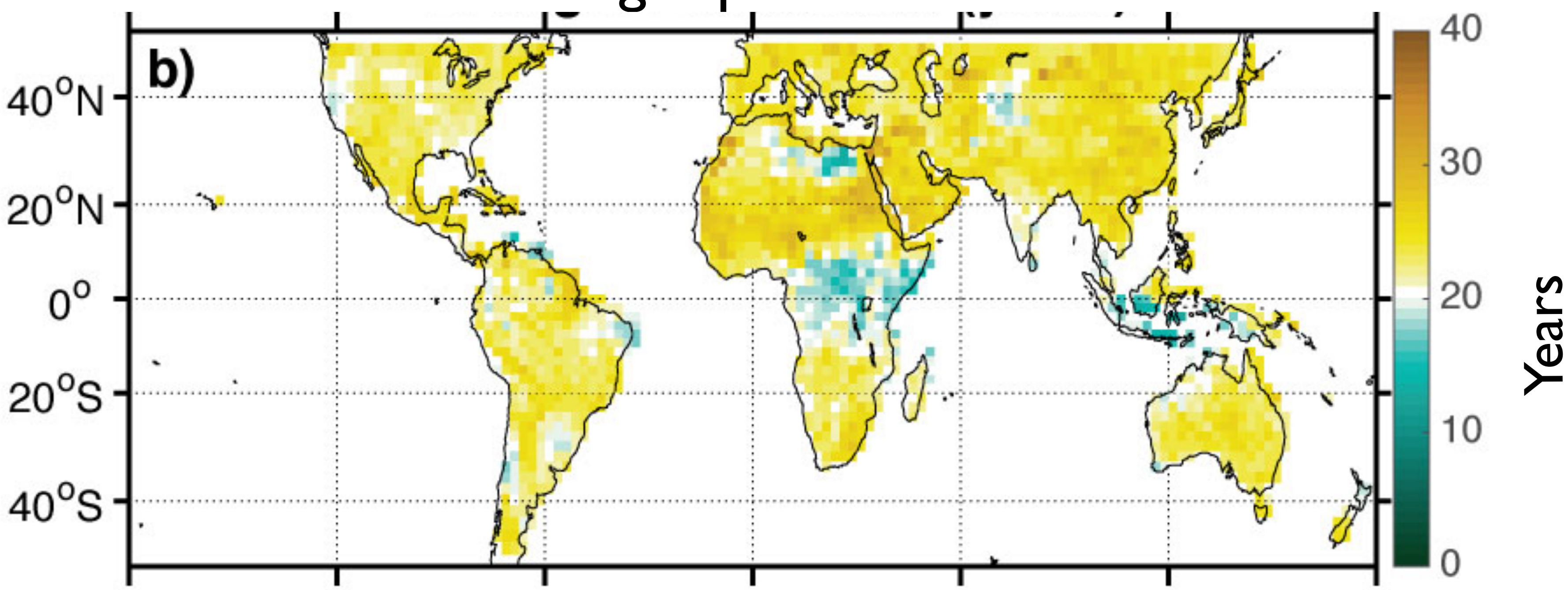
Climate variability:
ENSO amplitude

Megadrought persistence, risk

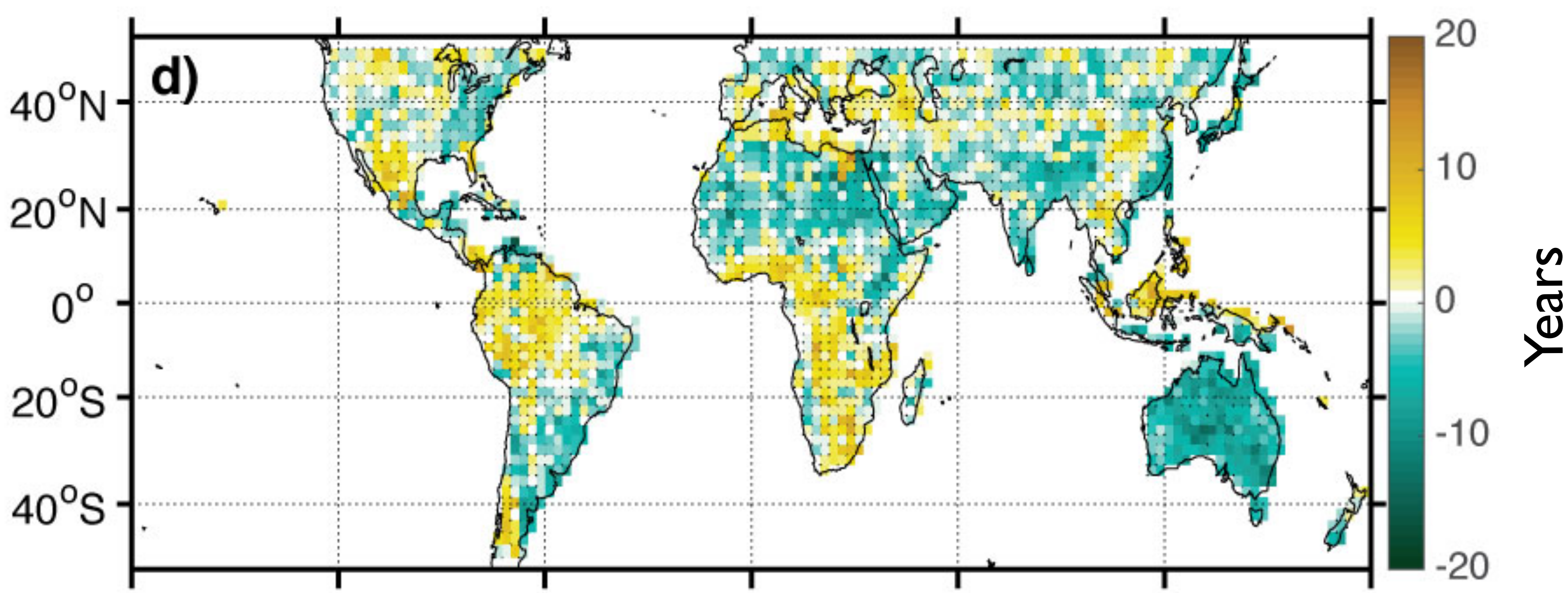
Risk = % years in megadrought

ENSO: strong influence on drought persistence

Drought persistence



Change in drought persistence when ENSO STRENGTHENS



15-year drought
(0.5σ threshold)

Stratified by mode
(above 60th/below 40th percentile)

Brown = higher drought risk
Green = lower drought risk

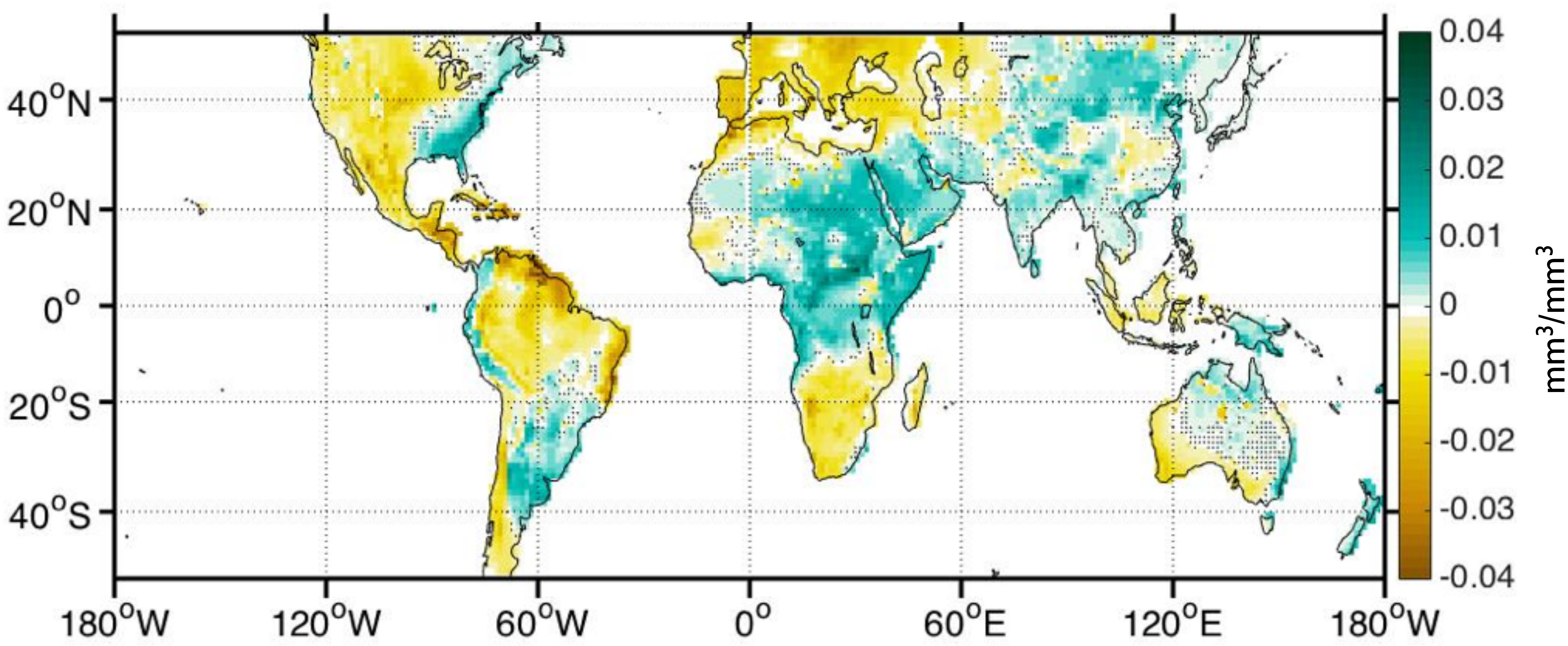
Stronger ENSO:

- **Shorter** drought in Australia, Africa, Southeast Asia, SW US
- **Longer** drought in Amazon basin, Mexico

Stevenson et al. (2017), in review

21st century: drying projected for western N. America, Amazon

Difference in 0-30cm soil moisture: (2006-2100) - (1920-2005), CESM Large Ensemble

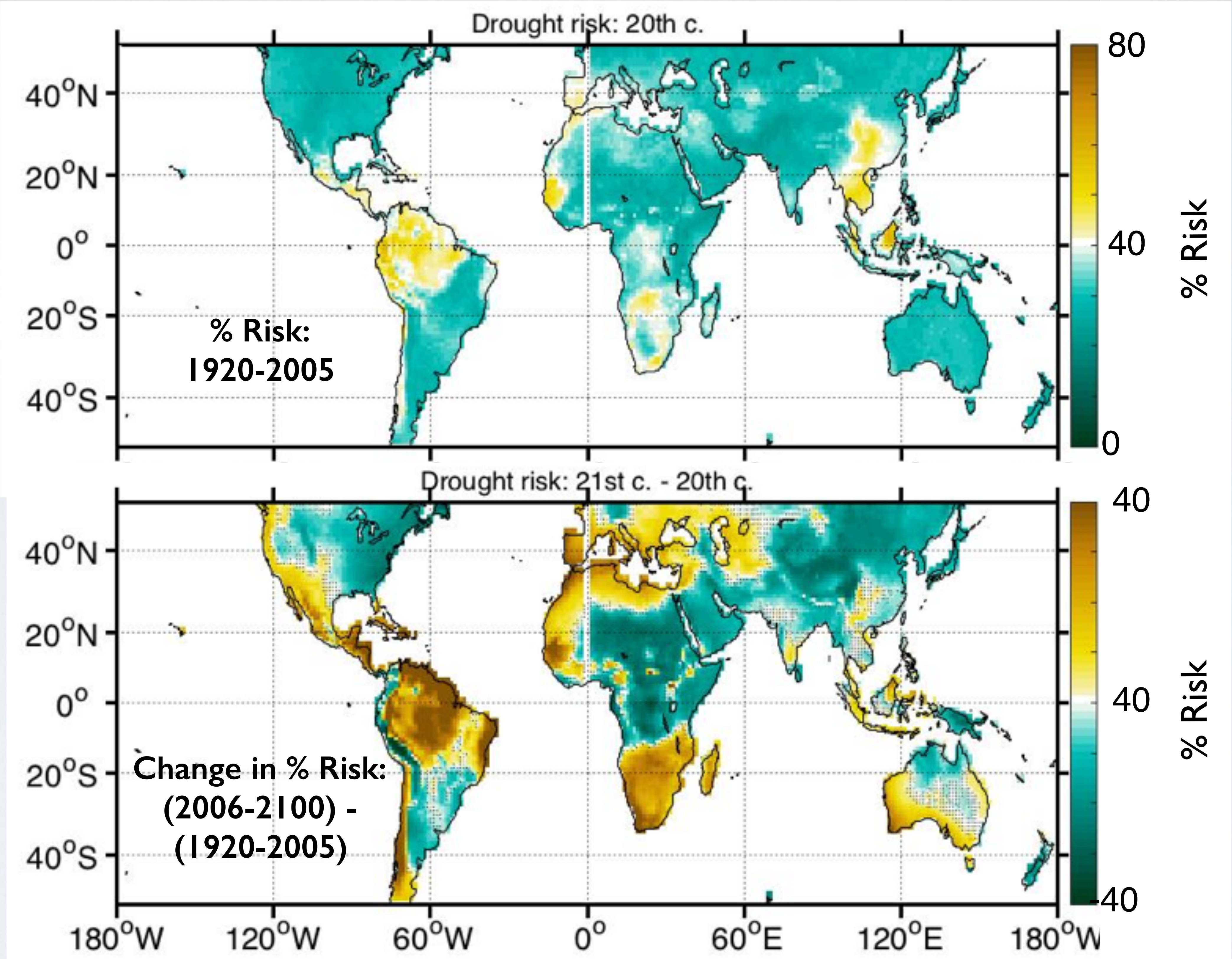


Stevenson et al. (2017), in prep for Nature Climate Change

Drought risk changes: function of both mean and variance shifts

15-year drought (0.5σ threshold)

Brown = higher drought risk; Green = lower drought risk



Stevenson et al. (2017), in prep for Nature Climate Change

Conclusions

Teleconnections are influenced by internal atmospheric variability, coupled atmosphere/ ocean/land processes, and impacts from external forcings

- Models capture ENSO teleconnections more reliably than AMO

- Strong inter-model differences in teleconnection performance: both structural differences among models and internal variability are important

- Large model ensembles can clear up differences, diagnose externally driven teleconnection responses

Large 20th/21st c. model ensembles, multi-centennial model simulations, and targeted observational improvements needed to constrain uncertainties in teleconnection estimates

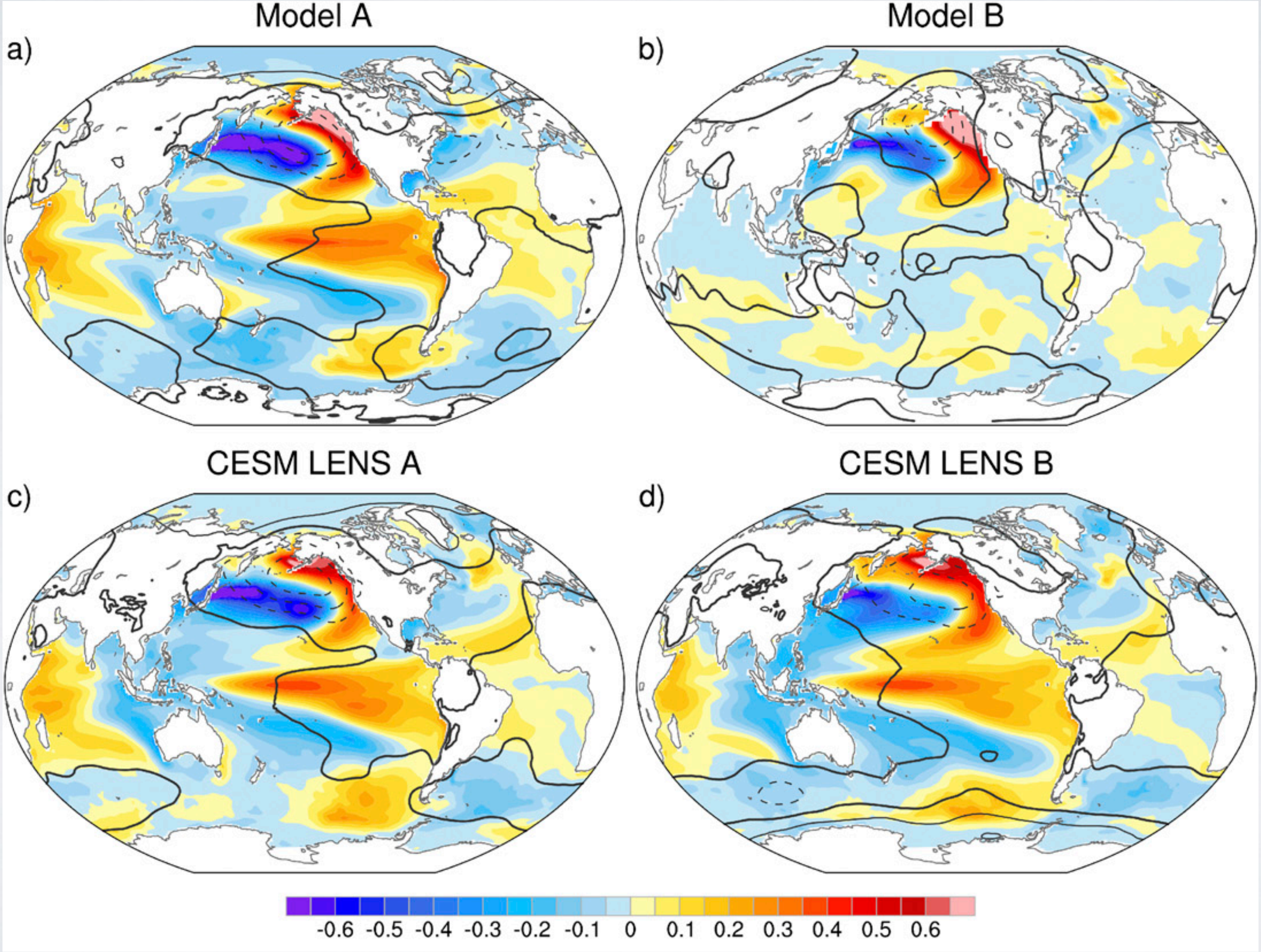
Advancing Teleconnection Simulations

Samantha Stevenson

National Center for Atmospheric Research, University of California at Santa Barbara

Issue: both structural, internal differences matter to teleconnections

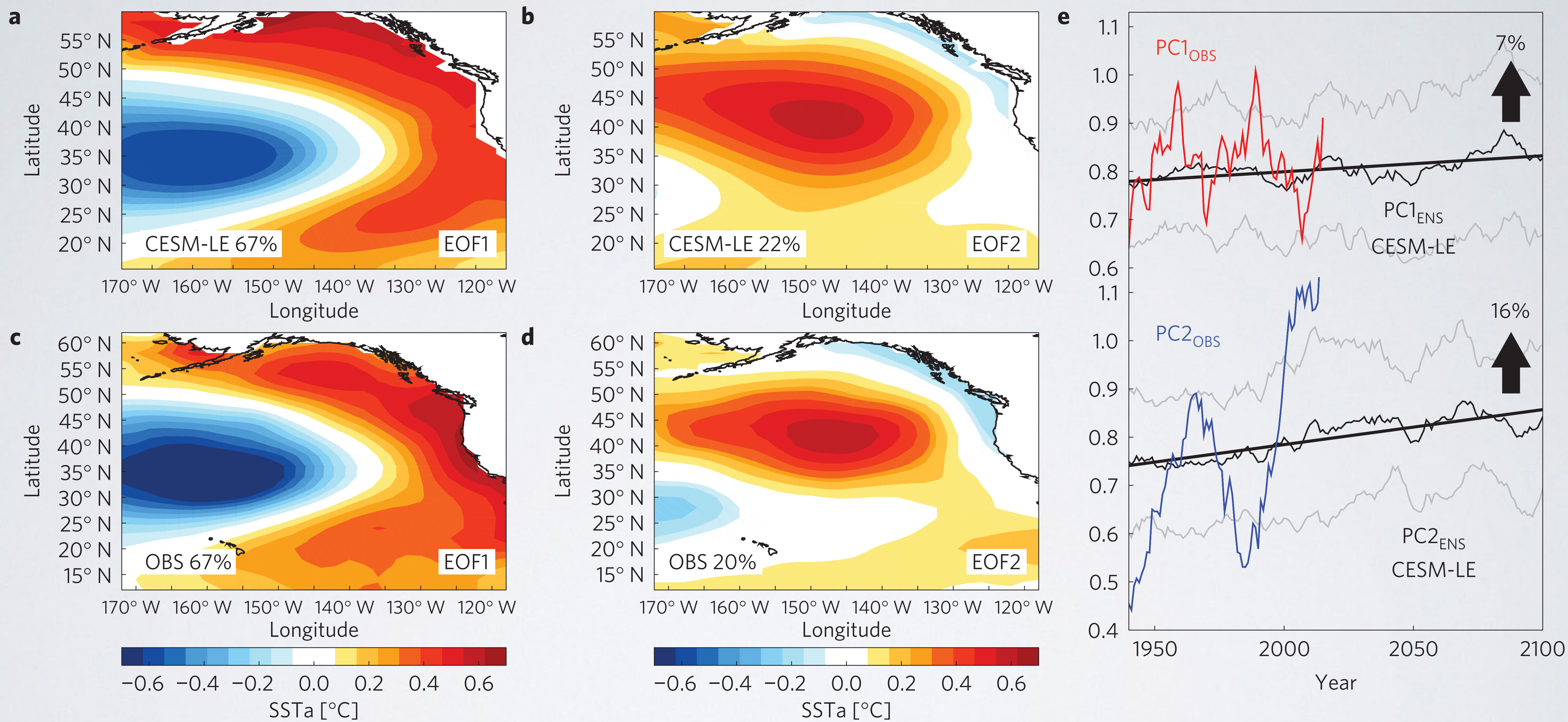
a), b): PDO spatial structure in CMIP5 models closest to, farthest from observations
c), d): Same as a), b) for members of the CESM Large Ensemble



Newman et al. (2016)

CESM LENS: enhanced meridional mode variability

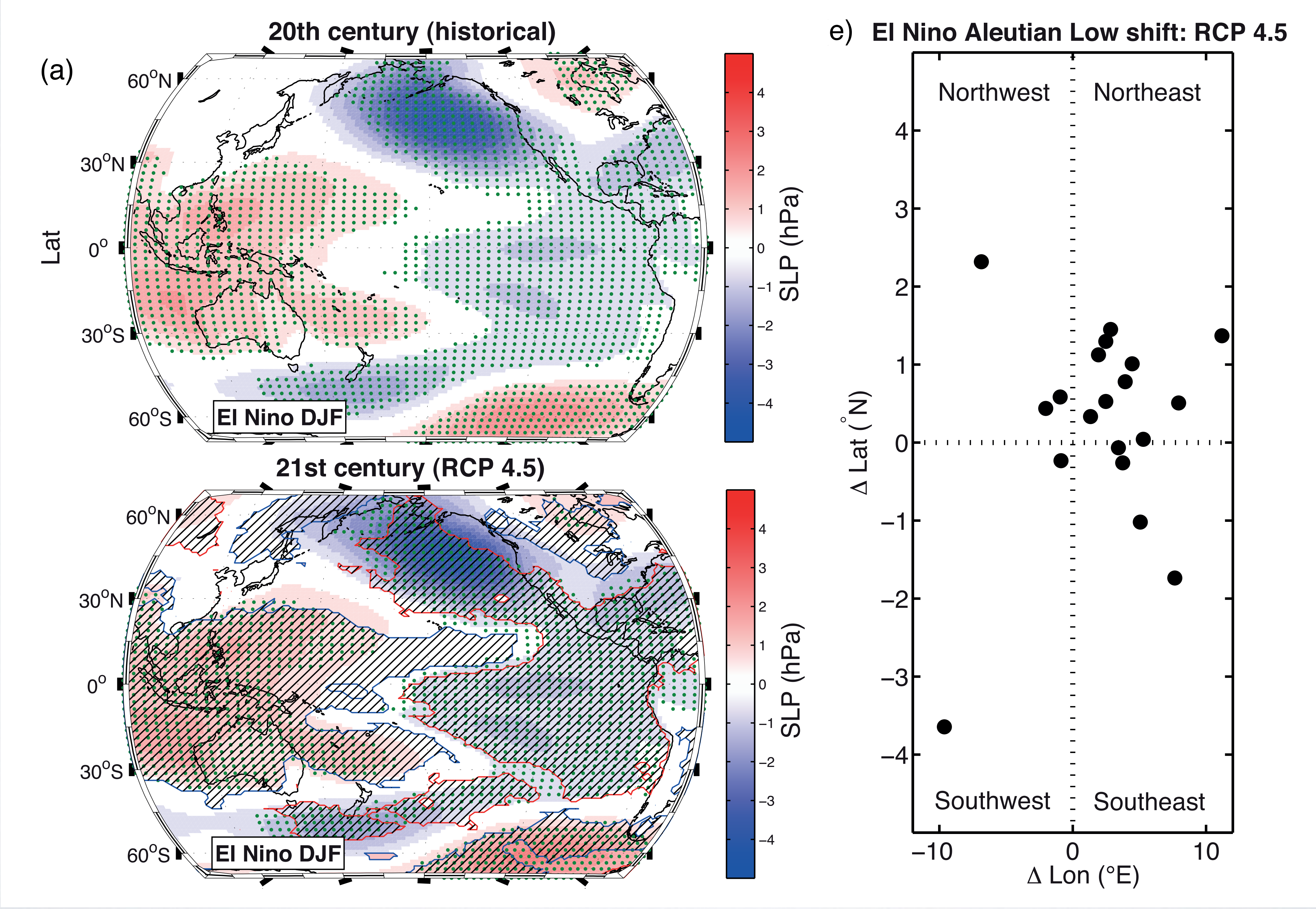
First two EOFs of North Pacific SST: CESM Large Ensemble, observations



Di Lorenzo & Mantua (2016)

CMIP5 projections: shift in location of ENSO teleconnections

SLP composites during DJF of El Nino peak: CMIP5 historical, RCP4.5 projections

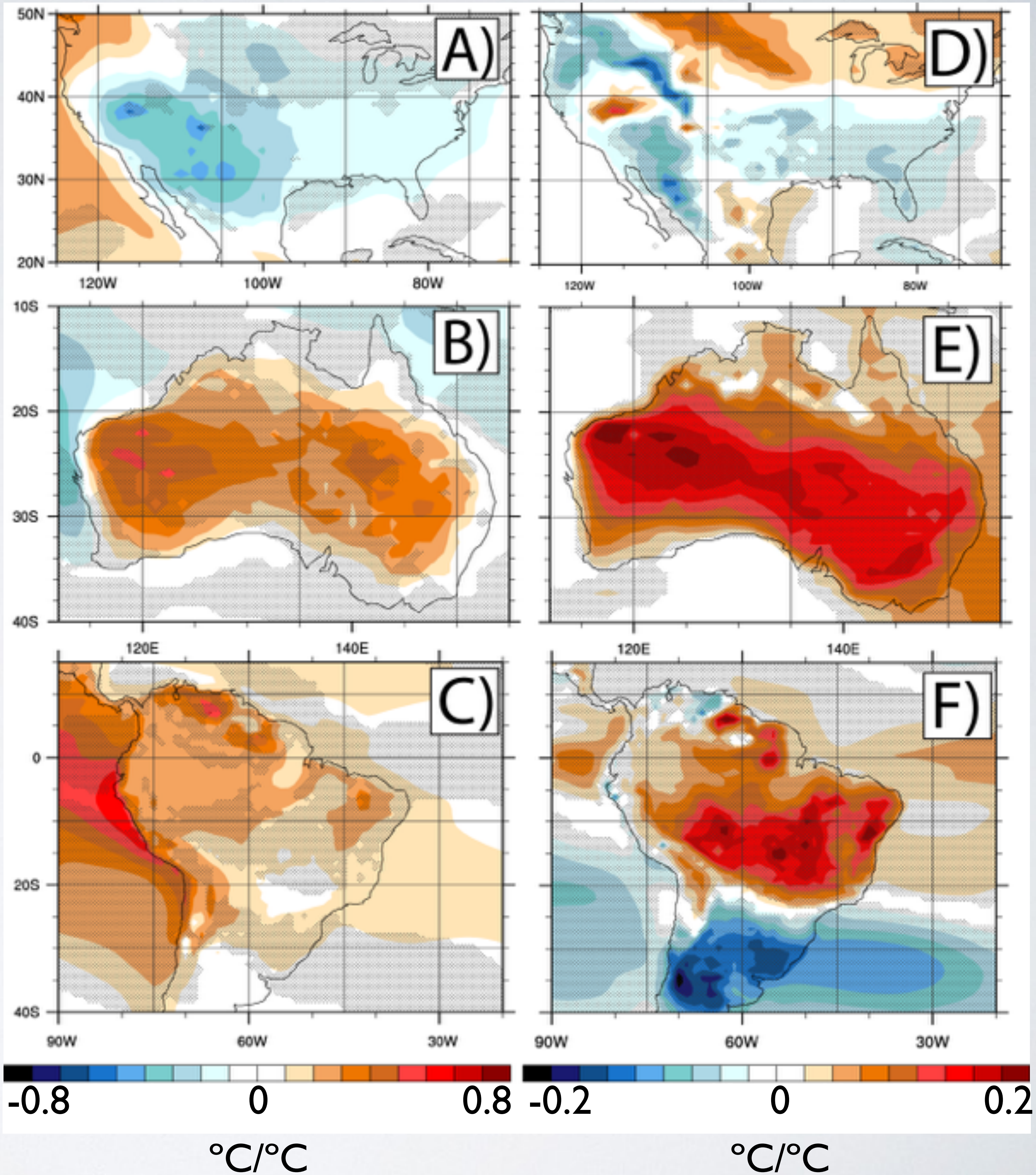


IPCC AR5 WG1

CESM, ESM2M ensembles: ENSO teleconnection intensification

Left: Regression of temperature onto NINO3.4 index in the CESM Large Ensemble (Kay et al. 2015)

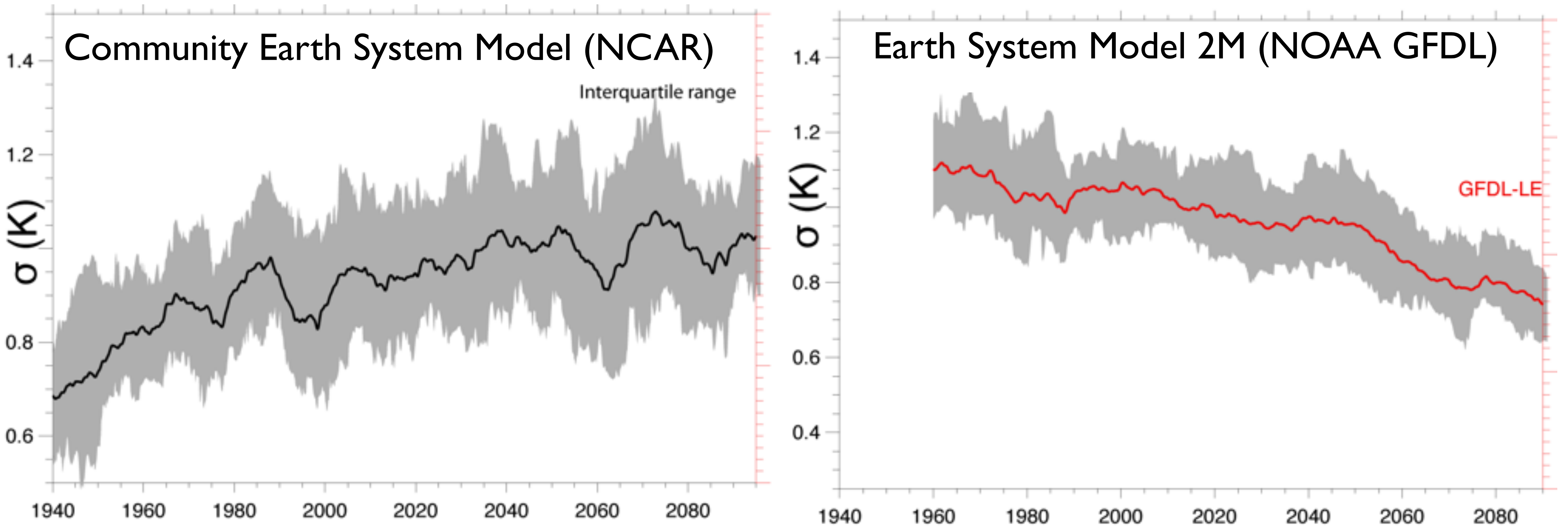
Right: *change* in the regression coefficient between 2040-2100 and 1920-1980



Fasullo, Otto-Bliesner, & Stevenson 2017, Nature Climate Change, in revision

No agreement on future changes in ENSO amplitude

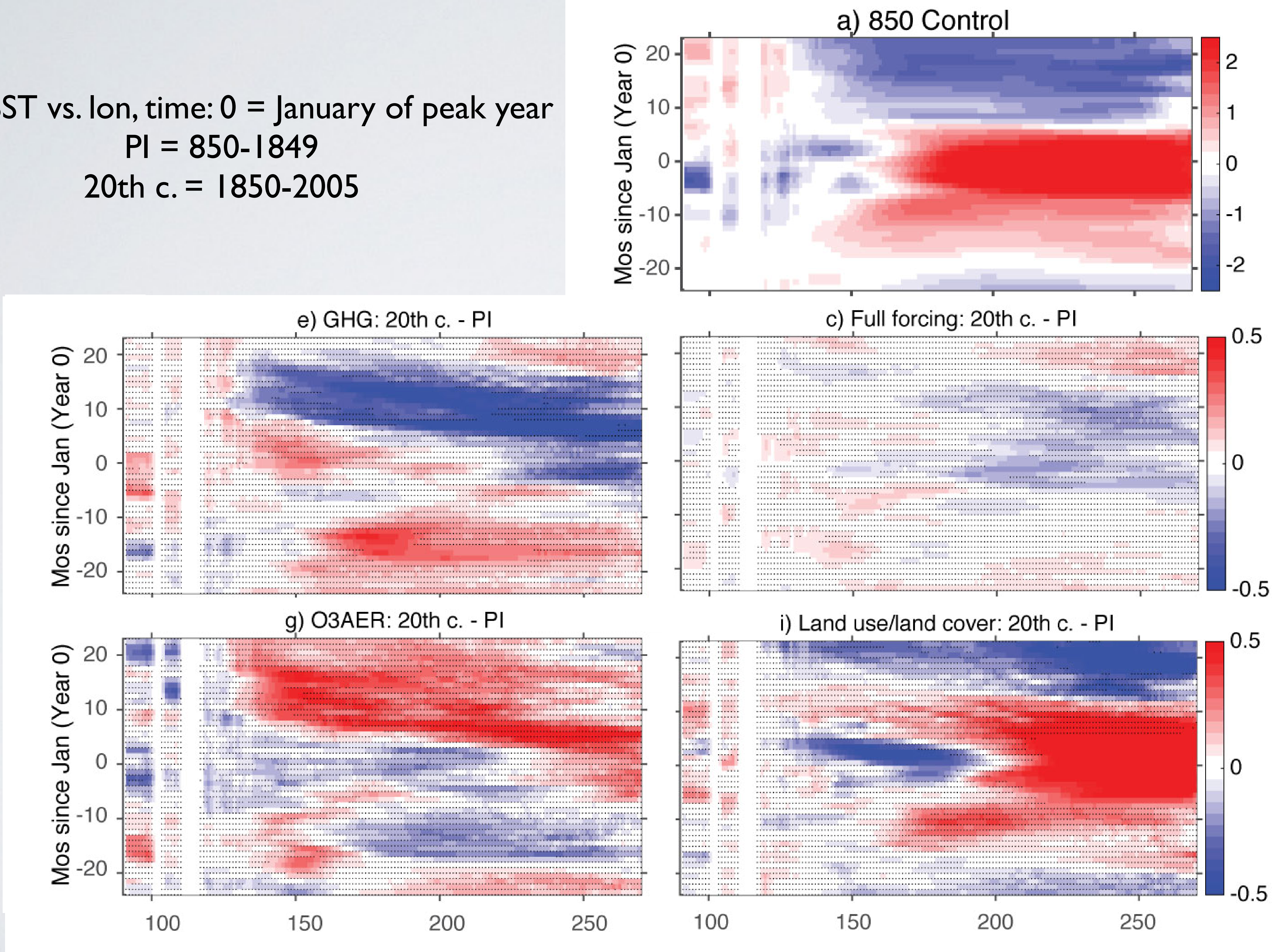
Running 20-year NINO3.4 variance, RCP8.5



Fasullo, Otto-Bliesner, & Stevenson 2017, Nature Climate Change, in revision

CESM: differential ENSO response to anthropogenic forcings

2S-2N SST vs. lon, time: 0 = January of peak year
PI = 850-1849
20th c. = 1850-2005



Stevenson et al. (2017), Climate Dynamics

What new simulations and observations are needed to improve understanding of teleconnections in climate models?

Simulations planned for CMIP6 (DECK)

Experiment short name	CMIP6 label	Experiment description	Forcing methods	Start year	End year	Minimum no. years per simulation	Major purpose
DECK experiments							
AMIP	*amip*	Observed SSTs and SICs prescribed	All; CO_2 concentration prescribed	1979	2014	36	Evaluation, variability
Pre-industrial control	*piControl* or *esm-piControl*	Coupled atmosphere–ocean pre-industrial control	CO_2 concentration prescribed or calculated	n/a	n/a	500	Evaluation, unforced variability
Abrupt quadrupling of CO_2 concentration	*abrupt-4×CO2*	CO_2 abruptly quadrupled and then held constant	CO_2 concentration prescribed	n/a	n/a	150	Climate sensitivity, feedback, fast responses
$1\,\%\,\mathrm{yr}^{-1}$ CO_2 concentration increase	*1pctCO2*	CO_2 prescribed to increase at $1\,\%\,\mathrm{yr}^{-1}$	CO_2 concentration prescribed	n/a	n/a	150	Climate sensitivity, feedback, idealized benchmark
CMIP6 historical simulation							
Past ~ 1.5 centuries	*historical* or *esm-hist*	Simulation of the recent past	All; CO_2 concentration prescribed or calculated	1850	2014	165	Evaluation

Eyring et al. (2016)

CMIP6: also supports "sub-MIPs" with specific scientific targets

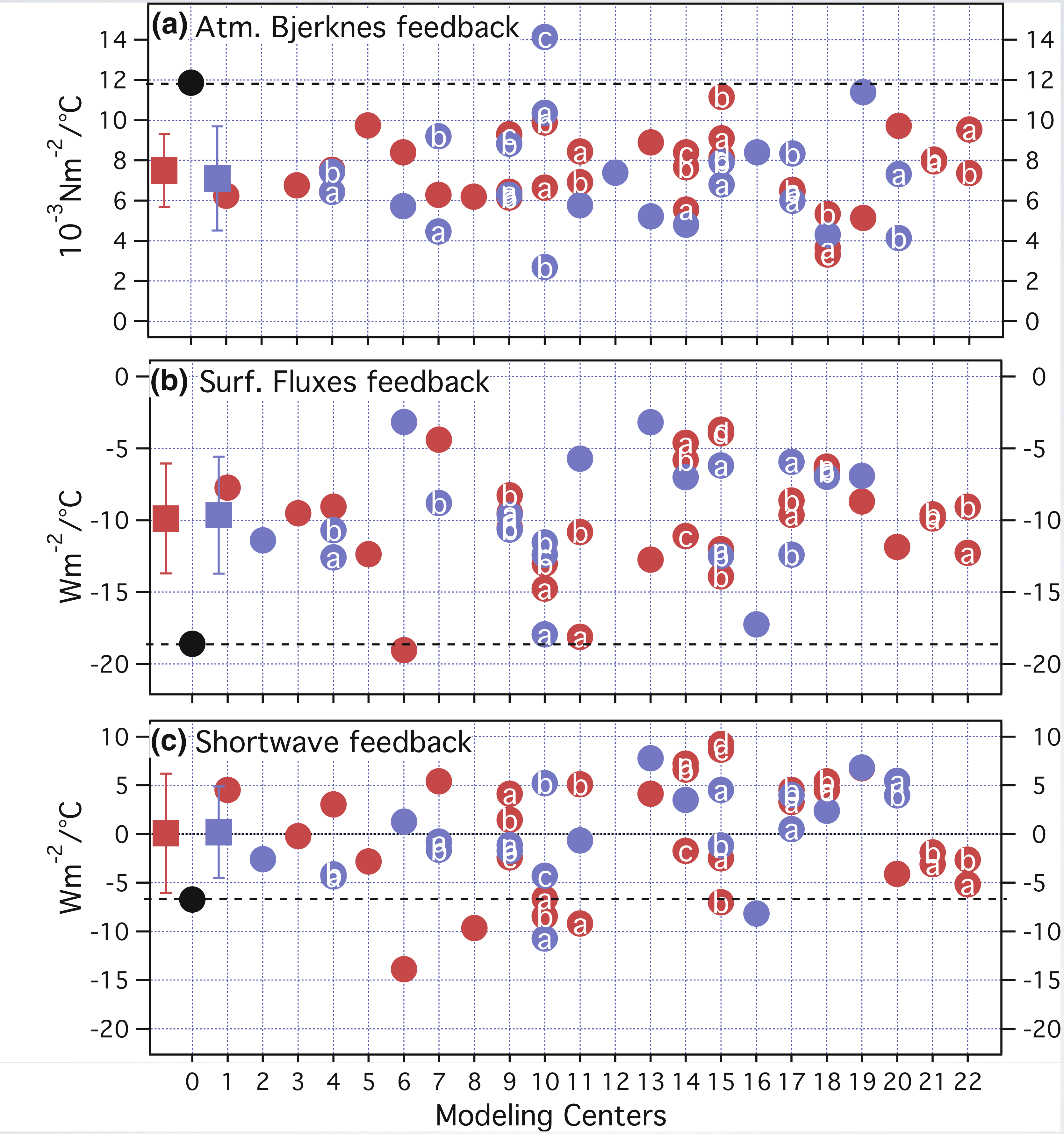
	Questions			Grand science challenges						
	Response to Forcing	Systematic Errors	Variability, Prediction & Projection	Clouds, circulation, sensitivity	Melting ice	Climate extremes	Changes in water availability	Regional sea level change	Biogeochemistry	Near term prediction
AerChemMIP	●		○						●	○
C4MIP	●		○				○		●	
CFMIP	●	○		●			○			
DAMIP	●		○		○	●				
DCPP	○		●				○	○		●
FAFMIP	●	○		○				●		
GeoMIP	○		●	●		○	○			
GMMIP		●	○	●			○			○
HighResMIP	○	●		○			●			
ISMIP6	●		○		●			●		
LS3MIP	○	●			○		●			
LUMIP	●		○				○		●	
OMIP		●	○					○	○	●
PMIP	●	○		●					○	
RFMIP	●		○	●						○
ScenarioMIP	○		●			●	●		○	
VolMIP	●	○		○						○
CORDEX	○		●			●	○			
DynVarMIP	○	●		○						○
SIMIP	○	●			●					
VIACS AB	○		●			●	○	○		

CMIP6: also supports "sub-MIPs" with specific scientific targets

		Questions			Grand science challenges						
		Response to Forcing	Systematic Errors	Variability, Prediction & Projection	Clouds, circulation, sensitivity	Melting ice	Climate extremes	Changes in water availability	Regional sea level change	Biogeochemistry	Near term prediction
Aerosols & Chemistry MIP	AerChemMIP	●		○						●	○
	C4MIP	●		○				○		●	
	CFMIP	●	○		●			○			
	DAMIP	●		○		○	●				
	DCPP	○		●				○	○		●
	FAFMIP	●	○		○				●		
	GeoMIP	○		●	●		○	○			
Global Monsoons MIP	GMMIP		●	○	●			○			○
	HighResMIP	○	●		○			●			
	ISMIP6	●		○		●			●		
Land Surface, Snow and Soil Moisture MIP	LS3MIP	○	●			○		●			
	LUMIP	●		○				○		●	
	OMIP		●	○					○	○	●
	PMIP	●	○		●					○	
Radiative Forcing MIP	RFMIP	●		○	●						○
	ScenarioMIP	○		●			●	●		○	
	VolMIP	●	○		○						○
	CORDEX	○		●			●	○			
Dynamics & Variability MIP	DynVarMIP	○	●		○						○
	SIMIP	○	●			●					
	VIACS AB	○		●			●	○	○		

Uncertainty quantification: process-level insights

Major feedbacks relevant to the ENSO cycle



Bjerknes: sensitivity of SST to wind stress

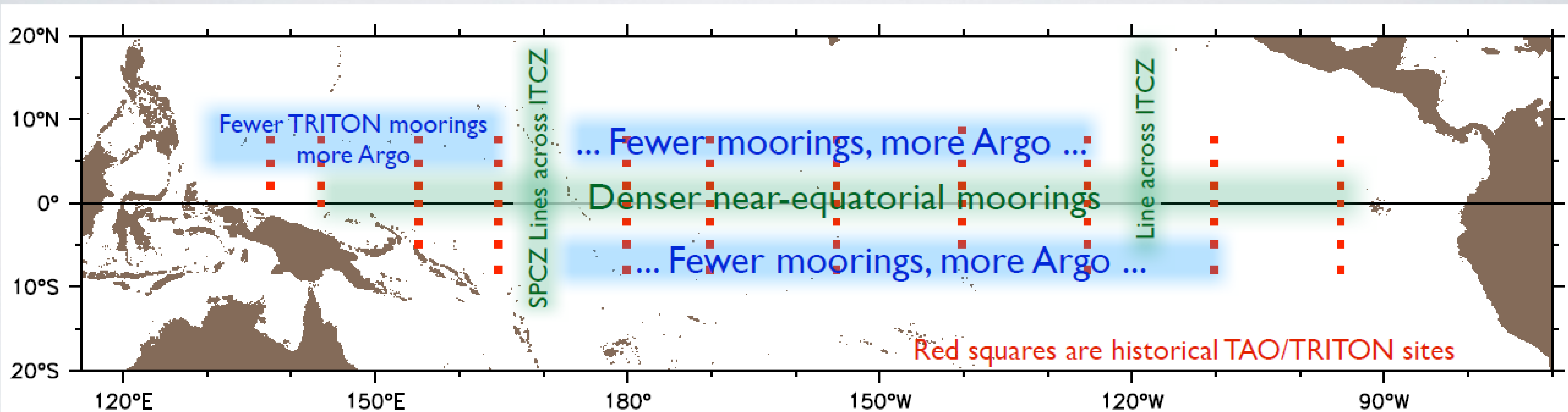
Surf. fluxes: damping of SST by latent heat flux

Shortwave feedback: damping of SST by shortwave fluxes

Bellenger et al. (2014)

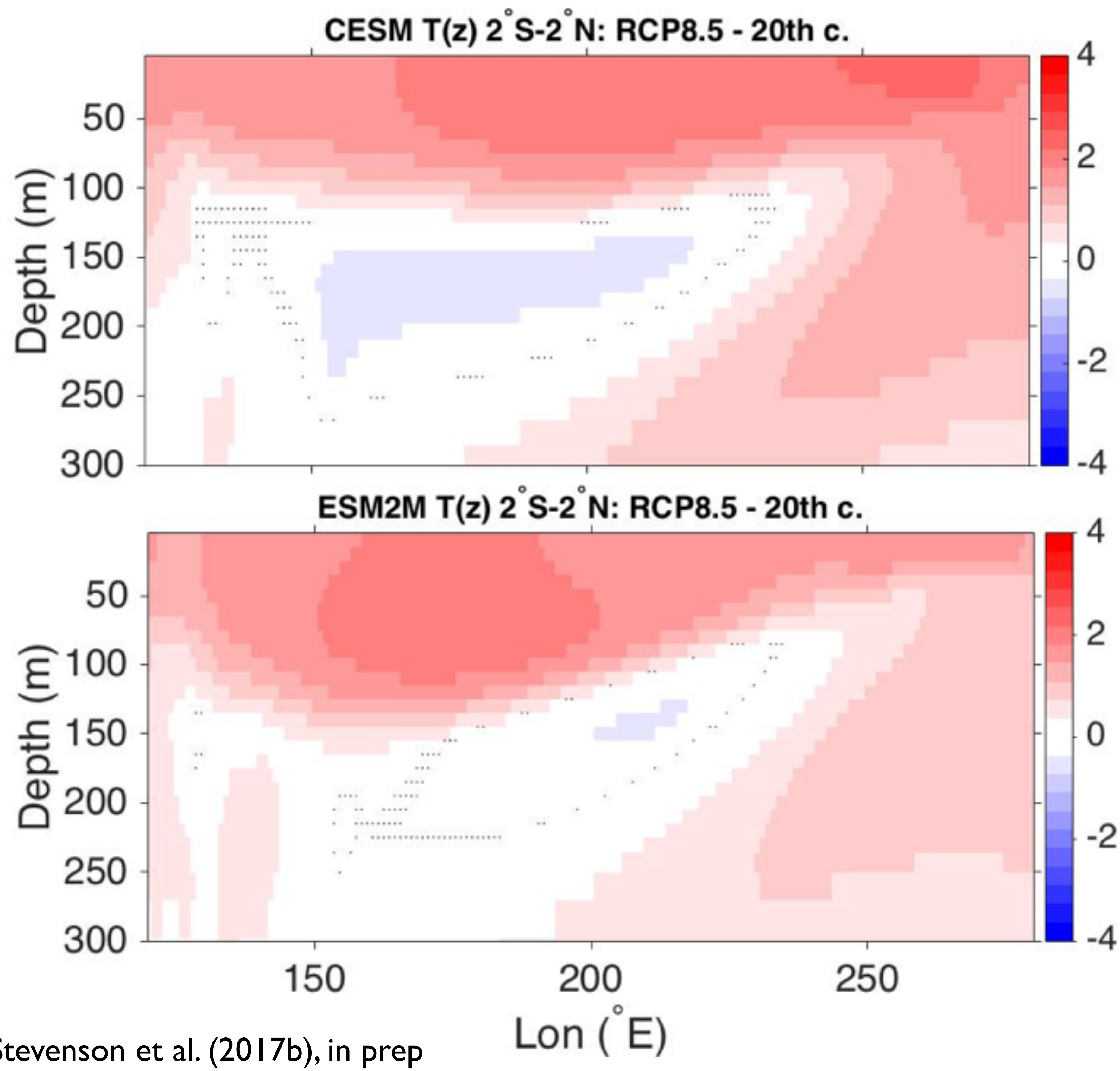
Important observational target: air-sea fluxes

Off-equatorial air/sea fluxes in precursor regions



TPOS2020 First Report, Second draft (September 2016)

Important observational target: vertical temperature structure



Stevenson et al. (2017b), in prep

CESM: zonal SST gradient weakens, vertical stratification increases

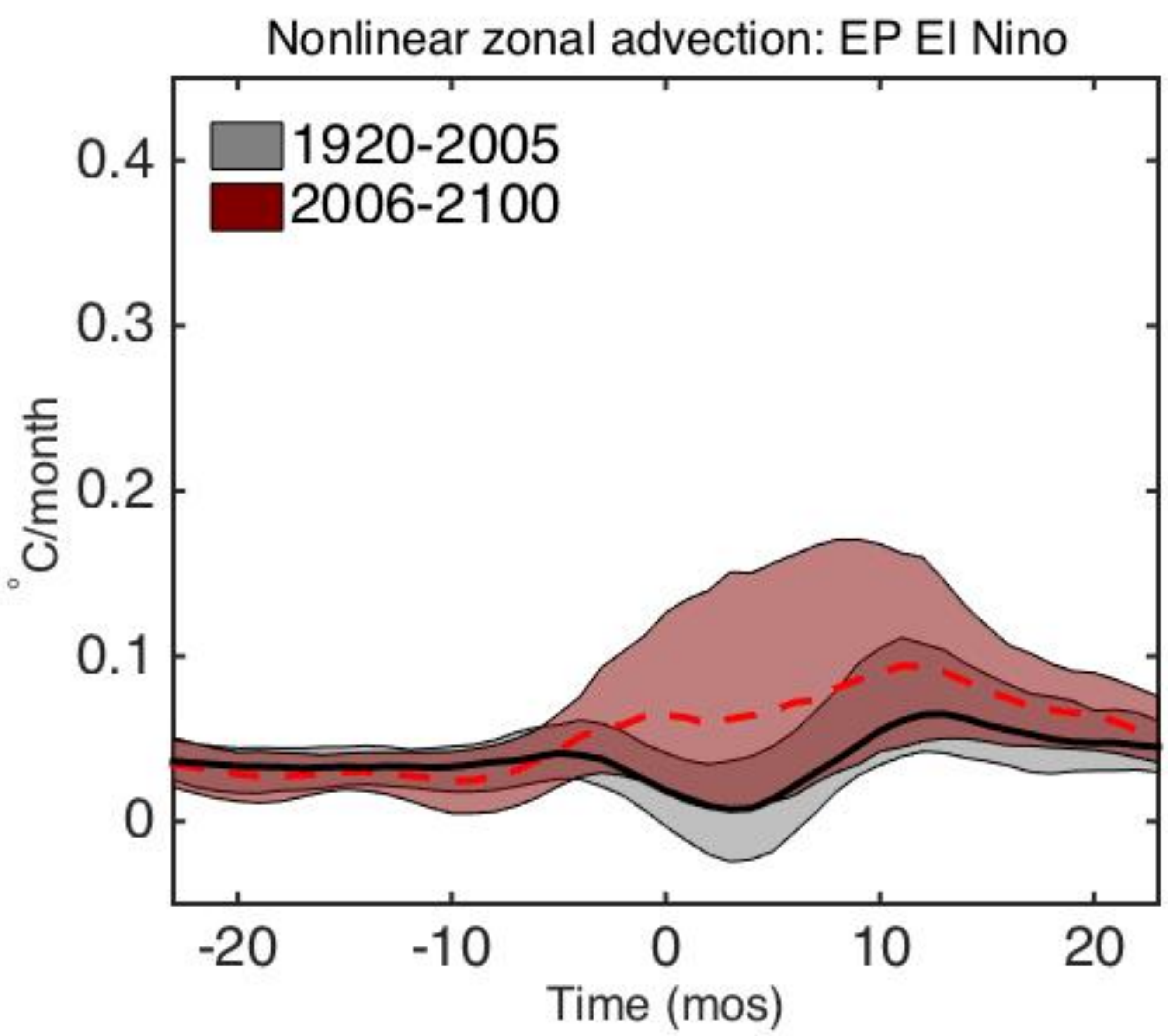
ESM2M: zonal SST gradient strengthens, vertical stratification doesn't increase as much as CESM

Important observational target: mixed-layer eddies

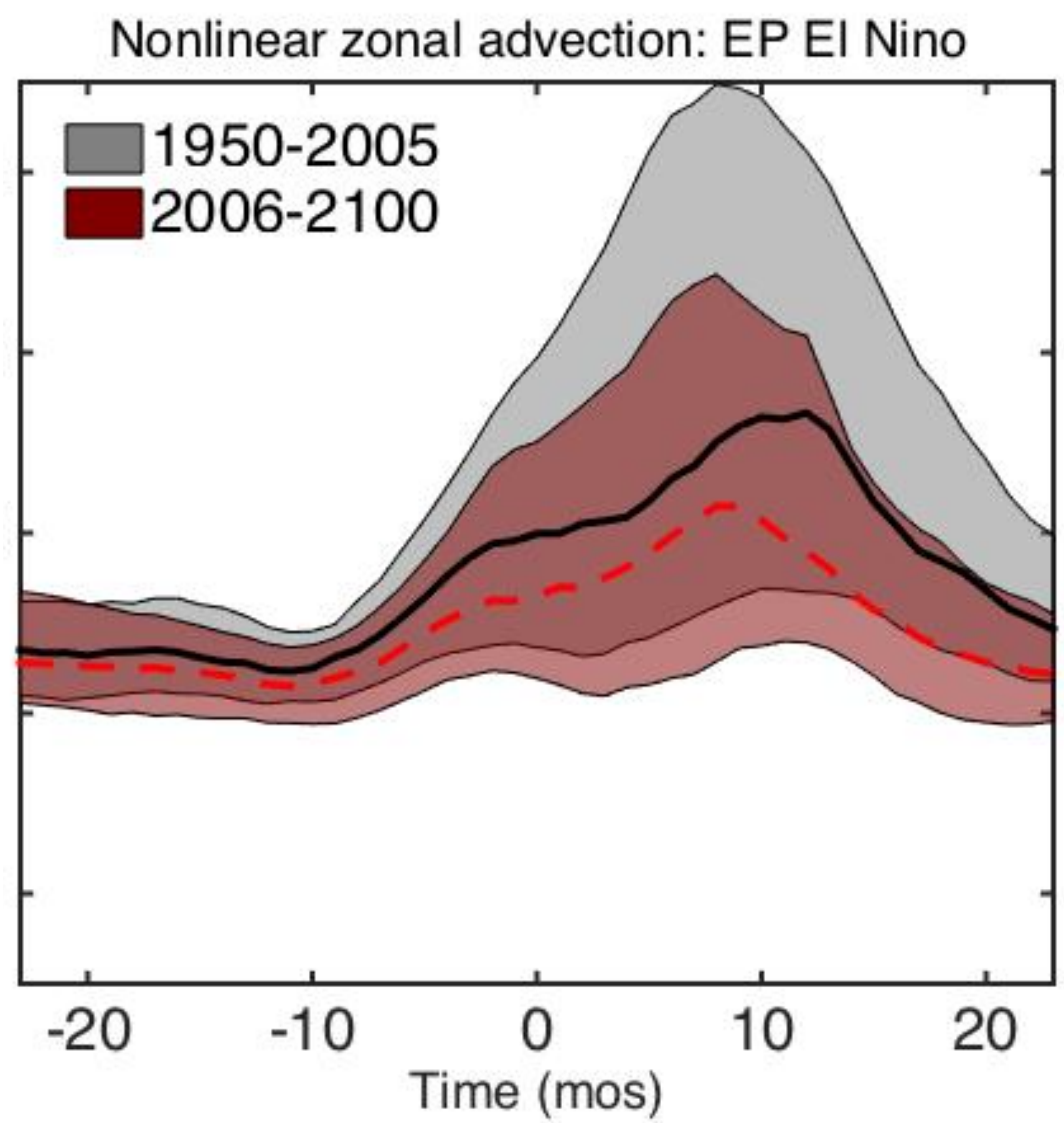
$-u' \cdot \nabla T'$

Nonlinear zonal advection: anomalous advection of anomalous gradient
NINO3: Eastern Pacific El Niño

CESM

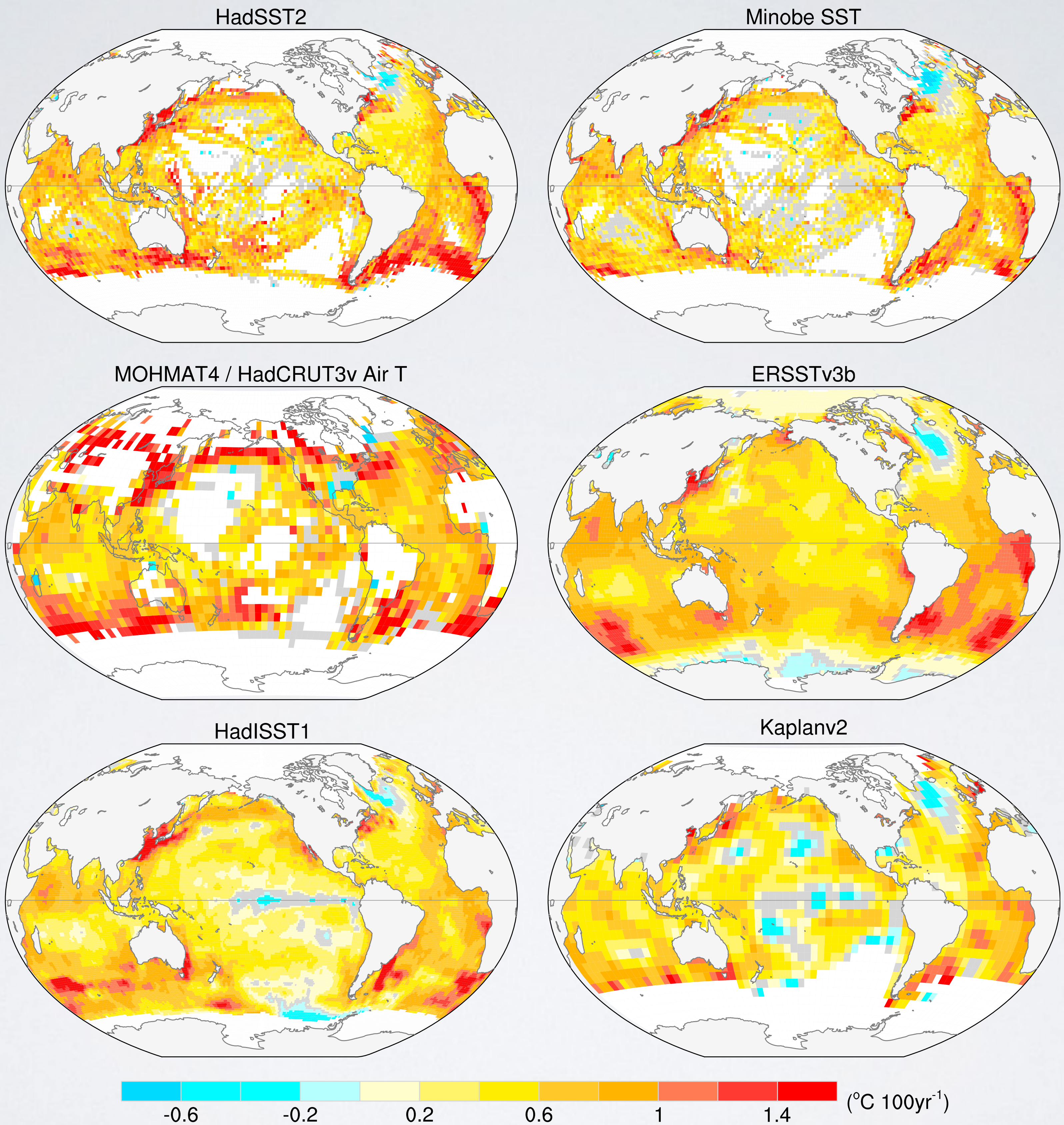


ESM2M



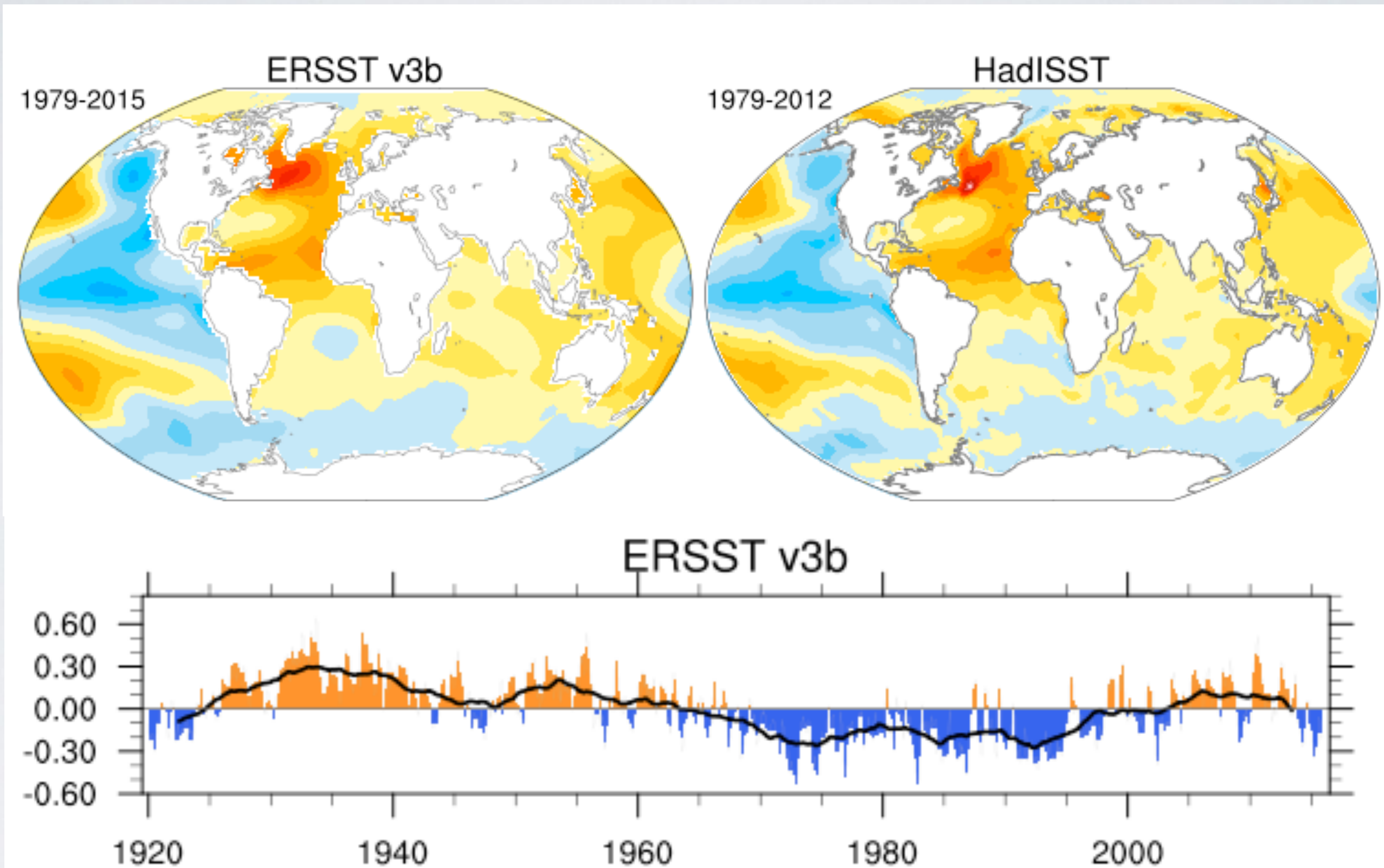
Stevenson et al. (2017b), in prep

Also critical: improving long-term 20th c. estimates

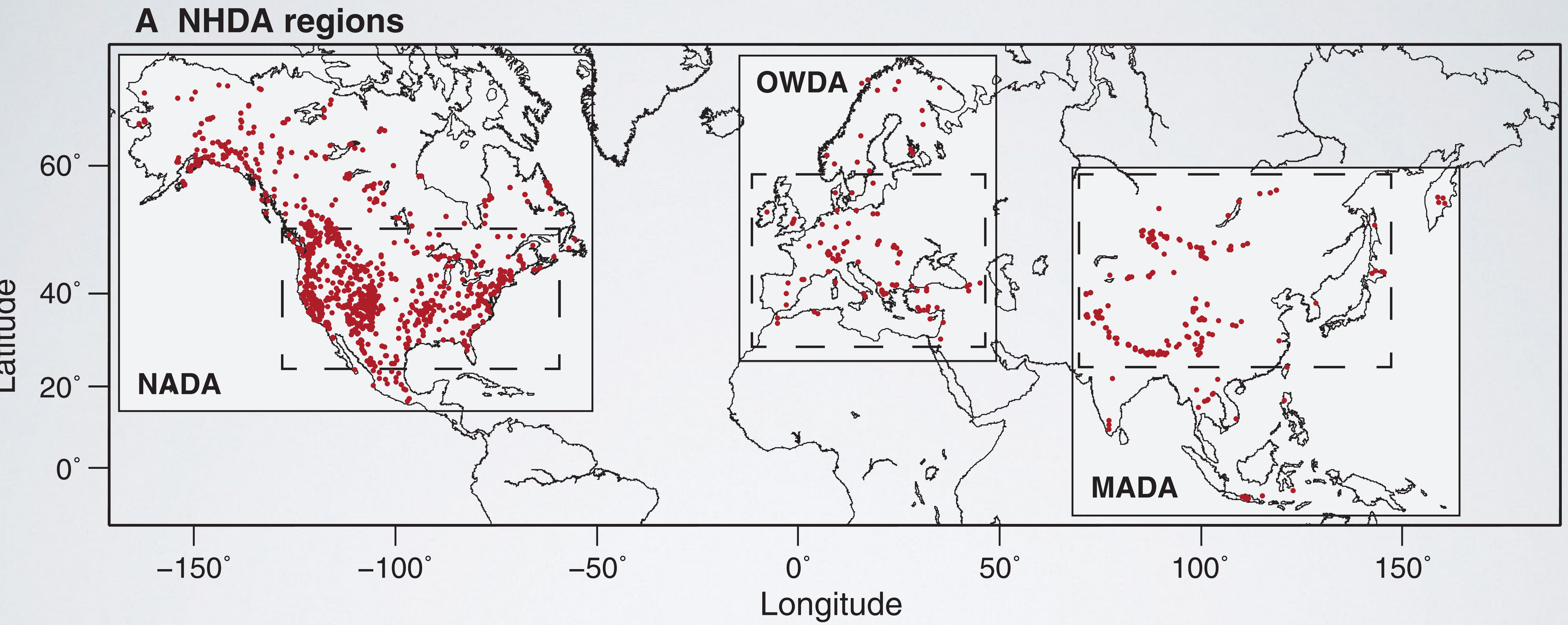


Deser et al. (2010)

Also critical: improving long-term 20th c. estimates

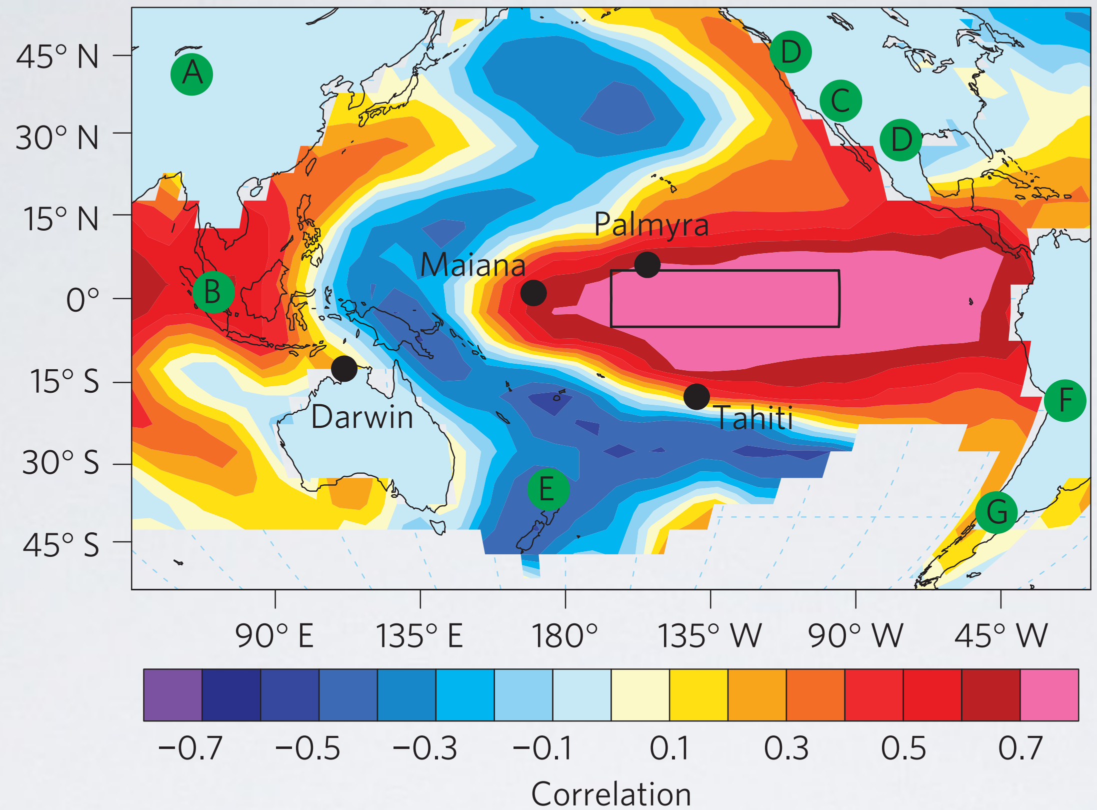


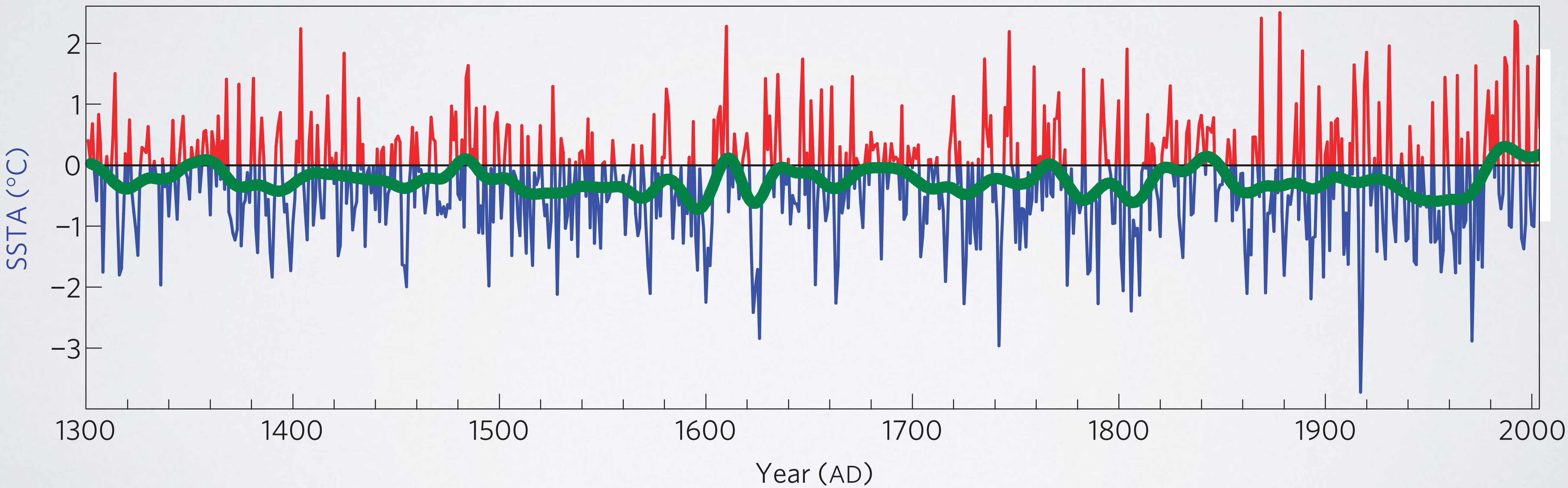
Paleoclimate: key piece of the puzzle



Cook et al. (2015)

Paleoclimate: key piece of the puzzle





Li et al. (2013)

Conclusions

21st c. teleconnected responses governed by changes to modal amplitude, atmospheric responses to SST variability

- Some teleconnection responses are robust across models (El Nino impacts), some may not be
- Anthropogenic forcing is extremely complex, implemented differently across models: e.g. details of land-use changes, aerosol microphysics
- CMIP6-endorsed MIPs may help clarify some issues, as may observational process studies

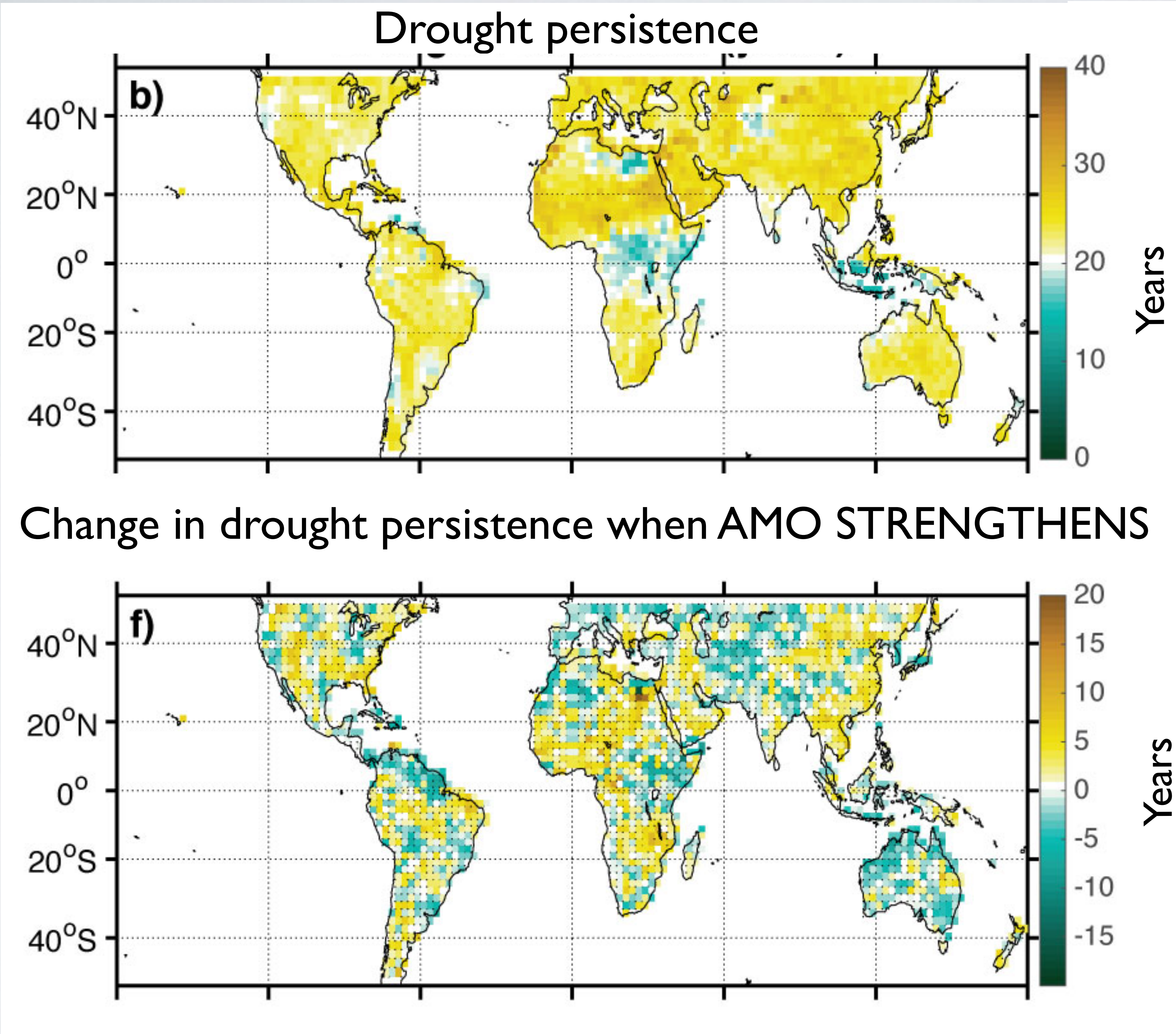
Discussion Questions

- Should US CLIVAR make recommendations on priorities for new model experiments/analyses of simulations planned for CMIP6?

- What are best practices for process-based model evaluation using observational data?

- What are the highest priority new observations to target for improvements in simulated teleconnections?

AMO: influence on drought persistence more moderate



15-year drought
(0.5σ threshold)

Stratified by mode
(above 60th/below 40th percentile)

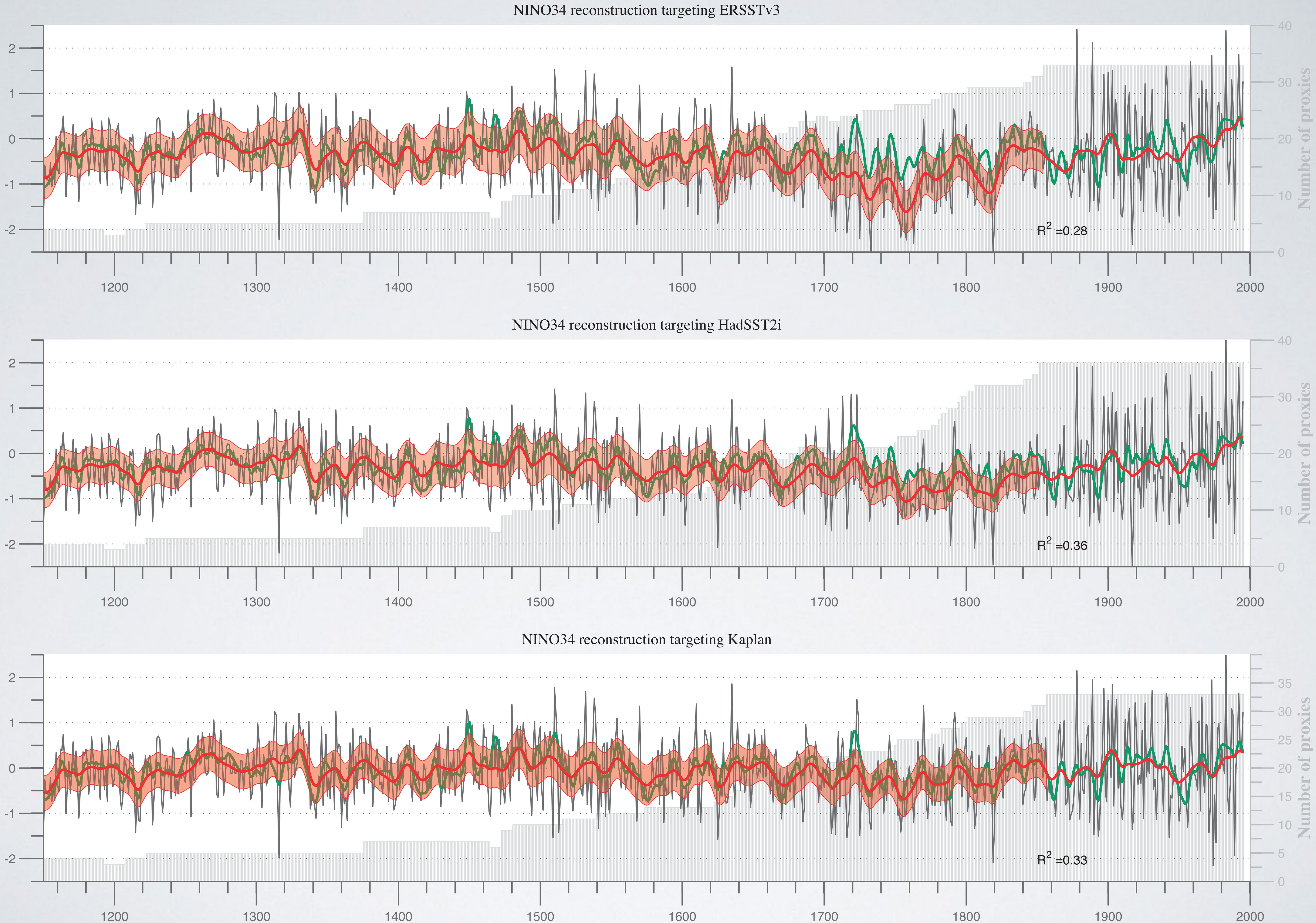
Brown = higher drought risk
Green = lower drought risk

Stronger AMO:

- **Shorter** drought in northern Amazon, parts of Australia
- **Longer** drought in SW US, monsoon Asia

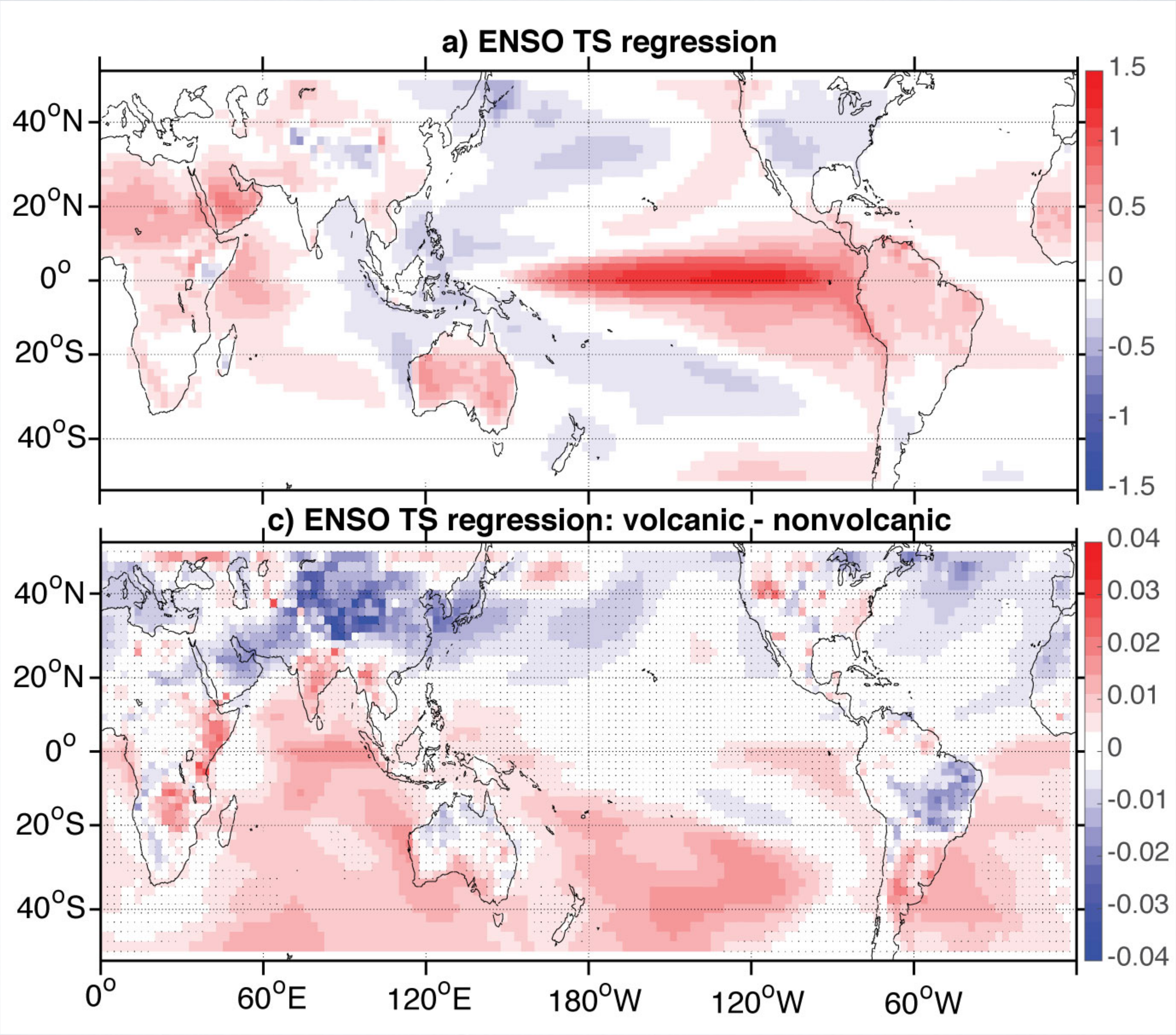
Stevenson et al. (2017), in review

Paleoclimate: key piece of the puzzle

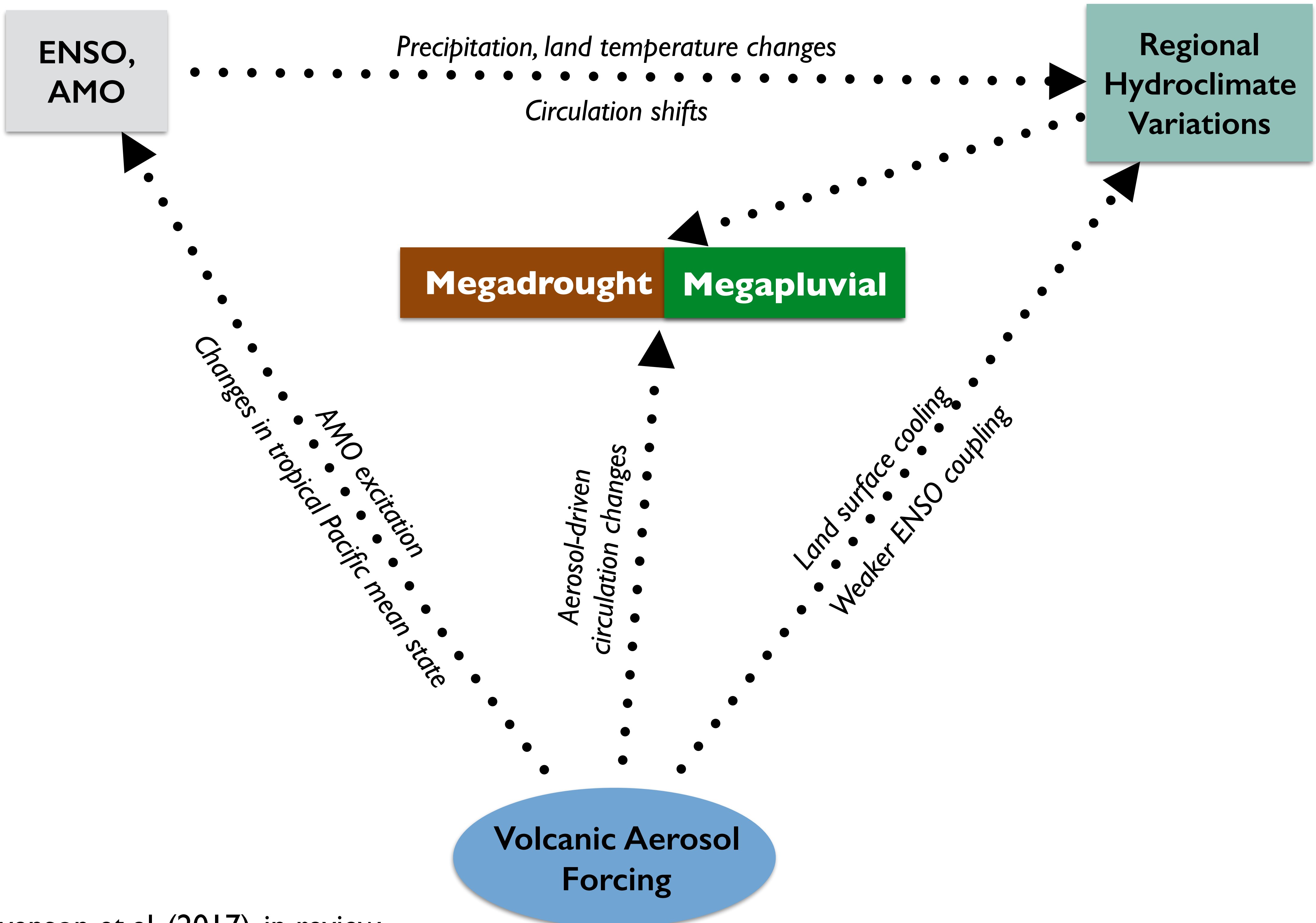


Emile-Geay et al. (2013)

Forced changes to teleconnections also matter



Stevenson et al. (2017), in review



Stevenson et al. (2017), in review