3rd Summer School on Theory, Mechanisms and Hierarchical Modeling of Climate Dynamics: Tropical Oceans, ENSO and their teleconnections
ICTP, Trieste, Italy

ENSO in a Changing Climate

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UNSW THE UNIVERSITY OF NEW SOUTH WALES | Climate Change Research Centre | climate extremes ARC centre of excellence | CSIRO

La Nina event tipped to be declared, points to stormy, wet times ahead

By Peter Hannam
September 28, 2020 – 6.25pm

https://www.smh.com.au/environment/weather/la-nina-event-tipped-to-be-declared-points-to-stormy-wet-times-ahead-20200928-p5600b.html

What is the meaning of La Niña and how will the weather event affect Australia's summer?

@donnadlu
Tue 23 Nov 2021 16.44

The weather pattern occurs every few years and typically brings increased rainfall to the country's north and east

- BoM declares 2021 La Niña weather event for Australia

https://www.theguardian.com/australia-news/2021/nov/23/la-nina-2021-weather-australia-meaning-definition-summer

https://theconversation.com/back-so-soon-la-nina-heres-why-were-copping-two-soggy-summers-in-a-row-173684

Jason O'Brien/AAP

https://theconversation.com/the-east-coast-rain-seems-endless-where-on-earth-is-all-the-water-coming-from-178316

'Triple La Niña': Australia may face another summer of flooding rains, US expert warns

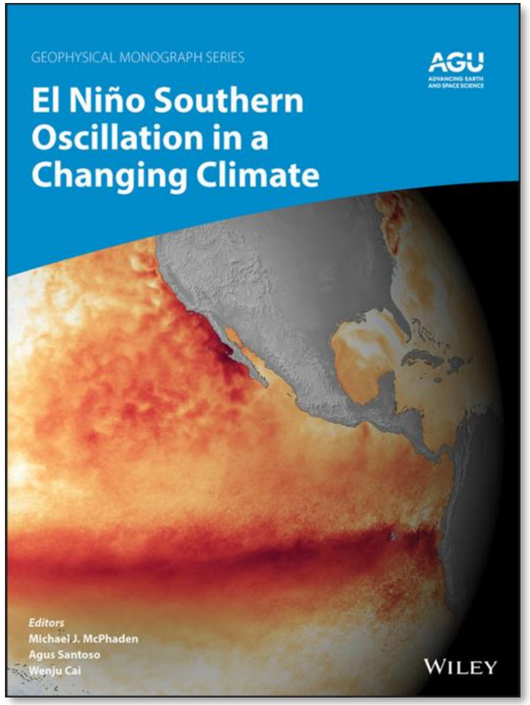
@readfearn
Fri 10 Jun 2022 03.30

Scientists are watching an area in Pacific Ocean that has been unusually cool – a signal current La Niña could linger

https://www.theguardian.com/environment/2022/jun/10/triple-la-nina-australia-may-face-another-summer-of-flooding-rains-us-expert-warns

Climate Change?

How will ENSO change in the future?



November 2020

Changing El Niño–Southern Oscillation in a warming climate

Wenju Cai[1,2,3]✉, *Agus Santoso*[3,4,5], *Matthew Collins*[6], *Boris Dewitte*[7,8,9], *Christina Karamperidou*[10], *Jong-Seong Kug*[11], *Matthieu Lengaigne*[12], *Michael J. McPhaden*[13], *Malte F. Stuecker*[14], *Andréa S. Taschetto*[4,5], *Axel Timmermann*[15,16], *Lixin Wu*[1,2], *Sang-Wook Yeh*[17], *Guojian Wang*[1,2,3], *Benjamin Ng*[3], *Fan Jia*[18], *Yun Yang*[19], *Jun Ying*[20,21], *Xiao-Tong Zheng*[1,2], *Tobias Bayr*[22], *Josephine R. Brown*[23], *Antonietta Capotondi*[24,25], *Kim M. Cobb*[26], *Bolan Gan*[1,2], *Tao Geng*[1], *Yoo-Geun Ham*[27], *Fei-Fei Jin*[10], *Hyun-Su Jo*[27], *Xichen Li*[28,29], *Xiaopei Lin*[1,2], *Shayne McGregor*[30], *Jae-Heung Park*[11], *Karl Stein*[15,16], *Kai Yang*[31], *Li Zhang*[1,2] and *Wenxiu Zhong*[21,32]

NATURE REVIEWS | EARTH & ENVIRONMENT

September 2021

Outline

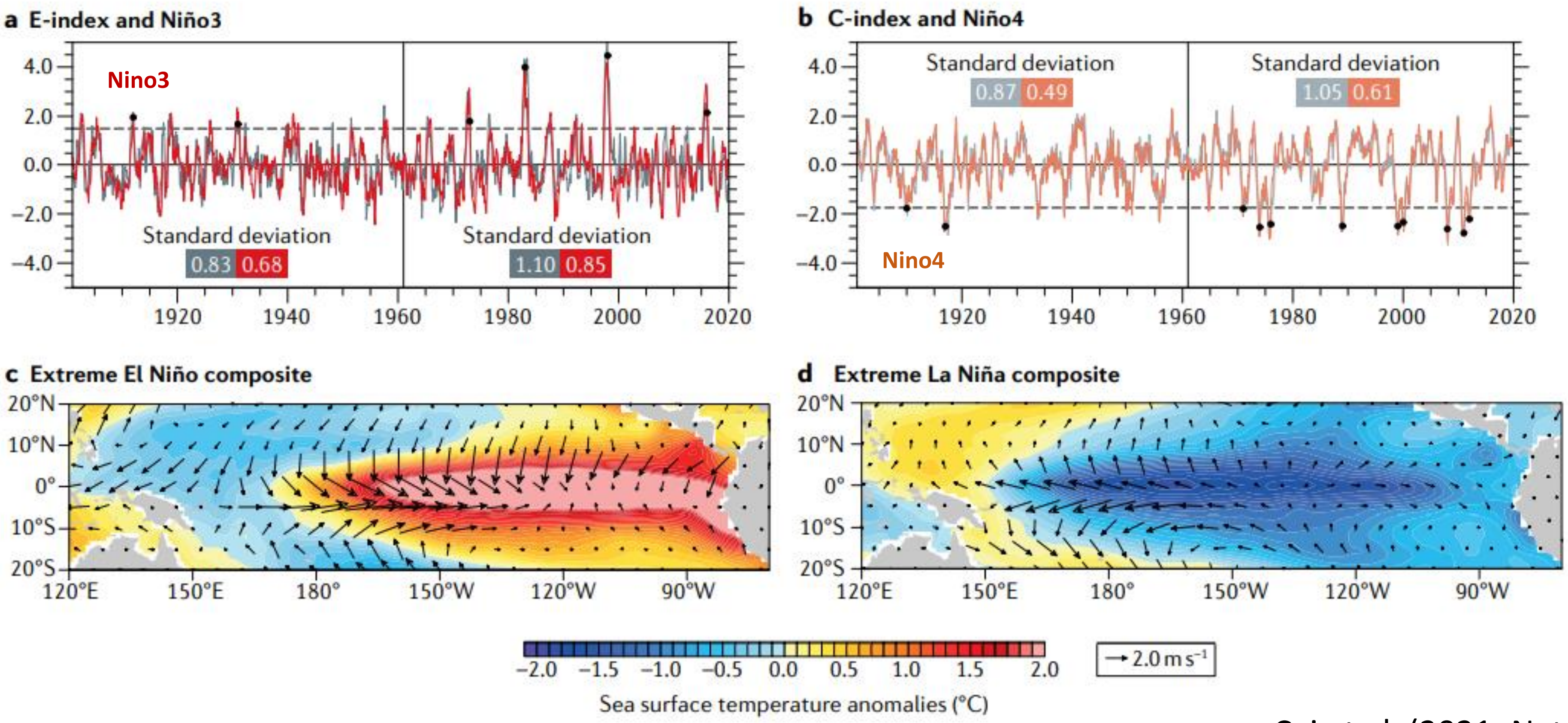
- Introduction
- Progress in ENSO future projections
- Factors affecting projections (cold tongue bias, inter-basin interactions, internal variability)
- Teleconnections

Focussing on 21st Century climate

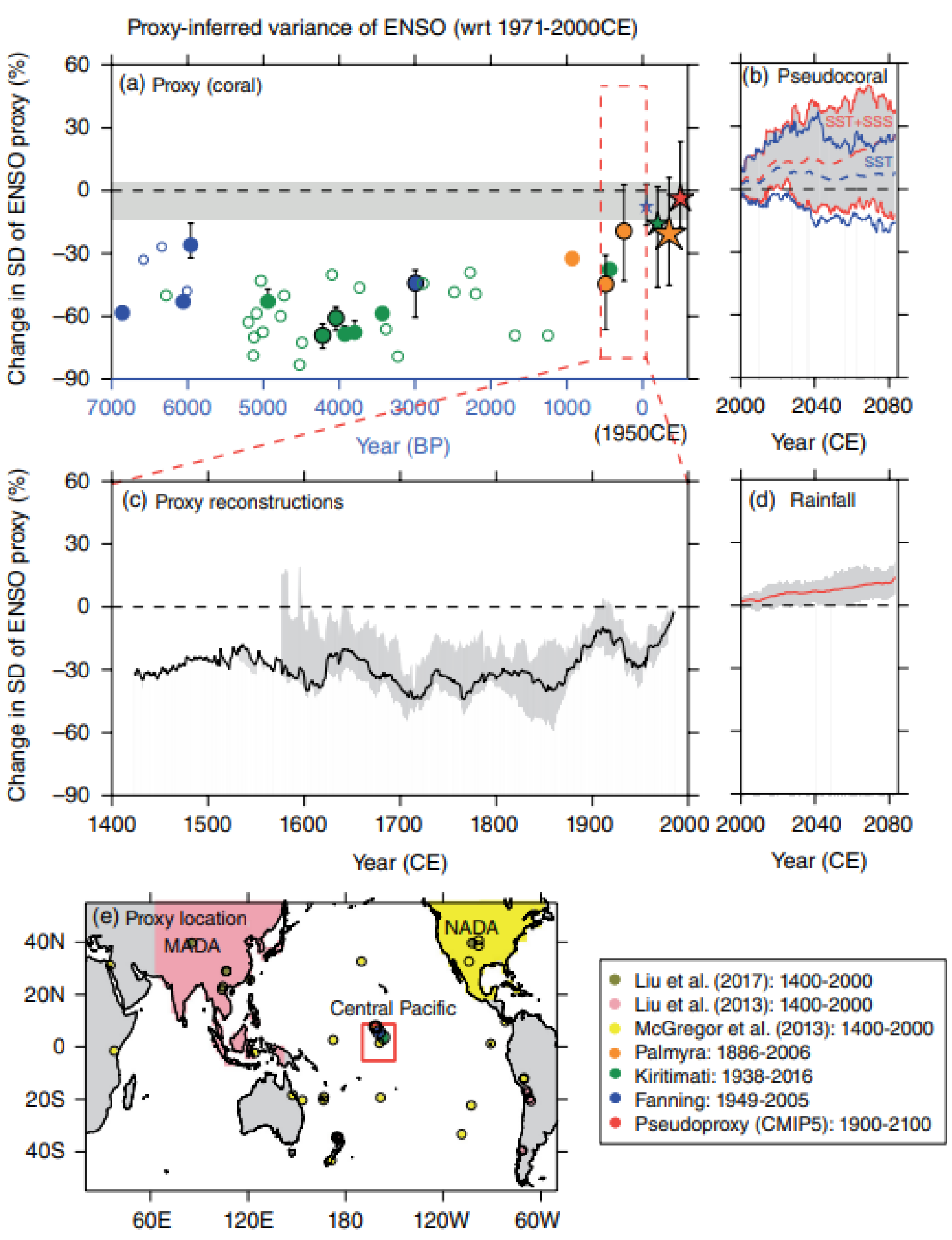
Introduction

Observations. Approx. 20% increase between pre-1960 and post-1960 in Eastern Pacific (EP) and Central Pacific (CP) ENSO variability.

Increase in EP and CP variability is characterised by more frequent extreme El Niño and extreme La Niña events, respectively.



Cai et al. (2021, Nature Rev. Earth & Environment)



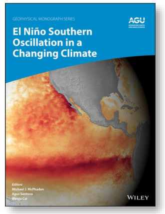
Karamperidou et al. (2020, Chapter 21 ENSO book)

Multiple paleo-ENSO proxy data sets point to an intensifying ENSO variability toward late 20th century relative to preindustrial (McGregor et al., 2013; Cobb et al., 2013; Li et al., 2013; Liu et al., 2017).

Interestingly, a **CMIP5-based** δ18O pseudo coral proxy network shows an increase in interannual variance that seems to continue the reconstructed trend from the real coral data. Similarly, changes in future simulated rainfall variance over a network of proxy locations are qualitatively consistent with the reconstructed ENSO-related hydroclimate variance trends.

This finding raises the issue as to whether 20th century changes in ENSO characteristics are already impacted by greenhouse warming and whether observed trends are already emergent against natural variability.

See Chapter 5 (Emile-Geay et al. 2020) for methods and challenges in proxy reconstructions.



Global warming

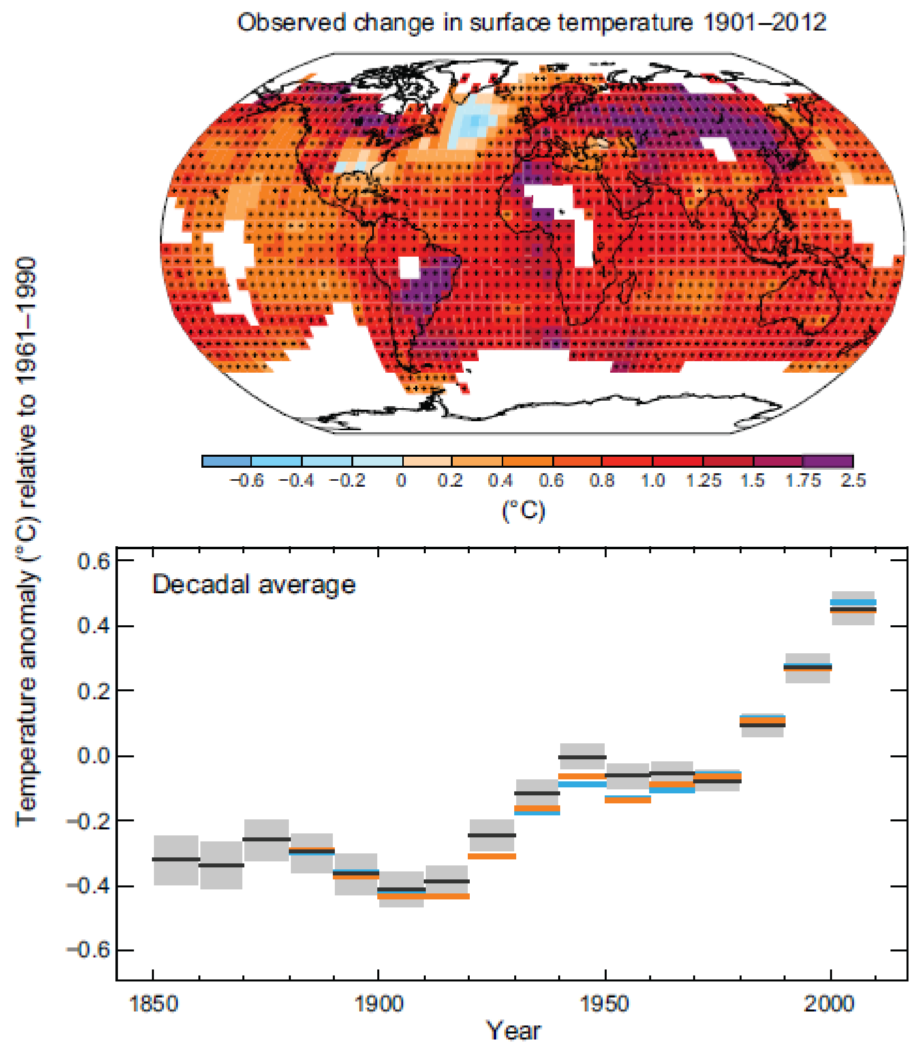
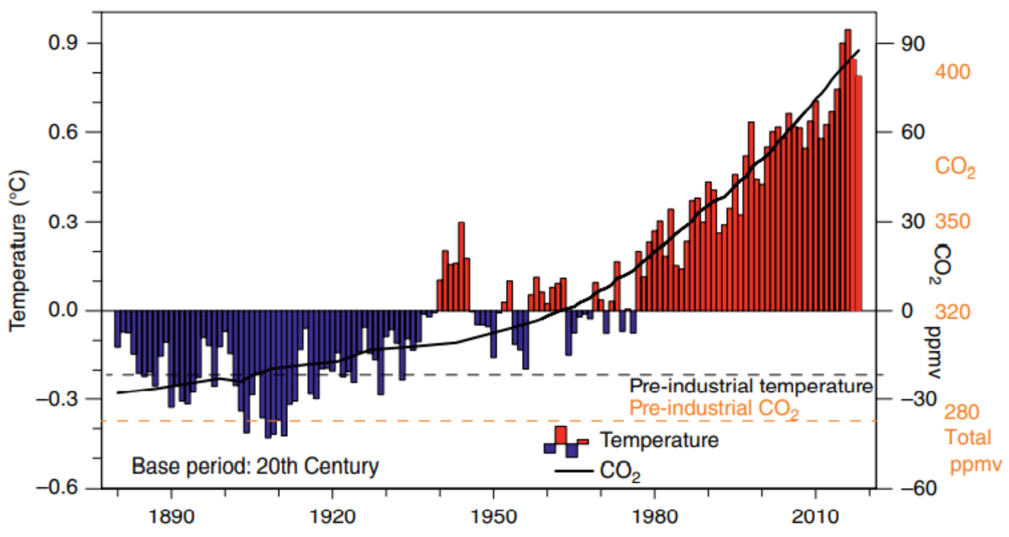


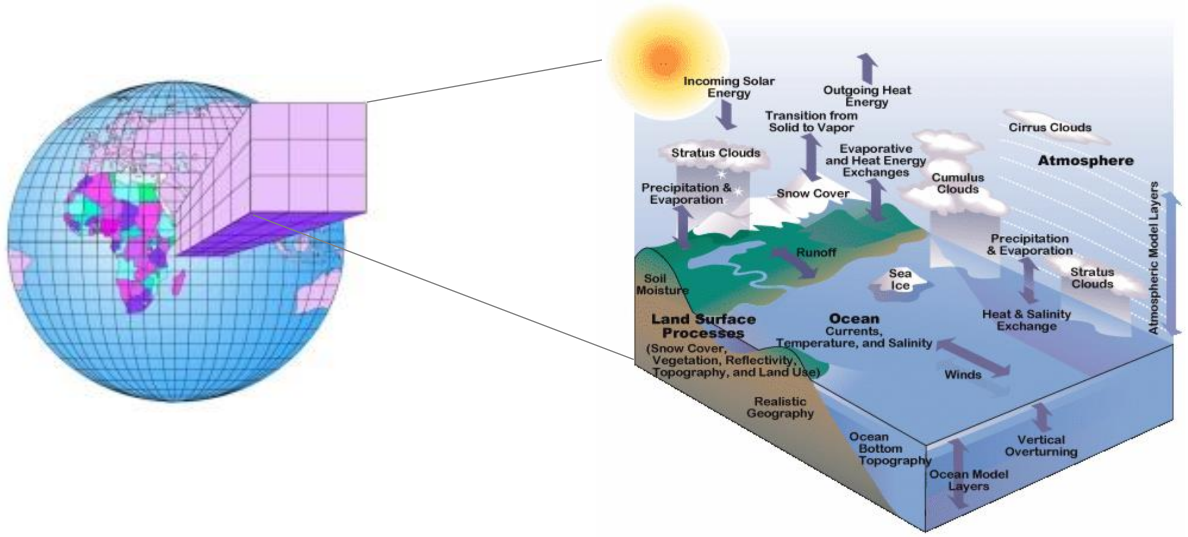
Image source: IPCC AR5



Earth is warming up as greenhouse gas emission continues to climb.

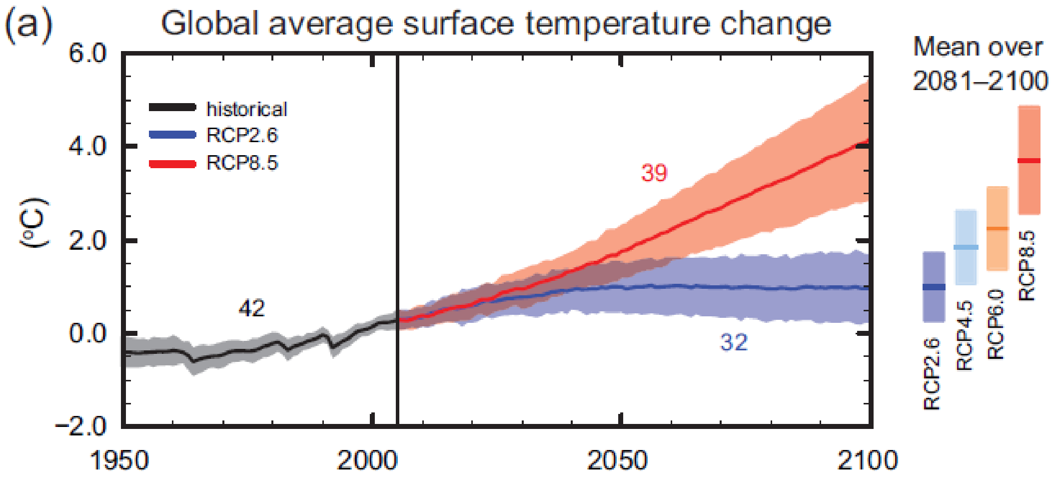
The increase in temperature is not smooth (staircase like) due to internal multi-decadal climate variability (e.g., Interdecadal Pacific Oscillation).

The warming is not distributed equally at all spatial locations.



We use climate models for projecting the future, by subjecting the models to specified emission scenarios.

The level of warming depends on how much we emit.



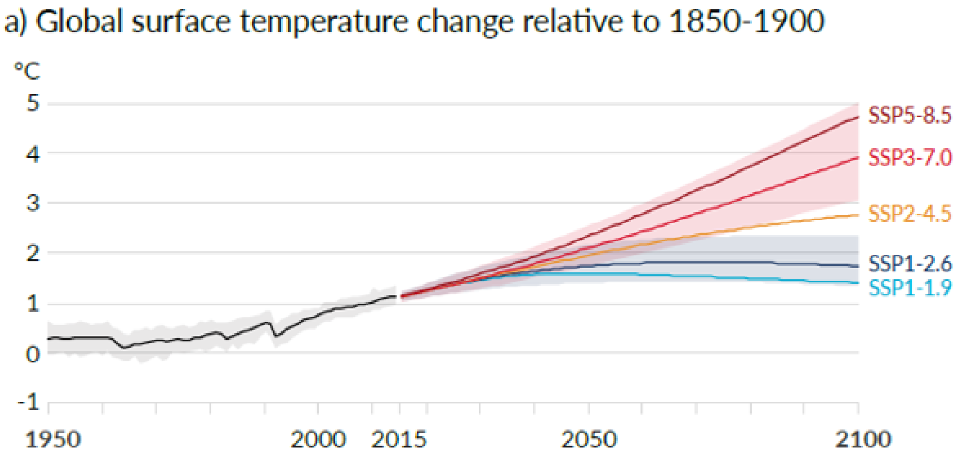
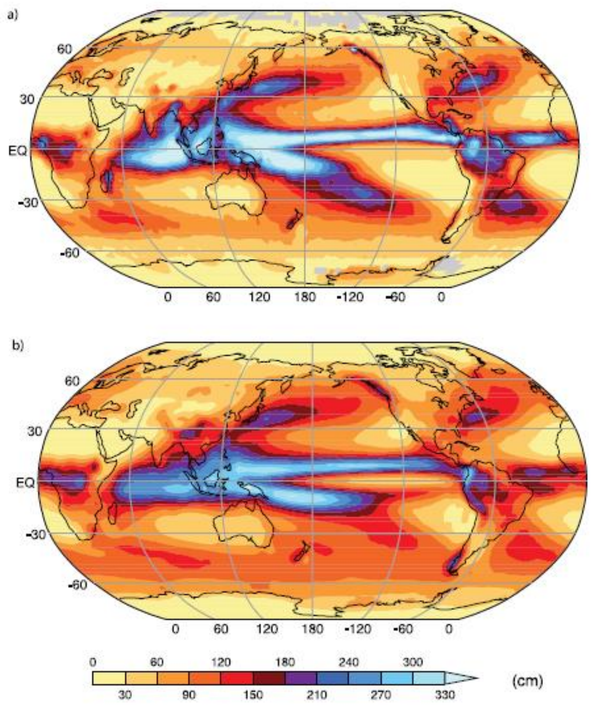
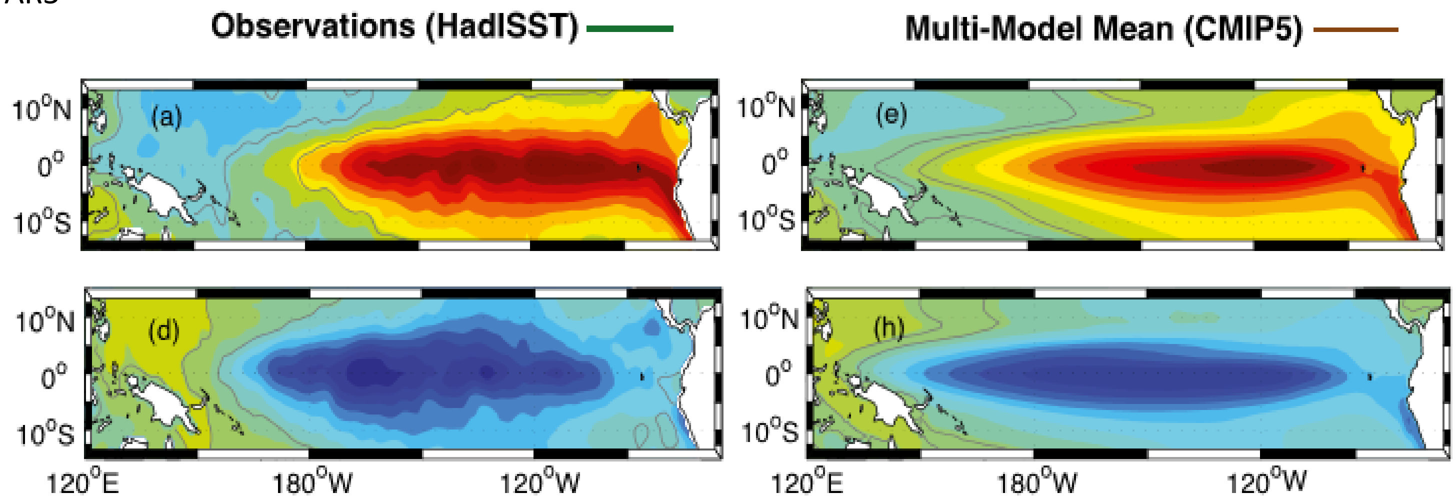


Image sources: IPCC AR5, AR6, http://www.ucar.edu/news/features/climatechange/ccsm-text.jsp, http://paos.colorado.edu/~dcn/ATOC7500/



IPCC AR5

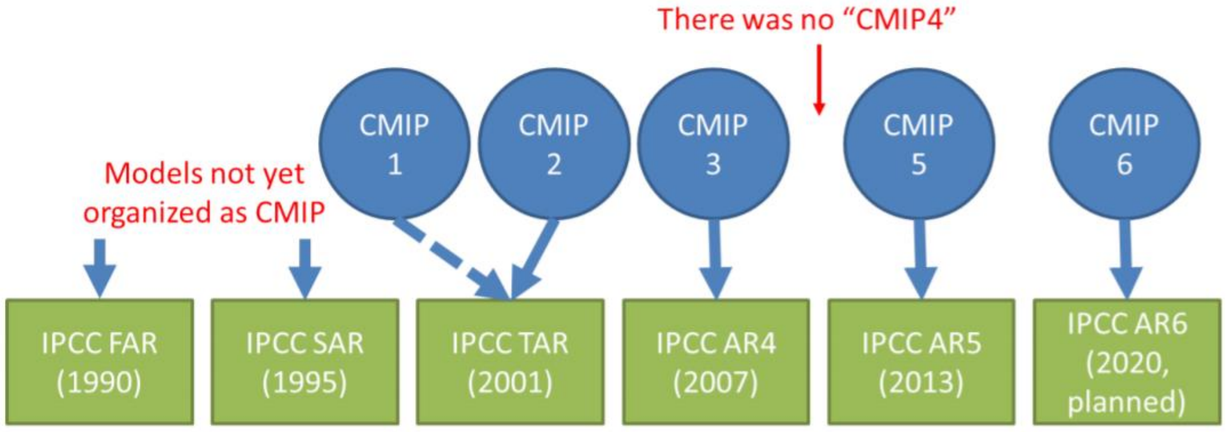
- There are over 60 climate models from about 30 modelling groups all over the world.
- Climate model data are provided under the efforts of Climate Model Intercomparison Project (CMIP)
- They can reasonably simulate the earth climate and modes of variability



Taschetto et al. 2014, J. Climate

Coupled Model Intercomparison Project (CMIP)

Progress in climate modeling



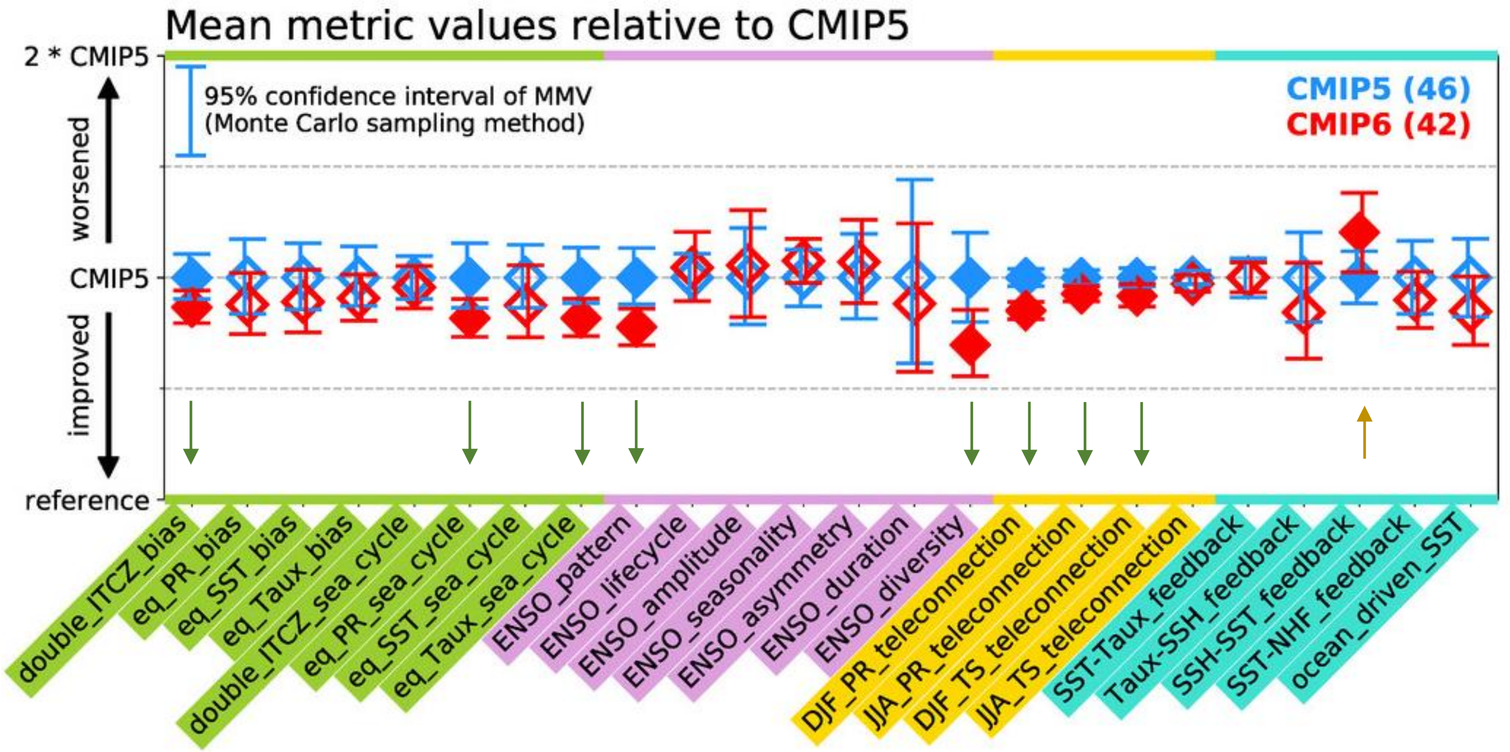
Fact Sheets
ipcc INTERGOVERNMENTAL PANEL ON climate change
UNEP
Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA)

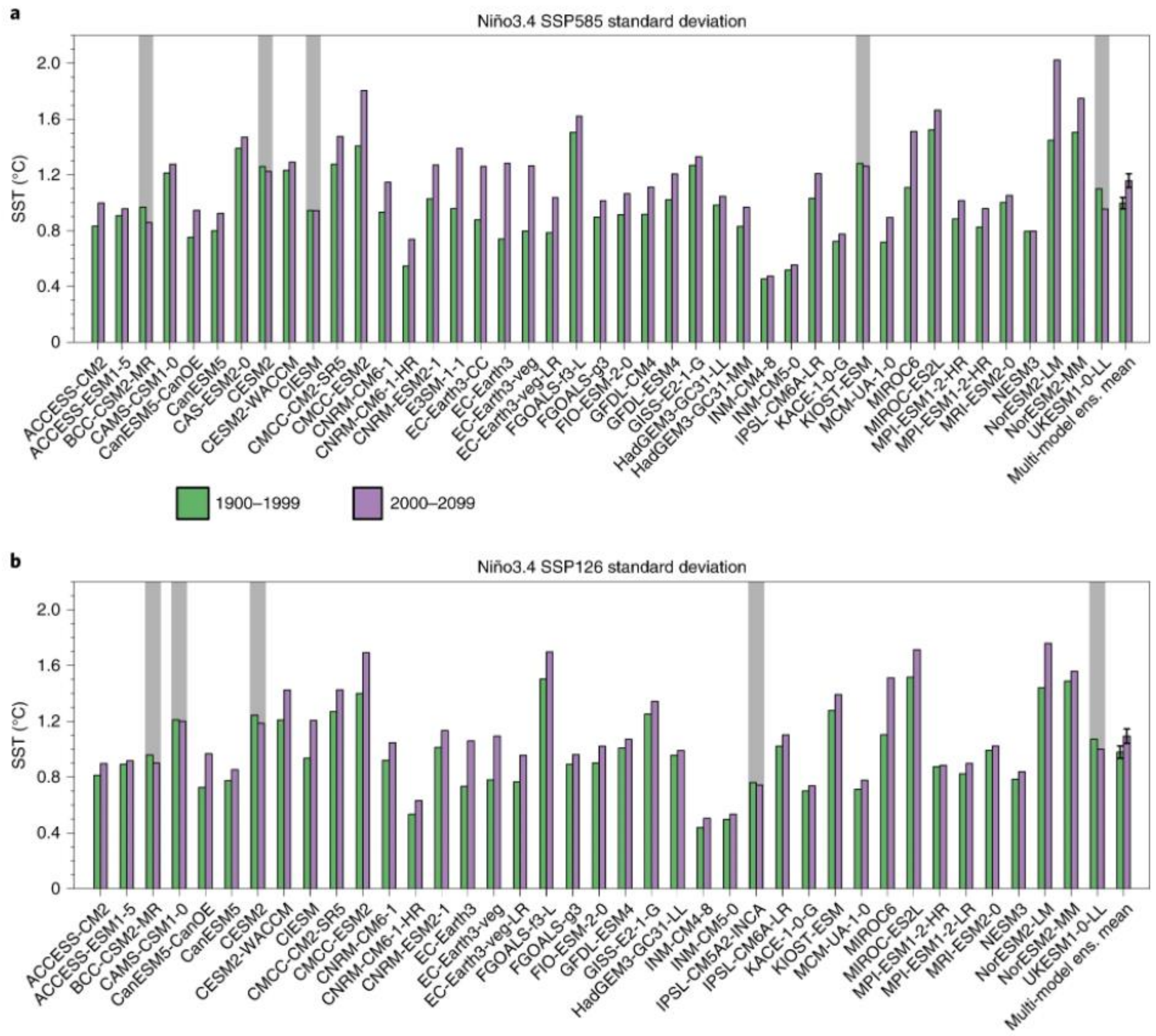
Model inter-comparison

Planton et al. 2021, J. Climate

CMIP6 outperforms CMIP5 in 8 out of 24 ENSO metrics (tropical Pacific time-mean, seasonal cycle, ENSO patterns, diversity, and remote teleconnections).

Worse in one metric (coupling between subsurface and surface temperature).





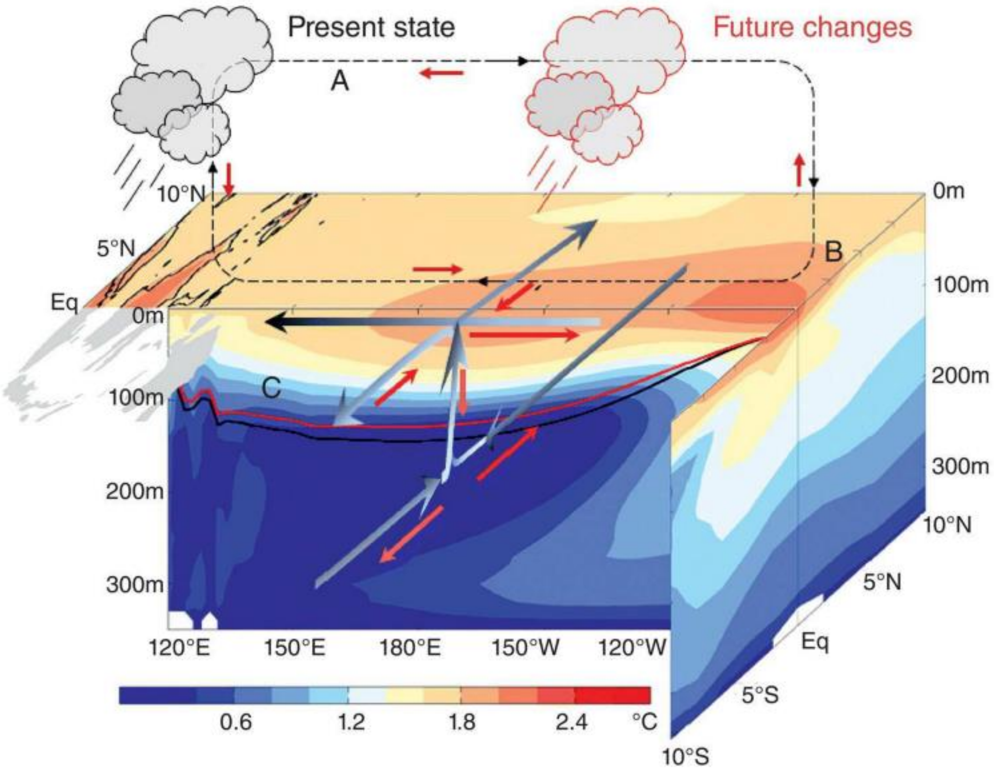
BRIEF COMMUNICATION
https://doi.org/10.1038/s41558-022-01282-z
nature climate change
Check for updates

OPEN

Increased ENSO sea surface temperature variability under four IPCC emission scenarios

Wenju Cai[1,2]✉, Benjamin Ng[2], Guojian Wang[1,2], Agus Santoso[2,3], Lixin Wu[1]✉ and Kai Yang[4]

Future mean state change



Cai et al. (2020, ENSO book Chapter 13)

The various components are described in e.g., Meehl & Washington 1996; Timmermann et al. 1999; Liu et al. 2005; Held & Soden 2006; Vecchi & Soden 2007; Xie et al. 2010, Stuecker et al. 2020, Heede et al. 2020.

Progress in ENSO projections

VOLUME 8 JOURNAL OF CLIMATE JUNE 1995

Simulation of El Niño–Southern Oscillation-like Variability in a Global AOGCM and its Response to CO_2 Increase

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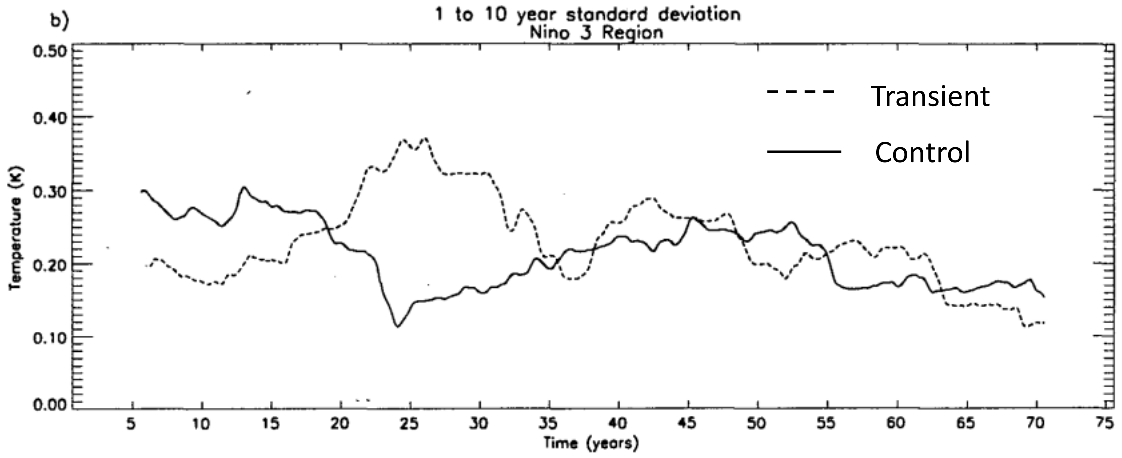
(Manuscript received 18 November 1993, in final form 22 June 1994)

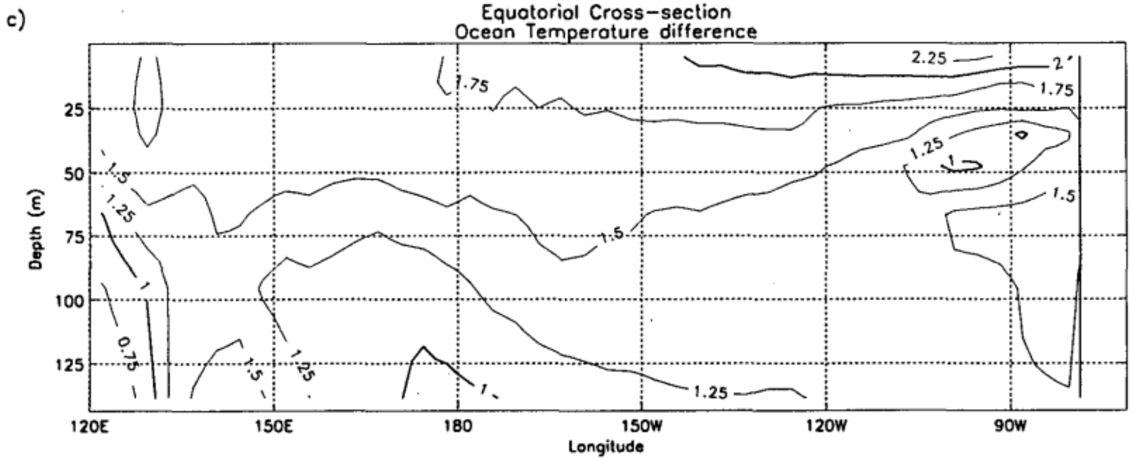
ABSTRACT

A 75-year integration of a coupled atmosphere–ocean model is examined for tropical interannual variability. The atmospheric model has interactive cloud and a seasonal cycle. The fluxes of heat and salinity into the ocean component of the model are flux corrected. The model has tropical variability that is qualitatively similar to that of the observed El Niño/Southern Oscillation (ENSO). The maximum amplitude of the model Nino3 signal is approximately half that observed and the modeled ENSO timescale is greater than that observed. In the first 50 years of the integration the model has eight warm events. Each event is one of two types: one characterized by a standing SST anomaly in the central and eastern Pacific and the other by a westward propagating sea surface temperature anomaly. The majority of the model warm events are of the first type.

The first type of event is triggered by the eastward propagation of Kelvin waves across the Pacific, and the second by westward propagation of warm temperature anomalies through the atmospheric response to a warm anomaly causing the suppression of equatorial upwelling. There is a coupling to the seasonal cycle for the first type of event. A positive feedback through changes in marine stratocumulus in the east Pacific is an important factor in some simulated warm events.

Another integration was carried out in which atmospheric CO_2 was increased at a rate of 1% (compounded) per annum. There is no significant change in the one to ten year interannual variance of SST in the east Pacific, and this suggests that the size of the SST anomalies during warm or cold events in the "greenhouse" world may not be significantly different from those of today.





Control: constant CO2 at 323 ppm (75 years integrated)
Transient experiment: CO2 increased at a rate of 1% per year (75 years integrated)
Both integrated for 75 years from the same initial conditions obtained from spin up run of 150 years

Atm (11 vertical levels) and Ocn models (17 levels with 7 in upper 100 m) have resolution of 2.5 lat, 3.75 lon.

Consistent message as Meehl et al. (1993)

Increased El Niño frequency in a climate model forced by future greenhouse warming

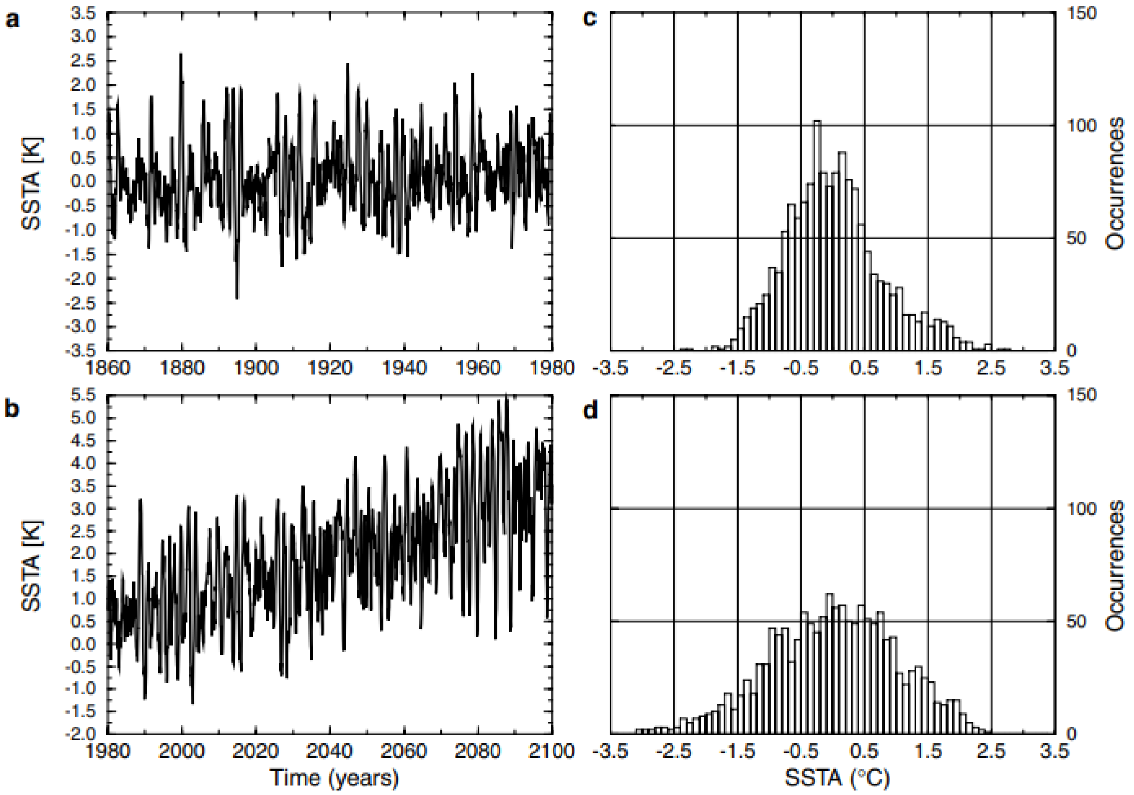
A. Timmermann, J. Oberhuber*, A. Bacher, M. Esch, M. Latif & E. Roeckner

*Max-Planck-Institut für Meteorologie and * Deutsches Klimarechenzentrum, Bundesstrasse 55, D-20146 Hamburg, Germany*

The El Niño/Southern Oscillation (ENSO) phenomenon is the strongest natural interannual climate fluctuation[1]. ENSO originates in the tropical Pacific Ocean and has large effects on the ecology of the region, but it also influences the entire global climate system and affects the societies and economies of many countries[2]. ENSO can be understood as an irregular low-frequency oscillation between a warm (El Niño) and a cold (La Niña) state. The strong El Niños of 1982/1983 and 1997/1998, along with the more frequent occurrences of El Niños during the past few decades, raise the question of whether human-induced 'greenhouse' warming affects, or will affect, ENSO[3]. Several global climate models have been applied to transient greenhouse-gas-induced warming simulations to address this question[4–6], but the results have been debated owing to the inability of the models to fully simulate ENSO (because of their coarse equatorial resolution)[7]. Here we present results from a global climate model with sufficient resolution in the tropics to adequately represent the narrow equatorial upwelling and low-frequency waves. When the model is forced by a realistic future scenario of increasing greenhouse-gas concentrations, more frequent El-Niño-like conditions and stronger cold events in the tropical Pacific Ocean result.

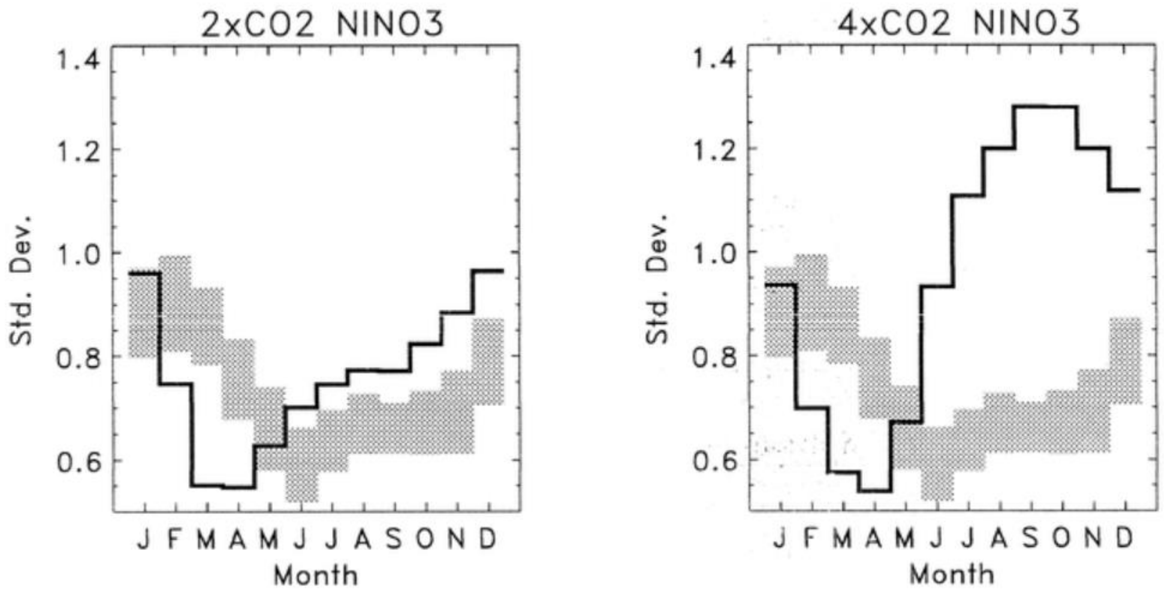
NATURE | VOL 398 | 22 APRIL 1999 | www.nature.com

GCM: ECHAM4/OPYC3 ~2.8° mesh, with meridional spacing reduction of the OGCM to 0.5° in the equatorial region. Two experiments: 300-yr fixed CO2, observed CO2 (1860-1990), IS92a 'business-as-usual' scenario (1990-2100).



- the mean climate in the tropical Pacific will change towards "El Nino-like" conditions. "It is therefore likely that events typical of El Nino will also become more frequent."
- "year-to-year variations may become more extreme under enhanced greenhouse conditions"
- "interannual variability will be more strongly skewed, with strong cold events (relative to the warmer mean state) becoming more frequent"
- long-term increase of vertical stratification in the eastern tropical Pacific enhanced the sensitivity of SST to ENSO-related wind stress forcing.

Collins, Matthew (2000, J. Climate, 1299-1312)

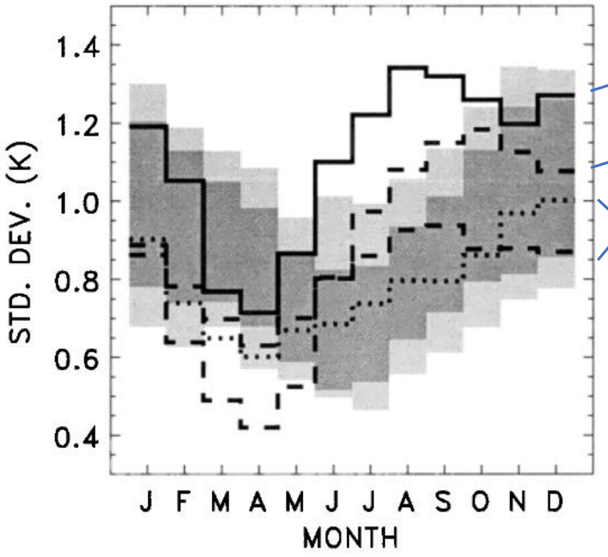


HadCM2: 2.5 lat x 3.75 lon (both AGCM and CGCM). AGCM has 19 levels, OGCM 20 levels

ENSO amplitude 20% larger due to a sharper thermocline.

Collins, Matthew (2000, GRL, 27, 3509-3512)

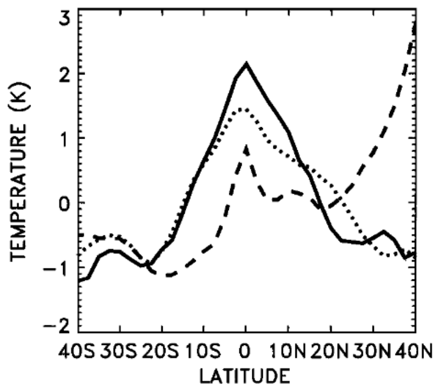
No significant change in ENSO at 4xCO2 in HadCM3 due to differences in response of meridional temperature gradients either side of equator (diff. in parameterisation schemes).



Flux forcing to mimic HadCM2

HadCM3: OGCM res. Increased to 1.25 x 1.25

Obs



Climate Dynamics (2006) 26: 329–348 DOI 10.1007/s00382-005-0084-6

Eric Guilyardi

El Niño–mean state–seasonal cycle interactions in a multi-model ensemble

"The models that exhibit the largest El Nino amplitude change in these GHG scenarios are those that exhibit a mode change towards a T-mode (either from S-mode to hybrid or hybrid to T-mode). This is all the more interesting as the 1976 climate shift in the tropical Pacific also involved such a mode shift and several studies suggested this shift was climate change related (although this issue it still hotly debated as it might also be a decadal variability signal—Trenberth and Hurrell 1994). In many respects, these models are also among those that best simulate the tropical Pacific climatology (ECHAM5/MPI-OM, GFDLCM2.0, GFDL-CM2.1, MRI-CGM2.3.2, UKMOHadCM3). This suggest the likelihood of increased El Nino amplitude in a warmer climate…"

GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L11704, doi:10.1029/2006GL026196, 2006

Shifts in ENSO coupling processes under global warming

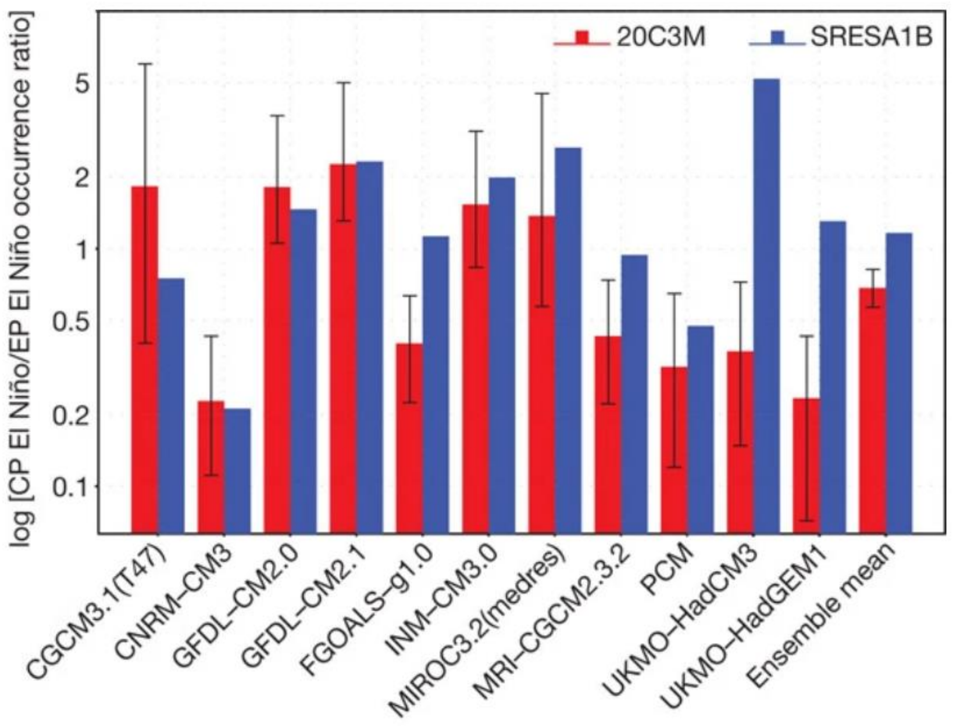
Sjoukje Philip[1] and Geert Jan van Oldenborgh[1]

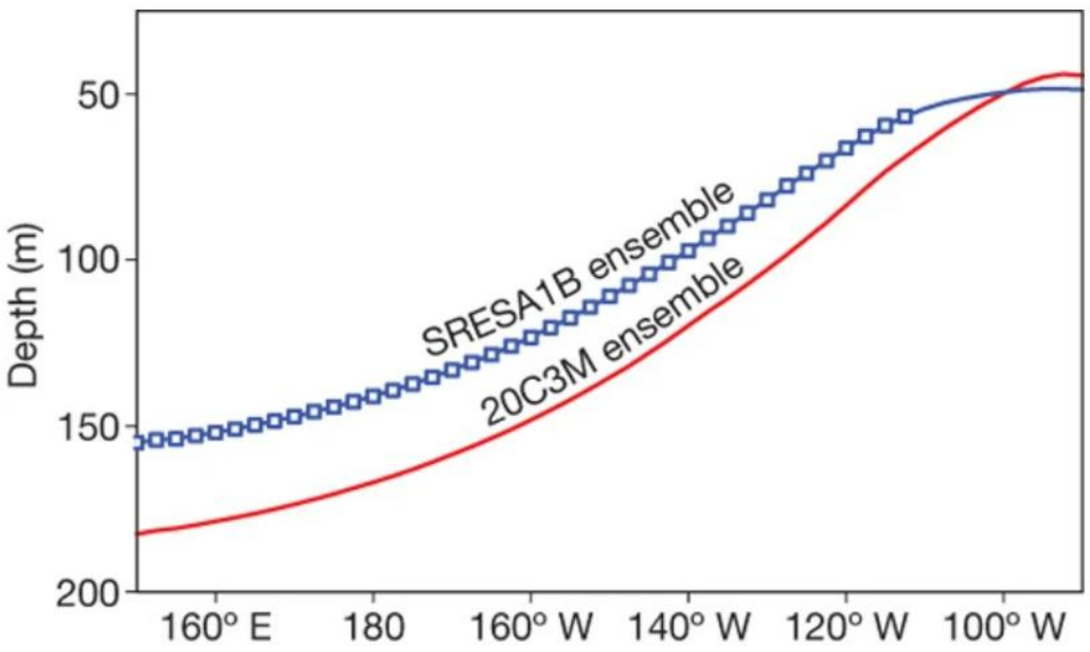
"Changes in the mean state affect the feedback loop. Higher mean SST provides higher damping through cloud feedback. The shallower thermocline and mixed layer depth increase SST sensitivity to thermocline variability and wind stress. Wind response to SST variability increases where the mean SST has increased the most. However, the higher damping and more stable atmosphere compensate the other changes and the residual change in ENSO properties is relatively small."

Yeh et al. (2009, Nature, 461, 511-514)

Based on analysis of 11 CMIP3 models finding a projected increase in frequency of CP El Nino compared to EP El Nino.   The change is related to flattening of the equatorial Pacific thermocline.

CP-EP ENSO definition is based on Nino4 and Nino3 indices.



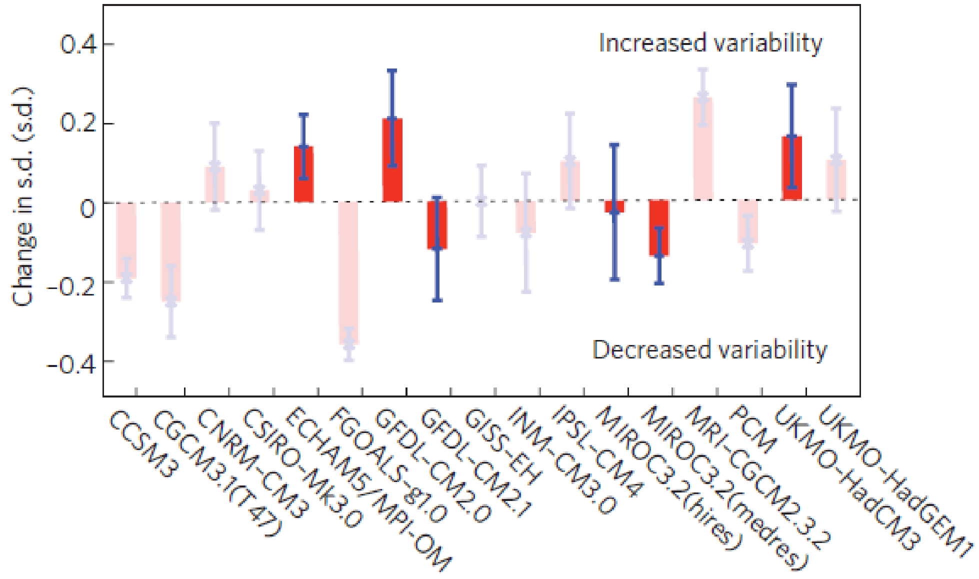


ENSO response to greenhouse warming?
No clear picture.....

nature geoscience
REVIEW ARTICLE
PUBLISHED ONLINE: 23 MAY 2010 | DOI: 10.1038/NGEO868

The impact of global warming on the tropical Pacific Ocean and El Niño

Mat Collins[1*], Soon-Il An[2], Wenju Cai[3], Alexandre Ganachaud[4], Eric Guilyardi[5], Fei-Fei Jin[6], Markus Jochum[7], Matthieu Lengaigne[8], Scott Power[9], Axel Timmermann[10], Gabe Vecchi[11] and Andrew Wittenberg[11]



$$\frac{\partial T'}{\partial t} = \underbrace{-u'\frac{\partial \bar{T}}{\partial x} - v'\frac{\partial \bar{T}}{\partial y} - w'\frac{\partial \bar{T}}{\partial z} - \bar{u}\frac{\partial T'}{\partial x} - \bar{v}\frac{\partial T'}{\partial y} - \bar{w}\frac{\partial T'}{\partial z}}_{\text{Linear advective terms}}$$

$$\underbrace{-u'\frac{\partial T'}{\partial x} - v'\frac{\partial T'}{\partial y} - w'\frac{\partial T'}{\partial z}}_{\text{NDH}} + res$$

$$\frac{\partial \langle T \rangle}{\partial t} \approx -\left(\frac{\langle \bar{u} \rangle}{L_x} + \frac{\langle -2y\bar{v} \rangle}{L_y^2} + \frac{\langle \bar{w} \rangle}{H_m} \right) \langle T \rangle - \langle u \rangle \left\langle \frac{\partial \bar{T}}{\partial x} \right\rangle - \langle w \rangle \left\langle \frac{\partial \bar{T}}{\partial z} \right\rangle + \langle \bar{w} \rangle \frac{\langle T_{sub} \rangle}{H_m} + \langle Q \rangle$$

$$\langle u \rangle = \beta_u \langle \tau_x \rangle + \beta_{uh} [h]$$

$$\langle w \rangle = -\beta_w \langle \tau_x \rangle$$

$$\langle h \rangle - [h] = \beta_h [\tau_x]$$

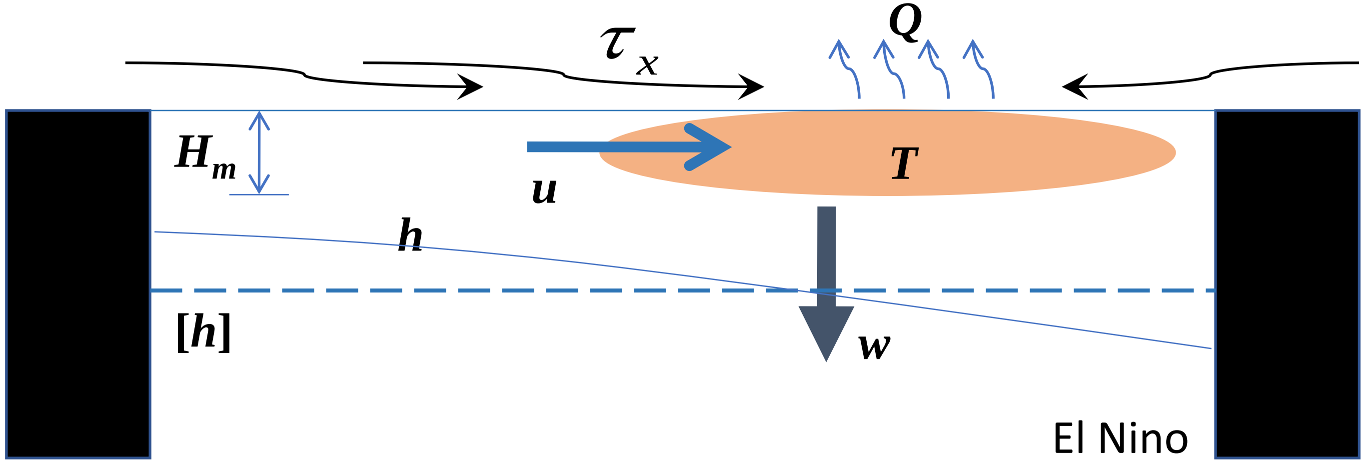
$$\langle Q \rangle = -\alpha \langle T \rangle$$

$$\frac{\partial \langle T \rangle}{\partial t} = 2I_{BJ} \langle T \rangle + \left(-\frac{\partial \bar{T}}{\partial x} \beta_{uh} + \frac{\bar{w}}{H_m} \right) [h]$$

$$2I_{BJ} \approx \underbrace{-\left(\frac{\langle \bar{u} \rangle}{L_x} + \frac{\langle -2y\bar{v} \rangle}{L_y^2} + \frac{\langle \bar{w} \rangle}{H_m} \right)}_{\text{MA}} \underbrace{-\alpha}_{\text{TD}} \underbrace{+ \mu_a \beta_u \left\langle -\frac{\partial \bar{T}}{\partial x} \right\rangle}_{\text{ZA}} \underbrace{+ \mu_a \beta_w \left\langle \frac{\partial \bar{T}}{\partial z} \right\rangle}_{\text{EK}} \underbrace{+ \mu_a^* \beta_h \left\langle \frac{\bar{w}}{H_m} \right\rangle}_{\text{TH}}$$

MA TD ZA EK TH

Bjerknes (BJ) stability index (Jin et al. 2006, GRL; decay rate if < 0, growth rate if > 0)



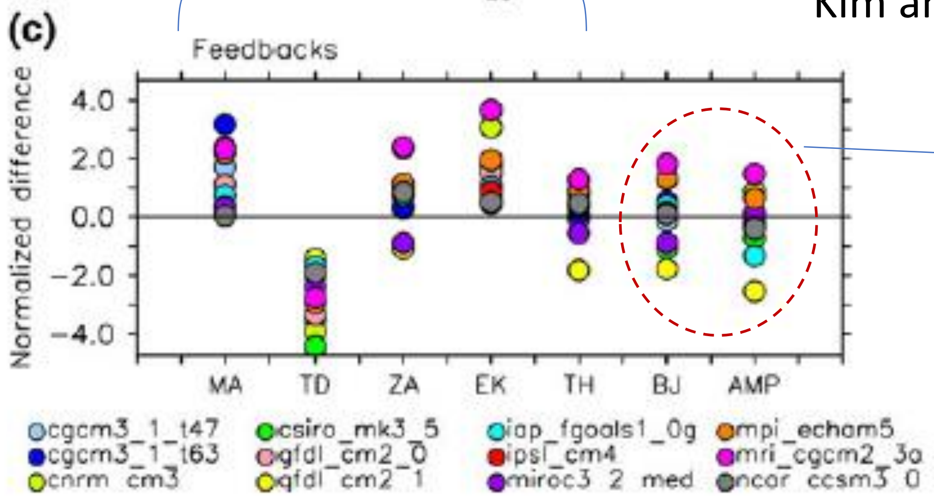
$$[\tau_x] = \mu_a^* \langle T \rangle$$

$$\langle \tau_x \rangle = \mu_a \langle T \rangle$$

$$\langle h \rangle = \frac{\langle T_{sub} \rangle}{a}$$

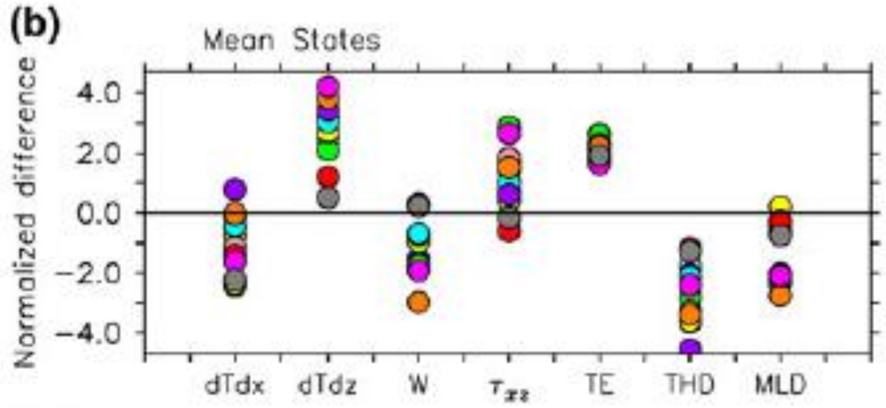
compensating feedbacks

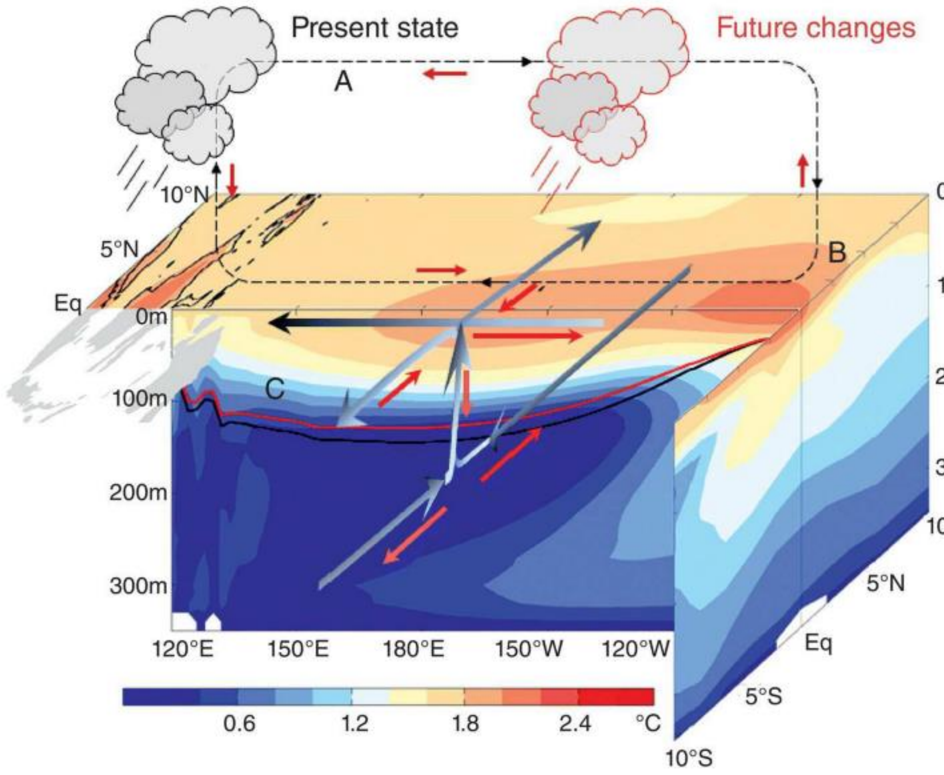
Kim and Jin (2011)



No model consensus in ENSO amplitude change

Despite strong consensus in mean state change: weakened Walker Circulation





Cai et al. (2020, ENSO book Chapter 13)

2015 Greenhouse warming -> increase in ENSO extremes

nature climate change
REVIEW ARTICLE
PUBLISHED ONLINE: 17 AUGUST 2015 | DOI: 10.1038/NCLIMATE2743

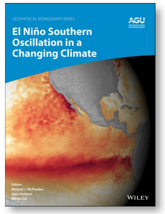
ENSO and greenhouse warming

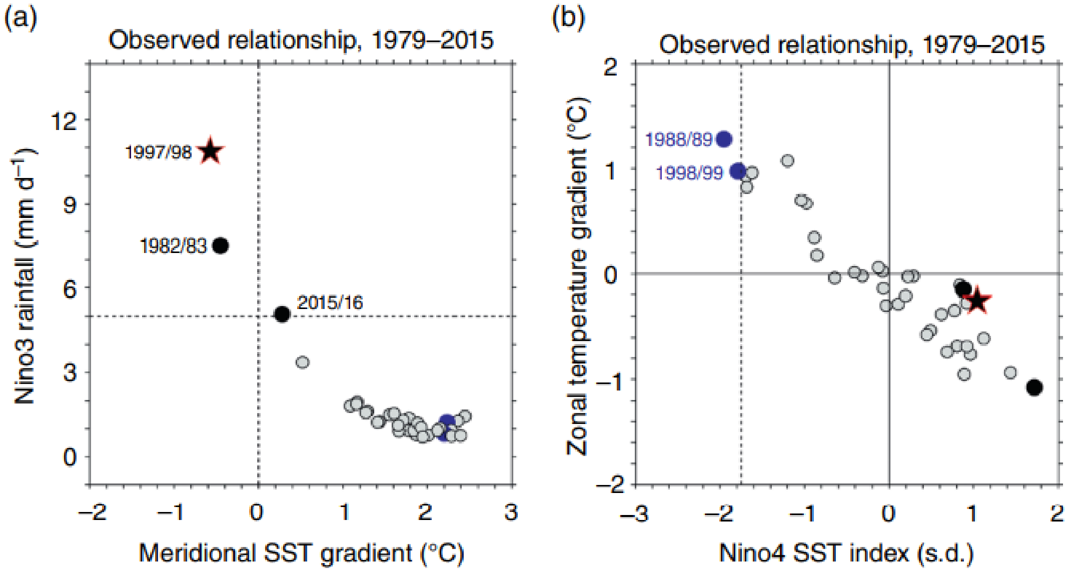
Wenju Cai[1,2*], Agus Santoso[3], Guojian Wang[1], Sang-Wook Yeh[4], Soon-Il An[5], Kim M. Cobb[6], Mat Collins[7], Eric Guilyardi[8,9], Fei-Fei Jin[10], Jong-Seong Kug[11], Matthieu Lengaigne[8], Michael J. McPhaden[12], Ken Takahashi[13], Axel Timmermann[14], Gabriel Vecchi[15], Masahiro Watanabe[16] and Lixin Wu[2]

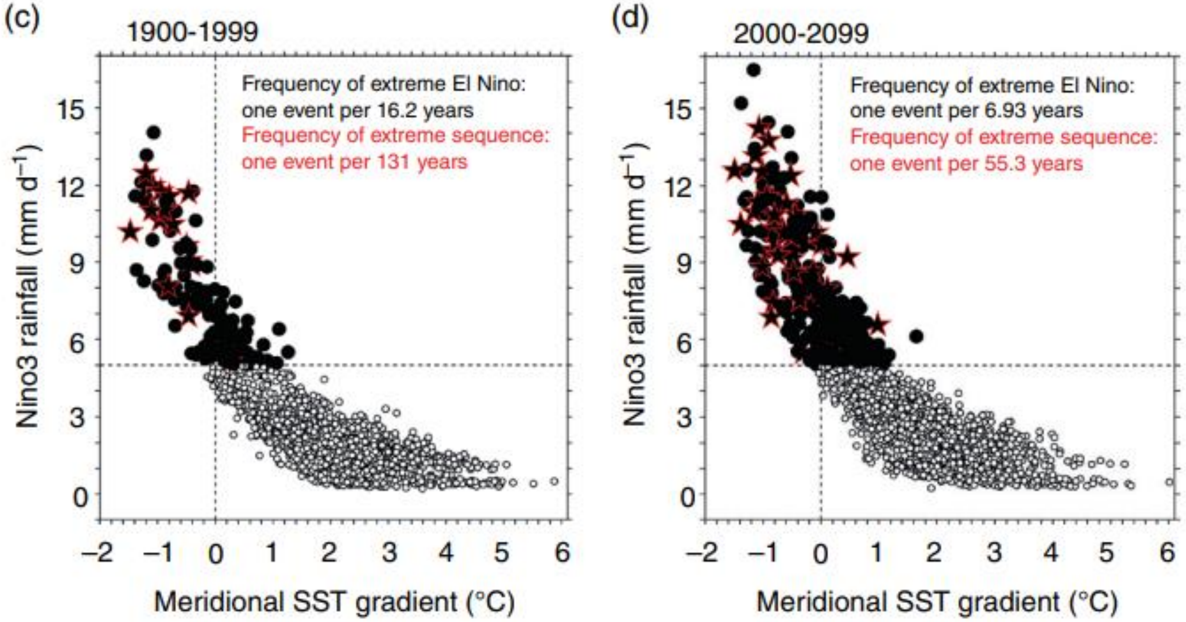
13

ENSO Response to Greenhouse Forcing

Wenju Cai[1,2], Agus Santoso[1,3], Guojian Wang[1,2], Lixin Wu[2], Mat Collins[4], Matthieu Lengaigne[5,6], Scott Power[7,8], and Axel Timmermann[9,10]





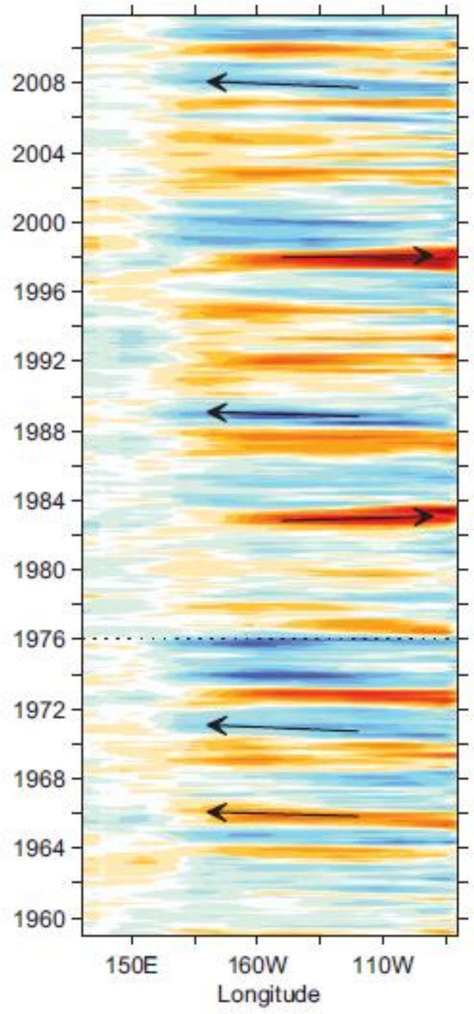


LETTER

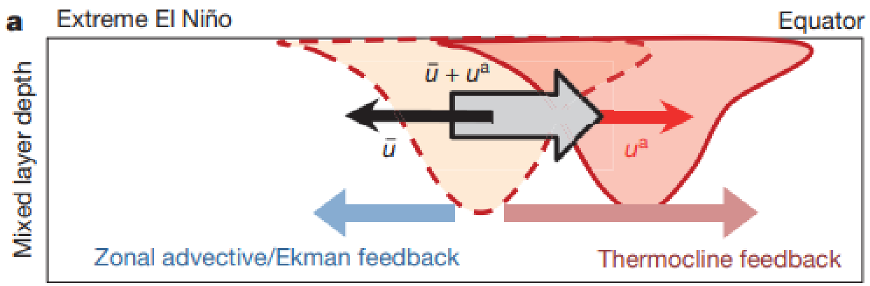
doi:10.1038/nature12683

Late-twentieth-century emergence of the El Niño propagation asymmetry and future projections

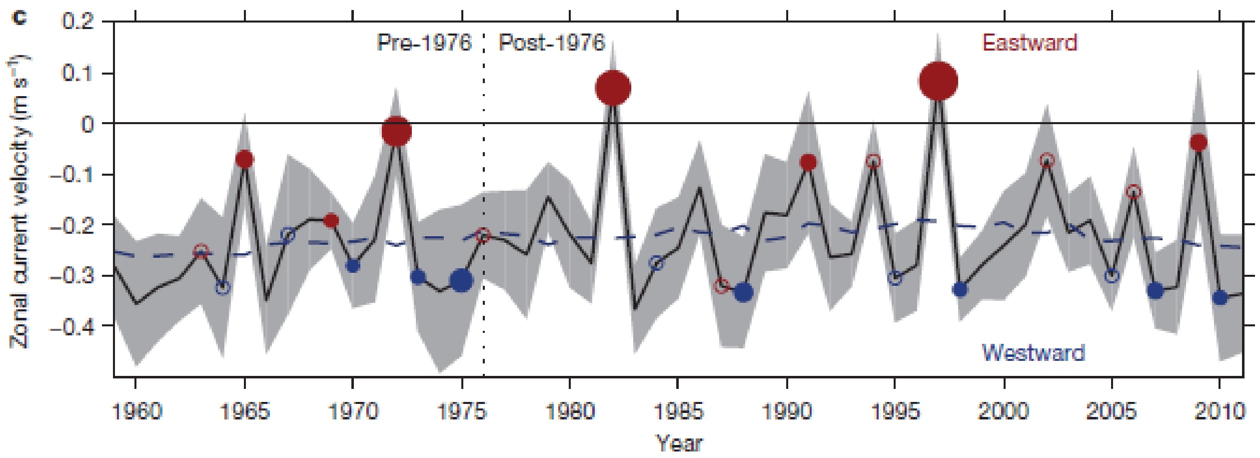
Agus Santoso[1], Shayne McGregor[1], Fei-Fei Jin[2], Wenju Cai[3], Matthew H. England[1], Soon-Il An[4], Michael J. McPhaden[5] & Eric Guilyardi[6,7]



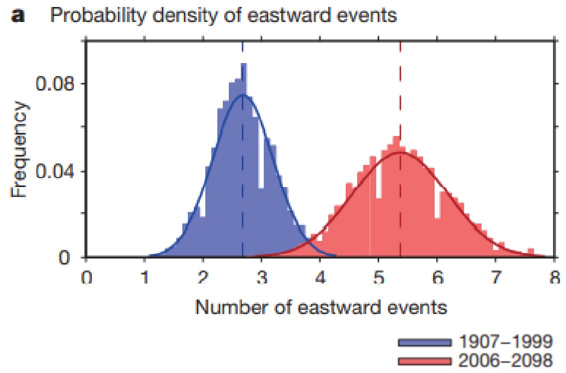
Eastward propagation and strong equatorial current reversal



<u>Equatorial current</u>



Projected weakening in mean current -> more occurrences of eastward propagating El Niño

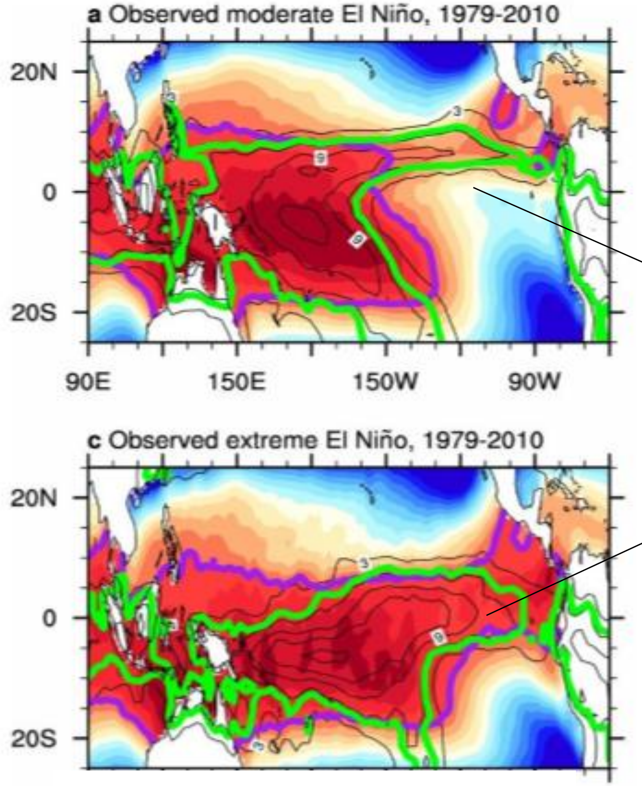


Santoso et al. (2013)

nature climate change
LETTERS
PUBLISHED ONLINE: 19 JANUARY 2014 | DOI:10.1038/NCLIMATE2100

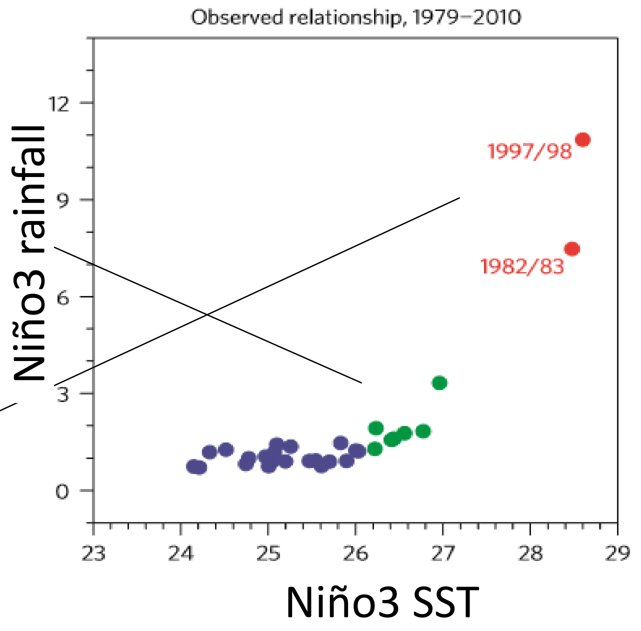
Increasing frequency of extreme El Niño events due to greenhouse warming

Wenju Cai[1,2*], Simon Borlace[1], Matthieu Lengaigne[3], Peter van Rensch[1], Mat Collins[4], Gabriel Vecchi[5], Axel Timmermann[6], Agus Santoso[7], Michael J. McPhaden[8], Lixin Wu[2], Matthew H. England[7], Guojian Wang[1,2], Eric Guilyardi[3,9] and Fei-Fei Jin[10]

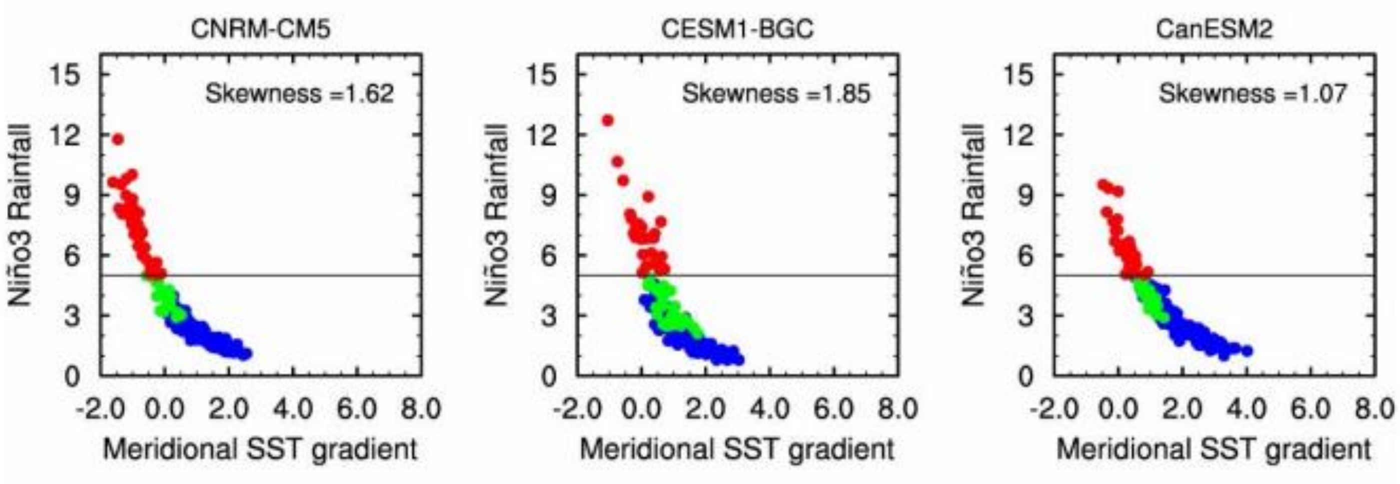


Green 5 mm per day
Purple 28°C isotherm

Eastern equatorial Pacific rainfall

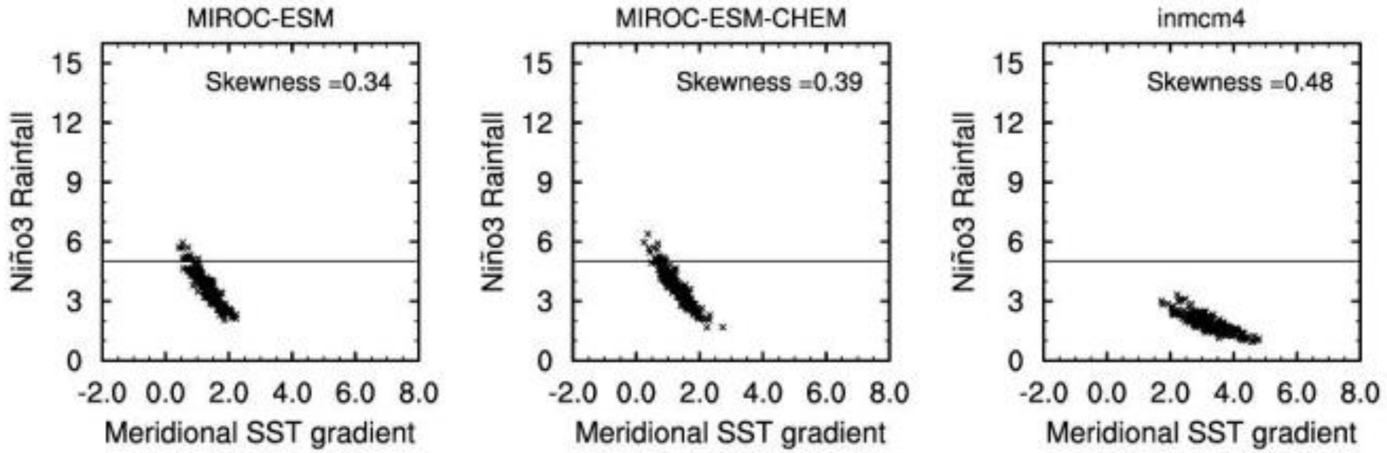


Define Extreme El Niño: DJF Niño3 Precip > 5 mm/day

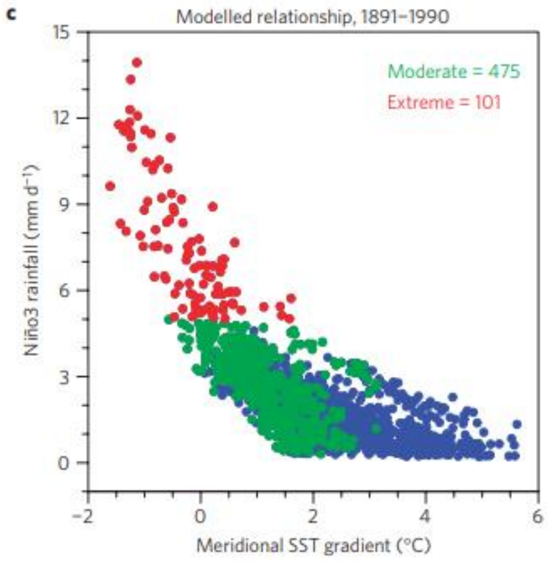


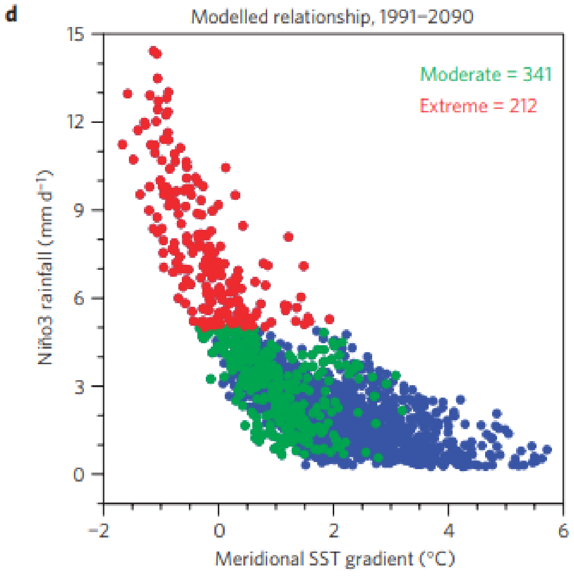
Examples of the selected models

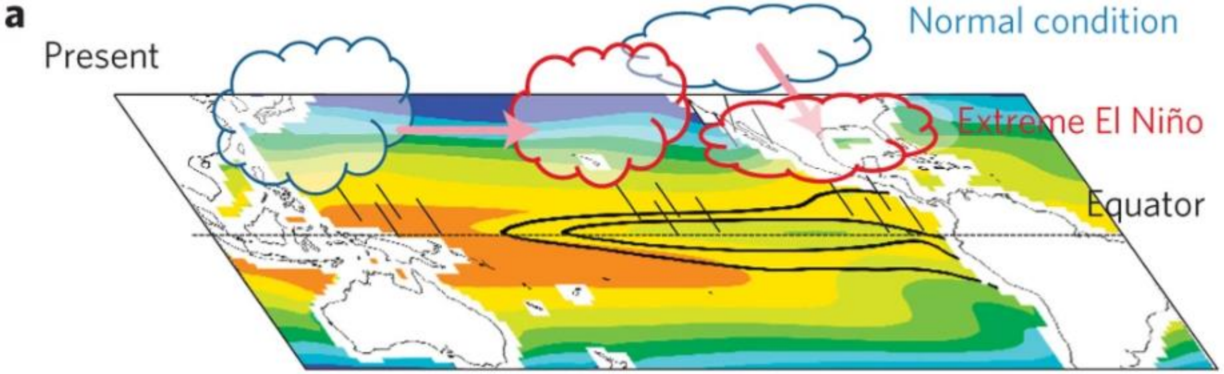
Nino3 rainfall skewness > 1
Able to simulate events with
Nino3 rainfall > 5 mm/day

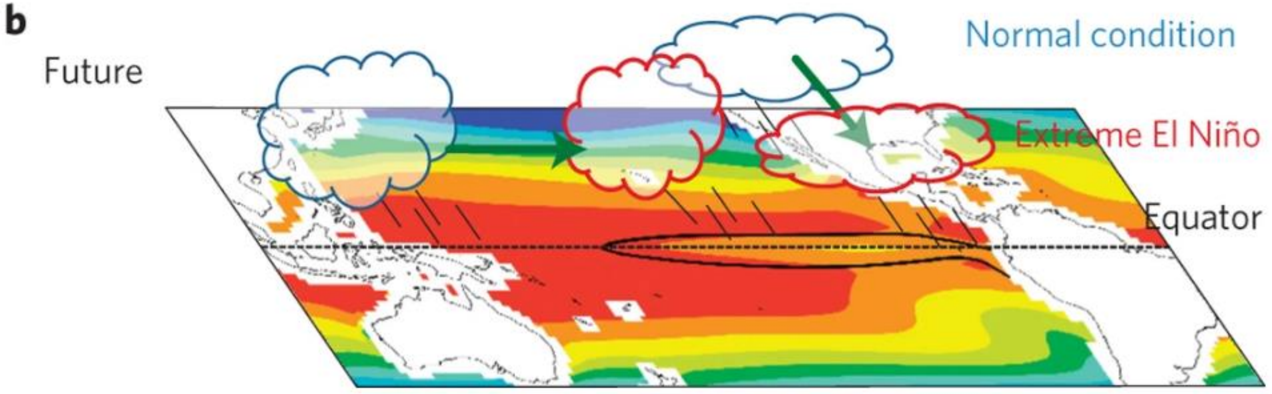


Examples of the discarded models









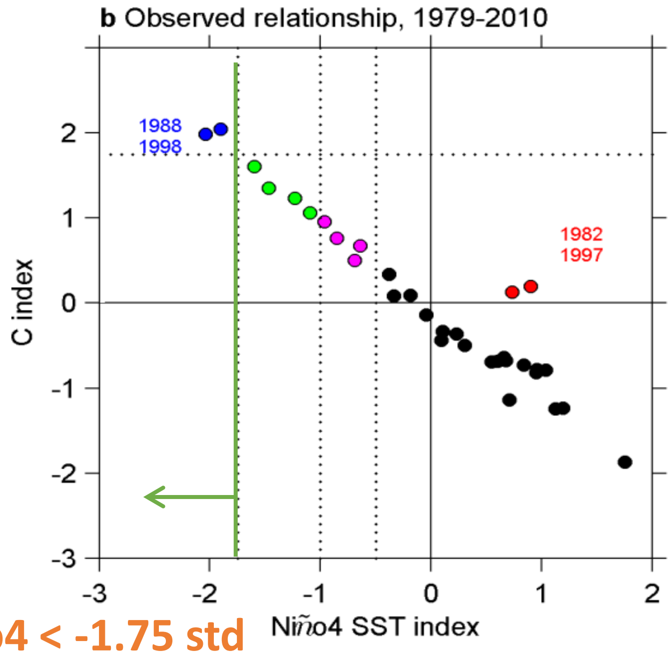
Cai et al. (2014)

LETTERS
PUBLISHED ONLINE: 26 JANUARY 2015 | DOI: 10.1038/NCLIMATE2492
nature climate change

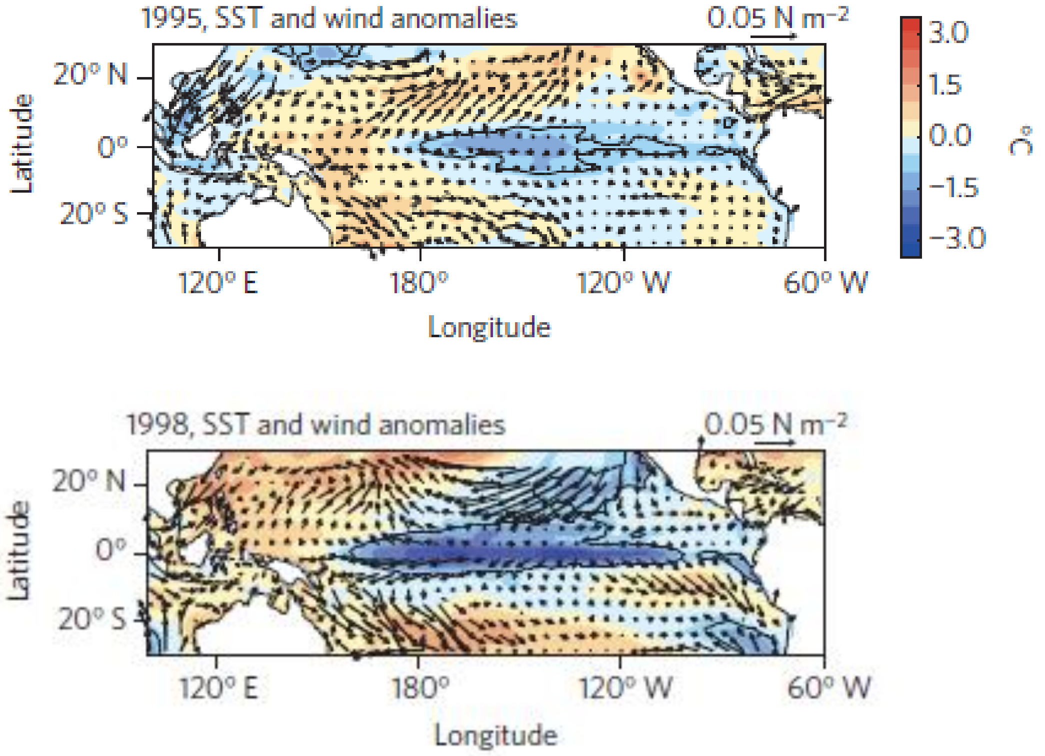
Increased frequency of extreme La Niña events under greenhouse warming

Wenju Cai[1,2]*, Guojian Wang[1,2], Agus Santoso[3], Michael J. McPhaden[4], Lixin Wu[2], Fei-Fei Jin[5], Axel Timmermann[6], Mat Collins[7], Gabriel Vecchi[8], Matthieu Lengaigne[9], Matthew H. England[3], Dietmar Dommenget[10], Ken Takahashi[11] and Eric Guilyardi[9,12]

Extreme La Niña: Central Pacific cooling



Niño4 < -1.75 std



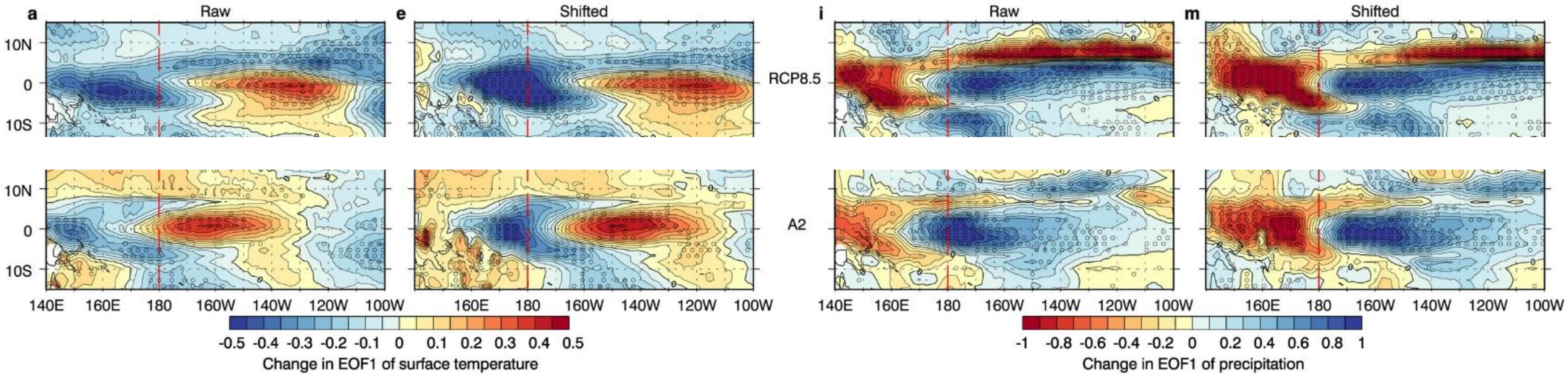
doi:10.1038/nature12580

Robust twenty-first-century projections of El Niño and related precipitation variability

Scott Power[1], François Delage[1], Christine Chung[1], Greg Kociuba[1] & Kevin Keay[1]

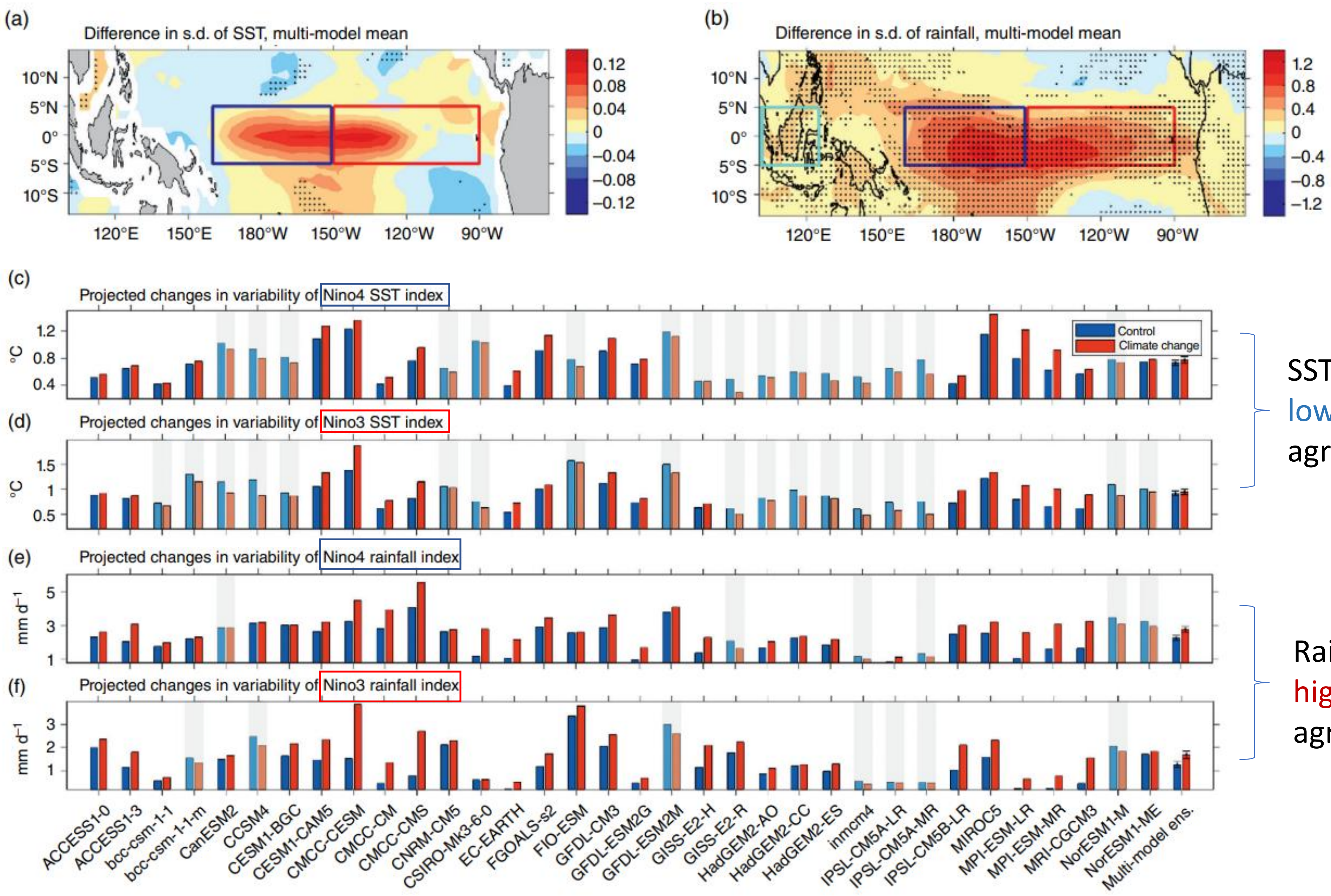
Change in surface temperature pattern

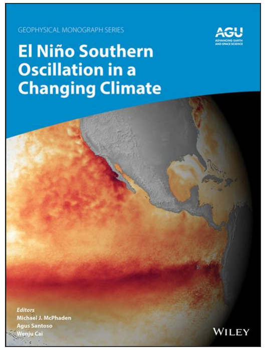
Change in rainfall pattern



colder warmer

drier wetter





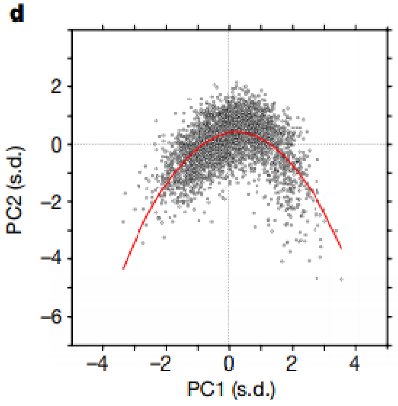
Chapter 13 (Cai et al.)

SST variability change: low inter-model agreement

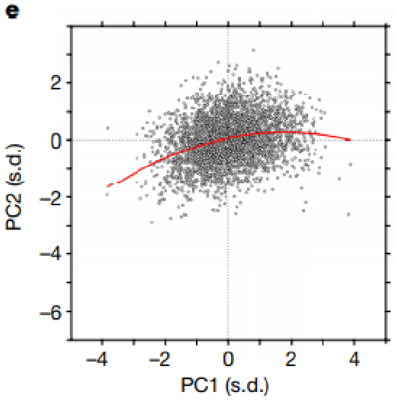
Rainfall variability change: high inter-model agreement

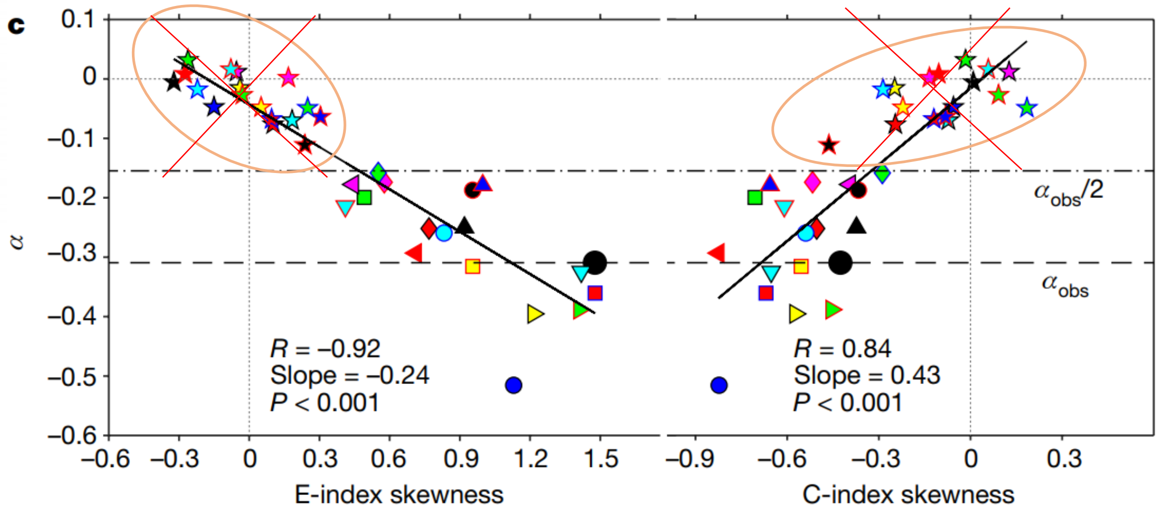
Cai et al. 2018, Nature

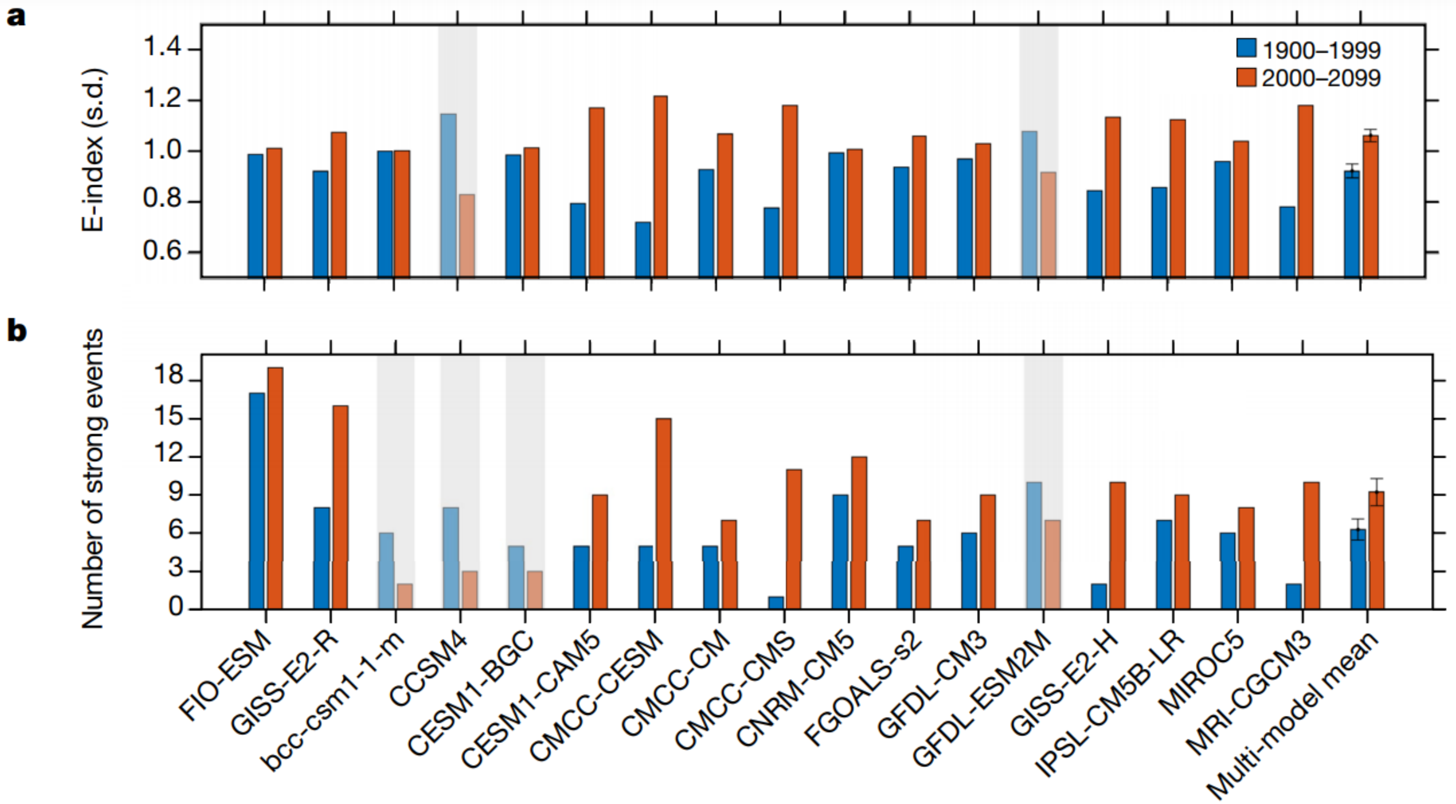
Selected models



Discarded models

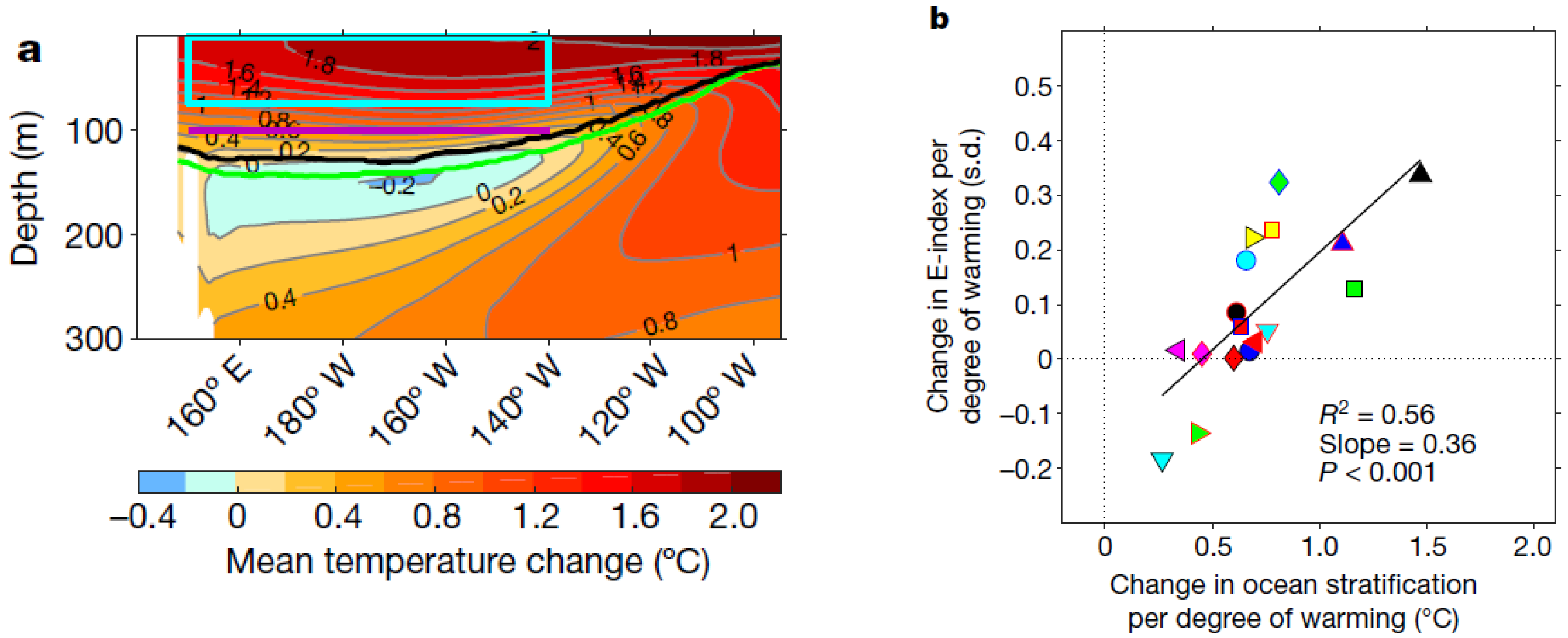




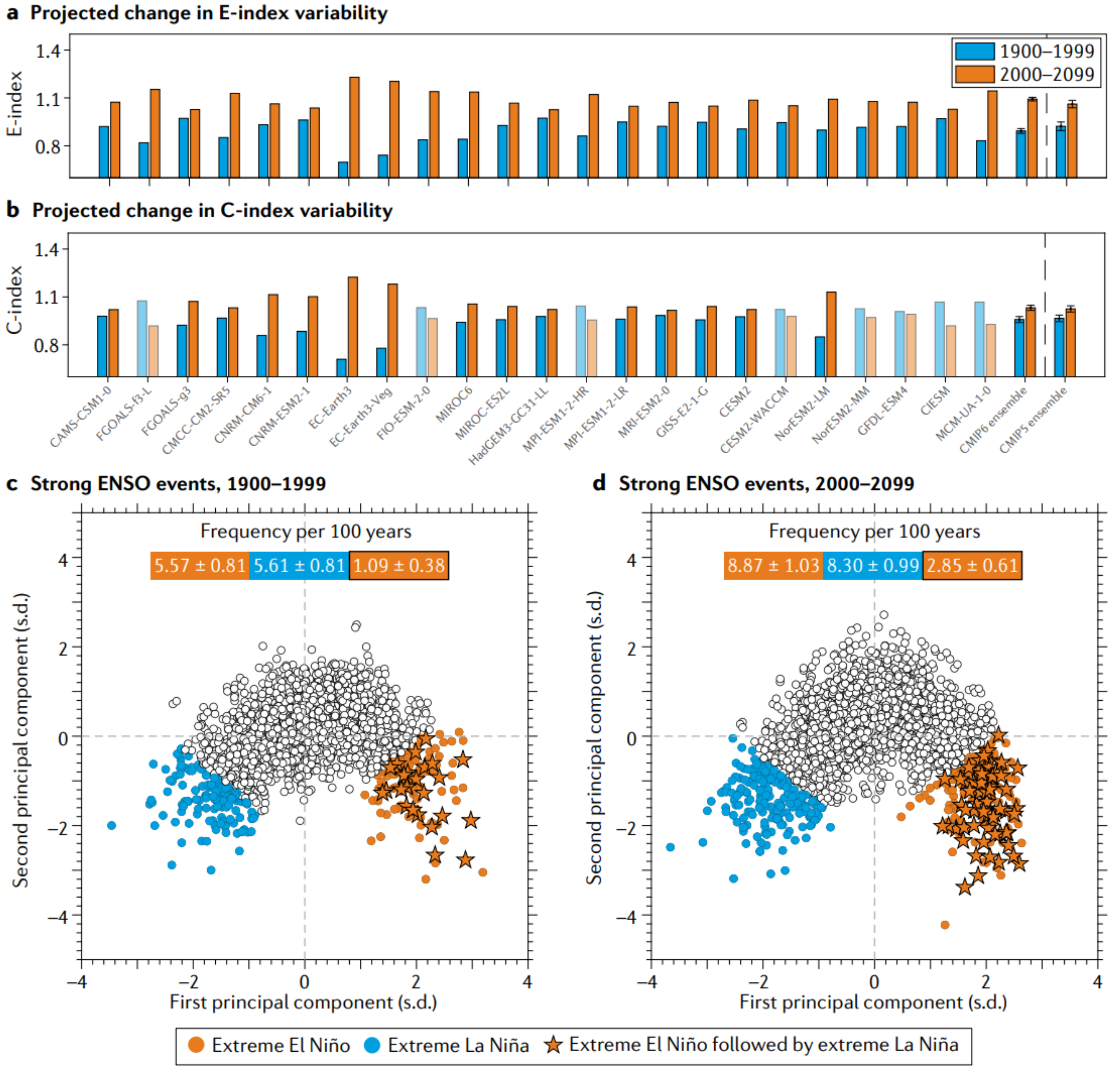


Increased variability of EP ENSO and frequency of strong El Nino events

Cai et al. (2018)



Increased ocean stratification under greenhouse forcing enhances air-sea interactions important for El Nino growth.



- **Future projections (20th vs 21st century).** All of 23 CMIP6 models indicate increased EP ENSO variability (**a**). 65% generate increased CP variability (**b**). The enhanced variability is associated with increased occurrence of extreme EP El Niño and extreme La Niña events (**c, d**).

- Without model selection, majority of CMIP6 models generate an increase in Niño3 and Niño4 SST variability, with 28 and 27 out of 34 models, respectively, producing an increase of 10–15%. There was little consensus in CMIP5.

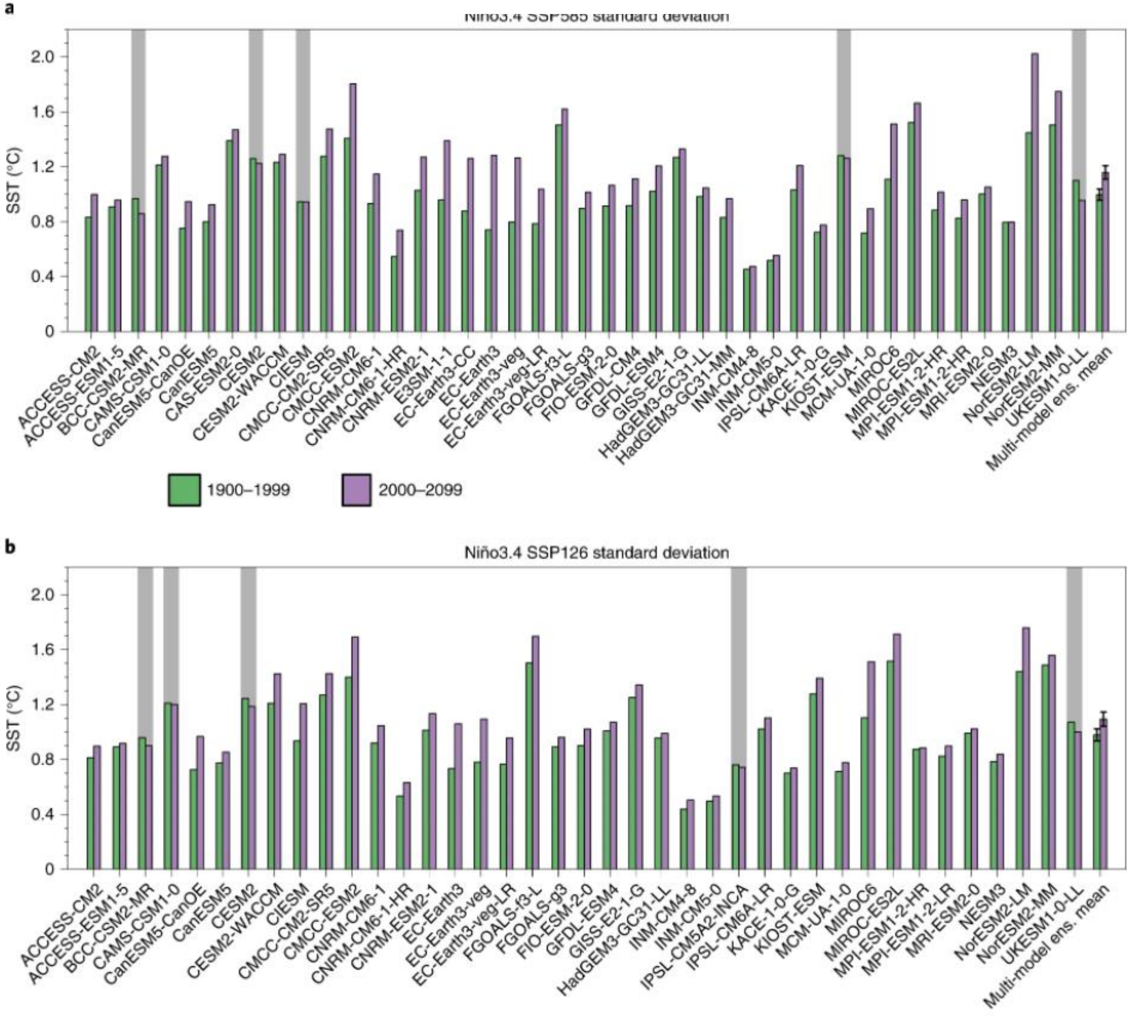
Cai et al. (2021, Nature Rev. Earth & Environment)

BRIEF COMMUNICATION
https://doi.org/10.1038/s41558-022-01282-z
nature climate change
Check for updates

OPEN

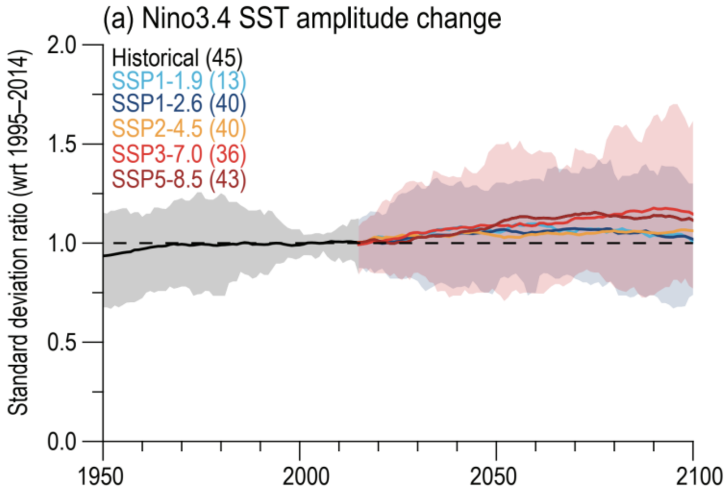
Increased ENSO sea surface temperature variability under four IPCC emission scenarios

Wenju Cai[1,2], Benjamin Ng[2], Guojian Wang[1,2], Agus Santoso[2,3], Lixin Wu[1] and Kai Yang[4]

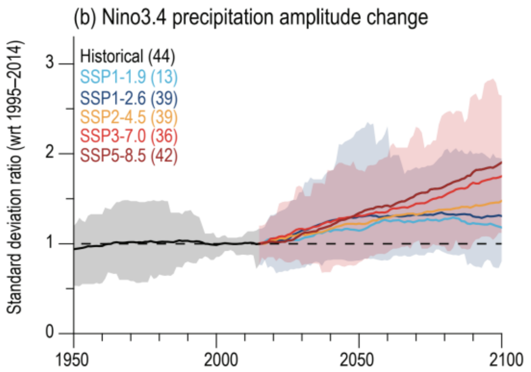


Abstract

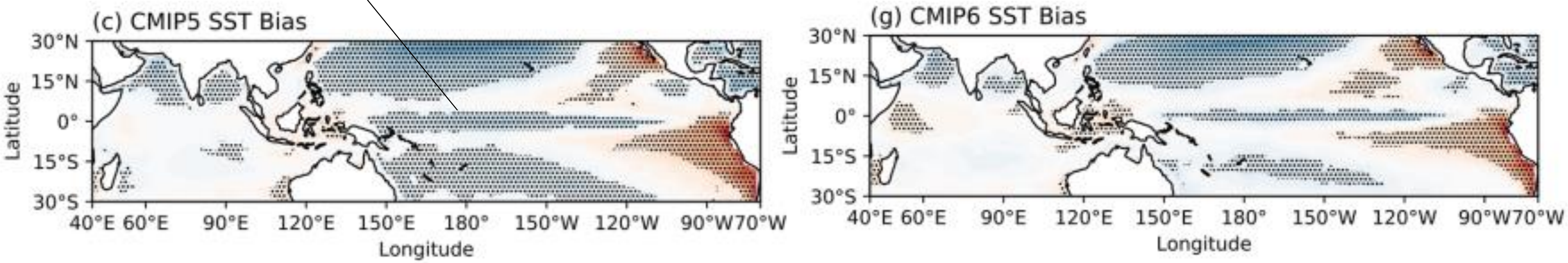
Sea surface temperature (SST) variability of El Niño–Southern Oscillation (ENSO) underpins its global impact, and its future change is a long-standing science issue. In its sixth assessment, the IPCC reports no systematic change in ENSO SST variability under any emission scenarios considered. However, comparison between the 20th and 21st century shows a robust increase in century-long ENSO SST variability under four IPCC plausible emission scenarios.



IPCC AR6 WG1 Chapter 4



Cold tongue bias



McKenna et al. 2020

SCIENTIFIC REPORTS
natureresearch

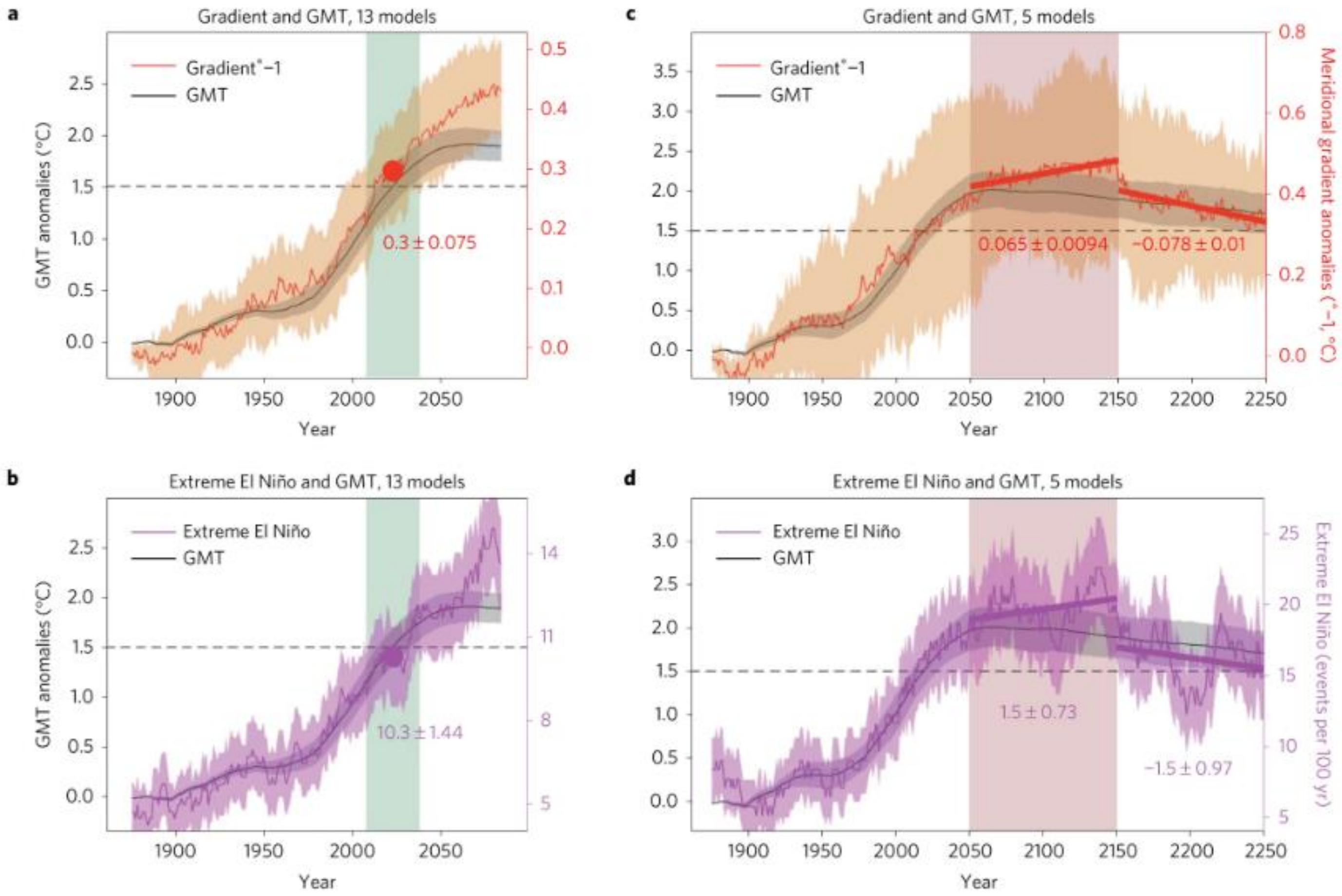
Indian Ocean Dipole in CMIP5 and CMIP6: characteristics, biases, and links to ENSO

Sebastian McKenna[1✉], Agus Santoso[1,2✉], Alexander Sen Gupta[1], Andréa S. Taschetto[1] & Wenju Cai[2,3]

Continued increase of extreme El Niño frequency long after 1.5 °C warming stabilization

Guojian Wang, Wenju Cai, Bolan Gan, Lixin Wu, Agus Santoso, Xiaopei Lin, Zhaohui Chen & Michael J. McPhaden

Wang et al. (2017, NCC, 7)

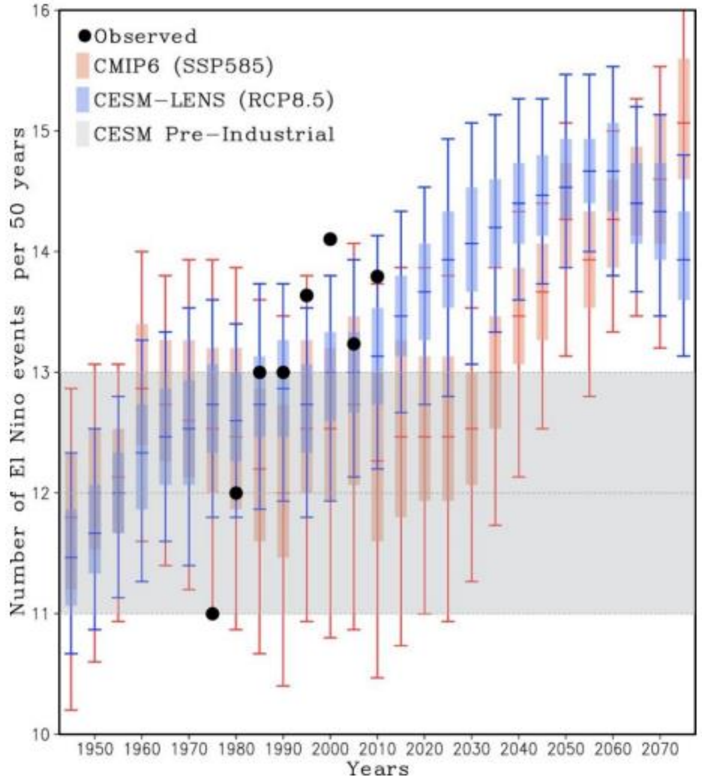


https://doi.org/10.1038/s41467-022-29519-7 OPEN

Lopez et al. (2022, Nature Comm., 13)

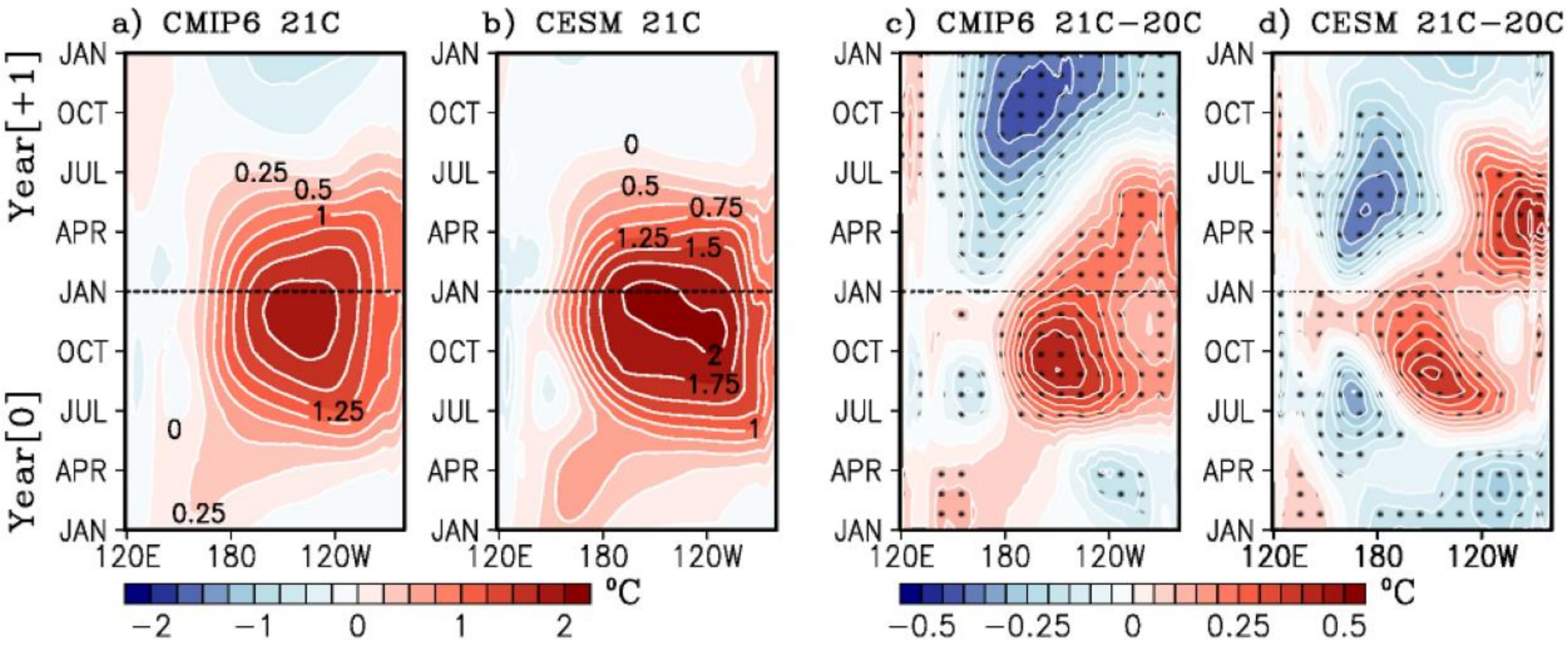
Projections of faster onset and slower decay of El Niño in the 21st century

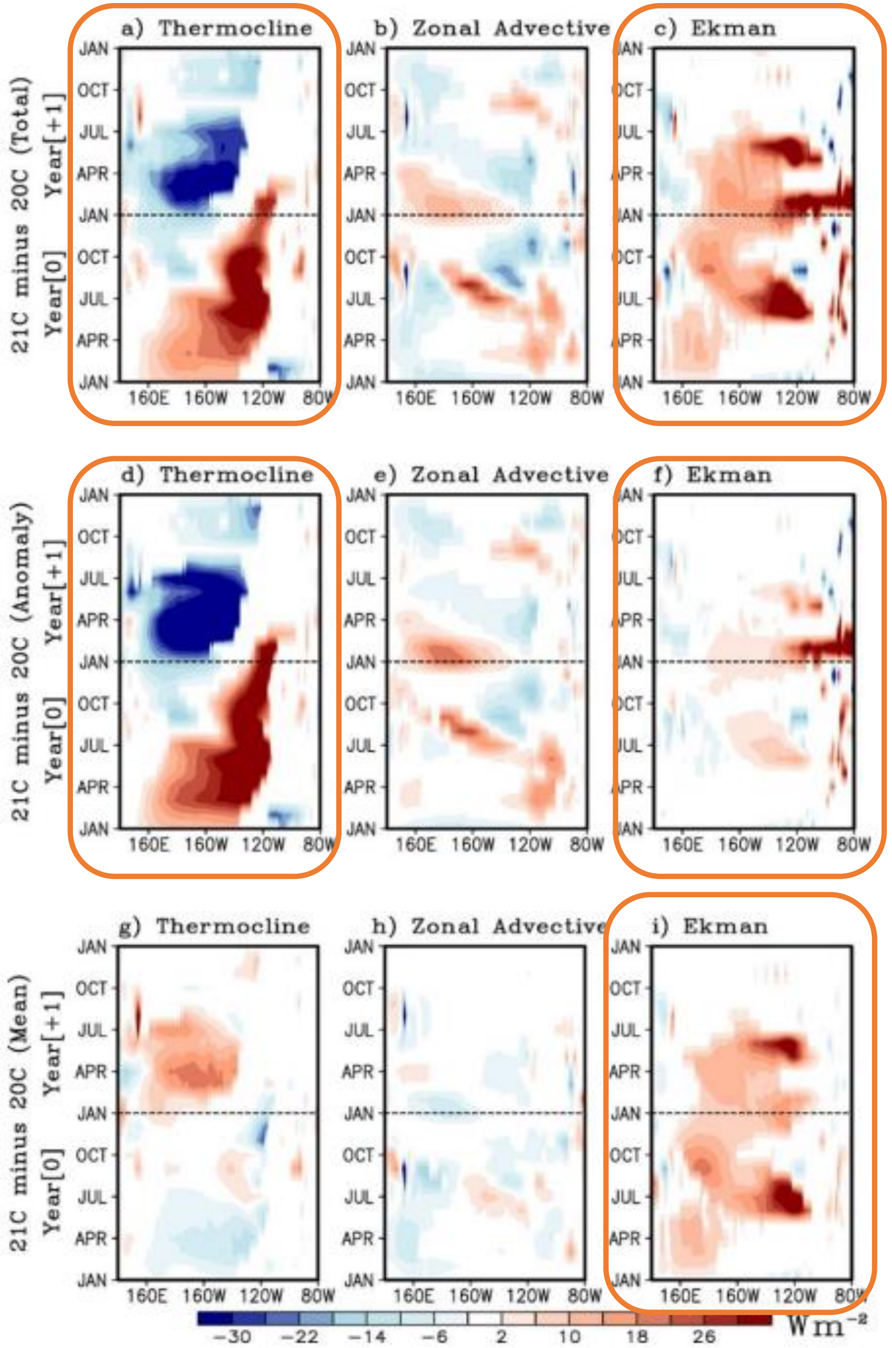
Hosmay Lopez [1✉], Sang-Ki Lee [1], Dongmin Kim [1,2], Andrew T. Wittenberg [3] & Sang-Wook Yeh [4]



Based on Fang and Yu (2020, GRL, 47) in defining onset, duration, and demise months based on SSTA exceeding 0.5°C.

Projected shift in the peak month from January to December (Nino4, Nino3.4)
Projected slower decay in the Nino3.
Increased decay over Nino4.
Eastward propagation of SST anomalies.





Supplementary Table 4. Relative contribution of changes in the mean climate (i.e., overbar) and changes in ENSO (i.e., prime) to the total feedback terms. The subscripts indicate whether the terms are evaluated in the 20C or 21C period.

	Thermocline Feedback	Zonal Advective Feedback	Ekman Feedback
Total changes	$\overline{w}_{21C}\frac{\partial T'_{21C}}{\partial z} - \overline{w}_{20C}\frac{\partial T'_{20C}}{\partial z}$	$u'_{21C}\frac{\partial \overline{T}_{21C}}{\partial x} - u'_{20C}\frac{\partial \overline{T}_{20C}}{\partial x}$	$w'_{21C}\frac{\partial \overline{T}_{21C}}{\partial z} - w'_{20C}\frac{\partial \overline{T}_{20C}}{\partial z}$
Changes in anomalies	$\overline{w}_{20C}\frac{\partial T'_{21C}}{\partial z} - \overline{w}_{20C}\frac{\partial T'_{20C}}{\partial z}$	$u'_{21C}\frac{\partial \overline{T}_{20C}}{\partial x} - u'_{20C}\frac{\partial \overline{T}_{20C}}{\partial x}$	$w'_{21C}\frac{\partial \overline{T}_{20C}}{\partial z} - w'_{20C}\frac{\partial \overline{T}_{20C}}{\partial z}$
Changes in the mean	$\overline{w}_{21C}\frac{\partial T'_{20C}}{\partial z} - \overline{w}_{20C}\frac{\partial T'_{20C}}{\partial z}$	$u'_{20C}\frac{\partial \overline{T}_{21C}}{\partial x} - u'_{20C}\frac{\partial \overline{T}_{20C}}{\partial x}$	$w'_{20C}\frac{\partial \overline{T}_{21C}}{\partial z} - w'_{20C}\frac{\partial \overline{T}_{20C}}{\partial z}$

Lopez et al. (2022, Nature Comm., 13)

Key Points:

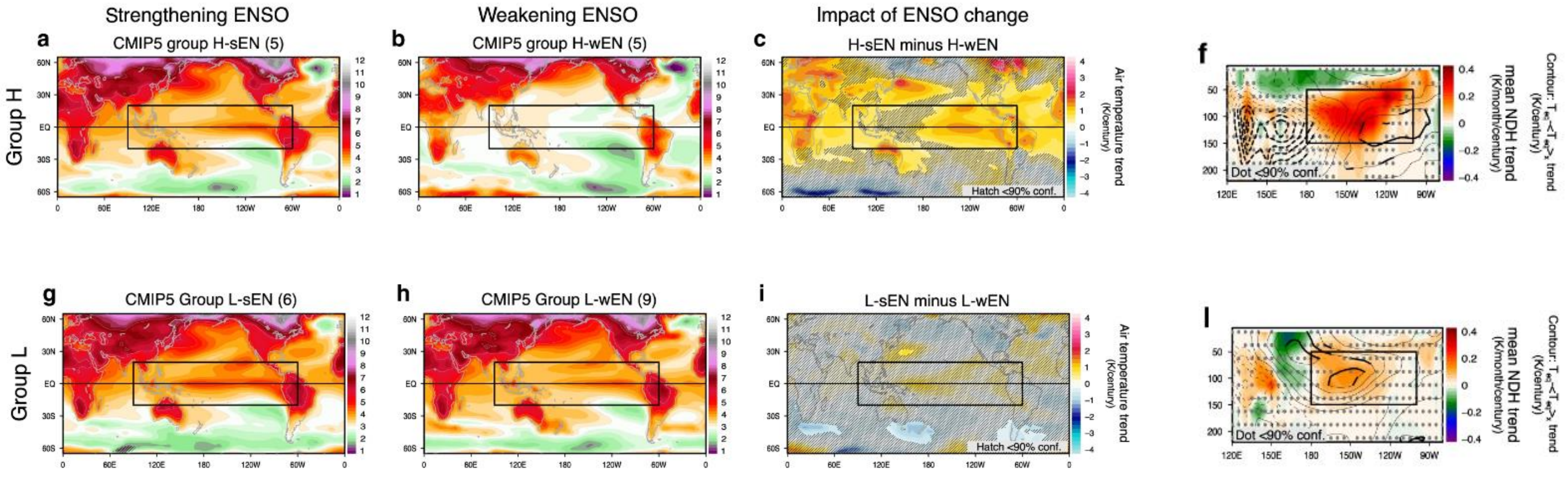
- Dynamical processes underpinning ENSO do respond to greenhouse forcing.
- Competing feedback processes can lead to undetectable change in ENSO amplitude.
- Changes in the dynamics can manifest in detectable change in some ENSO characteristics in models that simulate these characteristics.
- After a series of CMIPs, finally there is an inter-model consensus in increased ENSO amplitude in CMIP6 models.

Factors affecting ENSO projections

Cold tongue bias

Cold tongue bias can weaken Bjerknes feedback, while thermal damping is also weakened (Bellenger et al. 2014 Clim. Dyn.; Kim et al. 2014 Clim. Dyn.; Bayr et al. 2019 Clim. Dyn.)

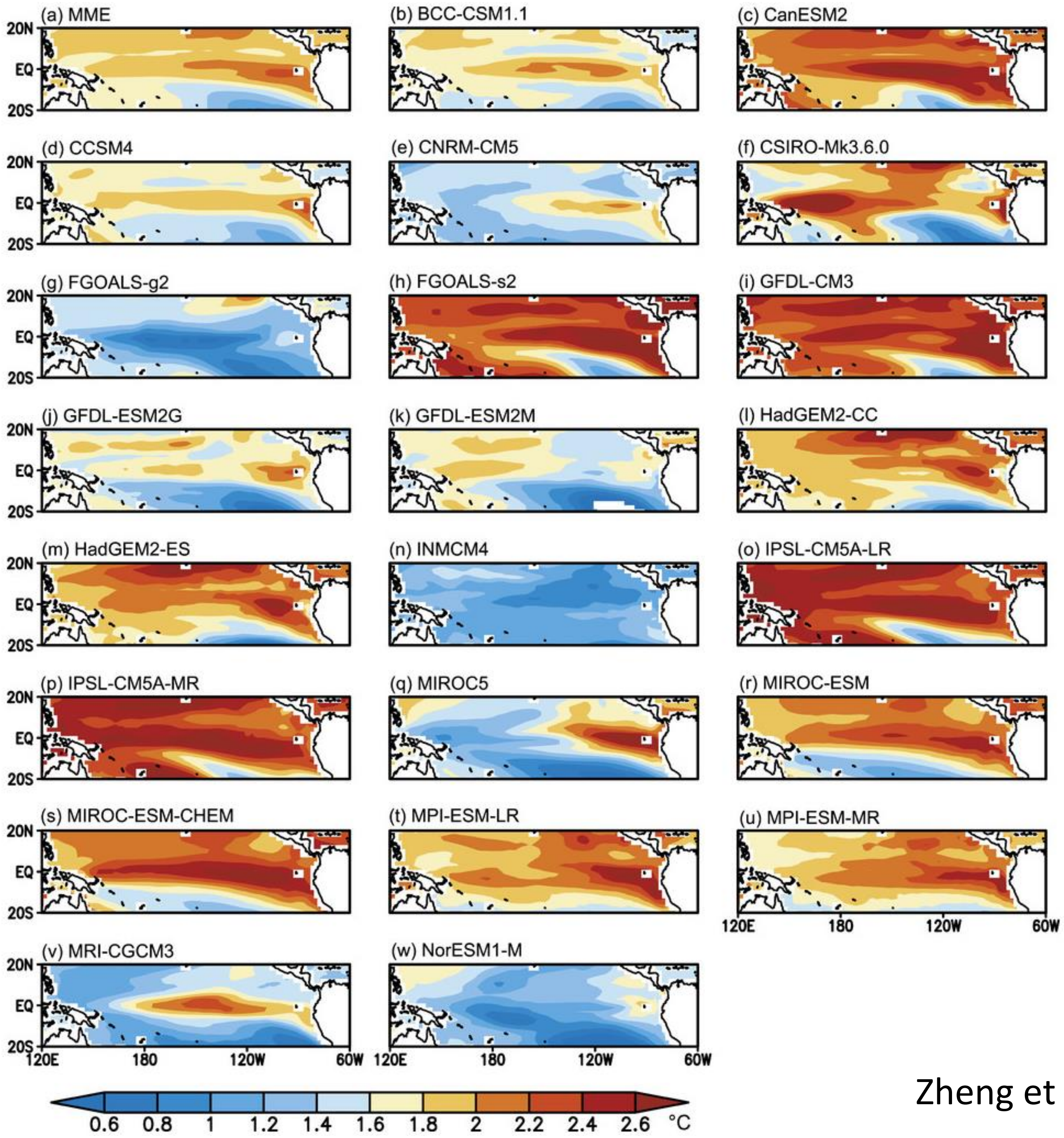
Hampers simulation of ENSO asymmetry (e.g., Hayashi et al. 2020 Nat. Com.)



$$\frac{\partial T'}{\partial t} = \underbrace{-u'\frac{\partial \bar{T}}{\partial x} - v'\frac{\partial \bar{T}}{\partial y} - w'\frac{\partial \bar{T}}{\partial z} - \bar{u}\frac{\partial T'}{\partial x} - \bar{v}\frac{\partial T'}{\partial y} - \bar{w}\frac{\partial T'}{\partial z}}_{\text{Linear advective terms}}$$

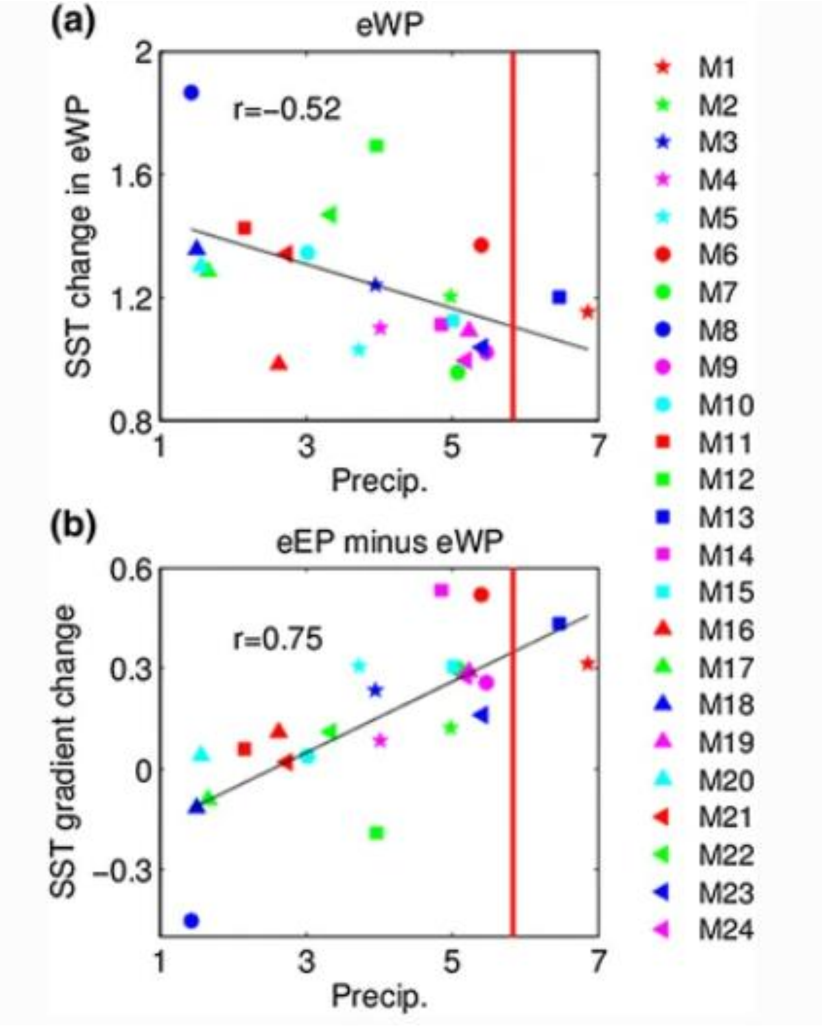
$$\underbrace{-u'\frac{\partial T'}{\partial x} - v'\frac{\partial T'}{\partial y} - w'\frac{\partial T'}{\partial z}}_{\text{NDH}} + res$$

Hayashi et al. (2020)



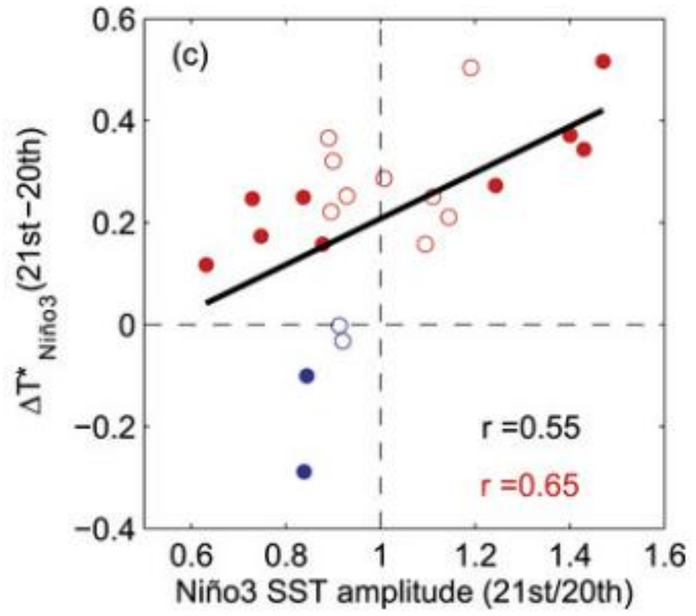
Zheng et al. (2016, J. Climate, vol. 29)

Li et al. (2016, Climate Dyn., 47)



Models with dry bias (cold-tongue bias) tend to project stronger SST warming in the equatorial western Pacific and weaker east-minus-west gradient of equatorial Pacific SST warming, i.e., 'La Nina-like' pattern.

Zheng et al. (2016, J. Climate, vol. 29)

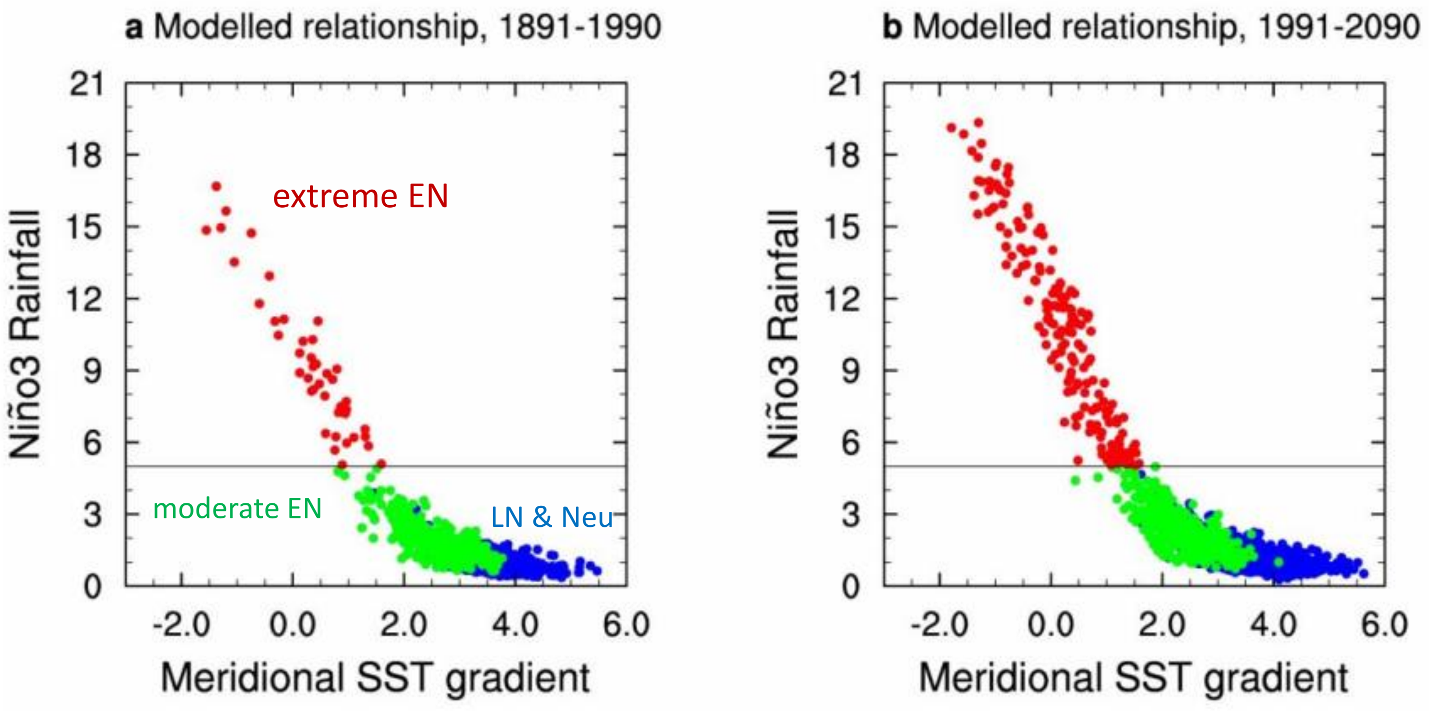


Uncertainty in ENSO amplitude change is related to the projected mean SST warming pattern

Stronger ENSO amplitude <-> "El Nino-like" warming

Li et al. (2016) result implies that correcting the cold-tongue bias would lead to more El Nino-like warming associated with stronger increase in ENSO amplitude.

Perturbed Physics Ensemble (PPE): a flux correction strategy applied directly within coupled models to reduce present-day mean-state bias (Collins et al., 2011).



33 SST-bias-corrected PPE experiments, conducted with the HadCM3 CGCM forced with historical radiative perturbations and a 1% per year CO_2 increase for the future climate change runs -> 4 times increase in extreme El Nino events.

- There are many other attempts in identifying sources of intermodel uncertainty in ENSO amplitude change that appear to be linked with uncertainty in the climatological mean state (e.g. Ham & Kug, 2016; Rashid et al., 2016; Chen et al., 2017).
- Model spread in ENSO amplitude change linked to the climatological location of the convergence zones in present-day simulation, which controls the air-sea coupling strength change and the amplitude of ENSO variability (Ham & Kug, 2016).
- Chen et al. (2017) found that the CMIP5 intermodel divergence in the ENSO amplitude change is closely tied to the spread in the thermocline feedback changes, which are in turn linked to changes in the mean equatorial upwelling and thermocline.

Such investigations should be continued, for other variables and for CMIP6 and future models.

Interbasin-interactions

Pantropical climate interactions

WENJU CAI, LIXIN WU, MATTHIEU LENGAIGNE, TIM LI, SHAYNE MCGREGOR, JONG-SEONG KUG, JIN-YI YU, MALTE F. STUECKER, AGUS SANTOSO, [...] PING CHANG +25 authors Authors Info & Affiliations

SCIENCE • 1 Mar 2019 • Vol 363, Issue 6430 • DOI: 10.1126/science.aav4236

Three-ocean interactions and climate variability: a review and perspective

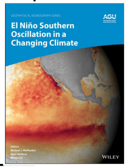
Chunzai Wang[1]

Climate Dynamics (2019) 53:5119–5136
https://doi.org/10.1007/s00382-019-04930-x

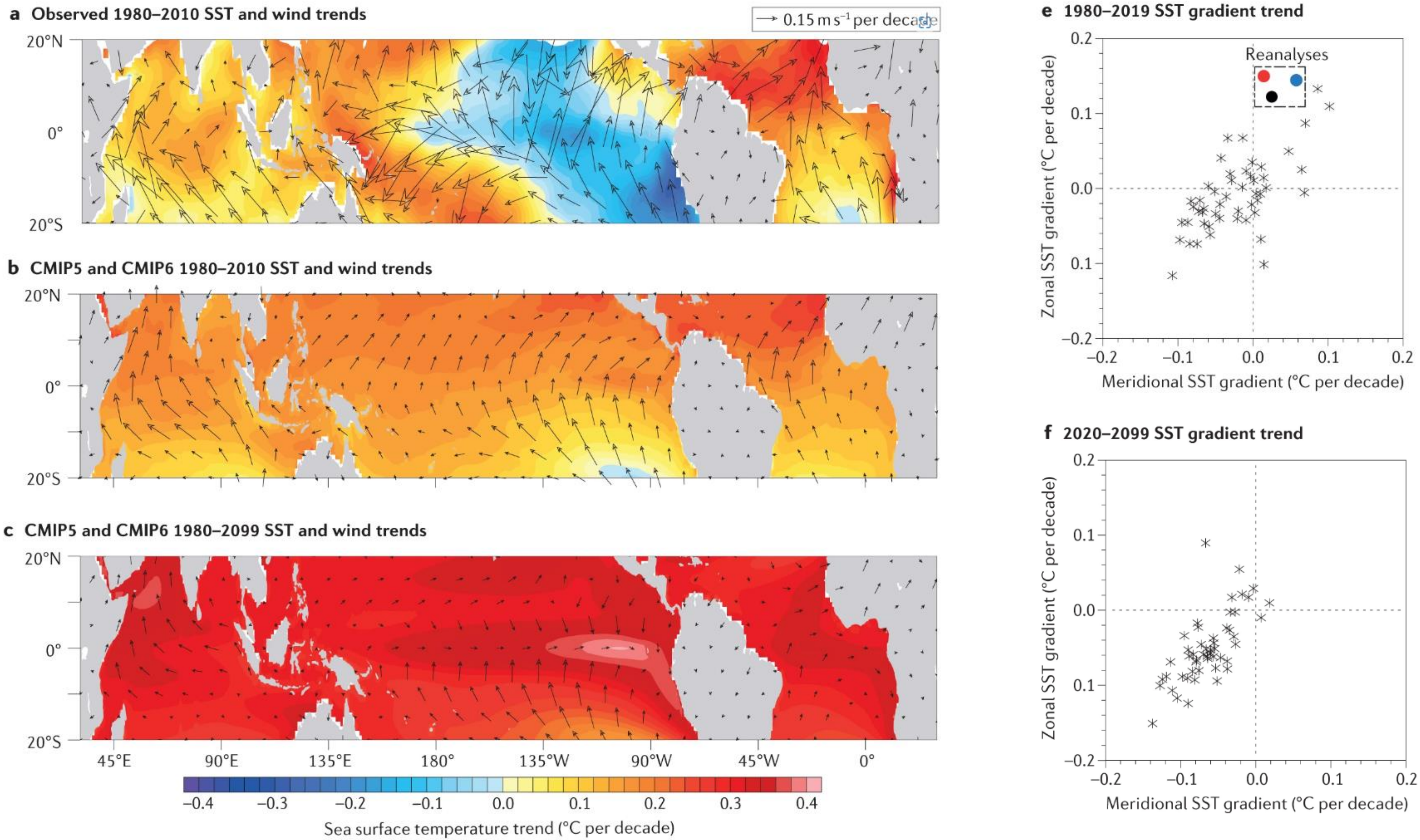
11

ENSO Remote Forcing: Influence of Climate Variability Outside the Tropical Pacific

Jong-Seong Kug[1], Jerome Vialard[2], Yoo-Geun Ham[3], Jin-Yi Yu[4], and Matthieu Lengaigne[2,5]



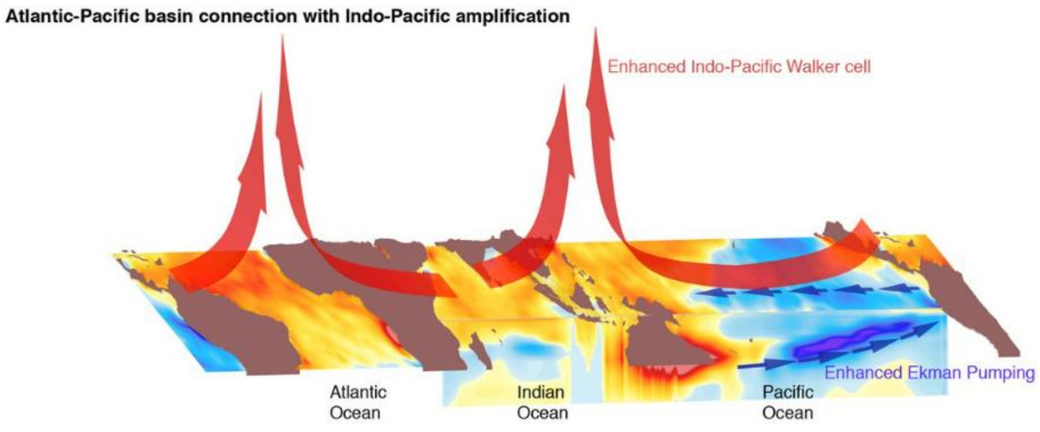
Cai et al. (2021, Nature Rev. Earth & Environment)



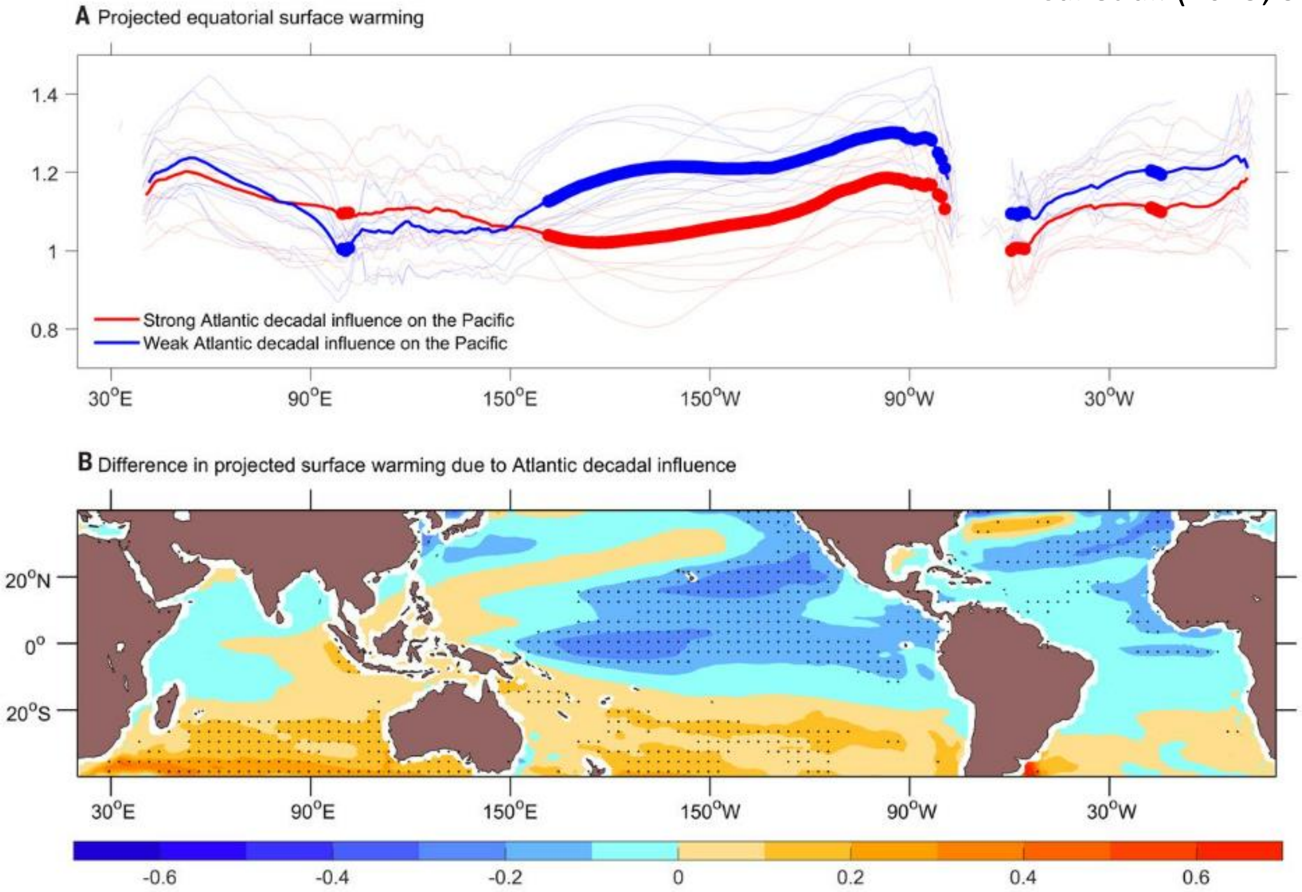
Possible differences between models and observations:

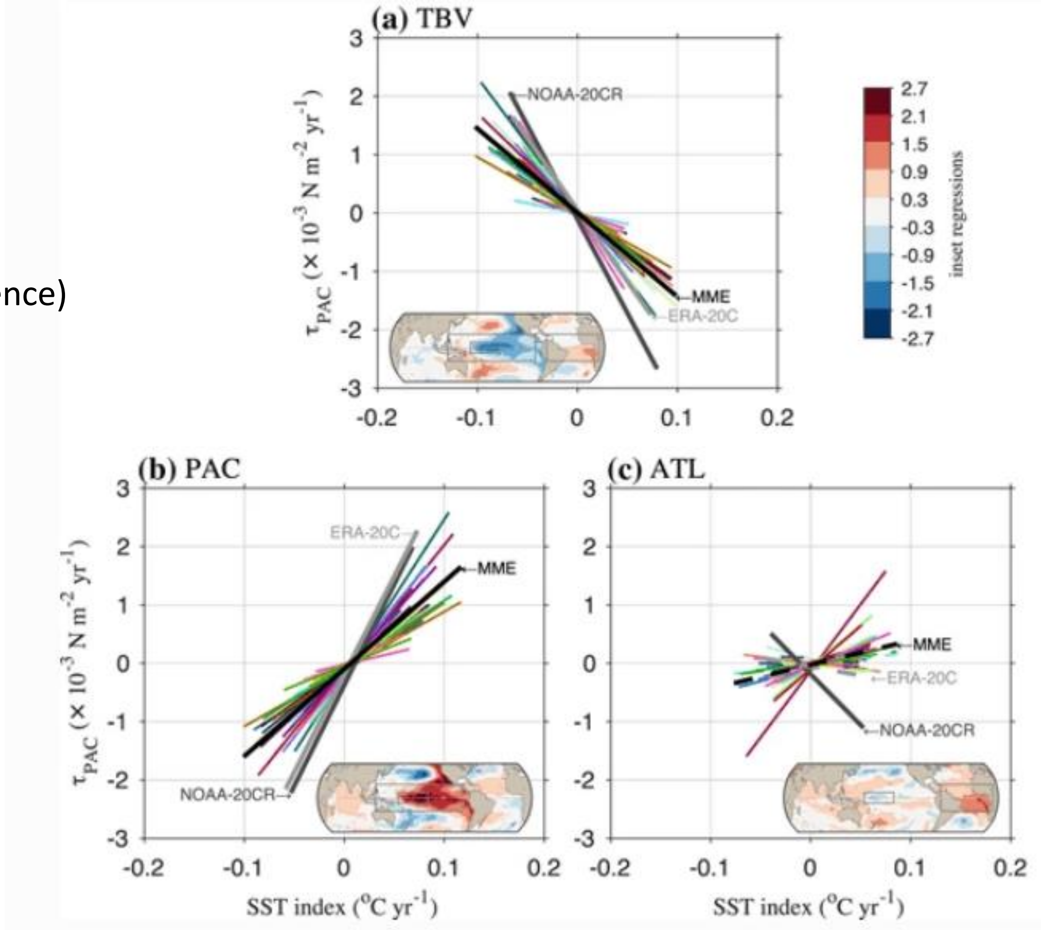
- **Internal variability** (e.g., IPO) – some models/ensemble members capture the observed strengthening of Walker Circulation (Chung et al. 2019, NCC) and equatorial zonal SST gradients (Watanabe et al. 2021, NCC).
- **West-east damping differential** (Knutson et al. 1995; Liu et al. 2005; Xie et al. 2010, JCLIM)
- **Ocean thermostat** (Clement et al. 1996 JCLIM)
- **Inter-basin interactions**

Luo et al. (2012, PNAS), McGregor et al. (2018, NCC), Kucharski et al. (2015, Clim. Dyn.), Luo et al. (2018, Clim. Dyn.)



Cai et al. (2019, Science)





Kajtar et al. (2018, Clim. Dyn.)

A positive NTA SST anomaly in boreal spring can trigger a central Pacific La Niña *(e.g., Ham et al. 2013 NGeo.; Wang et al. 2017 Nat. Comm.)*. Equatorial Atlantic Niña in boreal summer can force an EP El Niño *(e.g., Keenlyside & Latif 2007, J. Climate)*.

Positive IOD can favor the onset of El Niño, and an El Niño–forced IOB can accelerate the demise of an El Niño and its transition to La Niña *(Kug et al. 2006 J. Climate; Izumo et al. 2010 NGeo; Luo et al. 2010 J. Climate)*.

Modeling studies suggest that the net impact of the Indian and Atlantic Oceans on the ENSO cycle damps its amplitude and increases its frequency *(Kug et al. 2006 GRL, Ohba & Ueda 2007 J. Met Soc. Jap.; Terray et al. 2016 Clim. Dyn.; Kajtar et al. 2017 Clim. Dyn.; Dommenget & Yu 2017 Clim. Dyn.)*.

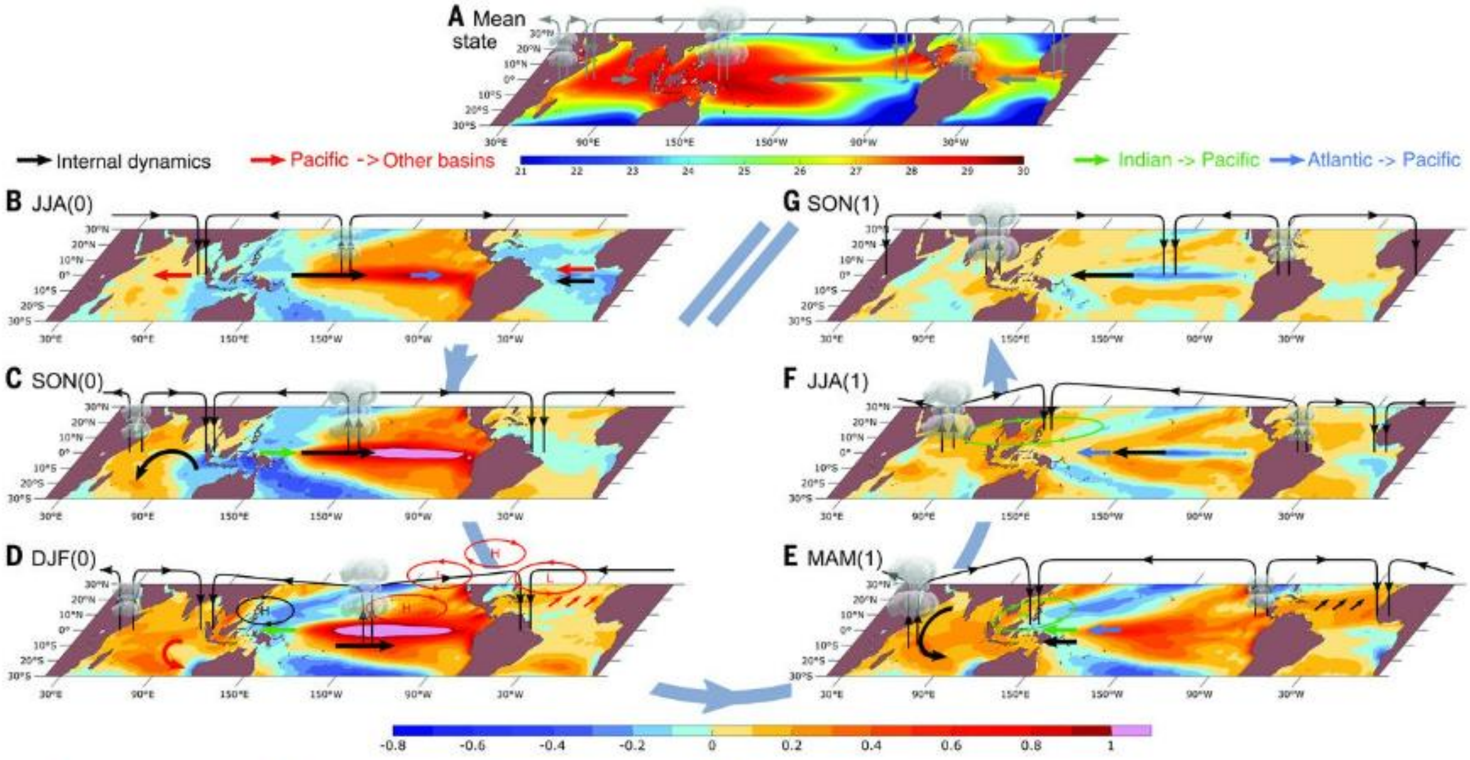
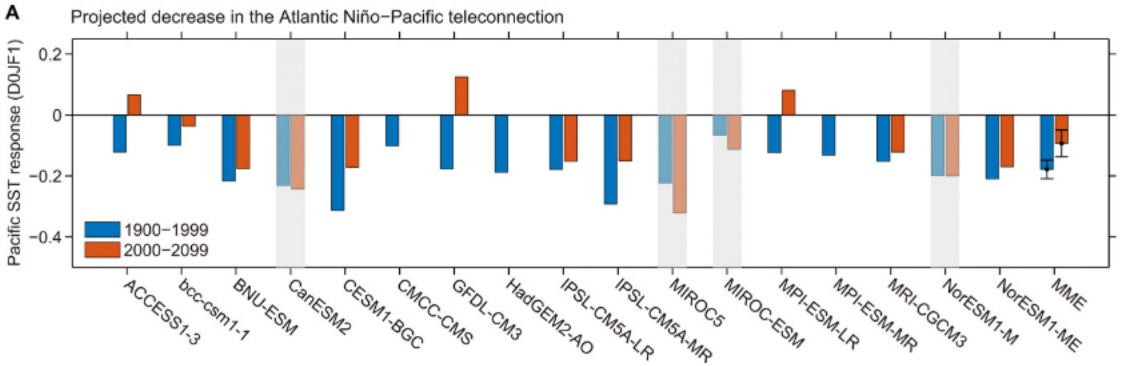


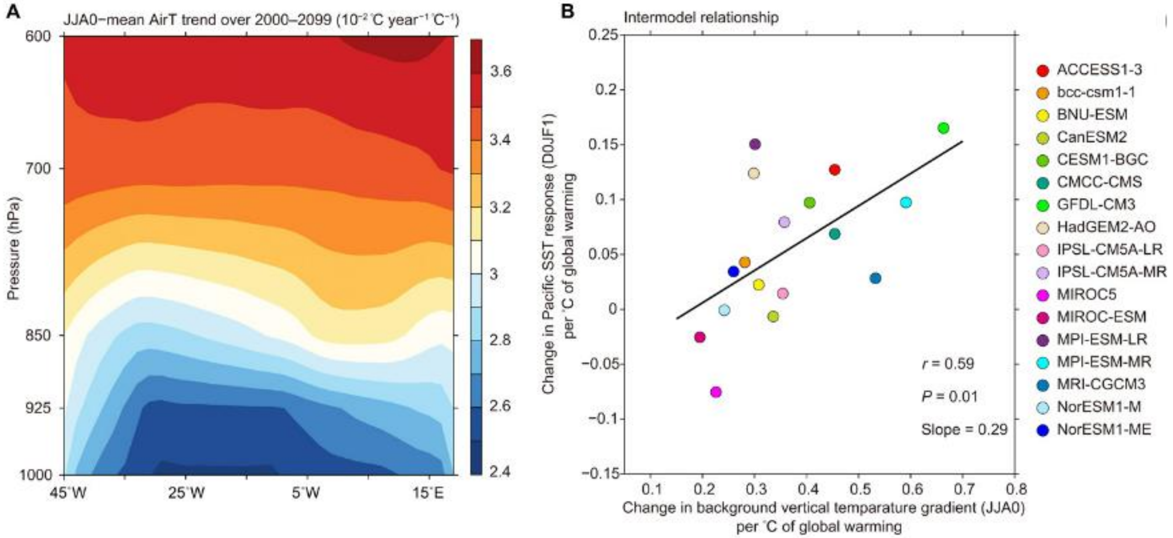
Fig. 1 Evolution of tropical interbasin interactions during a typical El Niño event.

Given these external influences, it is necessary to consider future projections of other modes of variability.

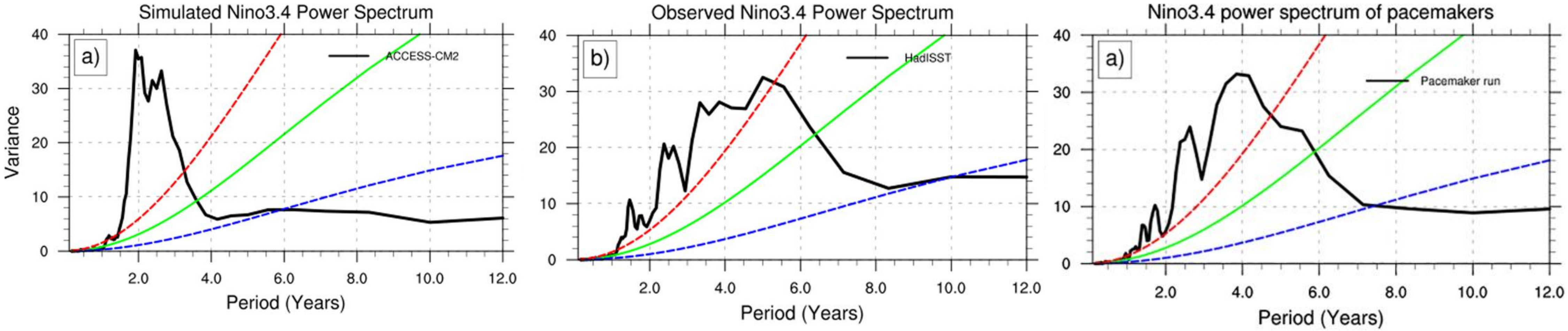
Weakening Atlantic Niño–Pacific connection under greenhouse warming

Jia et al. (2019, Science Advances)





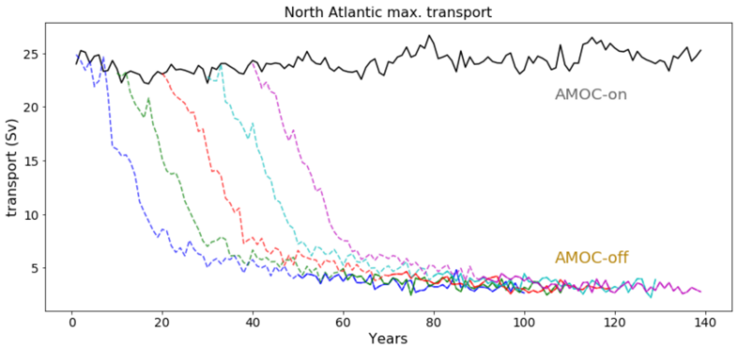
Bi et al. (2022, GRL)

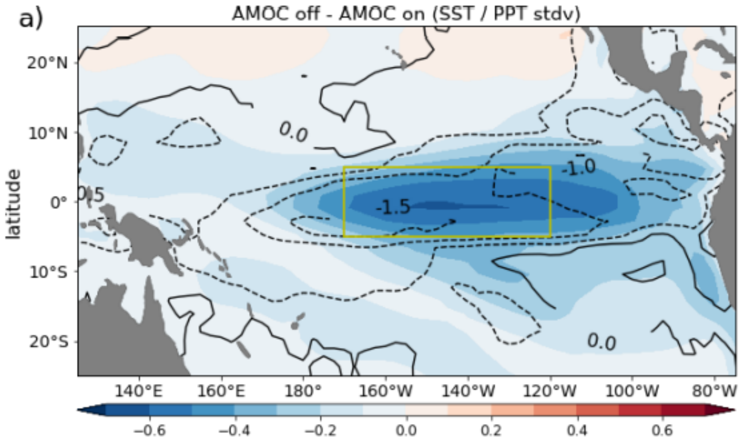


Reduced ENSO variability due to a collapsed Atlantic Meridional Overturning Circulation

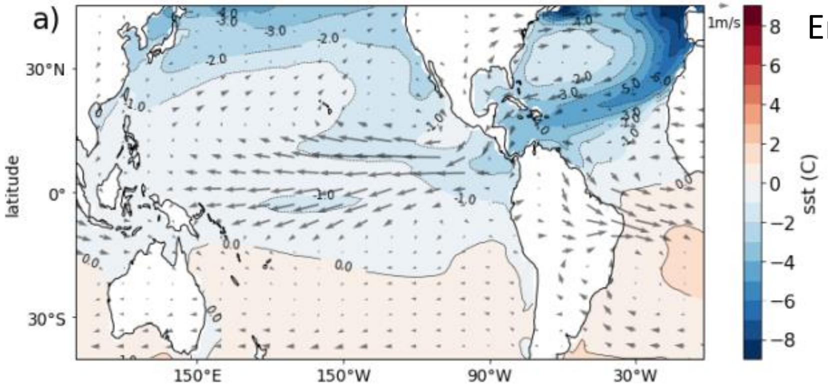
Orihuela-Pinto, Santoso, England, Taschetto (2022, J. Climate, 35)

NA freshwater hosing (CESM 1.2)

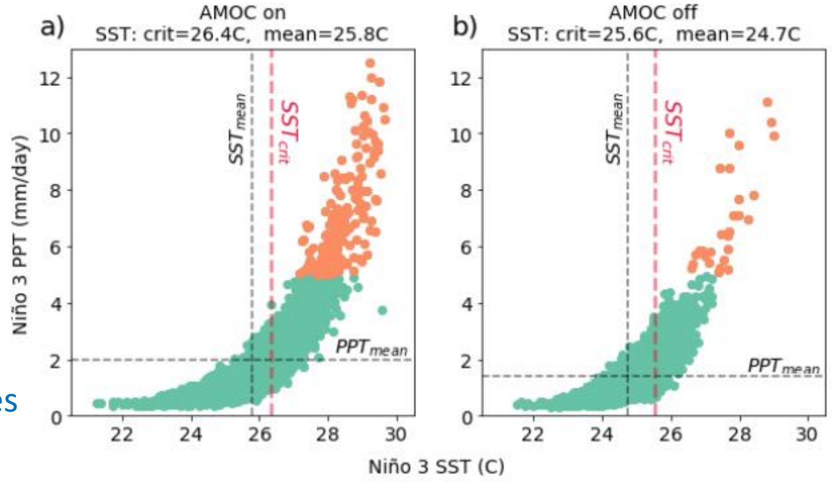




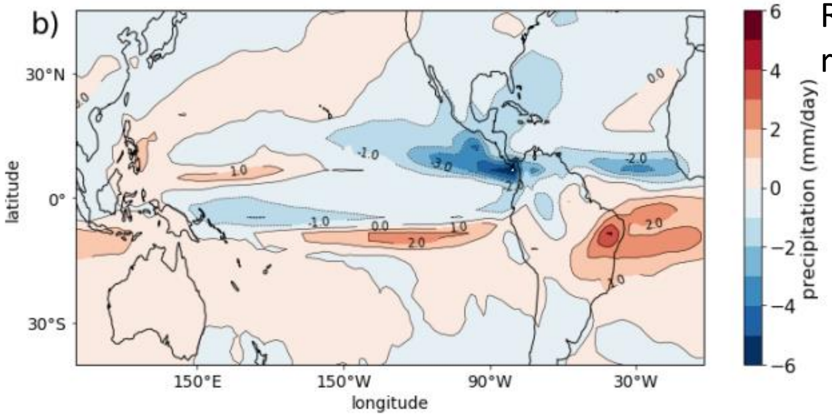
Reduced ENSO



Enhanced Walker Circulation

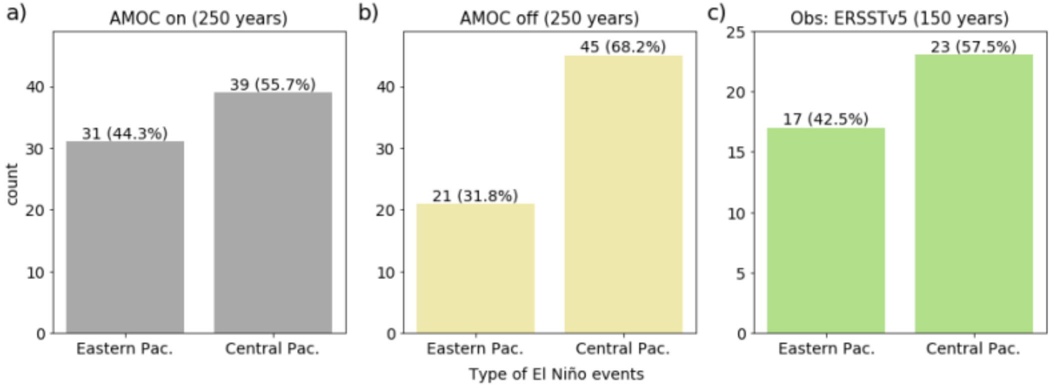


Reduced extreme El Nino occurrences



Reduced equatorial Pacific rainfall

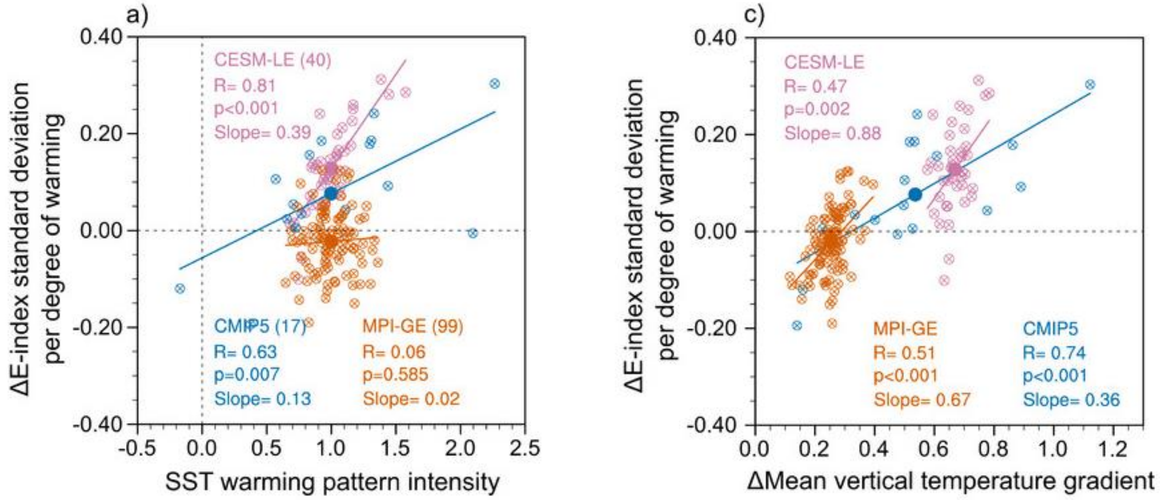
More CP El Ninos, less EP El Ninos



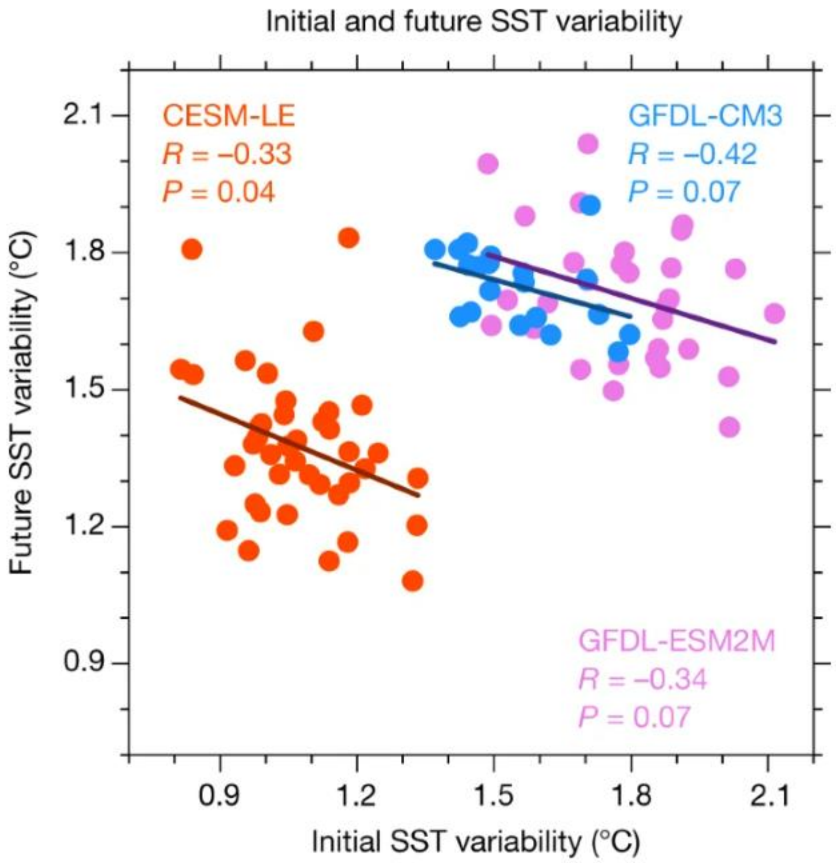
Internal variability

ENSO projections are also influenced by internal variability.

ENSO variability differs markedly across ensemble members of a single model, despite the same emission scenario (*Maher et al. 2018 GRL; Zheng et al. 2018 Clim. Dyn.; Ng et al. 2021 JClim*).



Ng et al. (2021)

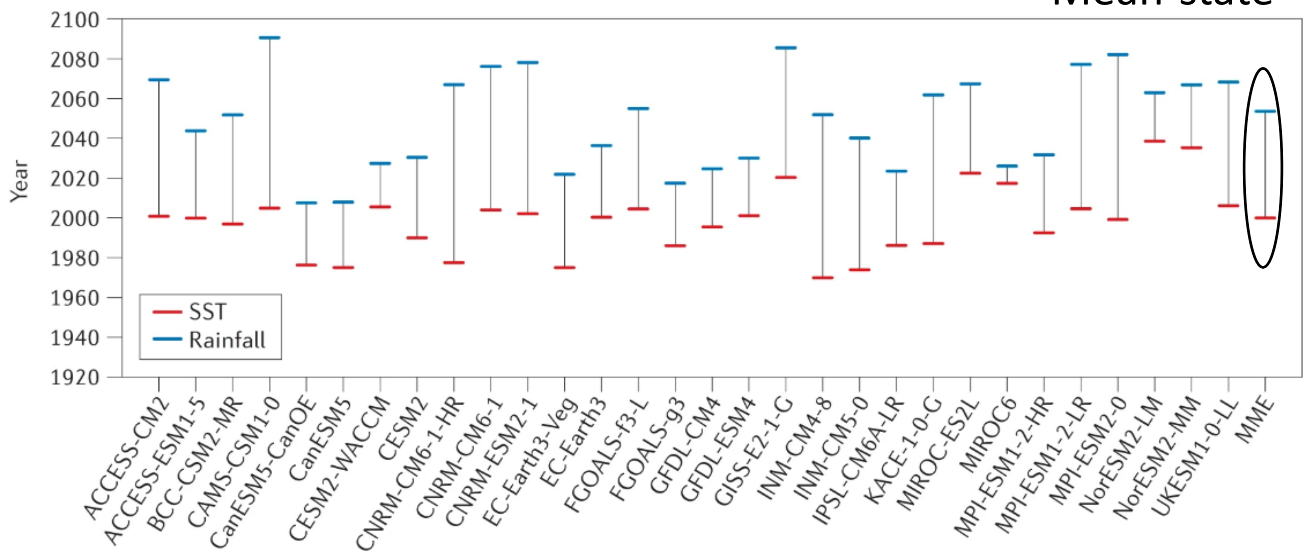


Cai et al. (2020, Nature)

Time of Emergence (ToE)

a Time of emergence for annual-mean value over the Niño3.4 region

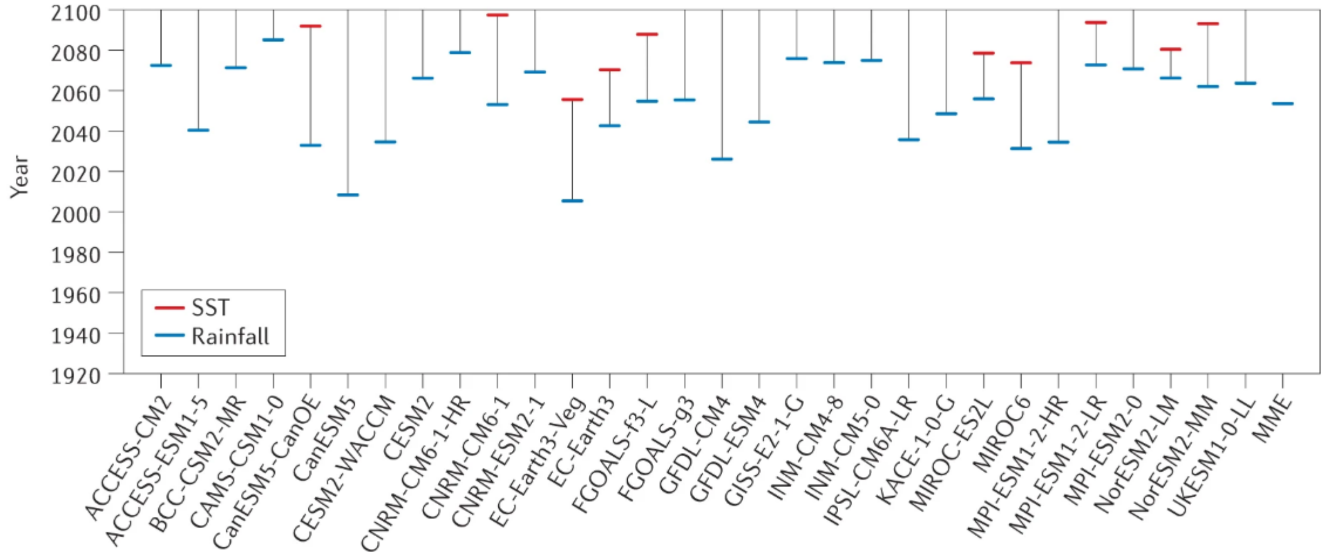
Mean-state



Under aggressive emission scenario (SSP5-8.5), the mean-state change in SST should be detectable around the turn of the 21st century. The rainfall ToE is around mid 21st century.

b Time of emergence for interannual variability over the Niño3.4 region

Interannual

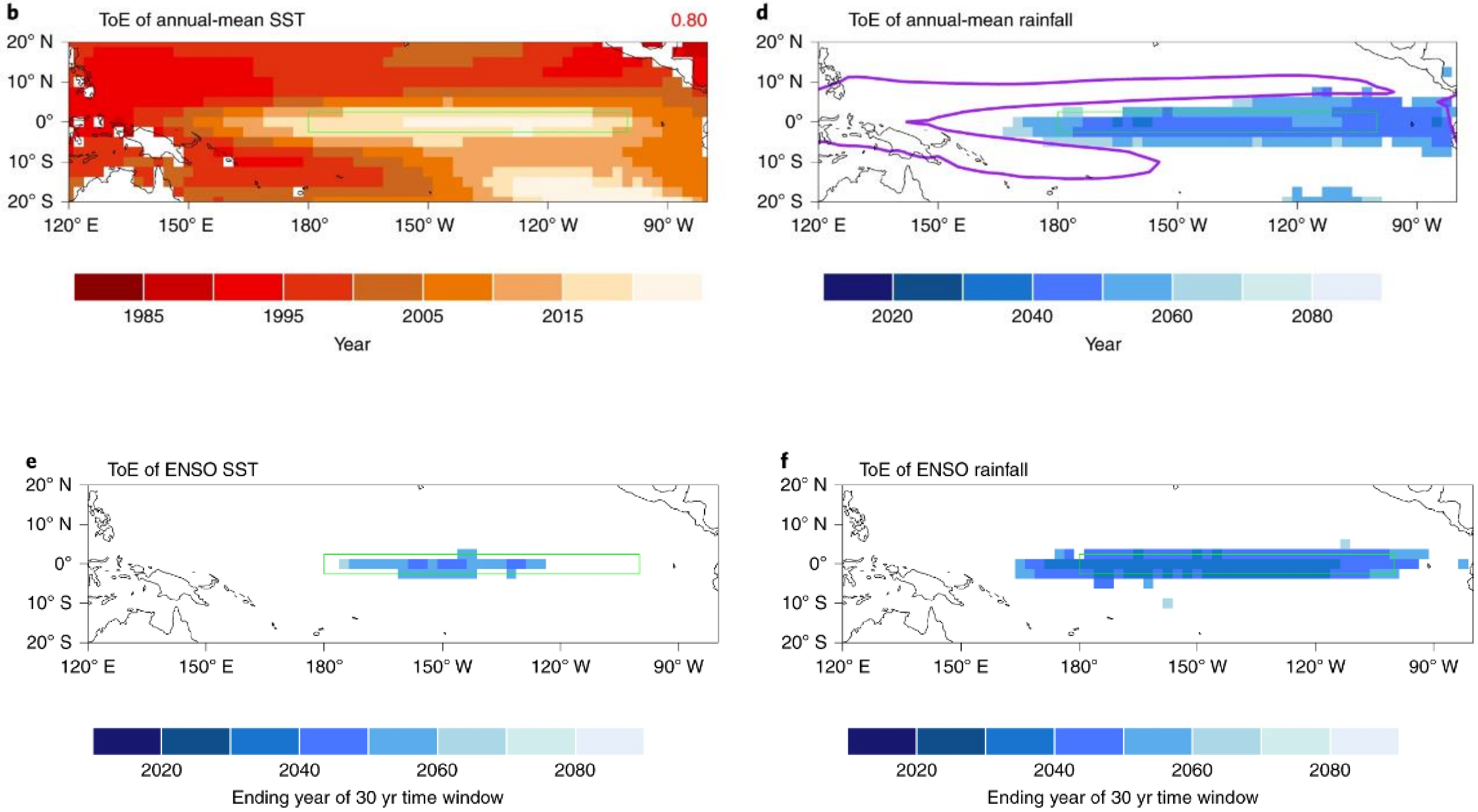


For interannual variability, it is the opposite: The rainfall ToE is earlier than SST.

Cai et al. (2021, Nature Rev. Earth & Environment)

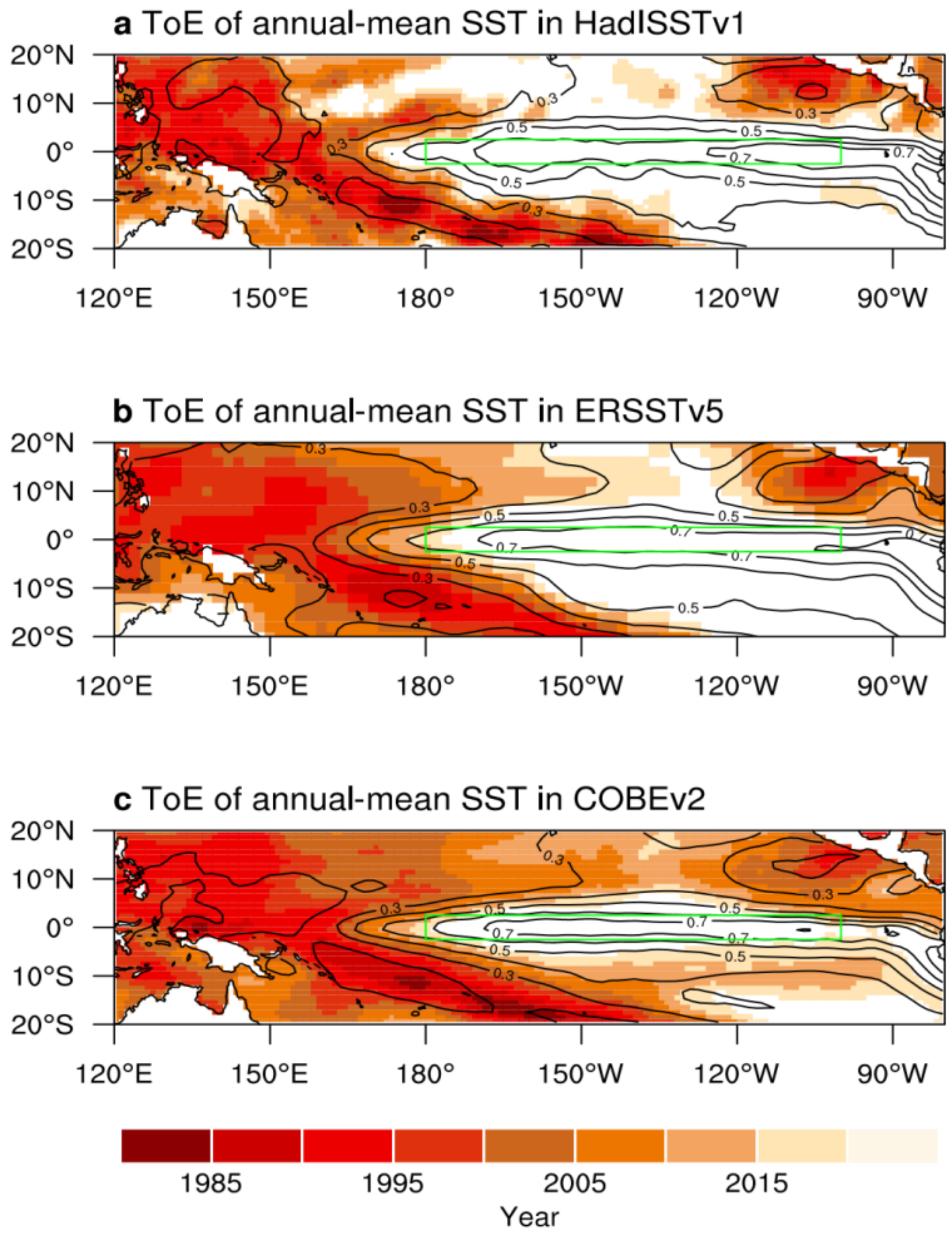
SSP585

Mean-state

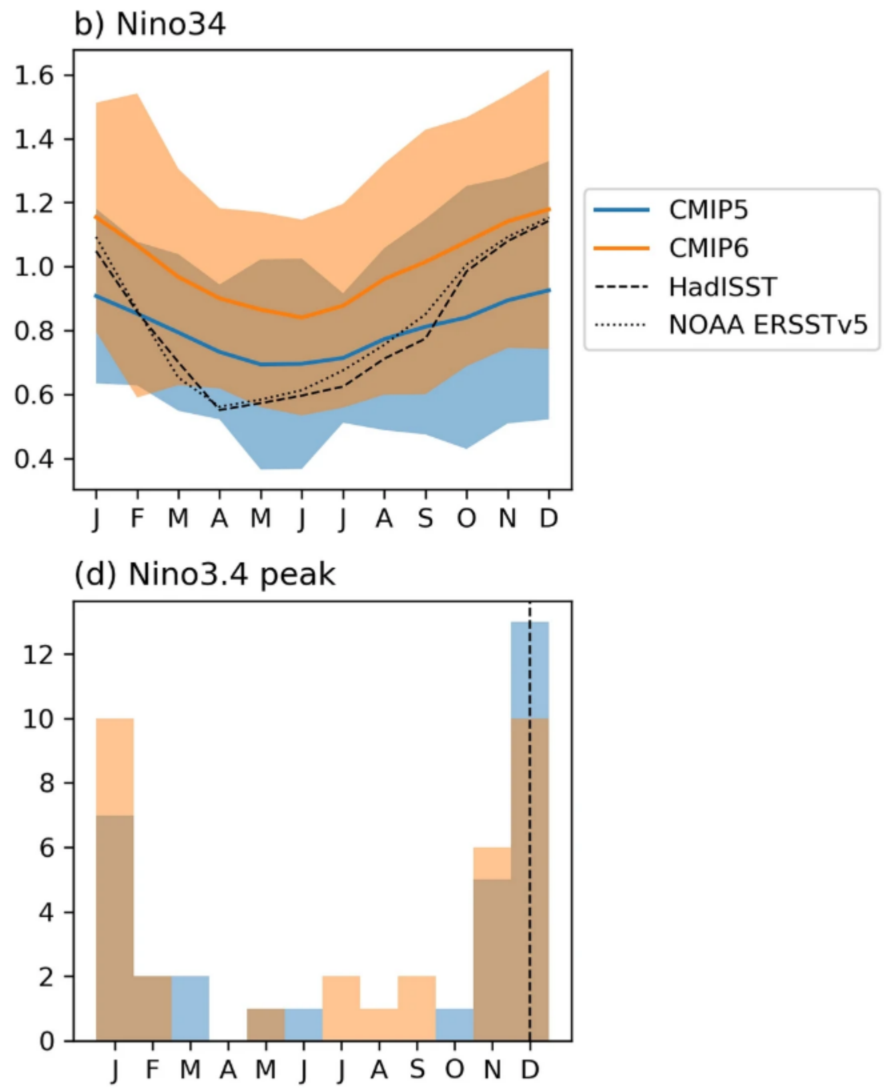


Interannual

Ying et al. (2022, NCC)



Ying et al. (2022, NCC)



McKenna et al. (2020, Sci. Reports)

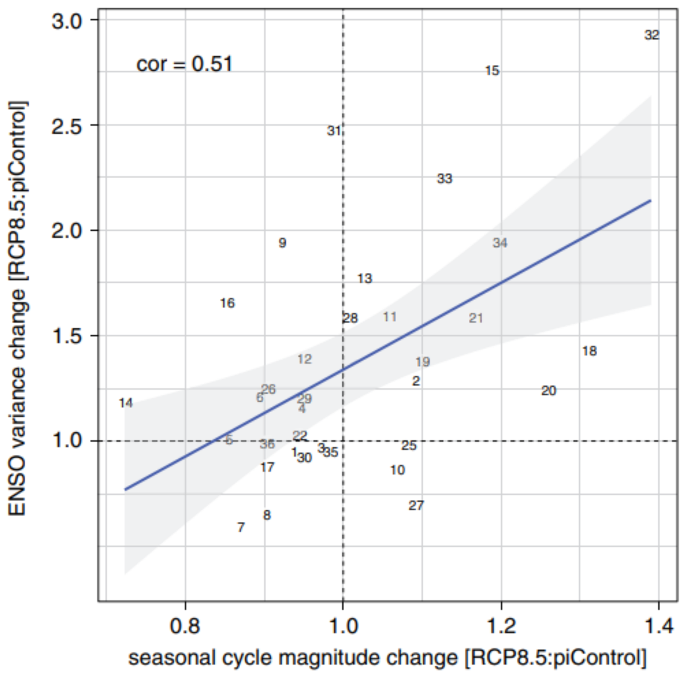
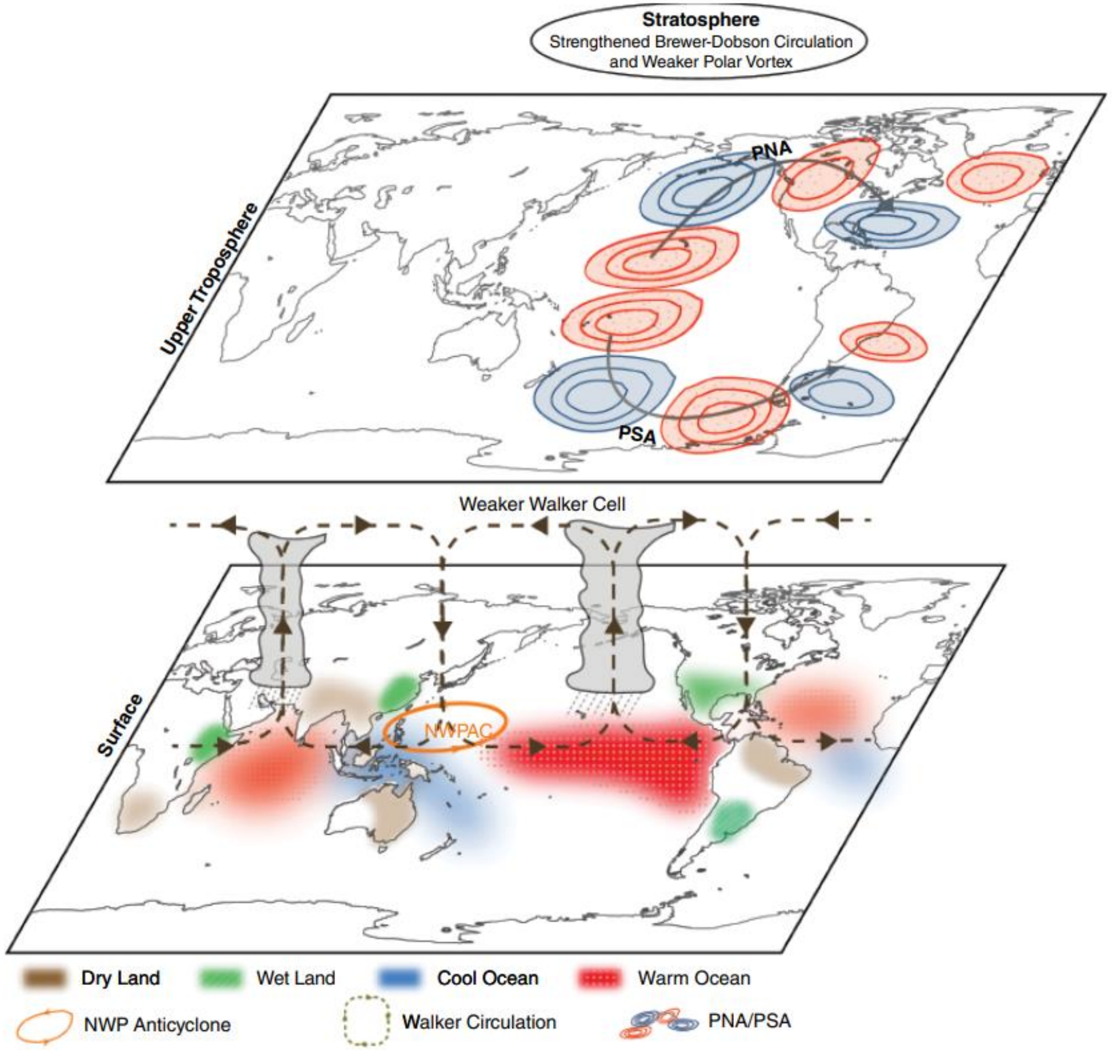


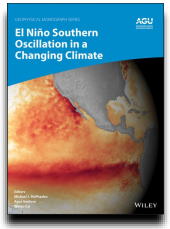
Figure 21.3 Seasonal cycle and ENSO variance changes in future CMIP5 simulations. Here the seasonal cycle is defined as the range of climatological SST in the Niño-3 region, while ENSO variance is defined as the variance of the SST anomalies in the Niño-3.4 region. The change is defined as the ratio of the high emissions scenario (RCP8.5) value over the preindustrial control value (piControl). Numbers indicate CMIP5 models as ordered in Karamperidou et al. (2017). The shaded area indicates the 95% confidence intervals for the linear regression fit. The clear positive relationship, which is consistent with the changes described in Timmermann et al. (2004), is indicative of the fact that coupled processes control both the magnitude of seasonal cycle and ENSO variability.

Karamperidou et al. (2021, Chapter 21 ENSO book)

Teleconnections



Chapter 14 (Taschetto et al.)



Section VI: Teleconnections and Impacts

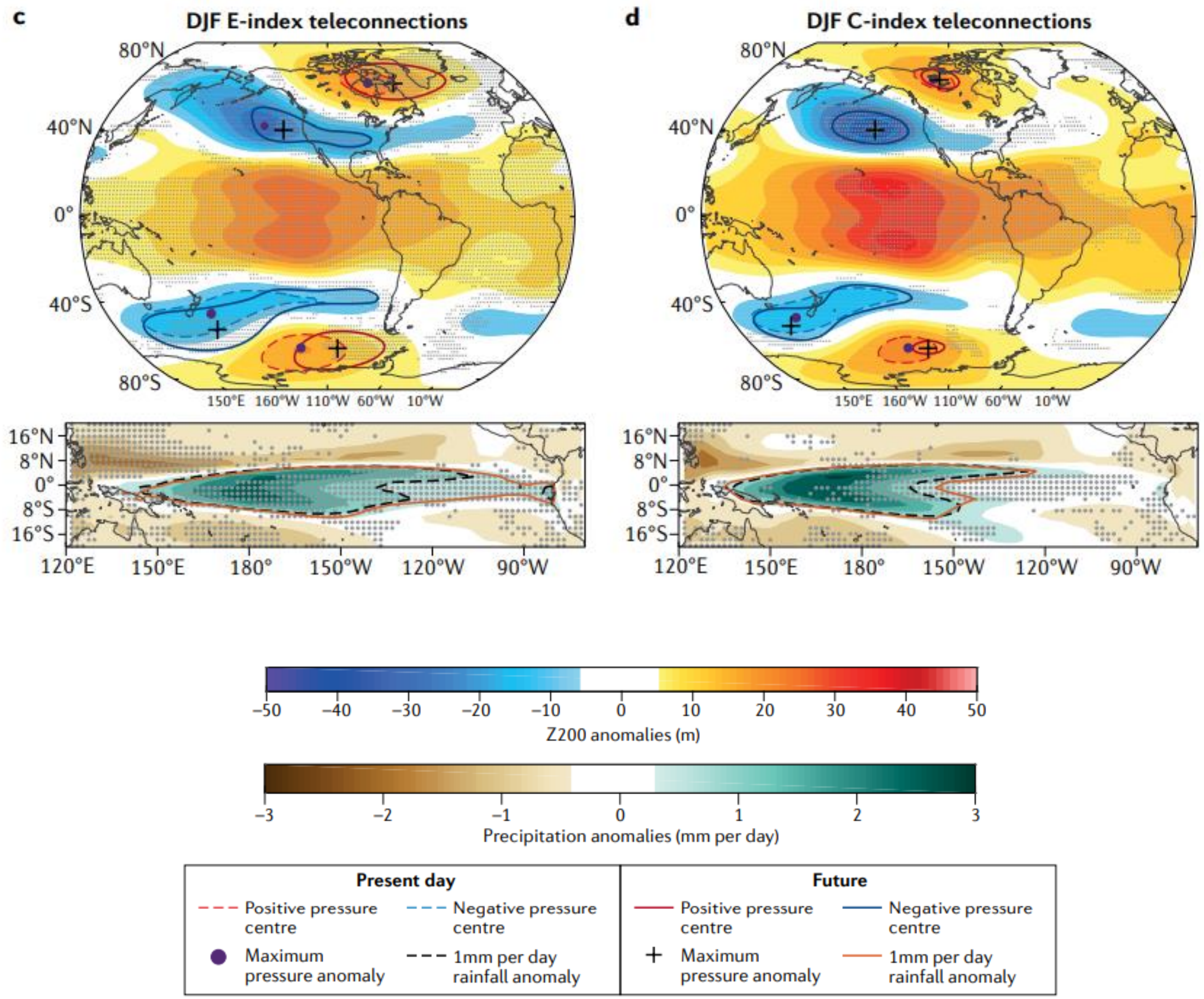
Projected change in ENSO teleconnection

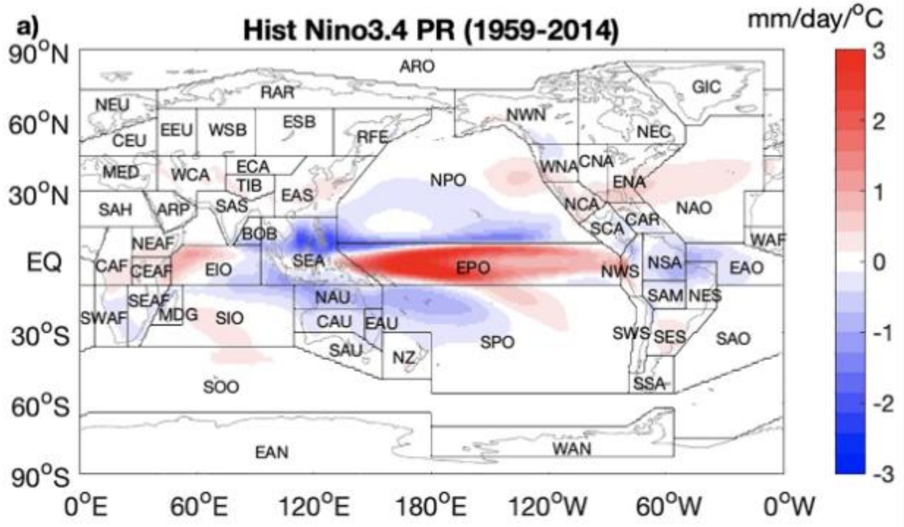
Cai et al. (2021, NREE)

As a result of projected faster warming in the eastern equatorial Pacific, mean convection centres shift eastward and **rainfall responses strengthen during both CP and EP ENSO events**.

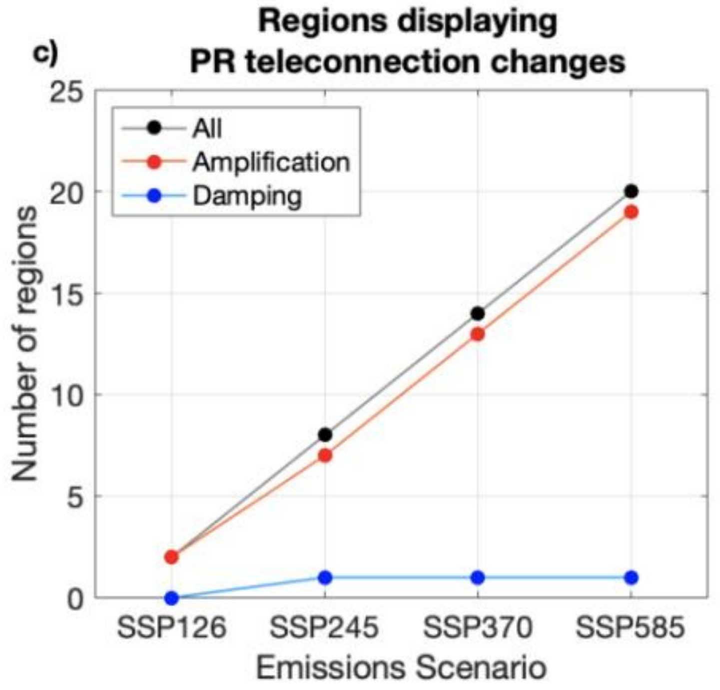
Many regions affected by ENSO in the present climate are likely to experience more intense ENSO-driven rainfall variability in the future (Power & Delage 2018, J. Climate).

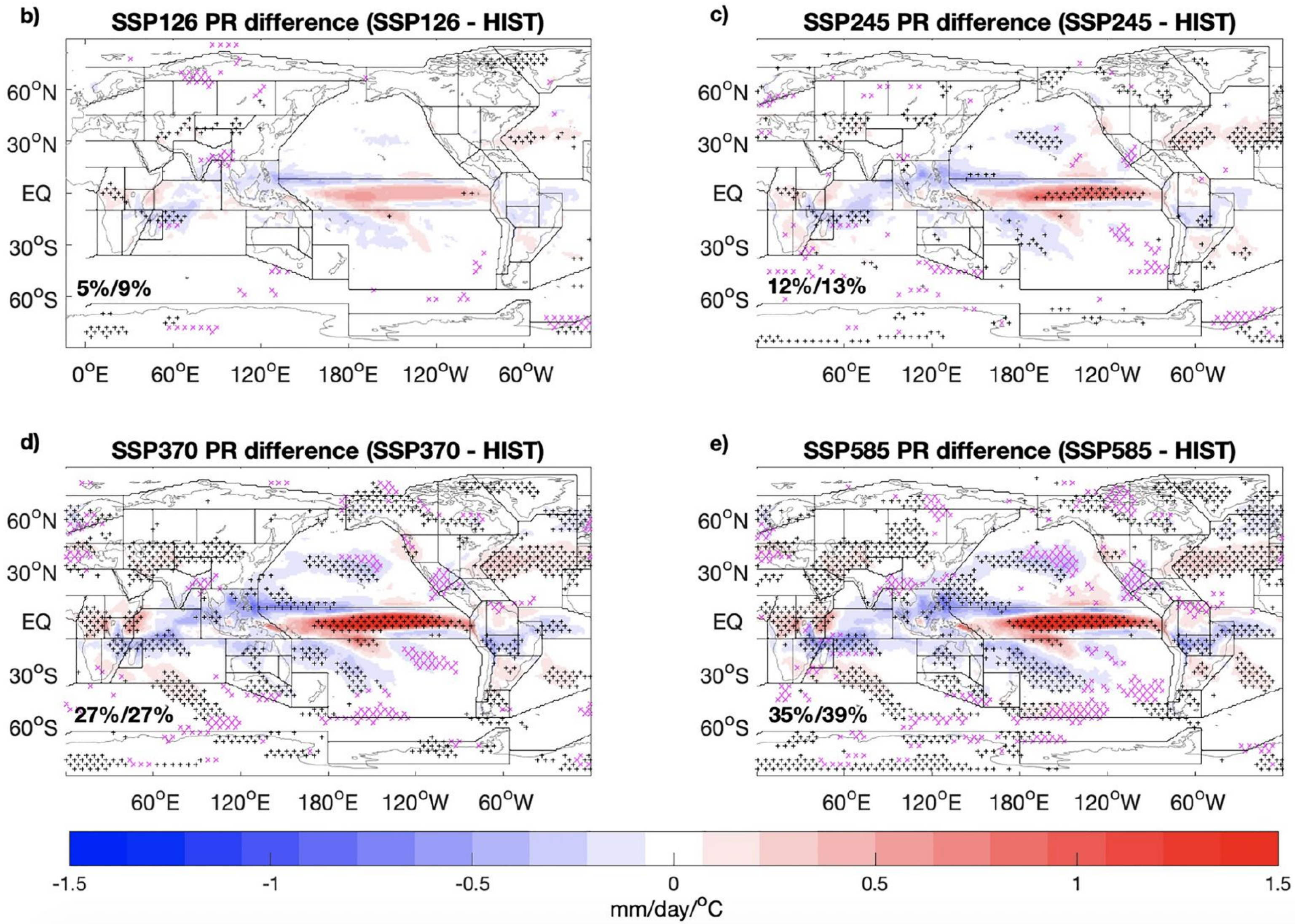
Due to increased mean-state moisture and increased ENSO variability under greenhouse warming, the asymmetric atmospheric response between El Niño and La Niña are expected to increase (Huang & Chen 2017, J. Climate).





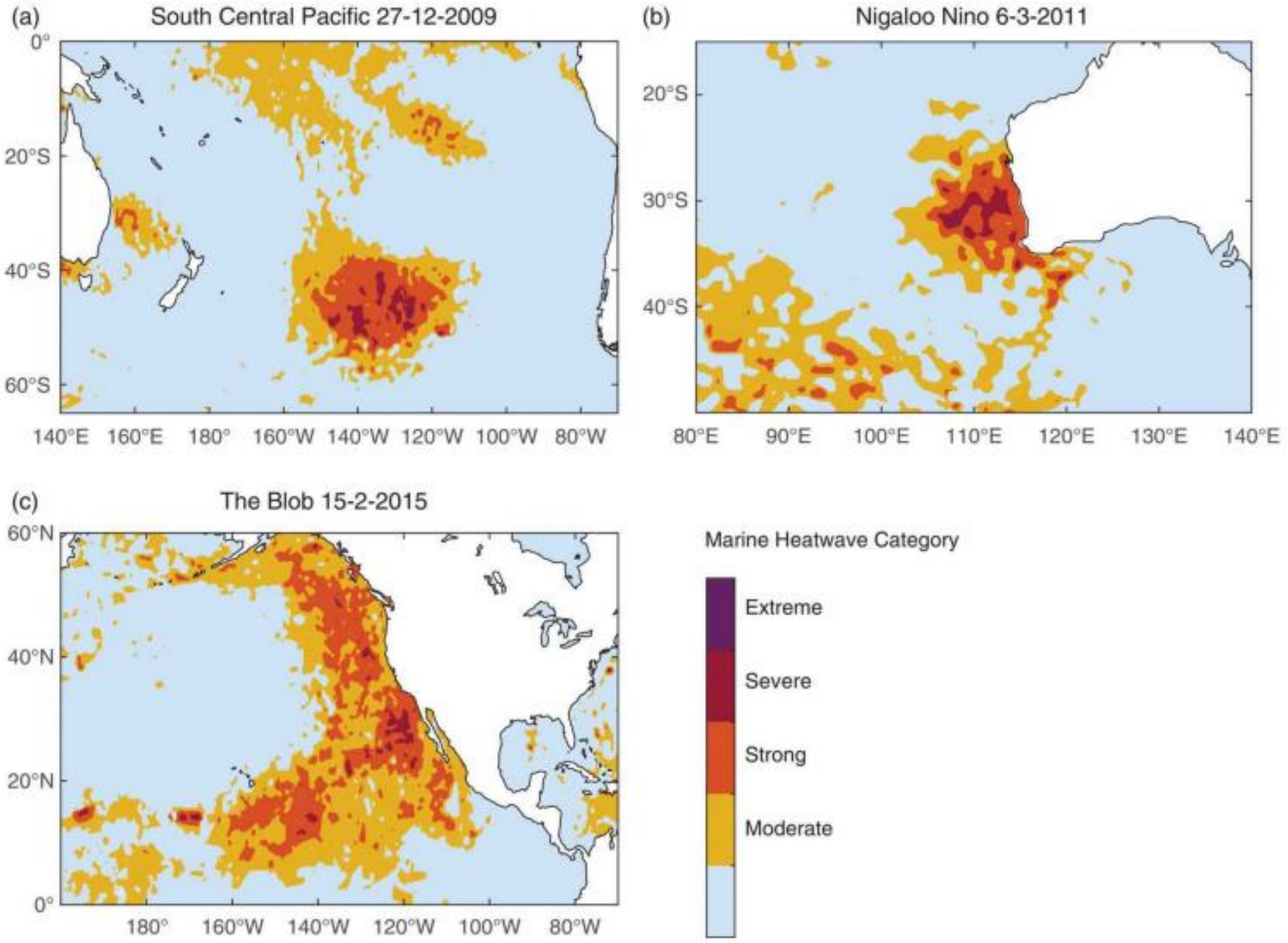
Projected ENSO precipitation pattern changes (DJF)



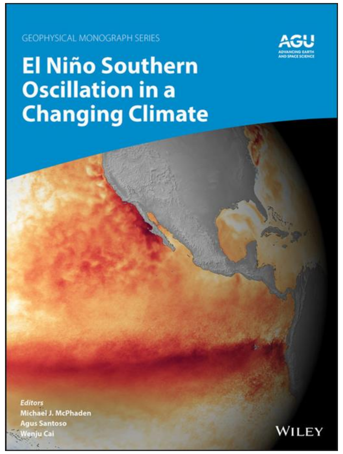


McGregor, S., Cassou, C., Kosaka, Y., & Phillips, A. S (2022) Projected ENSO teleconnection changes in CMIP6. Geophysical Research Letters,
49, e2021GL097511. https://doi.org/10.1029/2021GL097511

ENSO-associated marine heatwaves



Chapter 18
(Holbrook et al.)



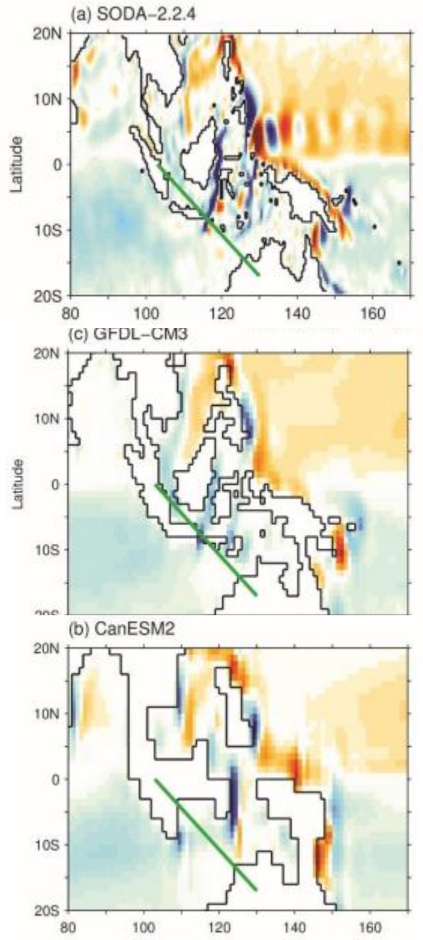
Also Chapter 15 (Sprintall et al.)
on oceanic teleconnection

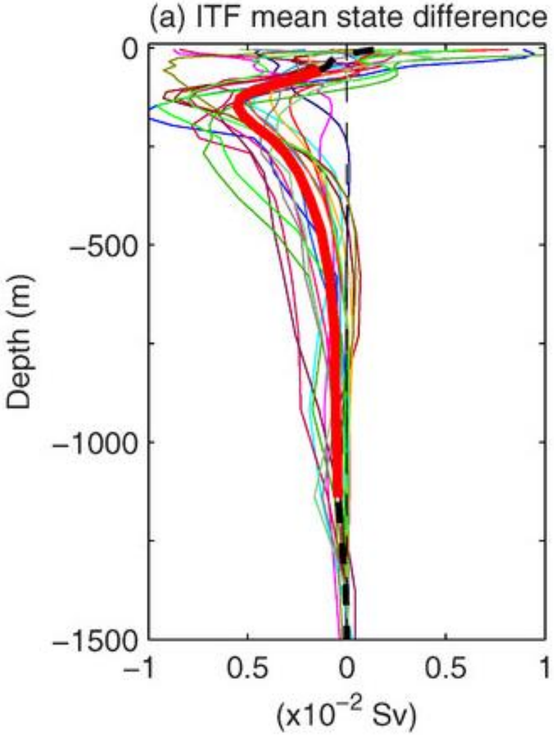
Journal of Climate

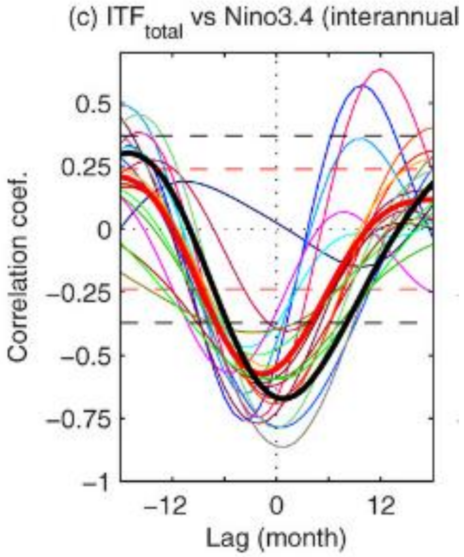
Indonesian Throughflow Variability and Linkage to ENSO and IOD in an Ensemble of CMIP5 Models

Agus Santoso[1,2,3], Matthew H. England[1,2], Jules B. Kajtar[4,5], and Wenju Cai[3,6,7]

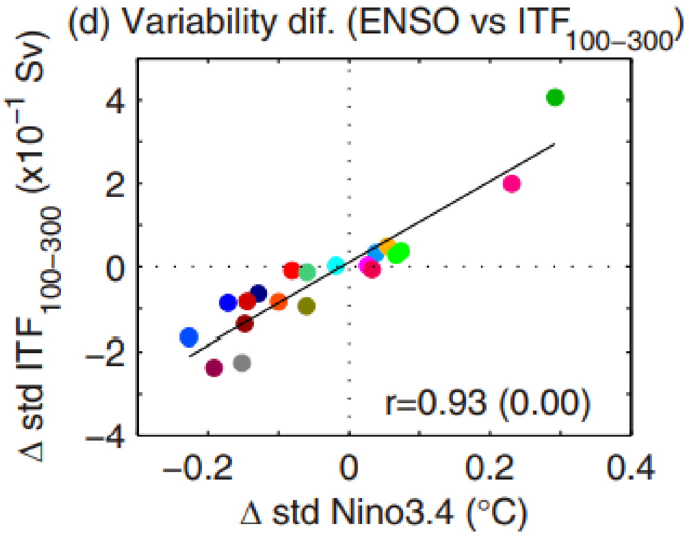
Published-online: 29 Apr 2022







El Nino corresponds with weaker ITF. La Nina with stronger ITF.



Significant inter-model correlations between projected changes in ITF variability vs ENSO future change.

Future Southern Ocean warming linked to projected ENSO variability

Guojian Wang[1,2], Wenju Cai[1,2], Agus Santoso[1,3], Lixin Wu[2], John C. Fyfe[4], Sang-Wook Yeh[5], Benjamin Ng[1], Kai Yang[6] and Michael J. McPhaden[7]

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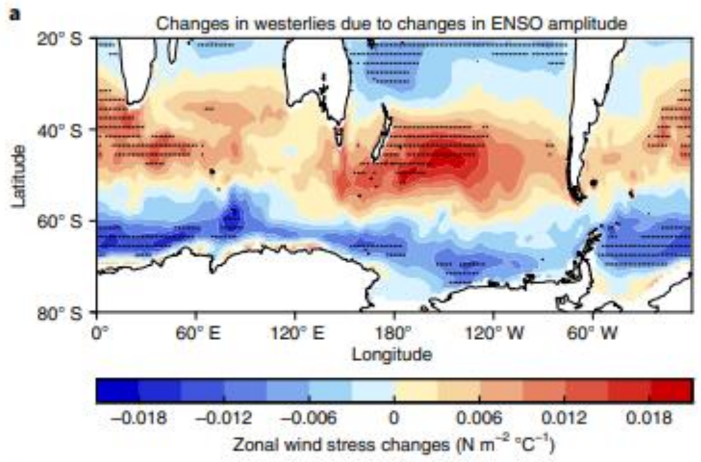

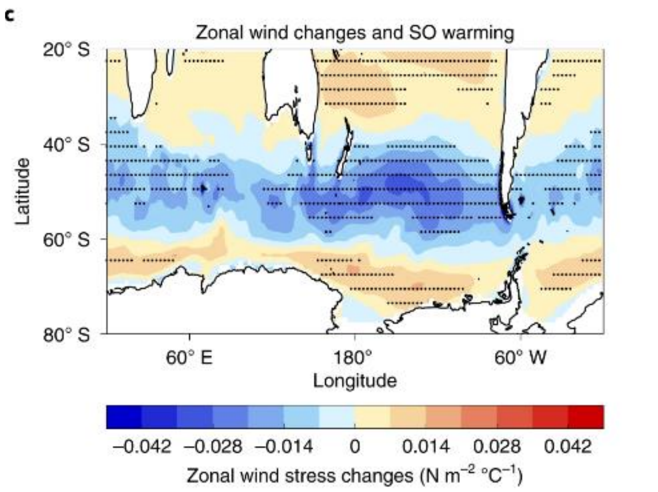

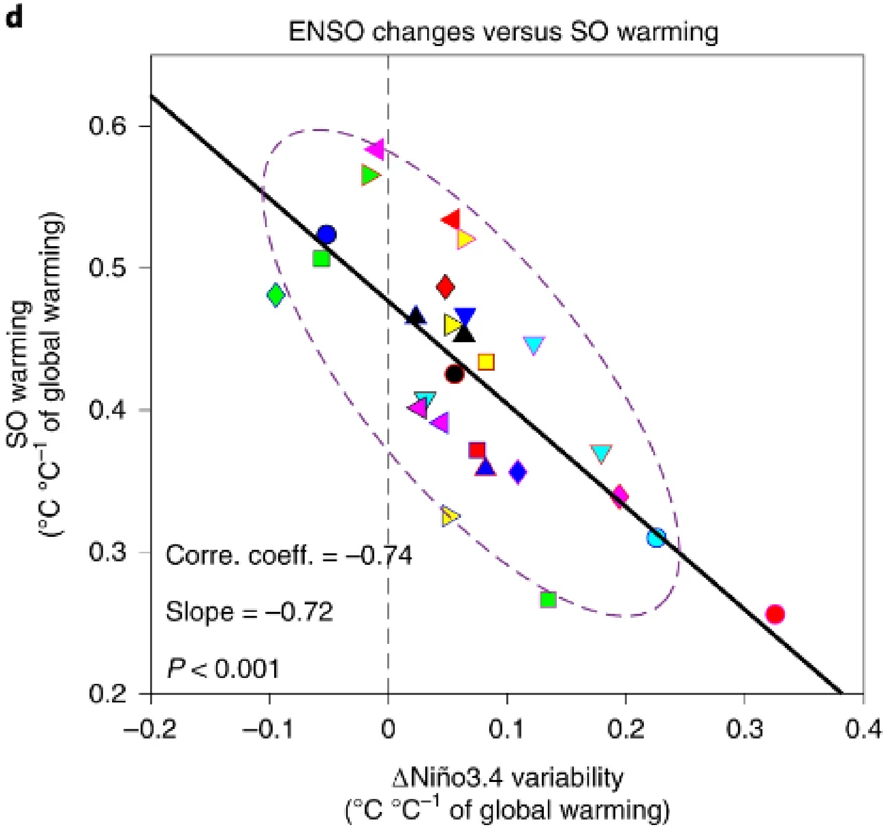

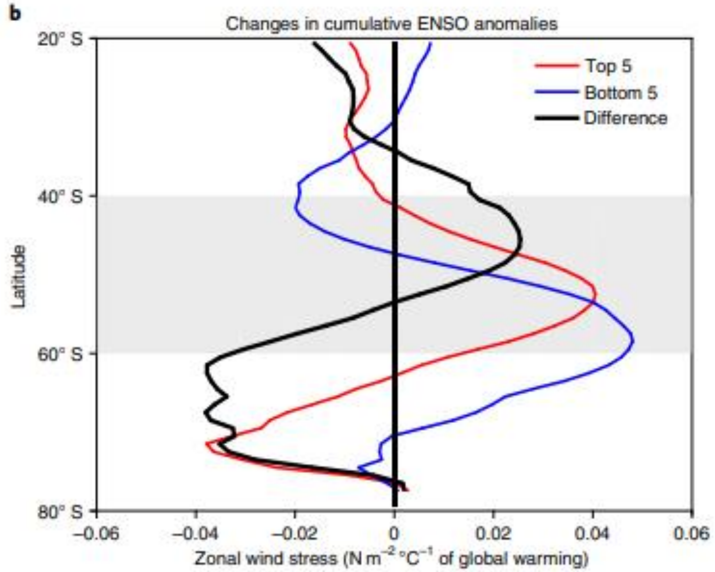

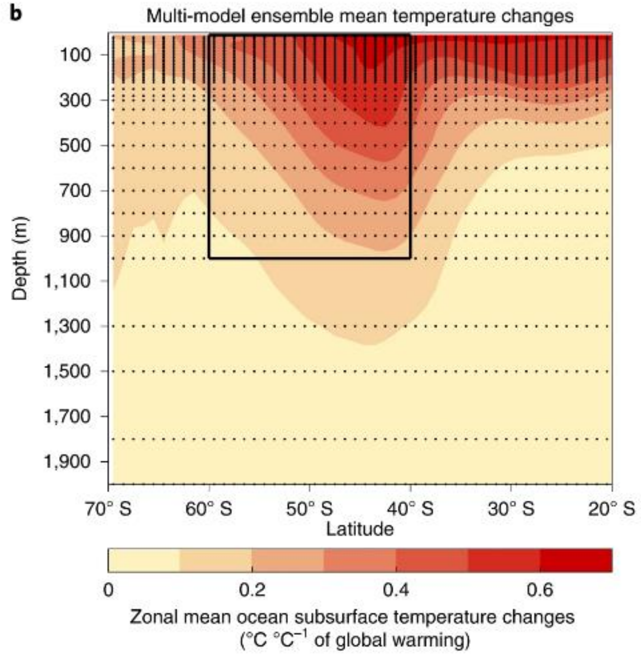

Summary

- Projecting future ENSO is a challenging task as it is linked to progress in climate modeling.
- The current standing is that there is an inter-model consensus among the latest generation of climate models (i.e., CMIP6) in projecting ENSO: increased ENSO variability, manifesting in more frequent extreme El Nino and extreme La Nina events.
- Regardless of how ENSO SSTs will change in the future, ENSO impacts are expected to increase.
- Projection uncertainties are linked to the projection of the mean climate. Model biases/deficiencies (e.g., cold tongue and associated biases, underestimated inter-basin interactions) and relatively short observations remain important source of these uncertainties.
- As ENSO impacts on myriad aspects of the climate system, achieving a reliable global climate projections requires an improved representation of ENSO in climate models.