Dietmar Dommenget

Overview

Introduction

Non-linearity

Teleconnections

How good are the models?

Climate Change

Overview

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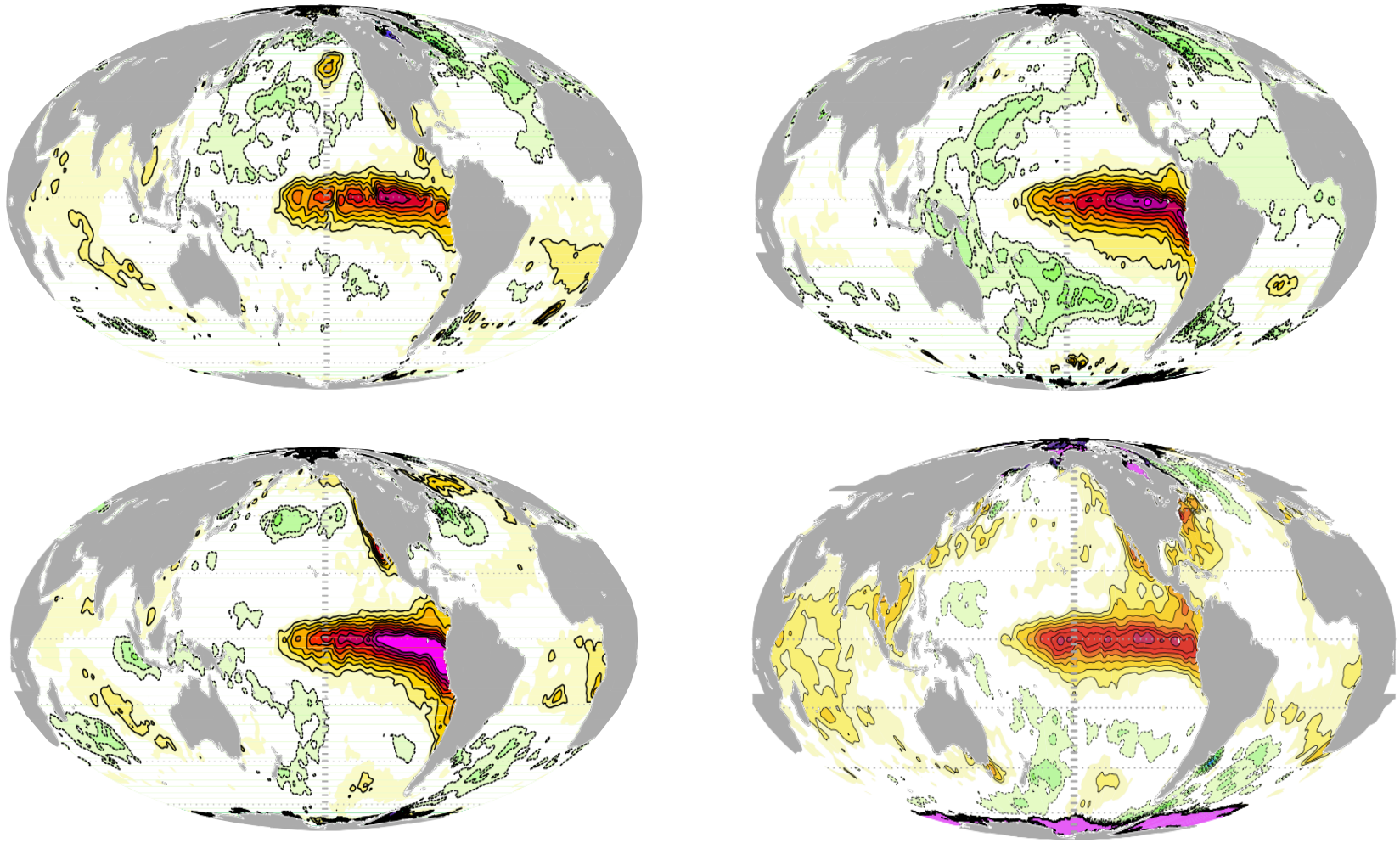
Non-linearity

Teleconnections

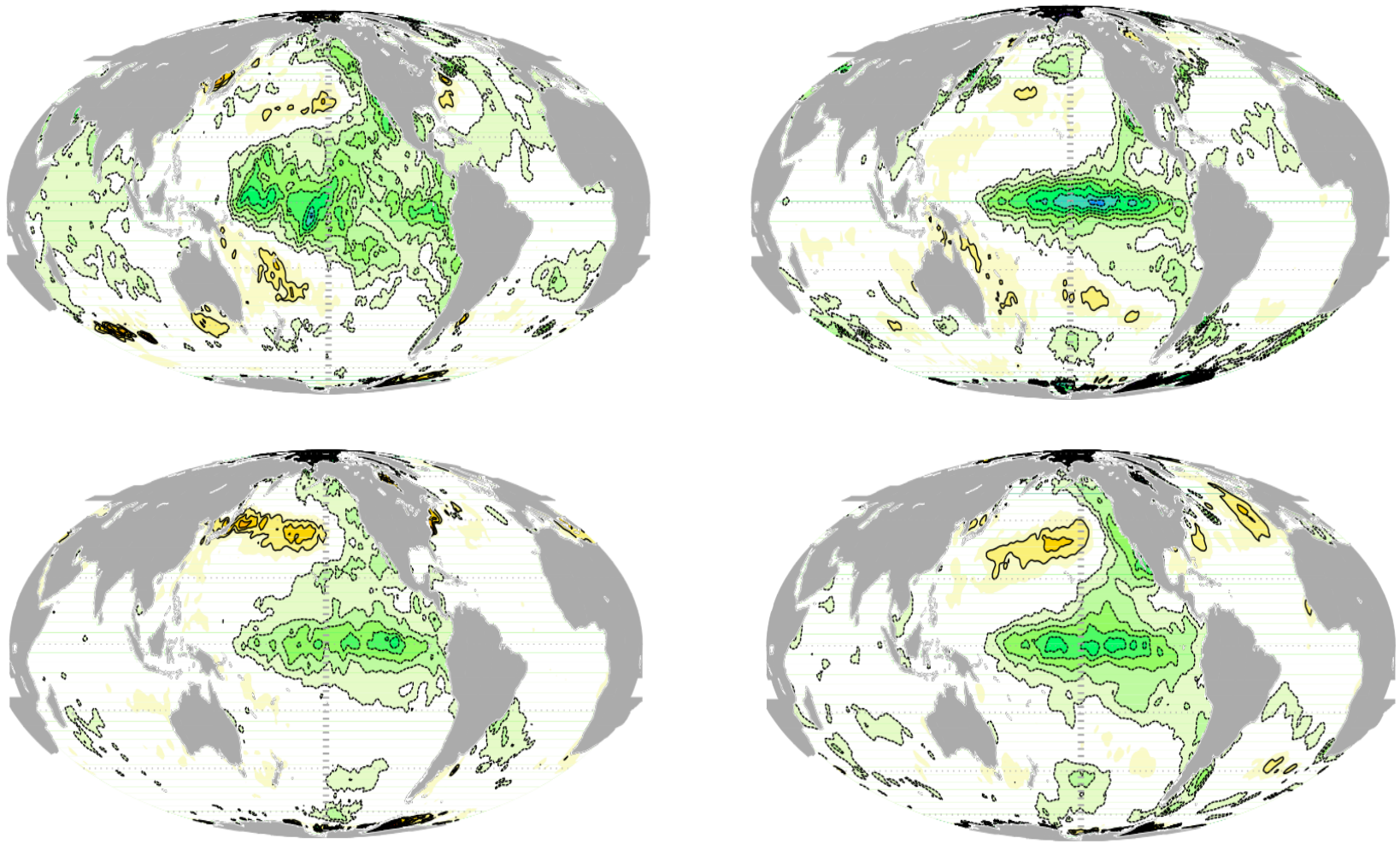
How good are the models?

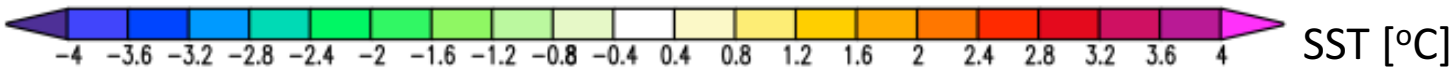
Climate Change

El Niño events

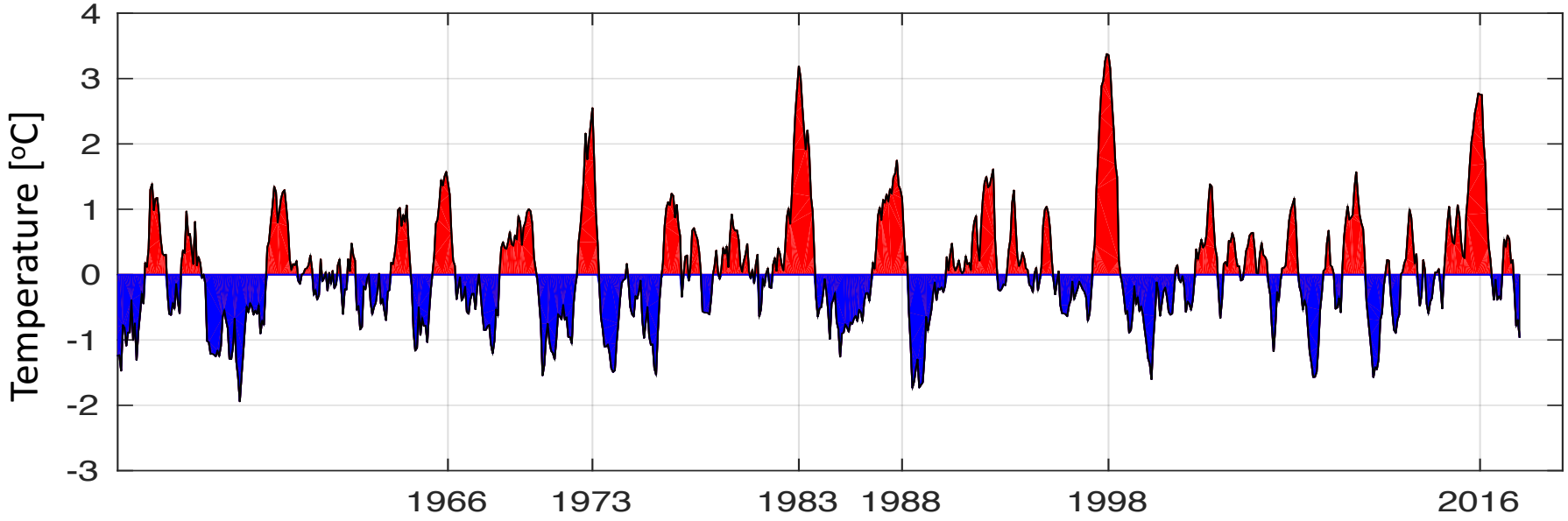


La Niña events

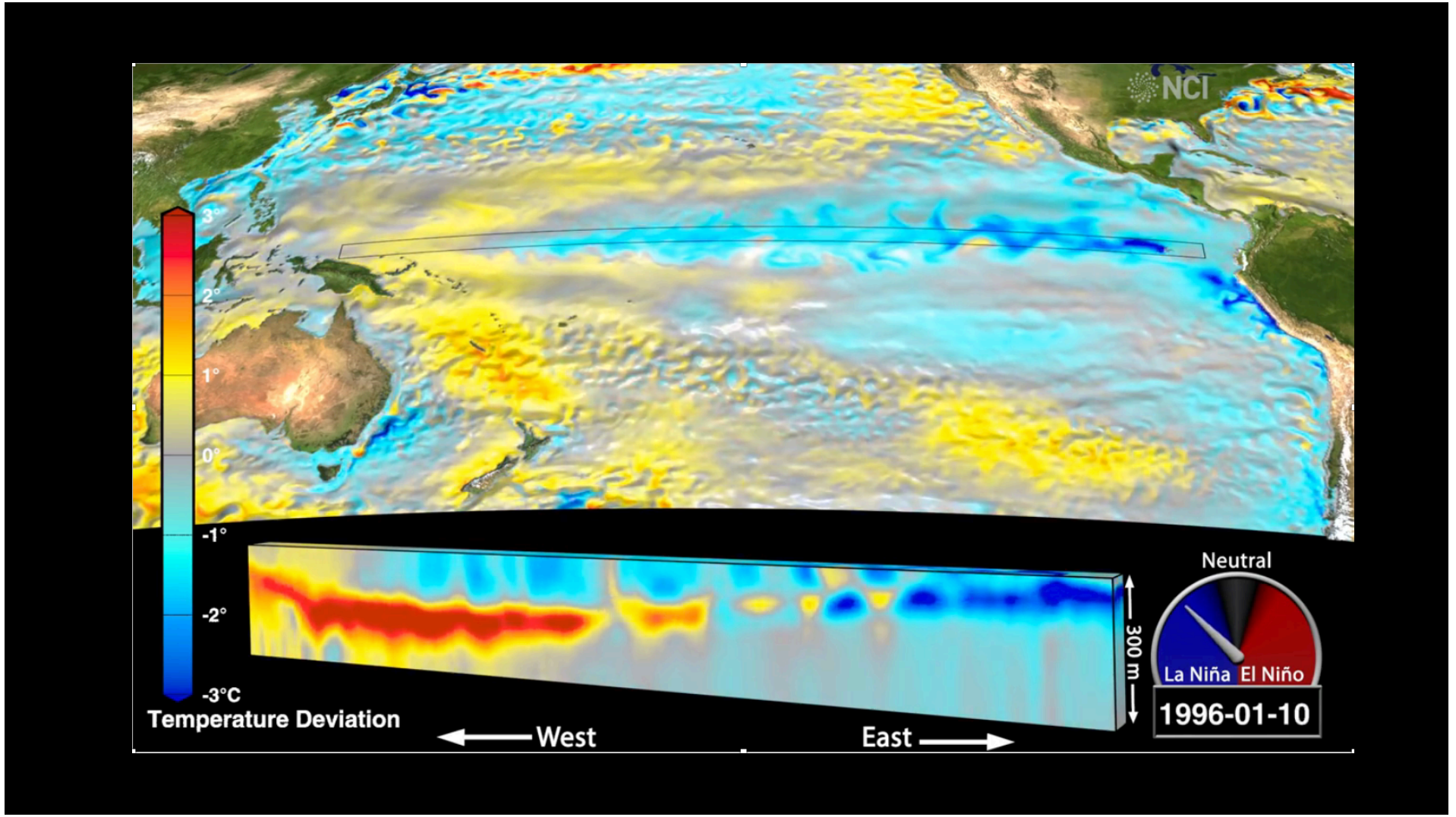




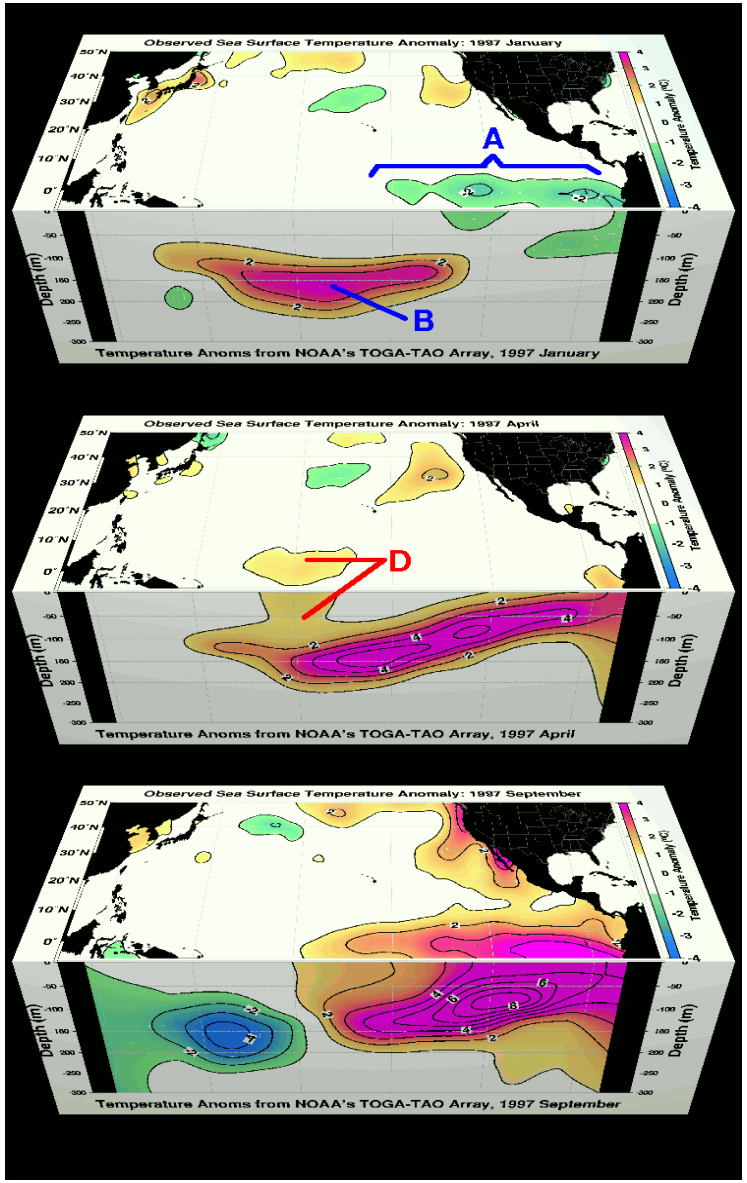
El Niño time series



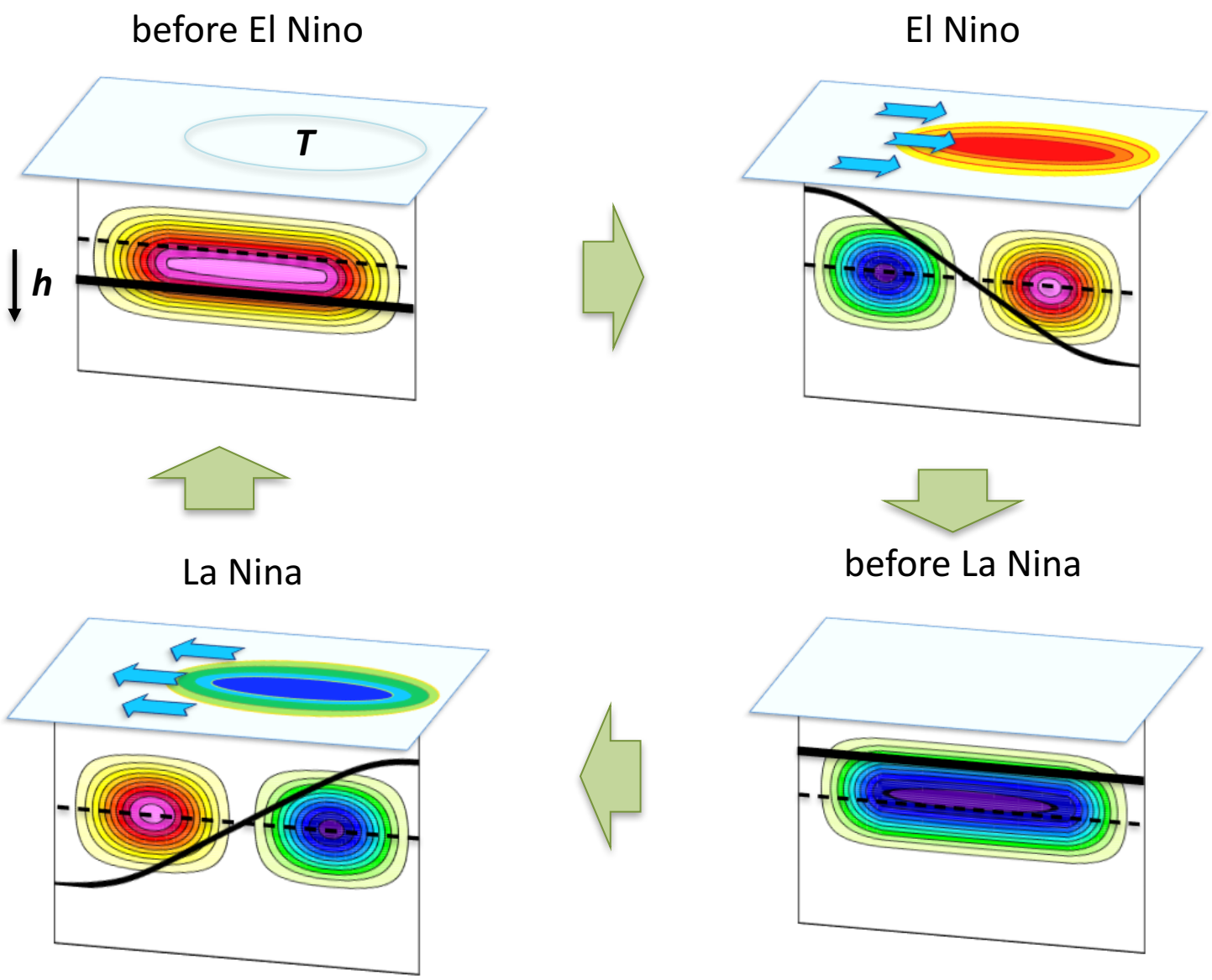
Recharge Oscillator model of ENSO



Recharge Oscillator model of ENSO



Recharge Oscillator model of ENSO

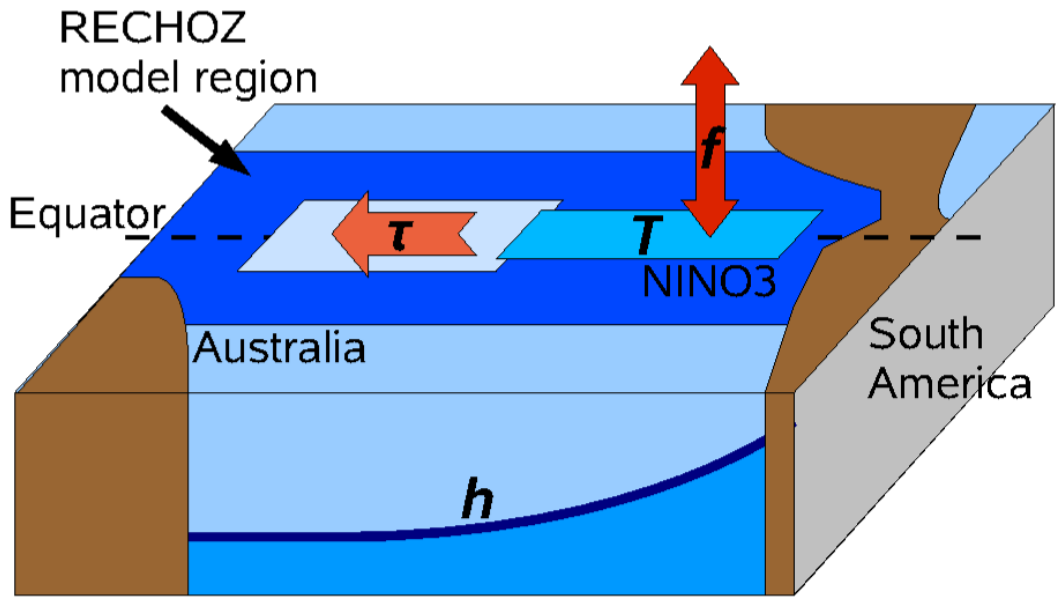


Recharge Oscillator model

$$\frac{dT}{dt} = a_{11}T + a_{12}h + \xi_T$$

$$\frac{dh}{dt} = a_{21}T + a_{22}h + \xi_h$$

- a_{11} = T growth rate (damping)
- a_{12} = coupling T to h
- a_{21} = coupling h to T
- a_{22} = h growth rate (damping)
- ξ_T = noise forcing T
- ξ_h = noise forcing h



Recharge Oscillator model

$$\frac{dT}{dt} = -|a_{11}|T + a_{12}h$$

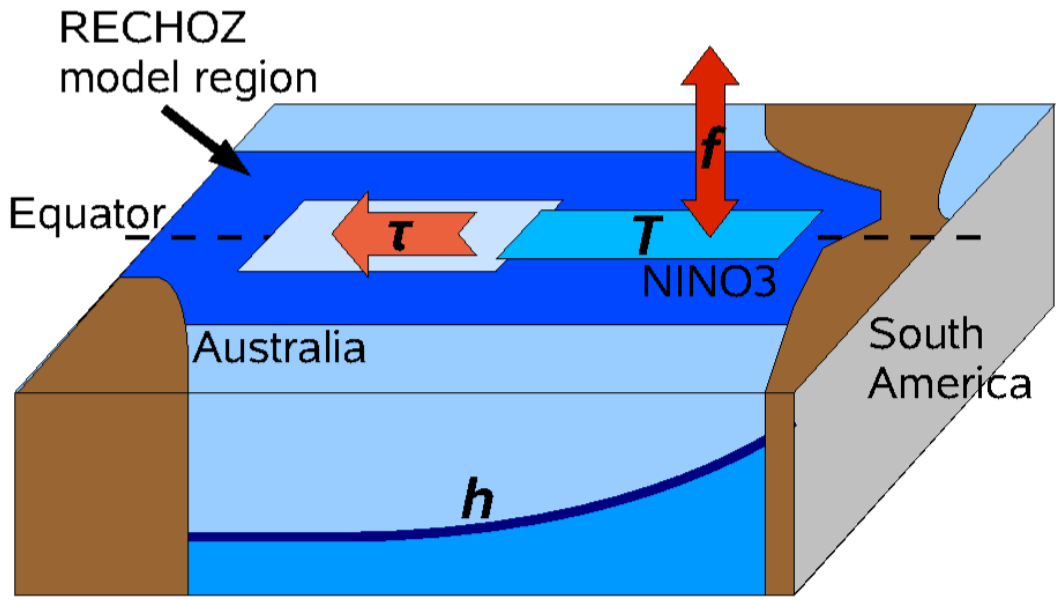
$$\frac{dh}{dt} = -|a_{21}|T - |a_{22}|h$$

$a_{11} = -0.076 \frac{1}{month}$

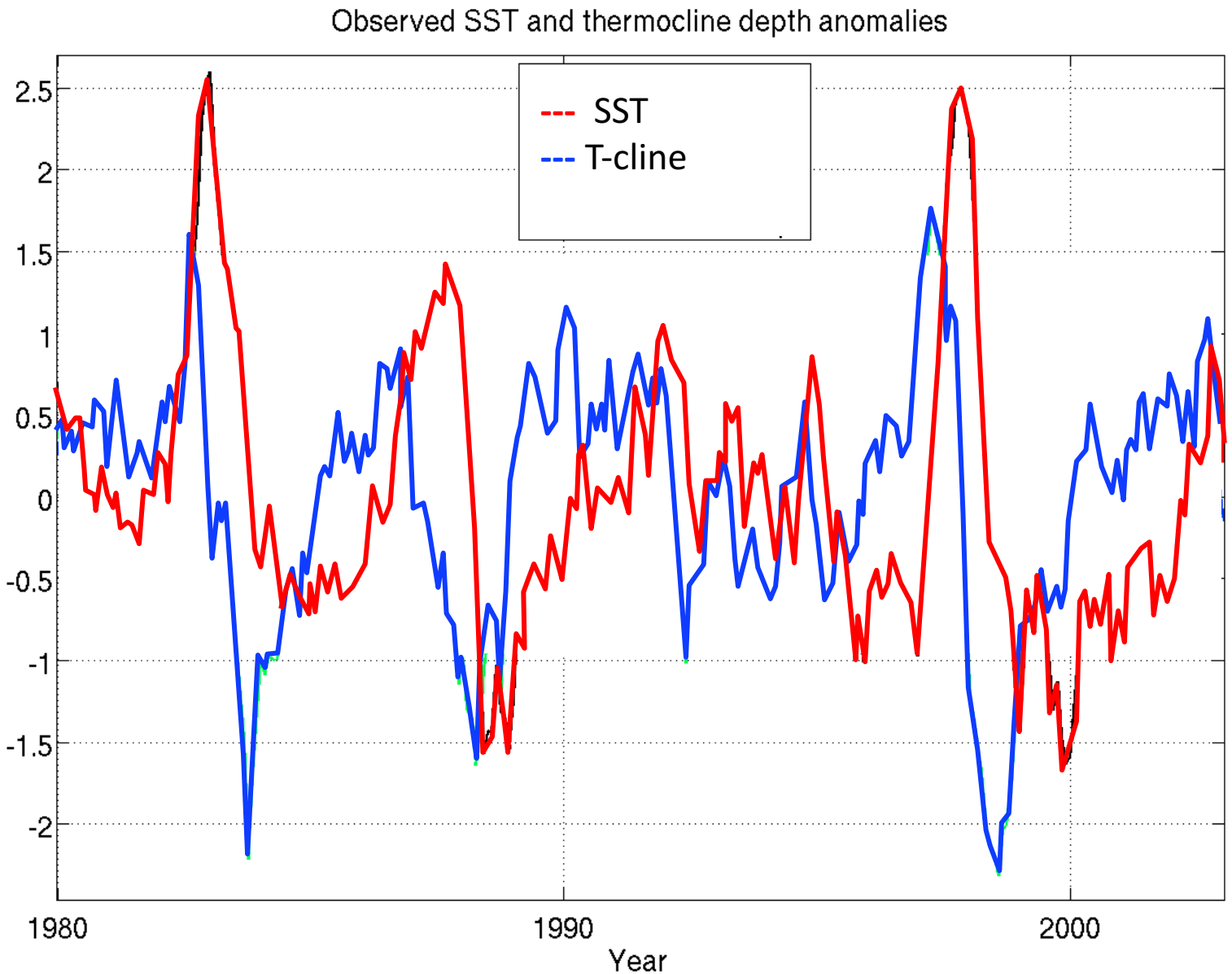
$a_{12} = +0.021 \frac{1}{month}$

$a_{21} = -1.4 \frac{1}{month}$

$a_{22} = -0.008 \frac{1}{month}$



Observed thermocline and SST interaction



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Teleconnections

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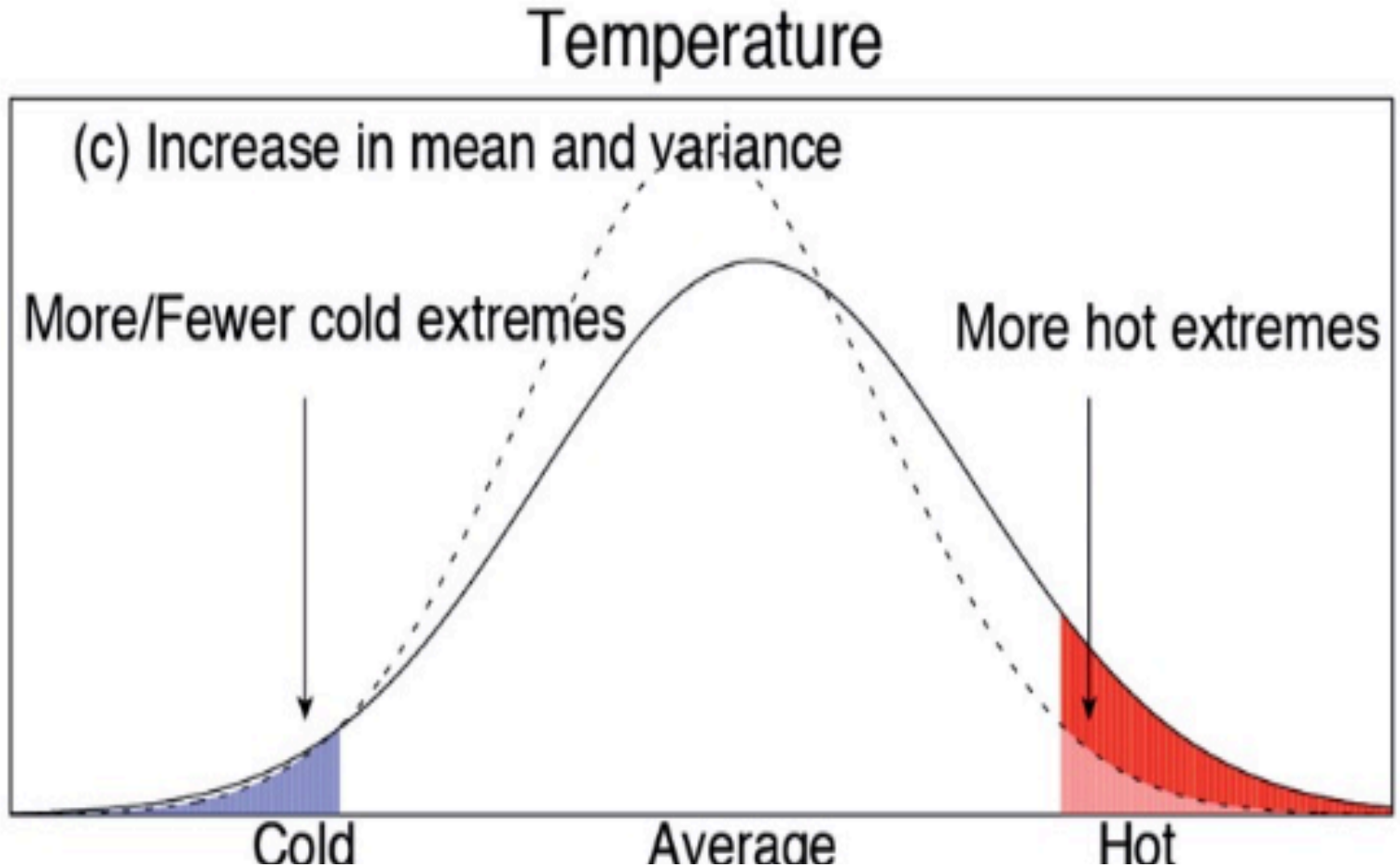
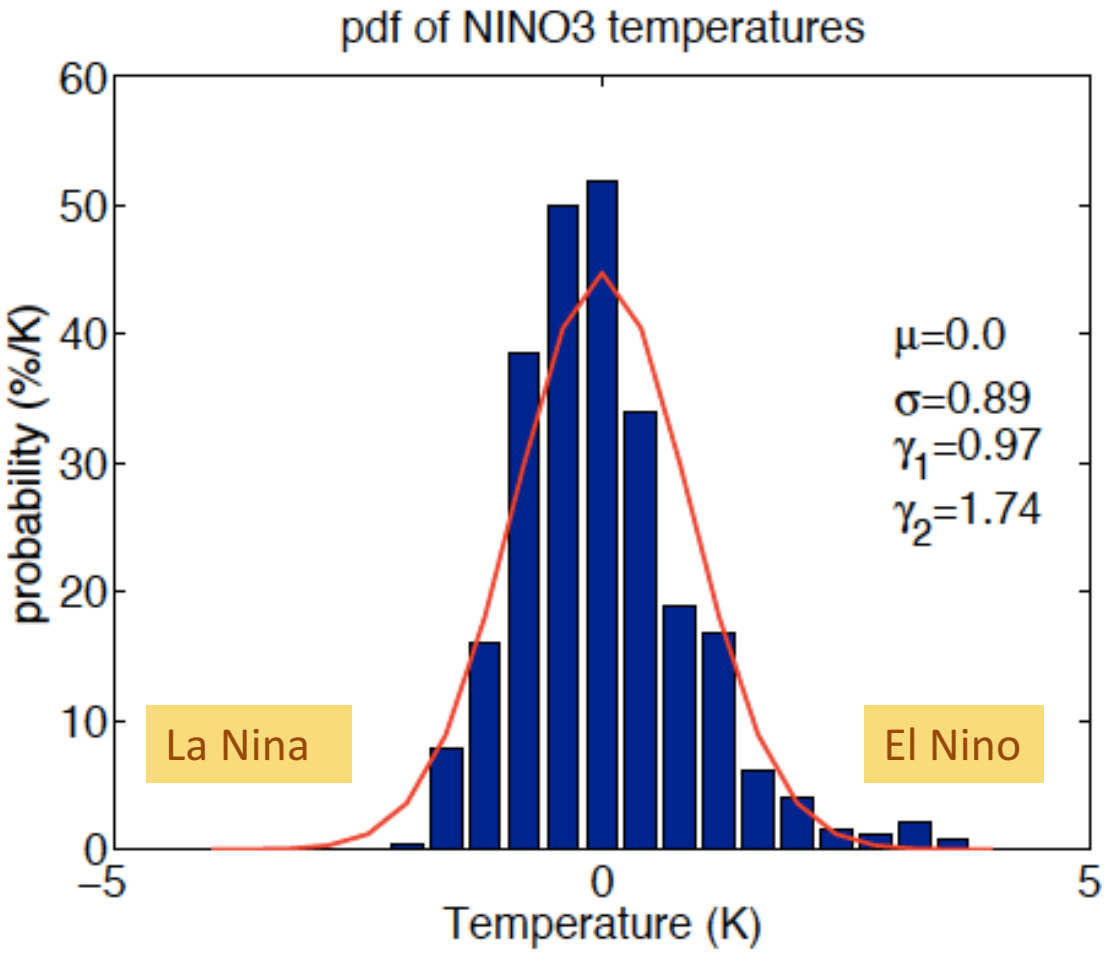
Climate Change

El Nino extremes = non-linearity



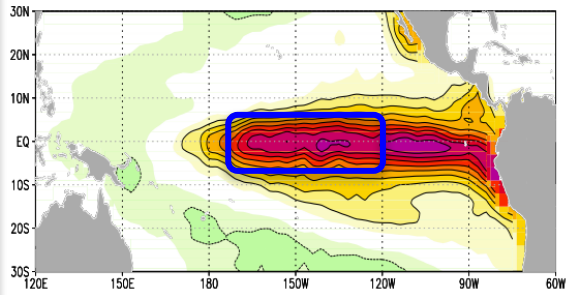
El Nino non-linearity

✧El Ninos are stronger than La Ninas

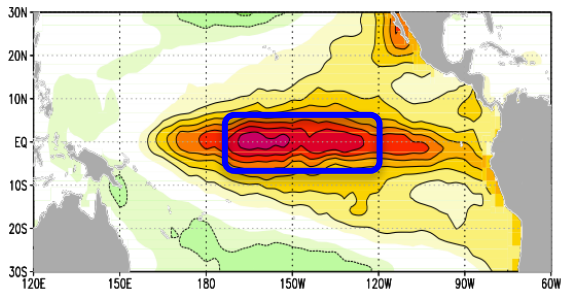


Pattern non-linearity

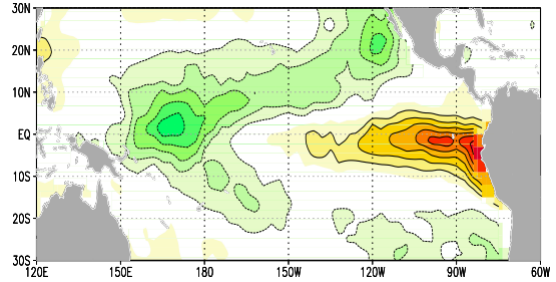
A Strong El Niño



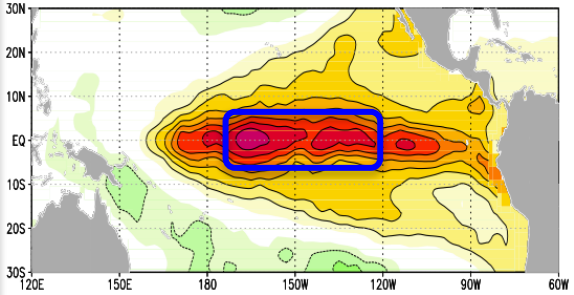
B Strong La Niña



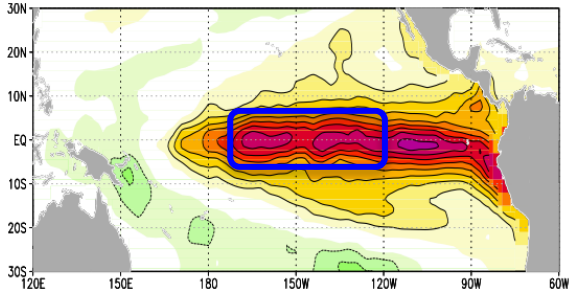
Diff. Strong **A** - **B**



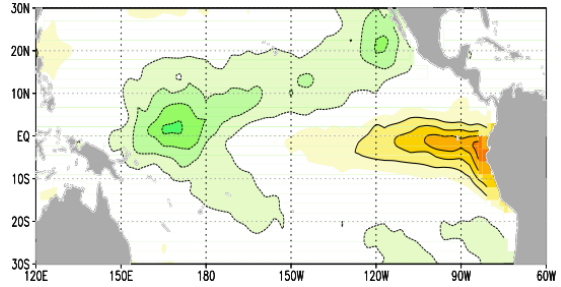
C Weak El Niño

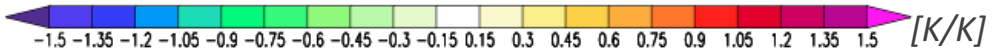


D Weak La Niña

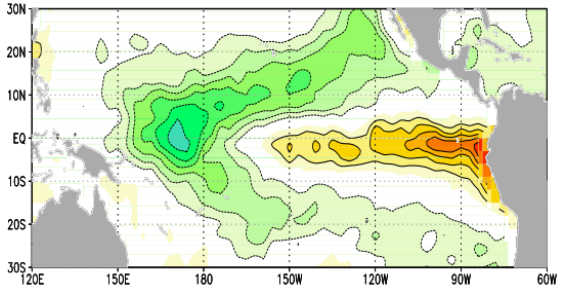


Diff. Weak **D** - **C**

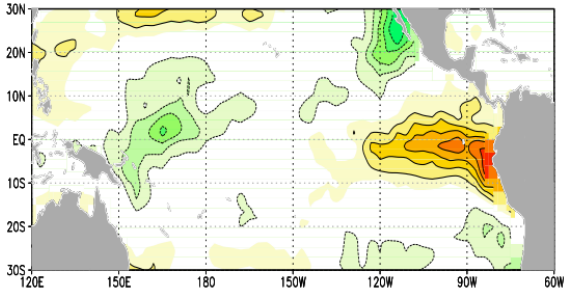




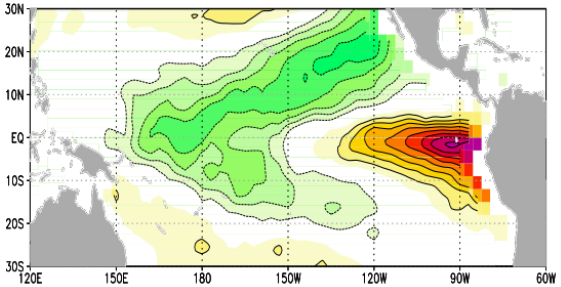
Diff. El Niño **C** - **A**



Diff. La Niña **D** - **B**

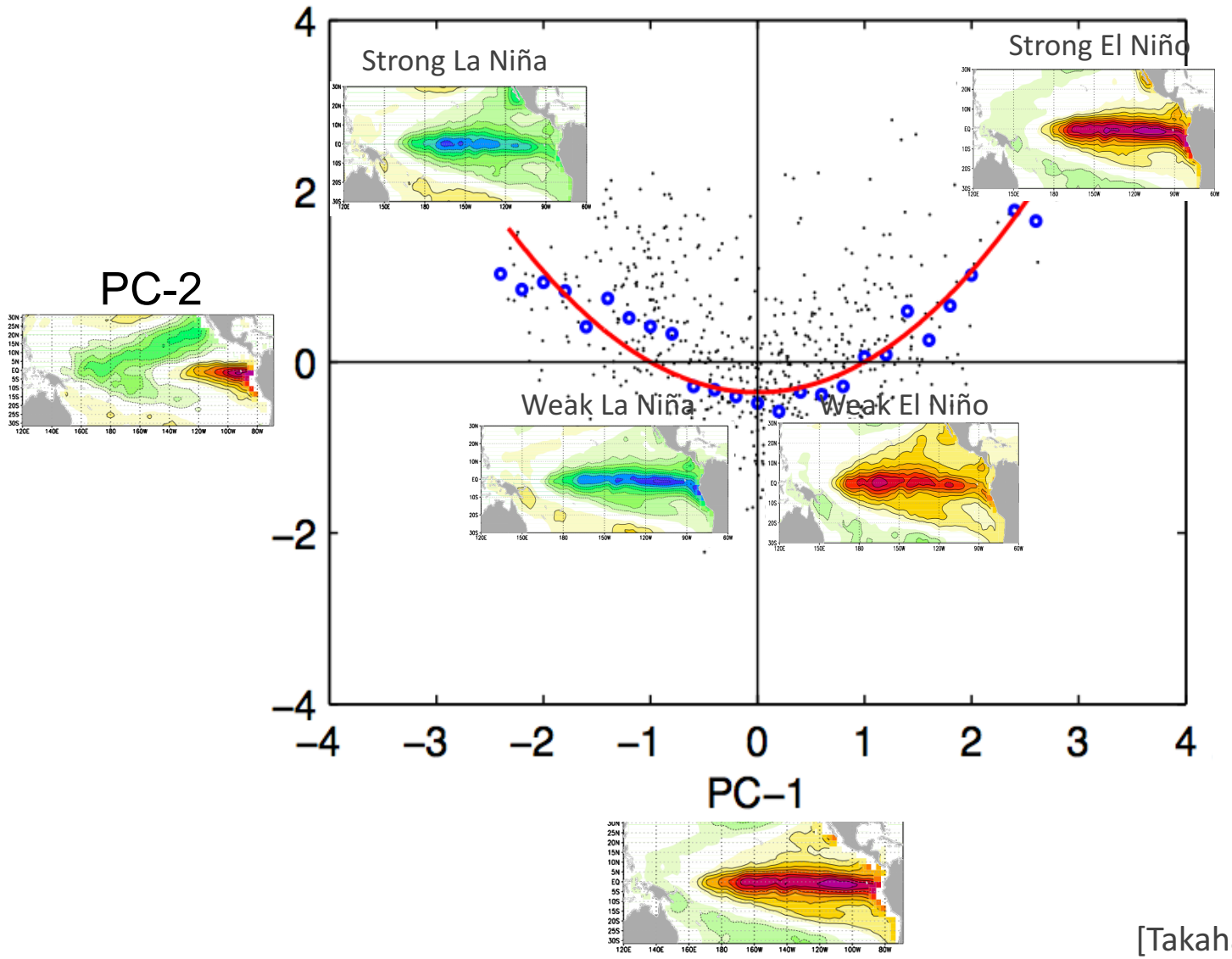


EOF-2



Composites are normalized by the mean NINO3.4 SST

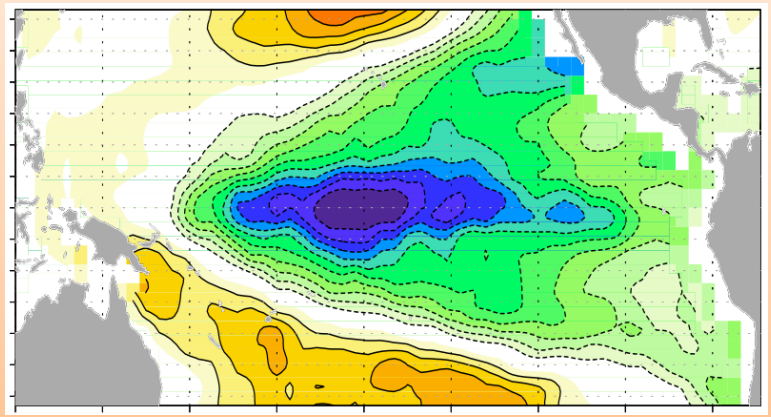
Pattern non-linearity



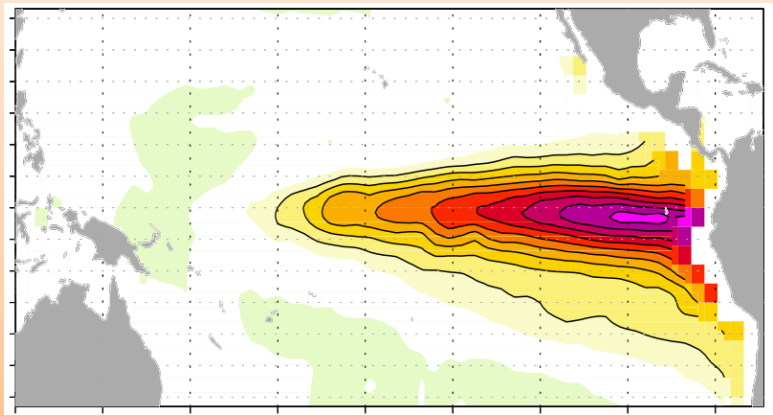
[Takahashi et al. 2011]
[Dommenget et al. 2013]

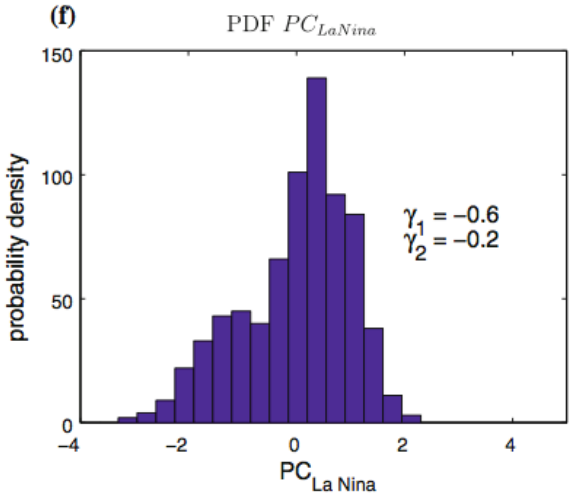
Idealized ENSO patterns

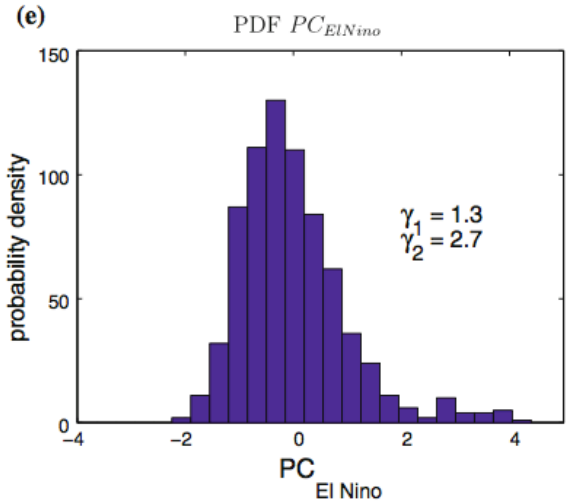
(-) La Niña



El Niño

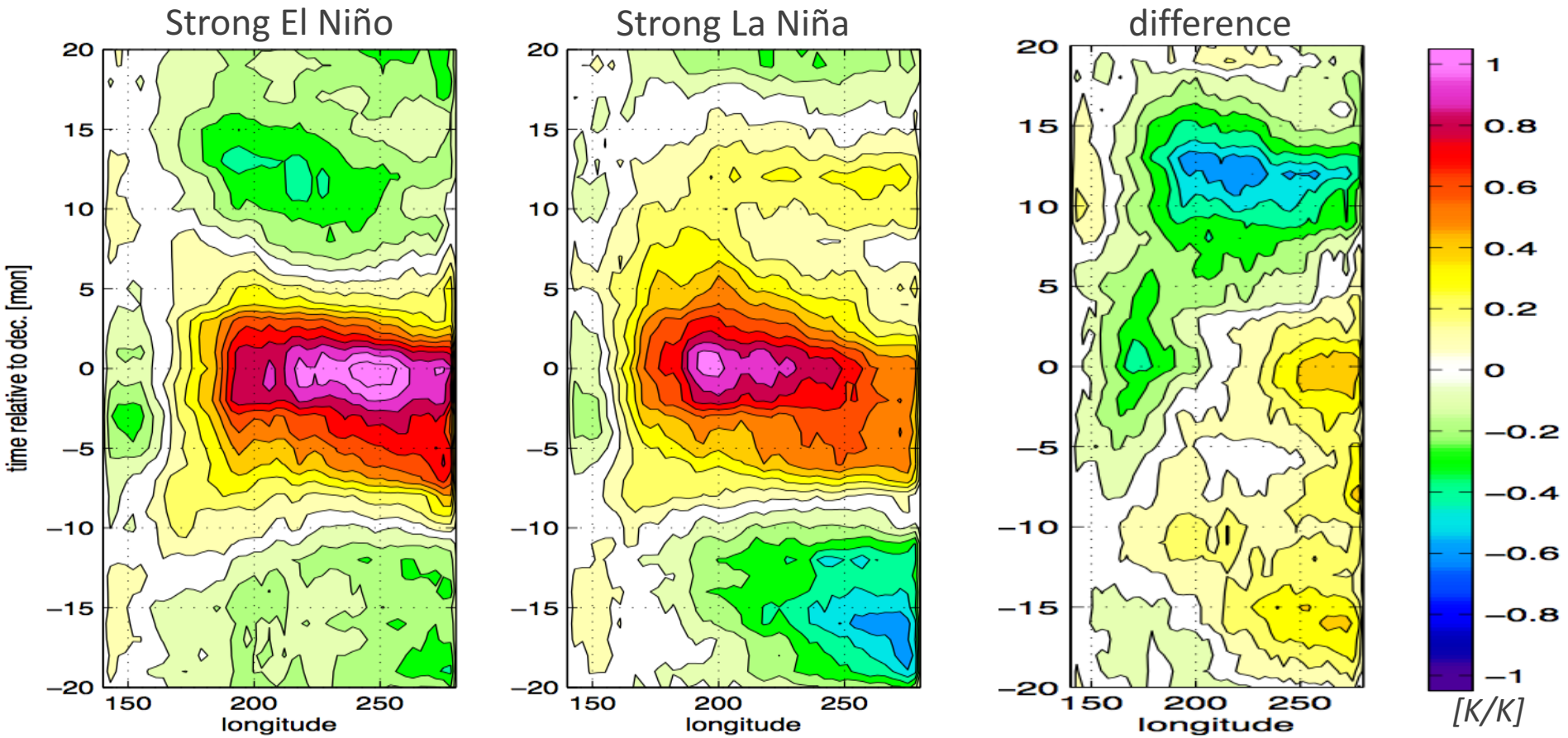






[Dommenget et al. 2013]

Time Evolution non-linearity

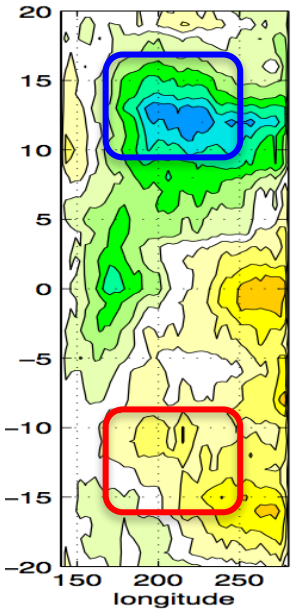


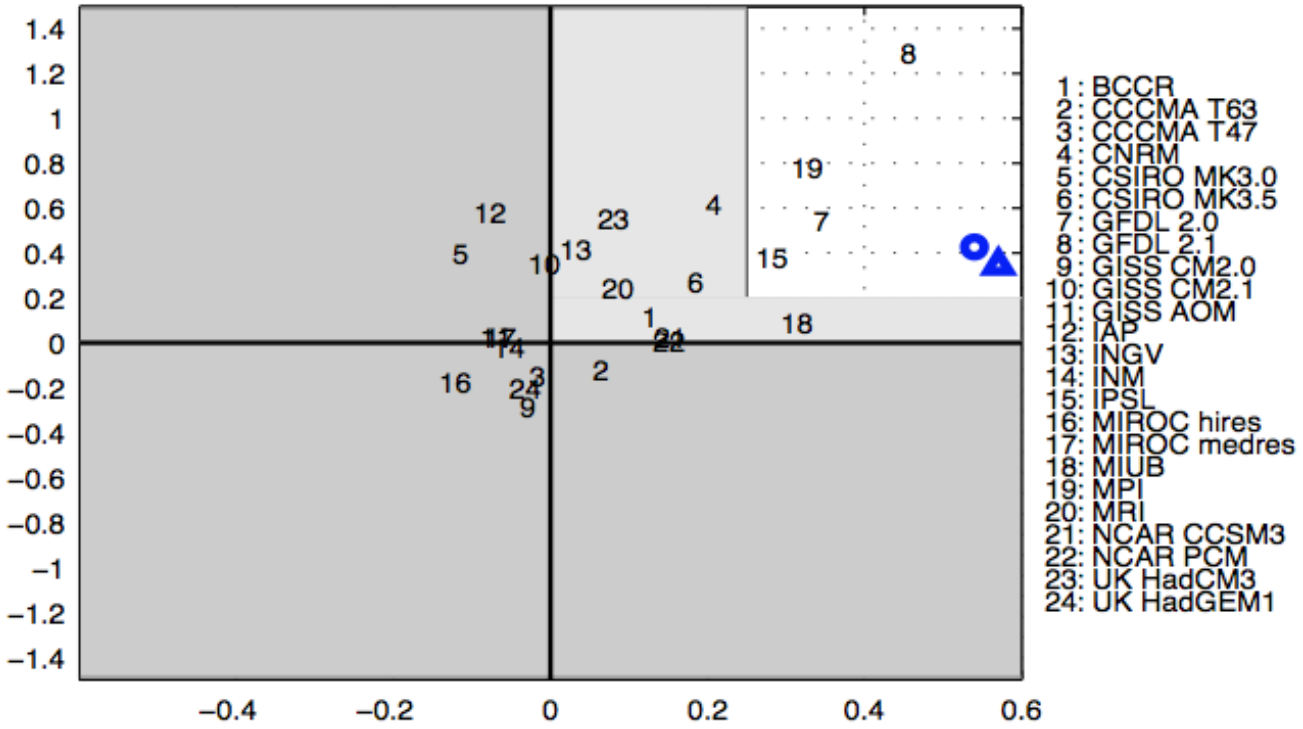
Composites are normalized by the mean NINO3.4 SST at lag 0

[Dommenget et al. 2013]

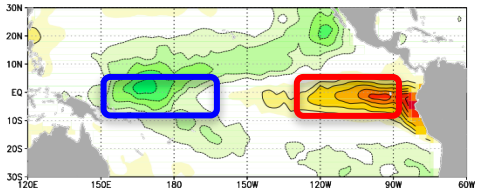
CMIP model non-linearity: pattern vs. time evolution

time evolution difference



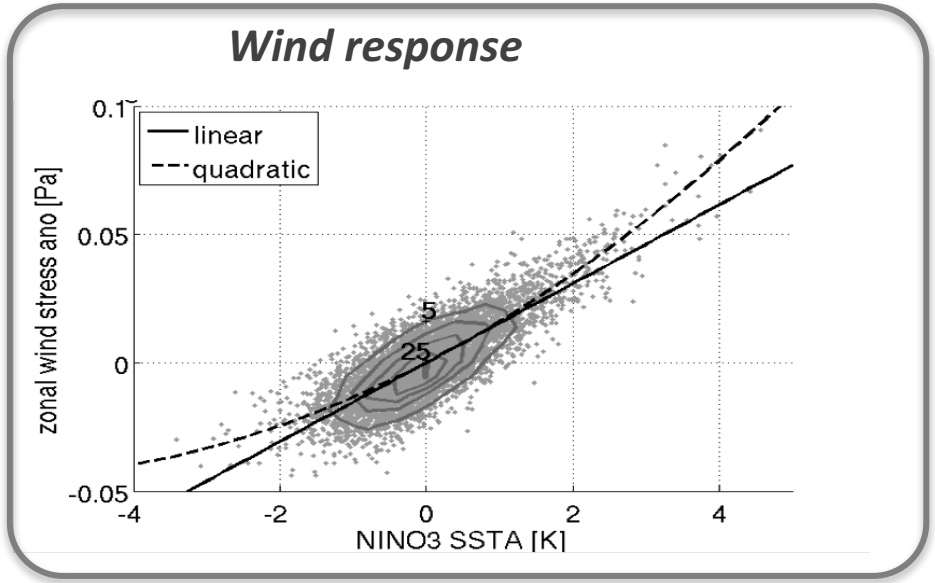


Pattern difference

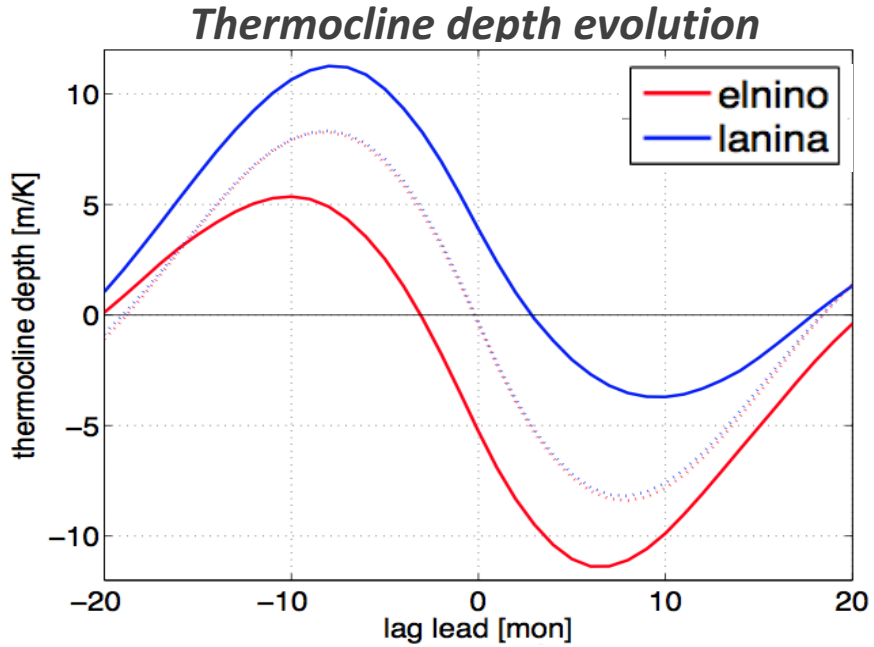


[Dommenget et al. 2013]

Wind-SST non-linearity



Model simulation with linear ocean

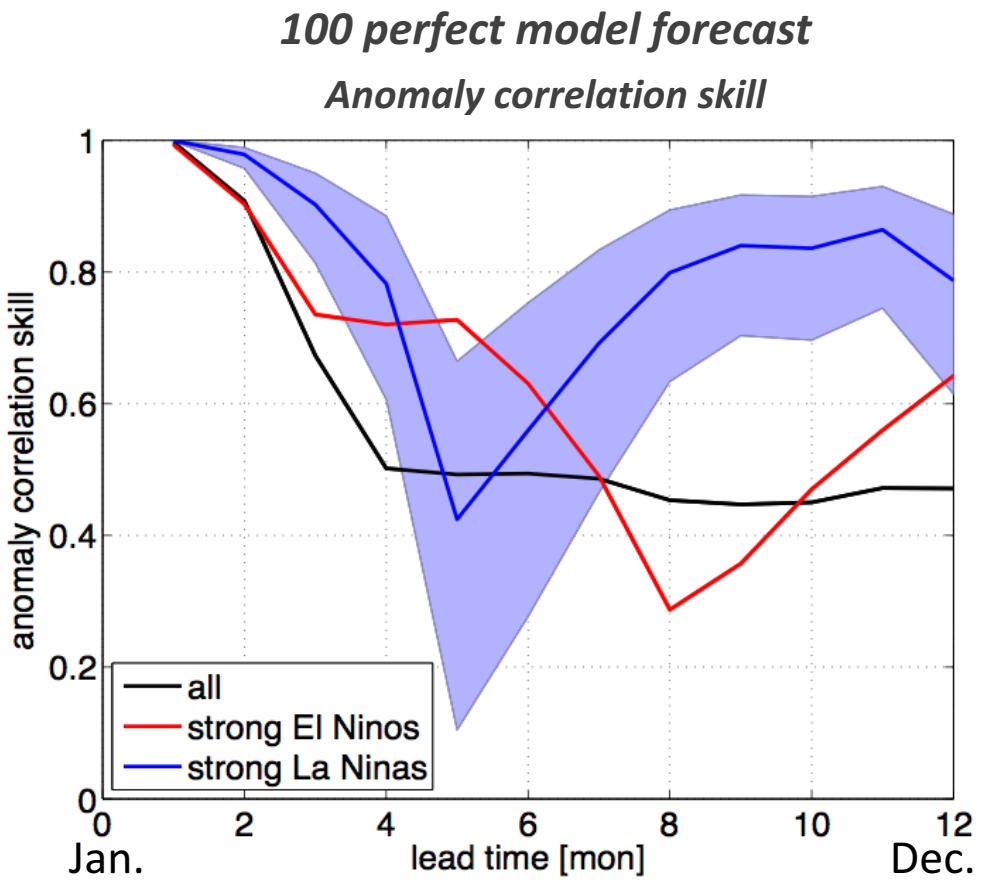


dashed: linear
solid: non-linear

[Dommenget et al. 2013]

Wind-SST non-linearity

RECHOZ Model Forecasts



[Dommenget et al. 2013]

Summary: non-linearity

- ***Pattern non-linearity:***
  - strong El Ninos are to the east
  - strong La Ninas are further west
  - Vice versa for weak events
  - Both, El Nino and La Nina have non-normal extremes

- ***Time evolution non-linearity:***
  - strong El Ninos are followed by La Ninas
  - strong La Ninas are preceded by El Ninos
  - Vice versa for weak events

- ***Wind Feedback non-linearity:***
  - strong El Ninos are forced by stronger zonal winds
  - Strong La Ninas are forced by stronger thermocline depth anomalies
  - The stronger thermocline depth is caused by the non-linear zonal wind

- ***Predictability non-linearity:***
  - strong La Ninas are better predictable than strong El Ninos

[Dommenget et al. 2013]

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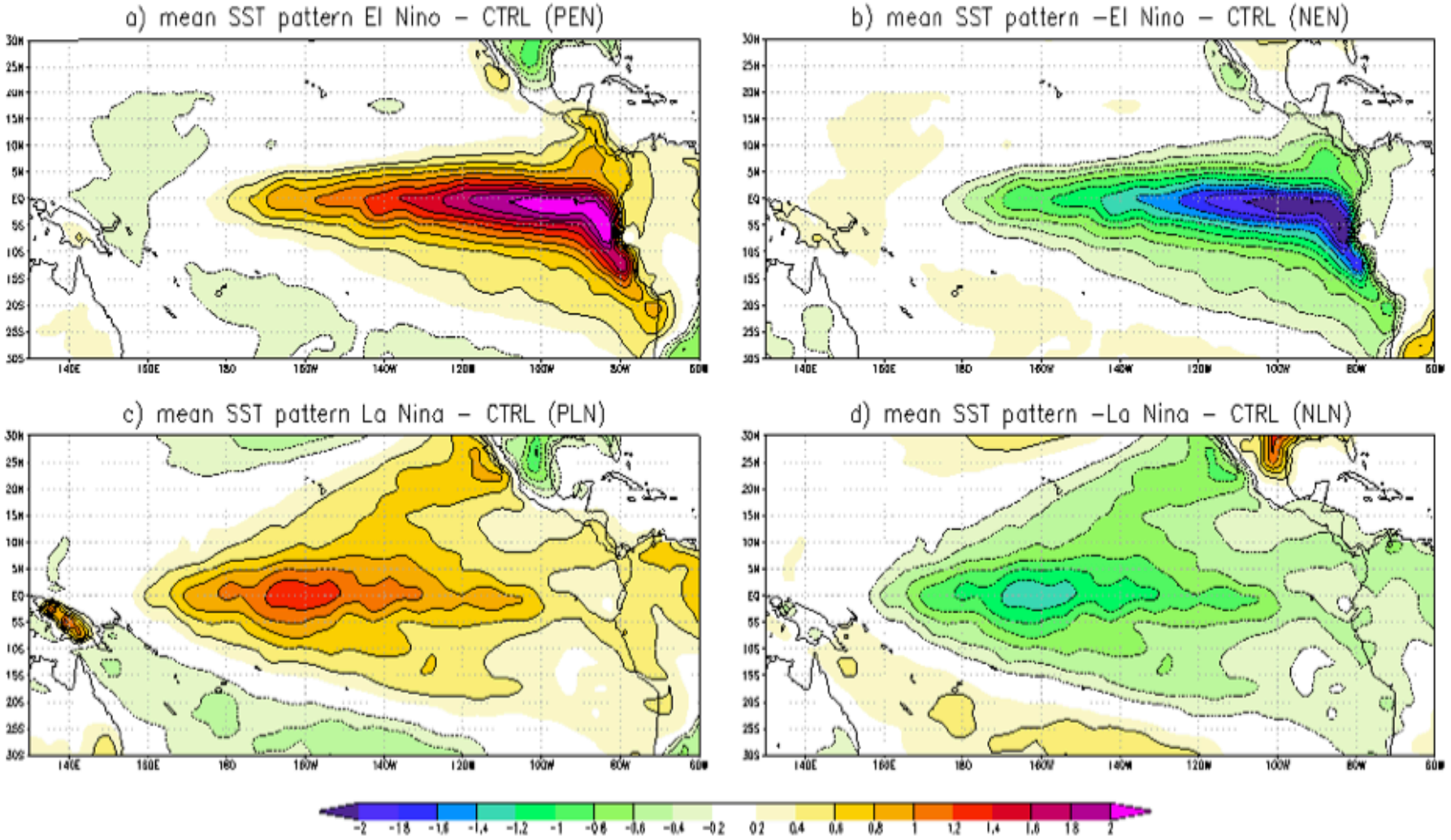
How good are the models?

Climate Change

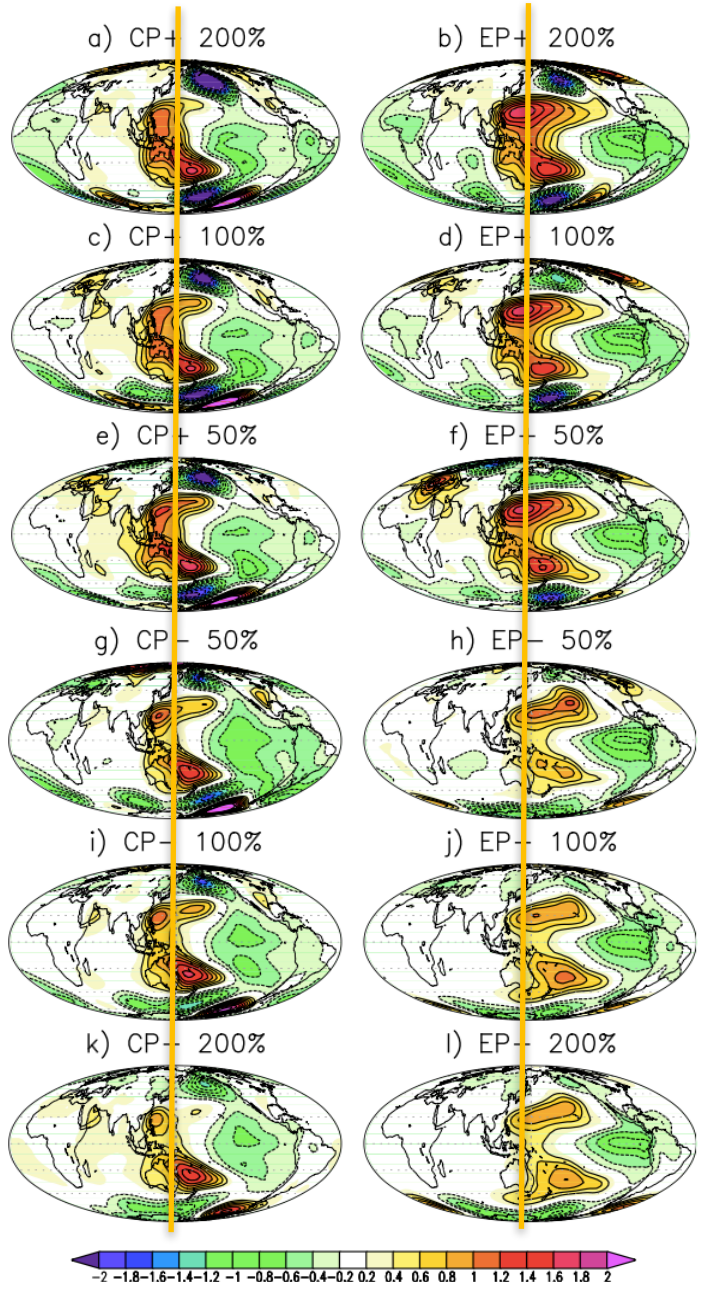
Non-linear ENSO Teleconnections

Response ACCESS experiments with idealized ENSO patterns



[Frauen et al. 2014]

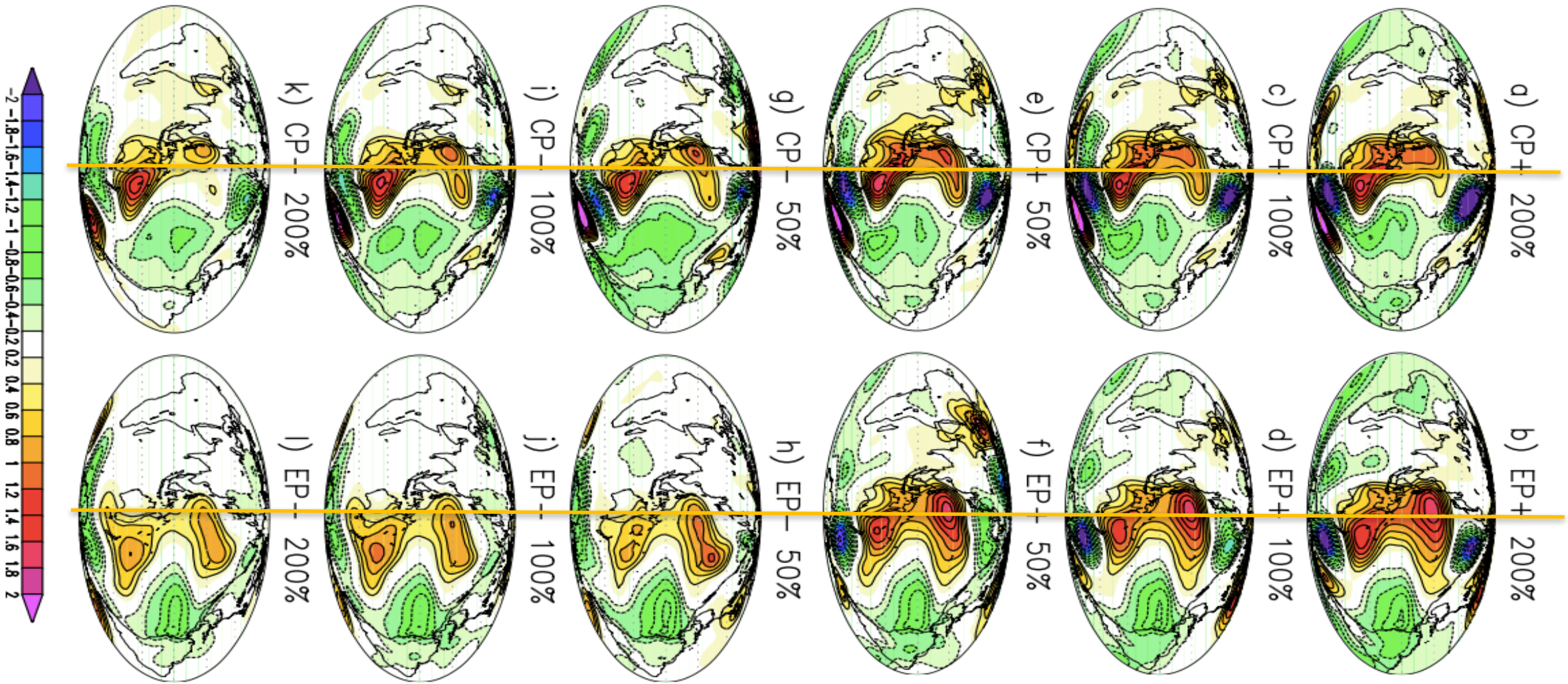
Non-linear teleconnections



Composites are normalized by the mean NINO3.4 SST

[Frauen et al. 2014]

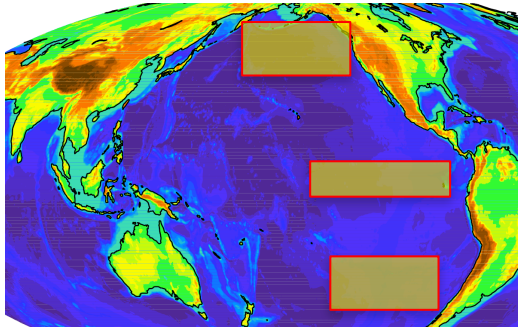
Non-linear teleconnections



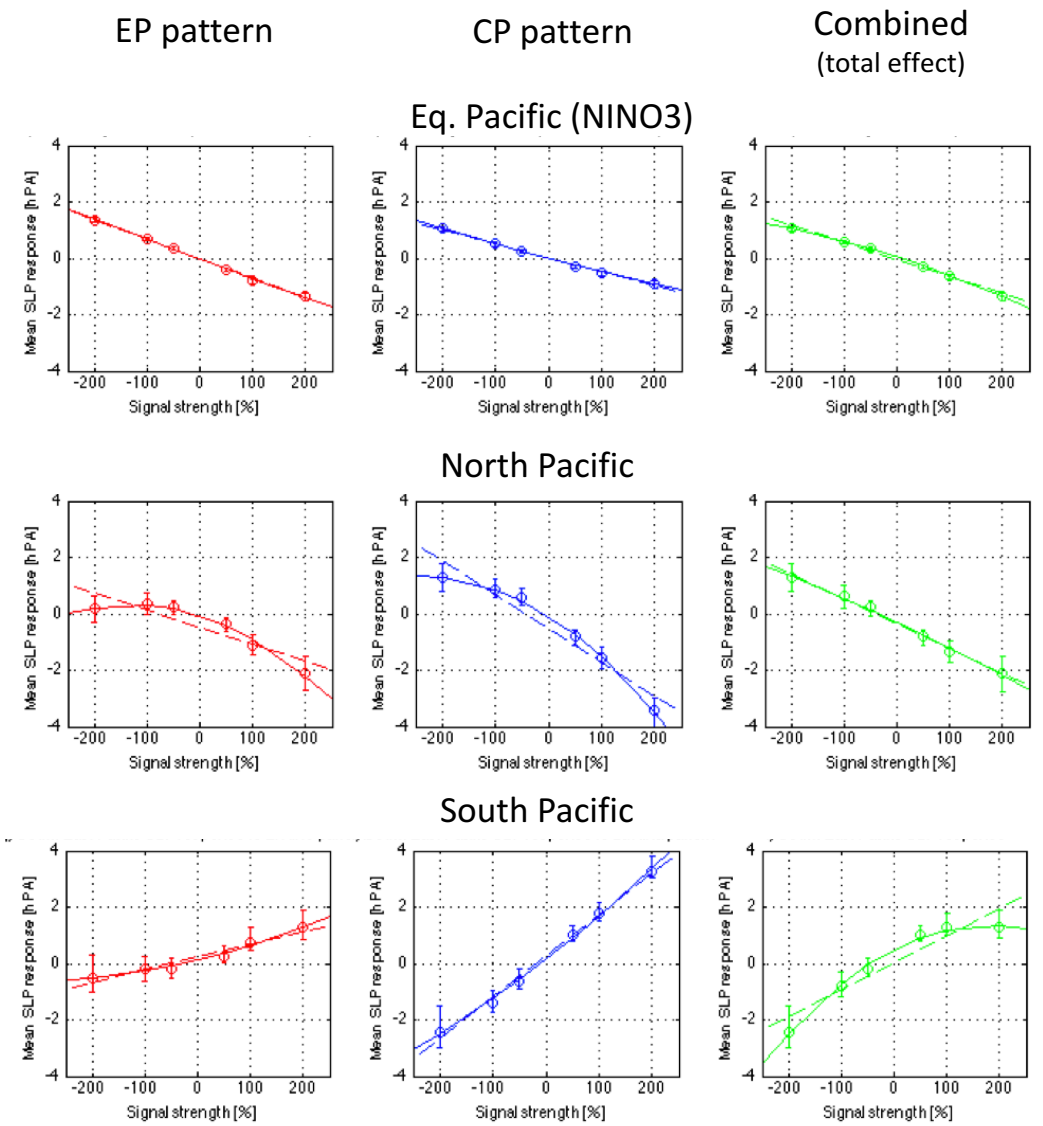
Composites are normalized by the mean NINO3.4 SST

[Frauen et al. 2014]

Non-linear teleconnections



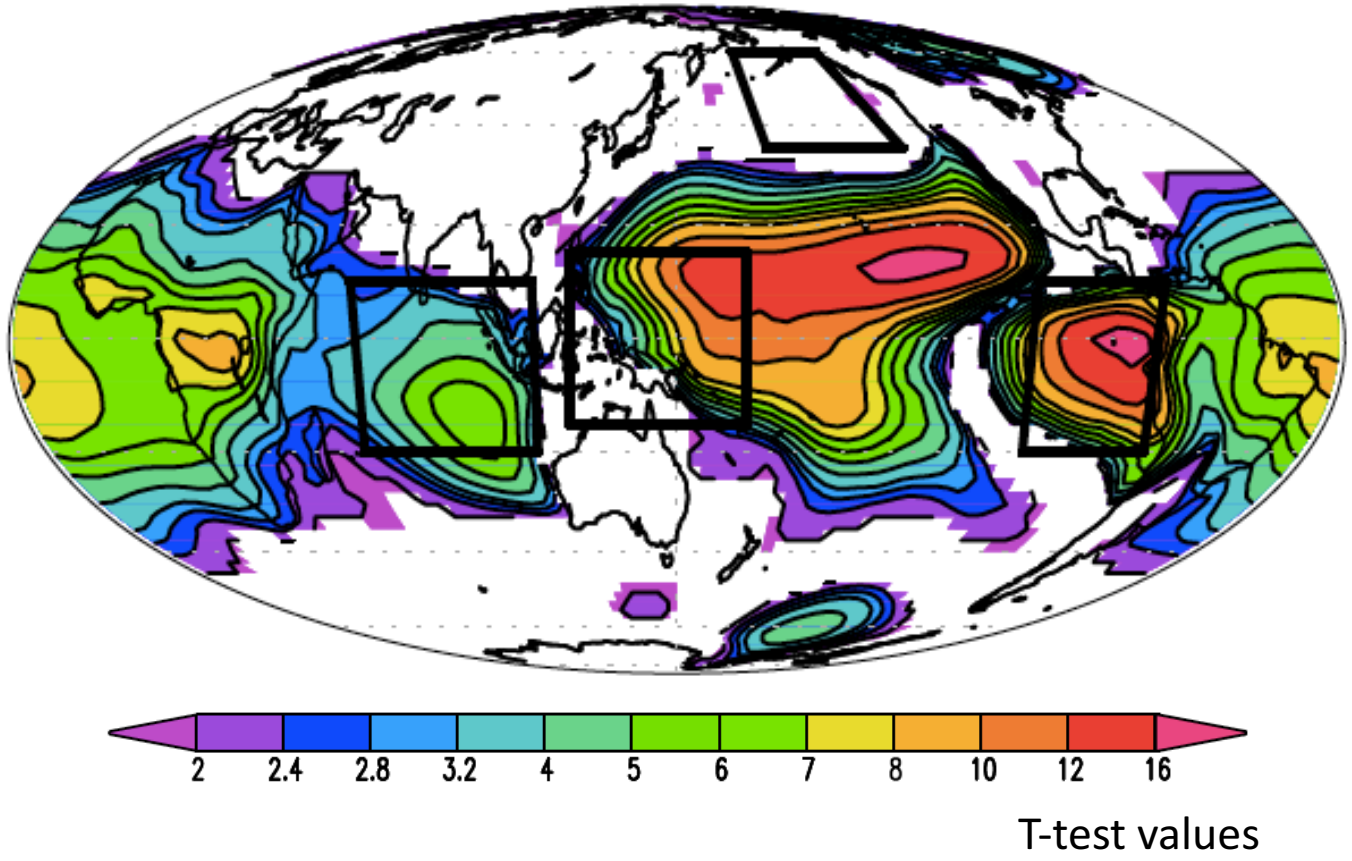
ACCESS SST-response experiments



[Frauen et al. 2014]

Non-linear teleconnections

Significant non-linear teleconnections
(based on idealized model simulations)



[Frauen et al. 2014]

Summary: Non-linear teleconnection

- ENSO teleconnections are strongly non-linear
- A combination of
  - A linear response to a non-linear SST pattern.
  - A non-linear response to a linear SST pattern.

[Frauen et al. 2014]

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ENSO processes

$$\frac{dT}{dt} = a_{11}T + a_{12}h + \xi_T$$

$$\frac{dh}{dt} = a_{21}T + a_{22}h + \xi_h$$

a_{11} = T damping

a_{12} = coupling T to h

a_{21} = coupling h to T

a_{22} = h damping

ξ_T = noise forcing T

ξ_h = noise forcing h

$$a_{11} = a_{11A} + a_{11O}$$

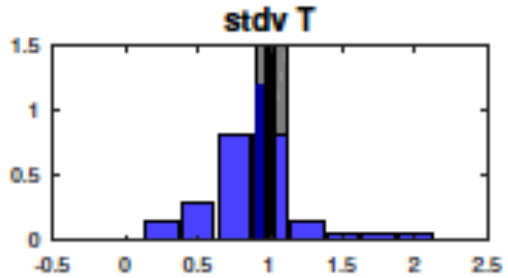
$$a_{11} = [c_1 C_{\tau T} + c_2 C_{fT}] + a_{11O}$$

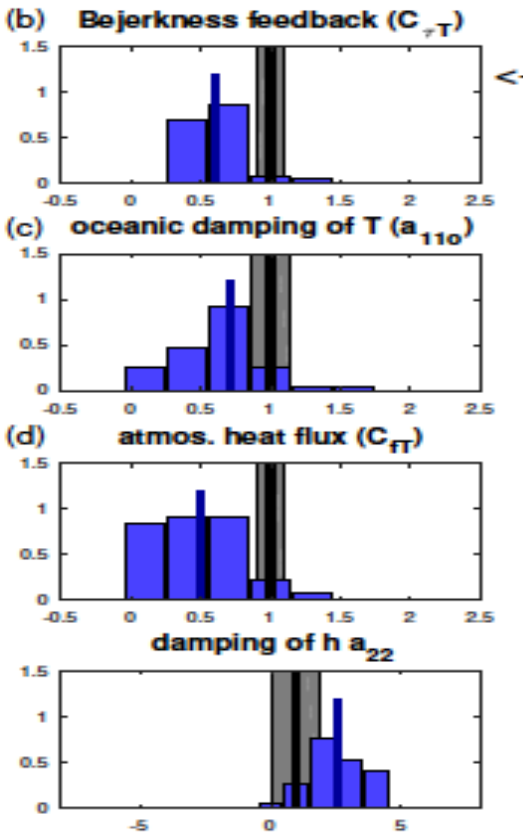
$C_{\tau T}$ = wind response

C_{fT} = net heat response

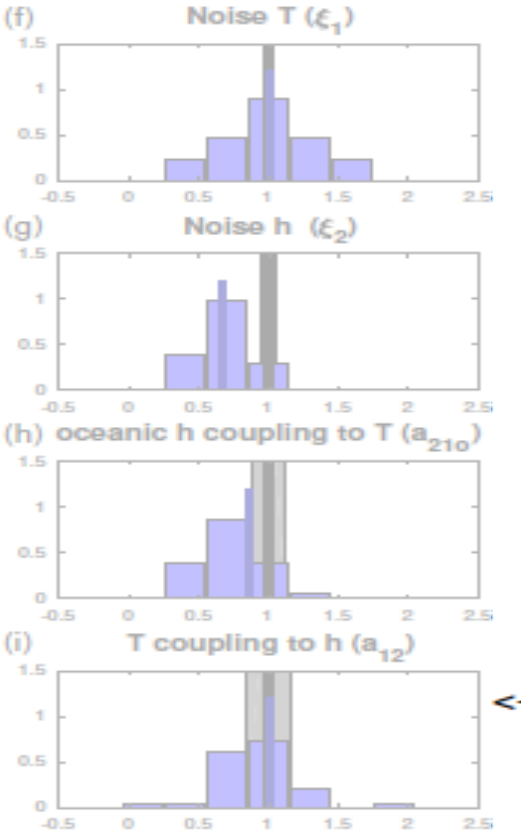
a_{11O} = T damping (ocean)

Common CMIP model biases





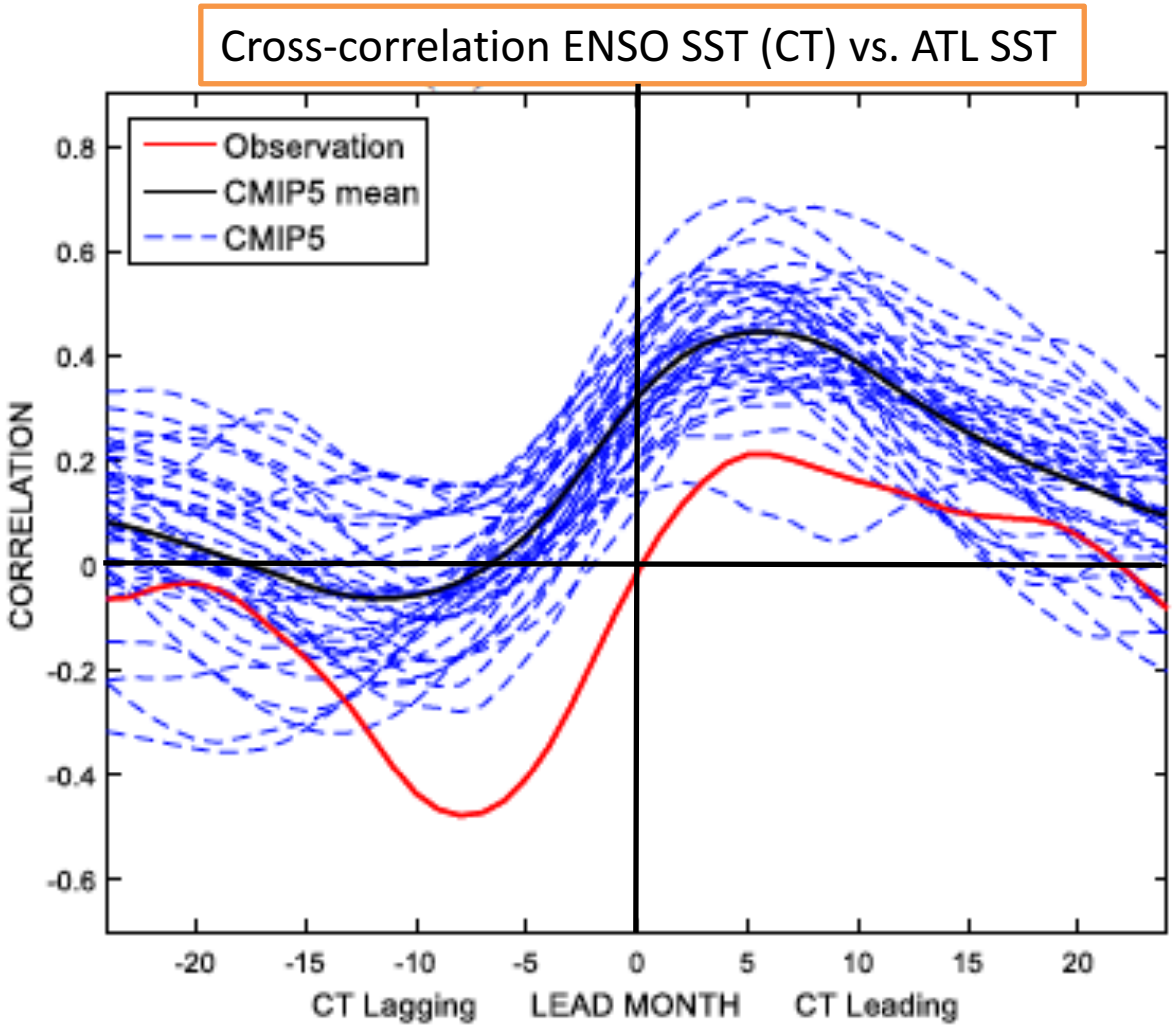
<-- most important



<-- least important

Vijayeta and Dommenget 2018

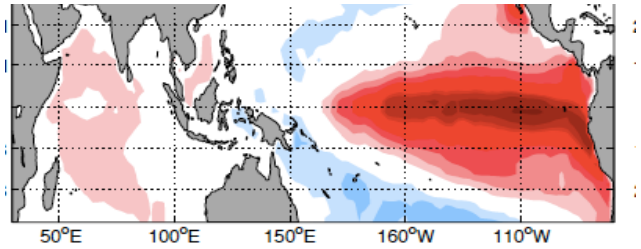
Common CMIP model biases: Atlantic forcing

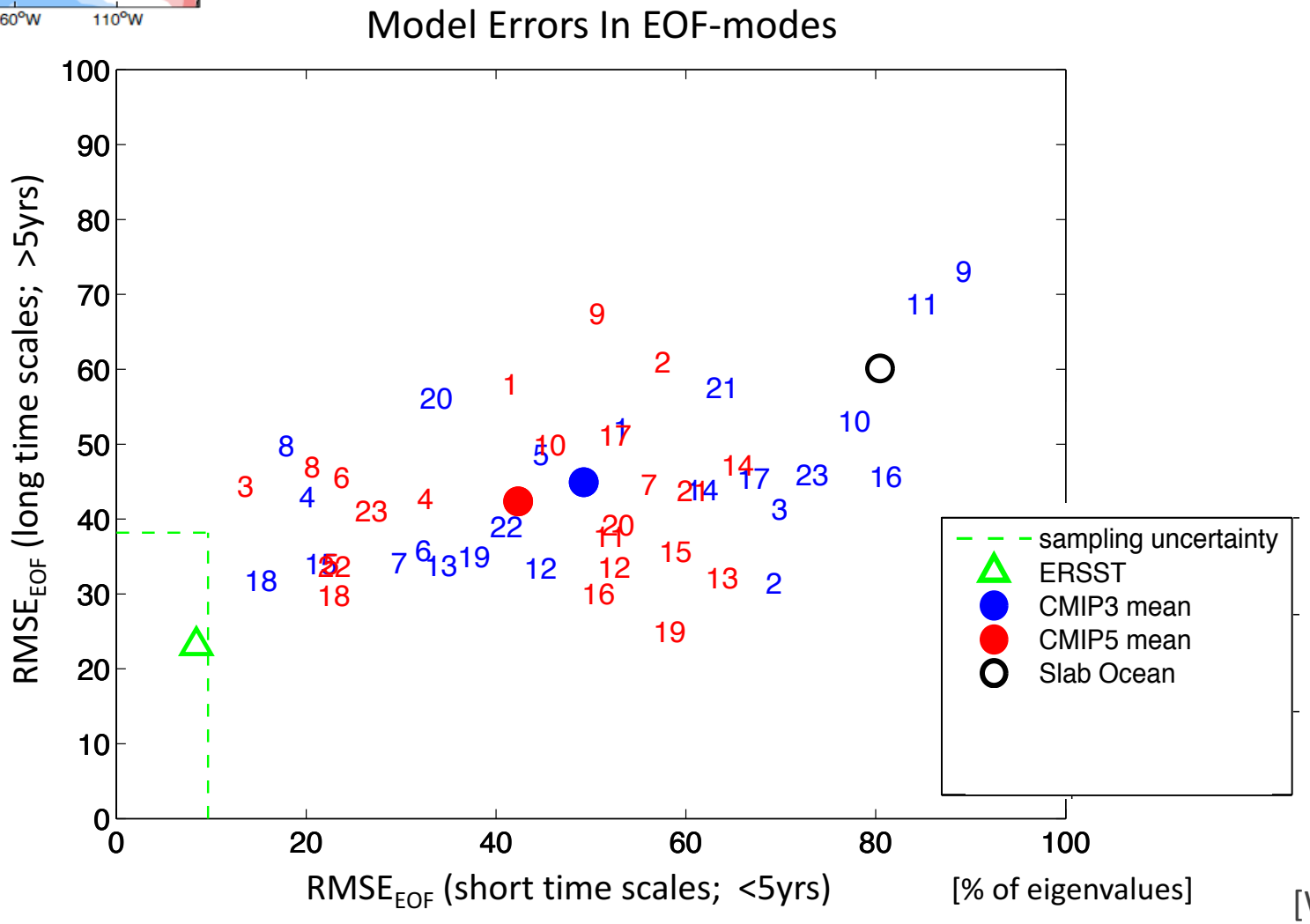


CMIP models under estimate the Atlantic influence on ENSO

Luo et al. 2017

EOF-modes: Models vs. Obs. error





[Wang et al. 2015]

How good are the models: Summary

@#$%*&

Overview

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The Future of ENSO

Ensemble mean CMIP model projections:

- El Nino like mean state changes
- Weakening and eastward shift of Walker circulation
- No changes in SST variability (strength)

I am not convinced, though!

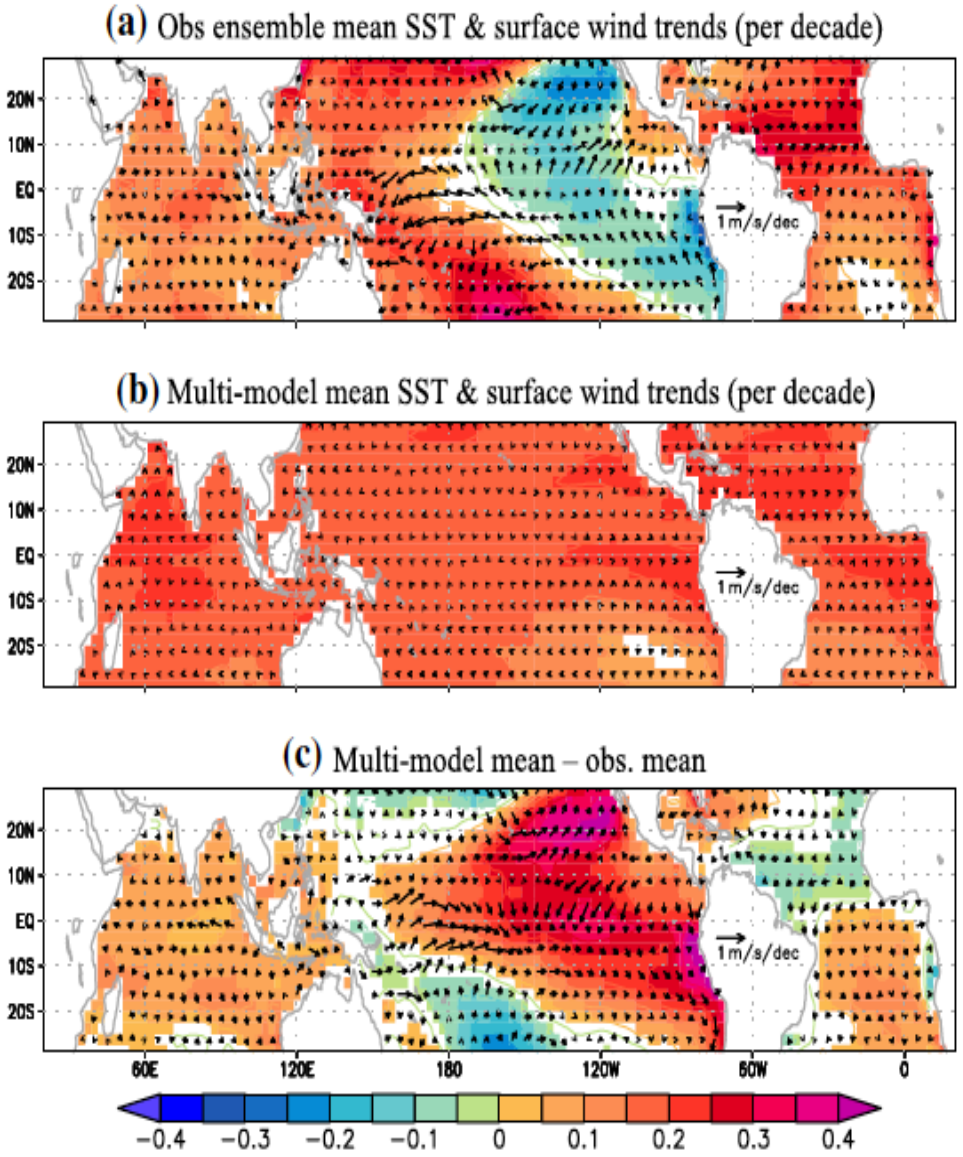
Arguments against the CMIP projections

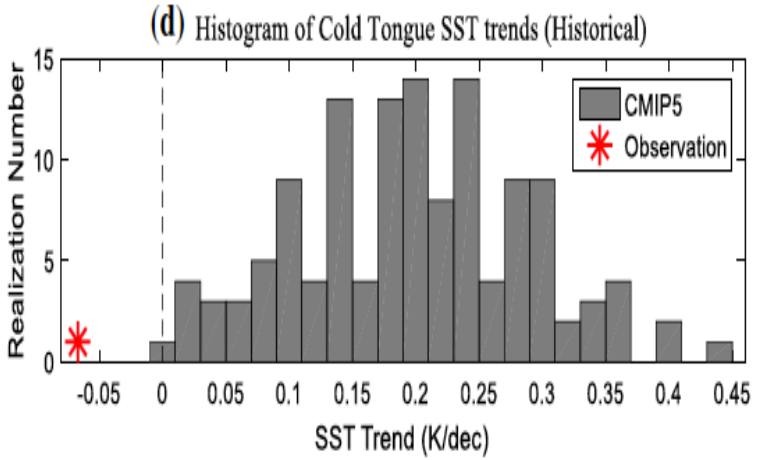
I. Observations

II. Common CMIP model biases

III. Lag of understanding

Observed vs. CMIP trends

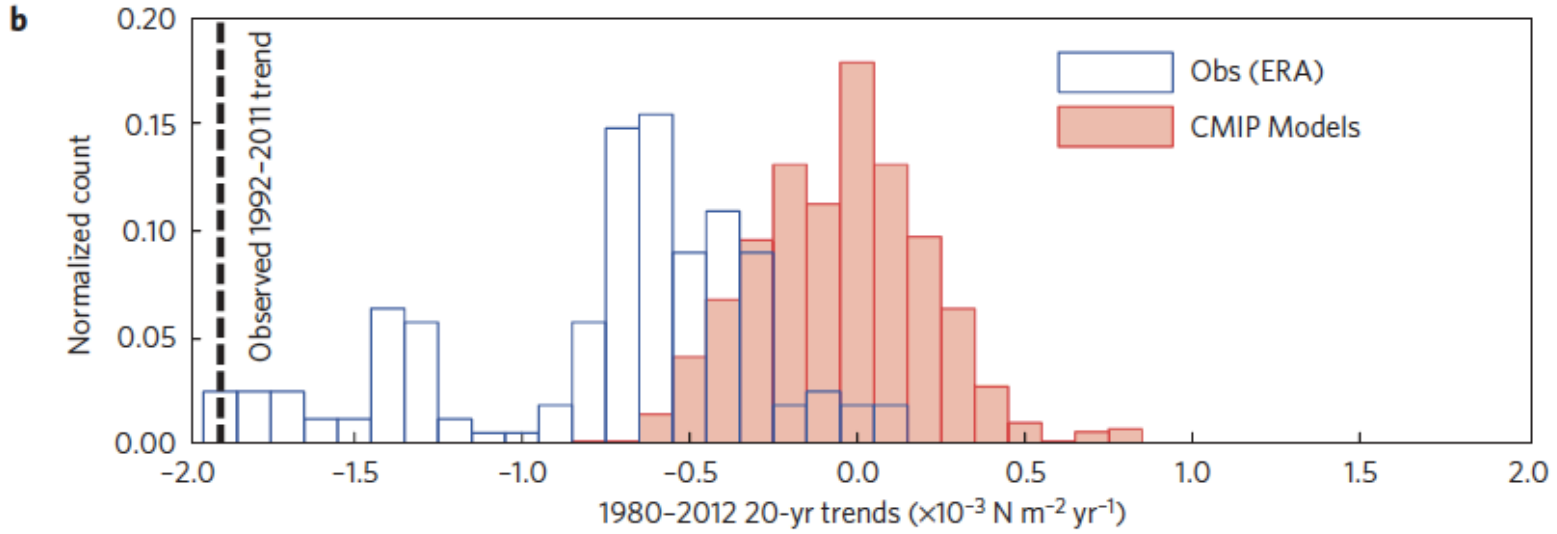




Luo et al. 2017

Observed vs. CMIP trends

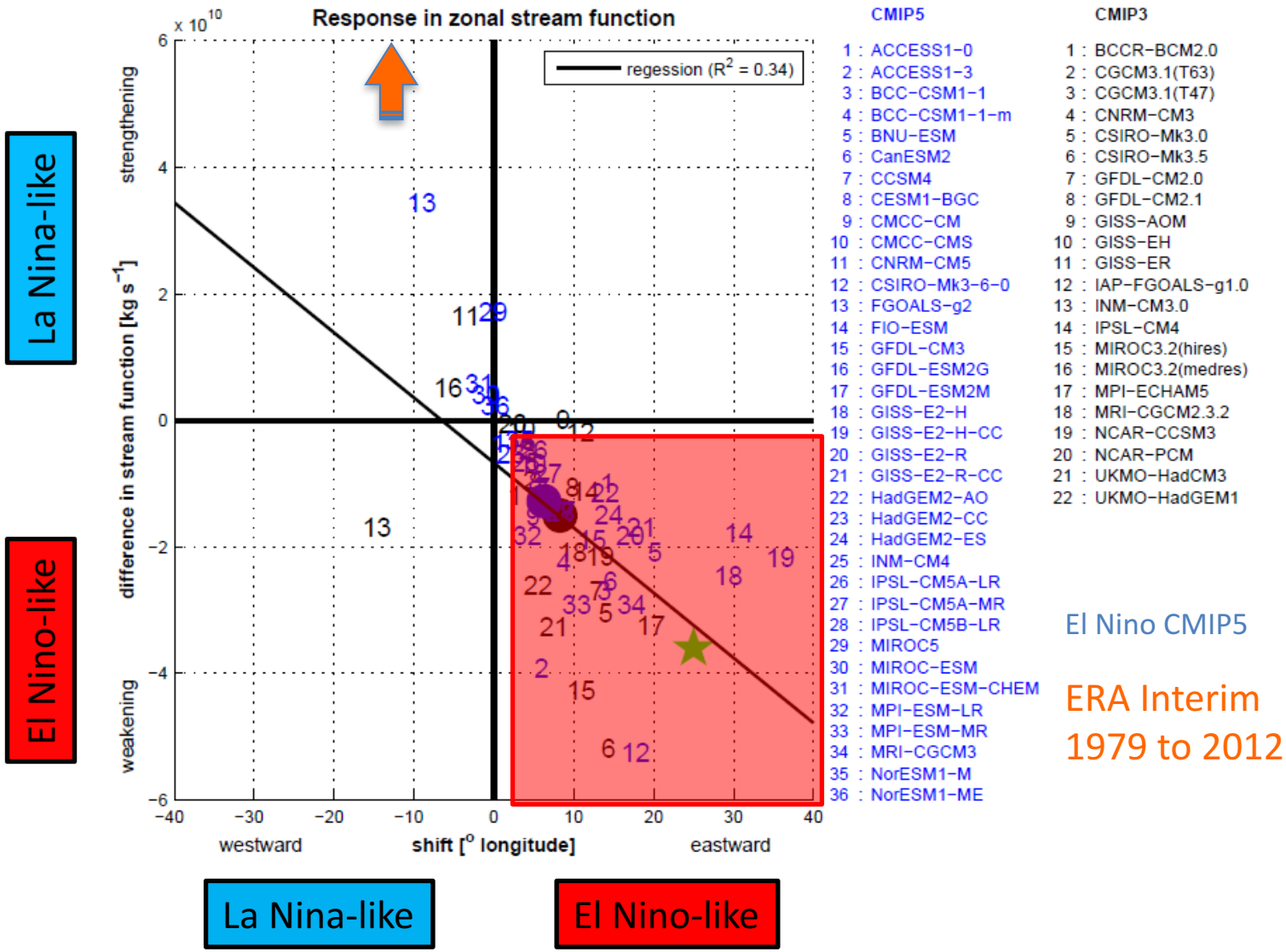
Tropical Pacific wind stress decadal trends



England et al. 2014

El Nino-like trend in CMIP models?

Walker Circulation trends



CMIP5	CMIP3
1 : ACCESS1-0	1 : BCCR-BCM2.0
2 : ACCESS1-3	2 : CGCM3.1(T63)
3 : BCC-CSM1-1	3 : CGCM3.1(T47)
4 : BCC-CSM1-1-m	4 : CNRM-CM3
5 : BNU-ESM	5 : CSIRO-Mk3.0
6 : CanESM2	6 : CSIRO-Mk3.5
7 : CCSM4	7 : GFDL-CM2.0
8 : CESM1-BGC	8 : GFDL-CM2.1
9 : CMCC-CM	9 : GISS-AOM
10 : CMCC-CMS	10 : GISS-EH
11 : CNRM-CM5	11 : GISS-ER
12 : CSIRO-Mk3-6-0	12 : IAP-FGOALS-g1.0
13 : FGOALS-g2	13 : INM-CM3.0
14 : FIO-ESM	14 : IPSL-CM4
15 : GFDL-CM3	15 : MIROC3.2(hires)
16 : GFDL-ESM2G	16 : MIROC3.2(medres)
17 : GFDL-ESM2M	17 : MPI-ECHAM5
18 : GISS-E2-H	18 : MRI-CGCM2.3.2
19 : GISS-E2-H-CC	19 : NCAR-CCSM3
20 : GISS-E2-R	20 : NCAR-PCM
21 : GISS-E2-R-CC	21 : UKMO-HadCM3
22 : HadGEM2-AO	22 : UKMO-HadGEM1
23 : HadGEM2-CC	
24 : HadGEM2-ES	
25 : INM-CM4	
26 : IPSL-CM5A-LR	
27 : IPSL-CM5A-MR	
28 : IPSL-CM5B-LR	
29 : MIROC5	
30 : MIROC-ESM	
31 : MIROC-ESM-CHEM	
32 : MPI-ESM-LR	
33 : MPI-ESM-MR	
34 : MRI-CGCM3	
35 : NorESM1-M	
36 : NorESM1-ME	

El Nino CMIP5

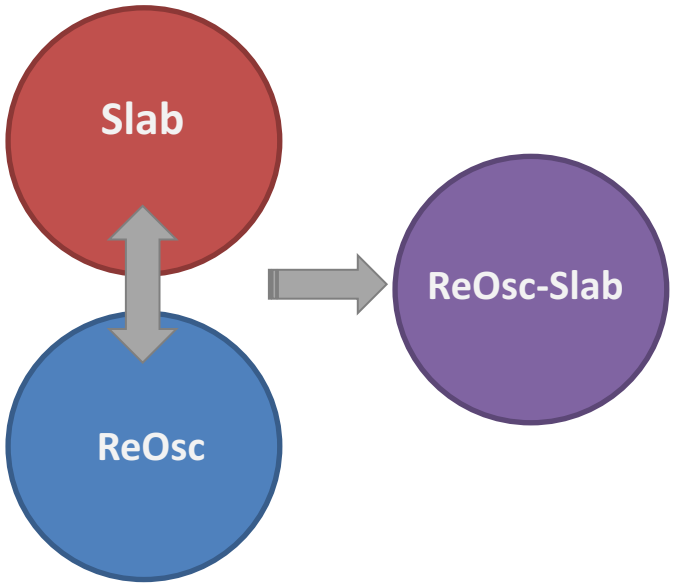
ERA Interim
1979 to 2012

Bayr et al. 2014

ACCESS ReOsc-Slab simulations

Slab Ocean

$$\gamma \frac{dSST(\vec{x},t)}{dt} = F_{atmos}(\vec{x},t)$$



Recharge Oscillator (ReOsc)

$$\frac{dT(t)}{dt} = a_{11}T(t) + a_{12}h(t) + a_{12}\lambda\tau(t) + \frac{f(t)}{\gamma}$$

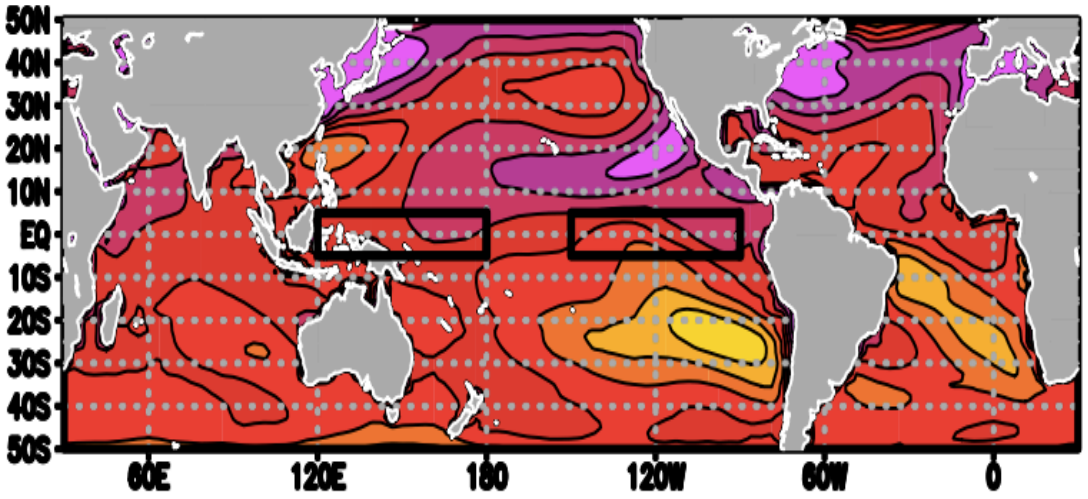
$$\frac{dh(t)}{dt} = a_{21}T(t) + a_{22}h(t) + \frac{\lambda}{2}a_{22}\tau(t),$$

- T = NINO3 SST anomaly
- dh/dt is not a function of T in global warming (T=wind)
- Better, relative SST: T = [NINO3 anomaly] - [global anomaly]
- Define new model: ***ReOsc-Slab-relative-SST***

ACCESS ReOs-Slab simulations

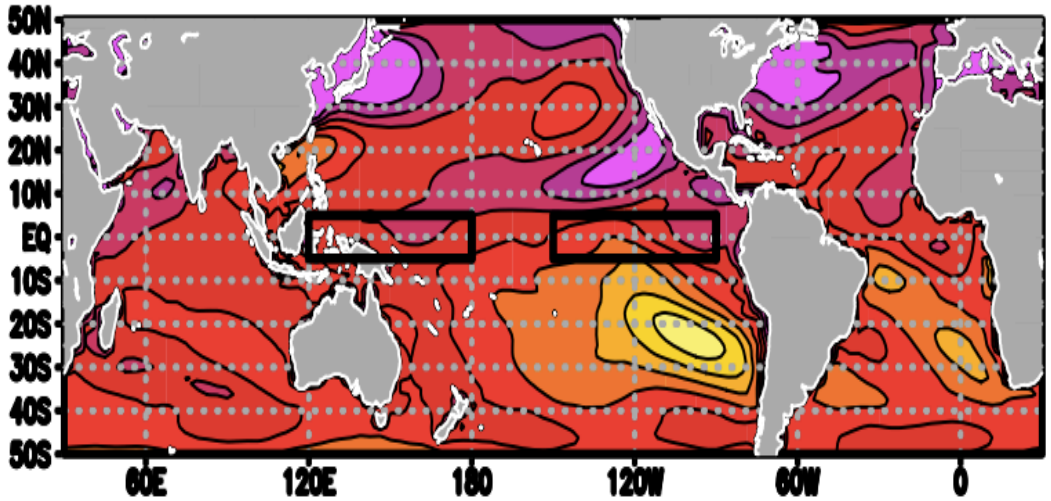
CGCM response to 2xCO_2 forcing

Slab Ocean



WPAC = 1.6 NINO3 = 1.5

ReOsc-Slab-relative-SST



WPAC= 1.6 NINO3 = 1.4

Summary: The Future of ENSO

- The CMIP projections do not agree with observations
- CMIP models have common biases that undermine confidence in projections of these models.
- No theoretical understanding of what the CMIP model predict.
- ENSO ReOsc dynamics lead to no changes
- In turn, ENSO changes are likely to be due to other processes
- A La Nina like climate change is possible.

Thank you!

Dietmar Dommenget