CESM CLIMATE VARIABILITY AND CHANGE WORKING GROUP MEETING
17 February 2022

Mechanisms of Fast Walker Circulation Responses to CO_2 Forcing

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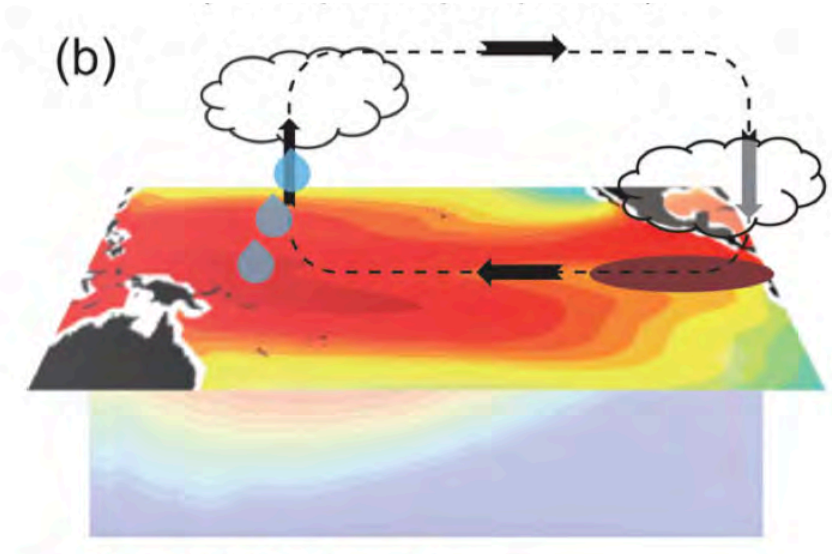
Introduction

Strengthening or Weakening of the WC?

As global CO_2 increases…

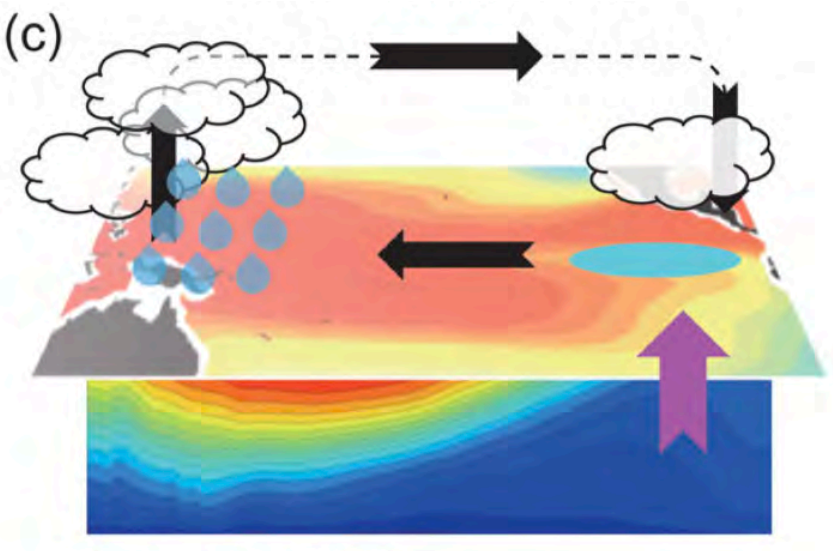
Weakening



- Deep convection moves eastward and weakens.
- Weakening of trade winds
- Less upwelling

or

Strengthening



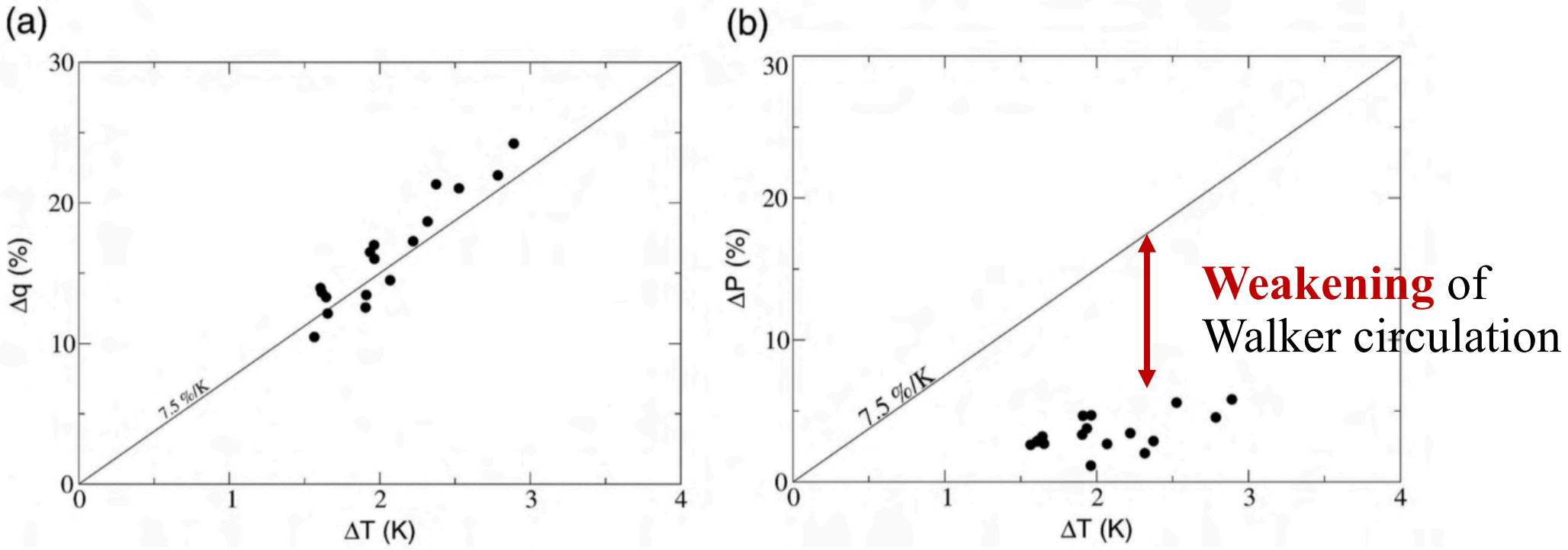
- Deep convection increases.
- Walker circulation expands westward
- Strengthening of trade winds
- Stronger upwelling

(Lian et al. 2018)

Introduction

Strengthening or Weakening of the WC?

Most climate models project a **long-term weakening** of WC in response to CO_2



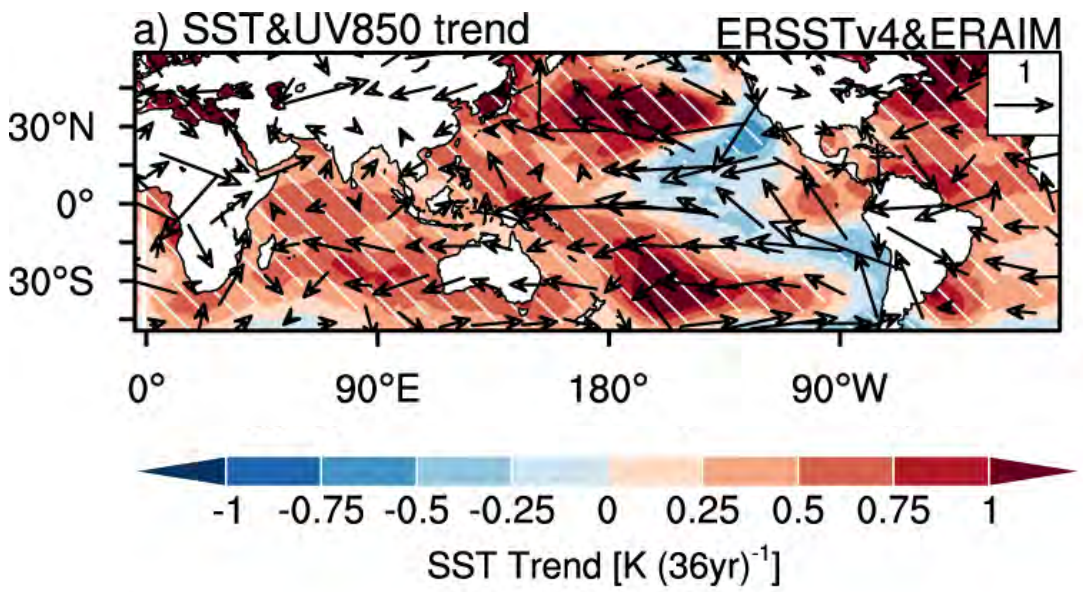
Percentage change in global-mean column-integrated (a) water vapor and (b) precipitation vs the global-mean change in surface air temperature

(Held and Soden. 2006)

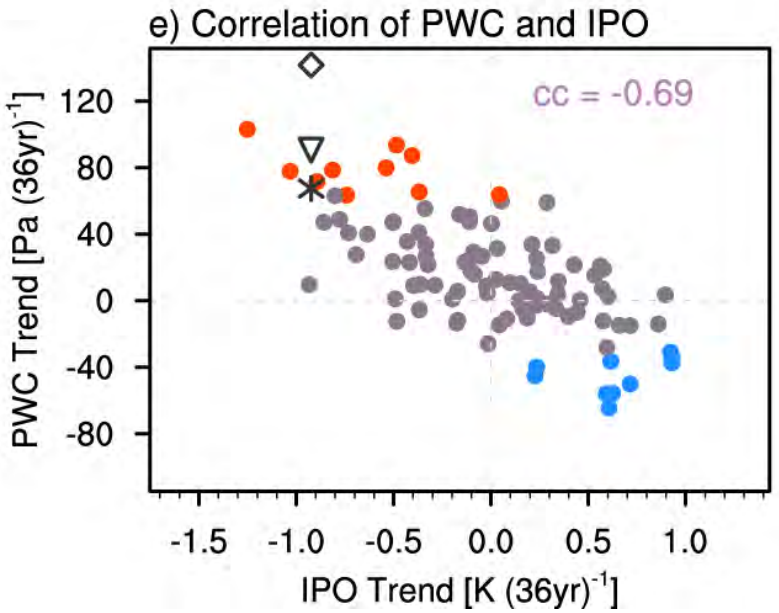
Introduction

Strengthening or **Weakening** of the WC?

The observations have shown a **strengthening** of the WC since 1979 which could be contributed by **internal variability**



Spatial distributions of trends in SST and wind at 850 hPa during 1980-2015 from observational dataset



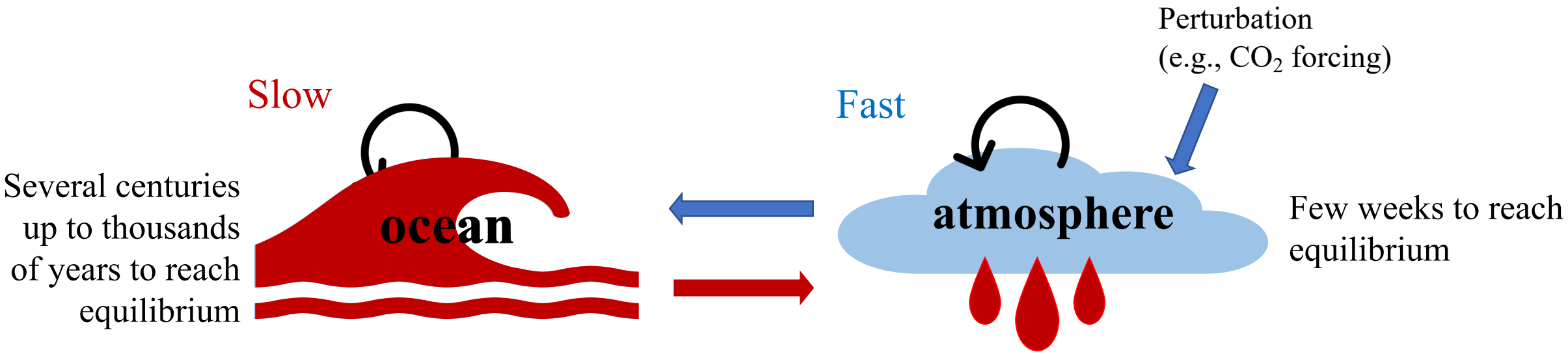
Scatter plot of Interdecadal Pacific Oscillation (IPO) index trends and PWC index trends during 1980-2015 among 100 MPI-GE members.

(Wu et al. 2021)

Introduction

Fast and Slow changes of the WC

Different mechanisms drive the changes of the WC at different time scales



- long-term warming of SST

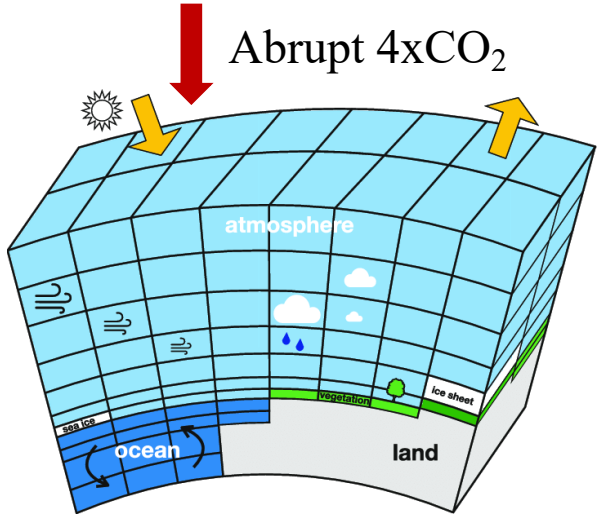
- Direct radiative (CO_2) forcing
- Land-sea thermal contrast
- Spatial pattern of SST changes

Introduction

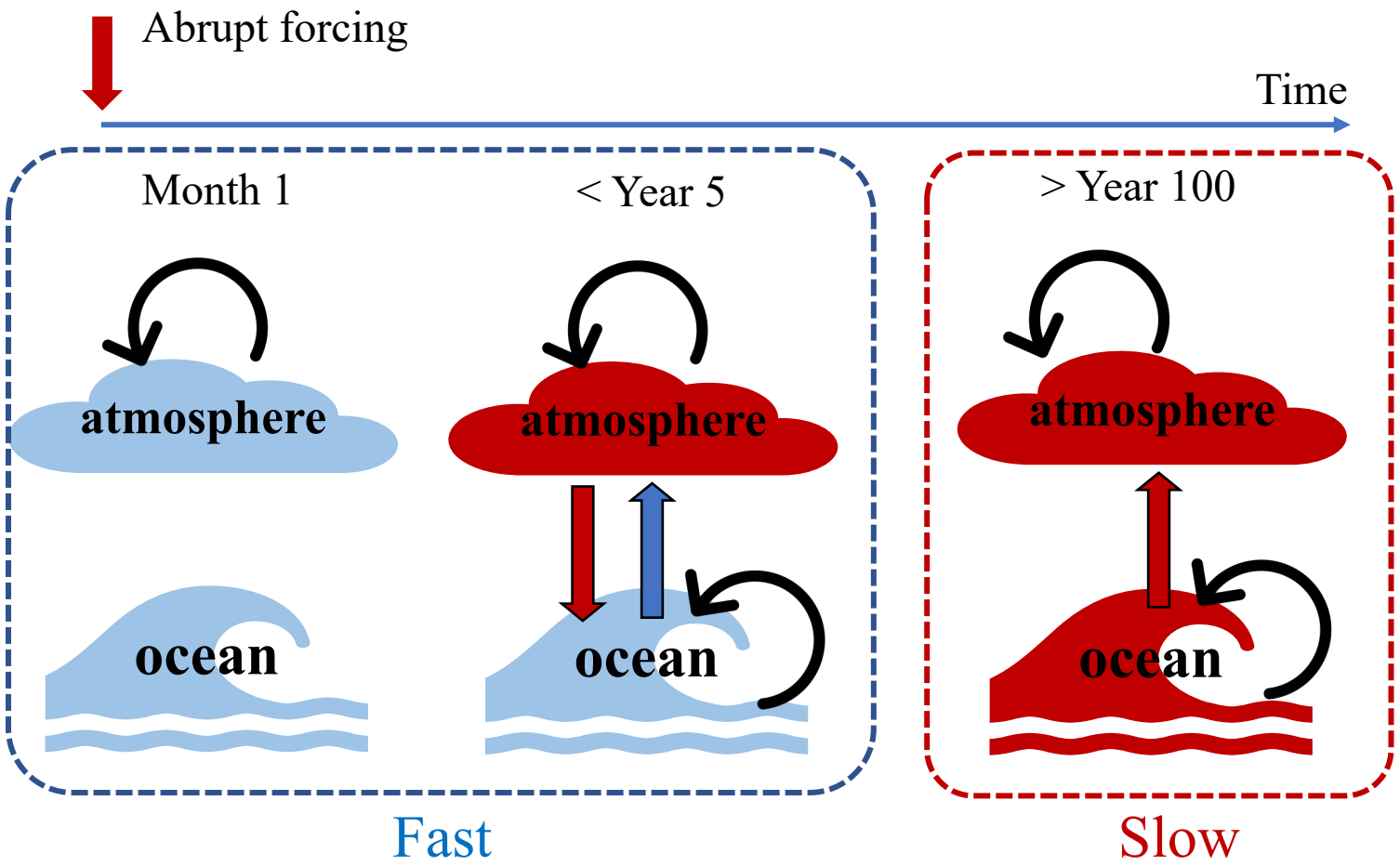
Fast and Slow changes of the WC

How do we separate fast and slow components?

Fixed-SST experiment
or
Fully coupled simulation
with abrupt forcing



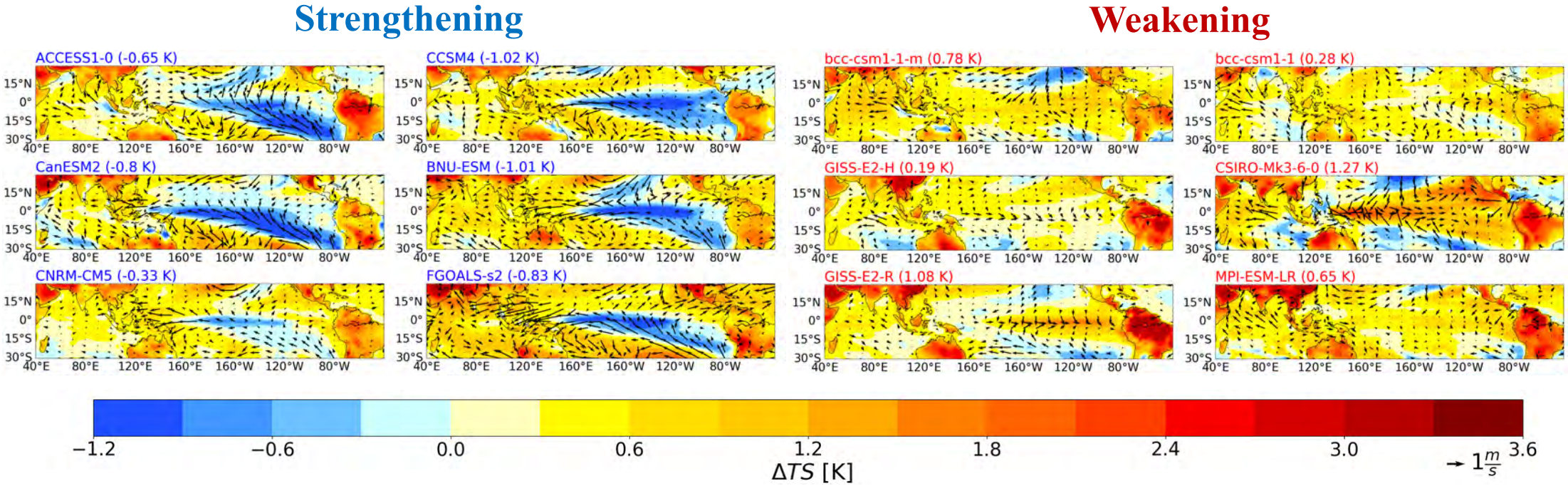
Fully coupled GCM



Introduction

Motivations of this study

- The interaction between the WC and SST especially during the fast response period is rarely investigated.
- What contribute to the inter-model discrepancy in the fast WC changes?

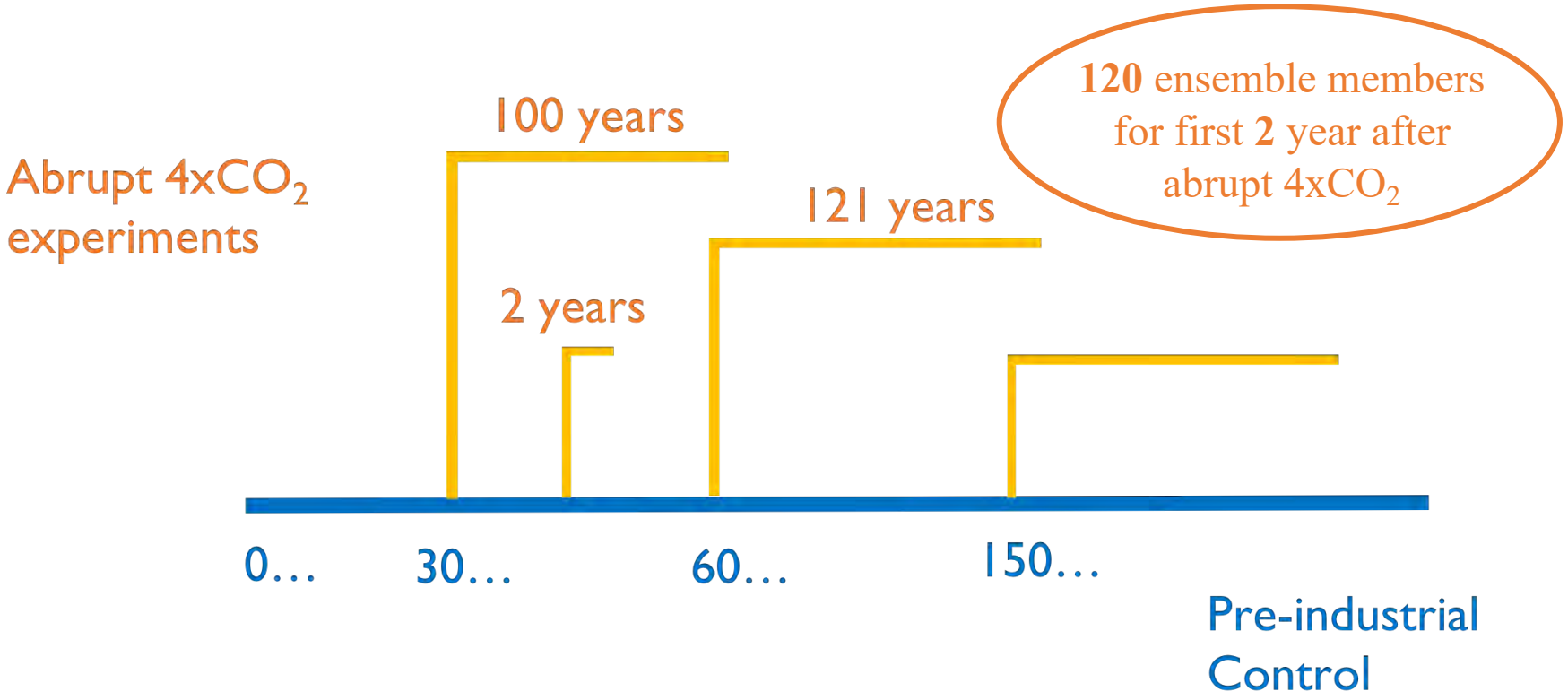


Changes in SST (shadings) and surface winds (vectors) averaged **over the first two years** in abrupt $4xCO_2$ experiment for randomly selected CMIP5 models

Method

CMIP5: 27 abrupt $4xCO_2$ model simulations from CMIP5 project. All the models are separated into the cold-group models (**CMIP5 CG**) and the warm-group models (**CMIP5 WG**).

CESM1 LE: Community Earth System Model v1 (CESM1) fully coupled model with 2° atmosphere and 1°ocean as resolution. The 120 ensembles are used to **eliminate internal variability**.



- Pre-industrial Control: 0-160 years
- $4xCO_2$ simulations branch off from different years as indicated
- Subtract control from $4xCO_2$ in the corresponding time to get one ensemble. Average all ensemble members

Method

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CESM1 LE: Community Earth System Model v1 (CESM1) fully coupled model with 2° atmosphere and 1°ocean as resolution. The 120 ensembles are used to **eliminate internal variability**.

Changes(Δ): $4\times CO_2 -$ pre-industrial control

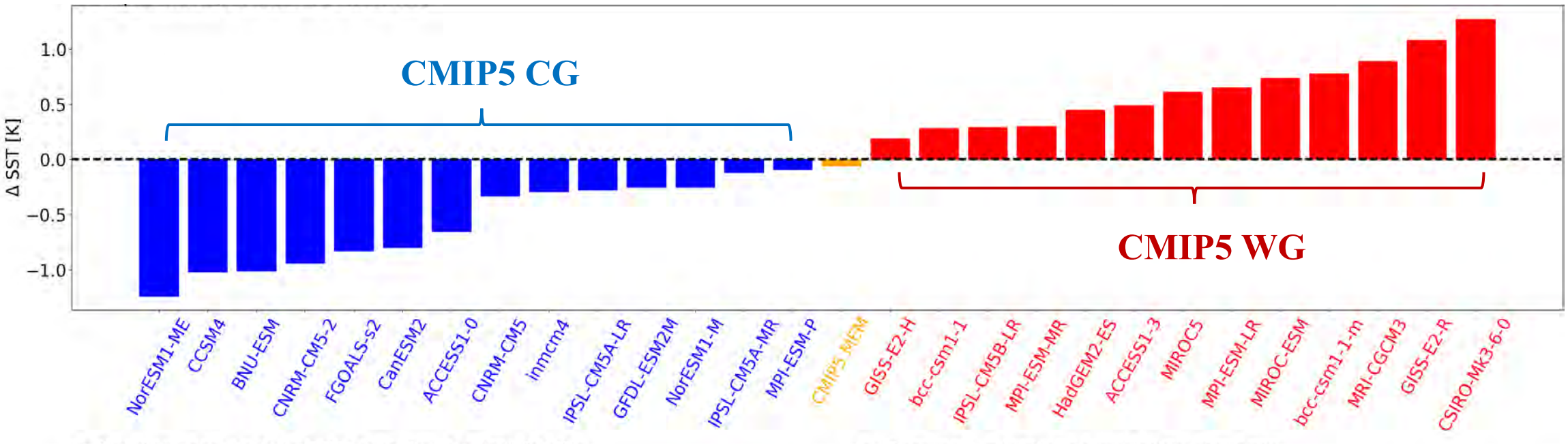
Total response:
Changes averaged over the last 30 years of the simulations

Fast response:
Any changes within the first two years

Slow response = **Total response** – **Fast response**

Method

Separation of CMIP5 cold-group models CG and warm-group models WG



SST changes in Niño 3.4 region among all 27 models in the first two years

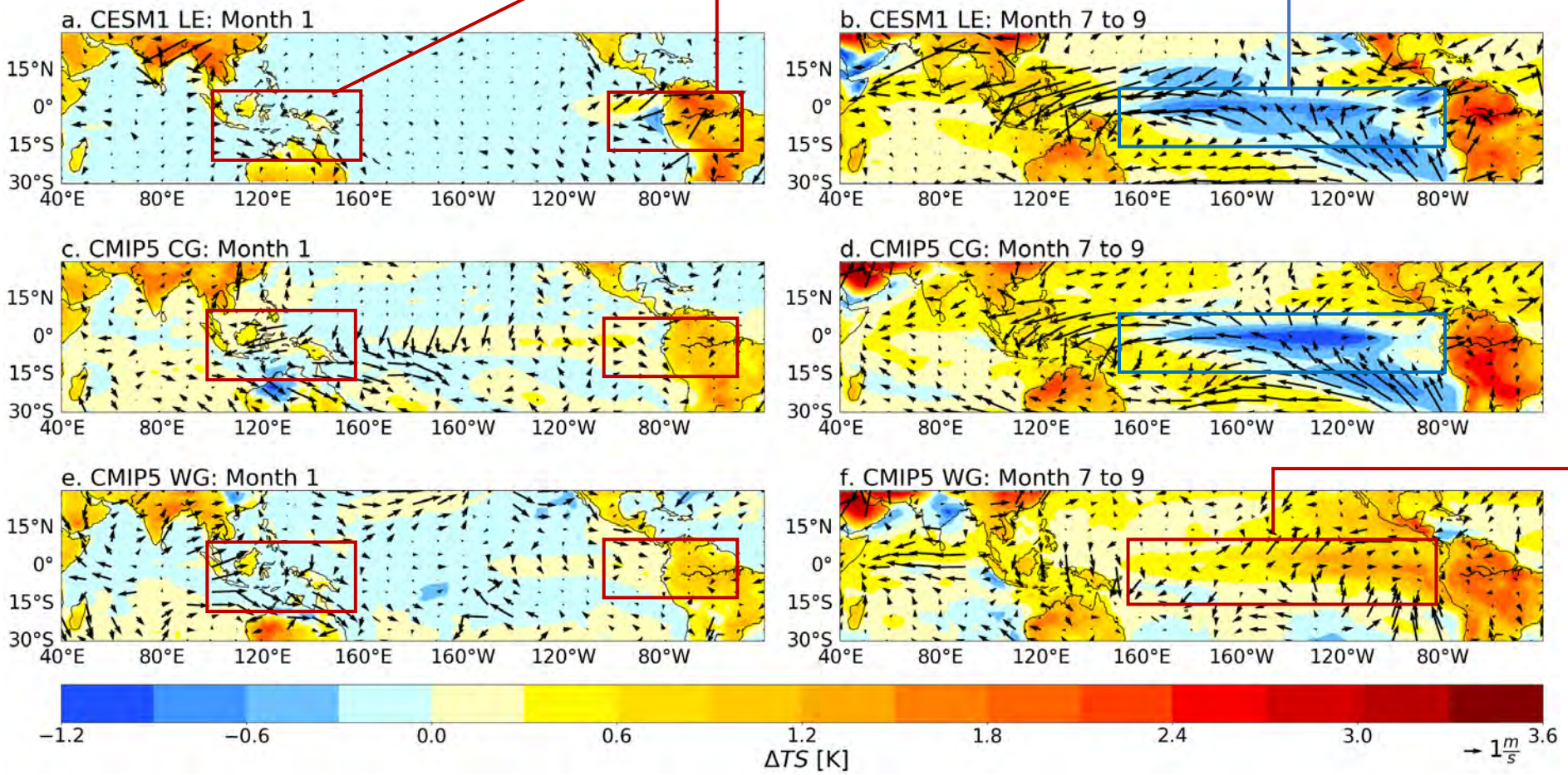
Results

Fast response

Immediately after abrupt $4xCO_2$

- Land-sea thermal contrast induces land-ward winds

- Central Pacific **cooling**
- Strong anomalous easterlies



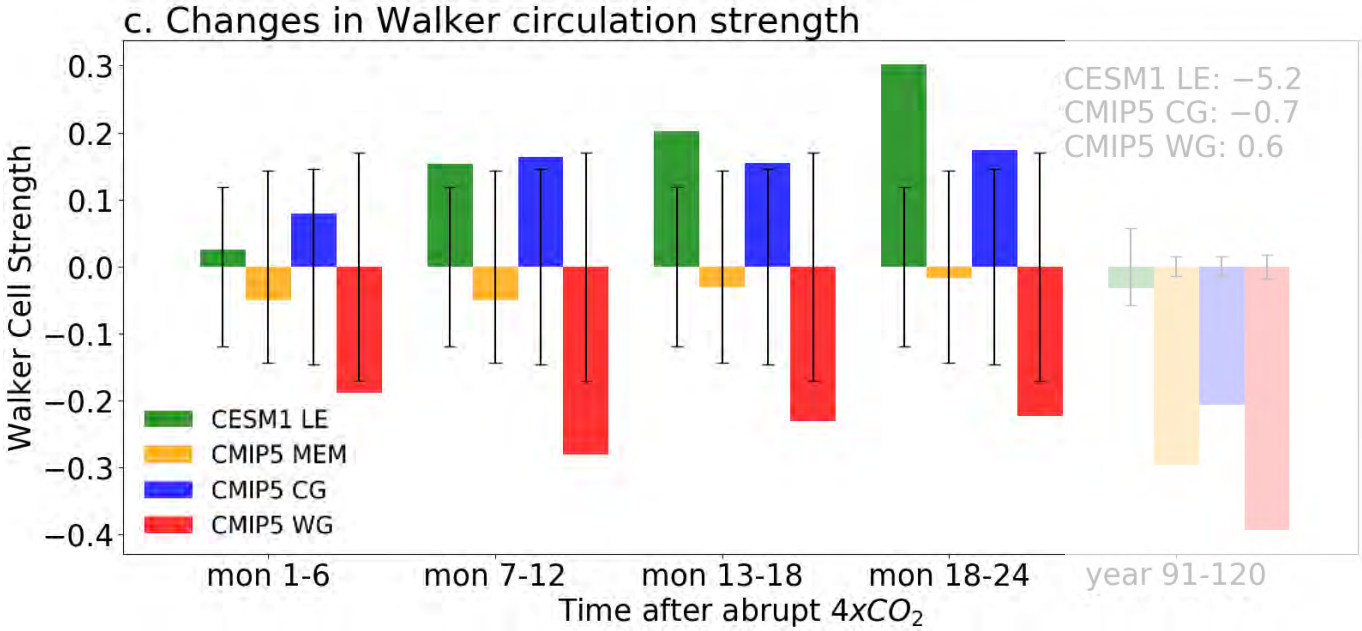
- Eastern Pacific **warming**
- No anomalous easterlies

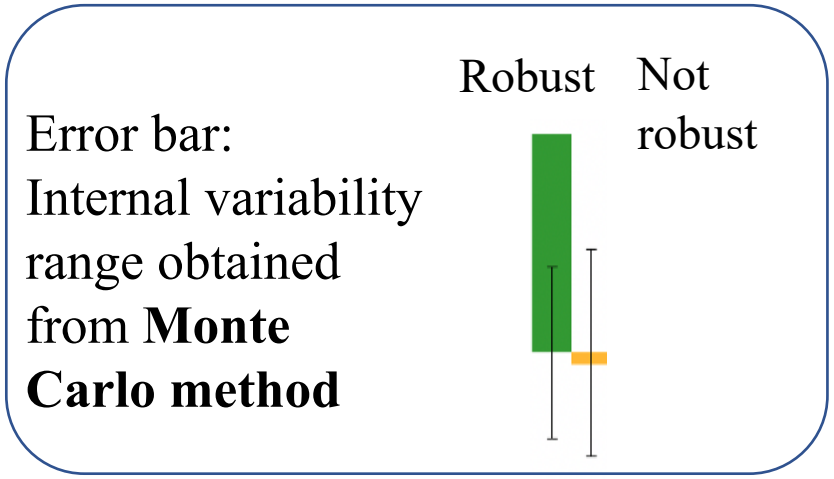
Results

Fast response

Why does fast response differ among models ?

1. Is the discrepancy robust (not contaminated by internal variability)? **Yes**





The WC strength is calculated as the difference of the 500 hPa pressure velocity between the Indian-West Pacific (50°–150°E and 10°S–10°N) and the central-east Pacific (210°–270°E and 10°S–10°N)

Results

Fast response

2. Does parent piControl simulations' ENSO state matter?

Maybe No

Model	E or L	Intensity	Model	E or L	Intensity
CMIP5 CG					
NorESM1-ME	E	1.06	CCSM4		
BNU-ESM	L	-1.33	CanESM2		
ACCESS1-0			NorESM1-M		
CNRM-CM5-2			IPSL-CM5A-LR	E	1.34
FGOALS-s2			IPSL-CM5A-MR		
inmcm4	E	0.522	MPI-ESM-P	E	1.52
CNRM-CM5	E	1.00	GFDL-ESM2M		
CMIP5 WG					
GISS-E2-H			MPI-ESM-MR	E	1.22
IPSL-CM5B-LR			bcc-csm1-1		
HadGEM2-ES			MIROC5		
ACCESS1-3			IPSL-CM5A-LR		
MIROC-ESM			bcc-csm1-1-m	E	1.62
GISS-E2-R			MRI-CGCM3		
CSIRO-Mk3-6-0					

The ENSO state in the parent pre-industrial simulations.

E: El Niño is happening when quadrupling CO_2

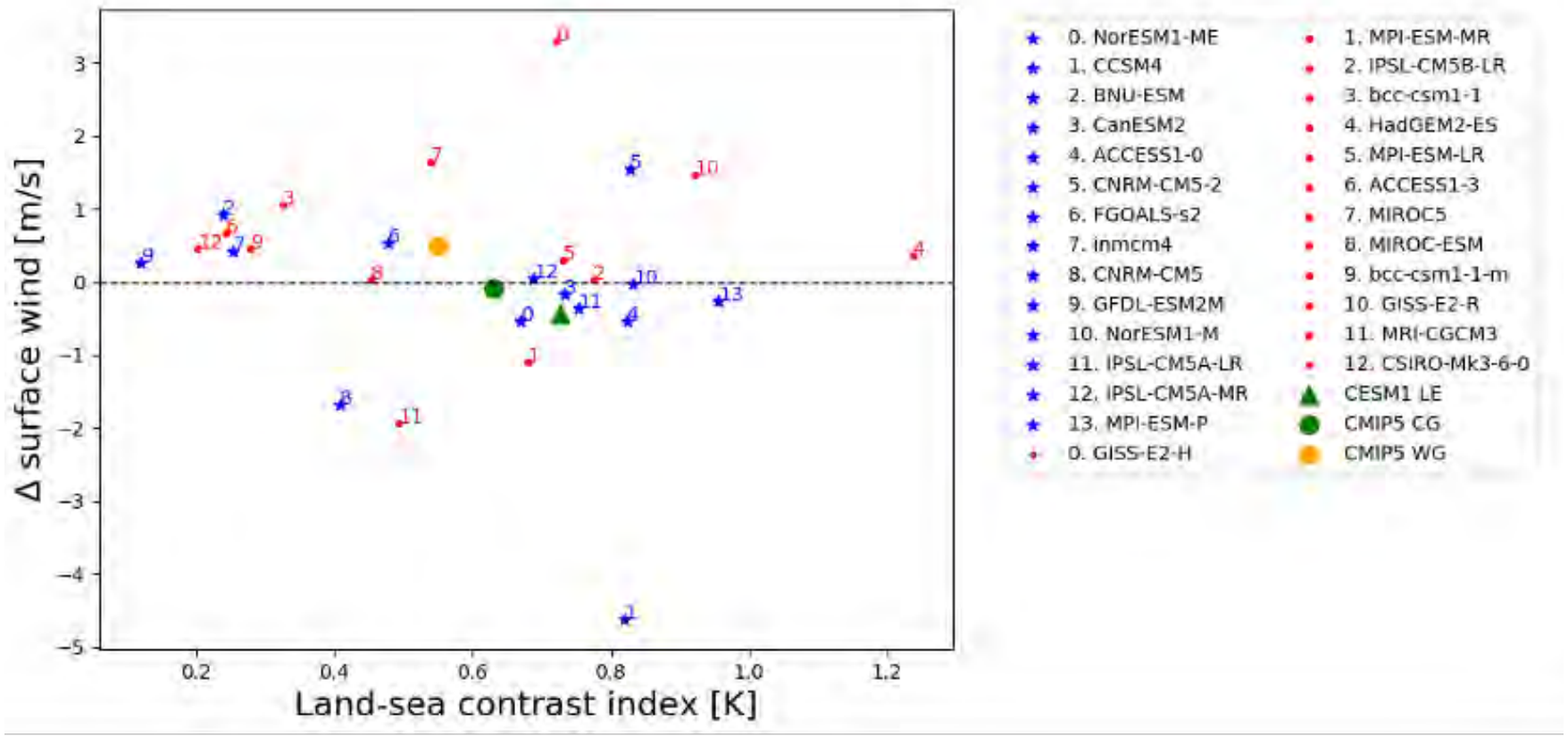
L: La Niña is happening when quadrupling CO_2

Results

Fast response

3. Is the discrepancy due to different land-sea thermal contrast among models?

No



Relationship between surface wind response in the warm pool and land-sea thermal contrast during the first three months

Results

Fast response

4. Does model simulate different air-sea coupling strength?

Quantify the models' air-sea interactions strength in the **pre-industrial** runs

Thermodynamic feedback — **TFI**

Bjerknes feedback — **BFI**

Zonal advection feedback — **ZFI**

$$Total\ FB = \underbrace{\frac{1}{\rho c_p h}\big(R(SW, SST) + R(LH, SST)\big)}_{\text{TFI}} + \underbrace{\frac{\overline{w}}{h} R(U_{850}, SST) R(D, U_{850}) R(T_e, D)}_{\text{BFI}} + \underbrace{\left(-\frac{\partial \overline{SST}}{\partial x} R(U_o, SST)\right)}_{\text{ZFI}}$$

Convective cloud feedback: < 0

WES feedback: > 0

BFI: > 0

ZFI: > 0

$R(Y, X)$: linear regression coefficients between two time series X and Y

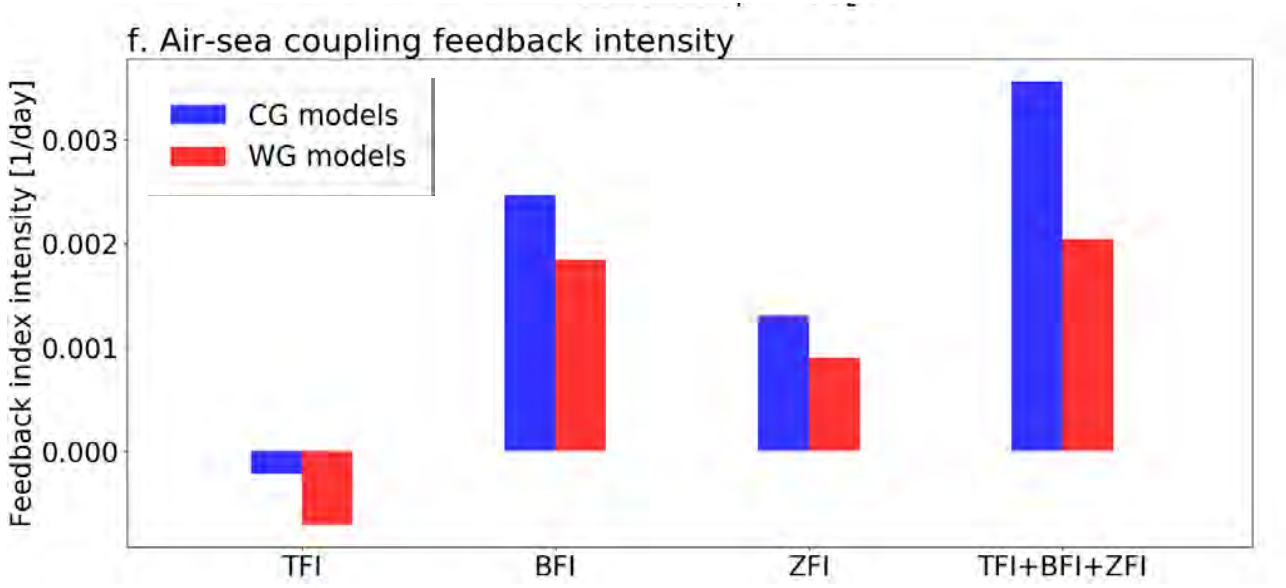
A **high** $Total\ FB$ indicates a more **sensitive** air-sea interaction

Results

Fast response

4. Does model simulate different air-sea coupling strength skills? **Yes**

$$Total\ FB = \underbrace{\frac{1}{\rho c_p h}\left(R(SW,SST) + R(LH,SST)\right)}_{\textbf{TFI}} + \underbrace{\frac{\overline{w}}{h} R(U_{850},SST)R(D,U_{850})R(T_e,D)}_{\textbf{BFI}} + \underbrace{\left(-\frac{\partial \overline{SST}}{\partial x} R(U_o,SST)\right)}_{\textbf{ZFI}}$$

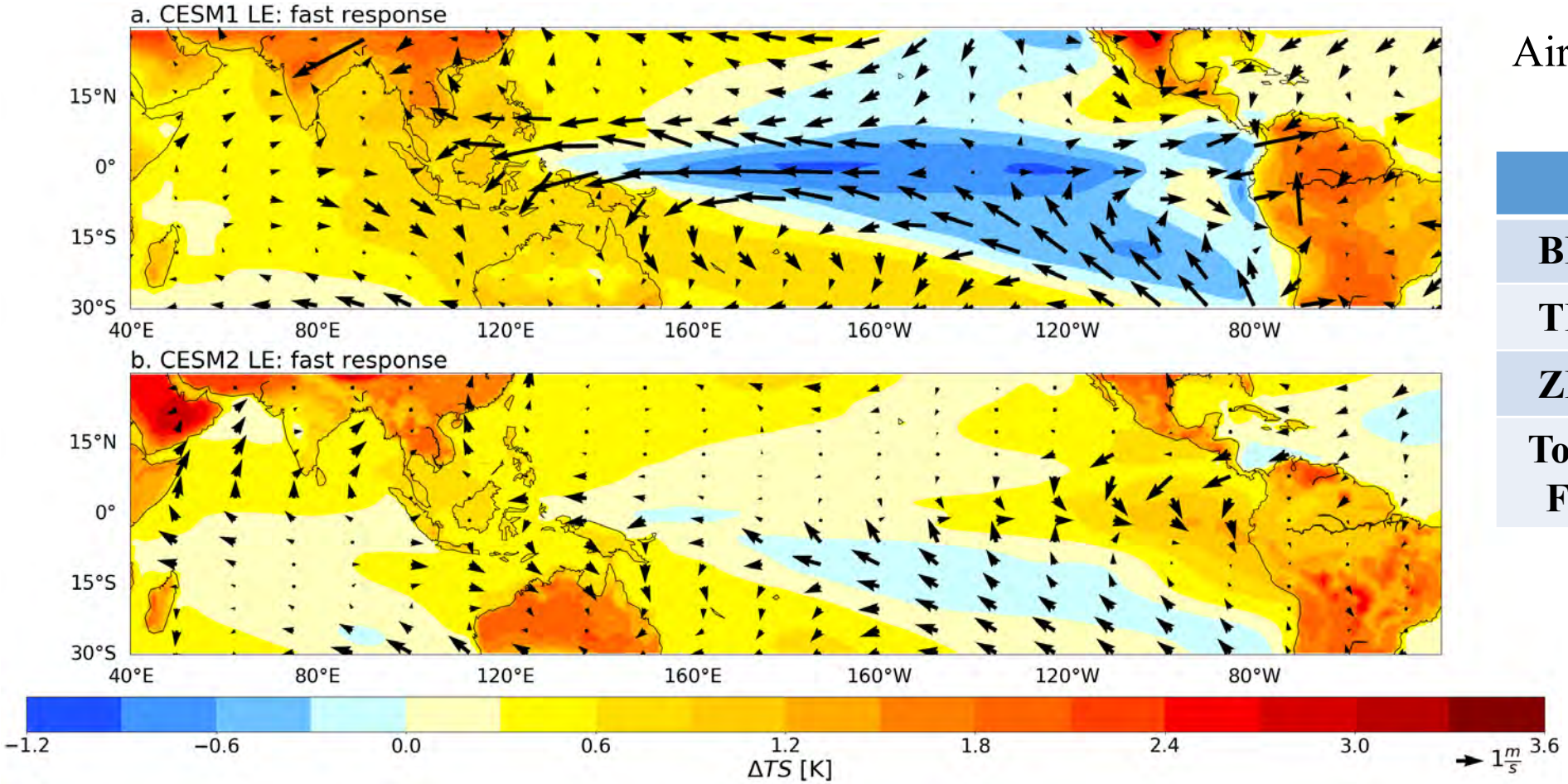


- CG models simulate stronger air-sea coupling
- Bjerknes feedback is easier to be triggered in the CG models than in the WG models

Results

Fast response

Comparison between CESM1 LE and CESM2 LE

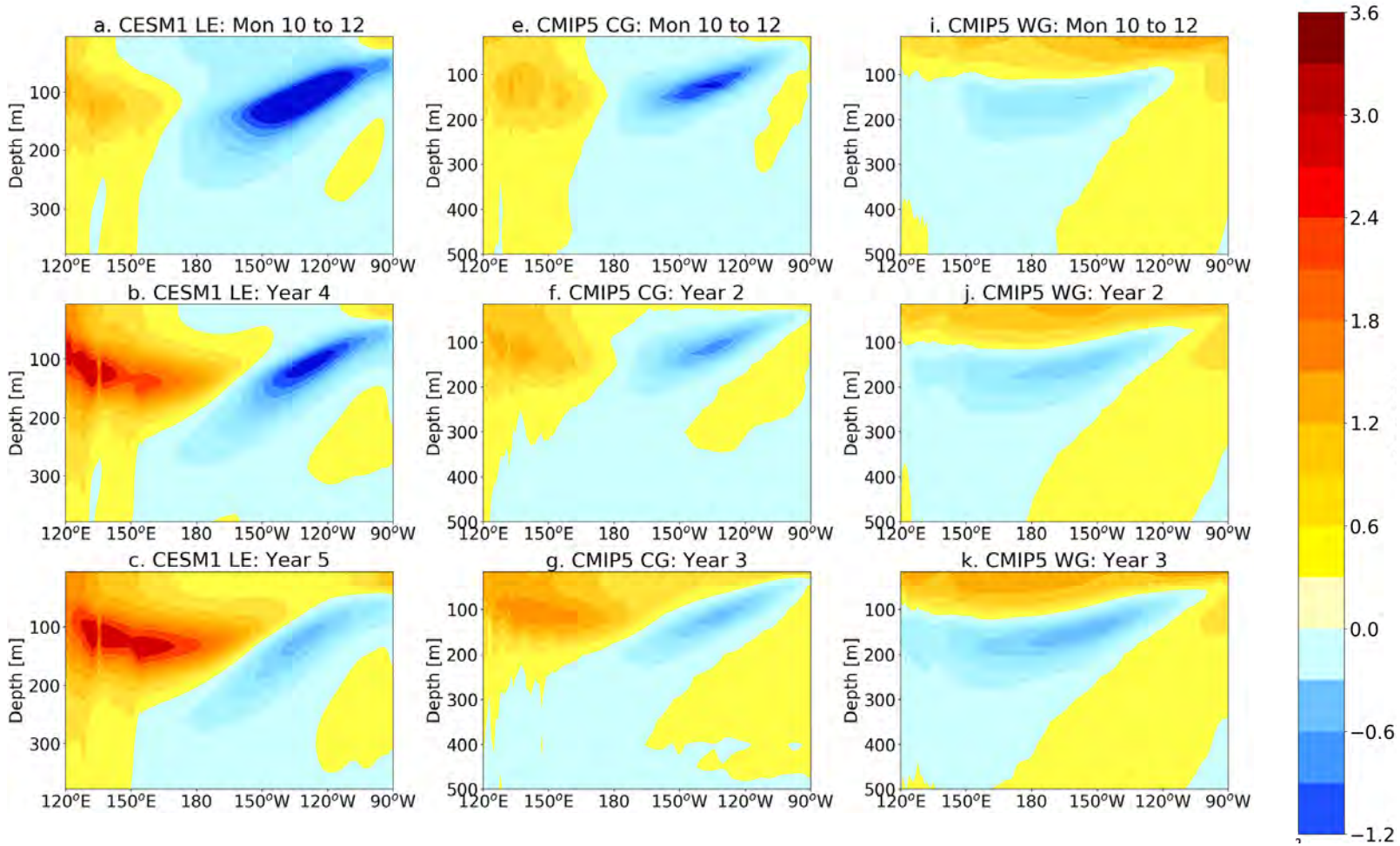


Air-sea coupling strength

	CESM1	CESM2
BFI	0.005	0.0009
TFI	5e-05	-1e-06
ZFI	0.0016	0.0014
Total FB	**0.0066**	**> 0.0023**

Results

From **fast** to **slow** response

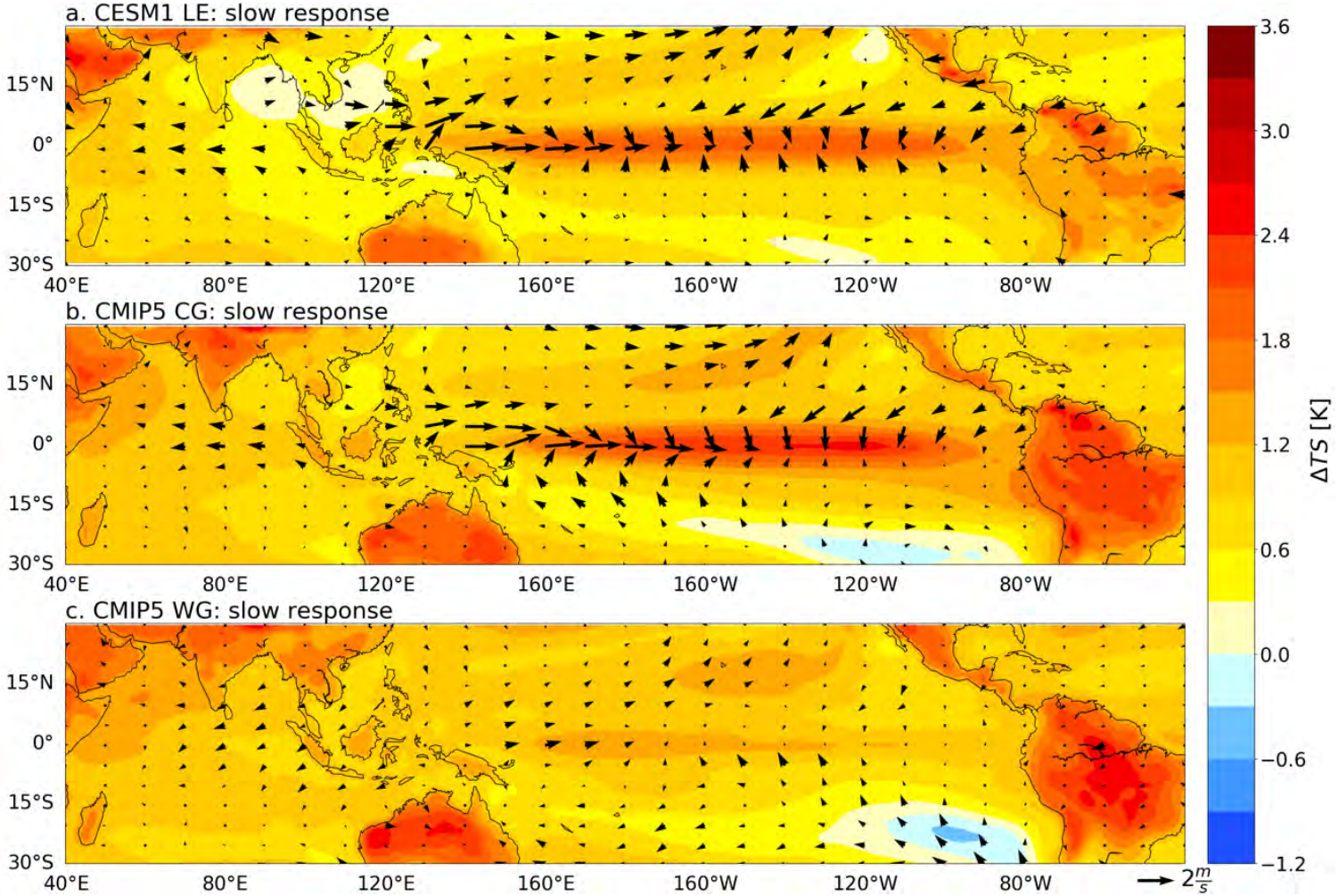


Time evolution of equatorial Pacific subsurface ocean temperature averaged over 2°S to 2°N

- Strong anomalous easterlies keep piling up warm water in the western equatorial Pacific
- Background warming gradually erases anomalous easterlies
- Downwelling oceanic Kelvin wave transports warm water from west to east

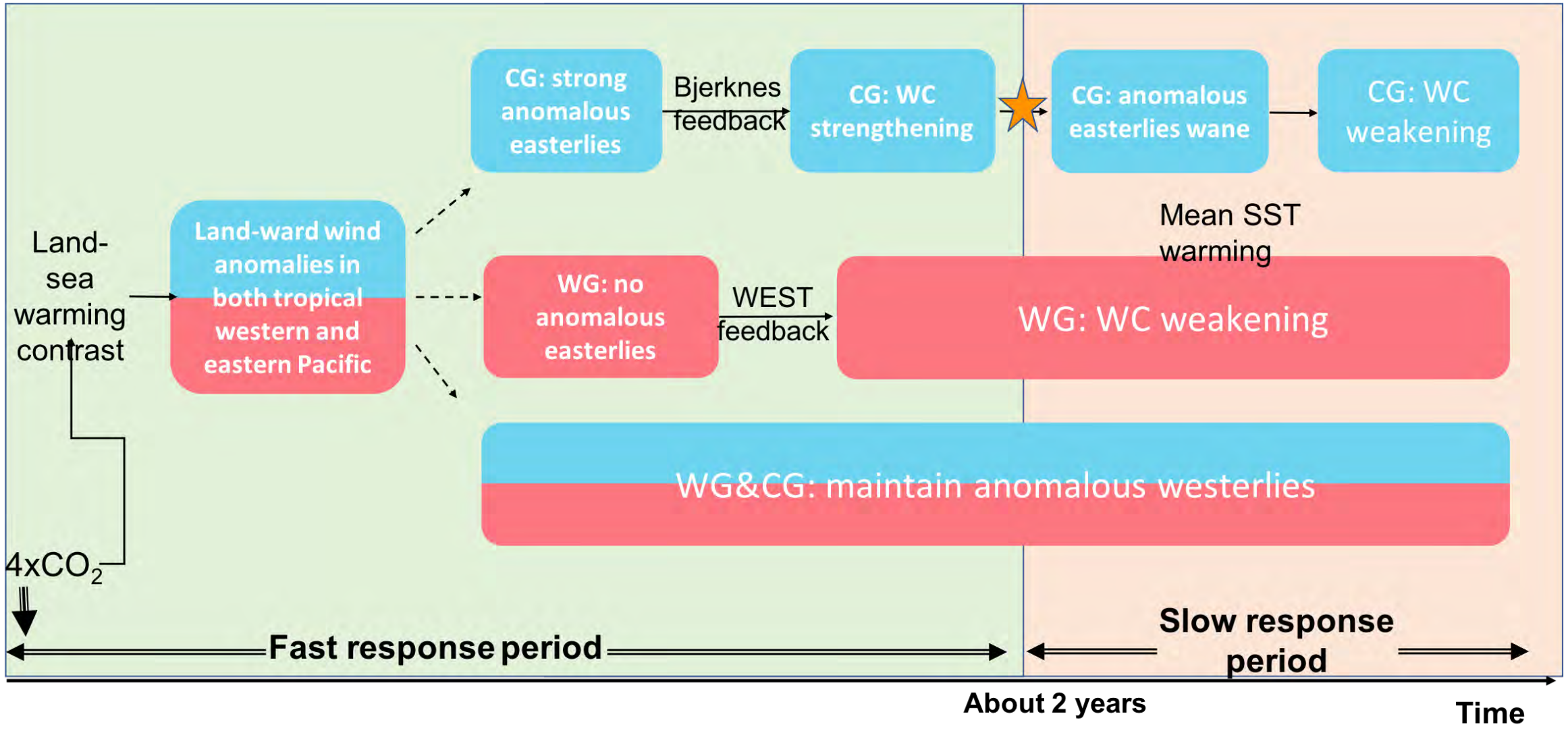
Results

Slow response



- Slow response features a **weakening** in most part of the WC
- Pattern of changes are similar across model groups

Summary


CG: strong anomalous easterlies
Bjerknes feedback
CG: WC strengthening
CG: anomalous easterlies wane
CG: WC weakening
Mean SST warming
Land-sea warming contrast
Land-ward wind anomalies in both tropical western and eastern Pacific
WG: no anomalous easterlies
WEST feedback
WG: WC weakening
WG&CG: maintain anomalous westerlies
4xCO2
Fast response period
Slow response period
About 2 years
Time

Q & A

Find out more in our paper:

Lu, K., He, J., Fosu, B., & Rugenstein, M. (2021). Mechanisms of fast Walker circulation responses to CO2 forcing. Geophysical Research Letters, 48, e2021GL095708.

Contact me here:

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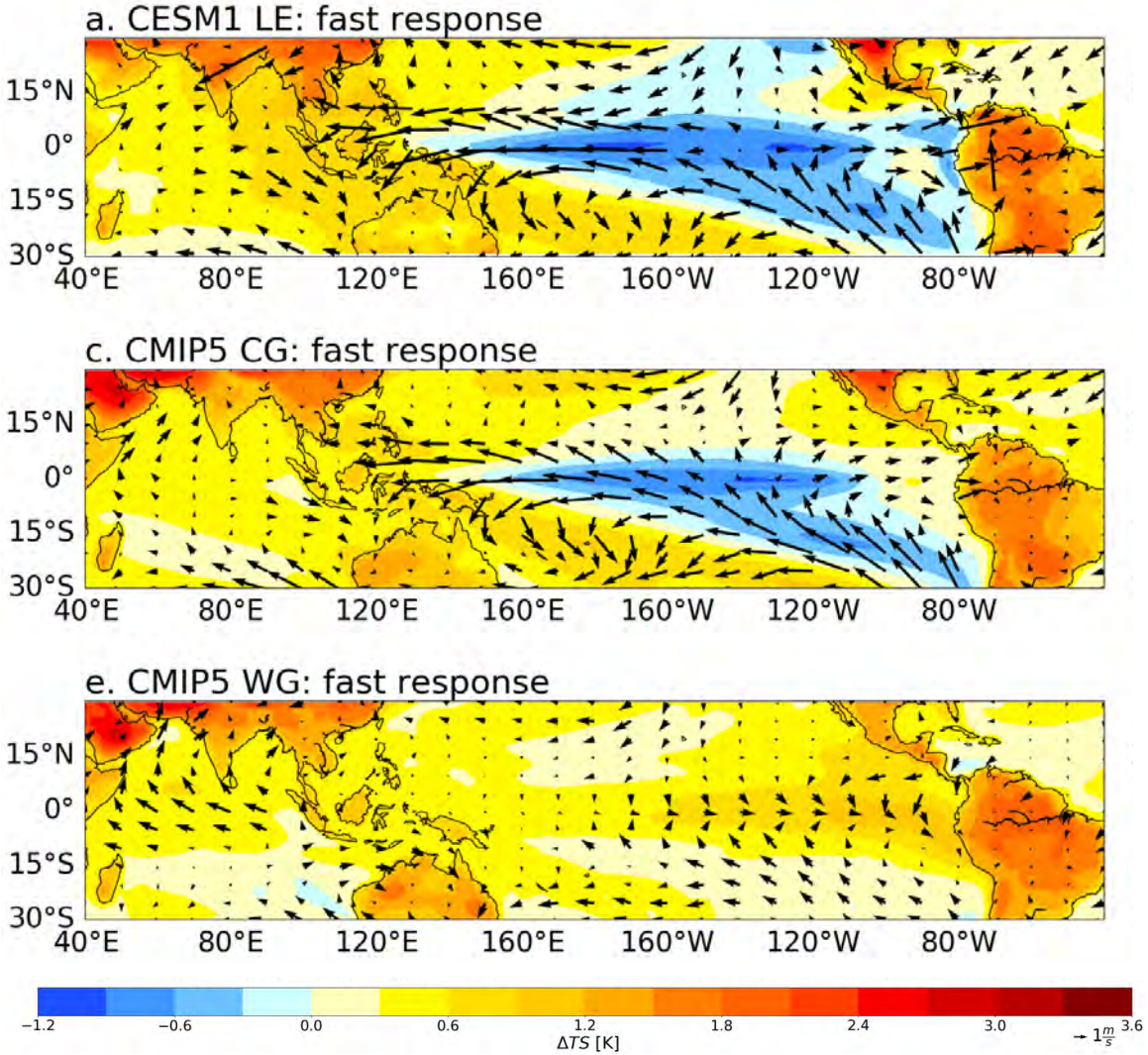
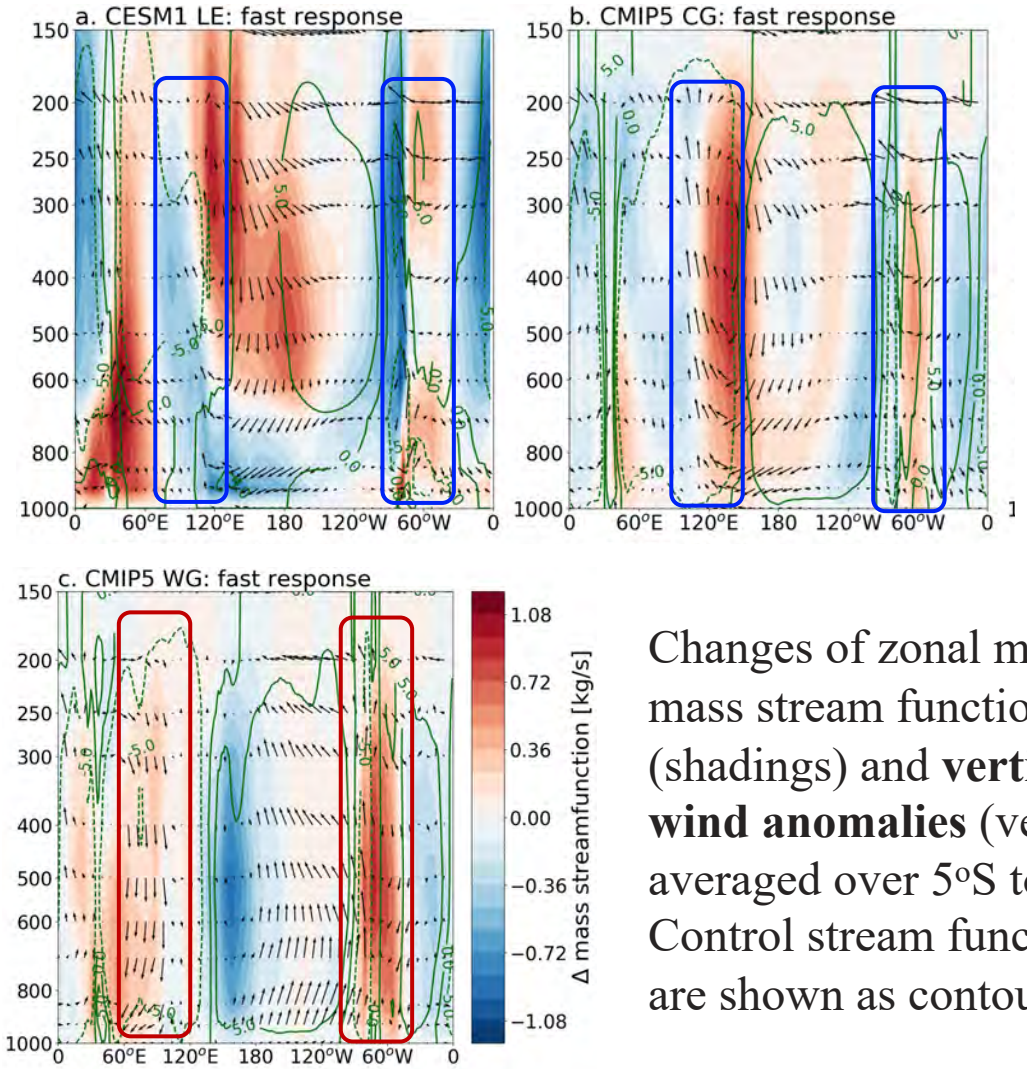
Extra

Fast response

First two years after abrupt 4xCO_2





Changes of zonal mean mass stream functions (shadings) and **vertical wind anomalies** (vectors) averaged over 5°S to 5°N. Control stream functions are shown as contours

Extra

Fast response – CESM1 LE and CESM2 LE