Sensitivity of the Pacific Cold Tongue and Double-ITCZ Biases to Convective Parameterization

Matthew Woelfle[1]
email: woelfle@atmos.washington.edu | twitter: @mdwoelfle

Sungduk Yu[2], Chris Bretherton[1], Mike Pritchard[2]
[1]University of Washington, Seattle, WA [2]University of California-Irvine, Irvine, CA

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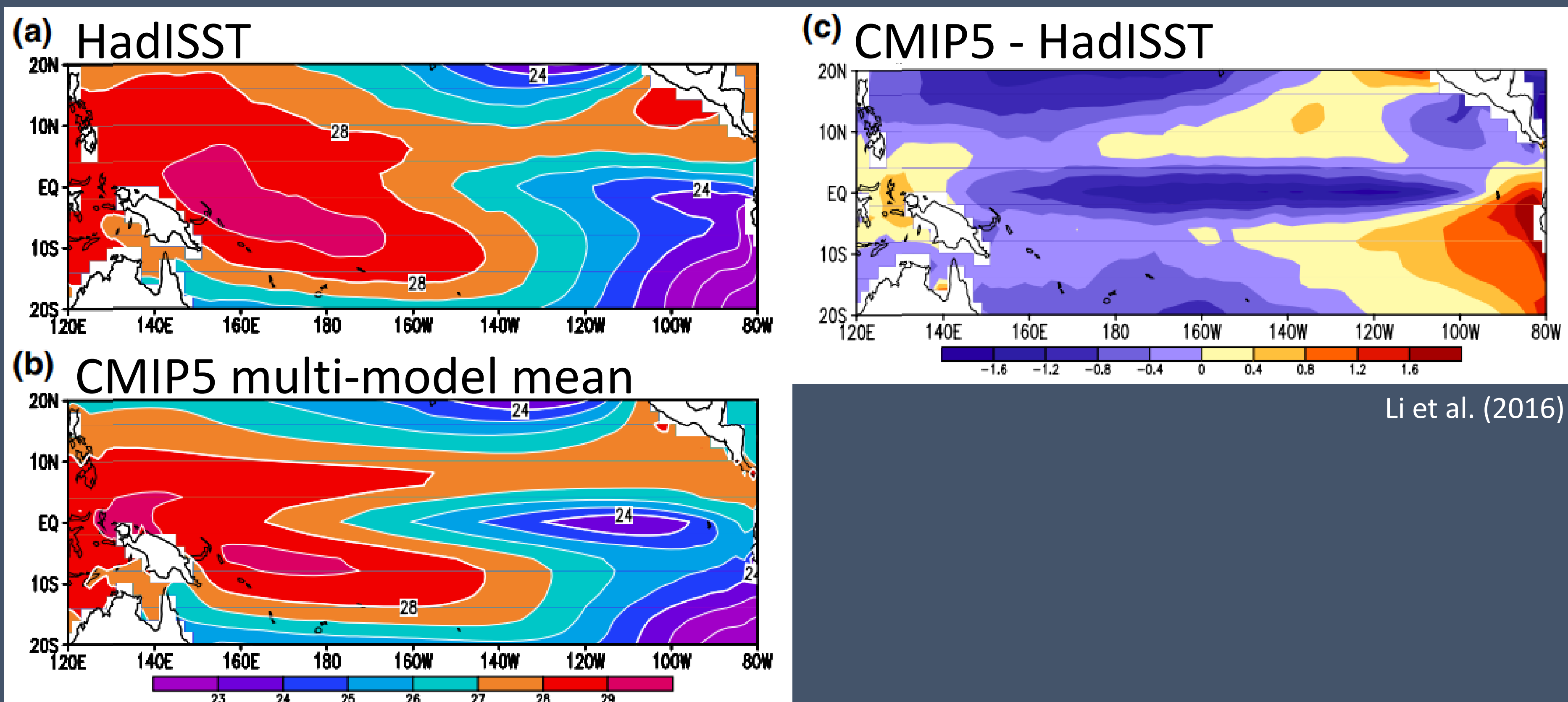
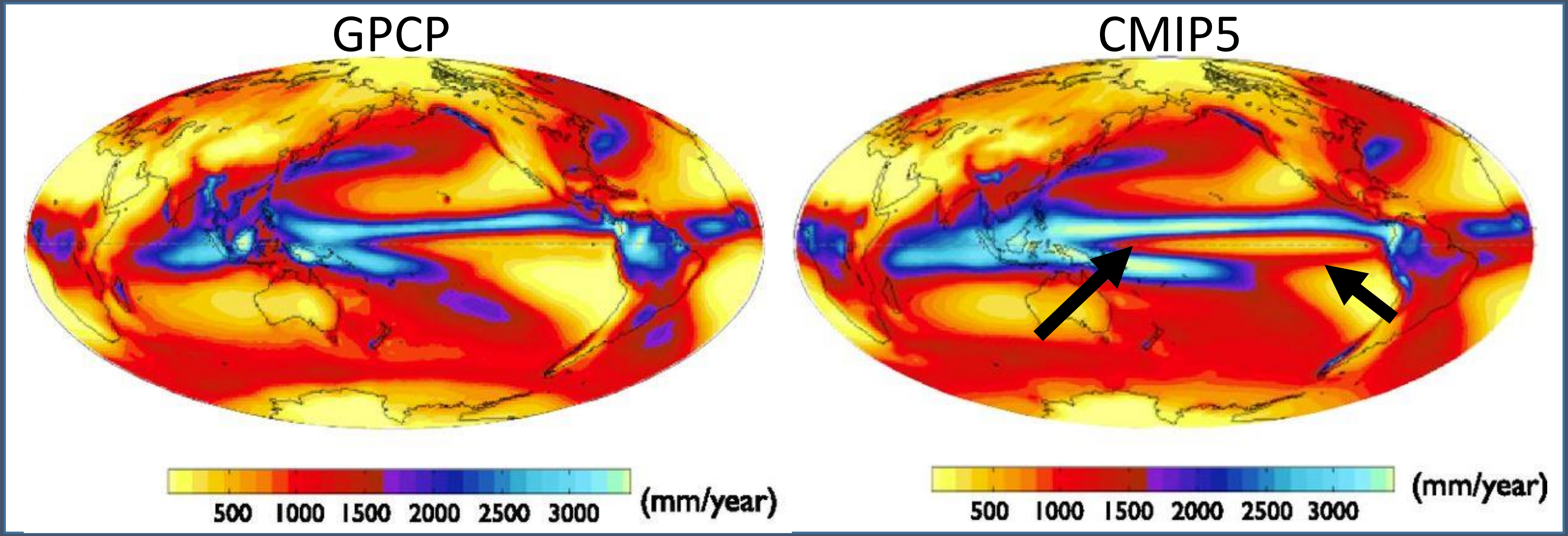
High-performance computing support from Yellowstone (ark:/85065/d7wd3xhc) was provided by NCAR's Computational and Information Systems Laboratory, sponsored by the National Science Foundation.

Simulated equatorial sea surface temperatures are too cold.



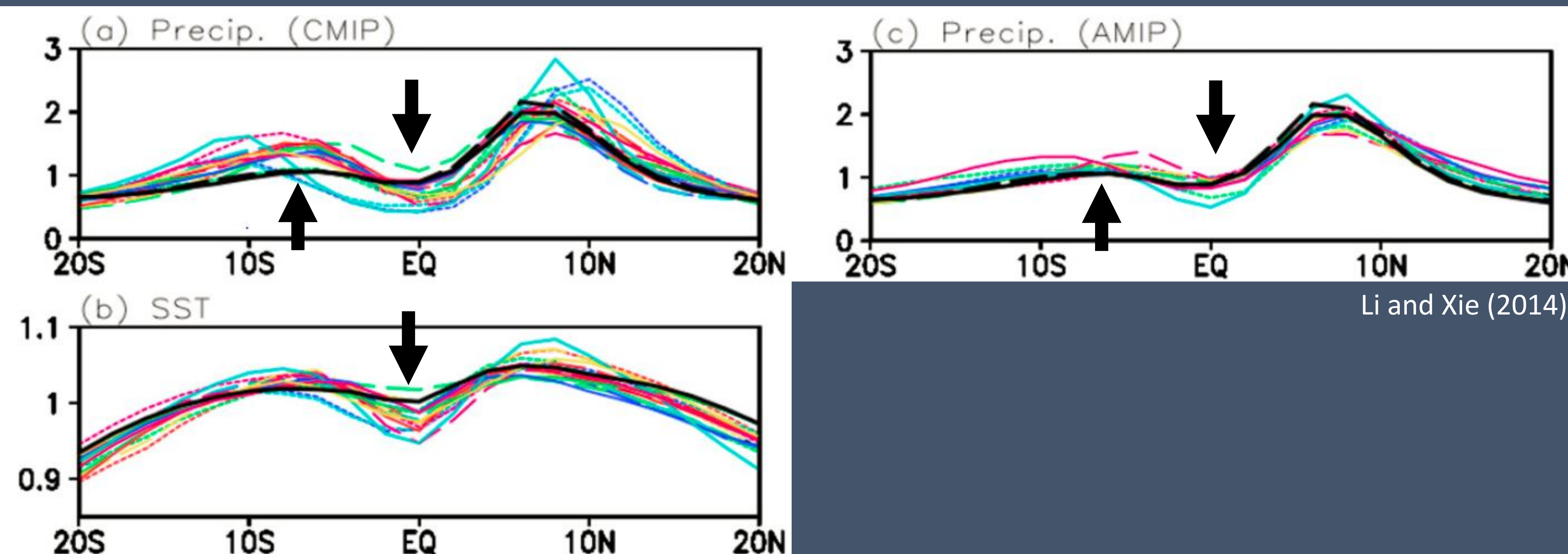
Li et al. (2016)

Excess rainfall in the southeast Pacific; Insufficient rainfall on the equator



Hwang and Frierson (2013)

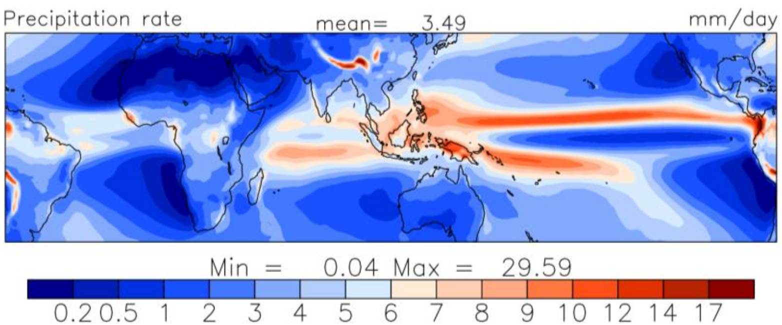
Precipitation biases amplified when coupled.



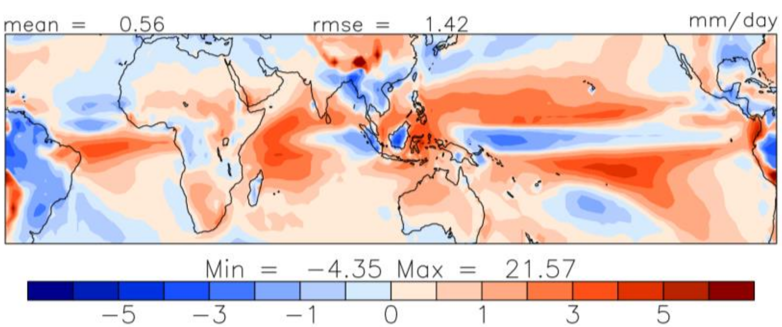
Li and Xie (2014)

These biases are found in the CESM-LENS.

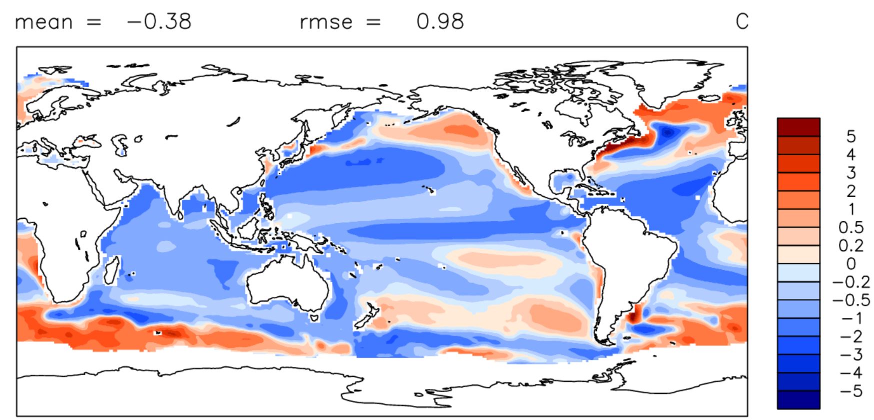
Precipitation (LENS.002)



Precipitation (LENS.002-GPCP)



SST (LENS.002-HadISST)



http://www.cesm.ucar.edu/experiments/cesm1.1/LE/

Suggested bias sources

- Extratropical controls
  - e.g. Hwang and Frierson (2013); Kay et al. (2016); Hawcroft et al. (2016)
- Coupled ocean-atmosphere feedbacks
  - e.g. Zhang et al. (2007), Liu et al. (2012)
- Inadequate convective parameterization
  - e.g. Song and Zhang (2009), Oueslati and Bellon (2015)

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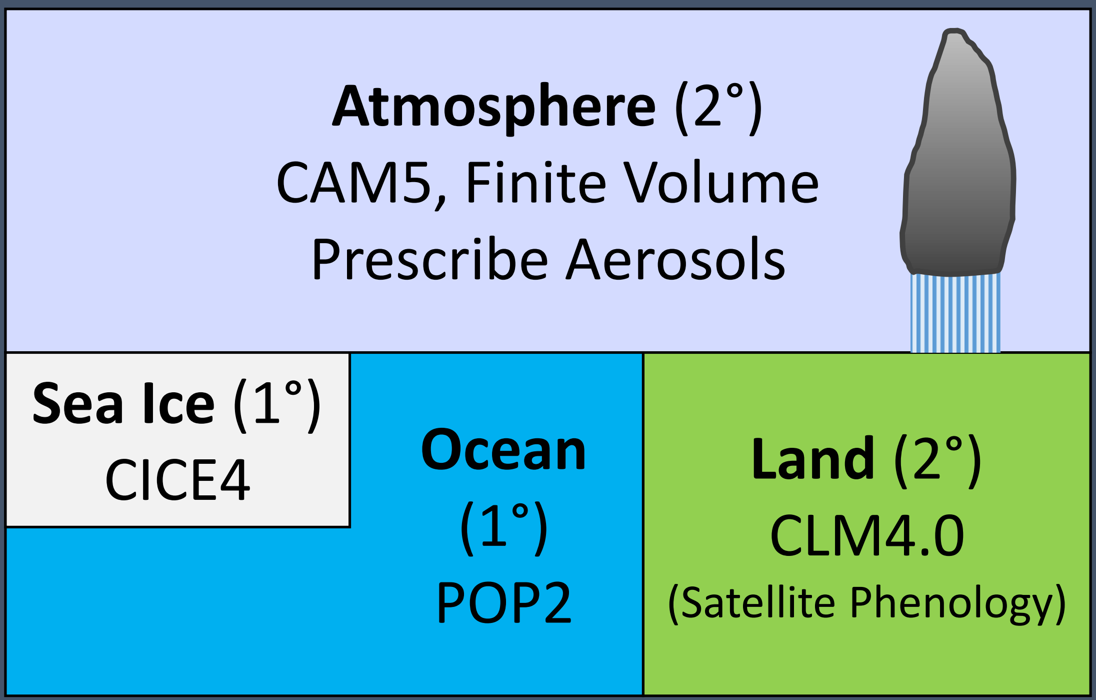
If convection plays a key role in coupled tropical feedbacks related to the double-ITCZ and cold tongue biases, **perturbations to convective parameterization should influence the development of these biases.**

Model simulations use CESM1



Comparison datasets

GPCP (Huffman et al., 2009)

- Precipitation

SODA (Carton and Geiss, 2008)

- Sea surface temperature (SST)
- Surface wind stress (τ)
- Ocean velocities

Simulation plan

[1] Spin up model components

Ocean/Sea Ice
(CORE2 Forced;
Large and Yeager, 2009)

Atmosphere IC
(ERA Interim)

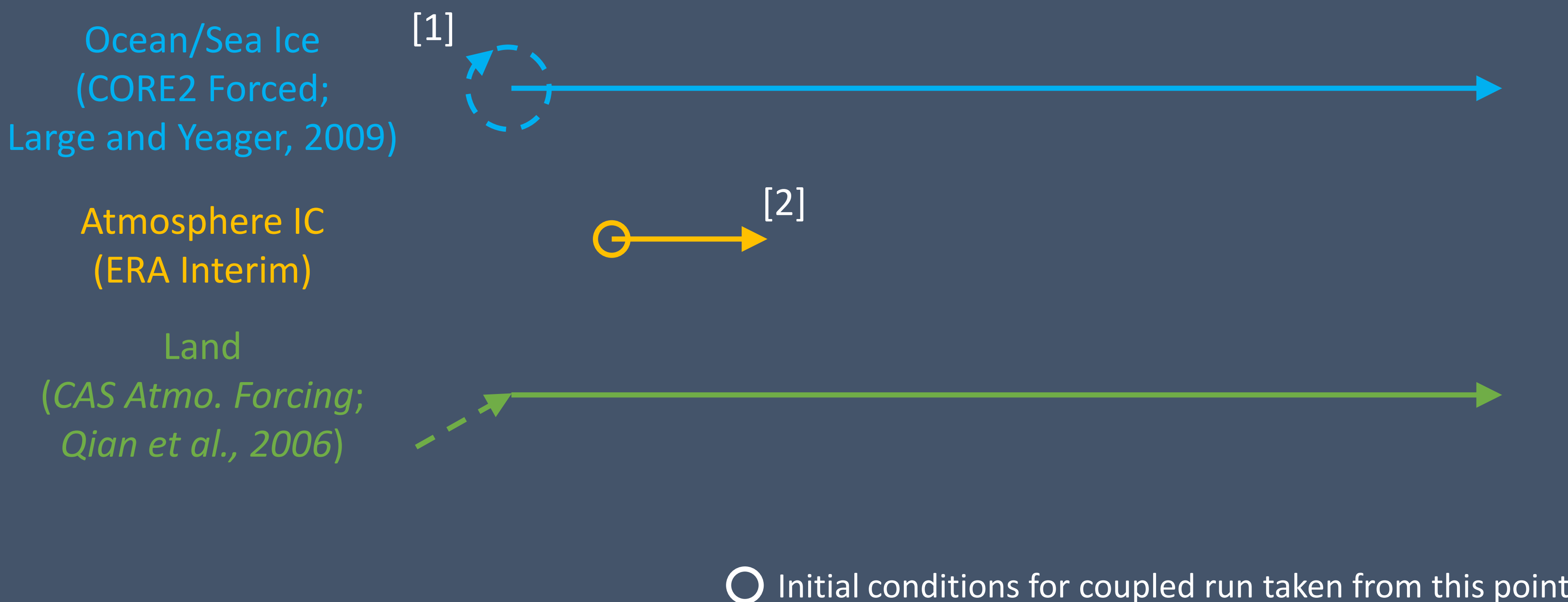
Land
(*CAS Atmo. Forcing;*
Qian et al., 2006)

○ Initial conditions for coupled run taken from this point

Simulation plan

[1] Spin up model components

[2] Run stand alone models forward

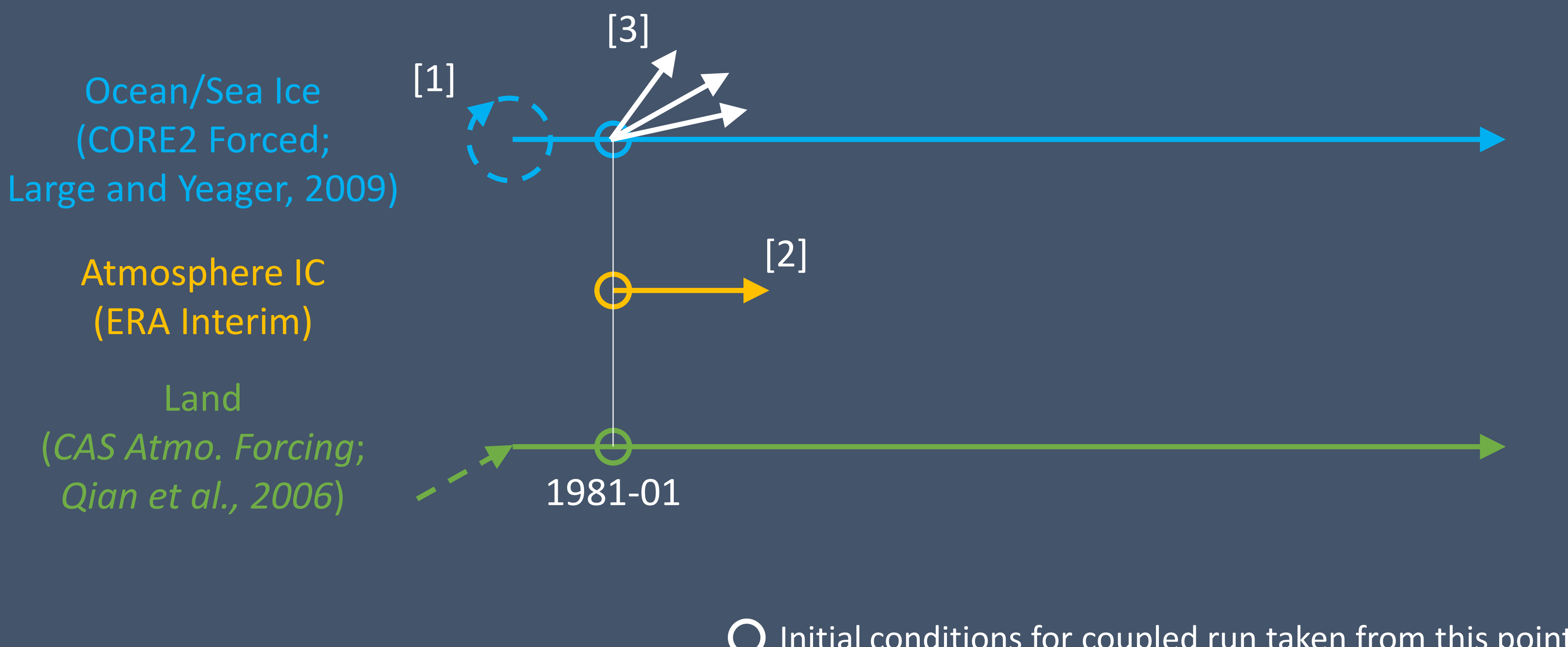


Simulation plan

[1] Spin up model components

[2] Run stand alone models forward

[3] Initialize fully coupled simulations from stand alone simulations



Simulation plan

[1] Spin up model components

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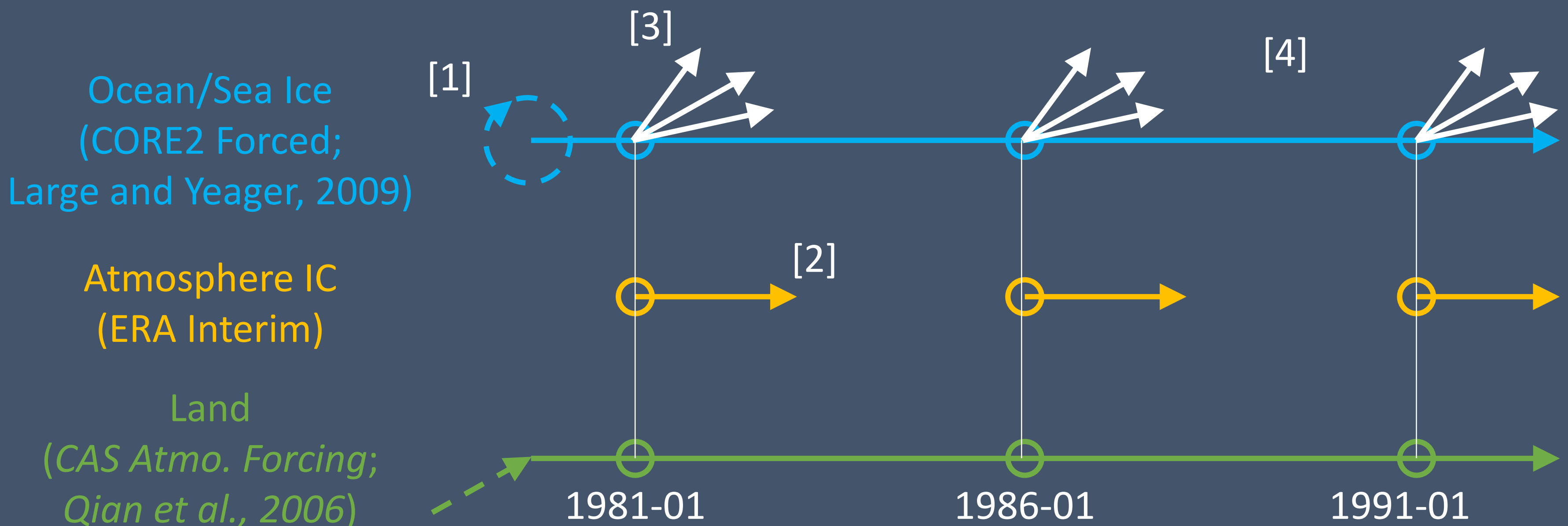
[3] Initialize fully coupled simulations from stand alone simulations

[4] Repeat [2,3] for multiple start dates



Initial conditions for coupled run taken from this point

Simulation plan

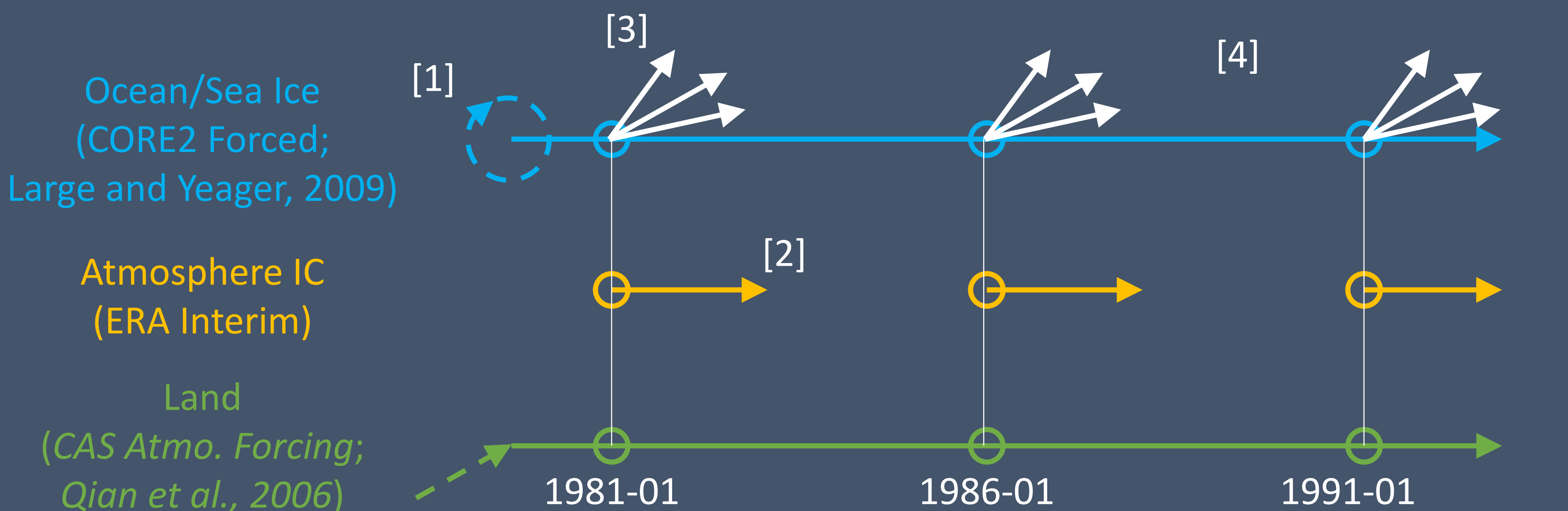
[1] Spin up model components

[2] Run stand alone models forward

[3] Initialize fully coupled simulations from stand alone simulations

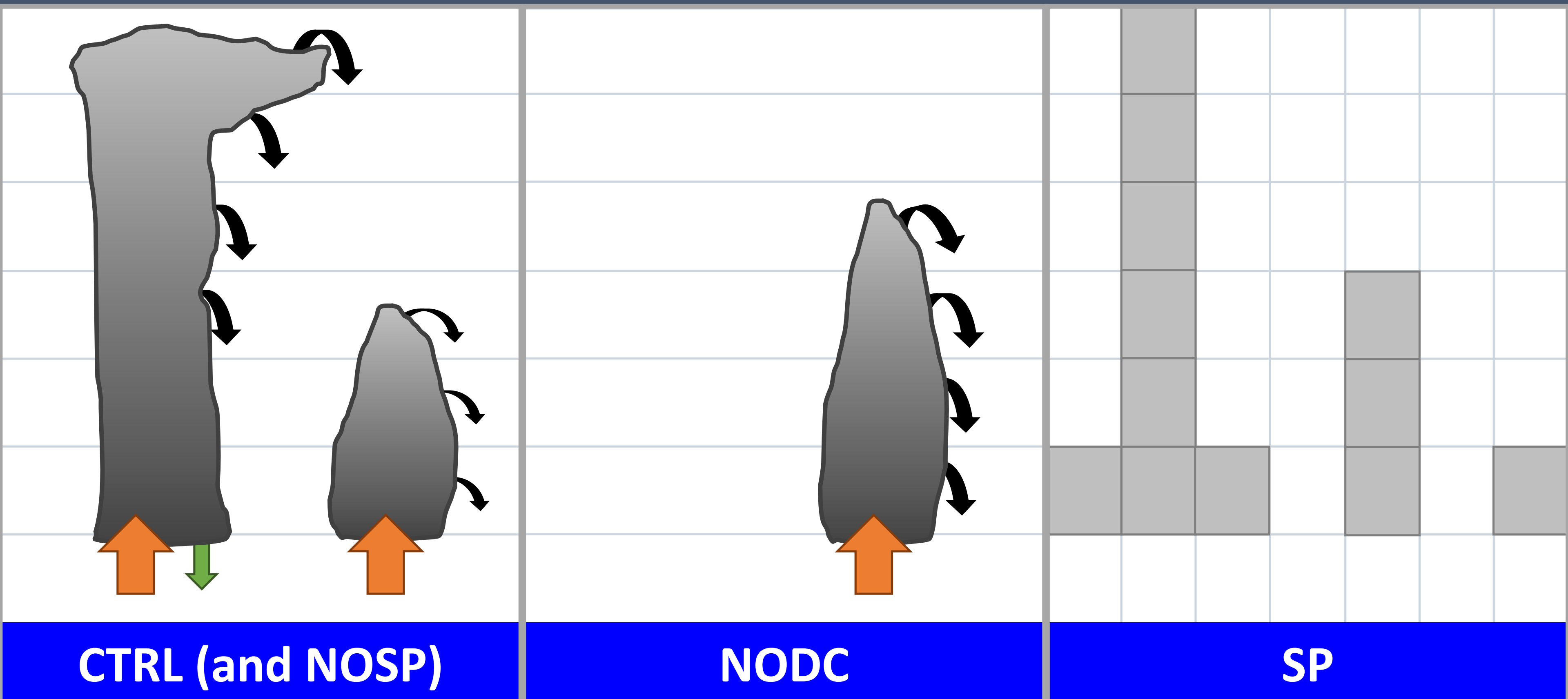
[4] Repeat [2,3] for multiple start dates

[5] Repeat [1-4] for multiple convective parameterizations



○ Initial conditions for coupled run taken from this point

Convective parameterizations used

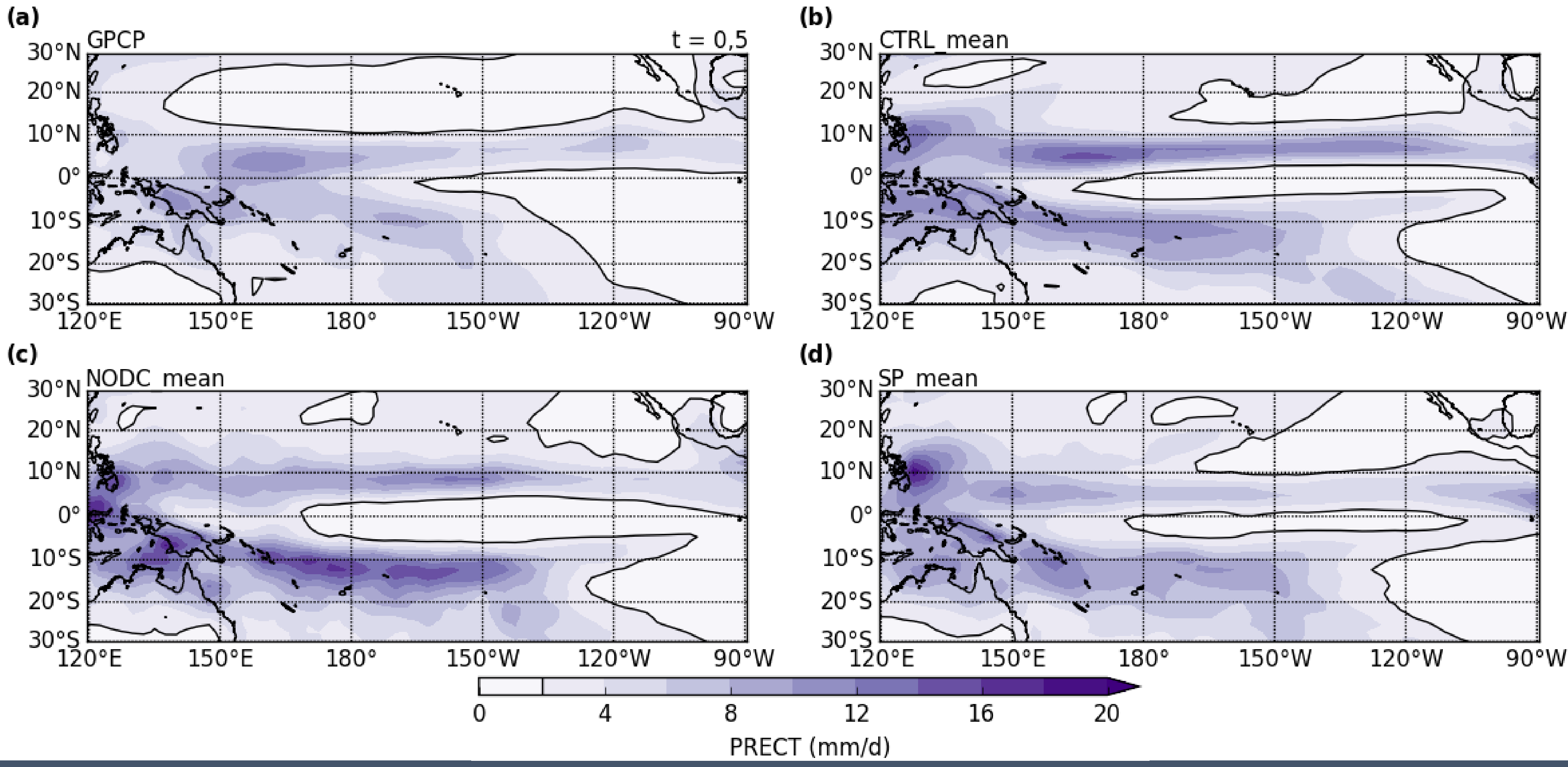


CTRL (and NOSP)
UW ShCu (Park and Bretherton, 2009)
ZM DC (Zhang and McFarlane, 1995)

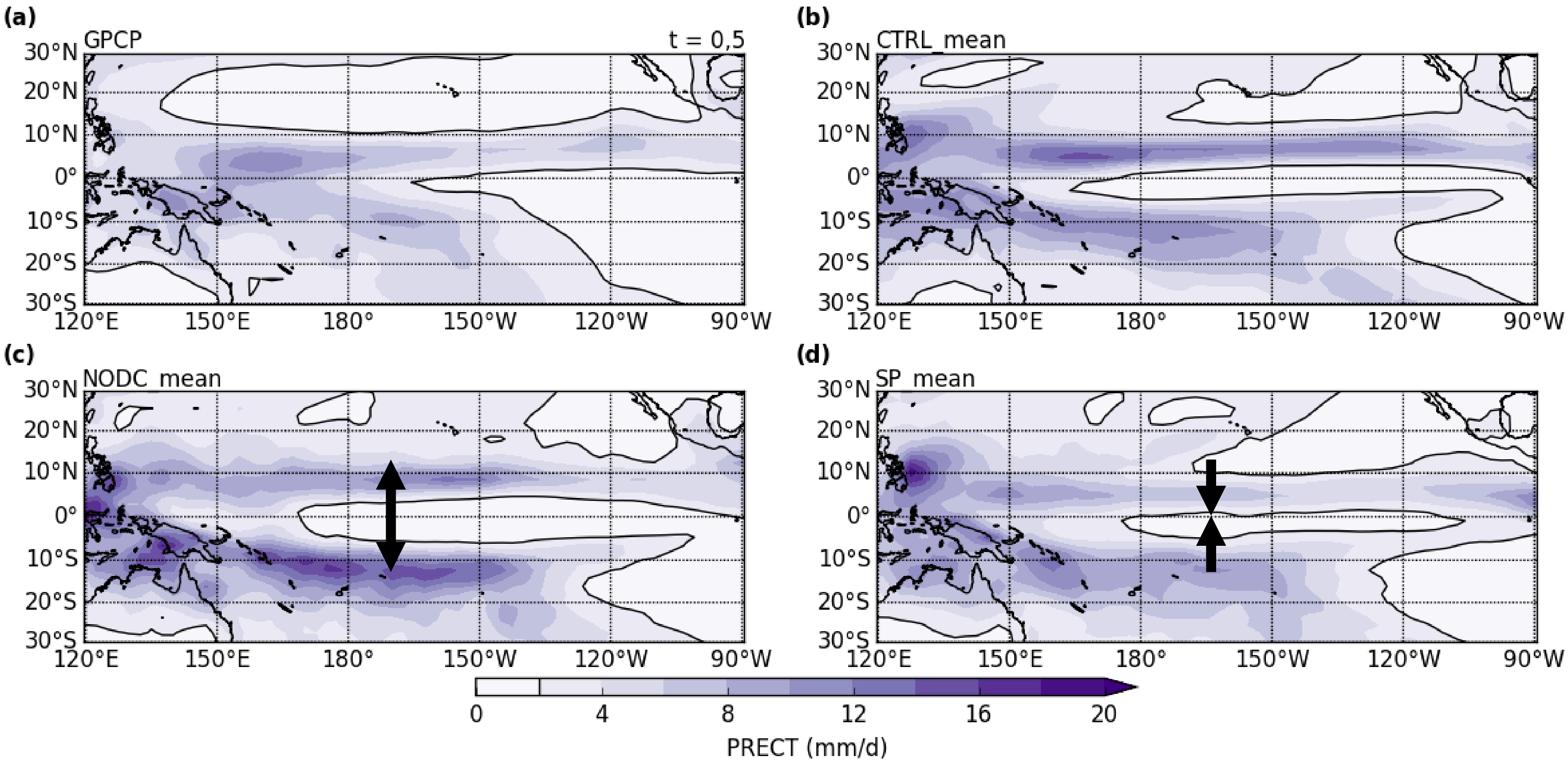
NODC
UW ShCu (Park and Bretherton, 2009)
~~ZM DC (Zhang and McFarlane, 1995)~~

SP
Embedded 2D cloud-resolving model replacing moist physics (Grabowski, 2001)

Precipitation: Jan-June 1981

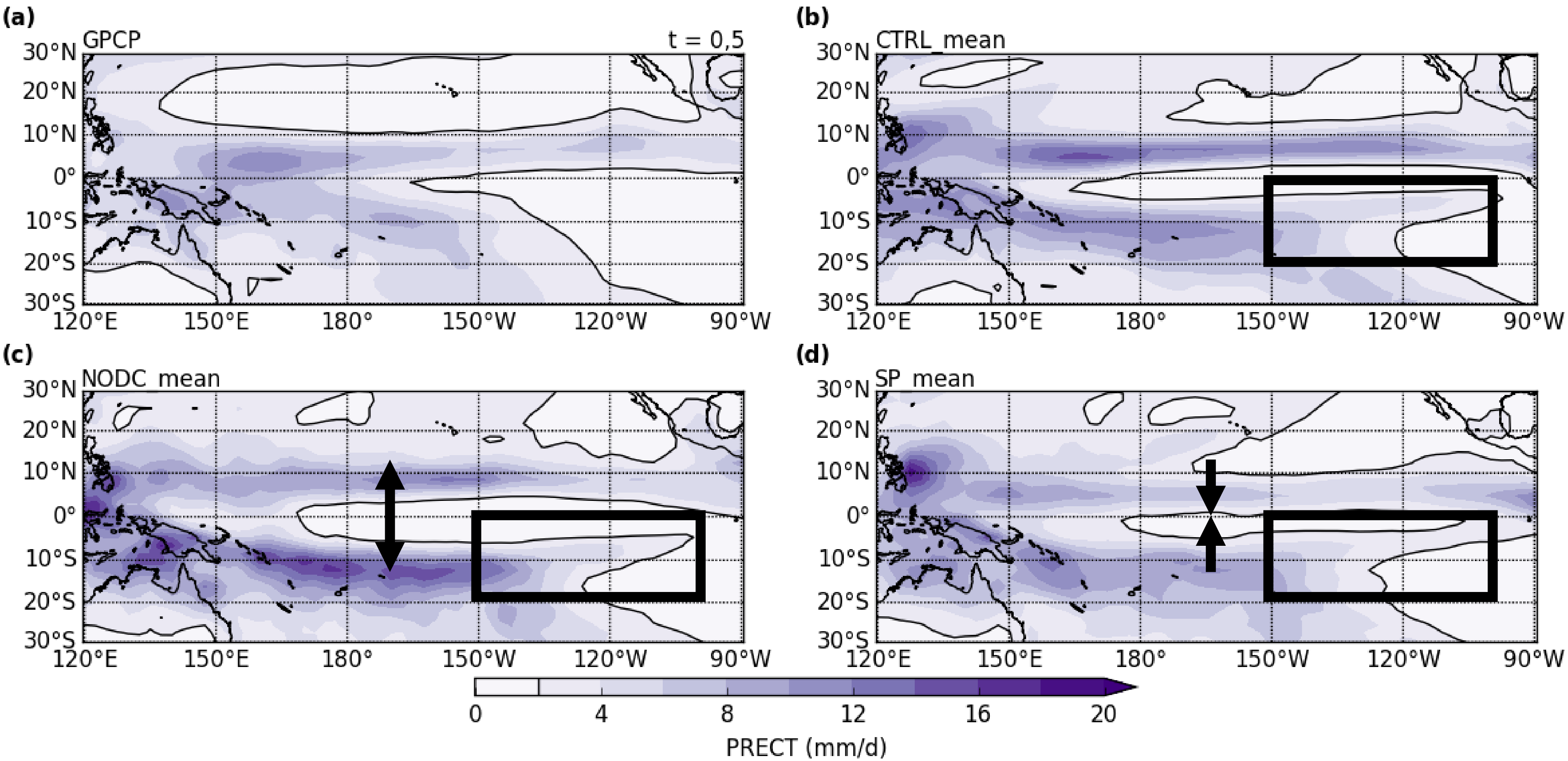


Convective parameterization affects meridional width of dry zone.

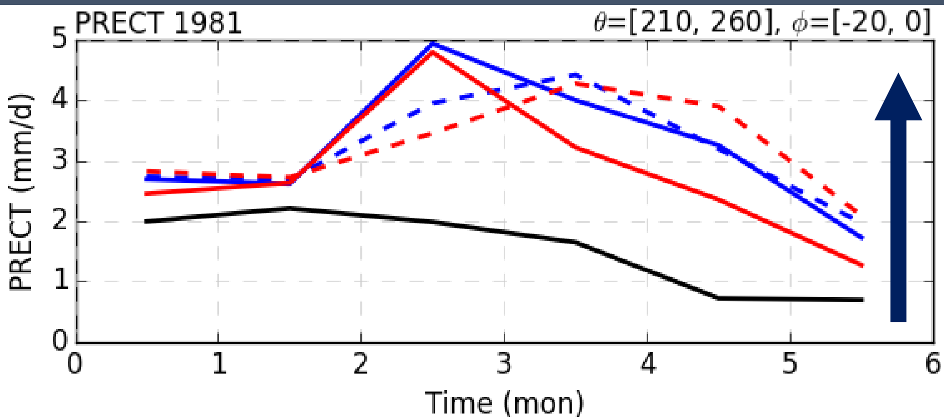


Convective parameterization affects meridional width of dry zone.

All simulations produce excess SE Pacific rainfall.

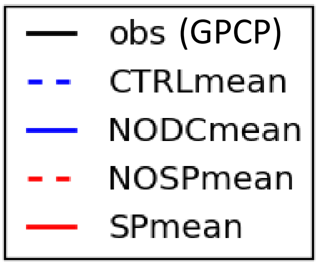


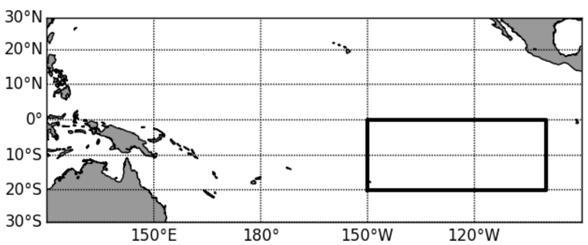
No consistent change in double-ITCZ bias.



Stronger double ITCZ

Time (mon)





Time (mon)

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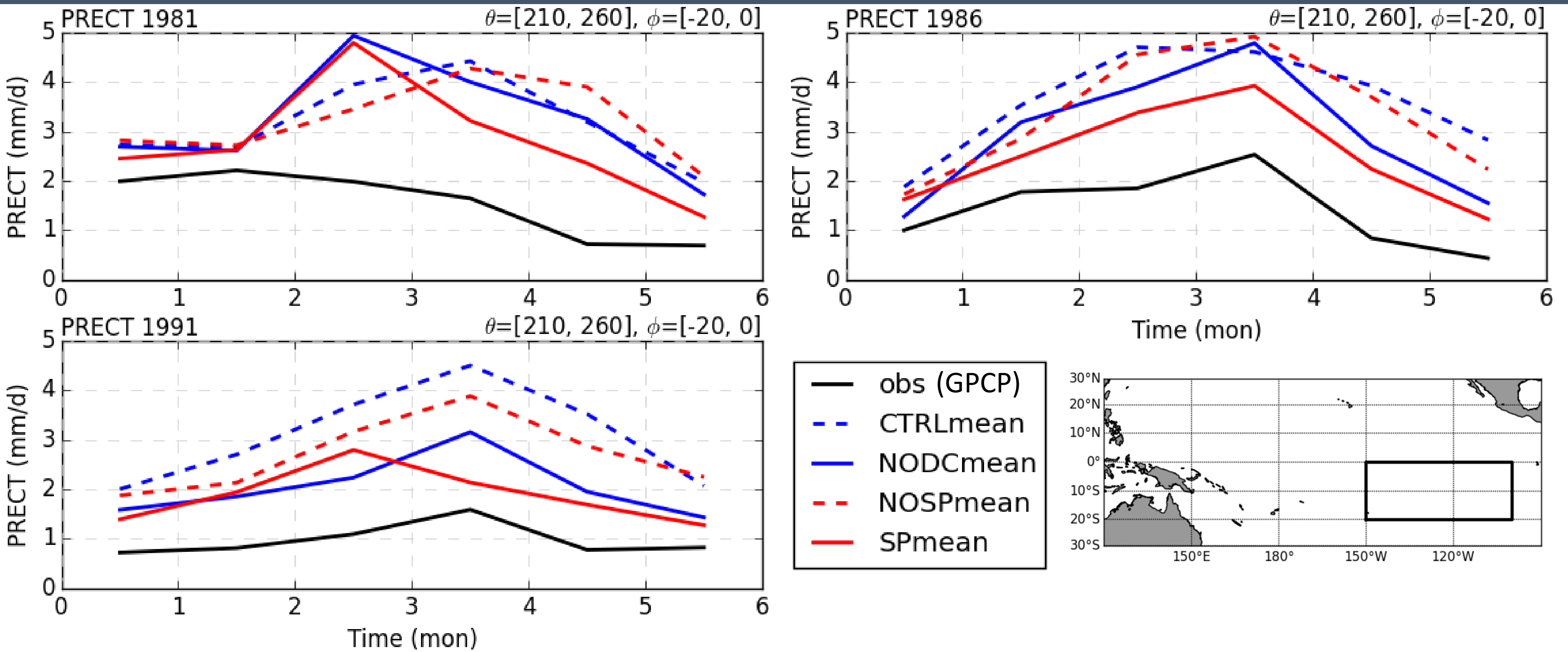
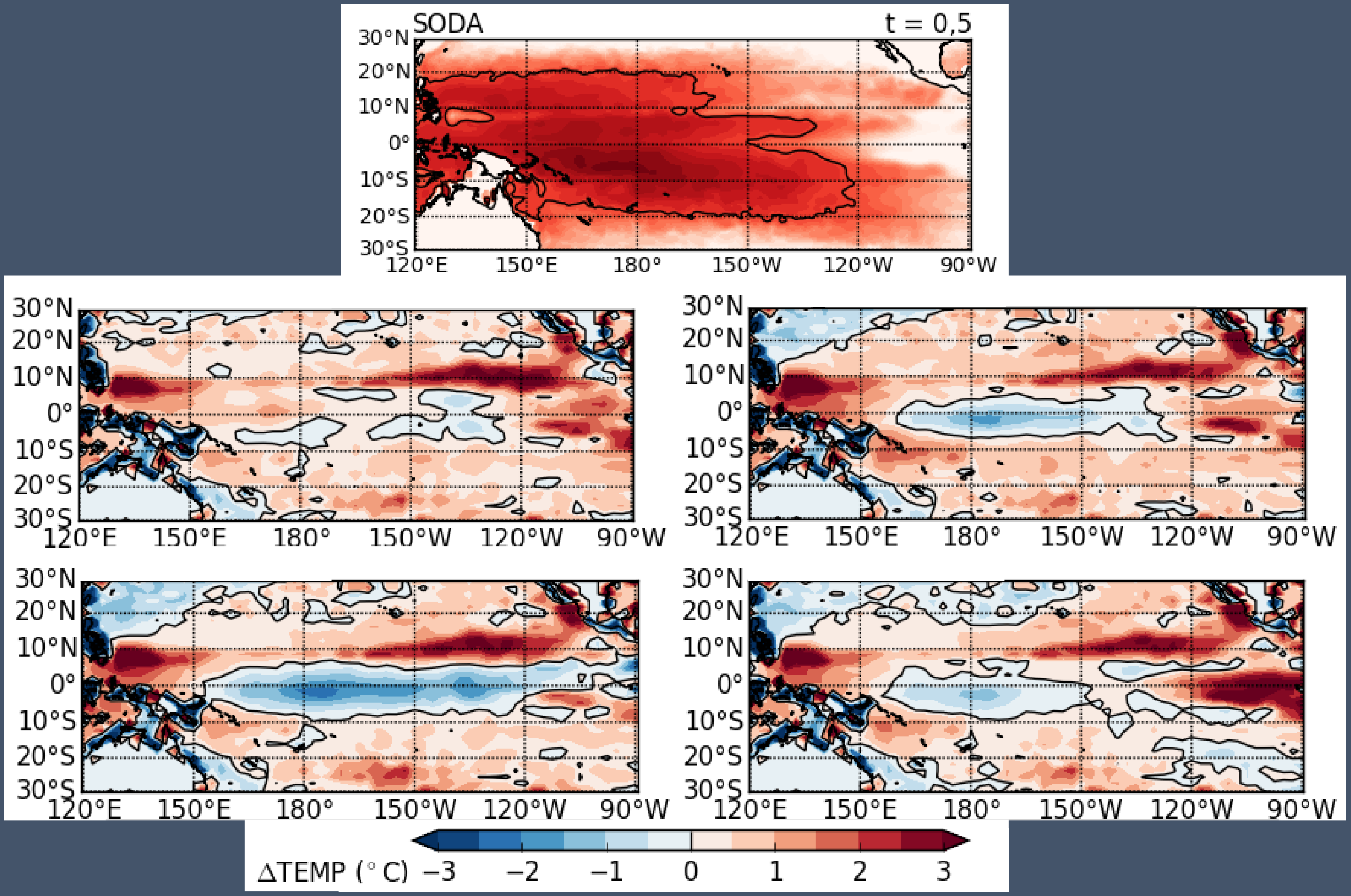


100 m ΔOcean Heat Content: Jan-June 1981 mean

OCN - SODA

NODC - SODA



CTRL - SODA

SP - SODA

100 m ΔOcean Heat Content: Jan-June 1981 mean

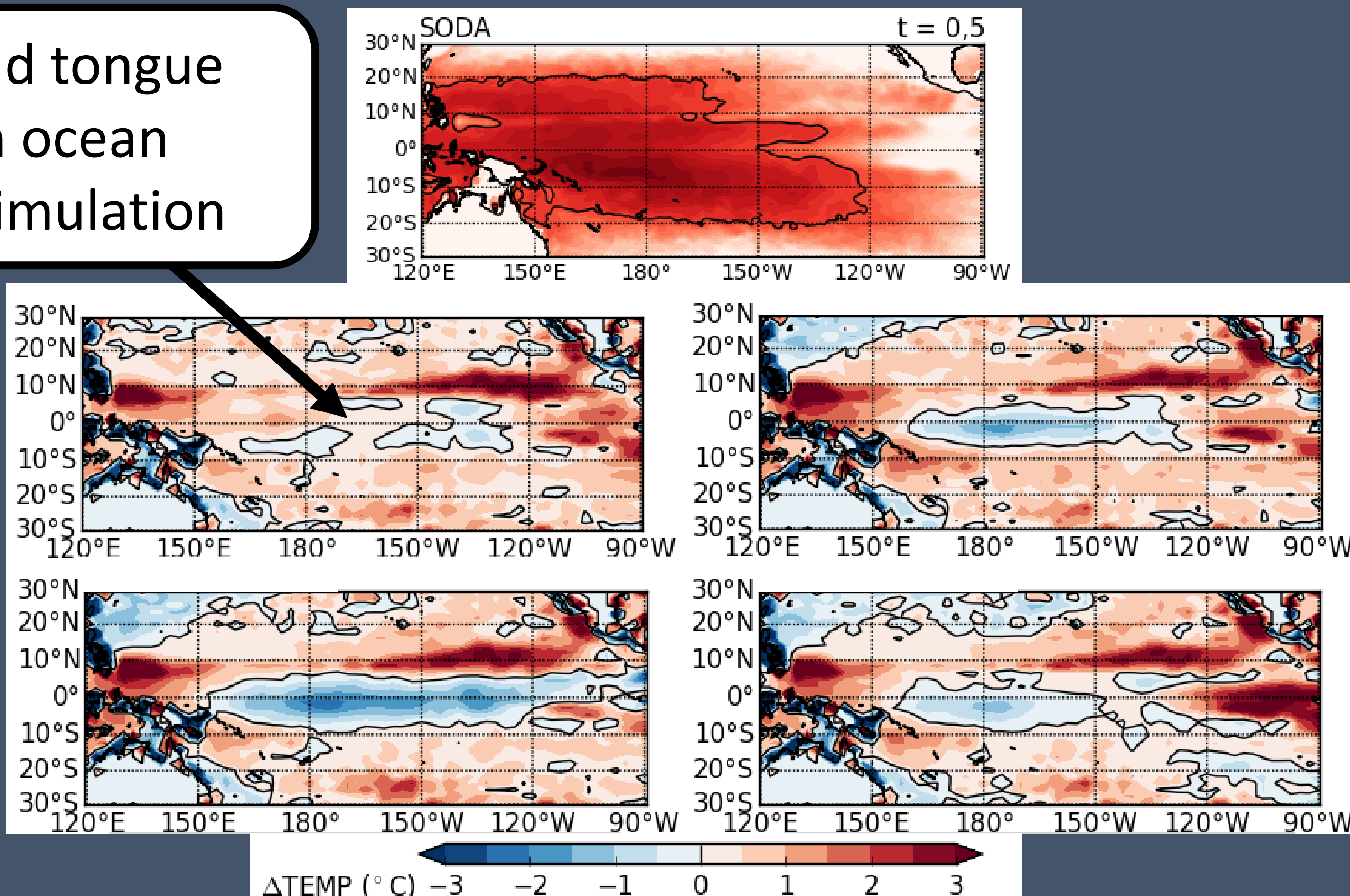
No cold tongue bias in ocean only simulation

OCN - SODA

NODC - SODA

CTRL - SODA

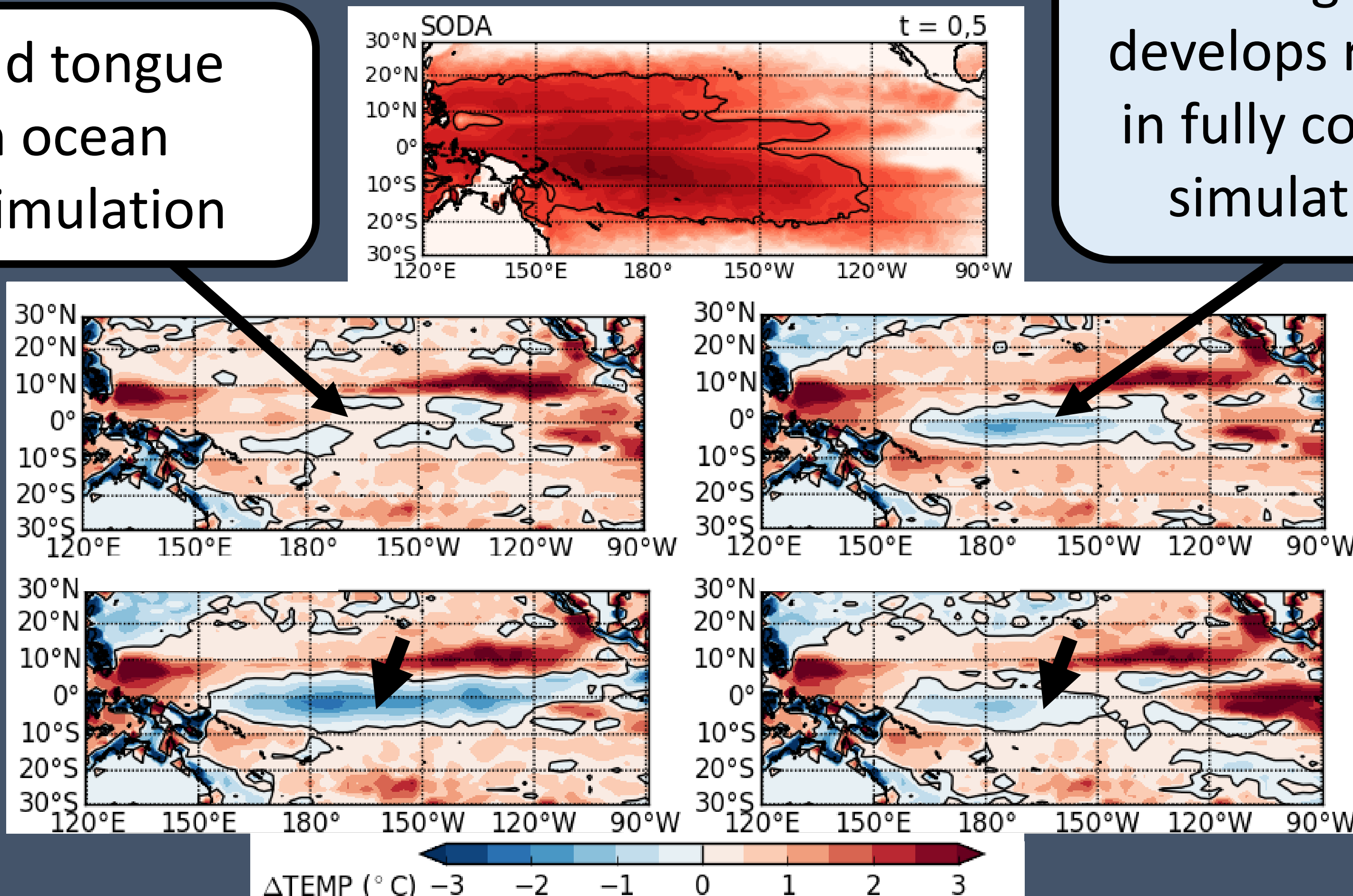
SP - SODA



100 m ΔOcean Heat Content: Jan-June 1981 mean

No cold tongue bias in ocean only simulation

Cold tongue bias develops rapidly in fully coupled simulations



OCN - SODA

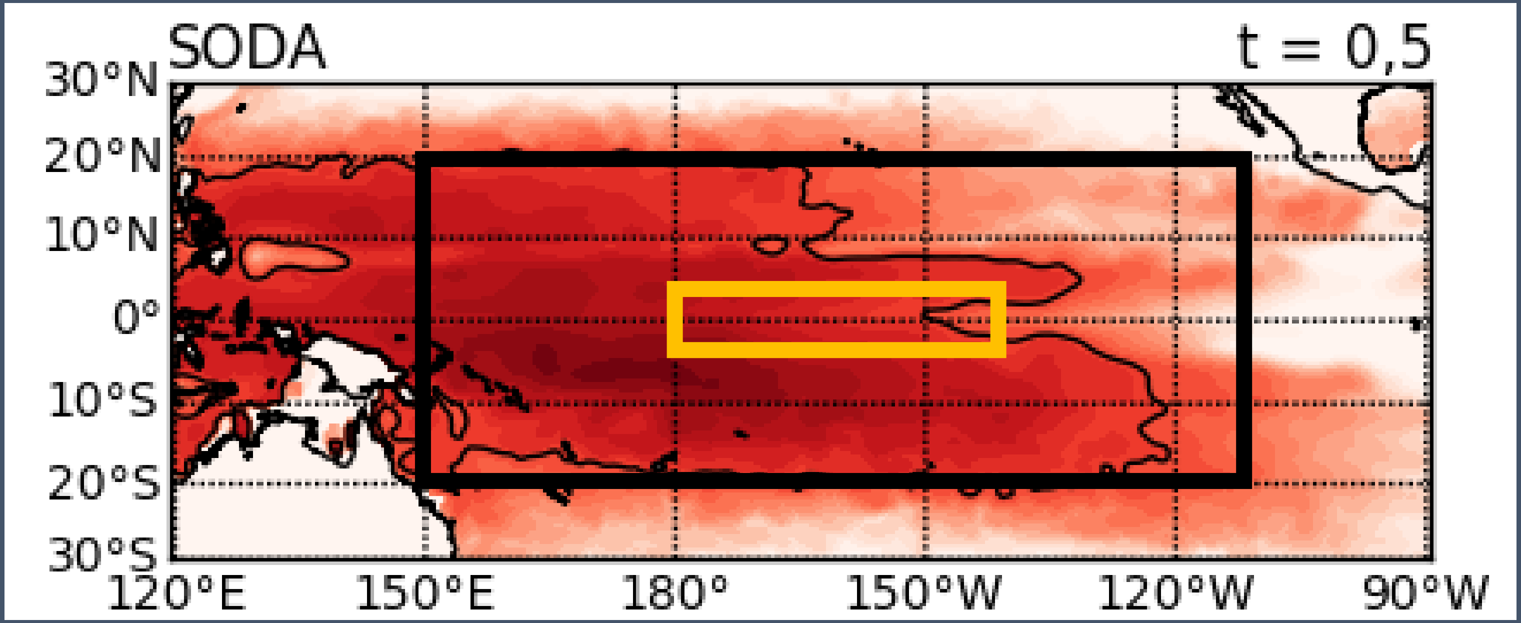
CTRL - SODA

NODC - SODA

SP - SODA

100 m ΔOHC: Jan-June 1981 mean

$$\underline{C}\text{old } \underline{T}\text{ongue } \underline{I}\text{ndex } = \frac{\text{OHC}(3°S{:}\,3°N, 180°{:}\,220°E)}{} - \frac{}{\text{OHC}(20°S{:}\,20°N, 150°E{:}\,250°E)}$$

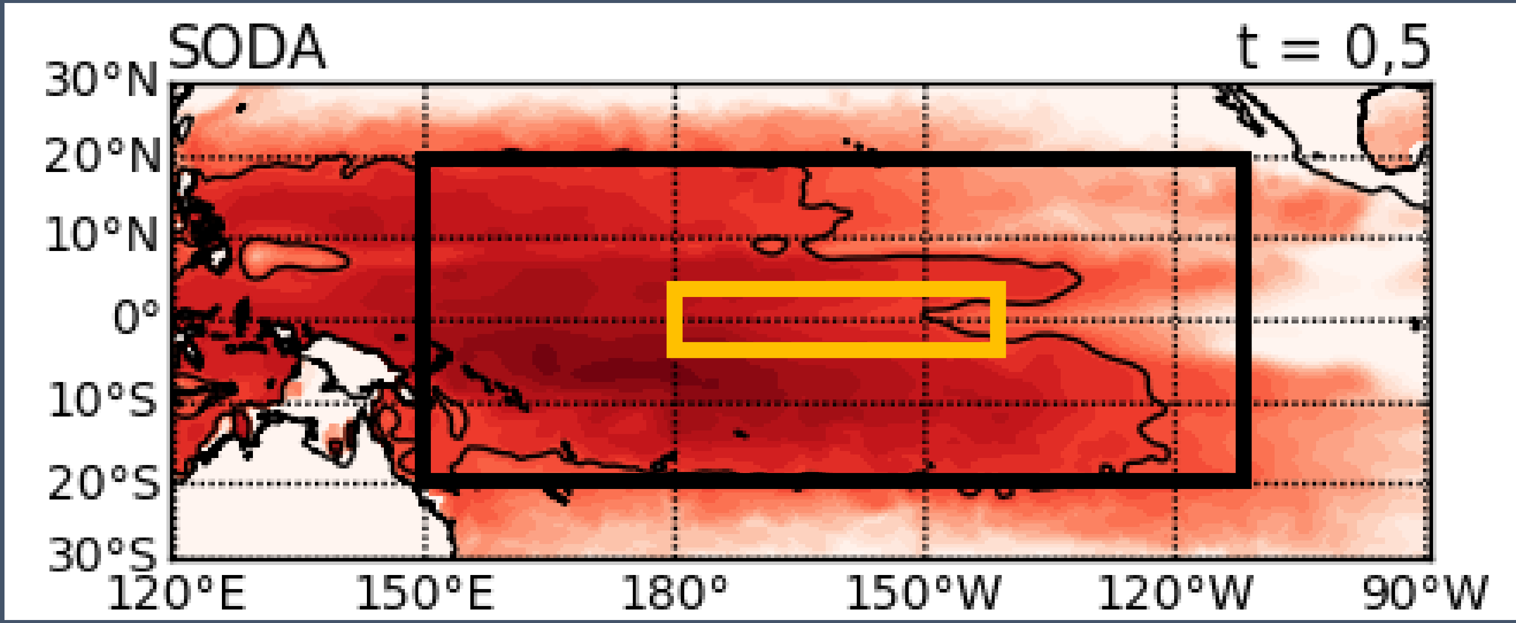


100 m ΔOHC: Jan-June 1981 mean

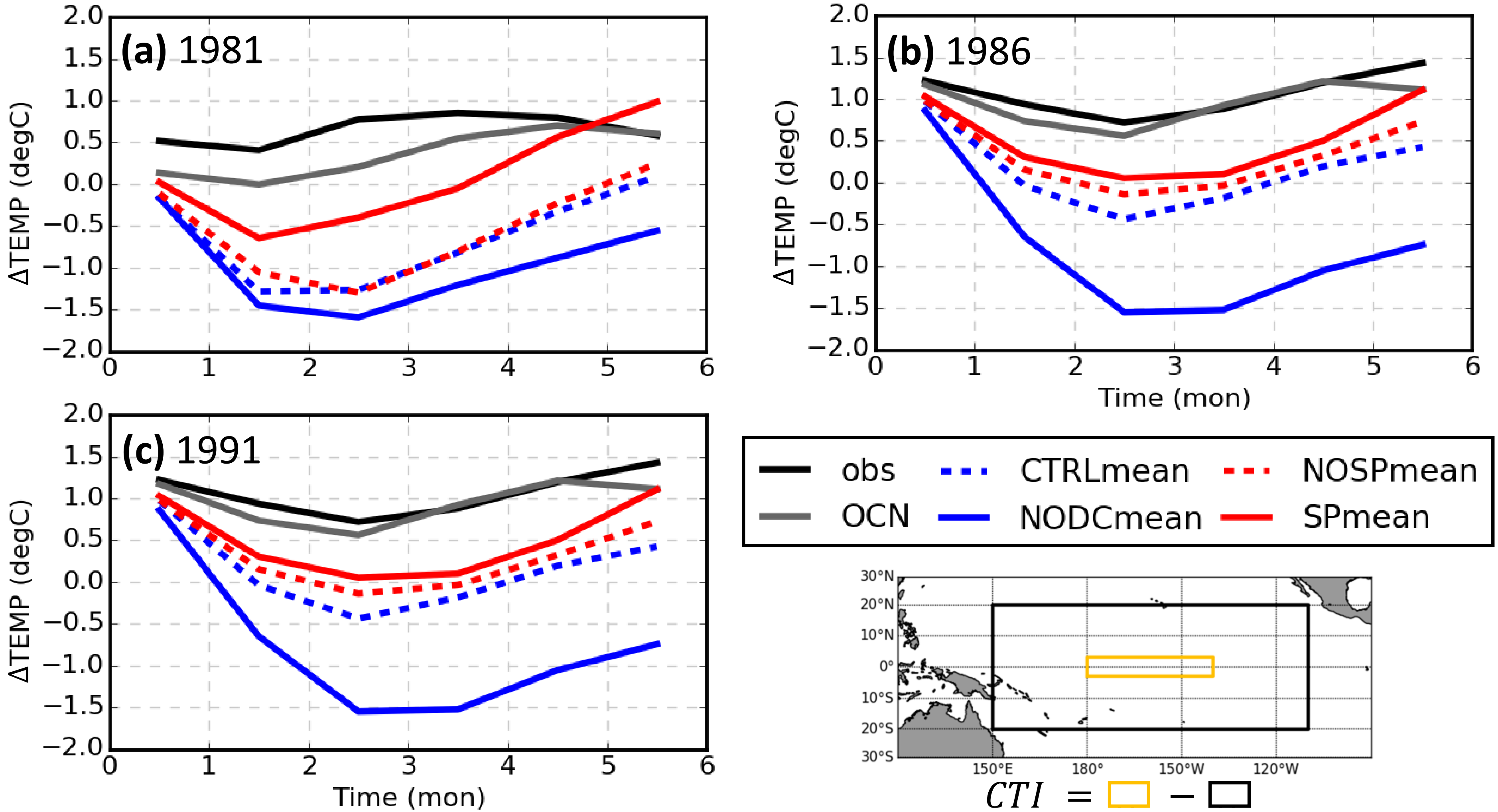
Cold Tongue Index =

$$\text{OHC}(3°S{:}\,3°N, 180°{:}\,220°E) - \text{OHC}(20°S{:}\,20°N, 150°E{:}\,250°E)$$

More negative
=
Stronger cold tongue

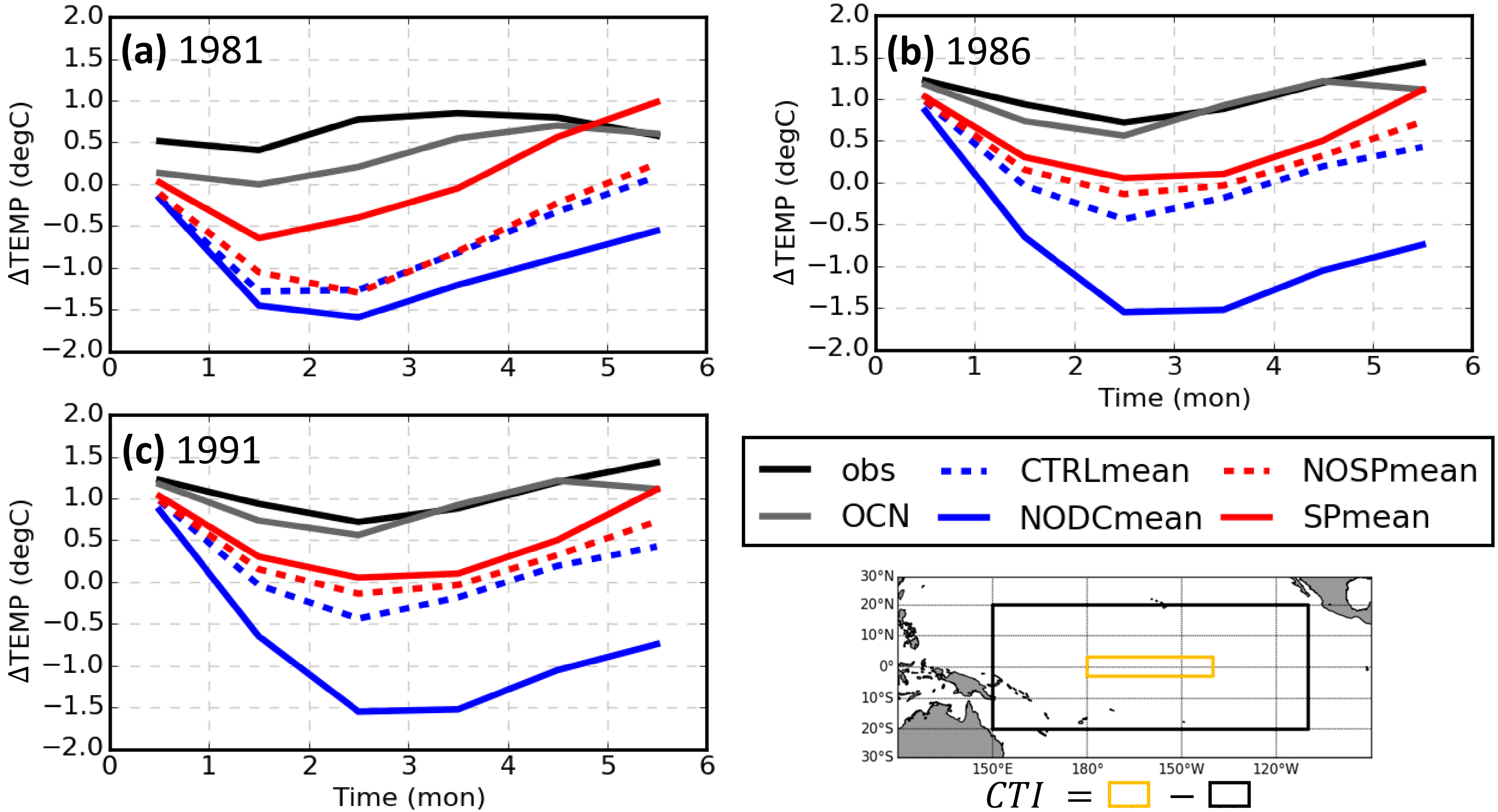


Cold tongue index



SP cold tongue improves

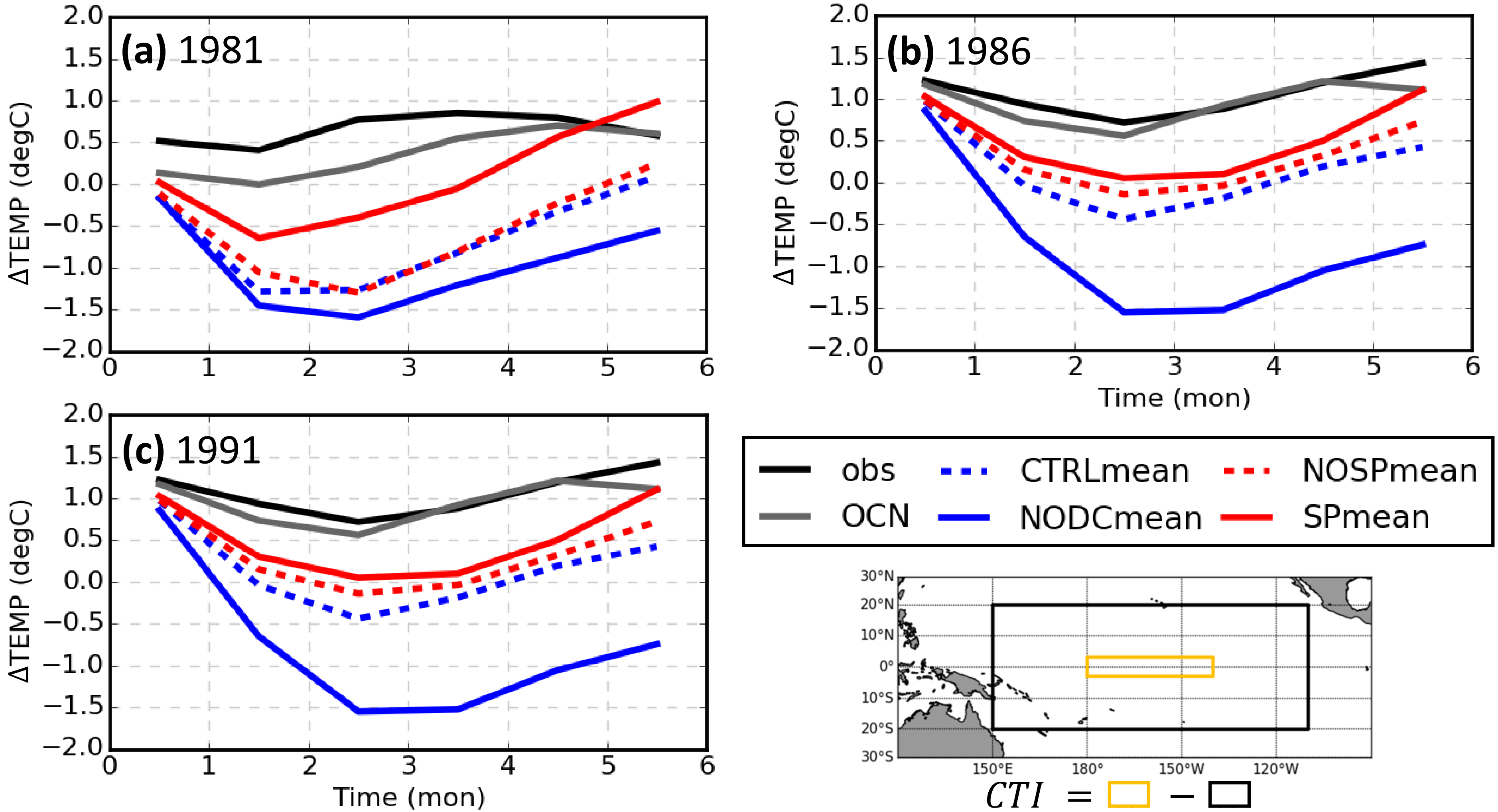
NODC cold tongue worsens



SP cold tongue improves

NODC cold tongue worsens

Majority of bias develops in first 3 months

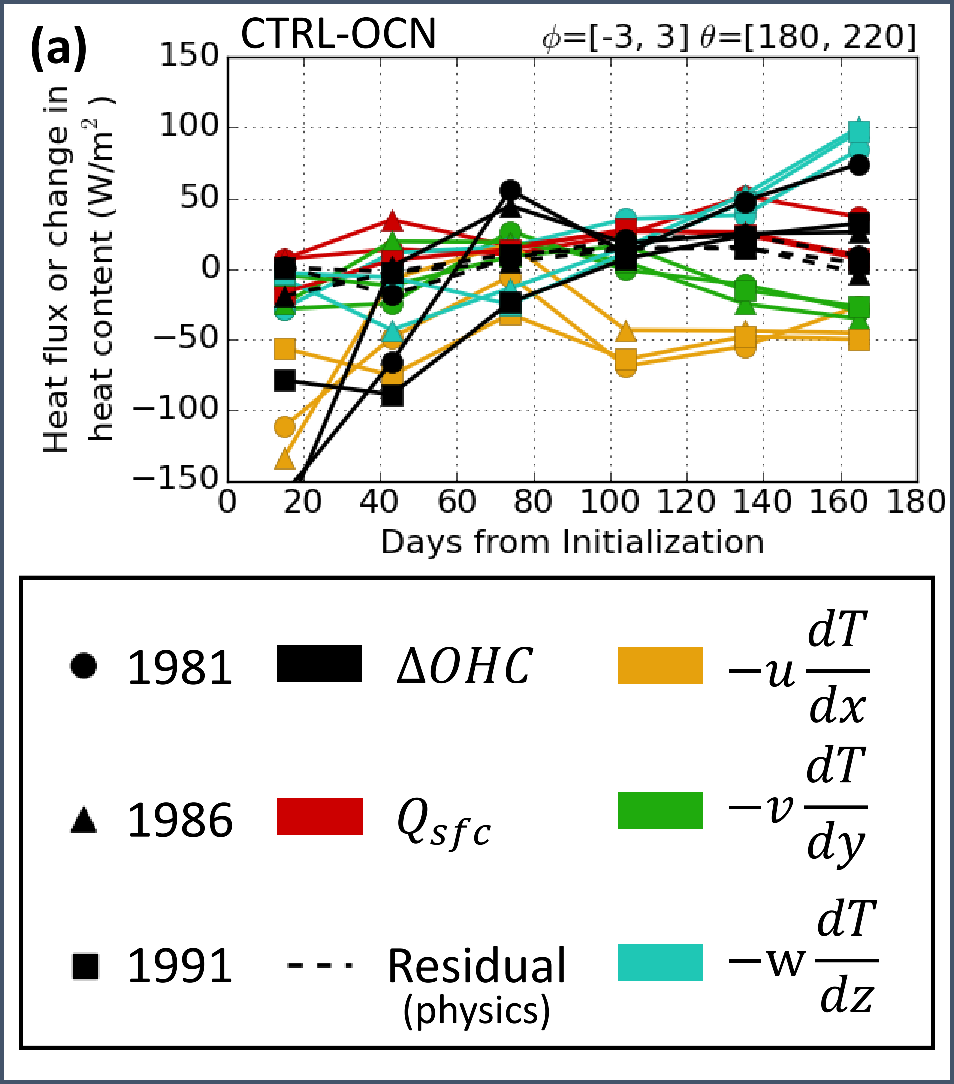


Ocean Heat Budget

ΔOcean heat content

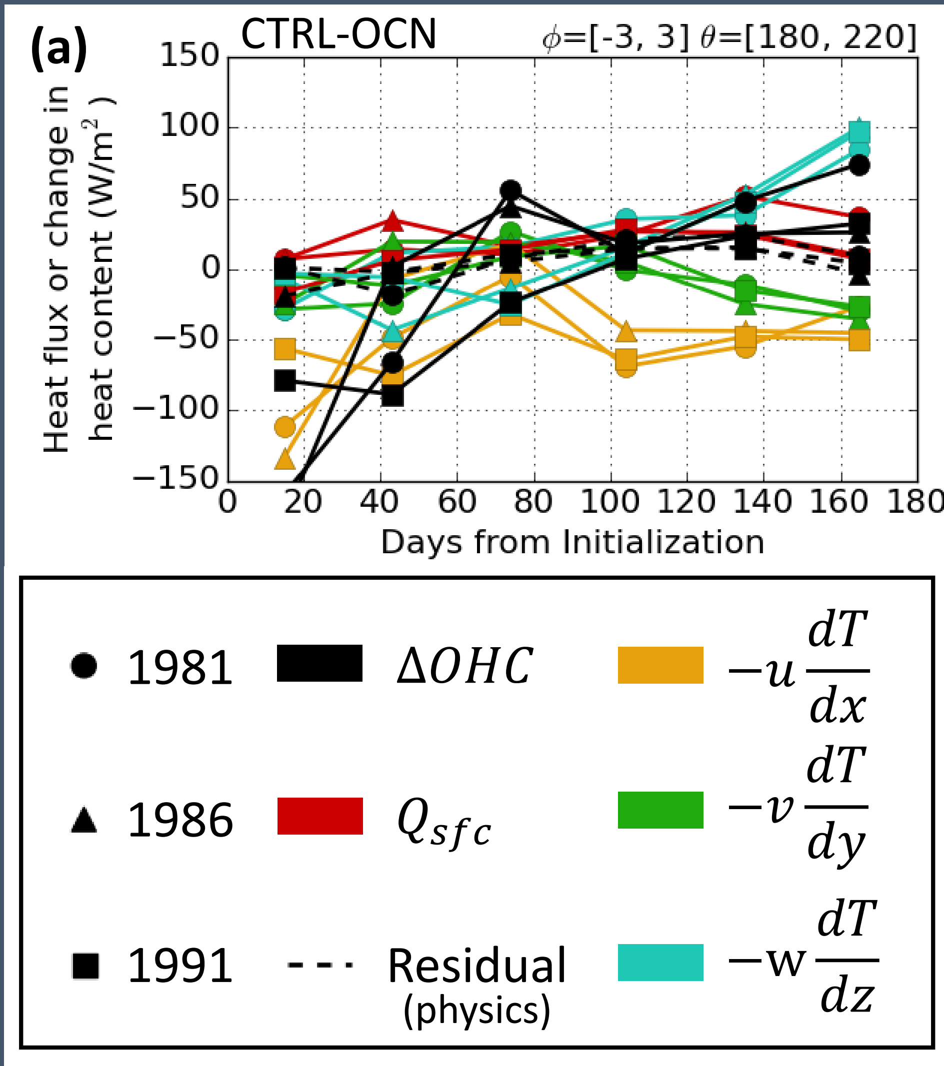
$$c_{p,ocn}\rho_{ocn}\frac{d}{dt}T_{ocn} = -u\frac{\partial T}{\partial x} - v\frac{\partial T}{\partial y} - w\frac{\partial T}{\partial z} + Q_{sfc} + Q_{physics}$$

Zonal advection	Meridional advection	Vertical advection	Net surface heat flux	Ocean physics

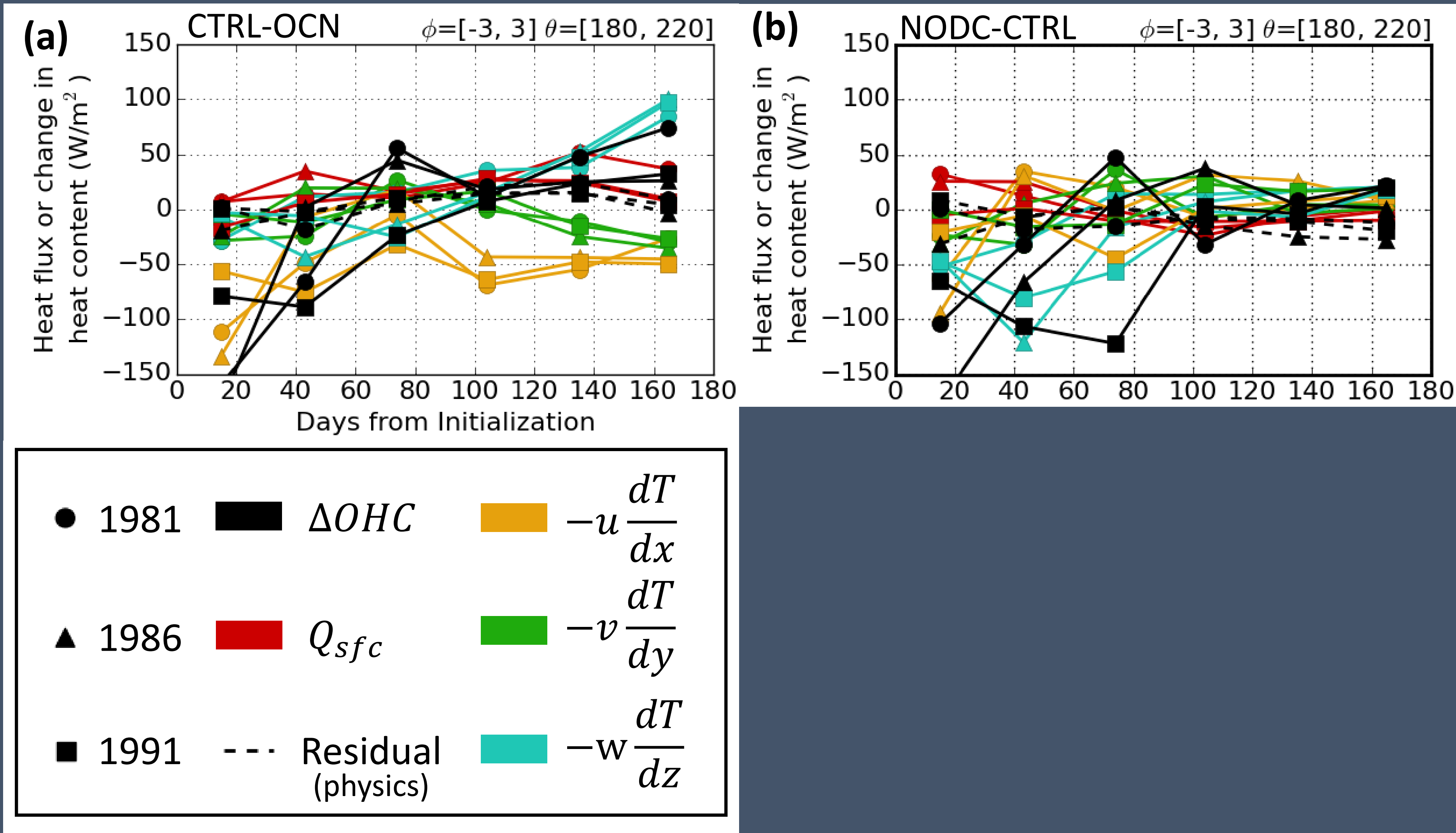


(a)
CTRL-OCN
ϕ=[-3, 3] θ=[180, 220]
Heat flux or change in heat content (W/m^2)
150
100
50
0
−50
−100
−150
0 20 40 60 80 100 120 140 160 180
Days from Initialization
1981
1986
1991
ΔOHC
Q_{sfc}
Residual (physics)
$-u\frac{dT}{dx}$
$-v\frac{dT}{dy}$
$-w\frac{dT}{dz}$

CTRL **cools** due to zonal advection

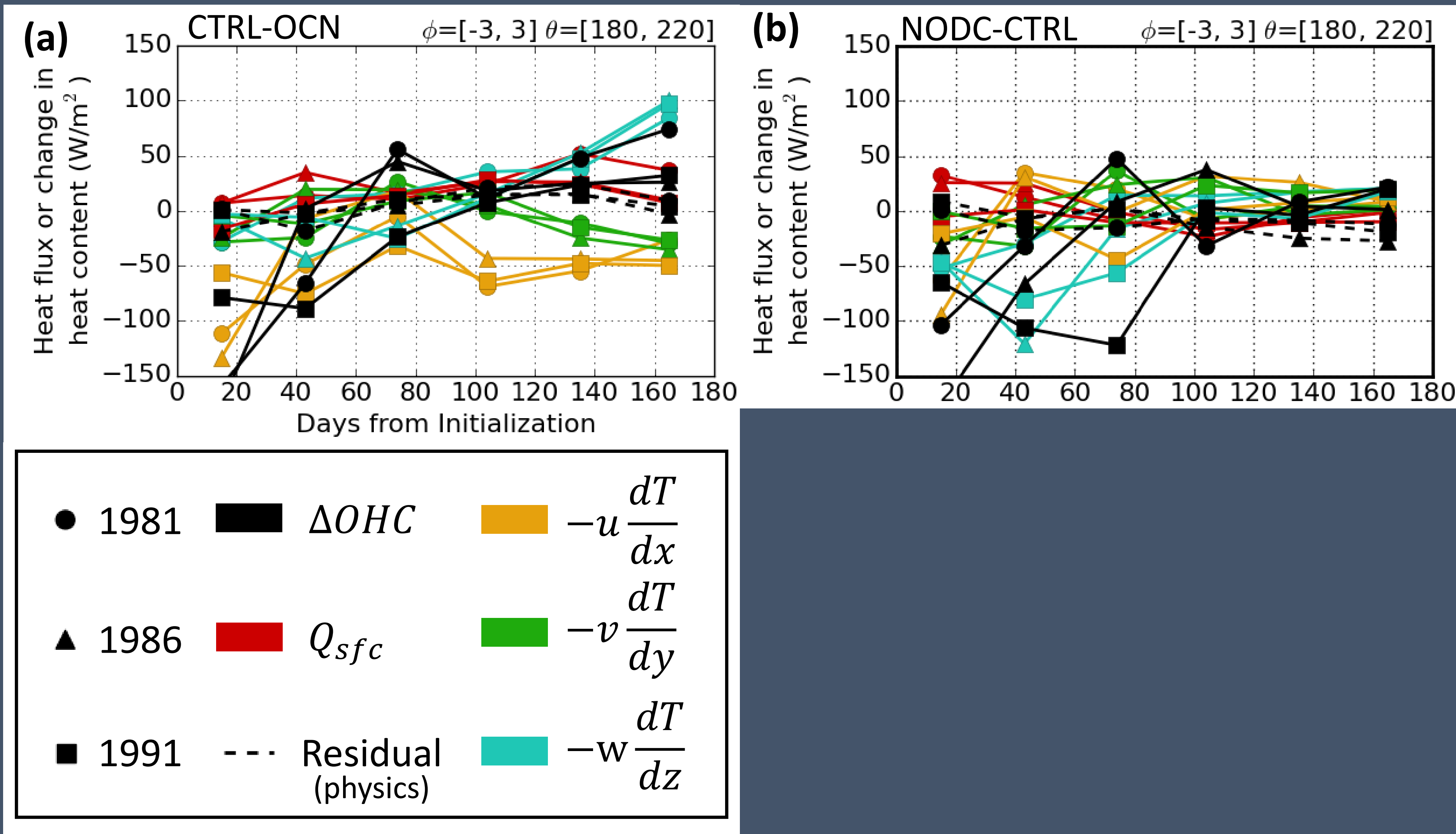


CTRL **cools** due to zonal advection



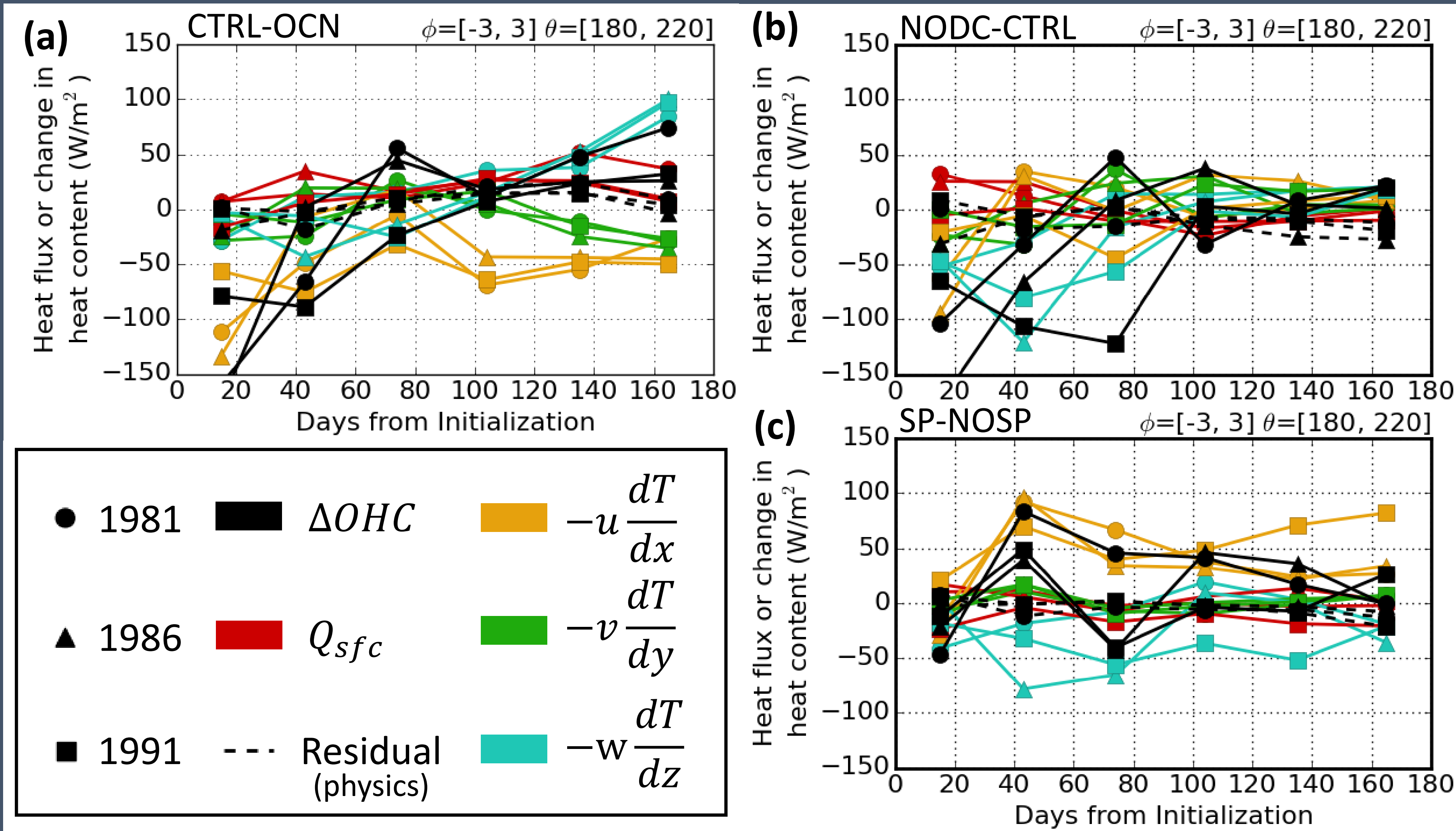
CTRL **cools** due to zonal advection

NODC cooler due to enhanced upwelling



CTRL **cools** due to zonal advection

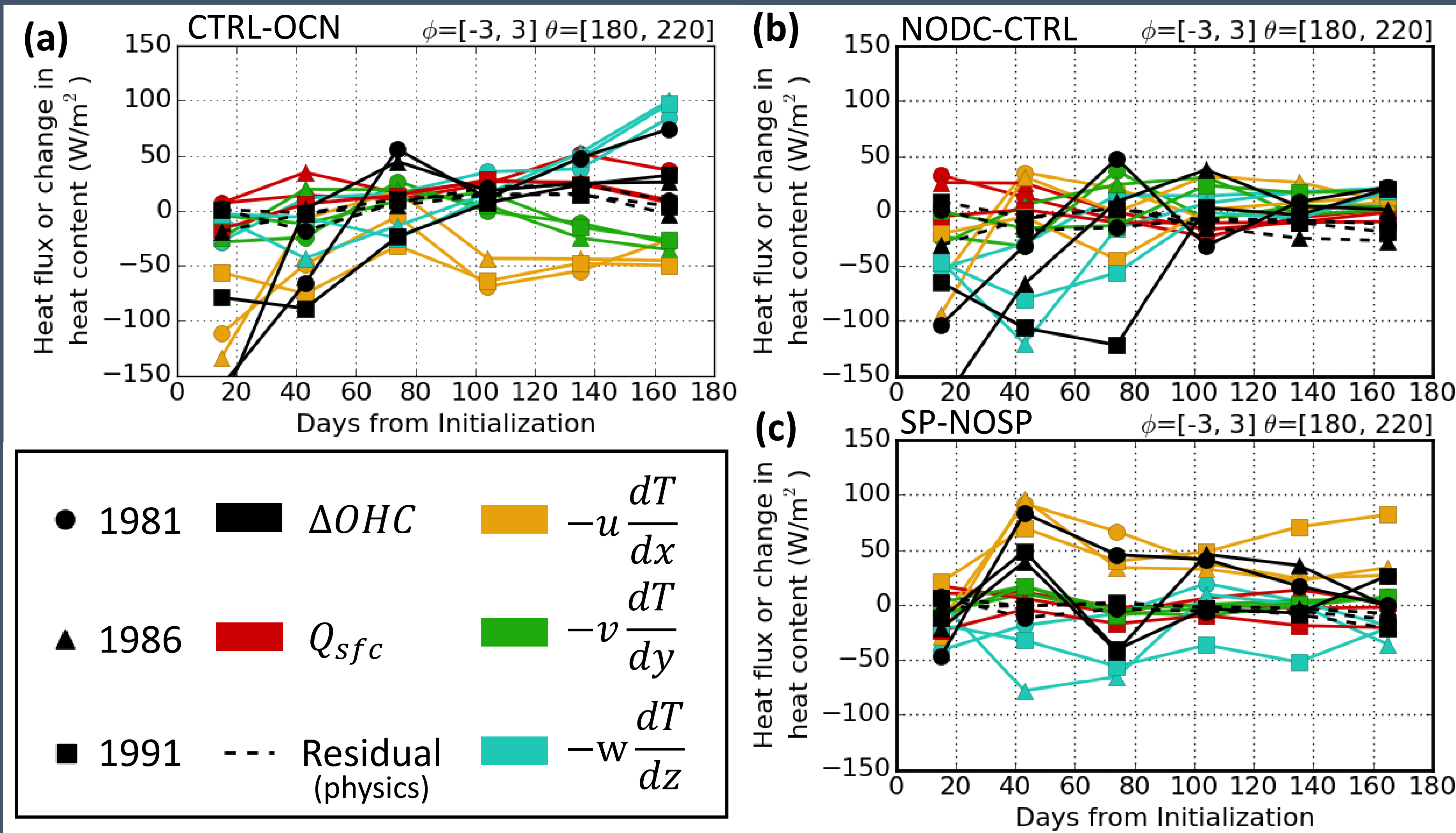
NODC cooler due to enhanced upwelling



CTRL **cools** due to zonal advection

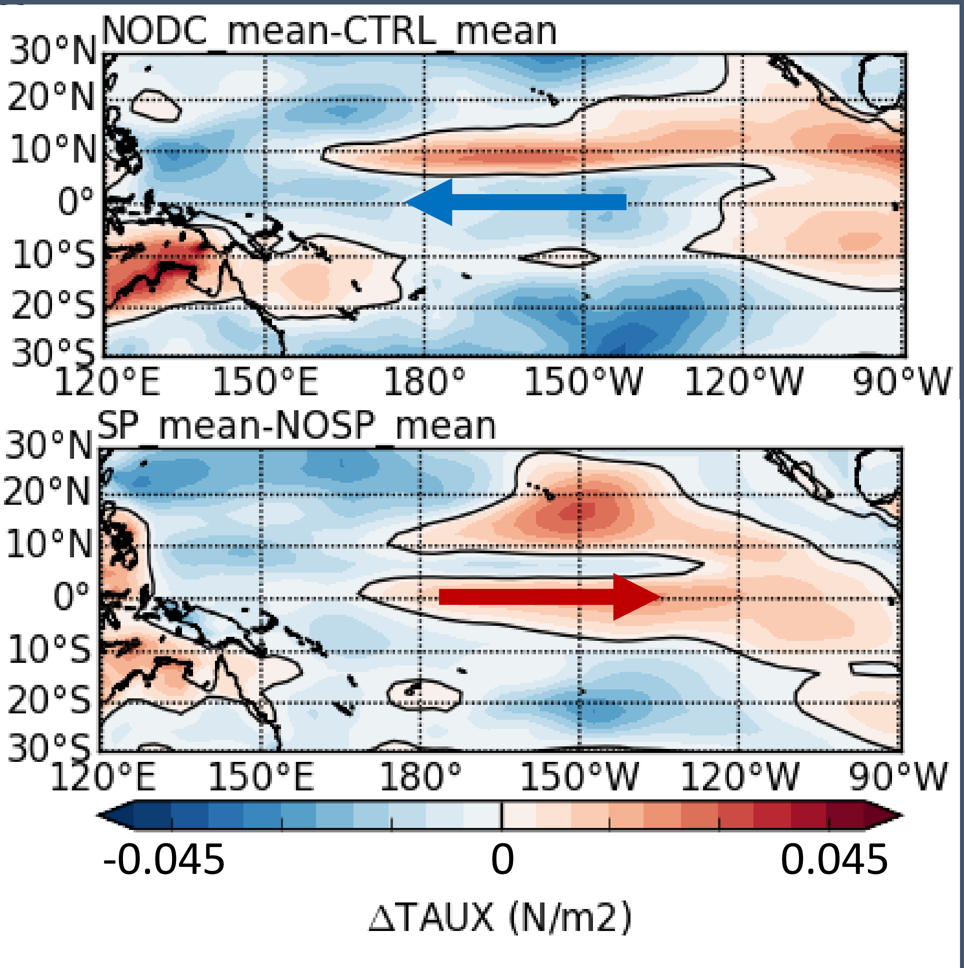
NODC cooler due to enhanced upwelling

SP warmer due to *reduced* zonal advection



Zonal wind stress:

Jan-June 1981 mean



Zonal wind stress:

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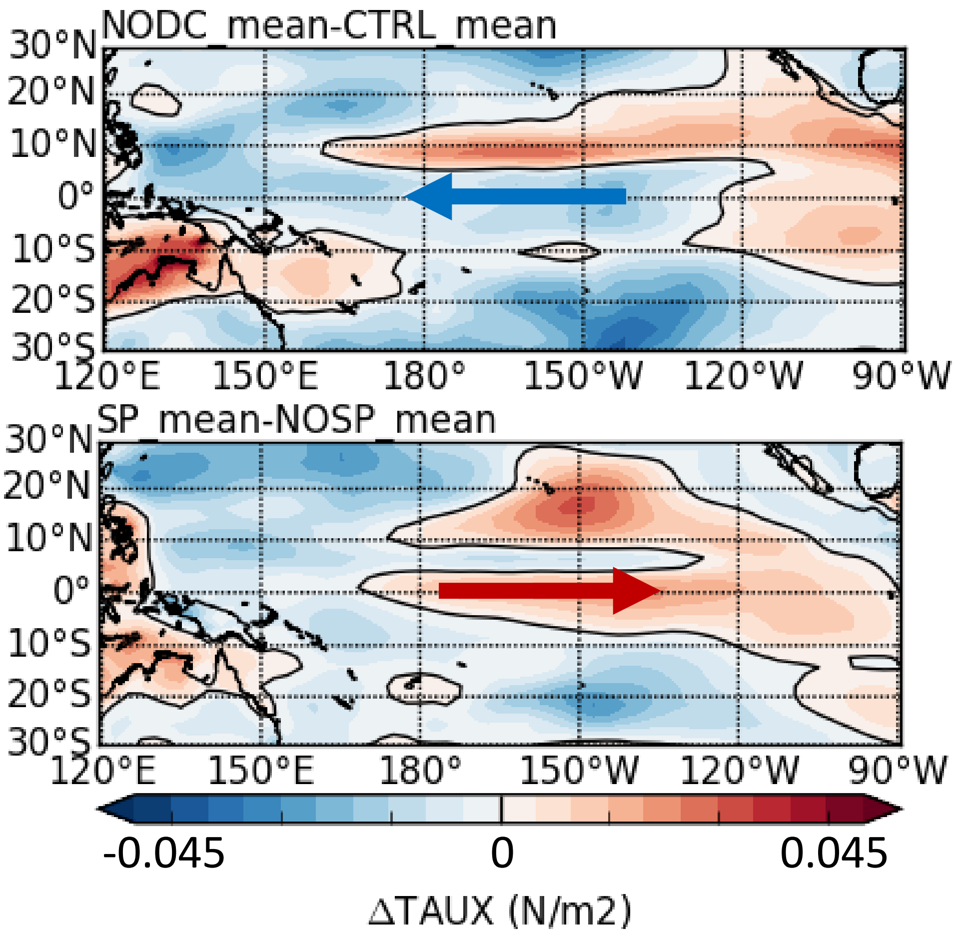
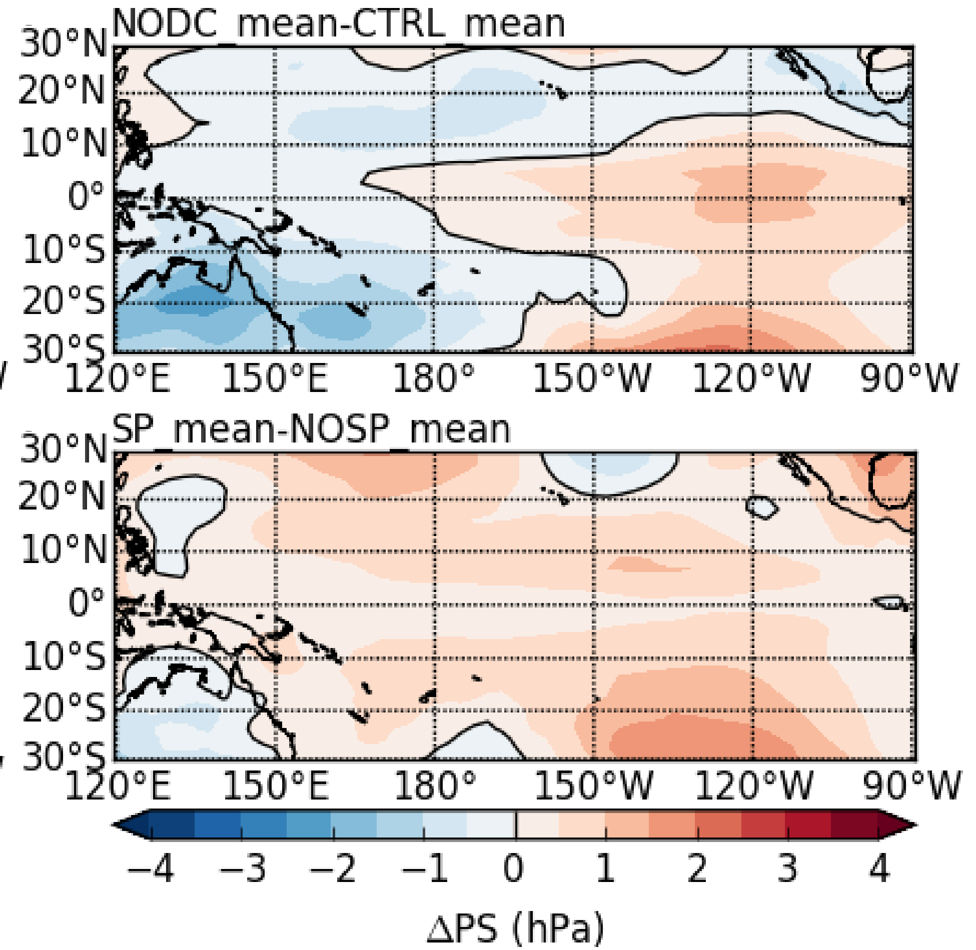


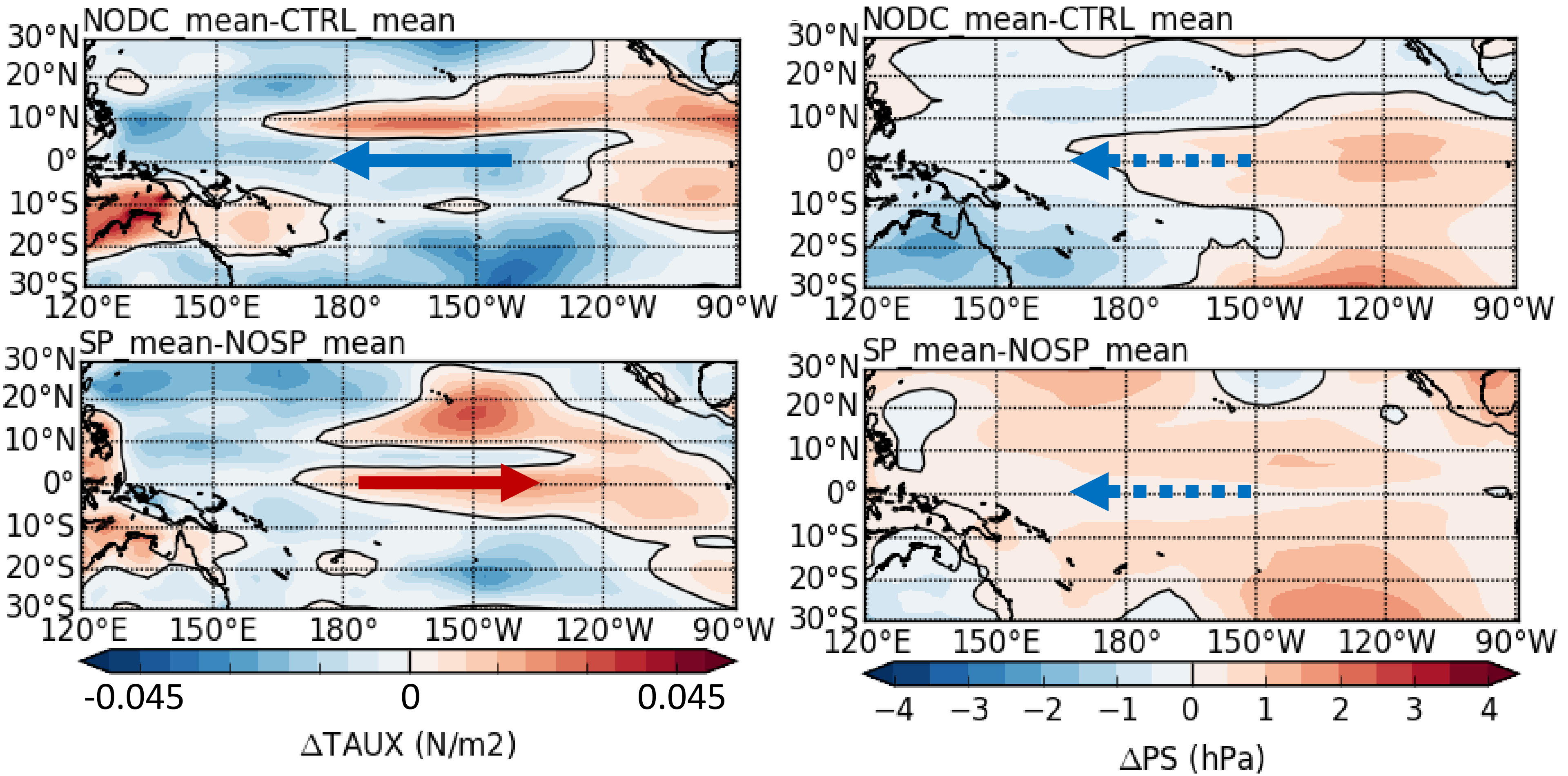
Surface pressure:

Jan-June 1981 mean



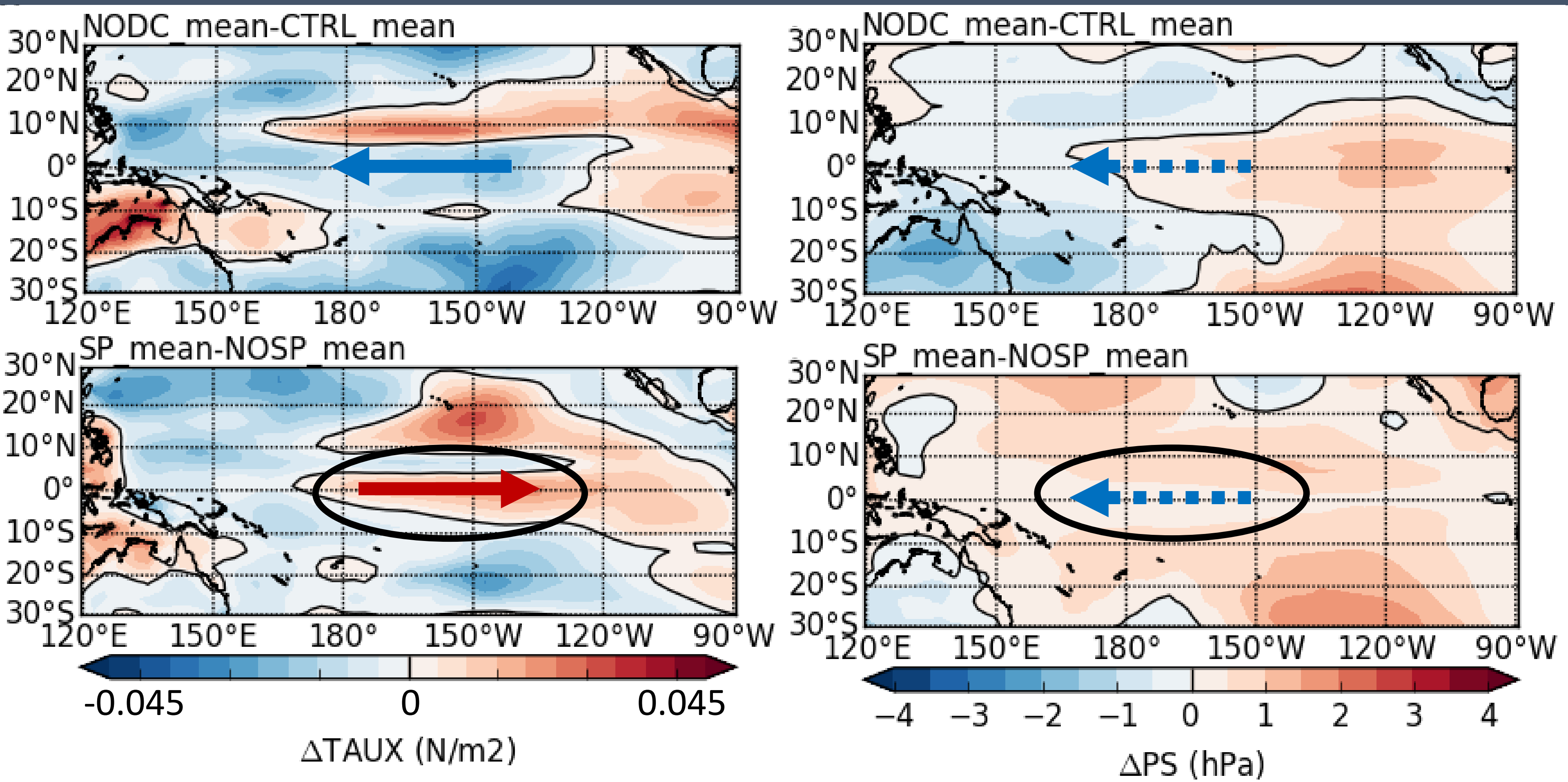
Zonal wind stress: Jan-June 1981 mean

Surface pressure: Jan-June 1981 mean



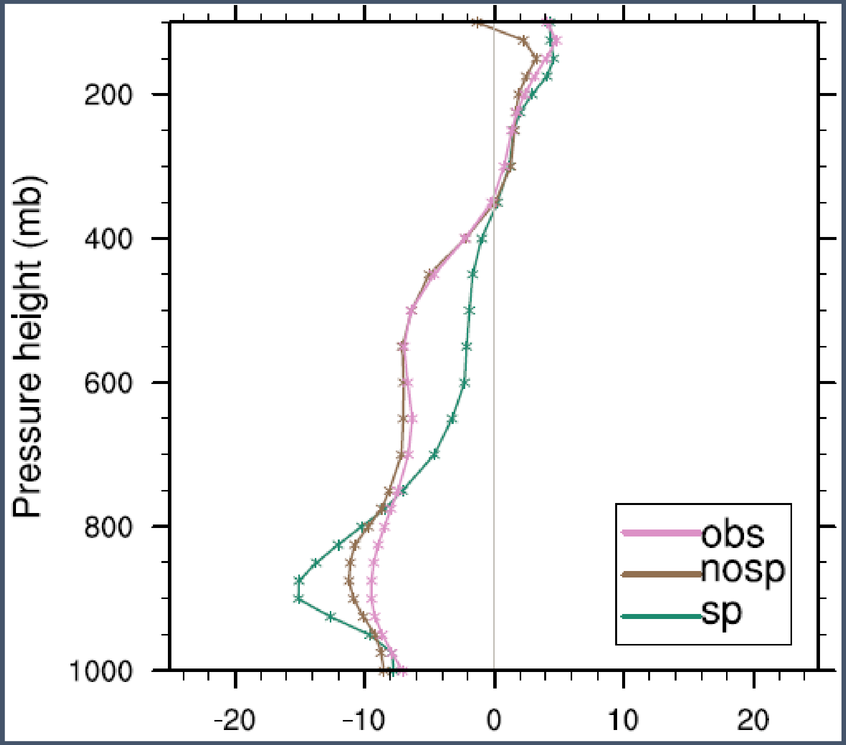
Zonal wind stress: Jan-June 1981 mean

Surface pressure: Jan-June 1981 mean

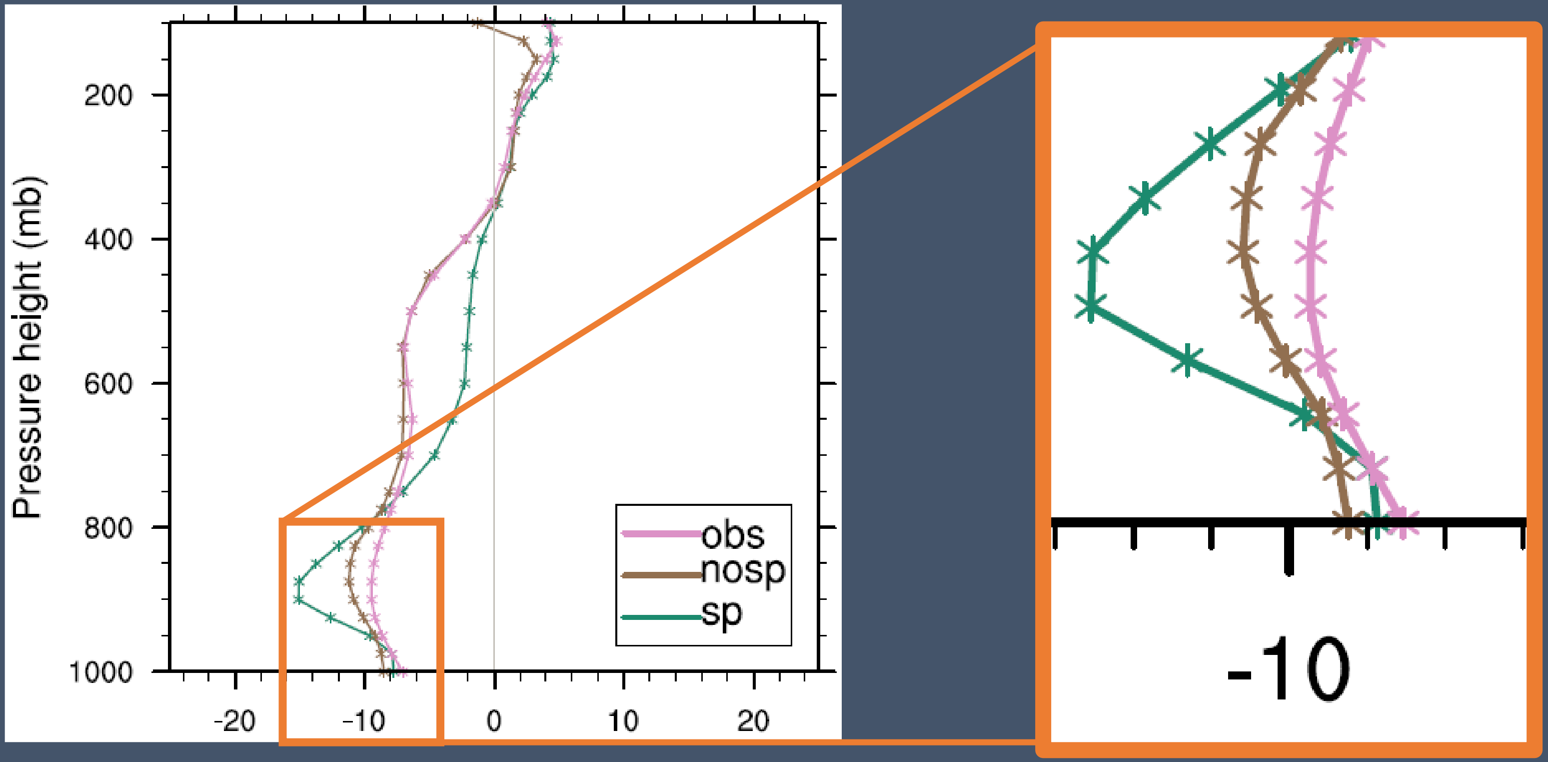


What is going on with SP?

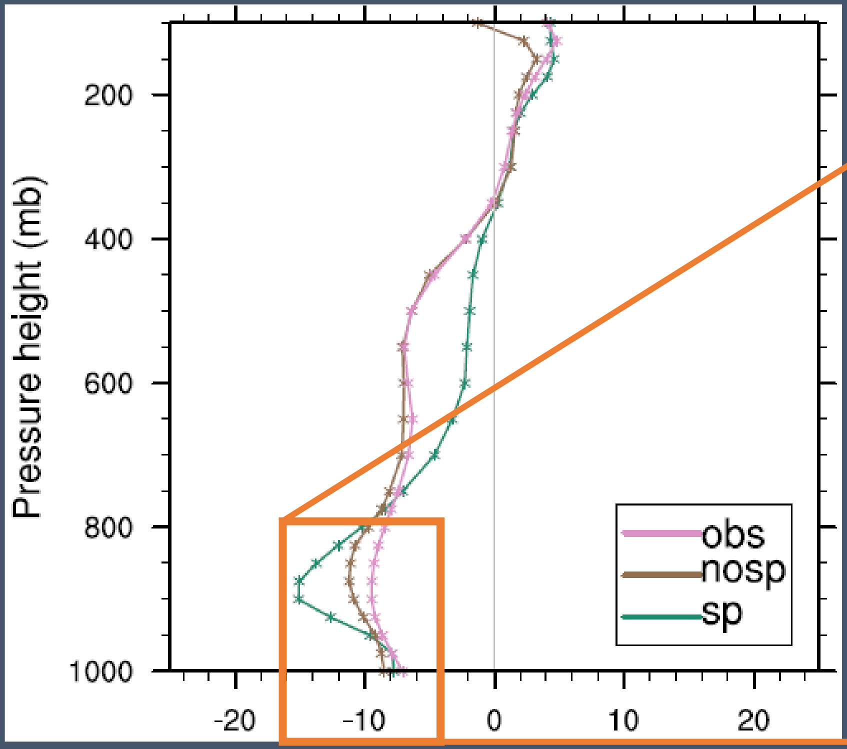
Zonal Velocity: Jan 1981

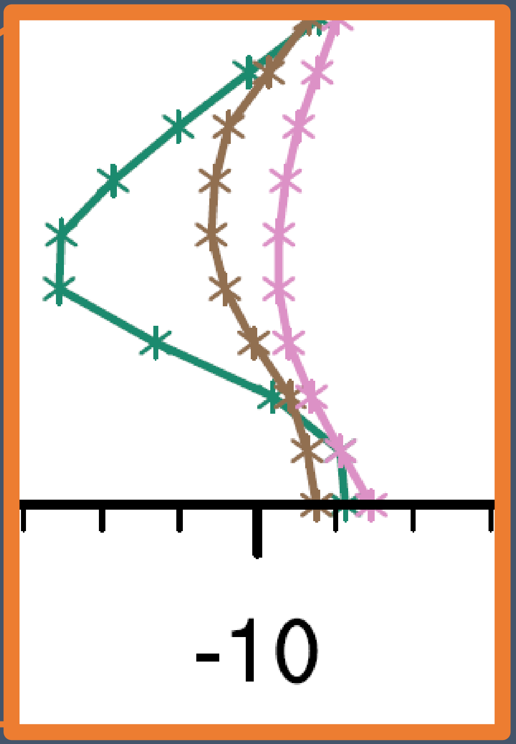


Zonal Velocity: Jan 1981



Zonal Velocity: Jan 1981

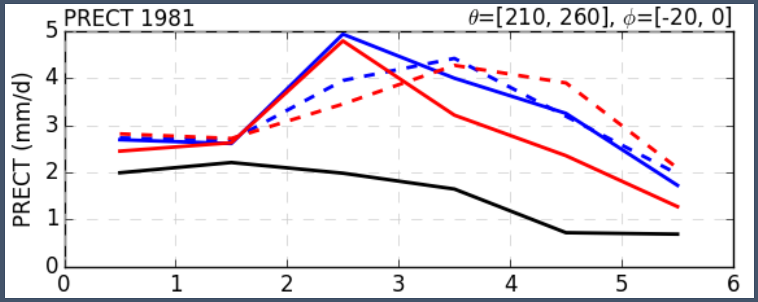


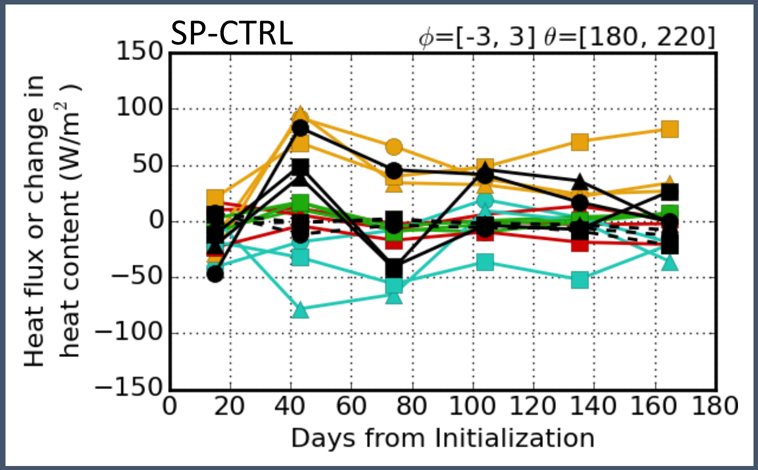


Surface wind decouples in SP

Convective parameterization changes…

Produce no consistent change in the double ITCZ bias.





Affect the strength of the Pacific cold tongue bias through ocean advection and zonal wind stress.

↳ Can be related to vertical convective momentum fluxes and large scale pressure field

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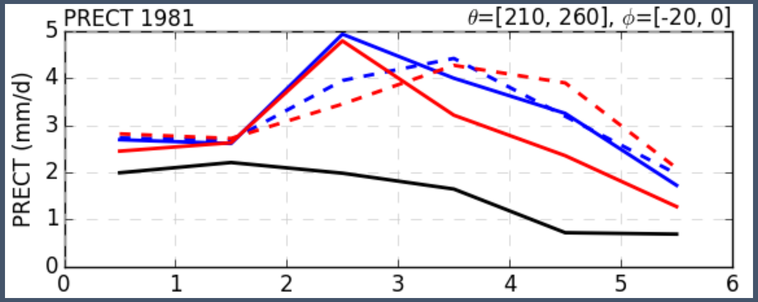
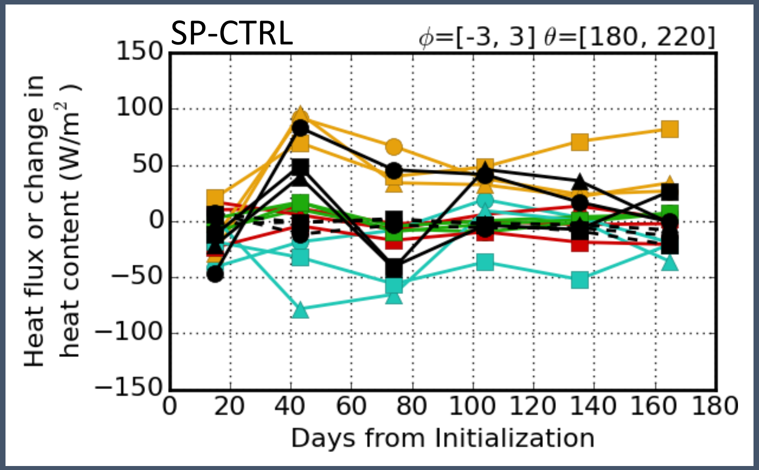
Produce no consistent change in the double ITCZ bias.





Affect the strength of the Pacific cold tongue bias through ocean advection and zonal wind stress.

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Matthew Woelfle | EMAIL: woelfle@atmos.washington.edu | TWITTER: @mdwoelfle

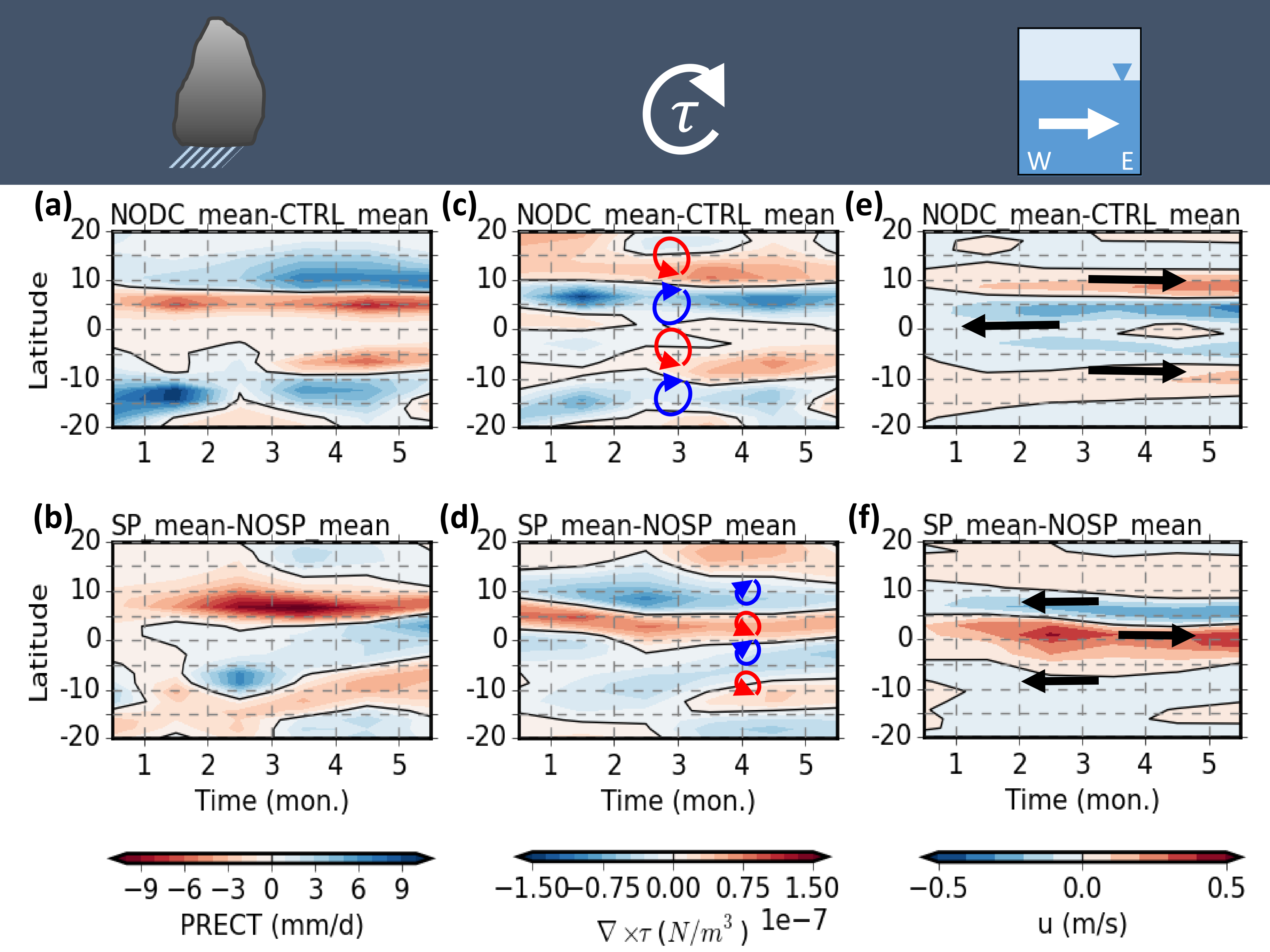
Remaining questions

Why is double-ITCZ bias insensitive to convective parameterization?

Why did CESM2's double-ITCZ disappear?

Can we predict the bias response from AMIP-style simulations?

Does the SP cold tongue degrade with inclusion of convective momentum flux parameterization?

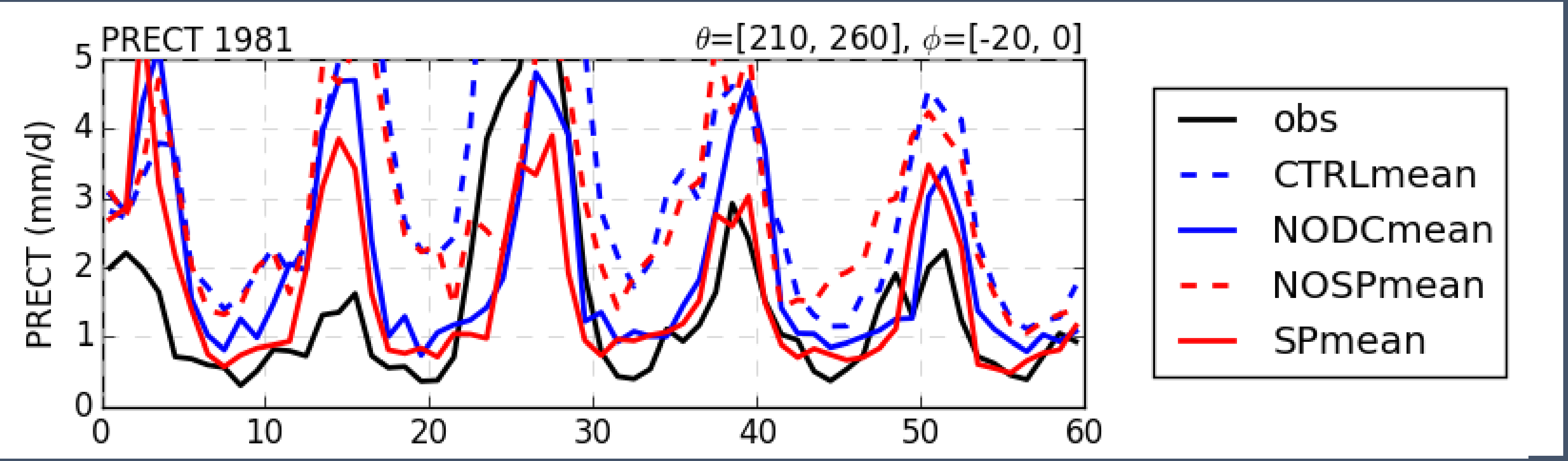


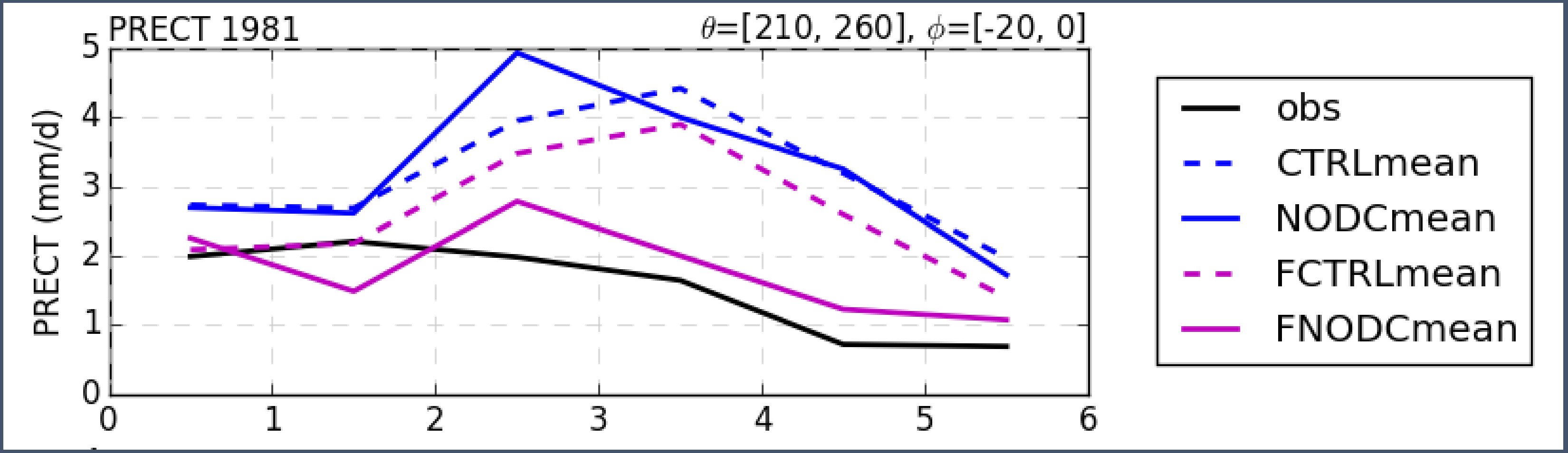
W
E
(a)
NODC_mean-CTRL_mean
(b)
SP_mean-NOSP_mean
(c)
NODC_mean-CTRL_mean
(d)
SP_mean-NOSP_mean
(e)
NODC_mean-CTRL_mean
(f)
SP_mean-NOSP_mean
Latitude
Time (mon.)
PRECT (mm/d)
$\nabla \times \tau \, (N/m^3)$ 1e−7
u (m/s)

Longer simulation shows moderate improvement with superparameterization

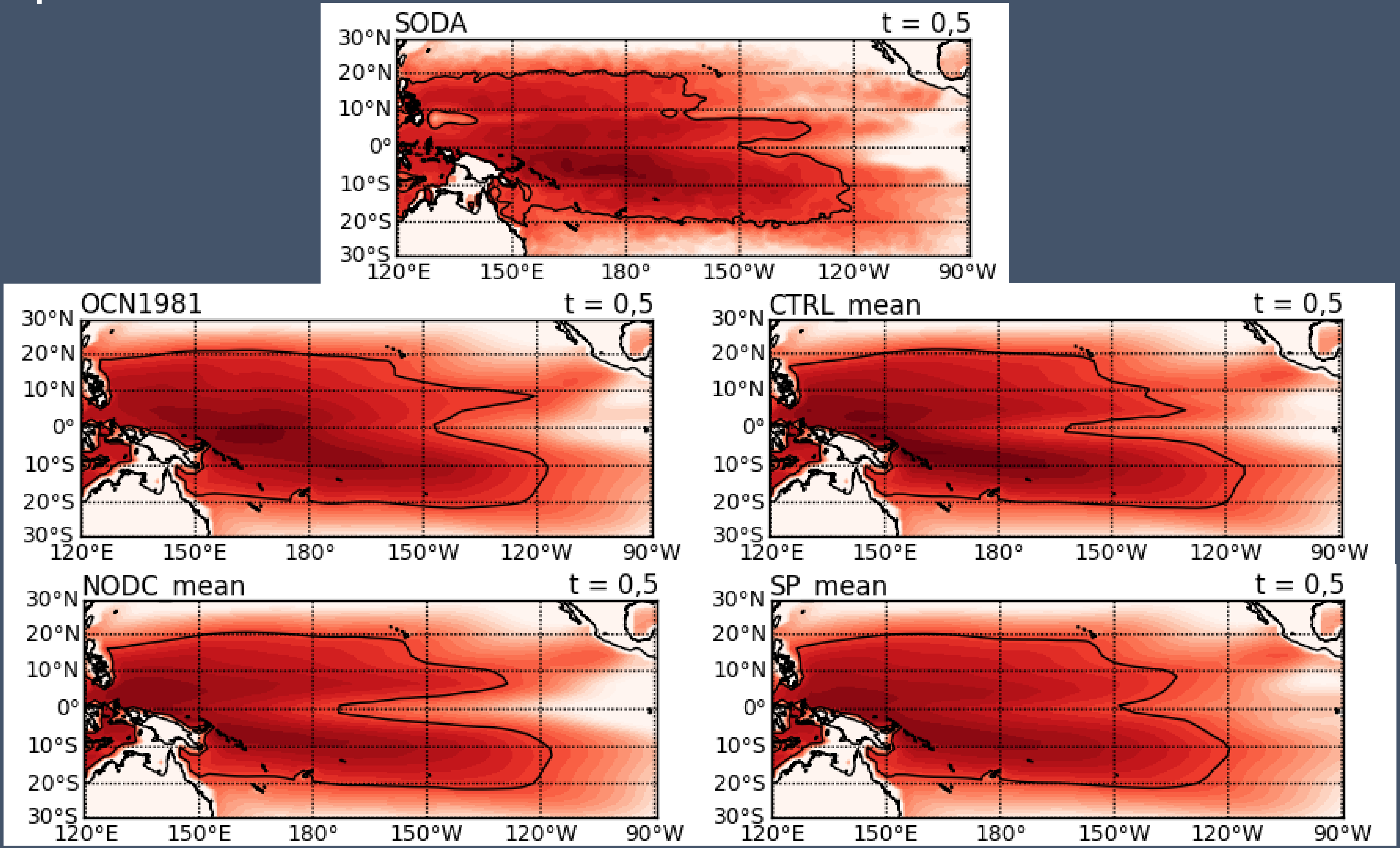
Fixed SST simulations versus **fully coupled** simulations for CTRL and NODC

(SP simulations yet to be analyzed)





100 m Ocean Heat Content: Jan-June 1981 mean



Surface wind stress and zonal currents

The geostrophic zonal current

$$M_G = \frac{1}{\beta} \int_{x}^{x_e} \frac{d}{dy} (\nabla \times \tau) dx - \frac{\tau_y}{f}$$

is the zonally integrated meridional gradient of surface wind stress curl plus Ekman transport