The annual cycle of the equatorial Pacific cold tongue bias in CESM1 hindcasts

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RGMA

CAPT Cloud-Associated Parameterizations Testbed

LLNL-PRES-767826
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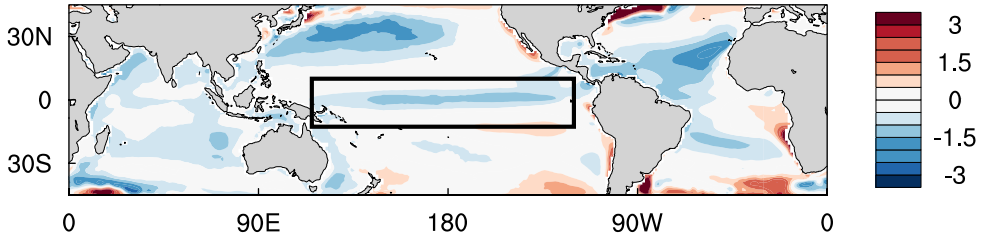
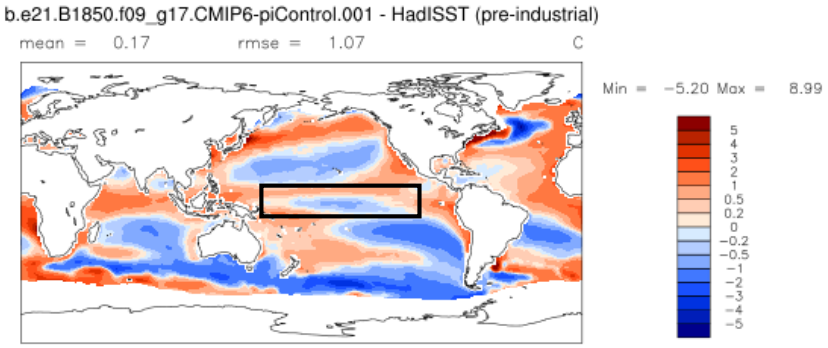
SST biases in CESM

CESM1 (LENS) SST mean bias



CESM2 piControl SST bias



- SST biases impact the fidelity of seasonal-to-decadal forecasts and future climate projections. For instance, over the equatorial Pacific cold tongue, both CESM1&2 exhibits a cold bias, which has been shown to affect ENSO simulations [AchutaRao and Sperber 2006; Jin et al. 2008, Zhang 2017].
- Diagnosing the cause of the cold tongue bias is challenging due to the complex and coupled processes involved.

→ **hindcast approach**

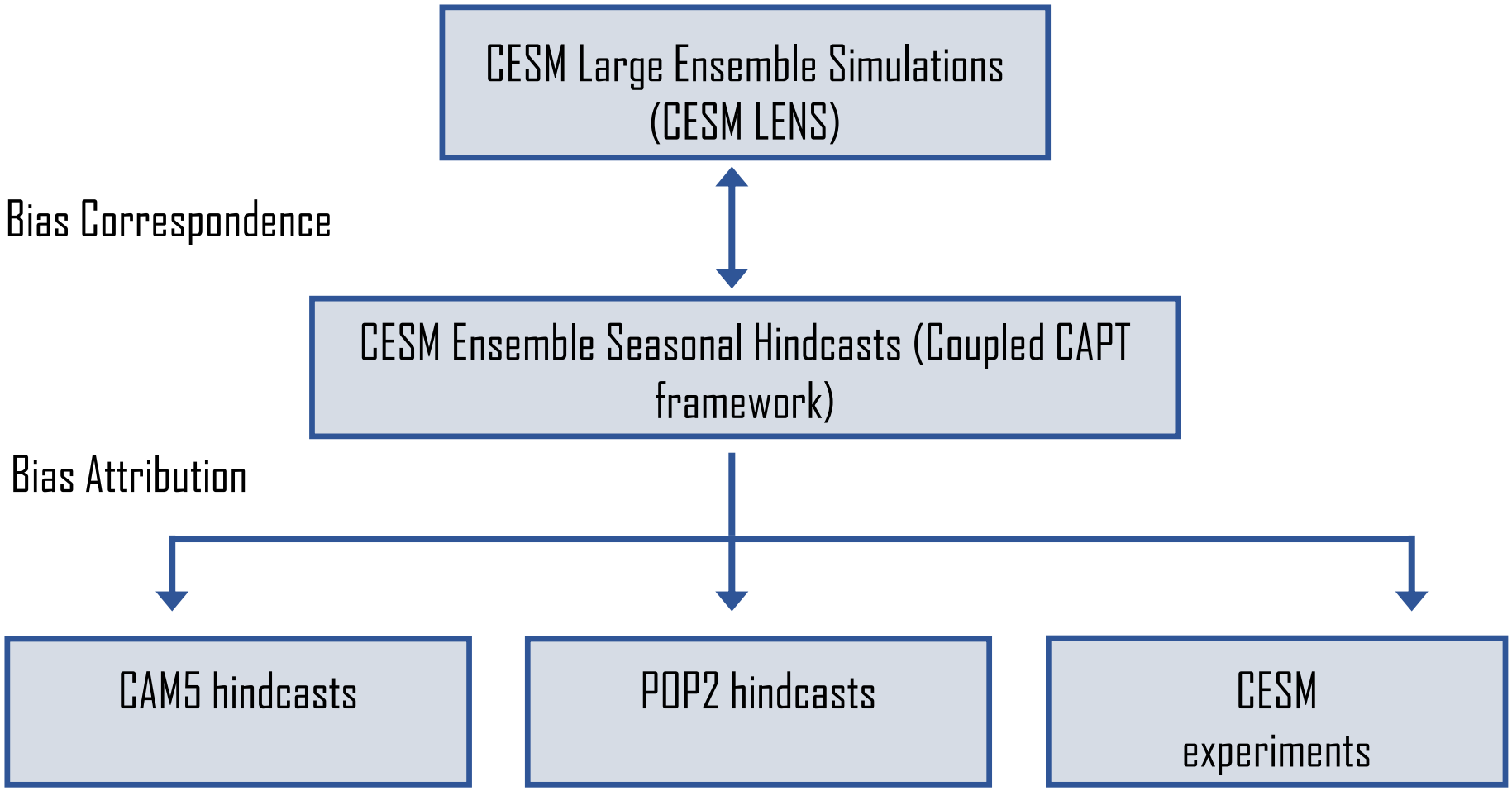
Prior Studies with hindcasts:

→ Tropical Pacific (Vanniere et al. 2013, 2014)

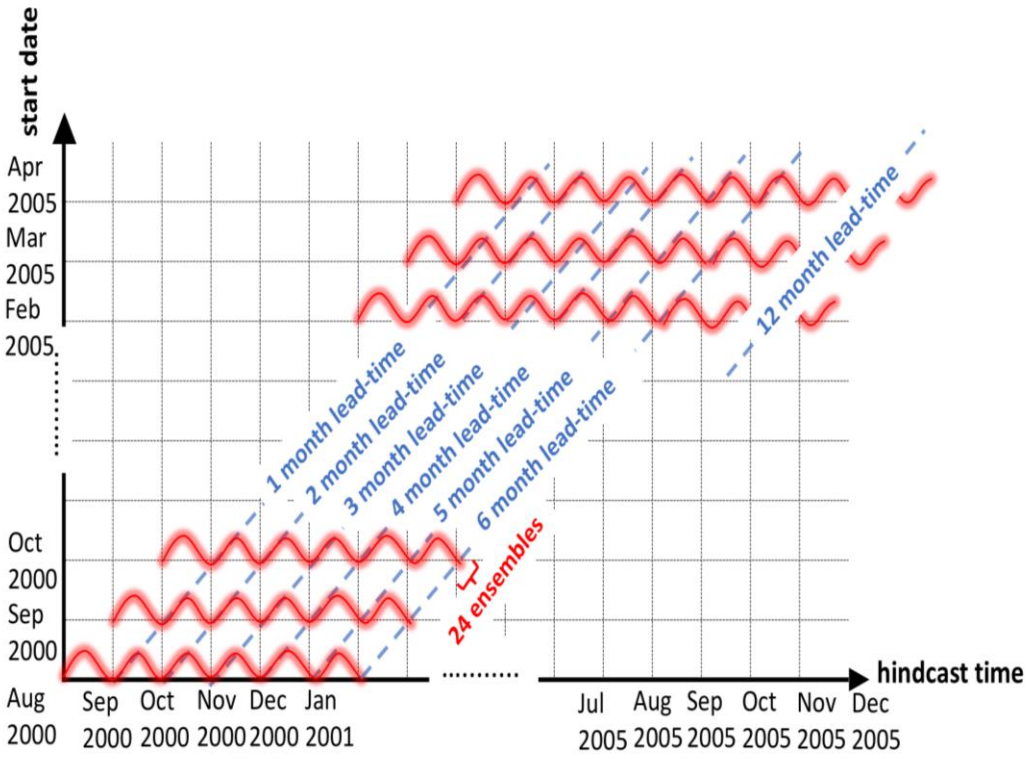
→ Tropical South Atlantic (Toniazzo and Woolnough 2014, Voldoire et al. 2014)

→ Double ITCZ (Liu et al. 2012, Zhang and Wang 2006)

A hindcast approach to diagnosing SST biases



Ensemble seasonal hindcast simulations with CESM1

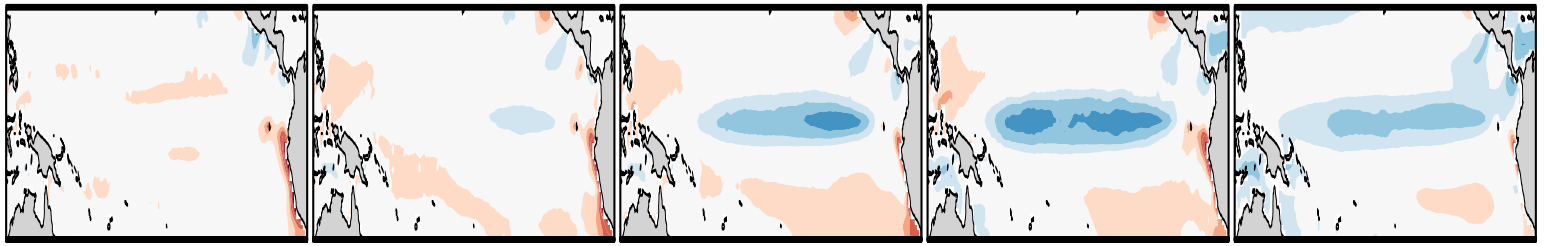


- Model: CESM1.1.2 with 0.9x1.25° resolution for land and atmosphere and 1° for ocean.
- 64 sets of hindcasts, each with 24 ensembles, covering the period Aug 2000-Dec 2005.
- Initial conditions for ocean from NCAR-DART [Karspeck et al. 2014] and for atmosphere from ERA-Interim CAPT framework [Ma et al. 2015].
- A reconstructed timeseries based on lead-time is used to study the annual cycle.

Bias correspondence: Mean State

Mean Bias

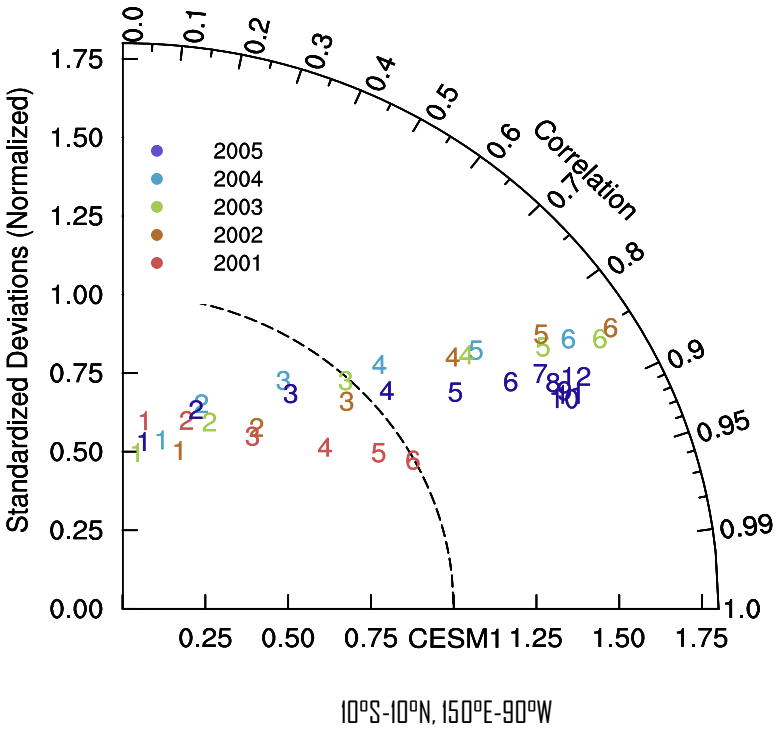
Initialized with observed state of atmosphere and ocean



month 1 month 3 month 6 month 12

hindcast lead time

Climatological Bias

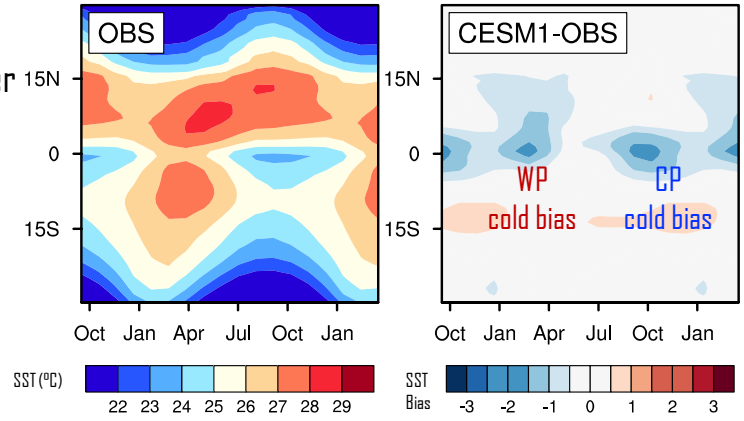


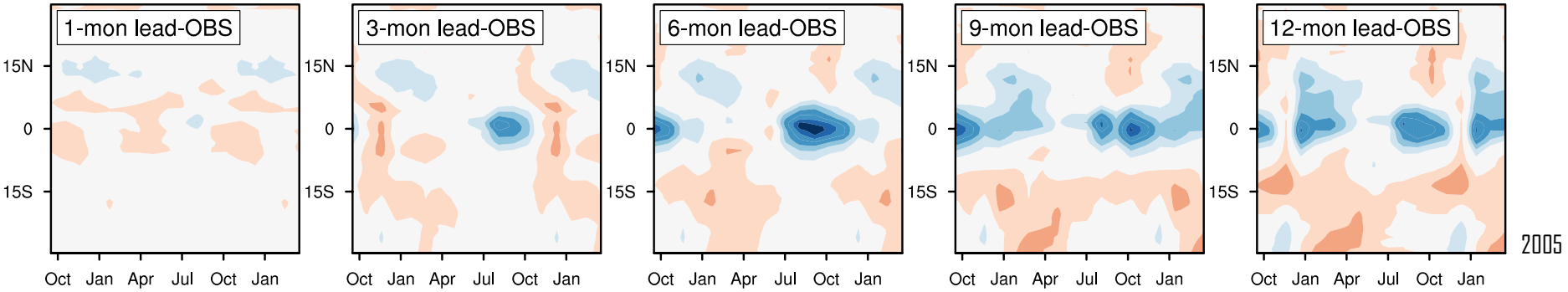
10°S-10°N, 150°E-90°W

- Bias emerges at 3 months of lead-time and starts at the eastern equatorial Pacific
- Similar bias growth is observed in other years, with differences in magnitude and variance

Bias correspondence: Seasonal Cycle

Latitude-month SST and SST bias over the eastern Pacific (90°-150°W)





- CESM1 exhibits a cold bias during both the warm (Feb-May) and cold phase (June-December) of the ECT
- Cold phase cold bias over the eastern equatorial Pacific develops within 6 months, but warm phase cold bias takes longer.

The cold phase cold bias

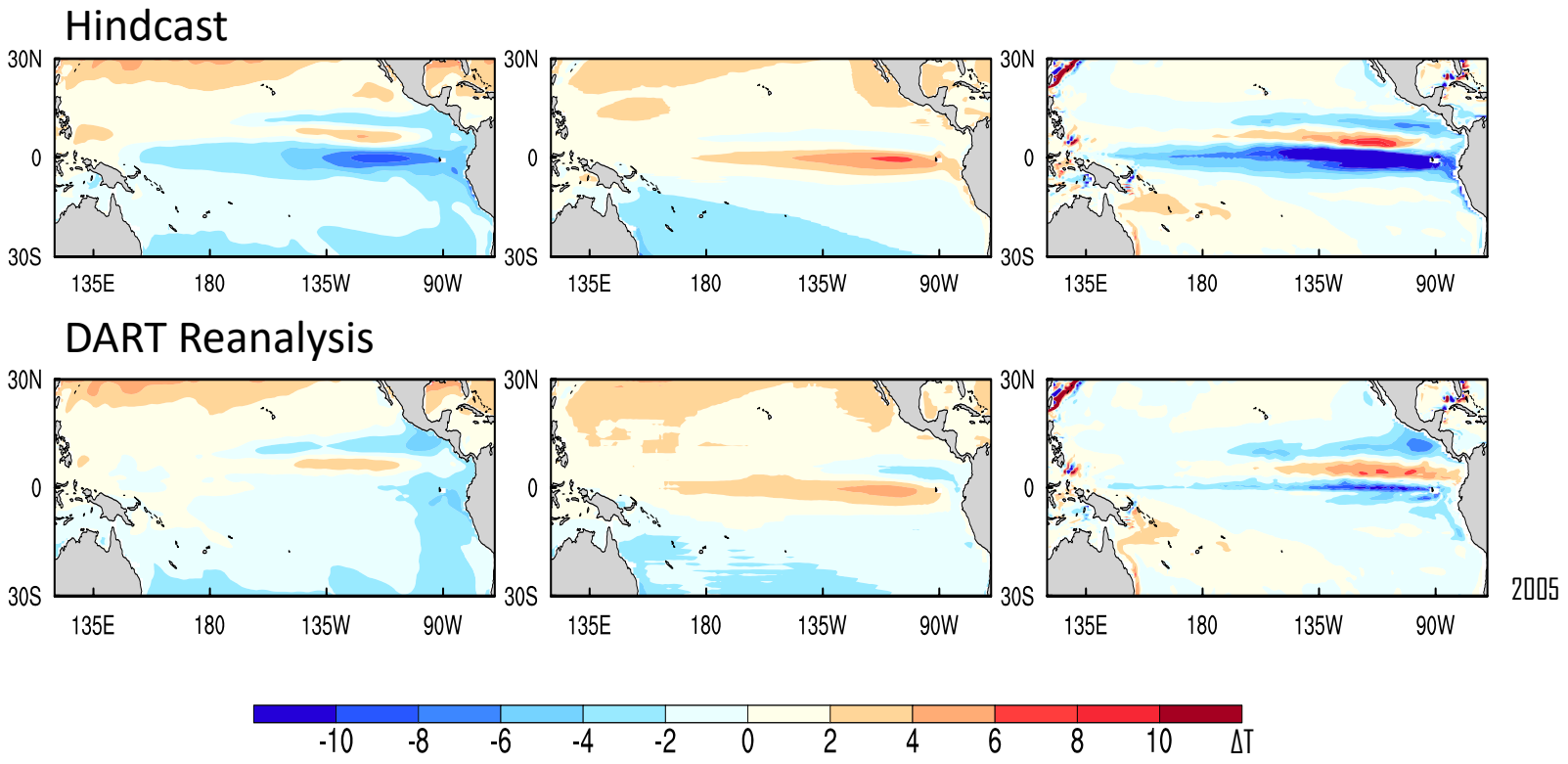
Upper ocean (100m) temperature budget

$$\int_{May}^{Oct}\left[\frac{\partial T}{\partial t}\right]dt = \int_{May}^{Oct}\left\{\frac{Q_{sfc}}{\rho c_p H} - \left[u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z}\right]\right\}dt$$

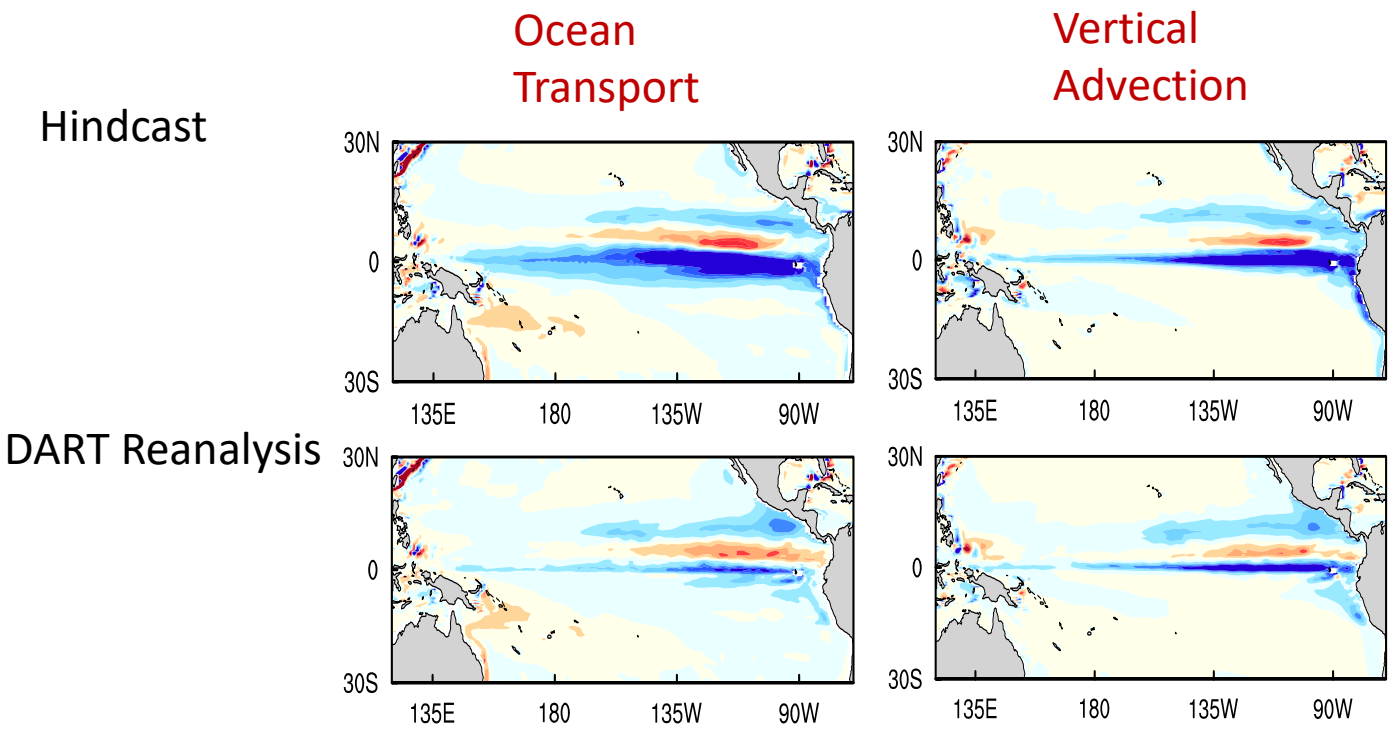
Temperature Tendency

Net surface heat flux

Ocean Transport



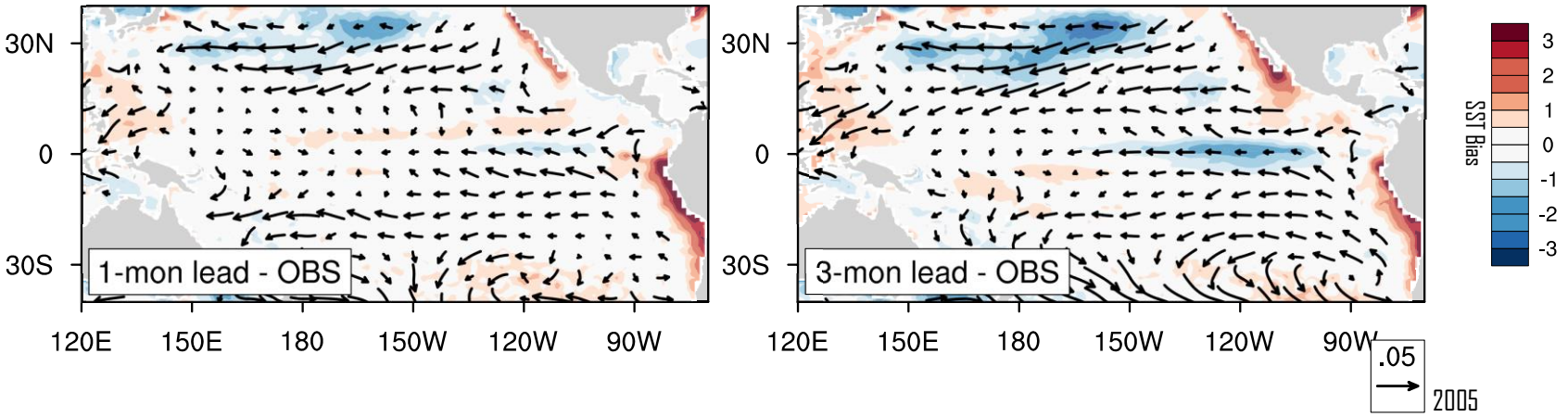
The cold phase cold bias



- Vertical advection accounts for much of the cooling tendency during the cold phase

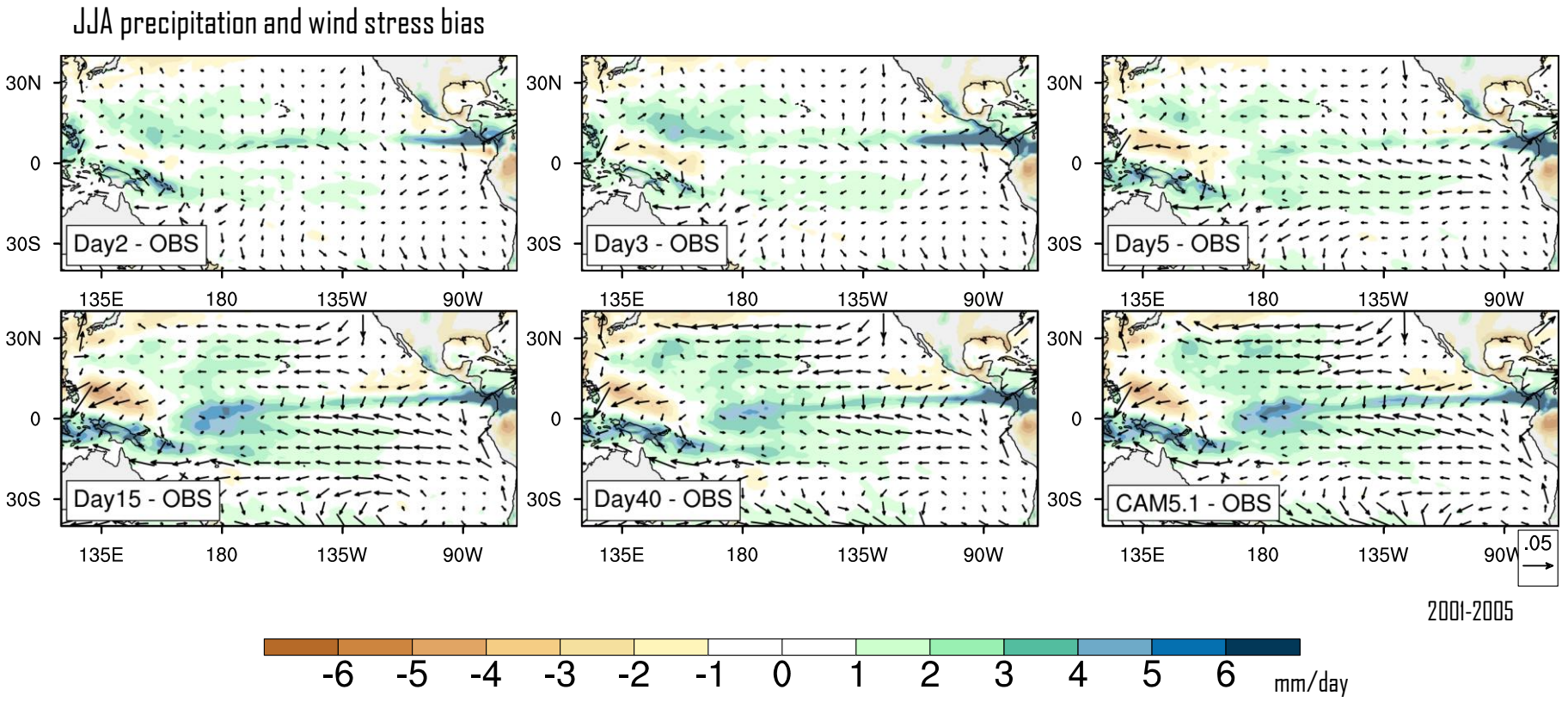
The cold phase cold bias: role of zonal wind stress

JJA



- A zonal wind stress bias is present since the first month of lead time, which drives upwelling and leads to the cold phase cold bias.

The zonal wind stress bias develops within a few days of atmosphere-only hindcasts

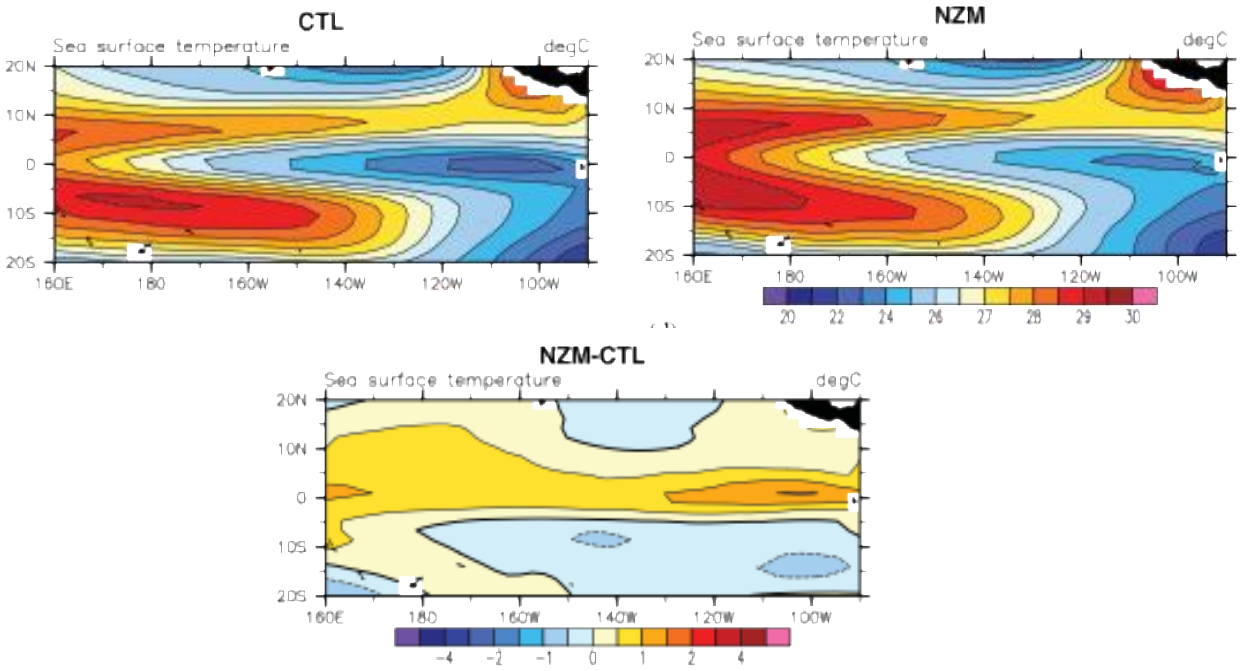


Role of convection scheme?

The Roles of Convection Parameterization in the Formation of Double ITCZ Syndrome in the NCAR CESM: I. Atmospheric Processes

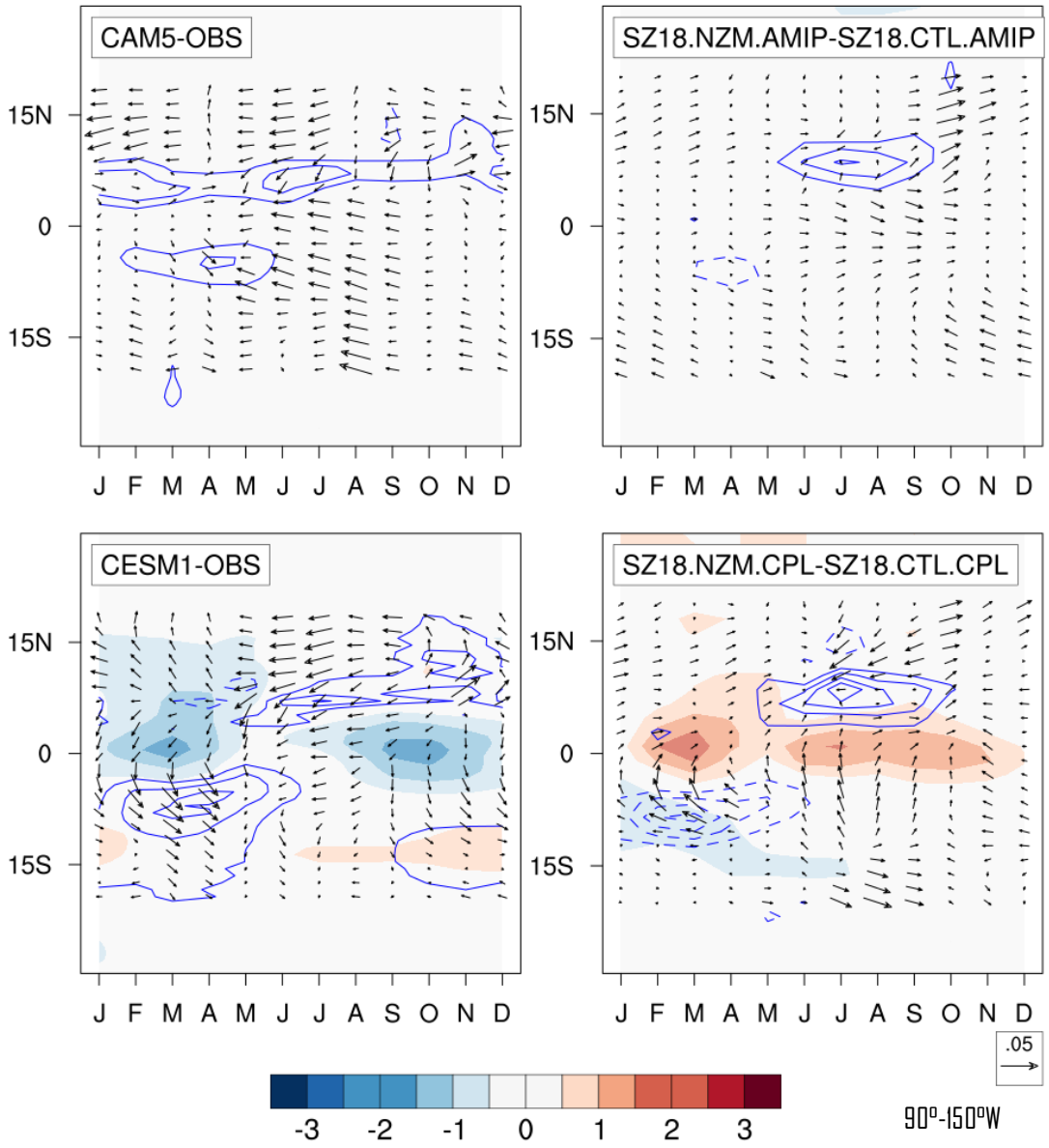
Xiaoliang Song[1] and Guang J. Zhang[1]

[1]Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA, USA



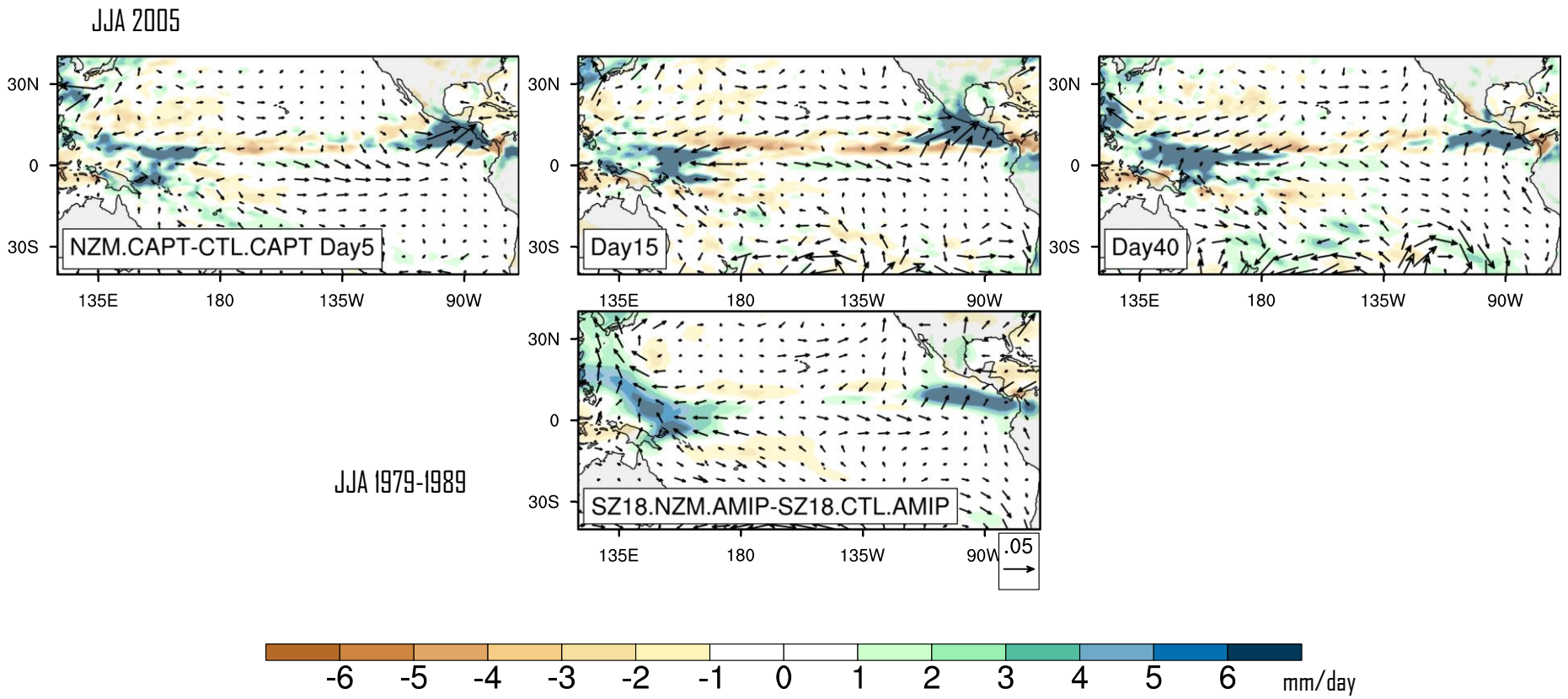
- With a modified ZM scheme [NZM; Song and Zhang 2018 (SZ18)], the double ITCZ bias is improved along with a reduction of the cold tongue bias in the mean state.

Role of convection scheme?



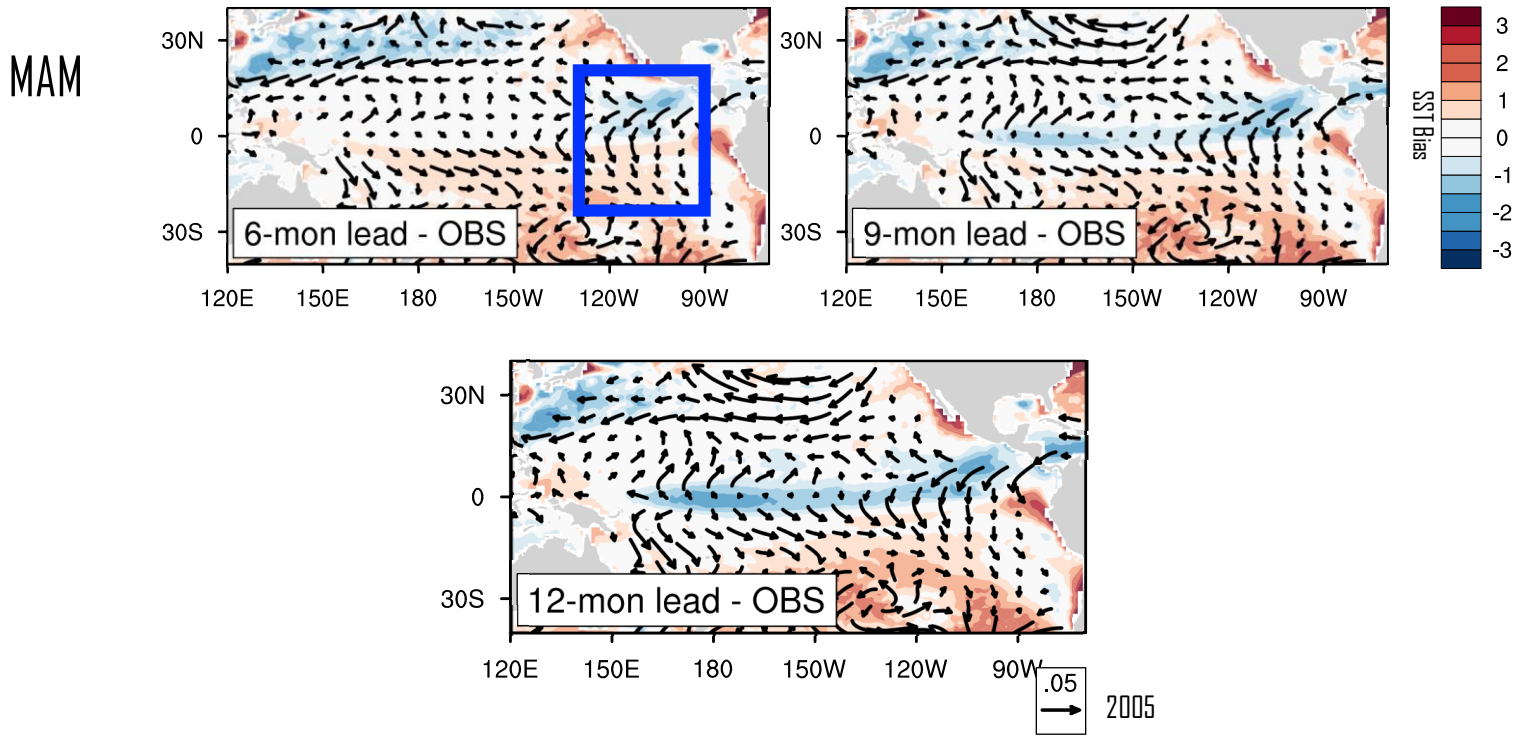
- With NZM in AMIP-type simulations:
  - JJA easterly wind is weaker.
  - JJA precipitation north of the equator is enhanced and MAM precipitation is decreased south of the equator.
- With NZM in coupled simulations:
  - SSTs are warmer in boreal spring and summer-fall.
  - Precipitation responds similarly to that in uncoupled simulation, but with greater magnitude

Testing the NZM scheme in CAPT atmosphere-only simulations



- With a modified ZM scheme, atmosphere-only hindcasts show weaker easterlies and stronger precipitation over the northeastern Pacific.

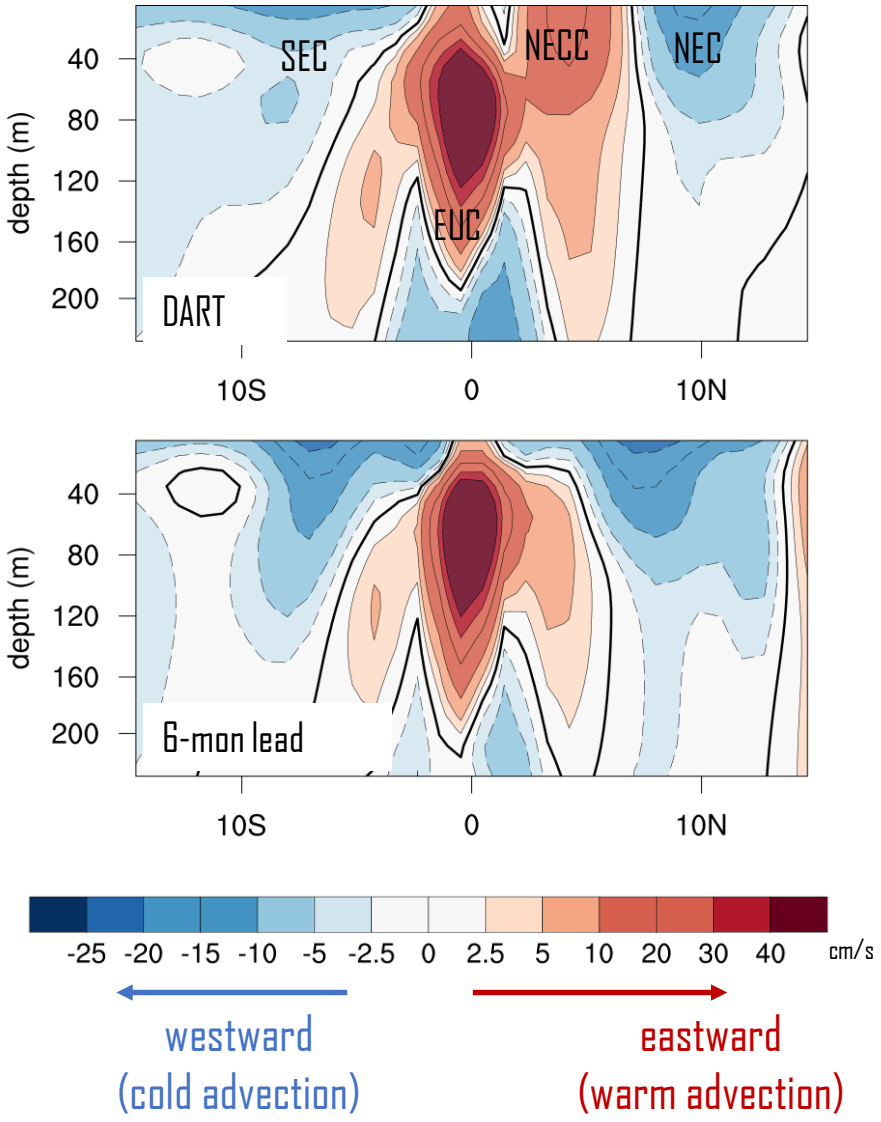
The warm phase cold bias



- A cold bias is present by 6 months of lead-time, located northeast of the eastern equatorial Pacific, accompanied by a northerly wind stress bias.
- By 12 months of lead time, the northeast cold bias spreads westward and equatorward.
- Why does the northeast Pacific have a cold bias?

The warm phase cold bias: role of zonal currents

Boreal spring (MAM) zonal current over the far eastern Pacific (90°-120°W)



SEC: South Equatorial Current
EUC: Equatorial Undercurrent NECC: North Equatorial Countercurrent
NEC: North Equatorial Current

- Westward NEC extends equatorward and NECC weakens, reducing warm advection
- Related to northerly wind stress bias and double ITCZ bias? [deSzoeke and Xie 2008; Wang et al. 2014]

Summary

1. Climatological SST biases such as the equatorial Pacific cold tongue bias emerge within 6 months of hindcasts

   → Seasonal hindcasts can be used for studying how SST biases emerge and develop

2. The rapid emergence of SST biases suggests that fast processes in the atmosphere and upper ocean are responsible

3. Ongoing work: Investigating the impact of ZM modifications on precipitation, winds, and SST biases.

4. The rapid emergence of SST errors means that initialized short duration simulations can profitably be used in the development of high-resolution coupled models.

5. A good "state estimation" initialization for the current period would allow one to use modern observations to assess and improve GCMs or ESMs.