2020 RGMA PI Meeting

Understanding the Dynamics and Thermodynamics of ENSO and its Complexity Simulated by E3SM and Other Climate Model

PI: F-F Jin (UH); Co-PIs: A. Wittenburg (GFDL), S-C Xie (LLNL)

***Contributors:** M Hayashi, S. Zhao, H-C Chen, A-Y Xu, J. Boucharel

GOALs

(i) To understand processes that control the dynamics and thermodynamics of ENSO in E3SM (CMIP6 & observations), using a hierarchy of dynamical frameworks.

(ii) To explore pathways towards improving E3SM's capability of simulating ENSO.

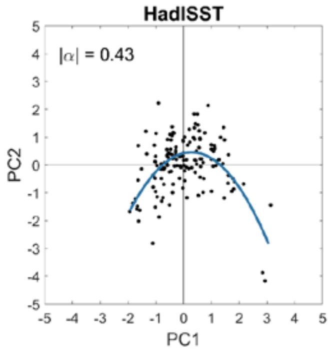
Progresses highlights since 2019

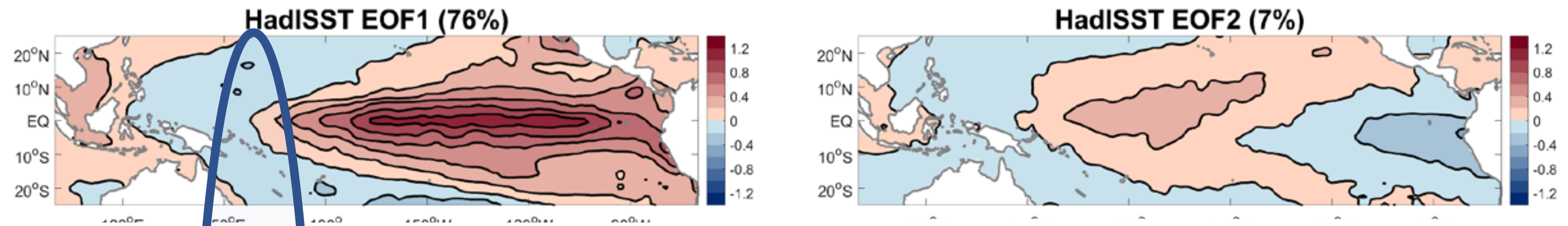
- **Comprehensive analyses of ENSO linear growth rate and frequency in terms of feedback processes**
- **Identifications for sources of error compensations in ENSO growth rates, asymmetry &phase locking**
- **A new framework to assess seasonally modulated feedbacks of Tropical Instability Wave (& WWB) on ENSO**

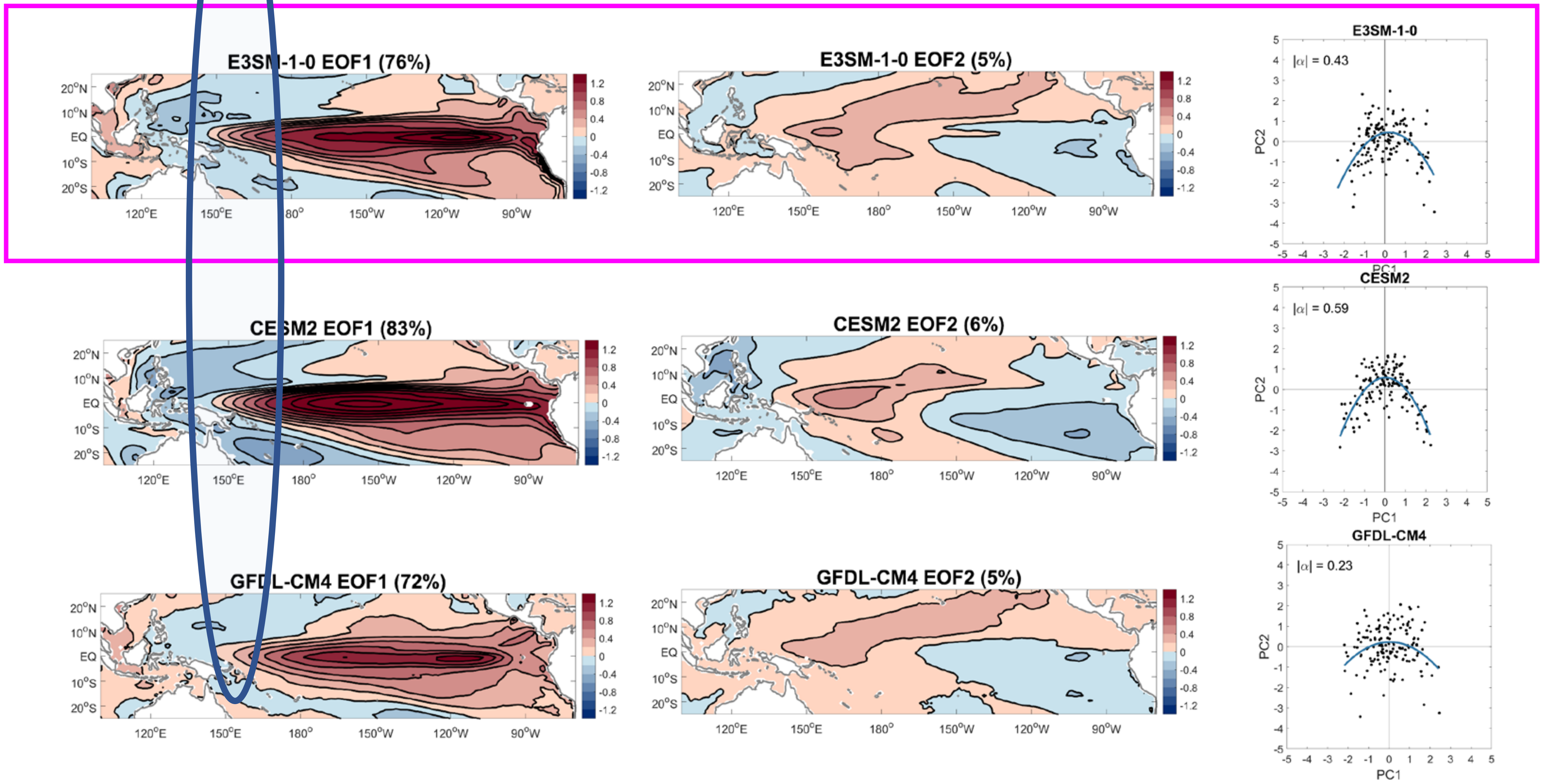
Data sets used

- E3SM & CMIP6 (38) model historical simulations for 1861-2004
- CMIP5 (40) model historical simulations for 1861-2004
- 7 ocean reanalysis products for 1961-2010
- Other observations from HadISST, GPCP, and TropFlux

1. E3SM captures basic features of ENSO

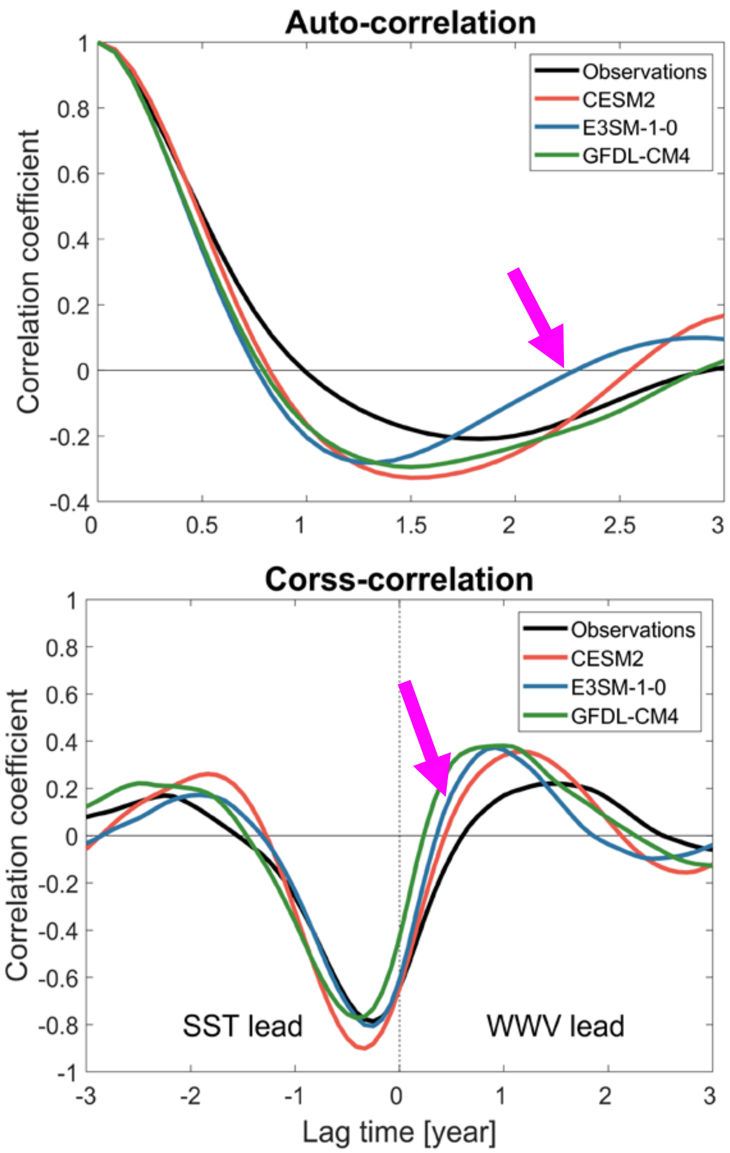






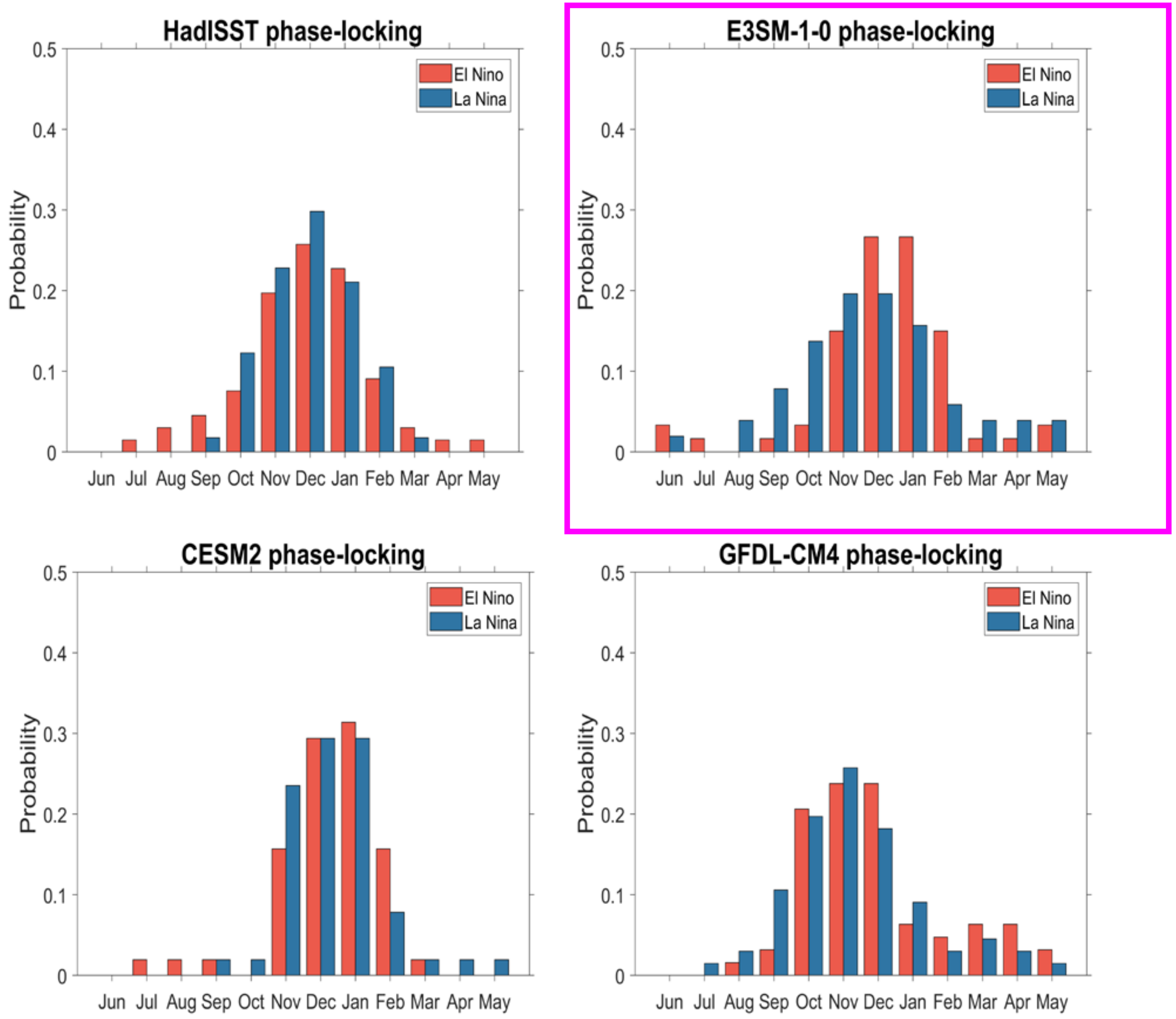
ENSO Recharge Oscillator Dynamics

(in Nino3.4 and hw Auto & Cross Correlations)



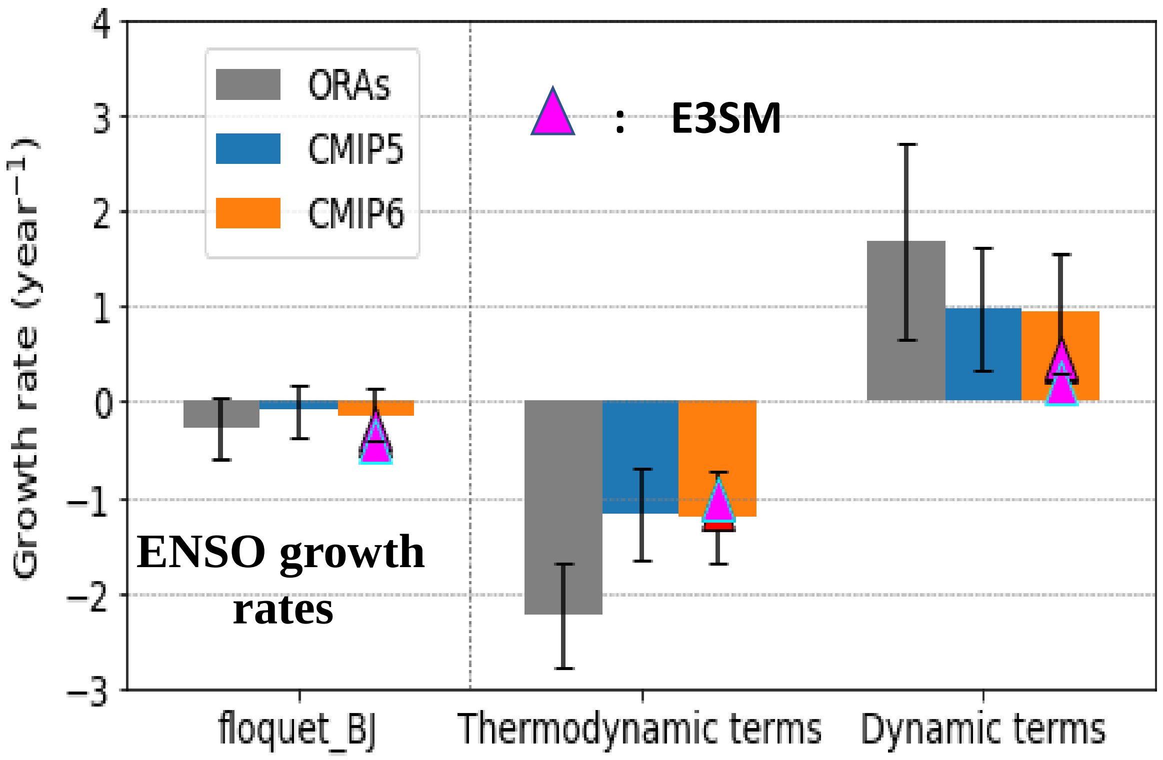
ENSO Phase locking

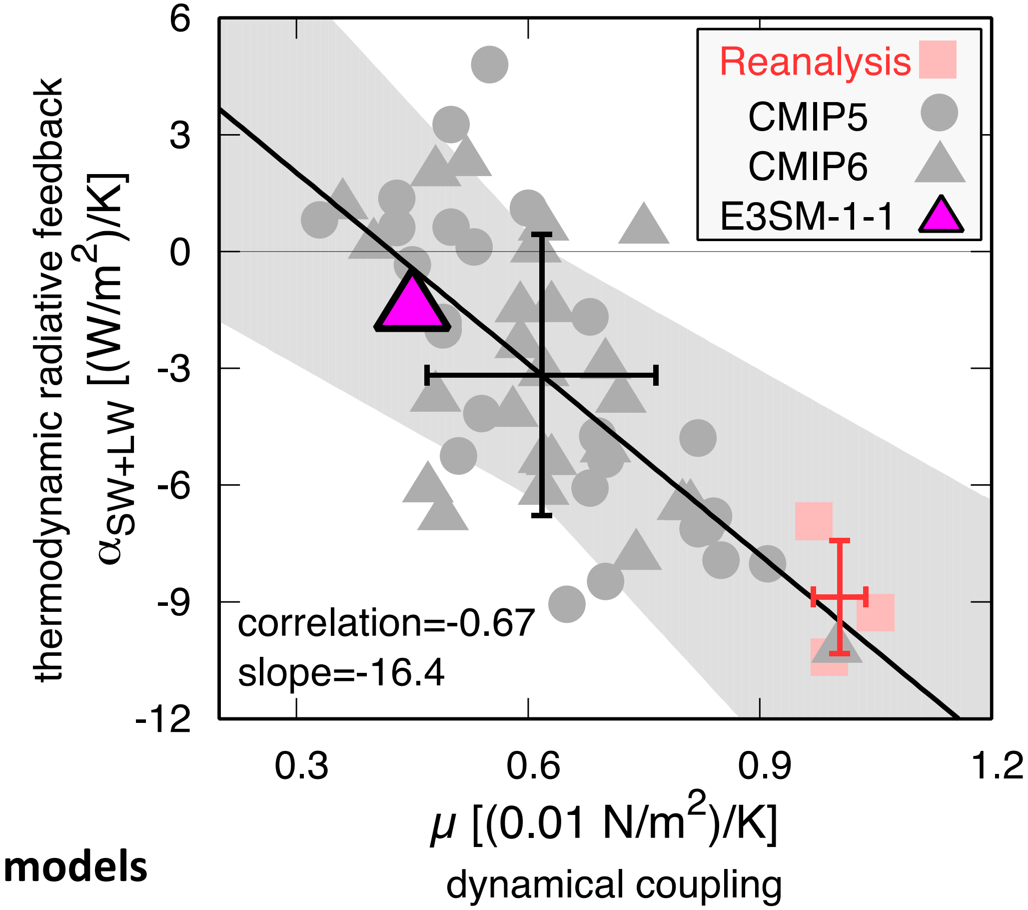
(histogram of Nino3.4 peak-phase months)



But ...

2. Strong error compensations occur in ENSO growth rates of E3SM & CIMP5/6 models simulations





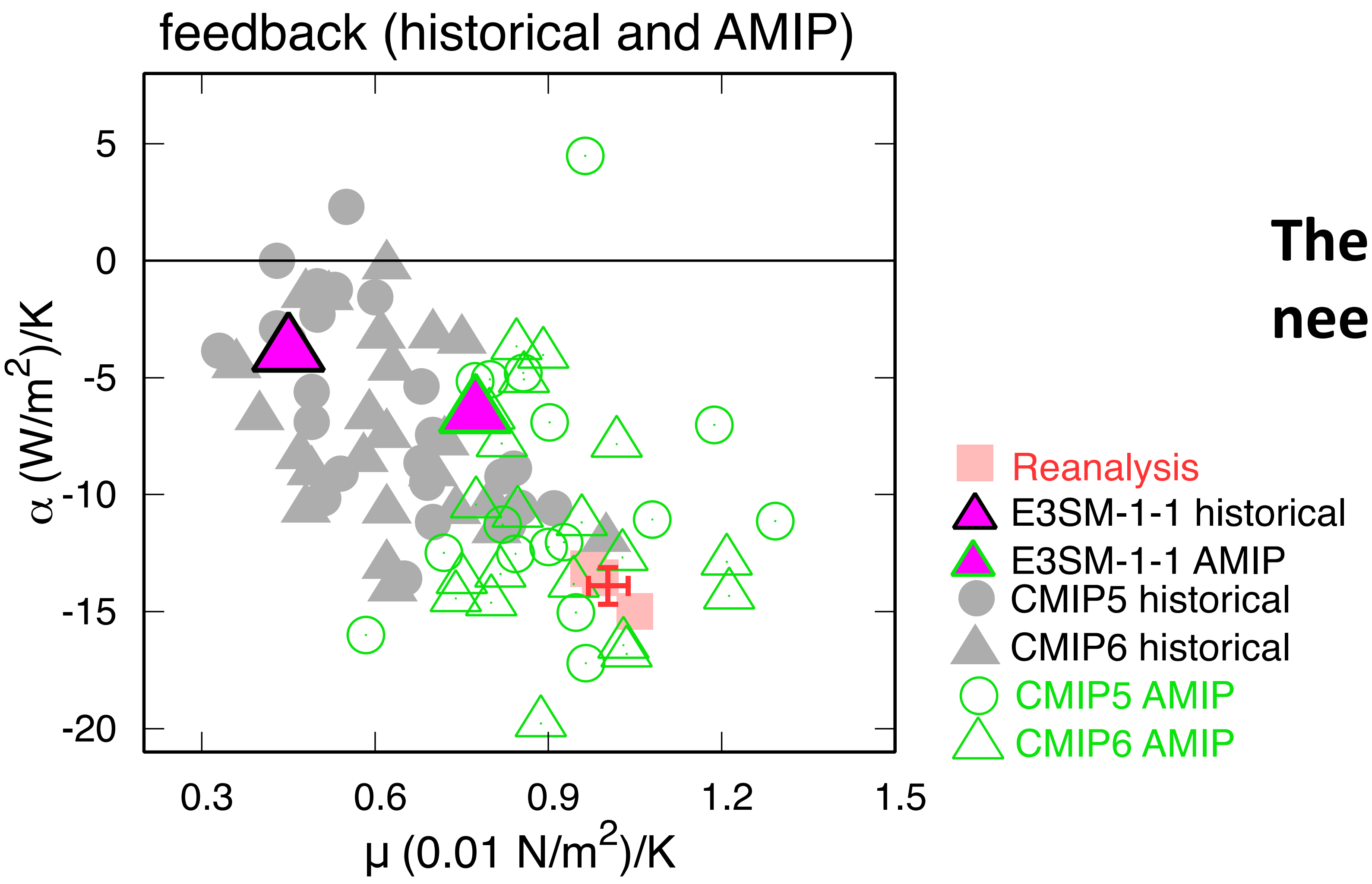
ENSO Bjerknes stability and Wyrtki periodicity indices in CMIP5/6 models

(Zhao and Jin 2020, to be submitted)

Regression coefficients of anomalies to Niño-3 SSTA

- **α_{SW+LW}: anomalous surface radiative heat flux in the Niño-3 and Niño-4 regions**
- **μ: anomalous zonal wind stress in the central Paicifc (150°E–120°W, 5°S–5°N)**

These biases occur in AMIP simulations



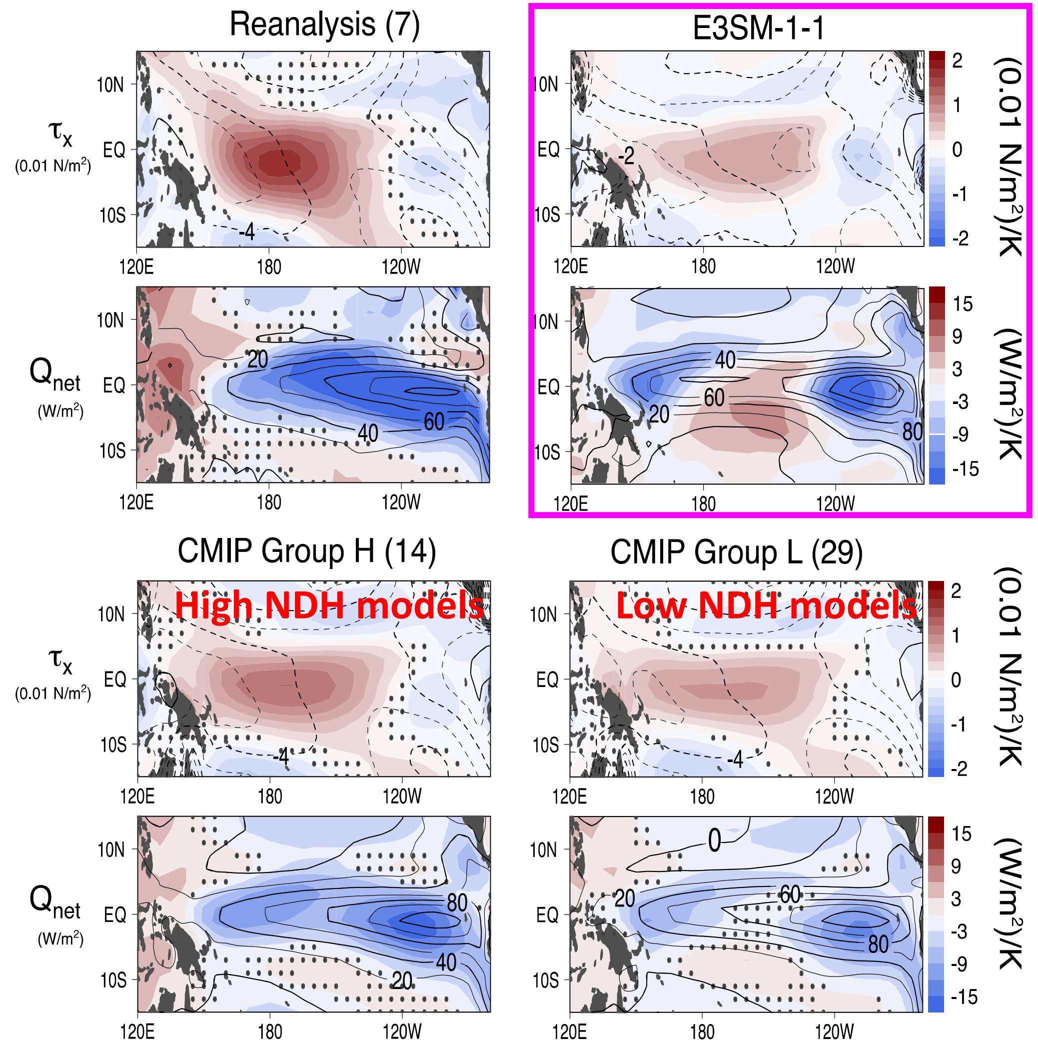
The causes of the biases need to be further explored.

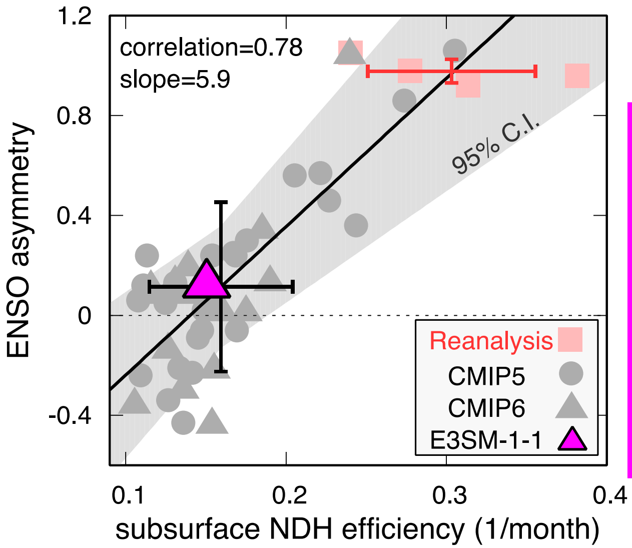
Regression coefficients of anomalies to Niño-3 SSTA

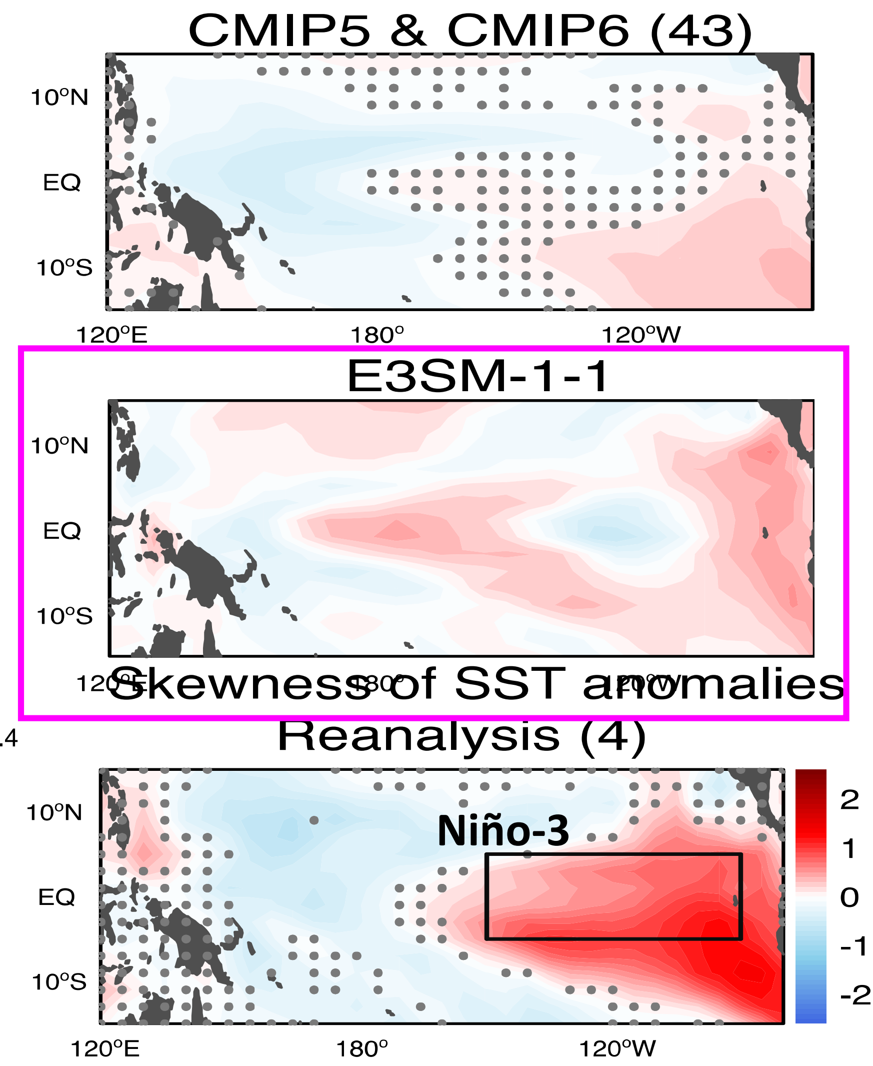
- **α: anomalous net surface heat flux in Niño-3 and Niño-4**
- **μ: anomalous zonal wind stress in the central Paicifc**

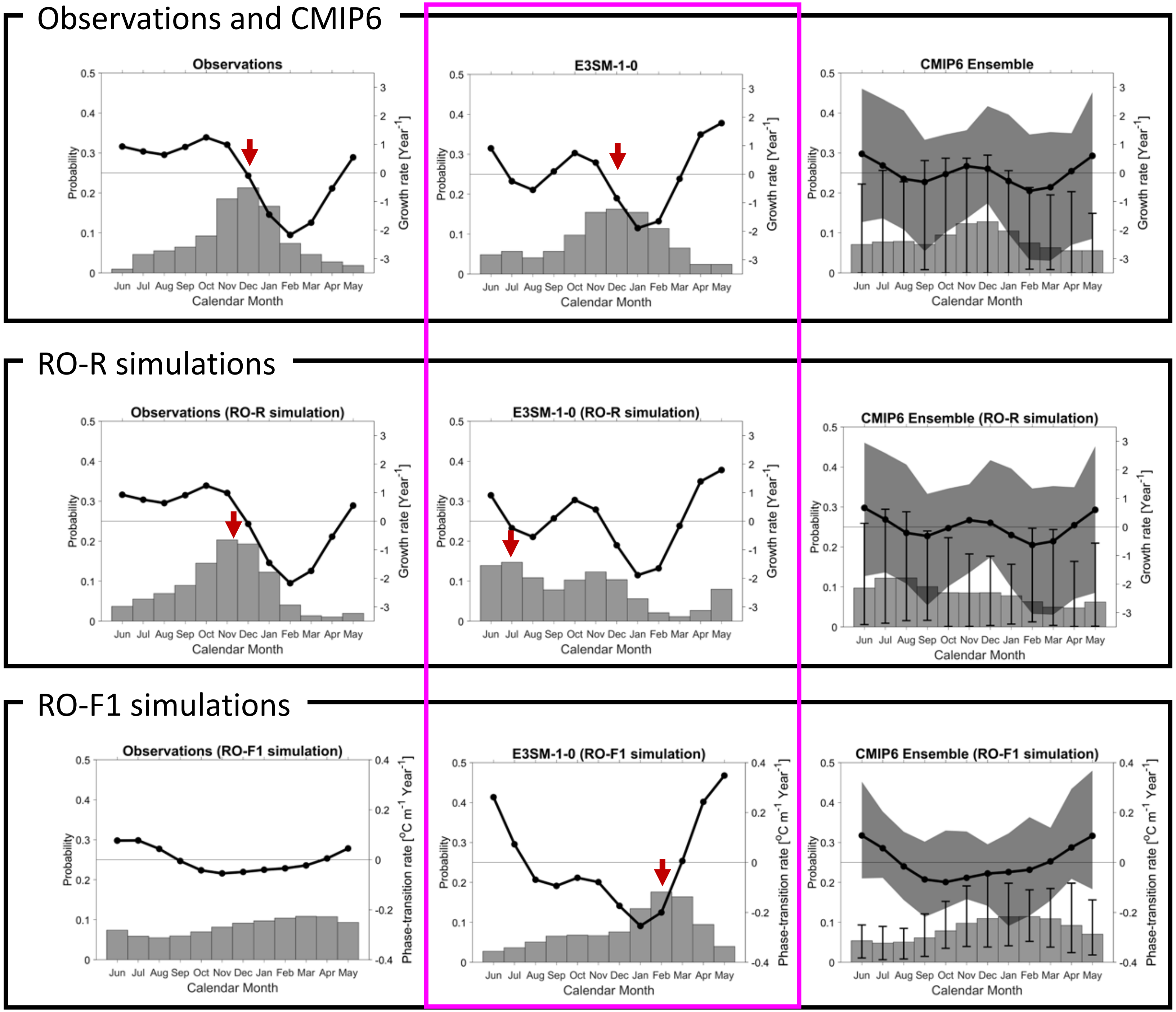
Hayashi, Jin and Stuecker (2020, Nature Communications)

weak wind response → weak NDH → weak ENSO asymmetry









3. E3SM may simulate ENSO "right" phase-locking for wrong reasons too.

Recharge oscillator model

$$\frac{dT}{dt} = RT + F_1 h + \sigma_T \xi_T$$

$$\frac{dh}{dt} = -rh - F_2 T + \sigma_h \xi_h$$

Seasonal modulated RO

Observations

Phase-locking is mainly determined by the seasonal modulation of SST growth rate, and has nothing to do with the SST phase-transition rate.

E3SM-1-0

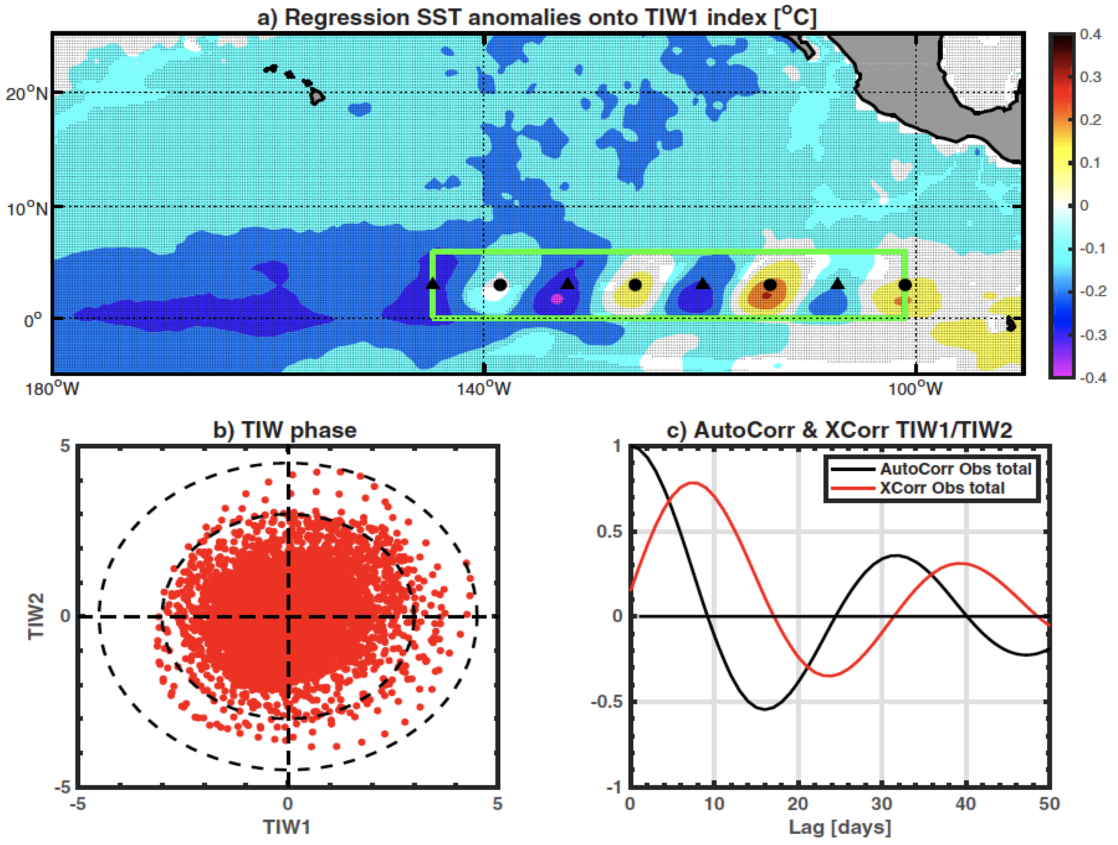
Phase-locked on wintertime is caused by the combined effect of SST growth rate and phase-transition.

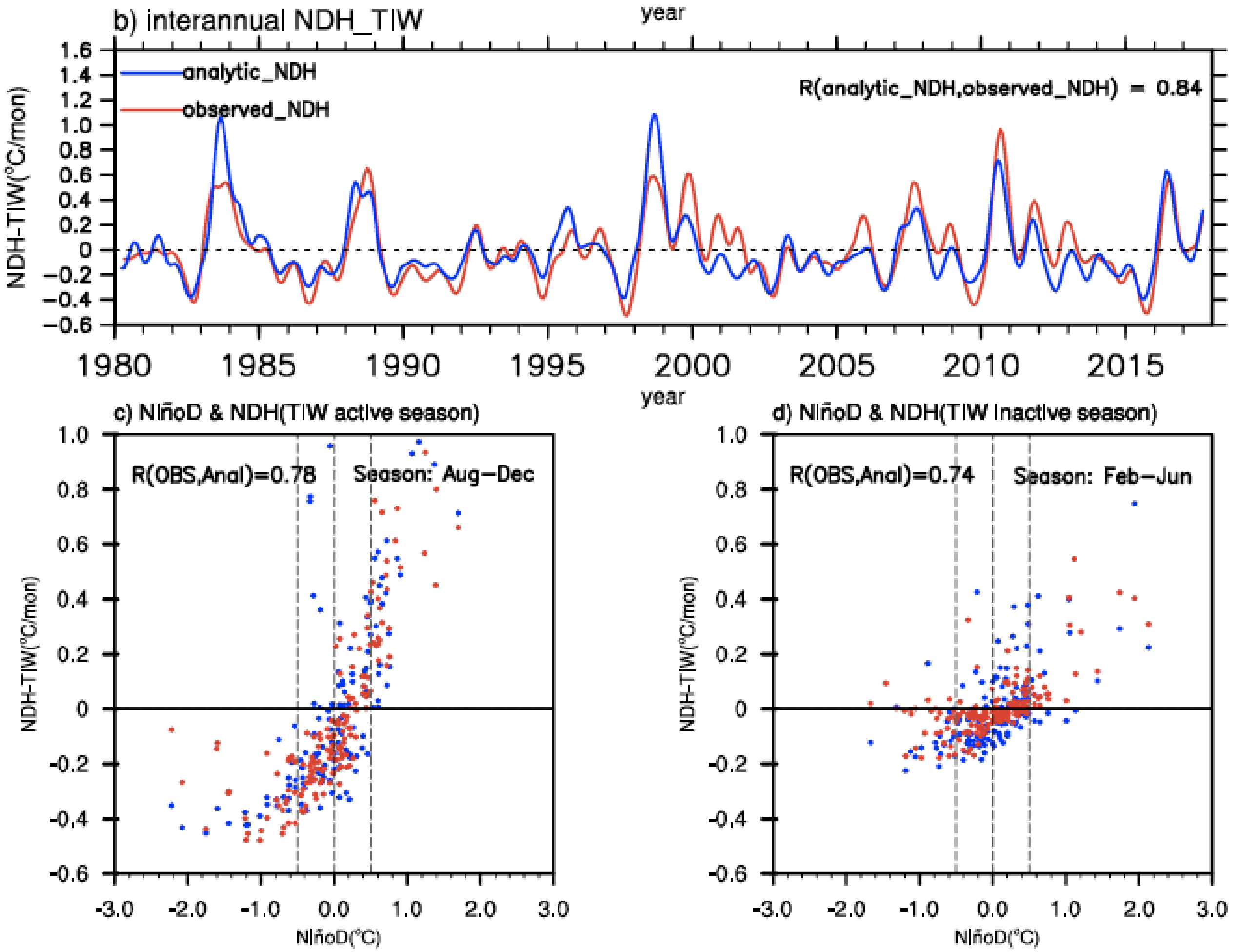
CMIP6 Ensemble

There is only a weak phase-locking in CMIP6 ensemble and the seasonal variation of SST growth rate is also weak .

Chen et al (2020, to be submitted)

A New Framework for the TIW feedback onto ENSO (Boucharel and Jin 2020, Xu et al 2020)





We developed multi-gird point indies for TIW’s a
a simple framework for ENSO and AC modulati
for TIW activity

$$\frac{dZ}{dt} = \left[-\left(\gamma_0 + \frac{2i\pi}{T}\right) + \left(\gamma_A \cos\frac{2\pi(t-\varphi)}{T_A}\right) + \left(\gamma_N \text{Niño3.4(t)}\right) + \left(\gamma_{N^3} \text{Niño3.4(t)}^3\right)\right] Z + \omega(t),$$

We shall use the framework to access TIW-ENSO Interaction in E3SM and other Climate models,

Summary

- E3SM captures ENSO pattern & its diversity and its basic RO dynamics reasonably well.

- E3SM has a strong error compensation in its ENSO growth rate from dynamic and thermodynamic feedbacks, largely from as the results of its weak atmospheric wind response & weak short-wave damping.

- This error compensation gives rise to “right” ENSO growth rate (amplitude) for wrong reasons and is a major source for its poor ENSO asymmetry simulation.

- The error compensation in the seasonal modulations of E3SM’s ENSO growth & phase transition produces a “right” phase –locking for wrong reasons too.

Ongoing : further process-level investigations and explorations of pathways for model improvements and of metrics/tools for mechanistic diagnostics.

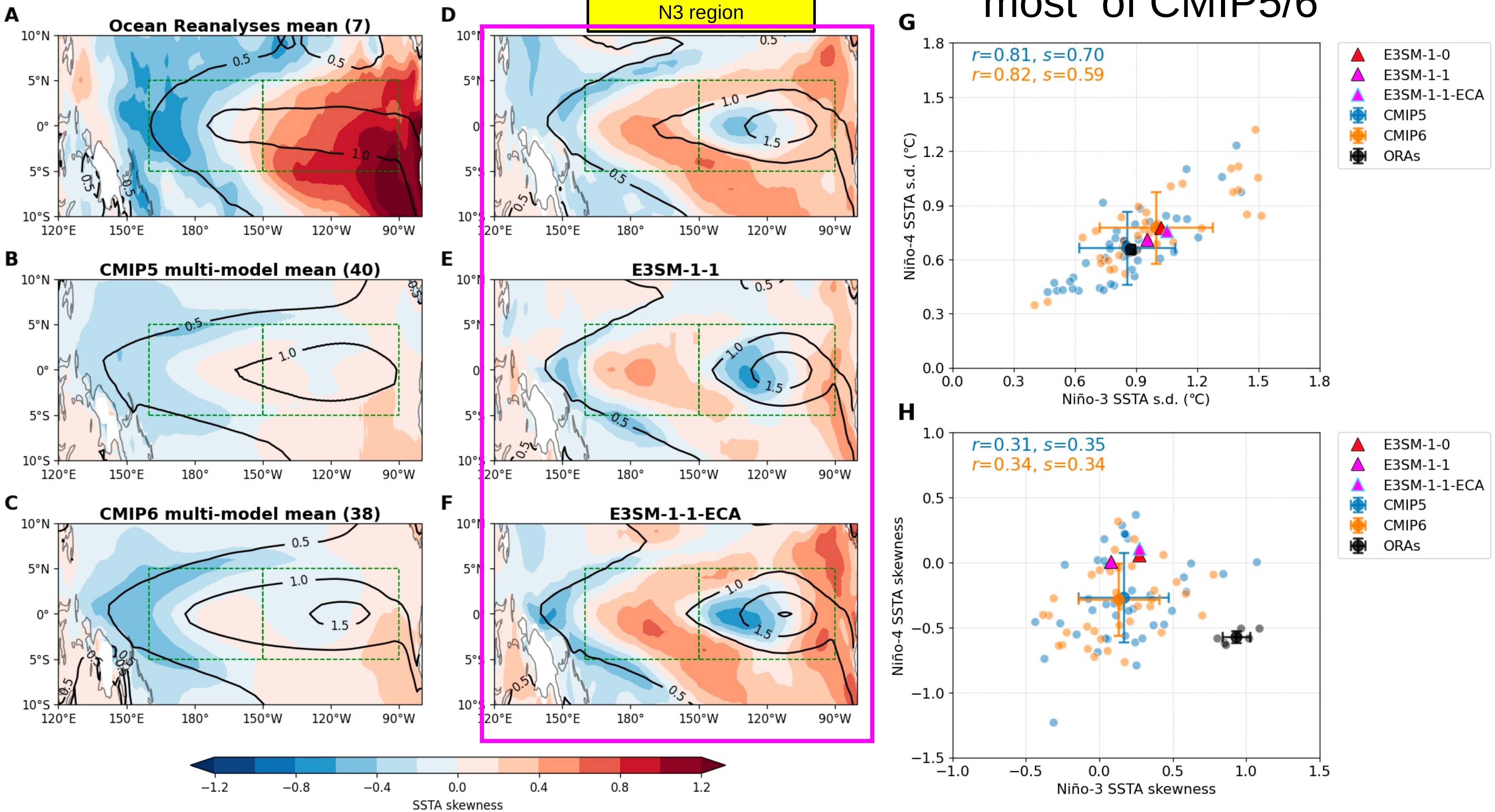
Supp. Slides

ENSO Amplitude and Asymmetry

SSTA standard deviation and skewness

A negative “hole” in SSTA skewness near N3 region

- E3SM ENSO amplitude is roughly right
- E3SM ENSO skewness is poor, as the most of CMIP5/6



ENSO Bjerknes stability and Wyrtki periodicity indices

ENSO RO theory (Jin 1997)

$$\frac{dT_\mathrm{E}}{dt} = RT_\mathrm{E} + F_1 h_\mathrm{W} + \xi_T$$

$$\frac{dh_\mathrm{W}}{dt} = -\varepsilon h_\mathrm{W} - F_2 T_\mathrm{E} + \xi_h$$

$$I_\mathrm{Bjerknes} = \mathrm{BJ} = \frac{(R-\varepsilon)}{2}$$

$$I_\mathrm{Wyrtki} = \mathrm{WJ} = \frac{4\pi}{\sqrt{4F_1F_2 - (R+\varepsilon)^2}}$$

(Jin et al. 2006; Lu et al. 2018; Jin et al. 2020)

- **East and west equatorial Pacific boxes can be divided by the node in the regression map of thermocline depth anomalies against the first EOF mode of the equatorial Pacific MLT anomalies following Kim and Jin (2011)**
- **R and F1 contain contributions of ENSO feedbacks using mixed layer temperature budget (H=50 m)**

$$\frac{\partial T_\mathrm{E}}{\partial t} = \frac{\langle Q_\mathrm{net}\rangle}{\rho_0 C_p H} - \langle \frac{\partial(\bar{u}T)}{\partial x} + \frac{\partial(\bar{v}T)}{\partial y}\rangle + \frac{\langle \overline{w}_H T_H\rangle}{H} - \langle u\frac{\partial \bar{T}}{\partial x}\rangle - \langle w\frac{\partial \bar{T}}{\partial z}\rangle - \langle v\frac{\partial \bar{T}}{\partial y}\rangle - \langle u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z}\rangle + \langle Q_\mathrm{SG}\rangle$$

Thermal damping (TD) | Dynamic damping (DD) | Thermocline feedback (TH) | Zonal adv. feedback (ZA) | Vertical adv. feedback (VA) | Meridional adv. feedback (MA) | Nonlinear adv. dynamic heating (NDH) | Residual: sub-grid scale contributions (SG)

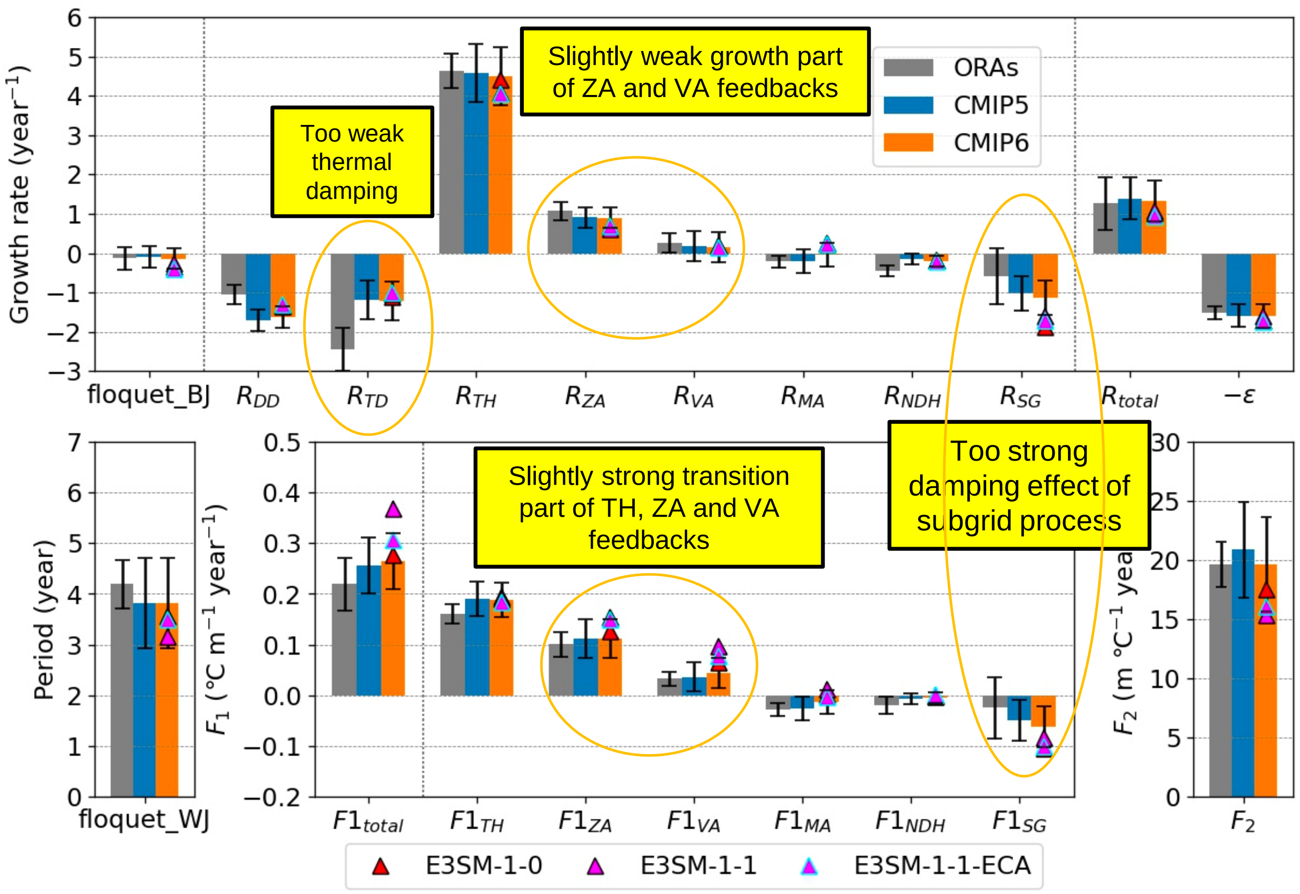
$$R = R_{TD} + R_{DD} + \frac{\langle \overline{w}_H M(\overline{w}_H)\rangle}{H}(e_1 + e_2 a_h \beta_T) + \langle -\frac{\partial \bar{T}}{\partial x}\rangle \beta_{uT} + R_{VA} + R_{MA} + R_{NDH} + R_{SG}$$

$$F_1 = e_2 \frac{\langle \overline{w}_H M(\overline{w}_H)\rangle}{H} a_h + \langle -\frac{\partial \bar{T}}{\partial x}\rangle \beta_{uh} + F1_{VA} + F1_{MA} + F1_{NDH} + F1_{SG}$$

(Zhao and Jin 2020, to be submitted)

ENSO BJ and WJ indices in E3SM and CMIP models

Annual mean ENSO feedbacks and floquet BJ and WJ indices



▲ : **E3SM**

- Total growth rate is very close to the observation, i.e., **near criticality.** However, there is a strong compensation between the thermodynamic (TD) and dynamic feedbacks (ZA, DD etc.).
- The Wyrtki period is about 3.3 year for E3SM models, slightly shorter than the observation about 4 year, mainly due to stronger transition part of TH, ZA and VA feedbacks

- **E3SM also yield right growth rate of ENSO for wrong reason due to error compensations**
- **Biases in processes in phase transition and thus shorter period**

(Zhao and Jin 2020, to be submitted)

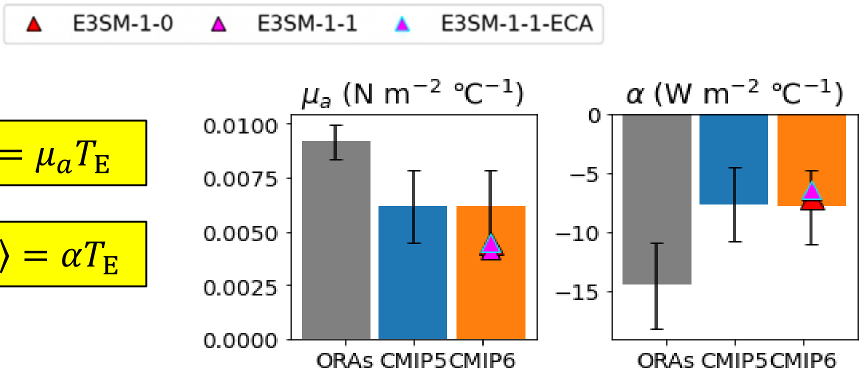
ENSO feedbacks in E3SM models

▲ : E3SM

Atmos. feedback

$$[\tau_x] = \mu_a T_E$$

$$\langle Q_{net} \rangle = \alpha T_E$$



Too weak dynamic coupling and thermal damping

TH feedback

$$R_{TH} = \langle \overline{w}_H M(\overline{w}_H) \rangle (e_1 + e_2 a_h \mu_a \beta_h)/H$$

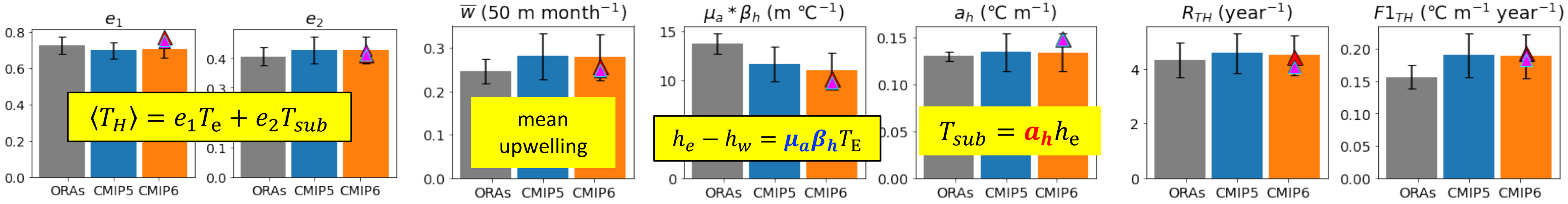
$$F1_{TH} = \langle \overline{w}_H M(\overline{w}_H) \rangle e_2 a_h / H$$

$$\langle T_H \rangle = e_1 T_e + e_2 T_{sub}$$

mean upwelling

$$h_e - h_w = \mu_a \beta_h T_E$$

$$T_{sub} = a_h h_e$$



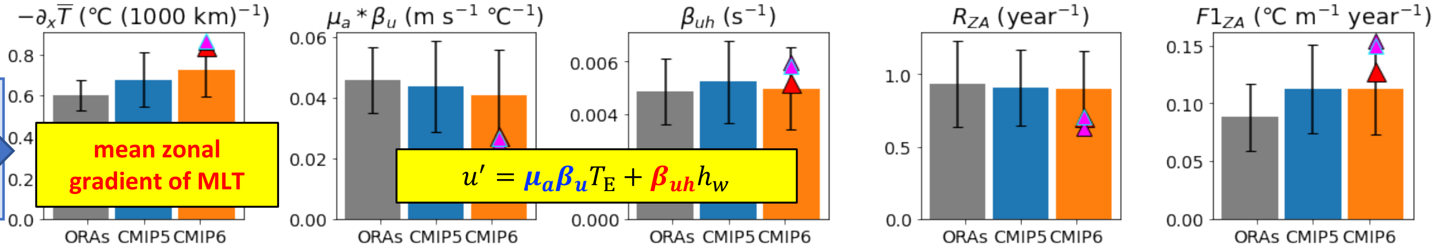
ZA feedback

$$R_{ZA} = \langle -\partial_x \overline{T} \rangle \mu_a \beta_u \qquad F1_{ZA} = \langle -\partial_x \overline{T} \rangle \beta_{uh}$$

more stronger cold biases of SST in eastern Pacific

mean zonal gradient of MLT

$$u' = \mu_a \beta_u T_E + \beta_{uh} h_w$$



(Zhao and Jin 2020, to be submitted)

- **Sources of E3SM ENSO growth rate error compensations is largely in the atmosphere**
- **Biases in in phase transition for shorter period is largely in mean SST gradient**