Understanding Equatorial Pacific Climate Processes via Hierarchical Coupled Modeling

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Thanks to: NOAA/CPO Climate Variability & Predictability Program

New postdoc
arriving March 2023!
(NCAR → Princeton)

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TROPICAL PACIFIC OBSERVING SYSTEM

Improving modeling is a key motivation for the new TPOS backbone & process studies.

Project reports:

Rep 1 (Cravatte et al. 2016): *"An urgent need to improve the skill, effectiveness & efficacy of **modeling** systems that are **critical to realizing the impact of an improved TPOS**… and to **advance understanding & modeling** through observing system infrastructure for **process studies**."*

Rep 2 (Kessler et al. 2019): *"Promote observing approaches that jointly measure the ocean & marine boundary layers and air-sea fluxes, principally to **support model development**…, **improve representation of key processes, constrain the coupled system, address biases in observations & models, and improve coupled data assimilation.**"*

Rep 3 (Kessler et al. 2021): *"Encourage process studies leading to **improved process parameterizations**, towards **reducing model biases** that degrade the efficacy of observational initializations… Accelerate advances in **understanding & predicting** tropical Pacific variability… **models and their assimilation products are an essential element.**"*

⇒ Called for denser obs (y & z) in cold tongue; more currents & surface fluxes

NOAA Climate Program Office (CPO) Climate Variability & Predictability (CVP) Program

Observation & Modeling in support of Tropical Pacific Process Studies, Pre-Field-II

Pacific Upwelling & Mixing Physics (PUMP), and
Air-sea Interaction at the Eastern Edge of the Warm Pool (EEWP)

Key focus: What should TPOS measure to improve understanding, modeling, and predictions?

8 new projects funded for 2023-2025
(building on 8 prior projects funded by Pre-Field-I, 2019-2021)

Ocean data assimilation & USV/UAV OSSEs (Mazloff et al.; Serra et al.; Zhang et al.)
Coupled boundary layers, fluxes, waves (Seo et al.; Subramanian et al.; Clayson et al.)
Improving mixing in OGCMs (Deppenmeier et al.)
Improving CGCMs for forecasts & projections (Wittenberg et al., GFDL/Princeton)

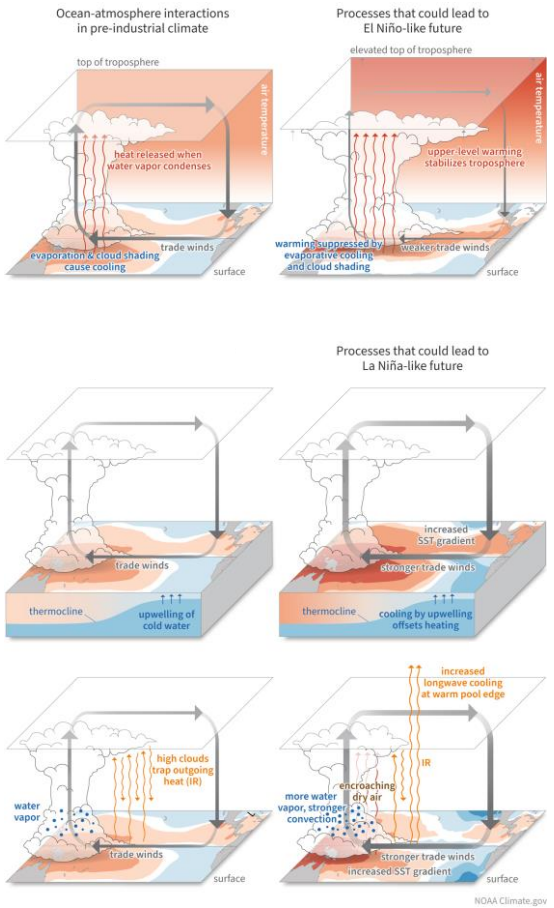
Focus on eqPac biases in CGCMs

Future tropical Pacific climate, ENSO, & global impacts depend on a subtle balance of **coupled, multi-scale, intermittent, often nonlocal** processes.

Unresolved physics in CMIP-class models:
Clouds & convection, diurnal cycle, TIWs, shears & mixing, barrier layers, air-sea fluxes, …
→ Errors + coupled feedbacks
→ **Model biases**
→ Degrade initializations, forecasts, projections

Need a **hierarchy of coupled model tools** to:
- Attribute emergent coupled biases
- Guide TPOS sampling to actually improve CGCMs
- Test new parameterizations in coupled/global context
- Identify where empirical corrections could help

Mechanisms of equatorial Pacific climate change
Lee et al. (npjCAS 2022) & Climate.gov ENSO blog



Objectives

1. **Improve the diagnostic hierarchy** for eqPac biases in CGCMs.

2. **Advance understanding** of eqPac's role in climate & ENSO, and of coupled nonlocal feedbacks across scales (diurnal, TIW, S2S, ENSO, TPDV, mean, future change).

3. **Attribute & reduce biases** in NOAA/GFDL CGCMs & products, via better eqPac physics (mixing, fluxes, convection, clouds), bias corrections, and emergent constraints.

4. **Inform the TPOS strategy.** Provide broad-scale *context* for TPOS "regime-based" sampling, and target obs to inform CGCMs and their products (reanalyses, S2D forecasts, projections).

Approach

Hierarchy of

- **Simulations**: resolution, coupling, obs constraints (global & regional)
- **Metrics**: heat/momentum/moisture/salt/mixing budgets; CLIVAR ENSO metrics
- **Reference datasets**: obs, reanalyses, LES & high-res sims from prior TPOS studies

Main modeling tools:

- **GFDL SPEAR & CM4** global CGCMs: large ensembles (1850-2100) & reforecasts
  Resolution: 1°A, 1°O → **0.25°A, 0.25°O**
  Free, nudged, and bias-corrected (FA, OTA)
  Assimilation-initialized & model-analog forecasts
- **GFDL MOM6** OMIP2: Global, regional, and 1d single-column versions
- **GFDL ECDA** (Ensemble Coupled Data Assimilation) System

Relevance & Broader Impacts

- TPOS process studies & backbone design → better **observations**

- Better scientific **understanding**
  → better parameterizations, bias corrections, *CLIVAR ENSO Metrics*
  → better **CGCMs**

- GFDL SPEAR model + ECDA → NMME → seasonal-to-decadal **forecasts**

- GFDL-CM5/ESM5 models → CMIP7 → IPCC **projections**

Recent Progress

- Completed **SPEAR free & FA ensembles** (1851-2100, 30 members each)
  - Atm/ocn resolution affects clouds, convection, rain, TIWs, mixing → ENSO
  - FA improves troPac climate & ENSO → boosts future ENSO rain extremes
  - Bias corrections (FA/OTA) improve SPEAR ENSO forecasts

- **MOM6 OMIP2** tests (1d, regional, global) vs. Argo & LES
  - Stratified shear-driven mixing (Jackson et al. 2008)
  - ePBL ocean boundary layer mixing + convection + Langmuir (Reichl & Li 2019)
  - **Refined vertical layers** (Δz^*) → smoothes mixing variations in warm pool
  - Weaken equatorial bkgd z-viscosity, ePBL mixing, submeso MLE restrat
    → **Much better diurnal cycle & near-surface stratification**
  - Strengthen equatorial background z-diffusivity → **deeper thermocline**
  - MOM6-1d with **GOTM GLS mixing** reproduces LES → valuable reference model!

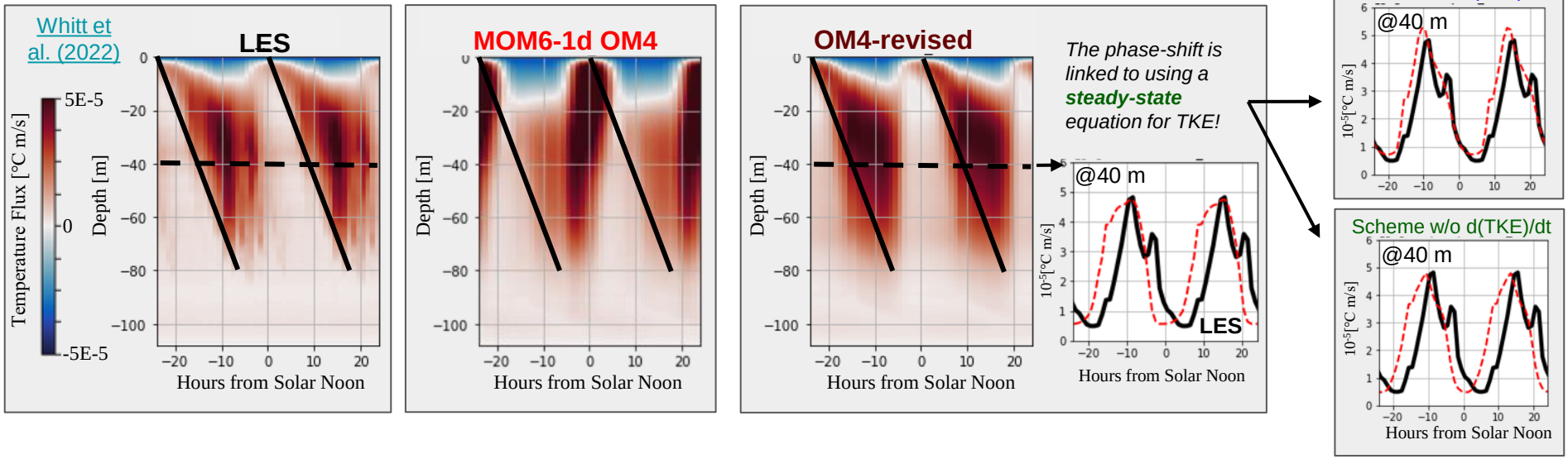
- Finalizing & analyzing **SPEAR_HI_25** (0.25°A, 0.25°O)

ePBL changes → Better eqPac upper-ocean diurnal cycle

from Brandon Reichl (AMS, Jan 2023)

LES & MOM6-1d simulations on **equator at 140°W**, forced by 8xdaily JRA55-do & ROMS, ~30 days

*Diurnal composite of **downward heat flux** (red=down) over full simulation*



- **OM4-revised corrects the problematic ePBL mixing → more realistic diurnal cycle**

- Phase-shift in downward propagation of turbulent fluxes remains → ongoing work

Mixing changes → Better eqPac dT/dz

from Brandon Reichl (AMS, Jan 2023)

0.25° MOM6 global OGCM

(forced by 8xdaily JRA55-do, 1999-2008)

Equatorial slice for upper 300m of ocean

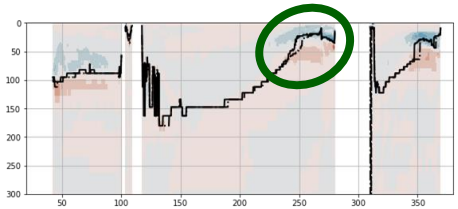
Impact of parameterization change

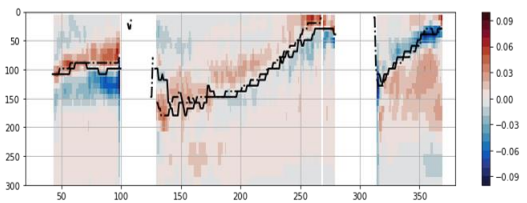
Simulated **dT/dz bias** [°C/m] relative to Argo (1999-2008)

Shallow & "steppy" thermocline

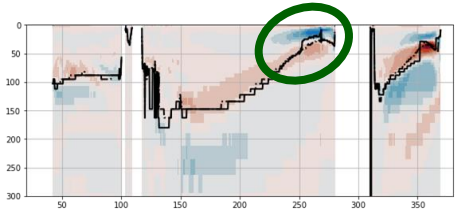
Original OM4

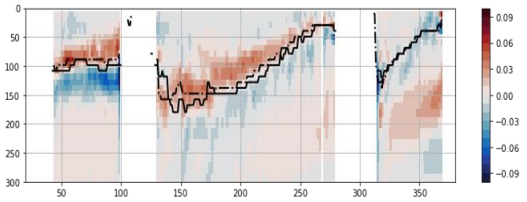
Better ePBL mixing (better diurnal cycle)



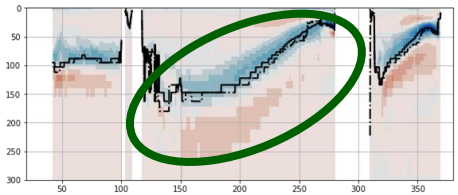


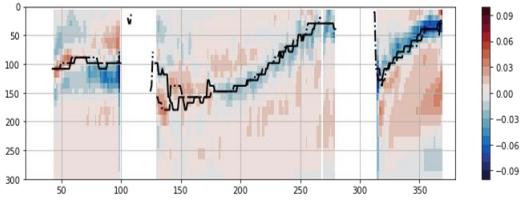
10x less background vertical viscosity (stronger shears)





2x more background vertical diffusivity





Reduced equatorial biases

Next Steps

- Test/tune **ocean mixing improvements** in global coupled SPEAR

- Finalize **SPEAR_HI_25**

- Monthly CVP/TPOS PI meetings
  Also meet with NCAR team (Deppenmeier, Cherian, Bryan) on 21 Feb

- Postdoc **Xian Wu** starts at GFDL on 13 March
  → Gather/process reference & simulation datasets
  → Spin up on literature, theory, models, diagnostics
  → Start analyzing eqPac heat budgets (mean, diurnal, TIW, ENSO)