The Seasonal & Interannual Mixed Layer Heat Budget in the Eastern Equatorial Pacific Ocean using a High-Resolution Coupled Model

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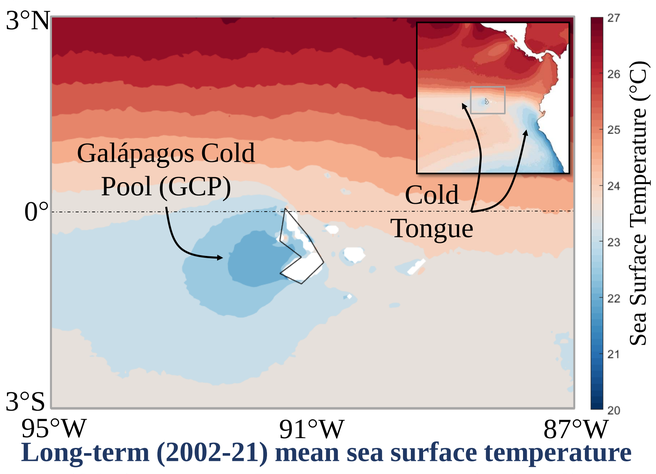
PROJECT BACKGROUND

- The Eastern Equatorial Pacific (EEP) plays a critical role in the global climate system through **widespread CO_2 outgassing**, cooler than average SSTs associated with the **Cold Tongue**, and strong natural variability associated with **ENSO**.
- The EEP is also home to the Galápagos Islands, one of the **most biologically diverse hotspots** on Earth.
- This unique biodiversity is the result of an isolated nutrient-rich cold ocean region west of the islands: **The Galápagos Cold Pool (GCP).**
- The GCP is caused *in part* by **upwelling** of the eastward-flowing subsurface current called the **Equatorial Undercurrent.**



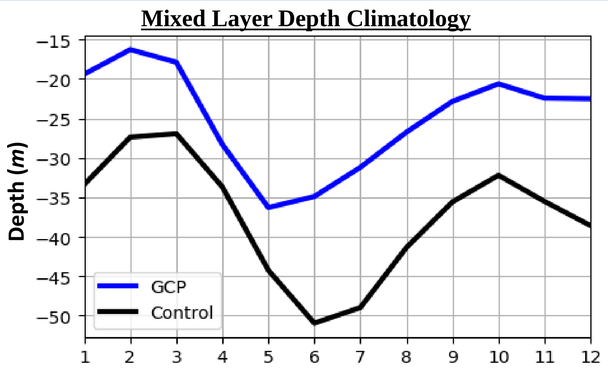
Long-term (2002-21) mean sea surface temperature (SST) near the Galápagos Islands (*MODIS*).

METHODS

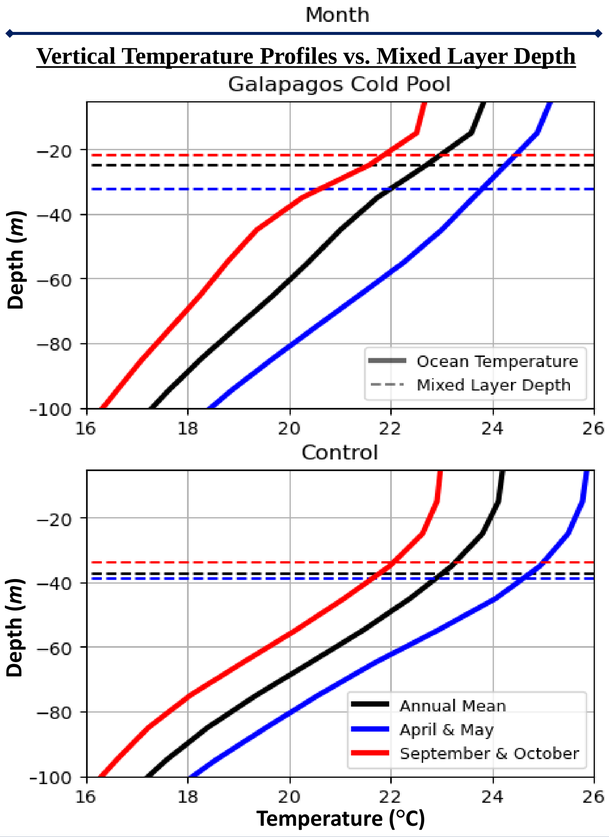
- We analyze the **mean seasonal climatology** and the effects of **ENSO** on the **ocean mixed-layer heat budget** of the EEP, particularly **in the GCP** and an open-ocean equatorial region in the western EEP using a 140-year present-day control simulation of a high-resolution version of CESM (v1.2.2; 0.1° ocean).
- Both regions experience upwelling, but upwelling in GCP is an order of magnitude higher due to differing mechanisms.

SEASONAL MIXED LAYER

Mixed Layer Depth Climatology



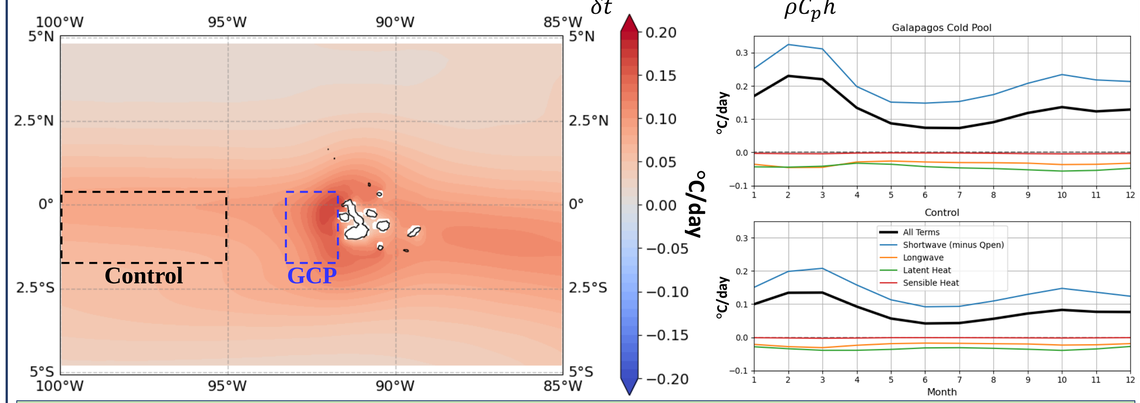
Vertical Temperature Profiles vs. Mixed Layer Depth



SEASONAL CLIMATOLOGY OF MIXED LAYER HEAT BUDGET

Term 1: Net Surface Heat Flux

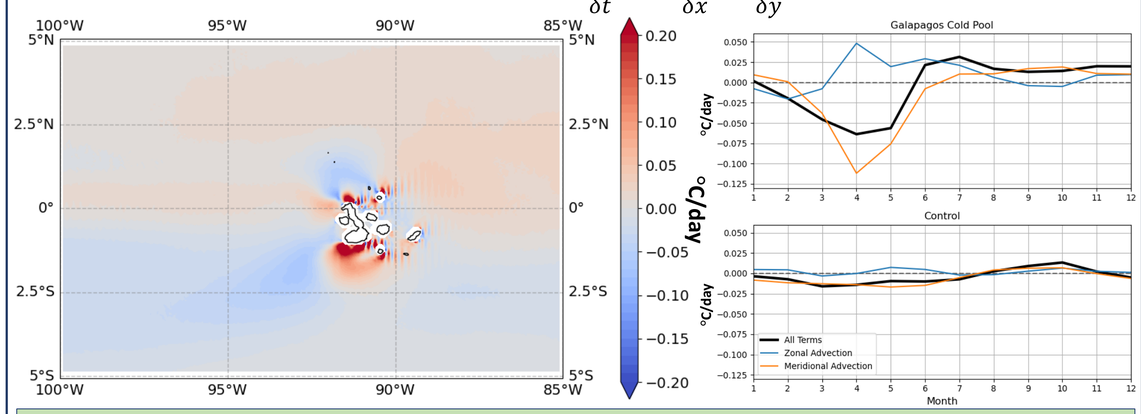
$$\frac{\delta T}{\delta t} = \frac{Q_{SW} - Q_{pen} - Q_{LW} - Q_{SH} - Q_{LH}}{\rho C_p h}$$



Key Takeaways: Shortwave dominates | GCP: less cloudy & slightly higher latent heat release

Term 2: Horizontal Advection

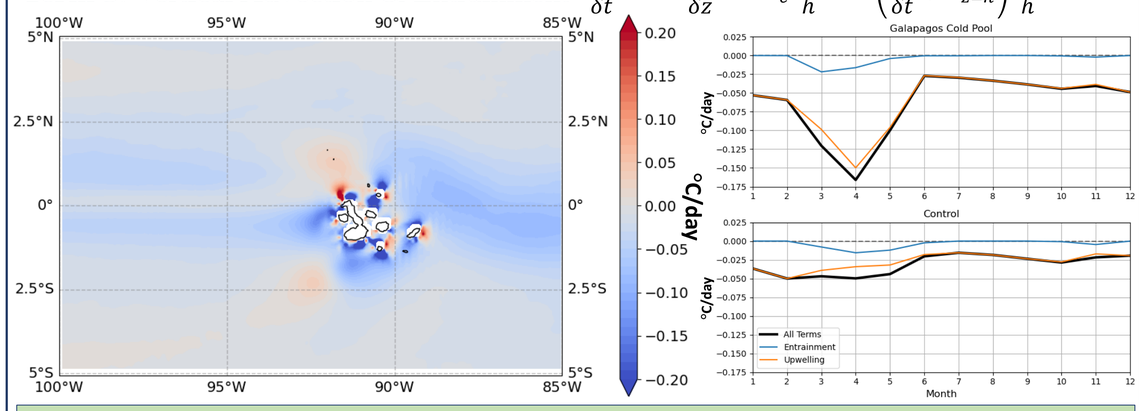
$$\frac{\delta T}{\delta t} = -u\frac{\delta T}{\delta x} - v\frac{\delta T}{\delta y}$$



Key Takeaways: Control: minimal effect | GCP: slight cooling in Spring via meridional advection

Term 3: Vertical Advection & Entrainment

$$\frac{\delta T}{\delta t} = -w\frac{\delta T}{\delta z} = -w_e\frac{\Delta T}{h} = -\left(\frac{\delta h}{\delta t} + w_{z=h}\right)\frac{\Delta T}{h}$$

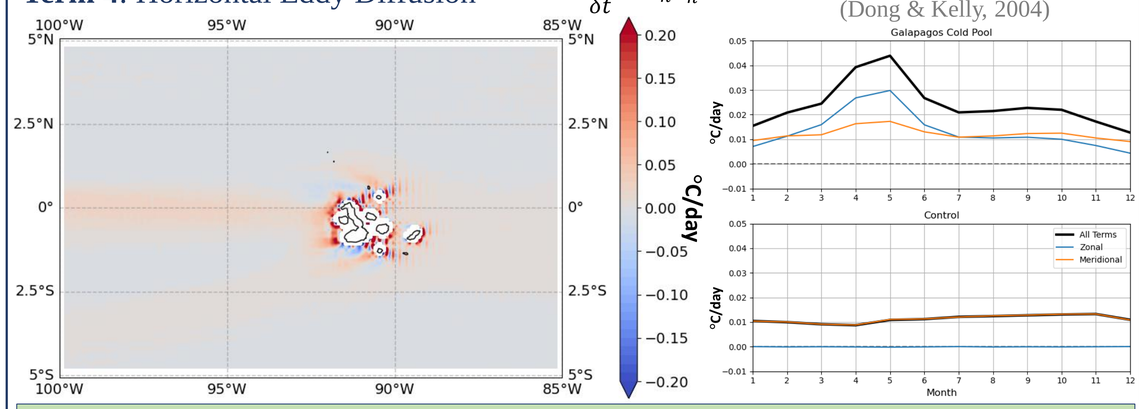


Key Takeaways: Entrainment is minimal | GCP: significantly larger & peaks when EUC strongest

Term 4: Horizontal Eddy Diffusion

$$\frac{\delta T}{\delta t} = K_h \nabla_h^2 T$$

K_h = 2000 m^2/s (Dong & Kelly, 2004)

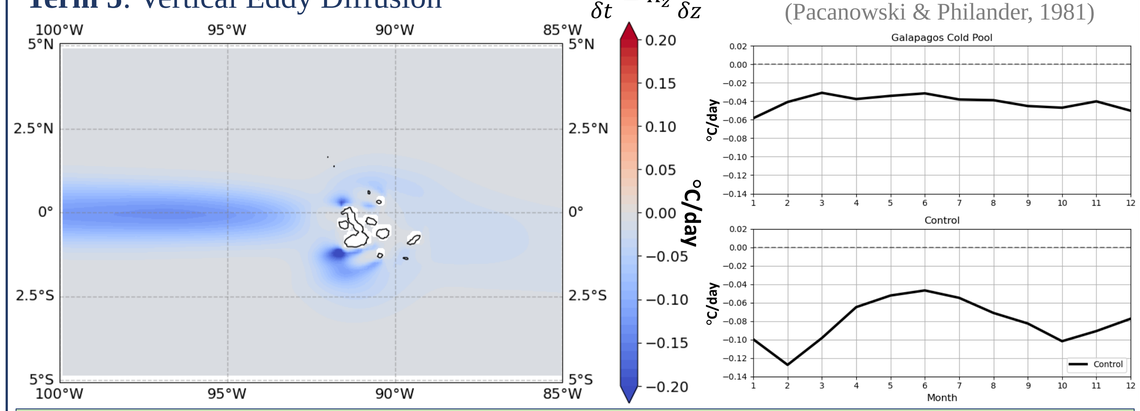


Key Takeaways: Both: moderate warming | GCP: larger magnitude and with noted seasonality

Term 5: Vertical Eddy Diffusion

$$\frac{\delta T}{\delta t} = K_z\frac{\delta T}{\delta z}$$

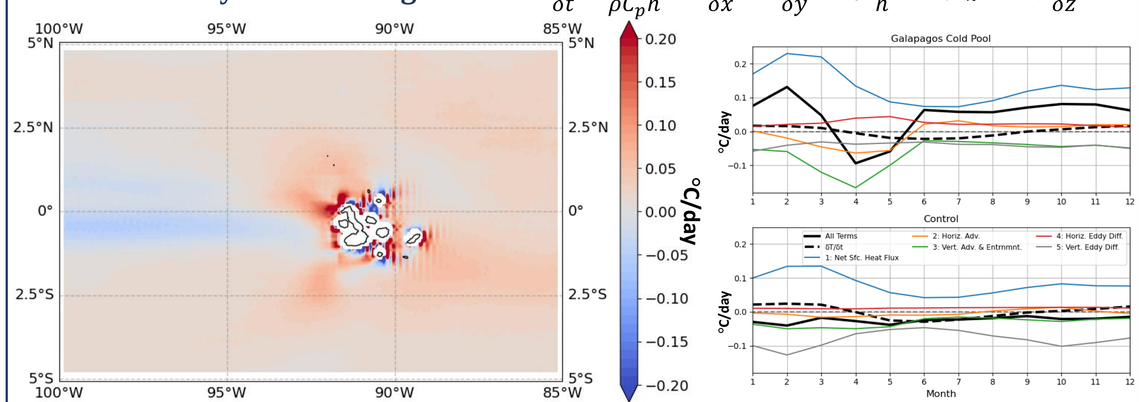
K_z conditioned on Richardson Number (Pacanowski & Philander, 1981)



Key Takeaway: Both: moderate cooling | Control: larger magnitude and with noted seasonality

Full Mixed Layer Heat Budget

$$\frac{\delta T}{\delta t} = \frac{Q_{net}}{\rho C_p h} - u\frac{\delta T}{\delta x} - v\frac{\delta T}{\delta y} - w_e\frac{\Delta T}{h} + K_h\nabla_h^2 T + K_z\frac{\delta T}{\delta z}$$



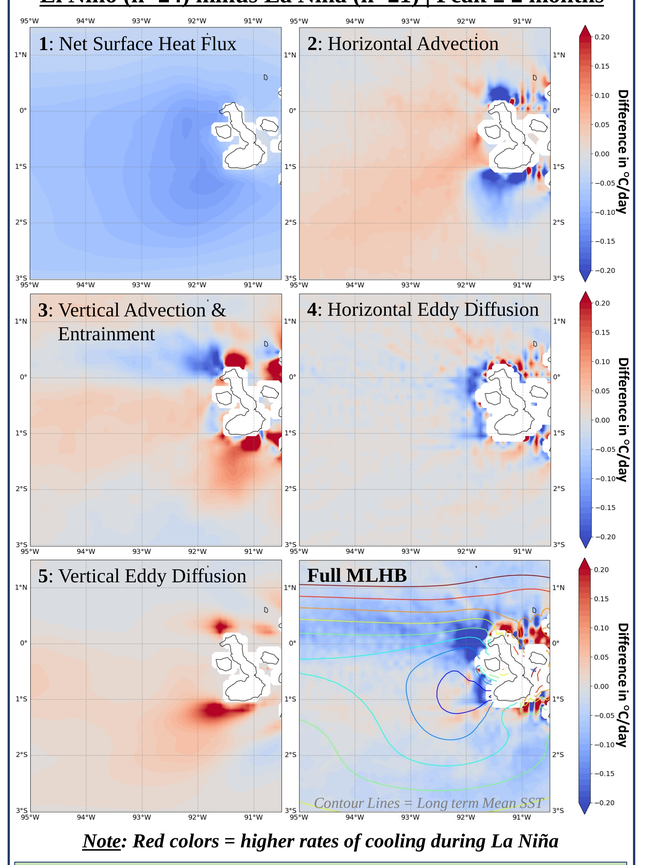
Key Takeaways: Relatively robust closure of MLHB | GCP: Vertical eddy diffusion, horizontal & vertical advection counteract stronger surface heat flux | Control: Vertical eddy diffusion offsets

MAIN RESEARCH OBJECTIVES

1. Diagnose the relative contributions of each term within the **mixed-layer heat budget (MLHB)**, with emphasis on **vertical advection, entrainment, and eddy diffusion**—processes that are especially important near the Galápagos Islands.
2. Determine the effects of the two primary modes of variability (>90% variance explained in PCA) in region: **seasonality and ENSO** on the mixed layer heat budget.

EFFECTS OF ENSO ON MLHB

El Niño (n=24) minus La Niña (n=21) | Peak ± 2 months



***Note*: Red colors = higher rates of cooling during La Niña**

Key Takeaways: La Niña: more cooling within GCP, enhanced by vertical advection & vertical eddy diffusion | El Niño: cloudier, more cooling NW of Galápagos Islands, enhanced by horizontal & vertical advection, & horizontal eddy diffusion.

Important Caveat: These results are *preliminary*, and it is not possible to fully interpret these results physically because they include averages across the onset and decay phase of each of the ENSO events. These plots are centered on the peaks of each event, but the overall warming or cooling depends on the time rate of change over the entire phase transition.

SUMMARY & CONCLUSIONS

- Relatively **robust closure of MLHB** using Dong/Kelly ‘04, Pacanowski/Philander ’81 diffusion parameterizations; slightly higher residual in GCP vs. control region.
- Main **differences between the control and GCP**: 1) less cloud cover due to cold waters in GCP; 2) enhanced vertical advection in GCP caused by EUC encountering islands; 3) widespread vertical mixing maintains cold tongue (control).
- ENSO impacts SST in both the broader cold tongue (control) and the Galapagos Cold Pool, but through a different blend of mechanisms; impacts of cloud cover and vertical processes in the ocean largely account for the differences.

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