Understanding Ocean Dynamics and Air-Sea Interaction in the Galápagos Cold Pool at Sub-seasonal to Interannual Timescales

Mikell Warms & Kristopher Karnauskas

Department of Atmospheric and Oceanic Sciences, University of Colorado Boulder, Boulder, CO

PROJECT BACKGROUND

- The Galápagos is home to 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; Figure 1)**
- The GCP is caused by **upwelling** of the eastward-flowing subsurface current called the **Equatorial Undercurrent (EUC)**
- EUC strength **mirrors that of the Pacific Walker Circulation**, acting as a release valve of the wind-driven build-up of sea level pressure in the Western Pacific
- There is strong potential for **coupled air-sea interactions and feedbacks** due to the existence of the GCP, which creates **strong horizontal SST gradients** that can influence the atmosphere.

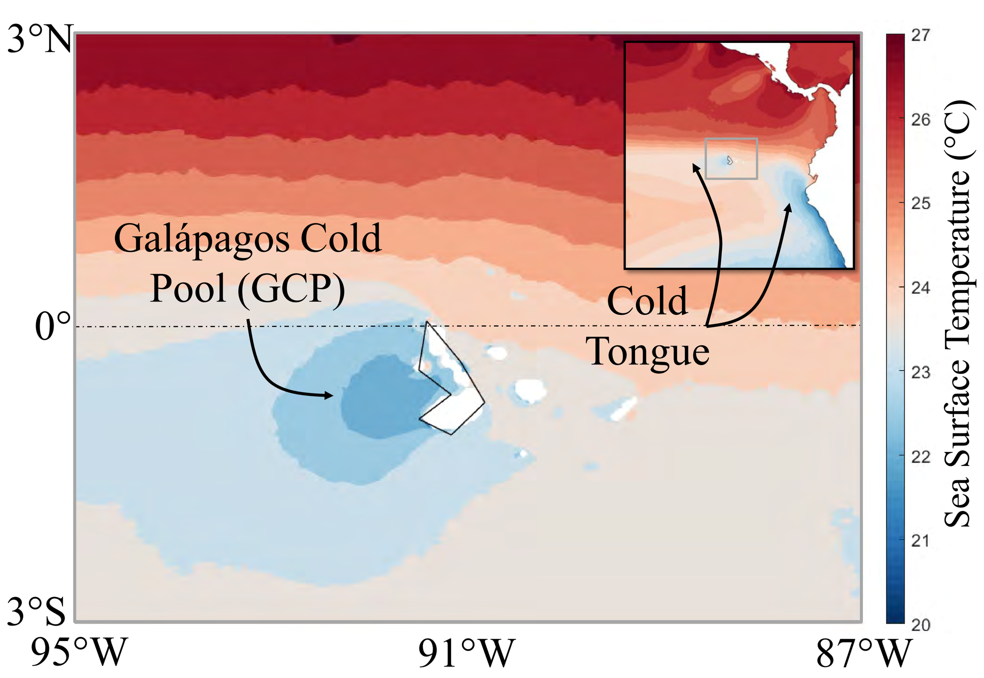


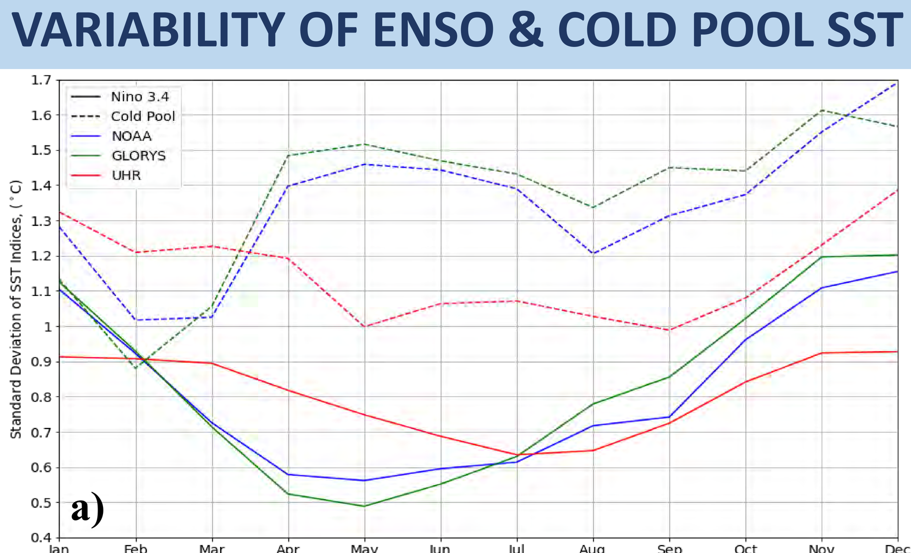
Figure 1. Long-Term (2002-2021) mean sea surface temperature (SST) near the Galápagos Islands (*MODIS*).

Key Takeaway: GCP has significantly lower avg. SST relative to the central Pacific Cold Tongue

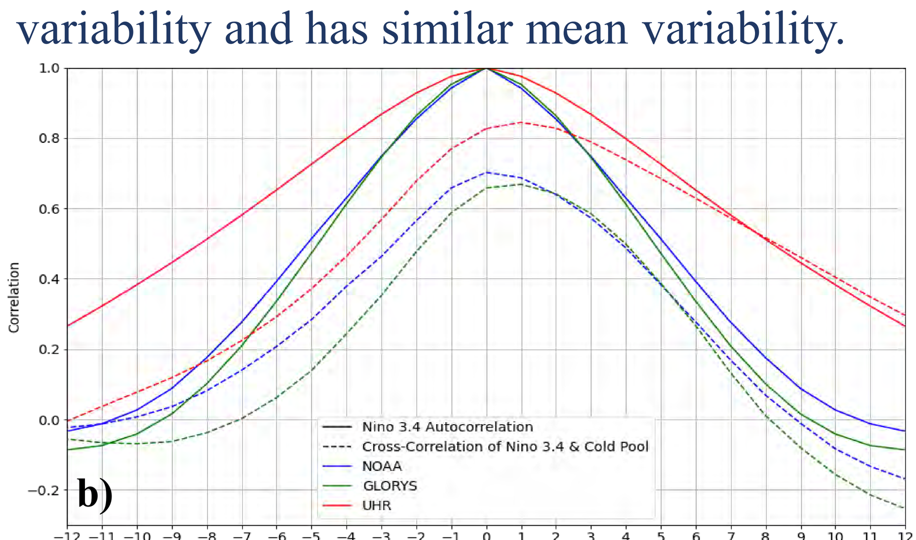
MAIN RESEARCH OBJECTIVES

1. Understand the effects of **ENSO and other modes of variability** on EUC strength and GCP temperatures
2. Determine how the EUC and GCP may be impacted **due to climate variability and change.**
3. Assess the effects of these impacts on the **Galápagos' ecosystems / industries,** e.g.:
   - Biological limits on temperature and nutrients for local flora and fauna
   - Exploring how changes to GCP SST could impact localized cloud cover

VARIABILITY OF ENSO & COLD POOL SST



Key Takeaway: UHR captures timing of peak variability and has similar mean variability.



Key Takeaway: UHR has similar Nino 3.4 auto-correlations to observations.

Figure 3. a) Monthly std. dev. of Nino 3.4 (solid) and GCP SST (dashed). b) Auto-corr. of Nino 3.4 (solid) and cross-corr. of Nino 3.4 and GCP SST (dashed).

PRIMARY PROJECT MOTIVATION

To **ensure the conservation and protection of the Galápagos Islands** through an enhanced understanding of the potential impacts of climate variability and change on the region, including changes to:

- Regional physical oceanography and wind-driven ocean currents
- Primary modes of variability (e.g., seasonality, ENSO)
- SST of the Galápagos Cold Pool related to changes in upwelling
- Local weather and climate

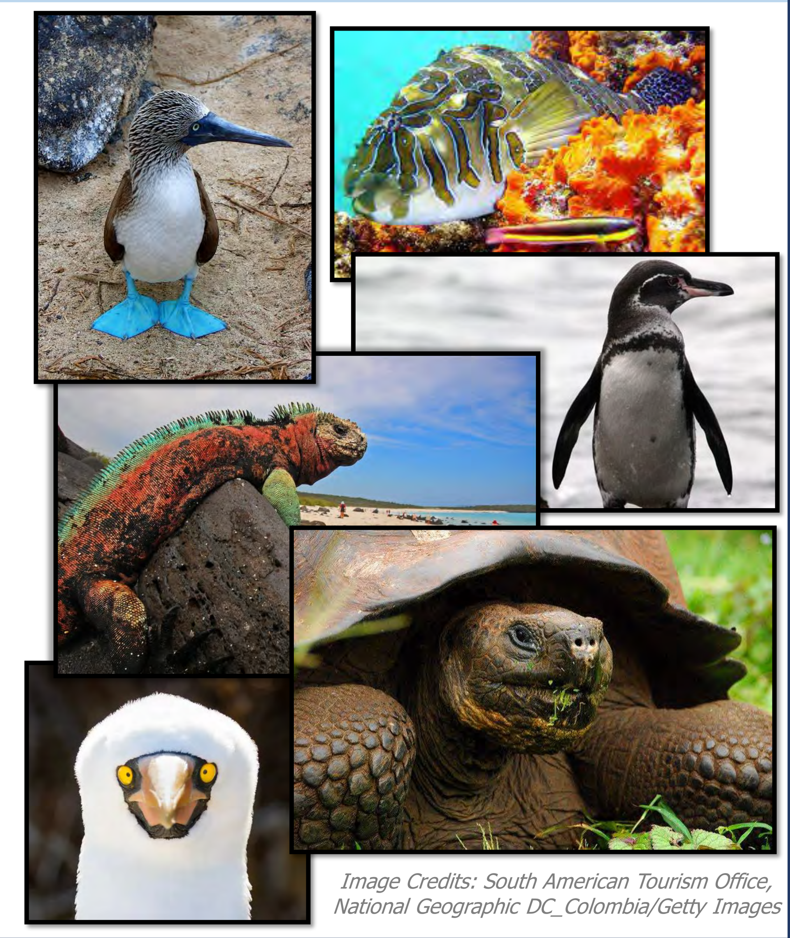


Image Credits: South American Tourism Office, National Geographic DC_Colombia/Getty Images

THE EQUATORIAL UNDERCURRENT AT 93°W

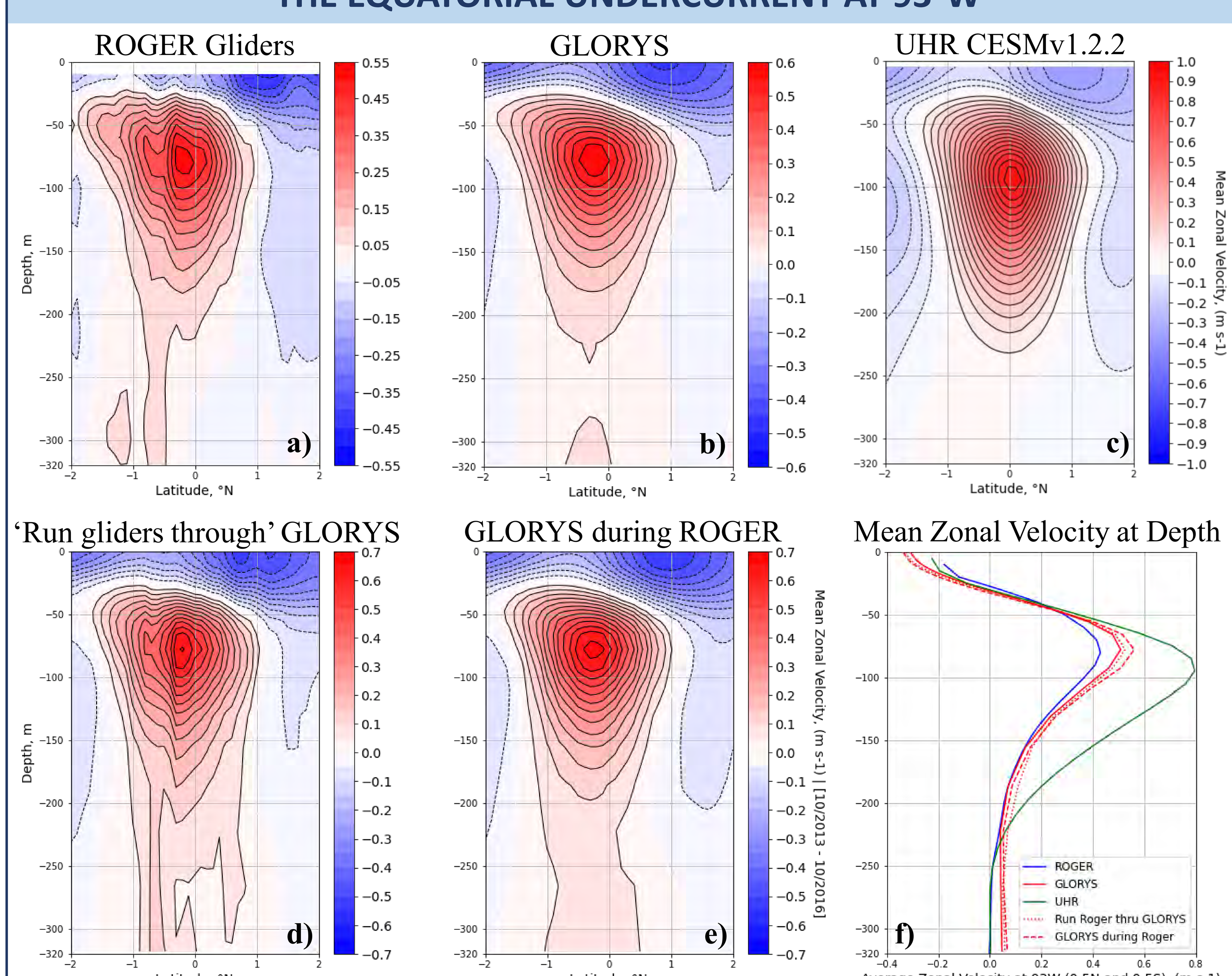
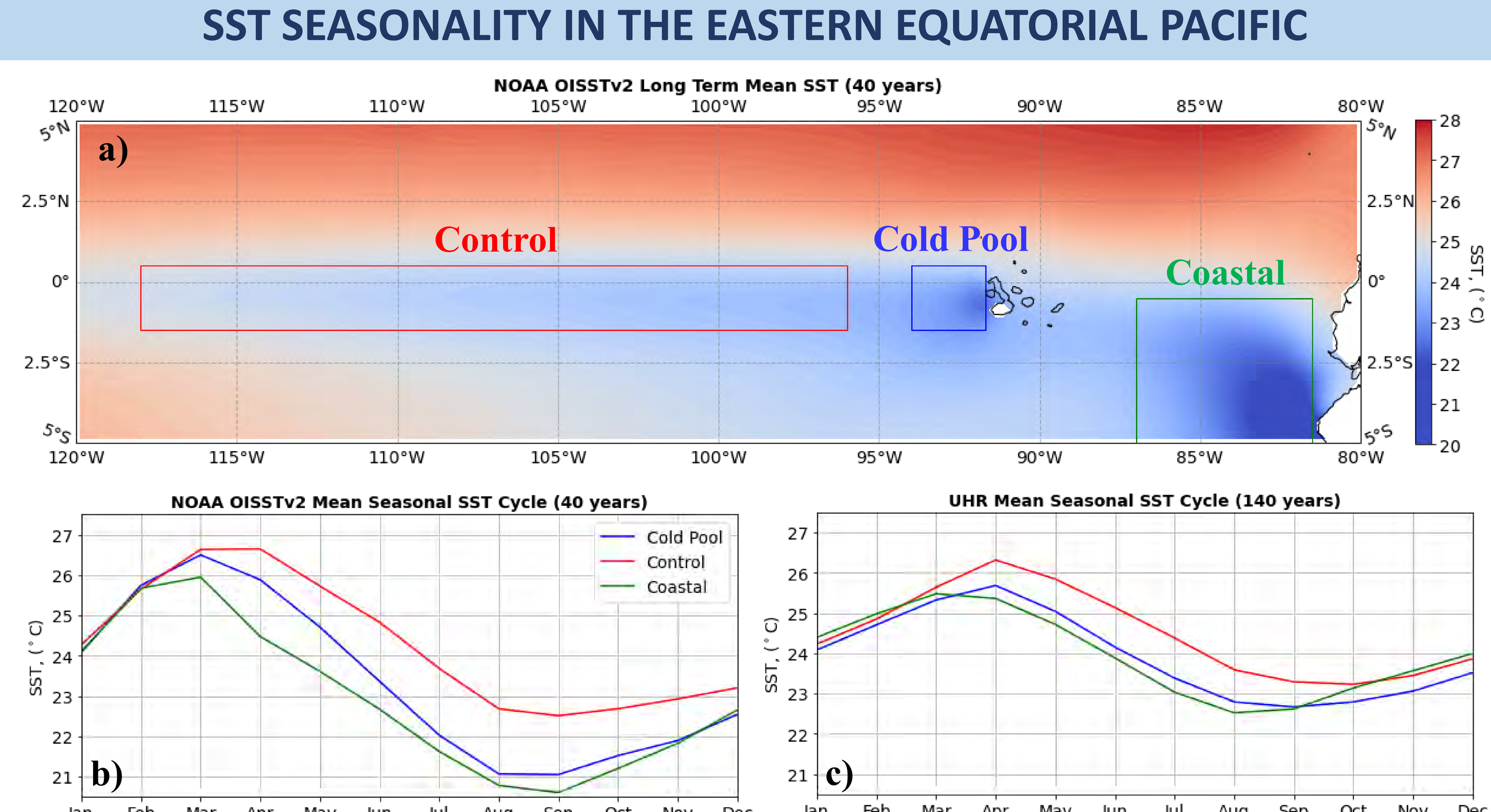


Figure 4. a-e) Mean zonal velocity cross-sections from 0-320 *m* depth between 2°N and 2°S at 93°W from various sources. f) Mean zonal velocity at 0-320 *m* between 0.5°N and 0.5°S from a-e.

Key Takeaway #1: At 93°W, the EUC center is located slightly south of the equator.

Key Takeaway #2: UHR is not perfect, but it captures the relative magnitude and location of the EUC well as compared to other lower resolution climate models.

SST SEASONALITY IN THE EASTERN EQUATORIAL PACIFIC



Key Takeaway: UHR captures the observed seasonal pattern well; lagged by ~1 month and with slightly lower magnitude temperatures in boreal Spring and Fall.

Figure 5. a) Long term (1982-2022) mean SST in the Eastern Equatorial Pacific (*OISSTv2*); b) mean seasonal SST cycle as averaged in boxes from a); c) as with b) but with UHR (140 years).

PRIMARY REFERENCES

- Houvenaghel, G. T. (1978). Oceanographic conditions in the Galápagos archipelago and their relationships with life on the islands. In R. Boje & M. Tomczak (Eds.), *Upwelling ecosystems* (Chapter 15, pp. 181–200). Berlin, Heidelberg: Springer.
- Jakoboski, J. K., R. E. Todd, W. B. Owens, K. B. Karnauskas, and D. L. Rudnick, 2020: Bifurcation and Upwelling of the Equatorial Undercurrent West of the Galápagos Archipelago. *J. Phys. Oceanogr.*, 50, 887–905.
- Karnauskas, K. B., J. Jakoboski, T. M. S. Johnston, W. B. Owens, D. L. Rudnick, and R. E. Todd, 2020: The Pacific Equatorial Undercurrent in Three Generations of Global Climate Models and Glider Observations. *J. Geophys. Res. Oceans*, 125(11).

METHODS

- In this study, we **validate an ultra-high resolution climate model** (CESM v1.2.2; resolution: 25 *km* atmosphere, 30 vertical layers; 0.1° ocean, 62 vertical layers) with satellite SST (NOAA OISSTv2), an ocean reanalysis product (GLORYS), and *in situ* data from ocean gliders (ROGER).
- Of importance is depiction of **variability, magnitude, location,** and **seasonality** of the Equatorial Undercurrent (EUC) and of the Galápagos Cold Pool (GCP).

Repeat Observations by Gliders in the Equatorial Region (ROGER)

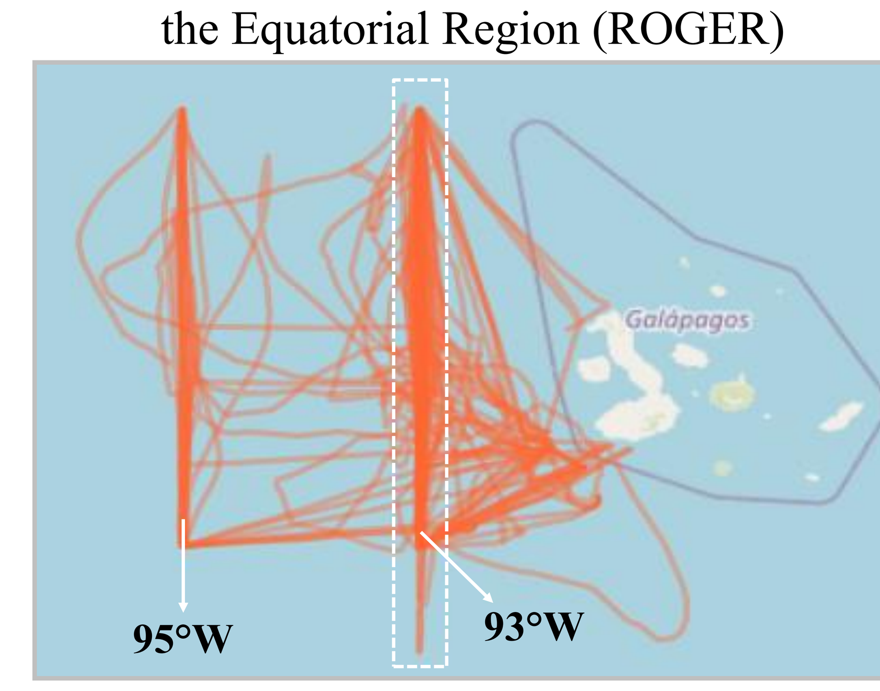


Figure 2. Locations of gliders ROGER (10/2013-10/2016). *Source: Rudnick et al., 2020.*

PRELIMINARY CONCLUSIONS & NEXT STEPS

1. Validated UHR model in terms of (a) seasonality, variability, and location of known SST patterns, and (b) location, depth, and strength of the EUC in the Eastern Equatorial Pacific.
2. Utilized UHR model to estimate changes to GCP temperature under two future climate scenarios (**Figure 6**).
3. Trends in GCP SST (1982-2022) indicate cooling (-0.5°C/40 years) tied to a strengthening EUC; however, UHR simulations predict significant long-term warming. What are the possible mechanisms/model biases at play? How might heightened vertical stratification due to atmospheric forcing mediate enhanced upwelling as horizontal shear increases?

UHR climate model estimates of Galápagos Cold Pool (GCP) SST Change

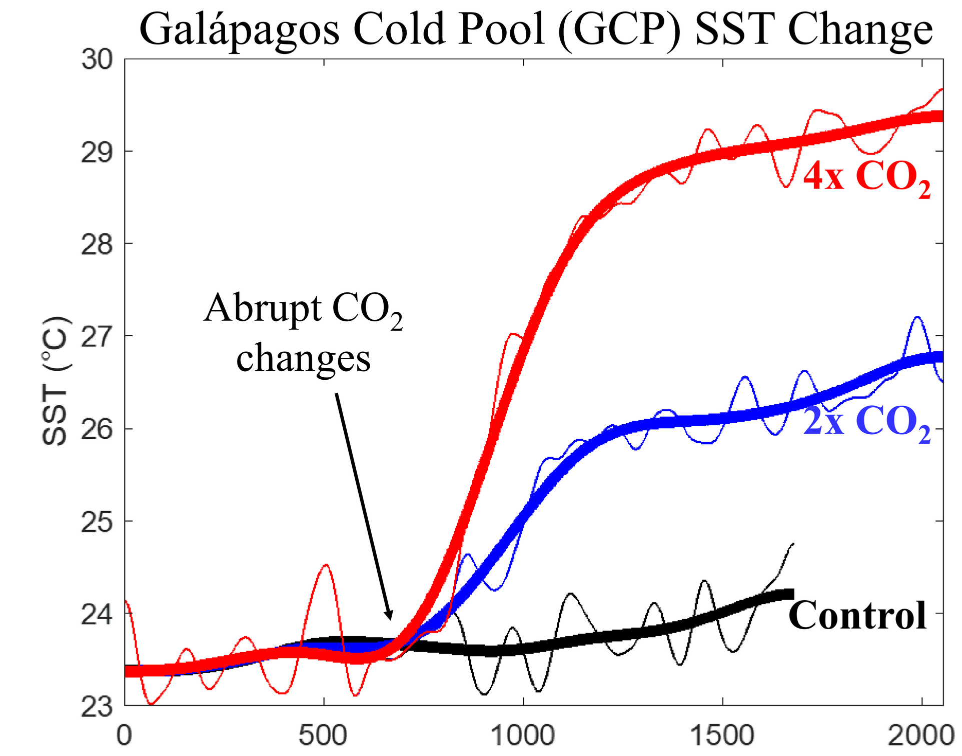


Figure 6. Ultra-high resolution (UHR) CESM v.1.2.2 estimates of future SST in the Galápagos Cold Pool. *Source: Karnauskas, K., (2020), unpublished.*

Key Takeaway: Significant changes to GCP SST.

ACKNOWLEDGEMENTS

This research is supported under the NASA *Future Investigators in NASA Earth and Space Science and Technology* (*FINESST*) Fellowship Program

CORRESPONDING AUTHOR

Mikell Warms, PhD Candidate

Dept. of Atmospheric and Oceanic Sciences

University of Colorado Boulder

Mikell.Warms@colorado.edu