Recent Decadal Changes in Tropical Pacific Sea-Surface Height due to Wind-Driven Sea-Surface Temperature Variability

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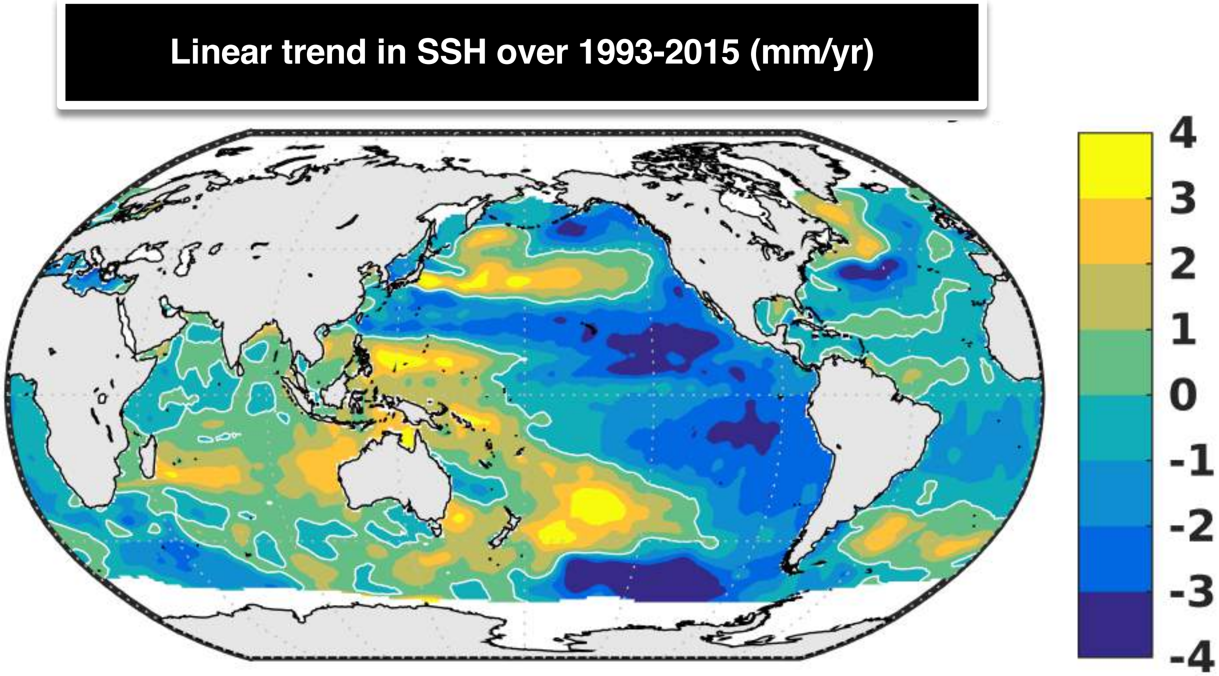
Introduction: Pacific SSH Variability

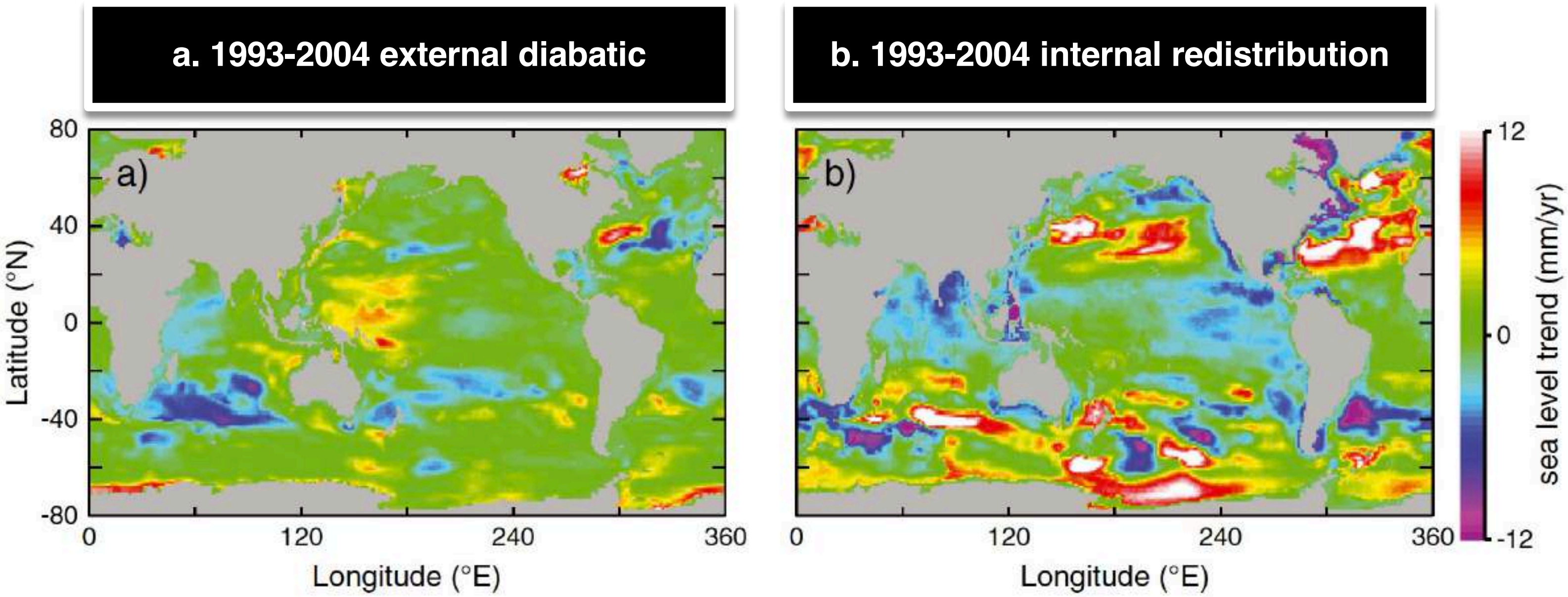
- Sea-surface height (SSH) over the western tropical Pacific has risen more rapidly than over the eastern tropical Pacific during the altimeter era.



- Many studies interpret this spatial pattern of SSH trends in terms of heat redistribution and adiabatic response to winds (Lee and McPhaden 2008; Feng et al. 2010; Timmermann et al. 2010; Merrifield 2011; Qiu and Chen 2012; Merrifield and Maltrud 2011; Merrifield et al. 2012, etc.).

Introduction: Pacific SSH Variability

- Others explicitly reason that diabatic effects and atmospheric exchanges might also be important to SSH trends (e.g., Fukumori and Wang 2013).

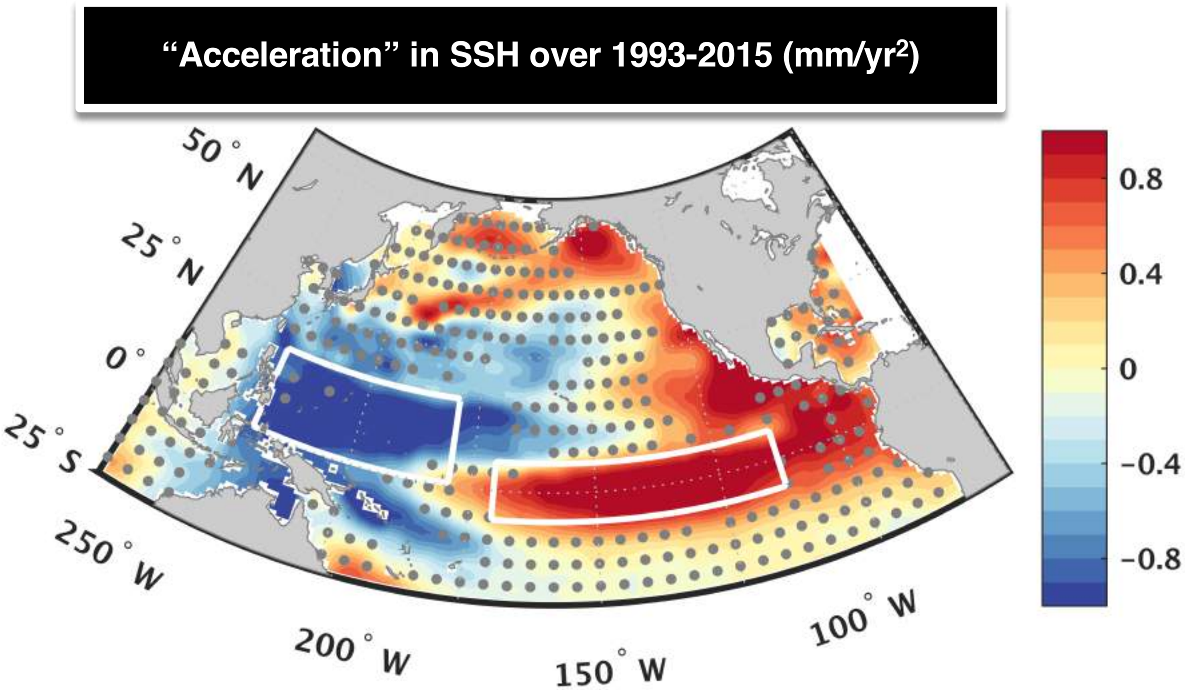


[Fukumori and Wang (2013), *Geophys. Res. Lett.*, **40**.]

- Pacemaker experiments show that coupling between winds and sea-surface temperatures over the eastern equatorial Pacific contributed crucially to the recent surface warming slowdown (Kosaka and Xie 2013; England et al. 2014; Watanabe et al. 2014; Delworth et al. 2015, etc.).

Introduction: Pacific SSH Variability

- The relative impacts of oceanic redistribution and atmospheric exchanges of buoyancy on decadal tropical Pacific SSH changes remain to be clarified.



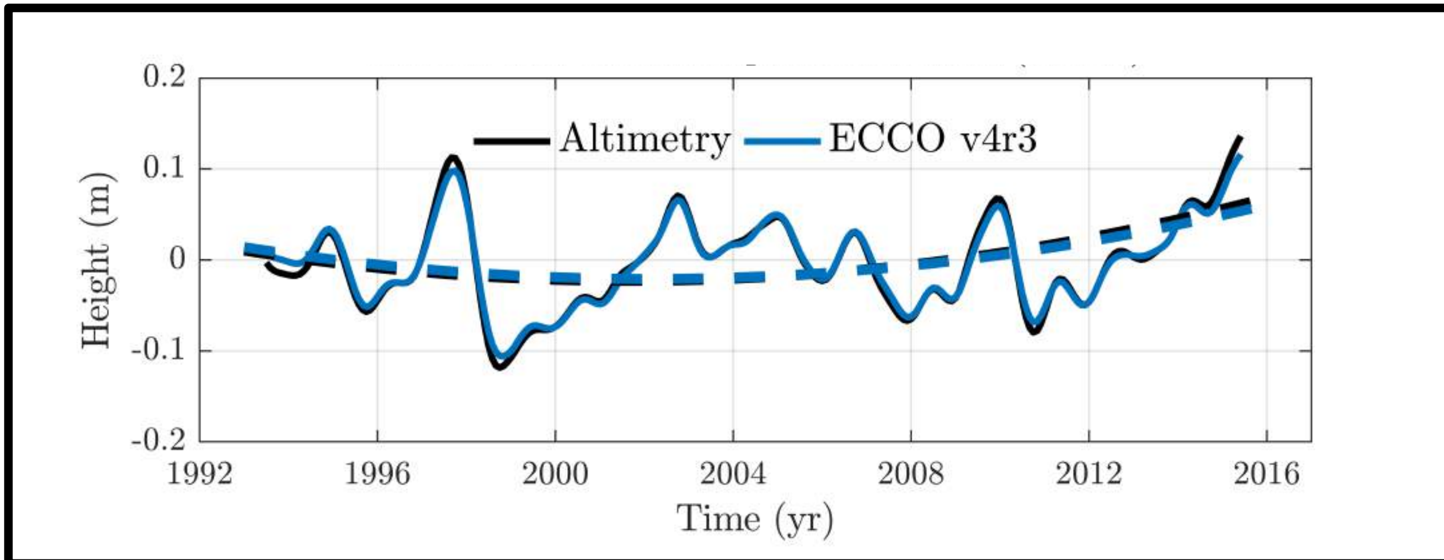
- As such, the nature of a recently reported reversal in Pacific SSH trend patterns (Hamlington et al. 2016) is unclear.
  - Due to change in the winds, or damping surface heat flux, or both?

This Study

- Question here:
  - What are the roles of oceanic heat redistribution and atmospheric fluxes in observed decadal changes in tropical Pacific SSH?
- Research tool—ECCO Version 4 Release 3:
  - Constrained to most ocean data over 1992–2015;
  - Agreement with data achieved via iterative optimization procedure;
  - State estimate is a physically consistent ocean model solution.
- To understand the contributing processes we:
  - Perform additional model experiments with modified forcing.
  - Use model diagnostic output to evaluate closed property budgets.

Results: State Estimate-Data Comparison

- We examine the Equatorial Pacific region (7.5°S–7.5°N, 105–175°W).

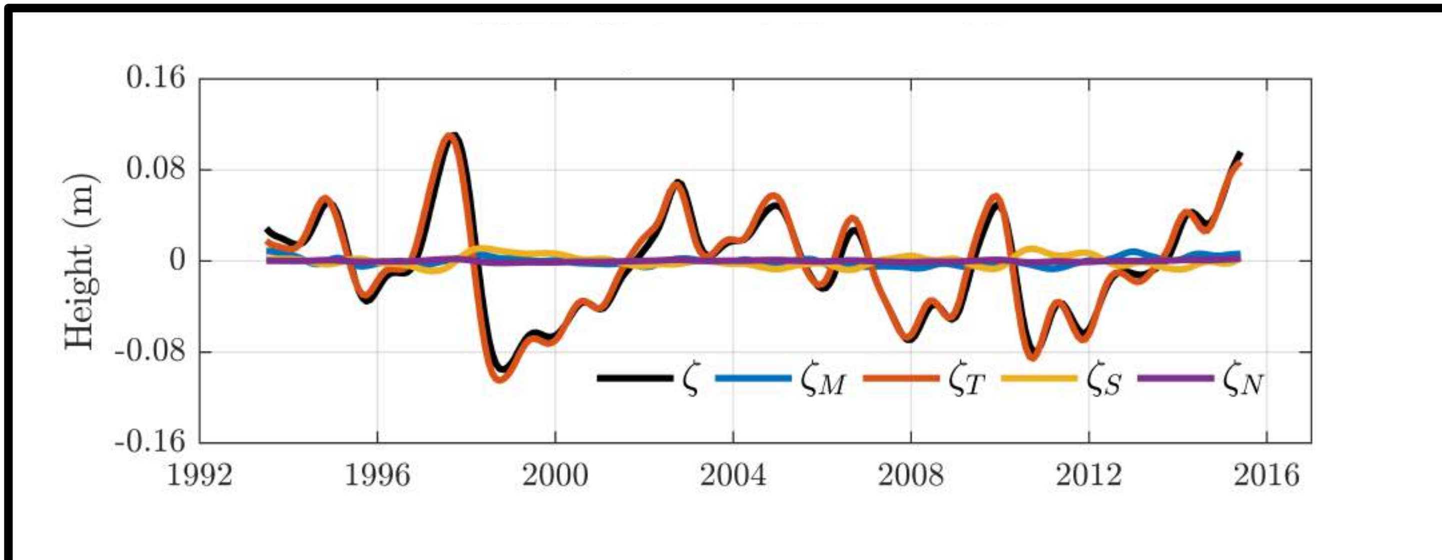


- ECCOv4 is an excellent fit to the altimeter data over this region.

Results: Hydrostatic Decomposition of SSH

- Decompose sea-surface height (ζ) using the hydrostatic equation into mass (ζ_M), thermosteric (ζ_T), halosteric (ζ_S), and nonlinear contributions (ζ_N):

$$\zeta = \zeta_M + \zeta_T + \zeta_S + \zeta_N.$$

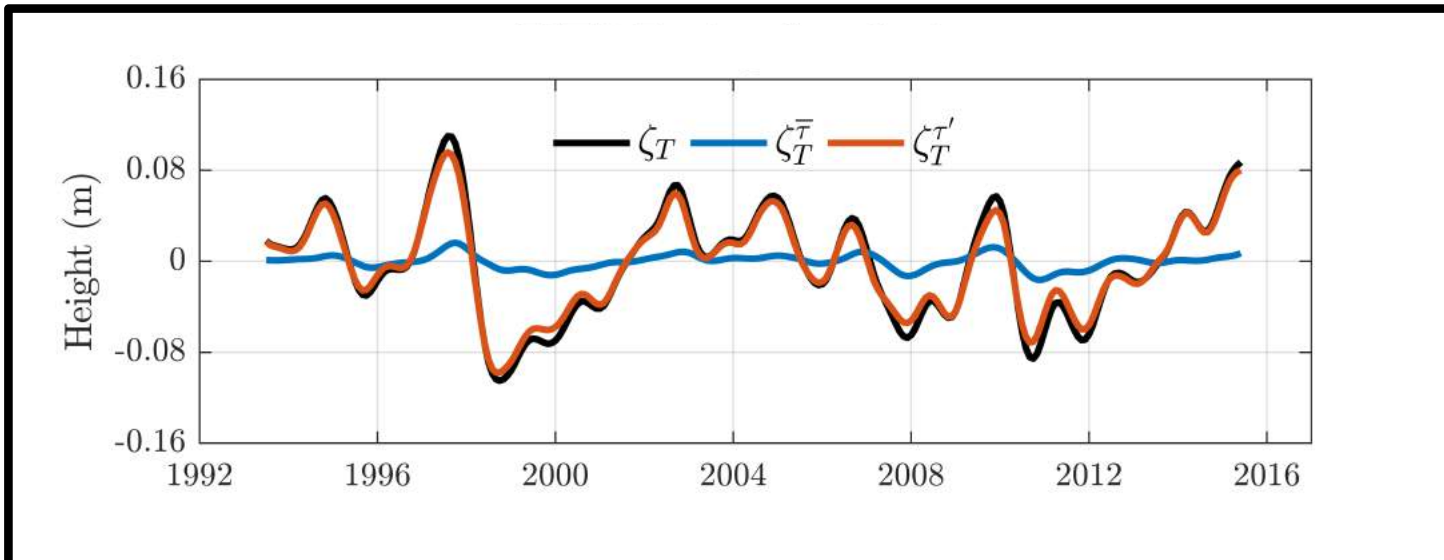


- Sea-surface height changes (ζ) in this region are mainly thermosteric in nature—due to changes in ocean heat storage (ζ_T).

Results: Forcing Experiments

- Perform forcing experiments to separate ζ_T contributions due to variable momentum forcing ($\zeta_T^{\tau'}$) from buoyancy and mass flux contributions ($\zeta_T^{\overline{\tau}}$):

$$\zeta_T = \zeta_T^{\tau'} + \zeta_T^{\overline{\tau}}.$$

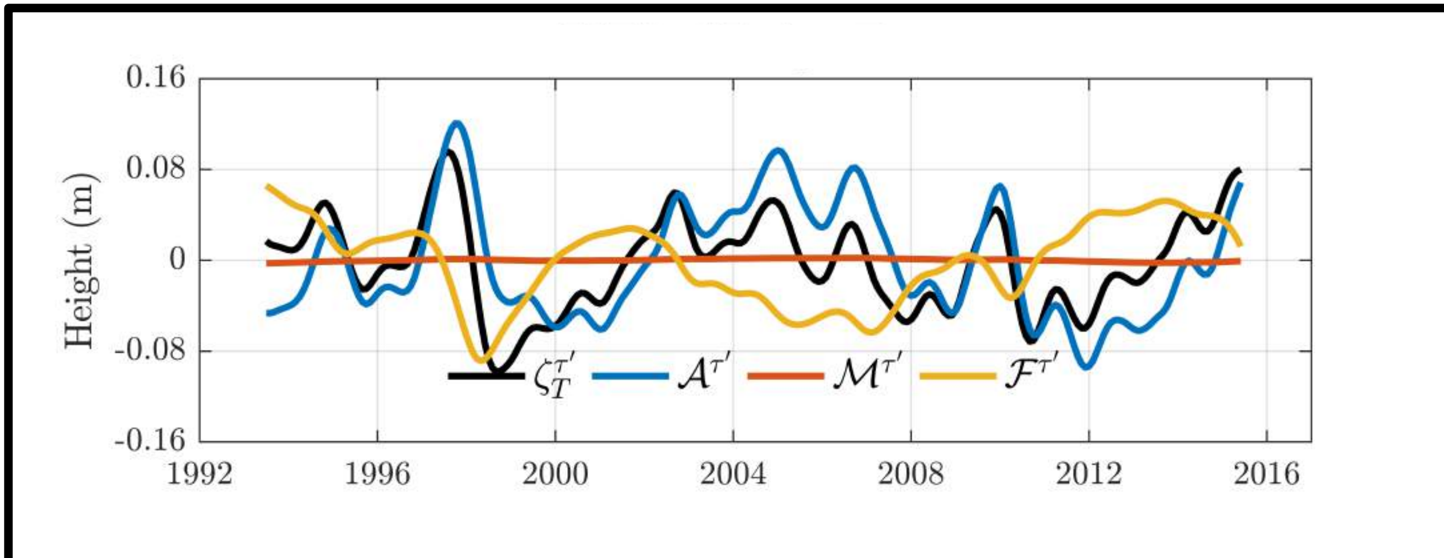


- Thermosteric SSH changes (ζ_T) are almost entirely related to variable momentum (wind) forcing ($\zeta_T^{\tau'}$).

Results: Thermosteric Budget Diagnosis

- Diagnose wind-driven thermosteric changes ($\zeta_T^{\tau'}$) due to ocean advection ($\mathcal{A}^{\tau'}$), diffusive mixing processes ($\mathcal{M}^{\tau'}$), and local surface heat flux ($\mathcal{F}^{\tau'}$):

$$\zeta_T^{\tau'} = \mathcal{A}^{\tau'} + \mathcal{M}^{\tau'} + \mathcal{F}^{\tau'}.$$

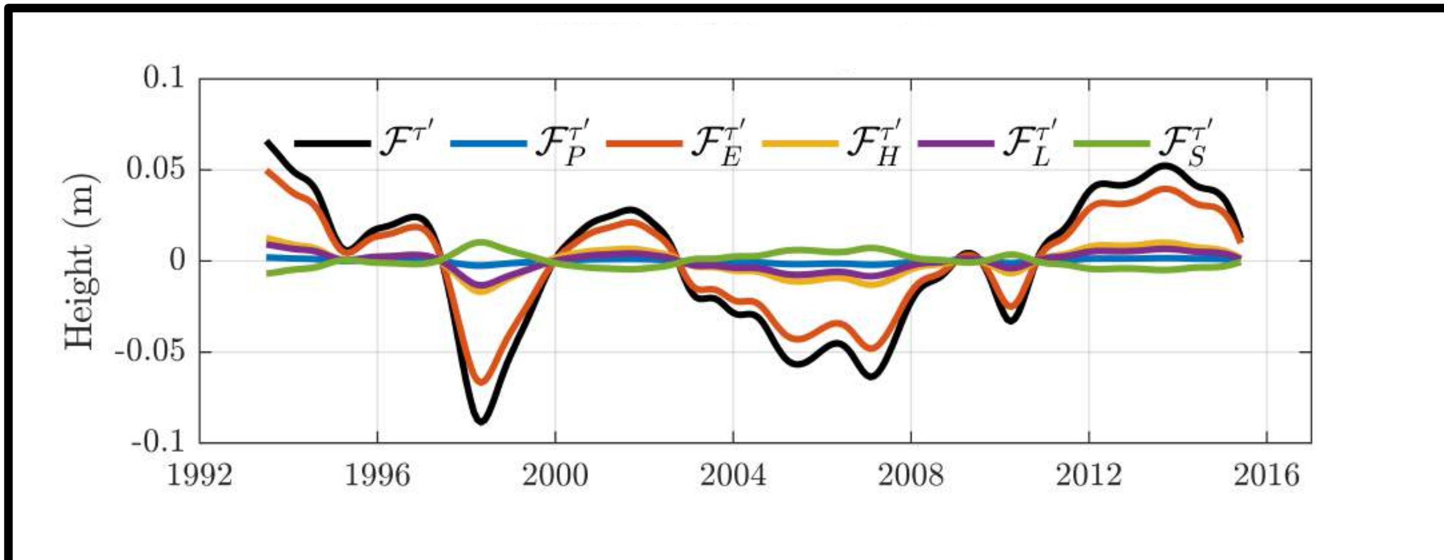


- The $\zeta_T^{\tau'}$ budget reflects a complex interweaving between ocean advection ($\mathcal{A}^{\tau'}$) and heat flux ($\mathcal{F}^{\tau'}$) contributions.

Results: Breaking Down the Surface Fluxes

- Partition the surface heat flux term ($\mathcal{F}^{\tau'}$) into latent ($\mathcal{F}_E^{\tau'}$), sensible ($\mathcal{F}_H^{\tau'}$), longwave ($\mathcal{F}_L^{\tau'}$), shortwave ($\mathcal{F}_S^{\tau'}$), and freshwater ($\mathcal{F}_P^{\tau'}$) contributions:

$$\mathcal{F}^{\tau'} = \mathcal{F}_P^{\tau'} + \mathcal{F}_E^{\tau'} + \mathcal{F}_H^{\tau'} + \mathcal{F}_L^{\tau'} + \mathcal{F}_S^{\tau'}.$$



- Latent (evaporative) heat fluxes ($\mathcal{F}_E^{\tau'}$) make most important contributions to the overall surface flux.

Summary & Next Steps

- In a state estimate, interannual and longer equatorial Pacific SSH changes are due to wind-driven changes in advection and latent surface heat fluxes.
- These results establish that the decadal adjustment in this region involves important diabatic processes.
- What sets the damping time scale of the heat flux?
- What are the relative influences of diabatic and adiabatic mechanisms in controlling the advection?
- How do sea-surface height changes over this region relate to other tropical or extratropical Pacific regions?

Thank you

Questions?