Using an Ocean State Estimate and Satellite Altimetry to Improve Sea Level Predictions along the U.S. Gulf Coast

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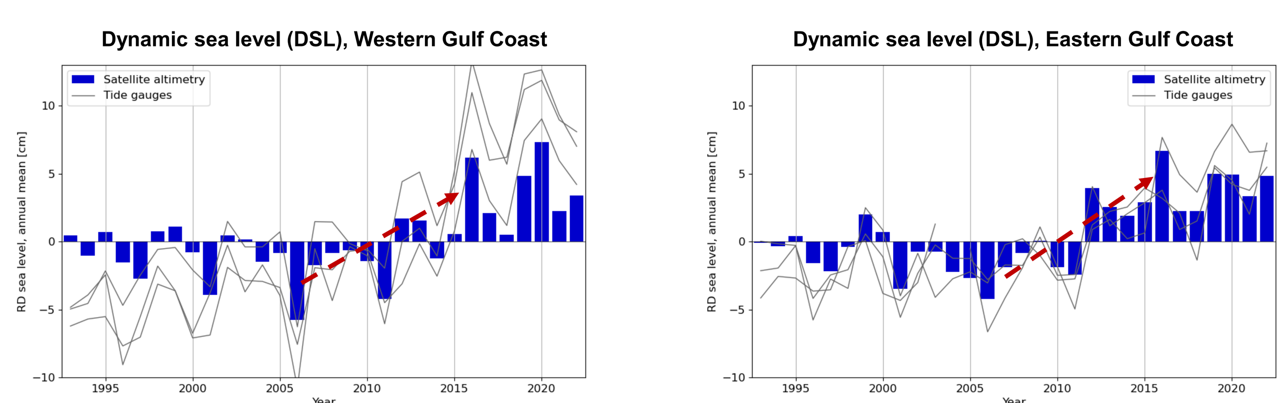
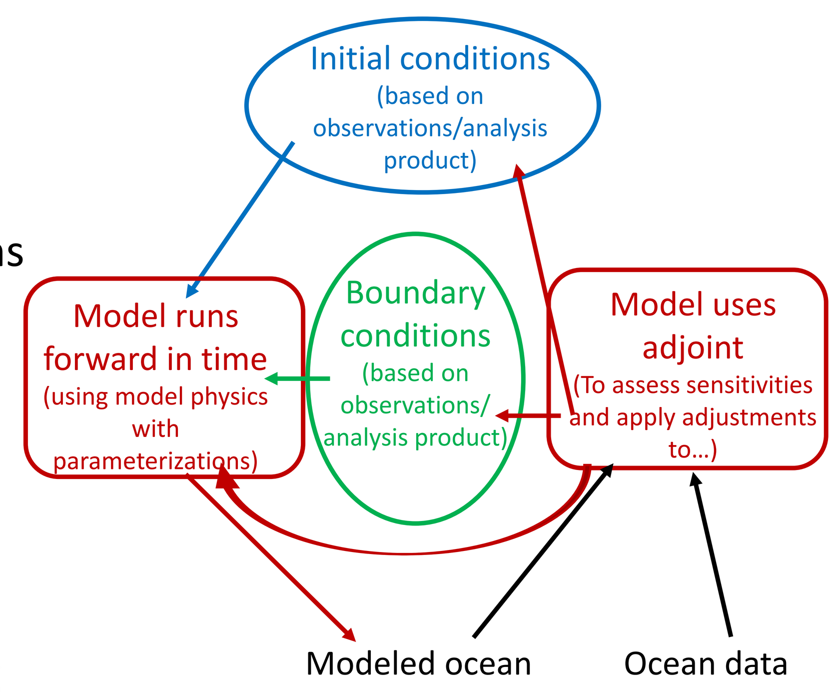
Motivation

- Sea level changes result from many types of changes in the ocean state (mass, temperature, salinity), both local and remote
- Ocean dynamics may induce regional changes in the **dynamic** sea level or DSL (excluding the global mean sea level change) that impact coastal communities
- **Sea level along the U.S. Gulf Coast rose rapidly (at 2-3x the global mean rate) from the late 2000s through at least the 2010s, independently of vertical land motion**
- Statistical analyses of ocean data are often insufficient to untangle numerous influences on sea level
- Fully-dynamic coupled prediction models often struggle with biases and spurious "drifts" in DSL, often related to the ocean state initialization



ECCO state estimate

- The Estimating the Circulation and Climate of the Ocean (ECCO) state estimate is generated through an iterative process
- Adjusts **initial** and **boundary** conditions as well as model **parameterizations** to better fit observations
- Adjoint is used to fit observations, by quantifying the **sensitivity** of ocean state variable (e.g., dynamic sea level) on initial conditions, boundary conditions (surface fluxes), and mixing parameters



$$S_p(x,y,t,\tau) = \frac{\partial \eta(t)}{\partial F_p(x,y,t-\tau)}$$

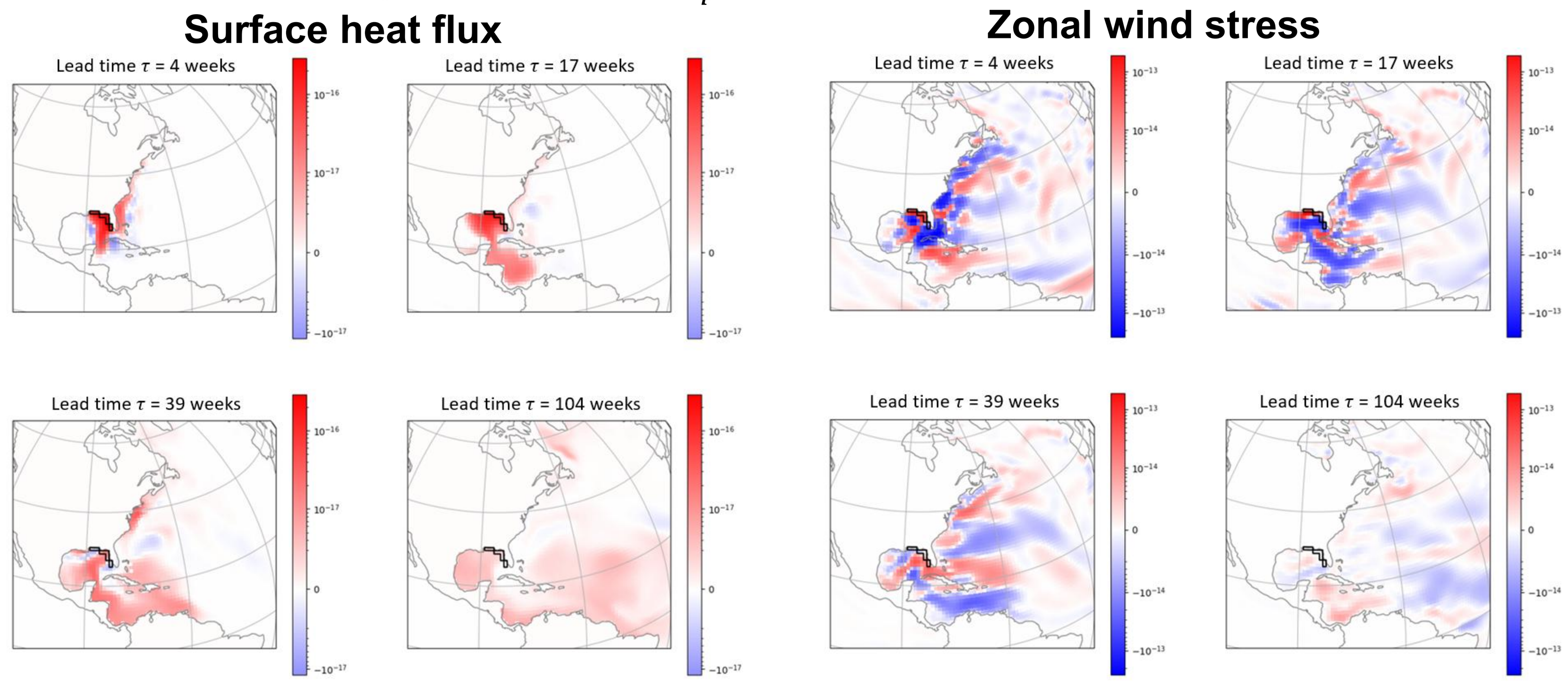
Dynamic sea level time series

Forcings (surface fluxes) at various locations & lead times:

Freshwater flux
Heat flux
Zonal wind stress
Meridional wind stress

Adjoint reconstructions

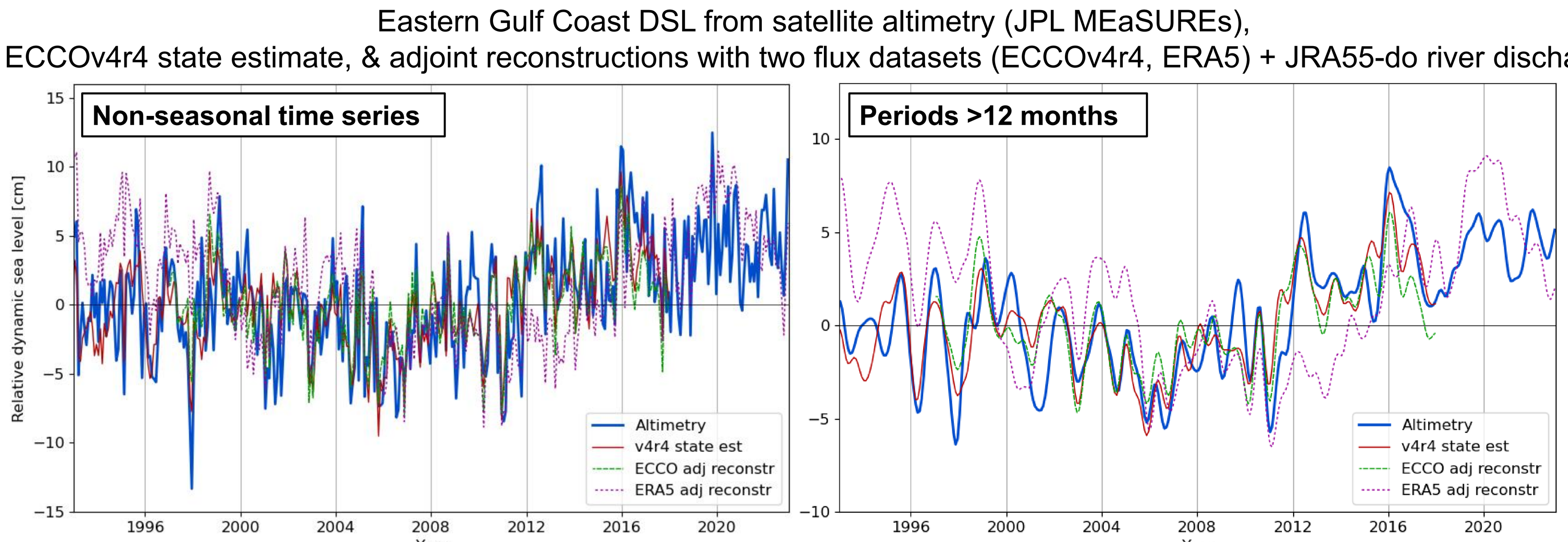
Adjoint sensitivities S_p of Eastern Gulf Coast DSL to:



Convolution of sensitivities and forcings to obtain DSL anomaly reconstruction

$$\eta'(t) = \sum_{p=1}^{4} \iiint S_p(x,y,t,\tau) \cdot F'_p(x,y,t-\tau)\, dx\,dy\,d\tau$$

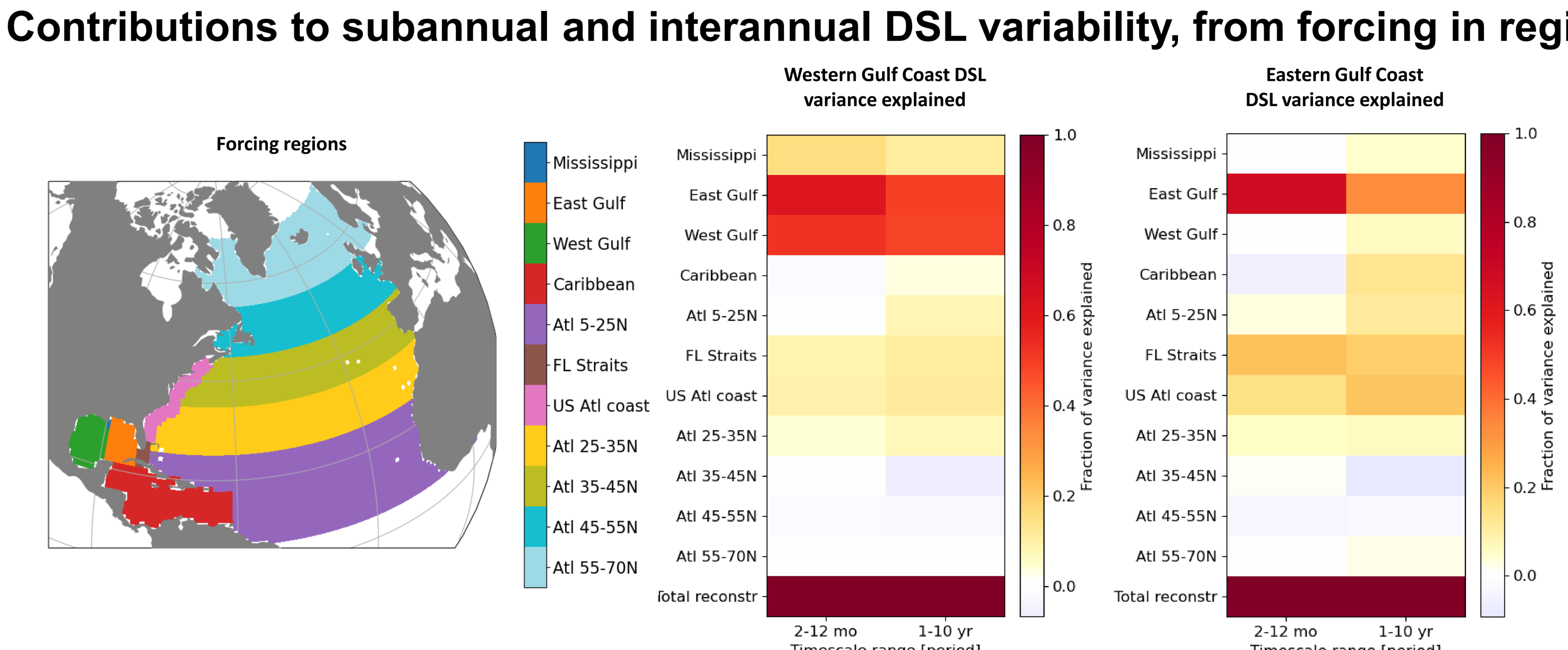
Eastern Gulf Coast DSL from satellite altimetry (JPL MEaSUREs), ECCOv4r4 state estimate, & adjoint reconstructions with two flux datasets (ECCOv4r4, ERA5) + JRA55-do river discharge



- **Reconstruction with ECCO fluxes is more successful than with ERA5 at interannual/decadal timescales**

Attribution of variability and trend

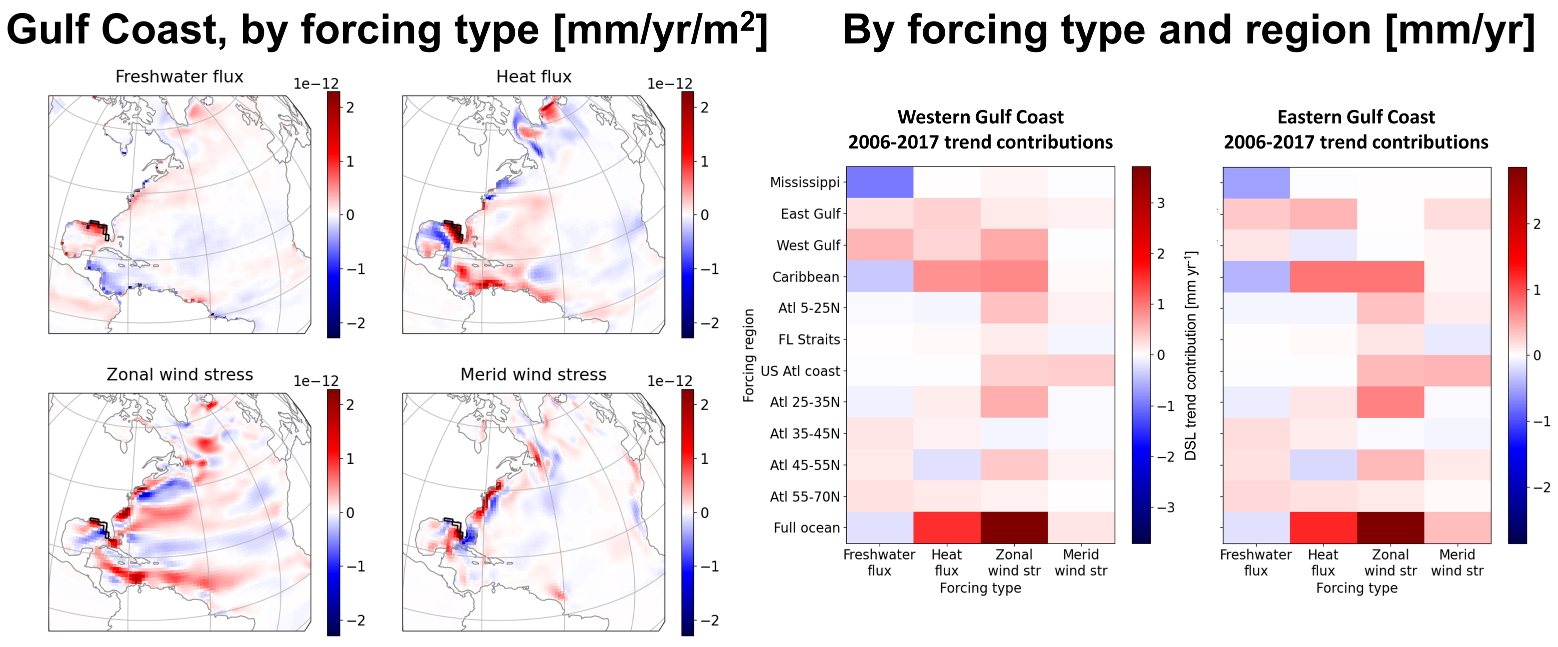
Contributions to subannual and interannual DSL variability, from forcing in regions



- DSL variability at longer timescales and on the Eastern Gulf Coast are more influenced by forcings outside of the Gulf (e.g. US Atlantic coast)

Contributions to 2006-2017 DSL trend

E Gulf Coast, by forcing type [mm/yr/m²] **By forcing type and region [mm/yr]**



- Decadal contributions to trends come from diverse regions; highest in the Caribbean, subtropical Atlantic, and along the US Atlantic coast

Seasonal-timescale prediction

Sea level predictions using the ECCO adjoint:

- **Dynamic persistence:** Only past forcing anomalies (e.g., from ECCO, ERA5) area used; lead times τ after τ_{init} are assumed to be seasonal climatology values
- **Hybrid prediction:** forcings from lead times τ after τ_{init} are provided by an existing atmosphere-ocean coupled prediction model (SEAS5)

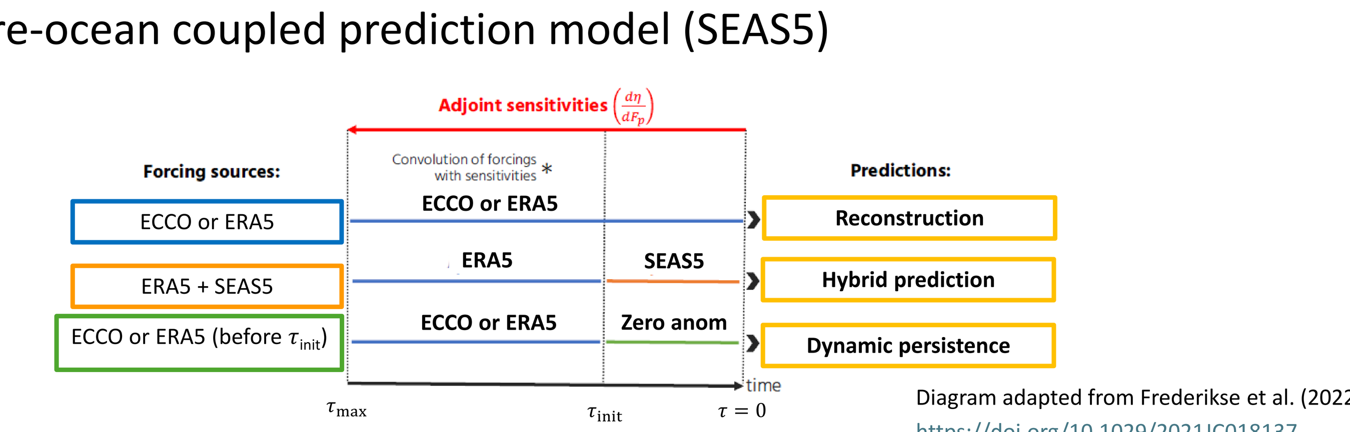
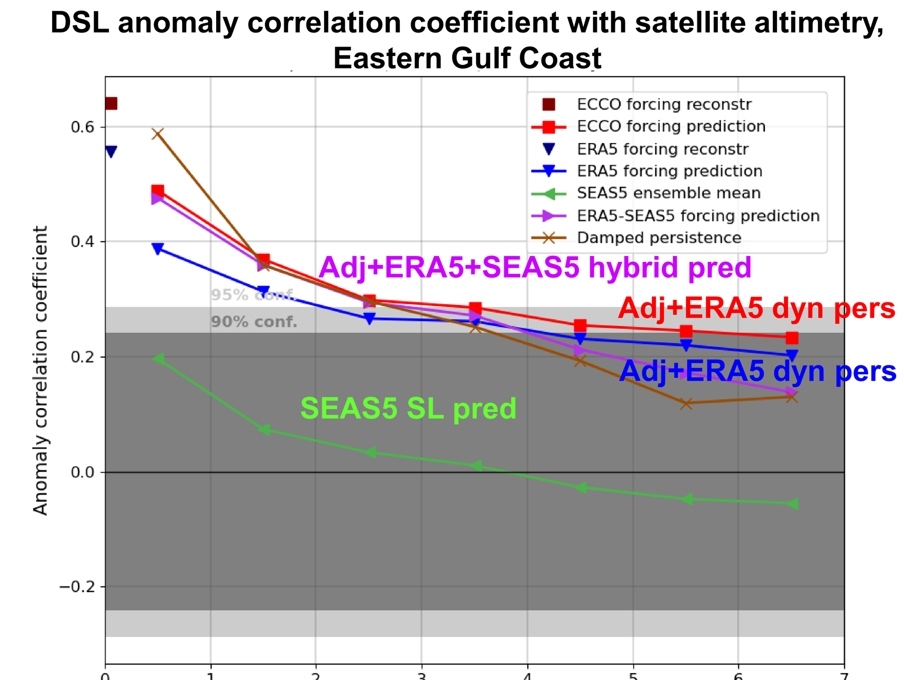


Diagram adapted from Frederikse et al. (2022) https://doi.org/10.1029/2021JC018137

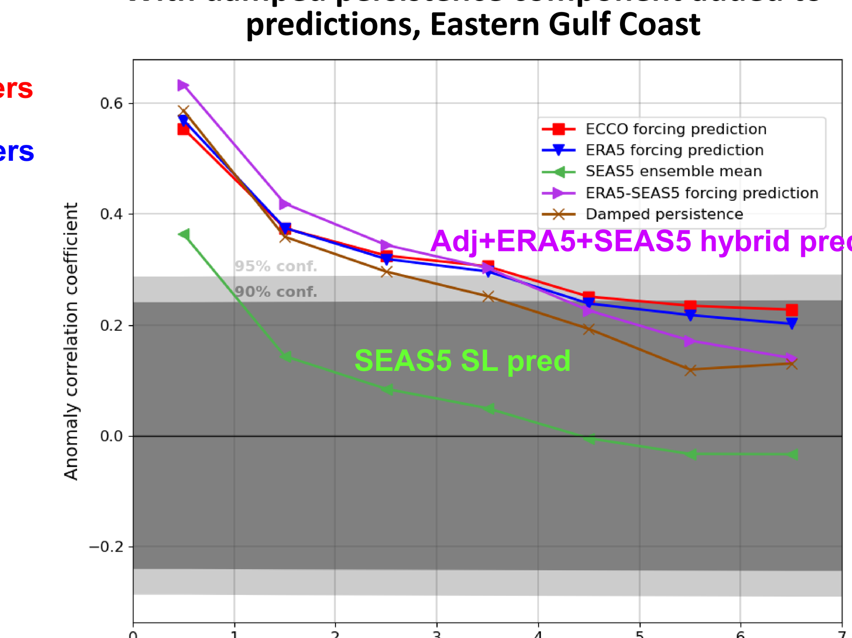
DSL anomaly correlation coefficient with satellite altimetry, Eastern Gulf Coast



- **Each of the predictions can be augmented by adding a damped persistence component to the obs – reconstr anomaly**

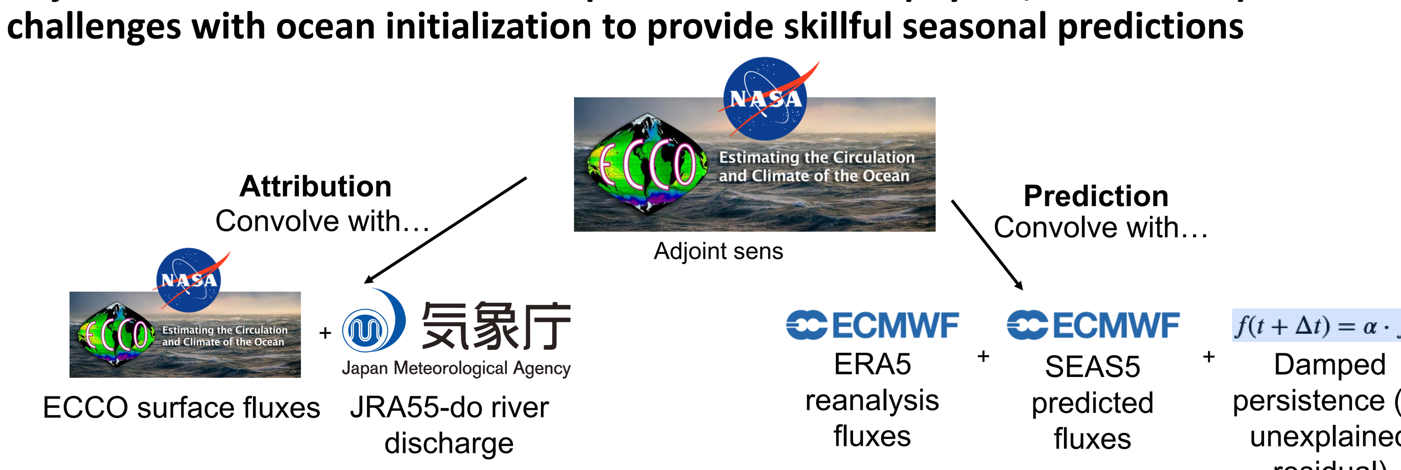
$$\eta' = \eta'_{\mathrm{forc}} + \eta'_{\mathrm{damp}} \qquad \eta'_{\mathrm{damp}}(t+\Delta\tau) = \alpha[\eta'_{\mathrm{obs}} - \eta'_{\mathrm{reconstr}}](t)$$

With damped persistence component added to predictions, Eastern Gulf Coast



Summary

- **Adjoint sensitivities from ECCO help illuminate ocean physics, and can help overcome challenges with ocean initialization to provide skillful seasonal predictions**



For preprint of the attribution study, scan here