A High-Resolution Simulation of the Gulf of Mexico Suitable for Climate Change Studies using CESM2

Variability and Teleconnections

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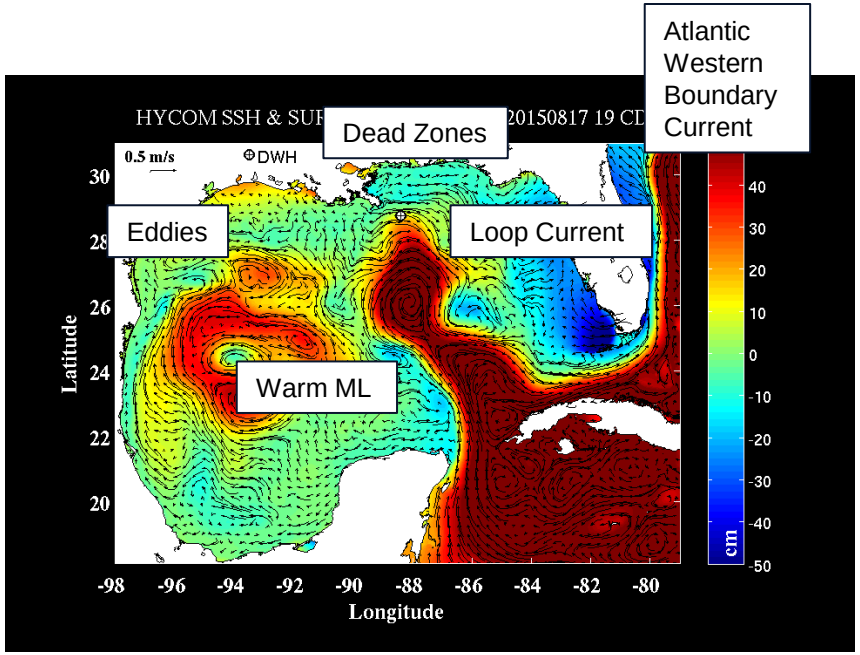
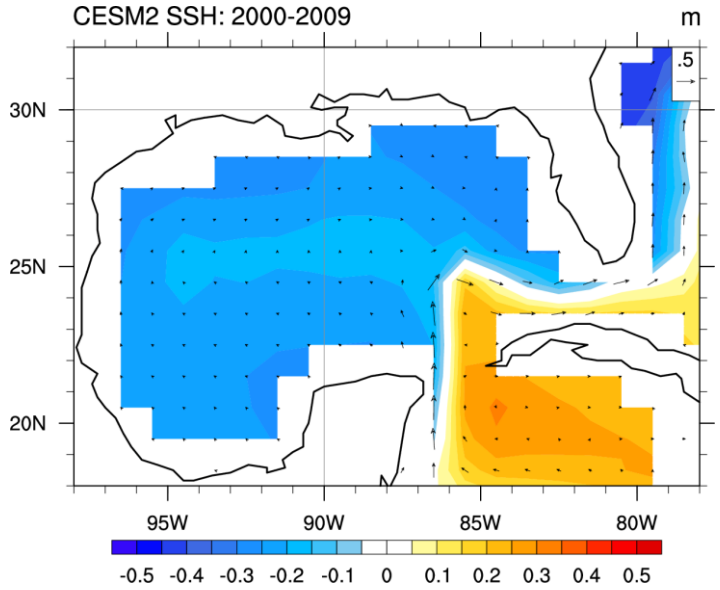
Goal

To produce the most accurate and detailed simulation possible of the Gulf of Mexico with a modeling design capable of imposing the projected forced response from CESM2.



The Challenge: The Gulf's circulation is characterized by small-scale features such as the Loop Current and the eddies it sheds, with significant roles in ventilation of dead zones, interactions with hurricanes, and impacts on ecosystems and the energy industry.

Significant detail also exists in coastal boundaries and bathymetry.



Science Questions

How will the socio-economically critical features of the Gulf* respond to climate change?

*Loop Current, shedded eddies, HABs, dead zones, mixed layer heat

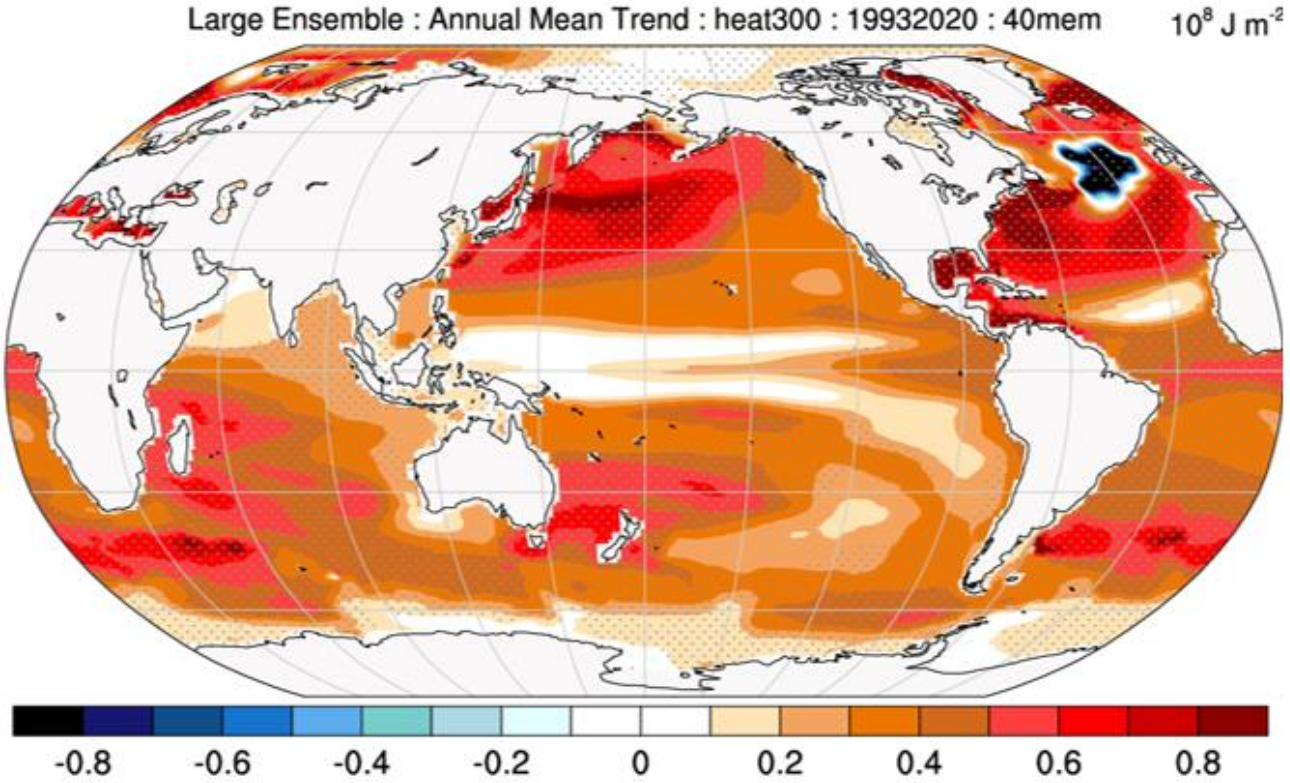
Key Points

1) A 1/25º boundary-forced simulation of the Gulf of Mexico from 1994-2020 using HYCOM is designed and produced.

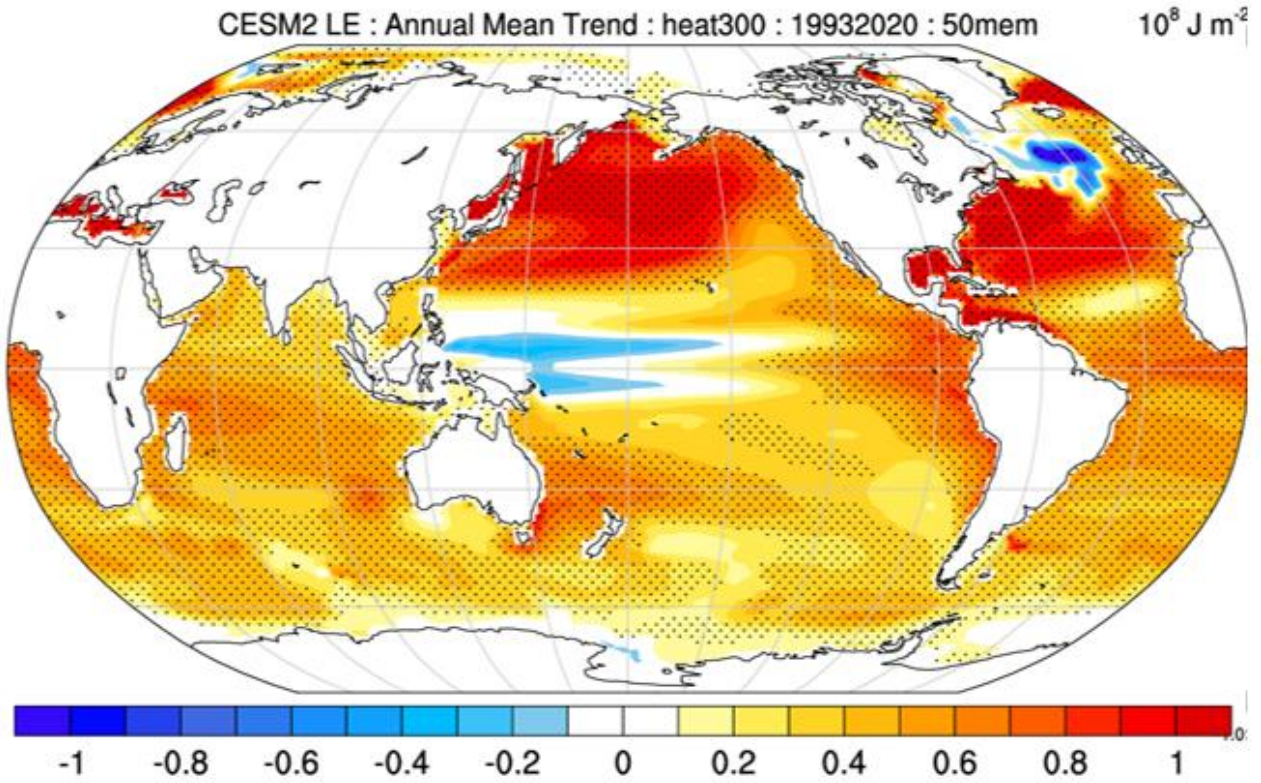
2) Detailed features of the Gulf's mean state and variability are diagnosed with GLORYS at 1/12º, new aspects revealed.

3) The HYCOM simulation accurately reproduces many observed features, without assimilating data in the ocean interior, allowing for teleconnections to be assessed. Suggests projections can be made by imposing CESM2 trends at boundaries.

Simulated Uptake in Ocean Heat Content in the Gulf of Mexico 1993-2020



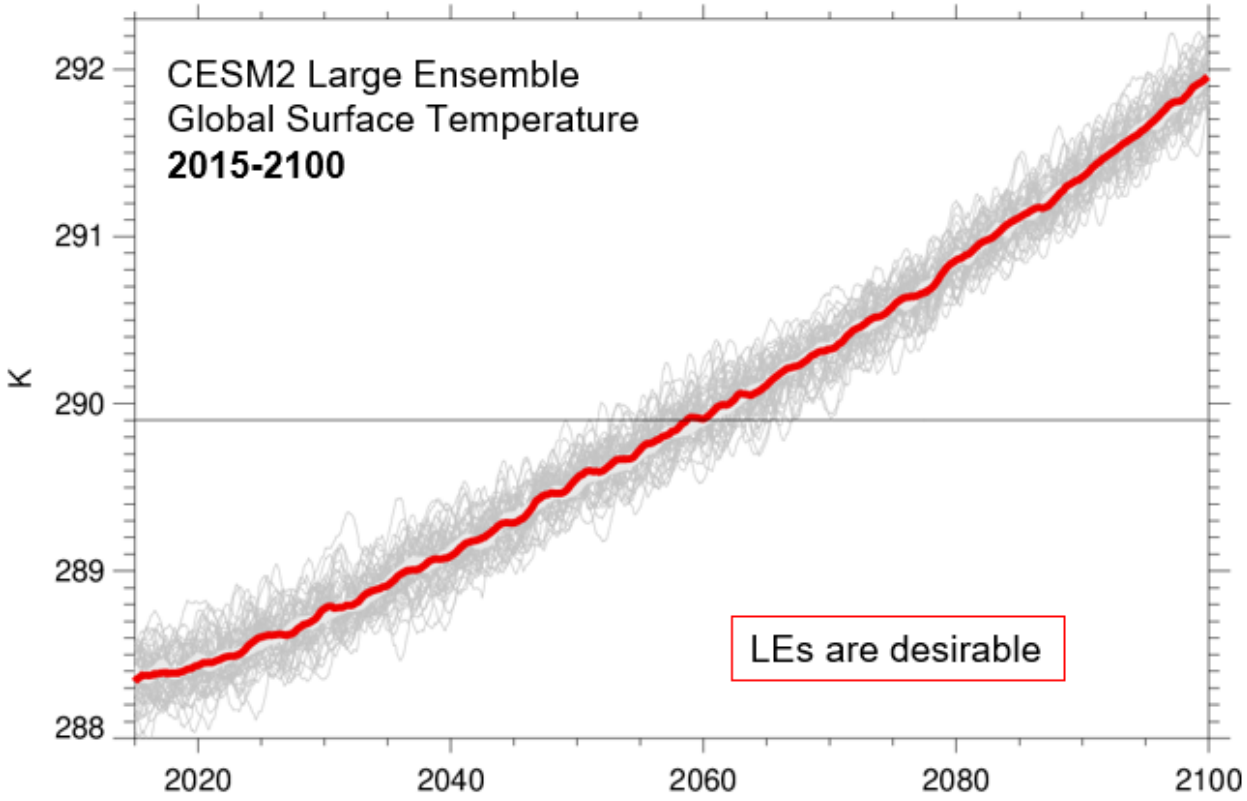
CESM1 Large Ensemble



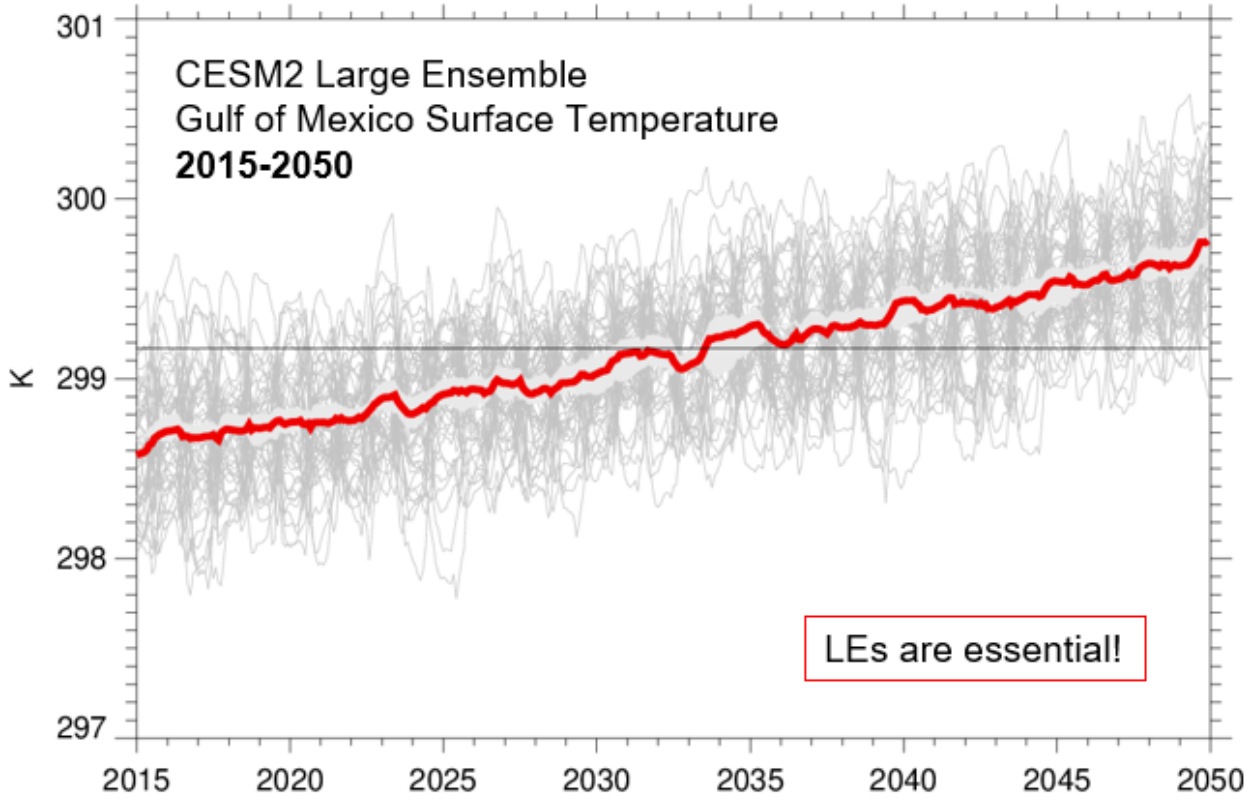
CESM2 Large Ensemble

The Gulf of Mexico is a hot-spot of climate change and is the source region of the Atlantic's western boundary current.

Motivation for Large Ensembles



Global: internal variability can obscure the signal of forced climate change. Single member trends still useful.



Gulf of Mexico: internal variability swamps the forced response, on short timescales individual members generally aren't useful for estimating the forced response. The PDF of outcomes is influenced nonetheless.

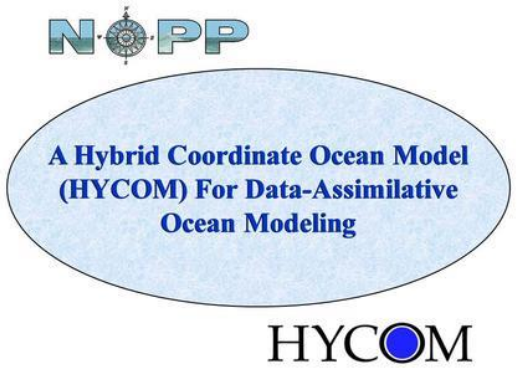
Methods and Data

Observations:
GLORYS version 12v1 (Lellouche et al., 2021)

- NEMO model
- 1/12º, monthly
- 50 levels
- ERA-I forcing
- assimilates altimetry, SST, CORA profiles.

Model:
HYCOM (Zamudio and Hogan 2008);

- 79º W to 98º W, 18º N to 31º N
- 1/25º
- 41 levels
- 12-hourly output



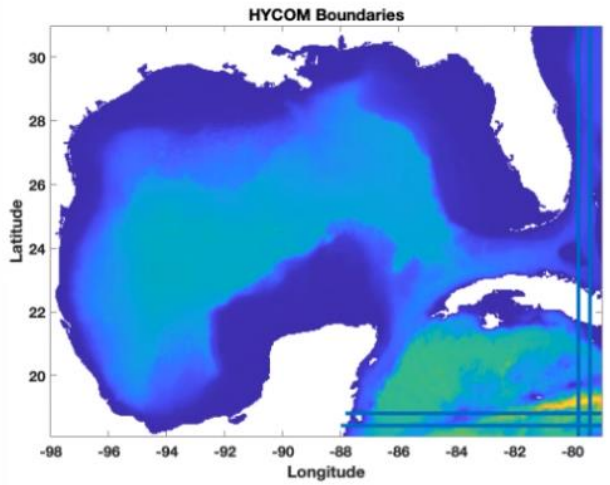
Model Design

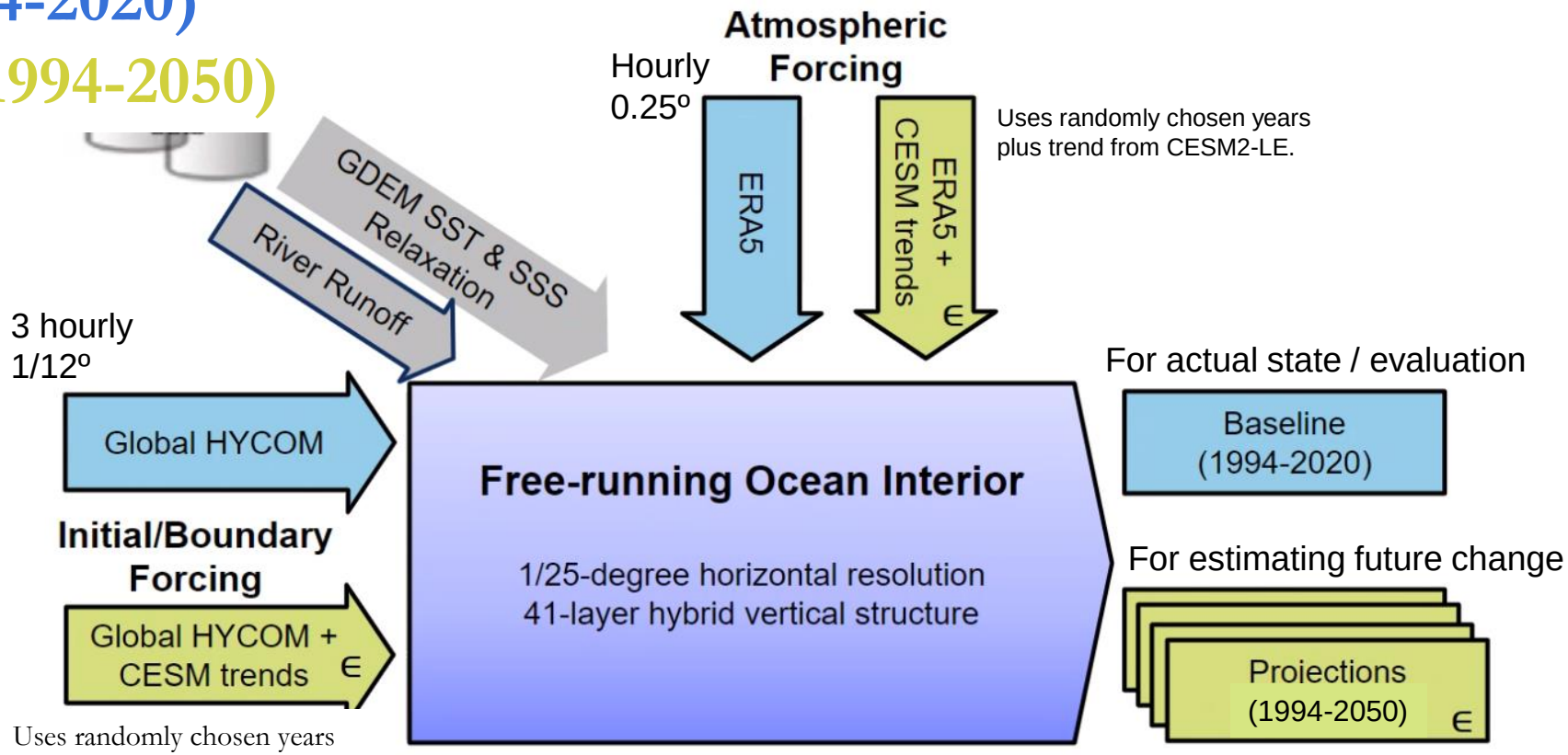
Schematic

To achieve the goal of a free running ocean (no data assimilation), only boundary forcings are used. Forced responses from CESM2 will be used to impose climate change trends.

Baseline (1994-2020)

Projections (1994-2050)





Key Finding 1: Accurate Reproduction of GLORYS

Baseline Simulation

Accurately reproduces large-scale features such as the gradients with the Caribbean and Atlantic. Also produces detailed features evident in GLORYS such as the Loop Current intensity/extent.

Eddies shed from the LC propagate westward at about the right frequency / latitude / speed. Even individual eddies are well simulated such as in Aug 2005 prior to Katrina.

Key Finding 2: The Loop Current Ridge Tends to Collapse in Early Fall

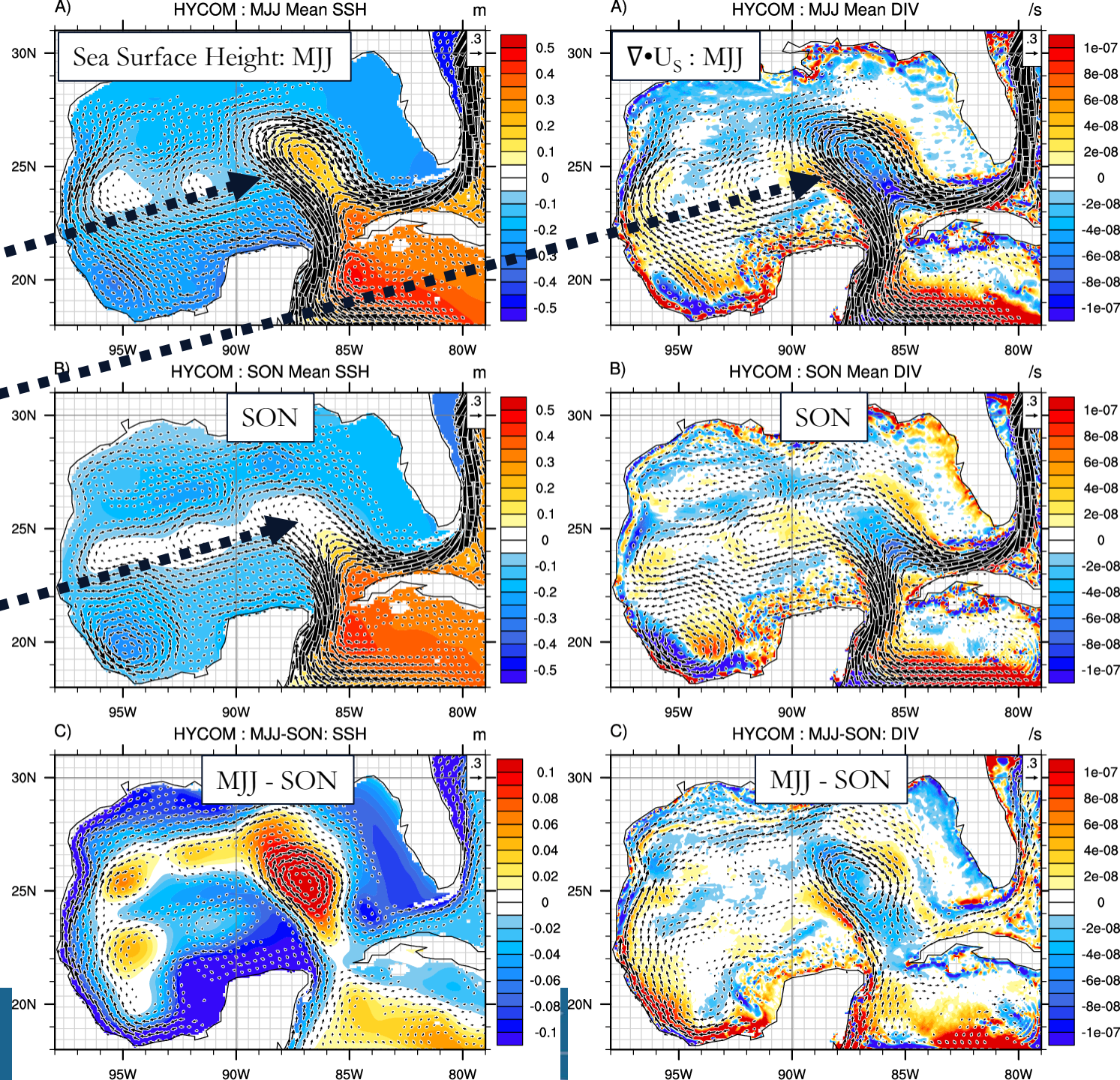
Loop Current Ridge (**LCR**) is evident in SSH gradients, surface currents, and $\nabla \bullet U_S$.

Top: The LCR peaks in MJJ. Along the ridge there is strong upper ocean convergence ($\nabla \bullet U_S < 0$) May to July.

Middle: The ridge collapses in late summer and by SON the current hugs the north coast of Cuba. $\nabla \bullet U_S$ weakens.

Bottom: The collapse impacts SSH, currents, and $\nabla \bullet$US across the basin.

Also: HYCOM closely reproduces GLORYS' representation of these features.



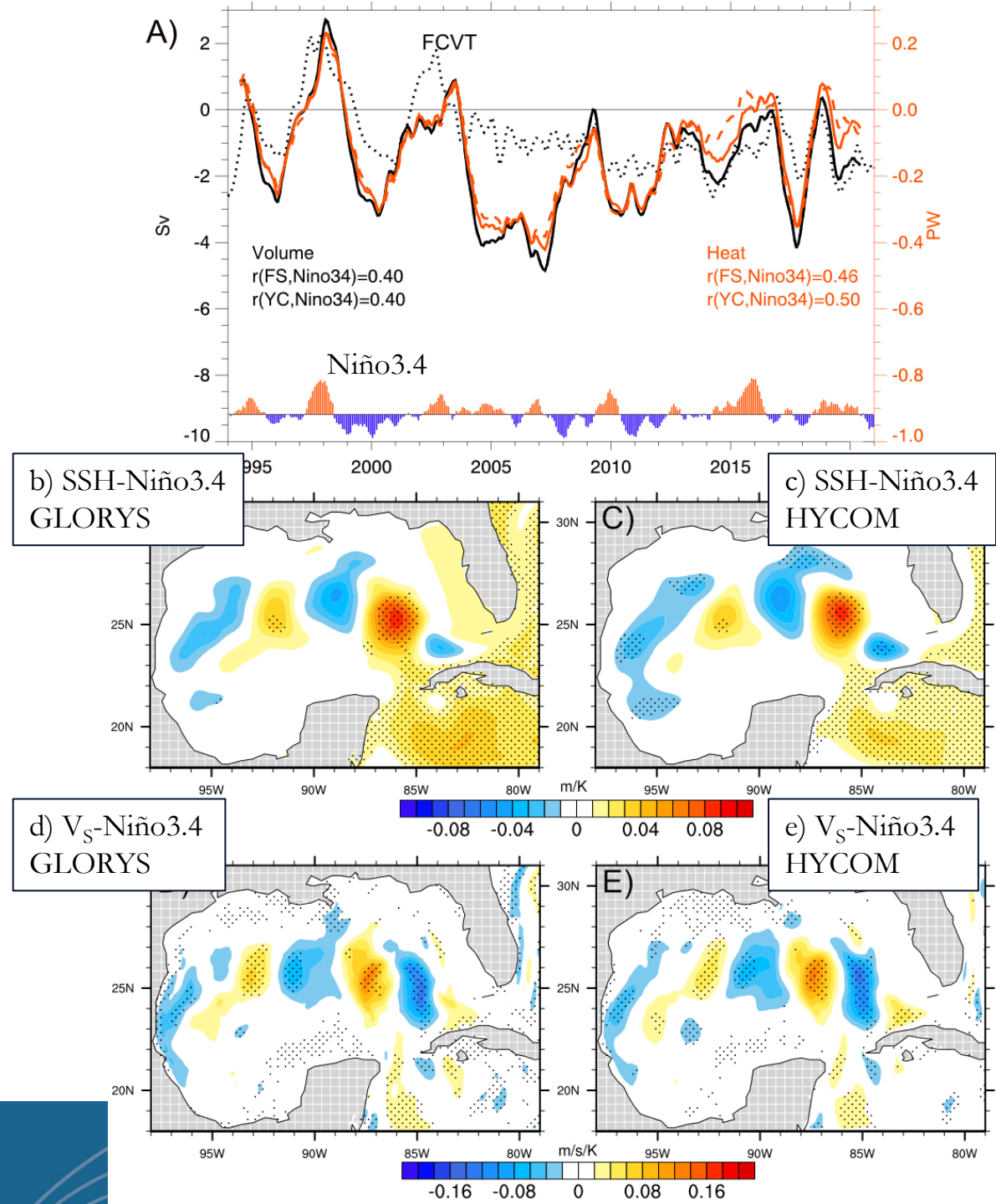
Key Finding 3: Robust Teleconnections - ENSO

Top: Transports of **heat** and **volume** through the Yucatán Channel (solid) and Florida Strait (dash) are tightly balanced (lines).

Variability in heat and volume transports are influenced by ENSO – with strong flows during El Niño and weak flows during La Niña.

Middle/Bottom: Regressions between Niño3.4 DJF SSH in GLORYS (**b**) and HYCOM (**c**), and V_S in GLORYS (**d**) and HYCOM (**e**). El Niño influences SSH gradients between Caribbean and GoM, strengthening the LCR SSH and V_S along its fringes – also eddies.

*Cable-derived estimates of Florida Current volume transport at 27°N also shown (FCVT, dotted).



Key Finding 3: Robust Teleconnections - CLLJ

Middle/Bottom: Regressions between the CLLJ index and SSH in GLORYS (**b**) and HYCOM (**c**), and V_S in GLORYS (**d**) and HYCOM (**e**). El Niño influences SSH gradients between Caribbean and GoM, strengthening the LCR SSH and V_S along its fringes.

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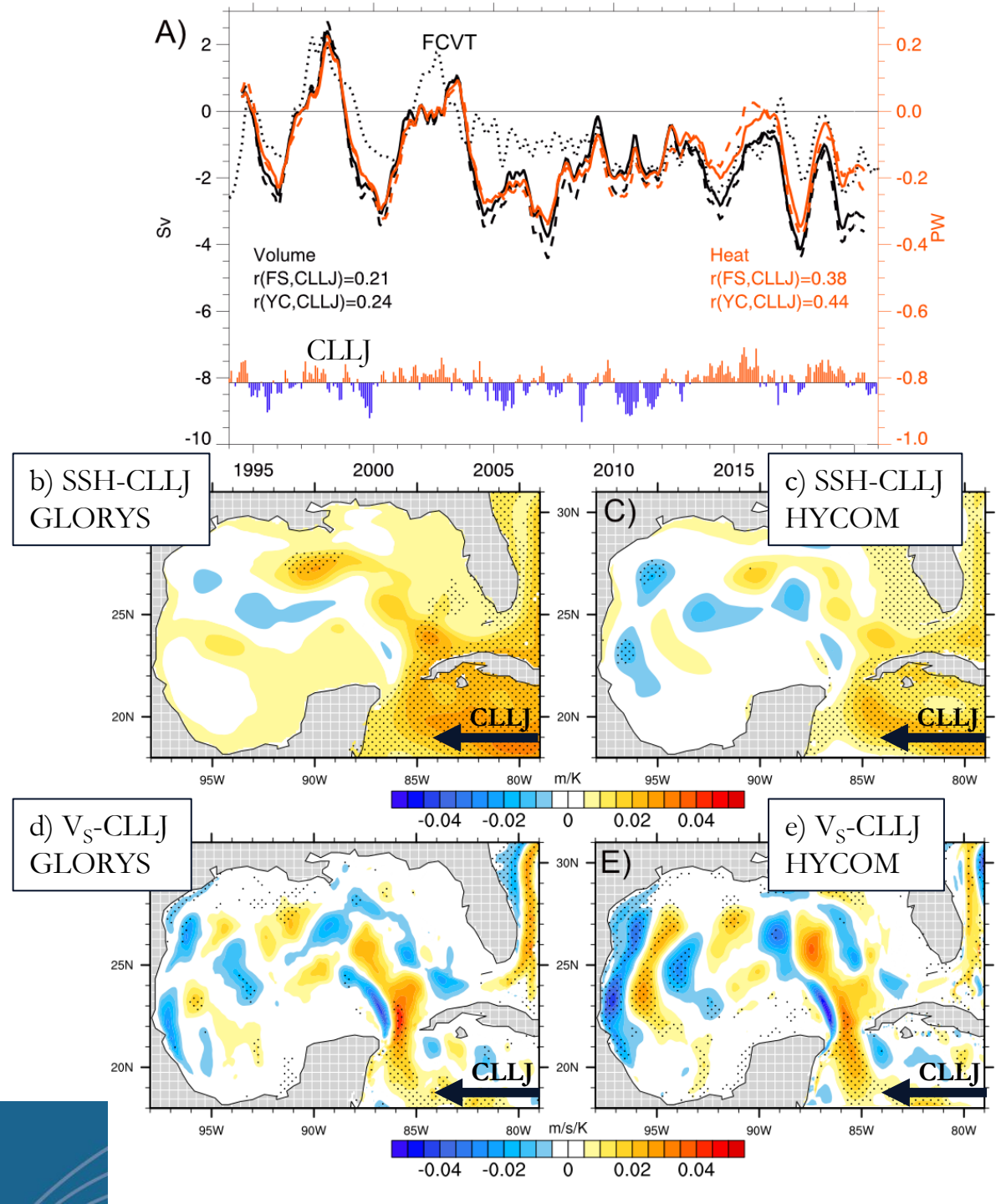

Conclusions and Ongoing Work

Summary:

A high-resolution boundary-forced HYCOM simulation reproduces the detailed features of the Gulf as diagnosed in GLORYS.

A seasonal collapse of the Loop Current Ridge in late summer is identified that is linked to variability in SSH and $\nabla \bullet U_S$ across the central Gulf.

Teleconnections are identified between ENSO/CLLJ and heat/volume transports in the Gulf and the Loop Current Ridge.

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Ongoing Work:

A 10-member ensemble from 1994-2050 imposing the FR from CESM2 at model boundaries is currently in production.

This ensemble will be a useful addition to the Gulf of Mexico experiments currently planned with CESM.

Comparisons are planned between HYCOM, iHESP, and nested-grid high-resolution CESM simulations to assess the benefits and drawbacks of each modeling approach.