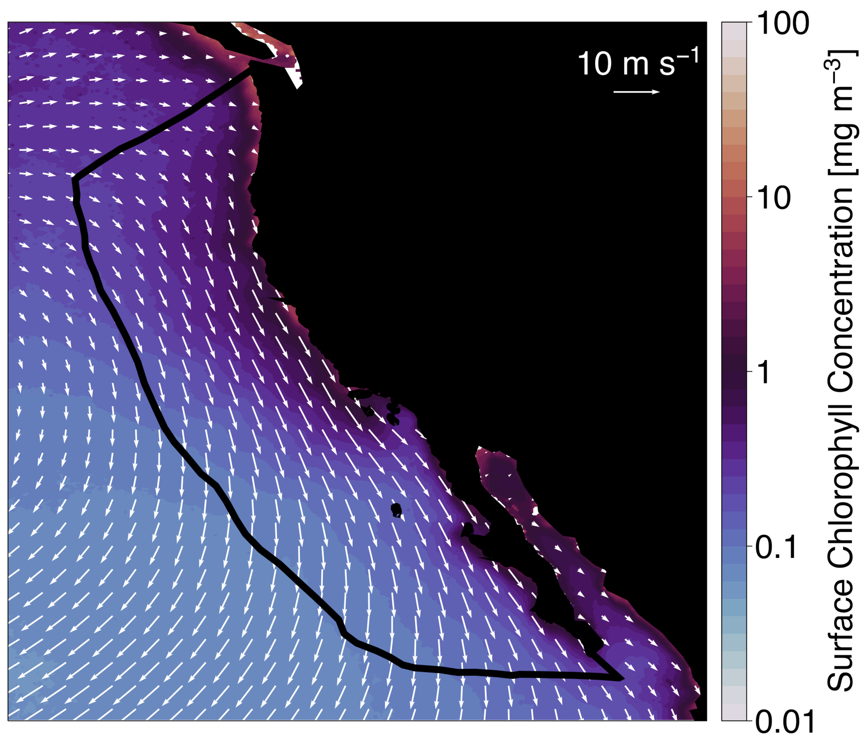
Skillful multiyear predictions of ocean acidification in the California Current System

Riley X. **Brady**, Nicole S. **Lovenduski**, Stephen G. **Yeager**, and Matthew C. **Long**

Motivation and Methods



The California Current System (CCS) is a wind-driven upwelling system that supports some of the world's most productive fisheries, which are valued at roughly \$6B per year to the United States economy. Waters upwelled to the surface are rich in nutrients, but are also corrosive, making the CCS particularly vulnerable to the effects of ocean acidification. Thus, accurate multi-year forecasts of critical ocean acidification parameters, such as pH, would be useful for ecosystem managers of the CCS.

Fig 1. Annual climatology from SeaWIFS surface chlorophyll and QuikSCAT surface winds in the CCS. The black region spans the Large Marine Ecosystem (LME) and is used to generate time series for assessment of region-wide predictability.

Decadal Forecasting System

The CESM Decadal Prediction Large Ensemble (CESM-DPLE) is a fully coupled Earth System Model that is initialized annually on November 1st from a forced ocean—sea ice reconstruction. Forty ensemble members are integrated forward for ten years from each initialization on a 1° x 1° ocean grid. Here we use the ensemble mean to evaluate our ability to forecast surface pH in the CCS.

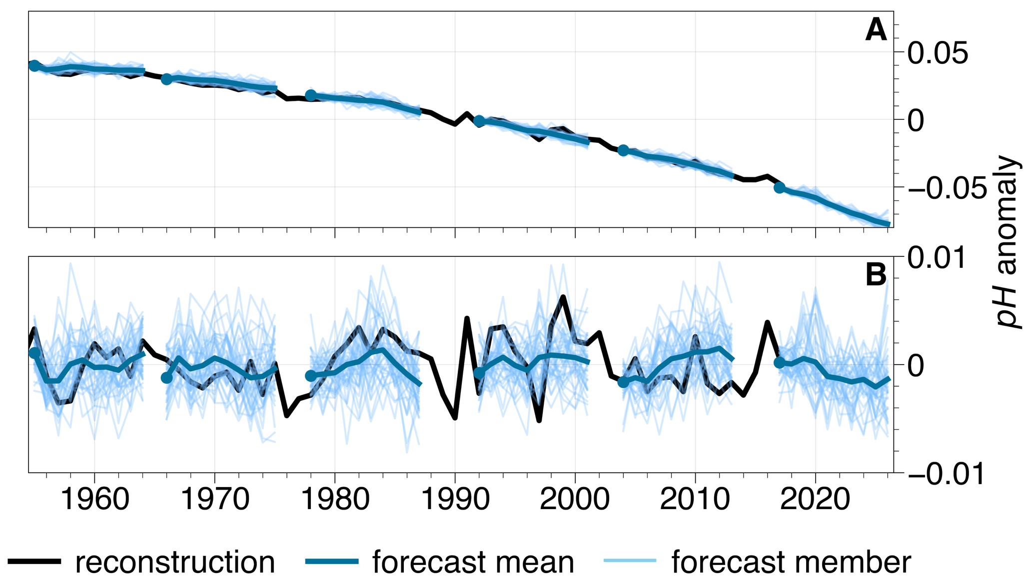


Fig 2. Forecasts of surface pH in the CCS-LME. (**A**) Raw anomalies including the ocean acidification signal. (**B**) Anomalies after removing a second-order fit. Only a subset of the 64 initializations are shown here.

Model Evaluation

We compare the reconstruction to an independent gridded pH product from the Japanese Meteorological Agency (JMA) in the CCS-LME over 1990—2005. The reconstruction fits the long-term trend, seasonal cycle, and variability well over this period.

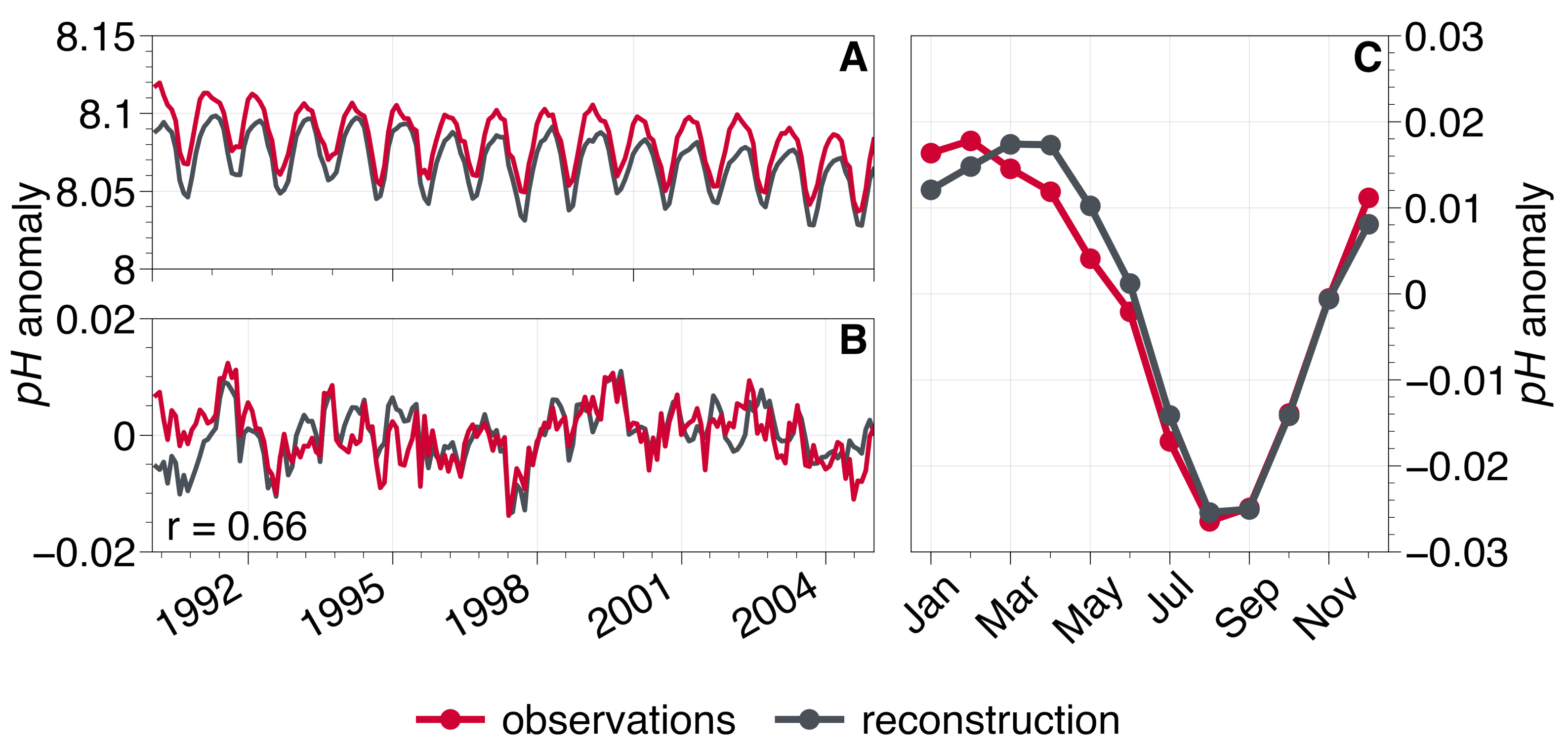


Fig 3. Evaluation of pH in the reconstruction compared to the JMA observational product in the CCS-LME. (**A**) Raw pH, (**B**) detrended and deseasonalized anomalies, and (**C**) the mean seasonal cycle.

High Potential to Predict Surface pH

CESM-DPLE has the potential to predict surface pH offshore in the central and southern CCS out to five years. For two years, CESM-DPLE has significant predictability over persistence in most of the region, save for the Pacific Northwest. The initialized forecasts improve upon persistence nearly everywhere for five years.

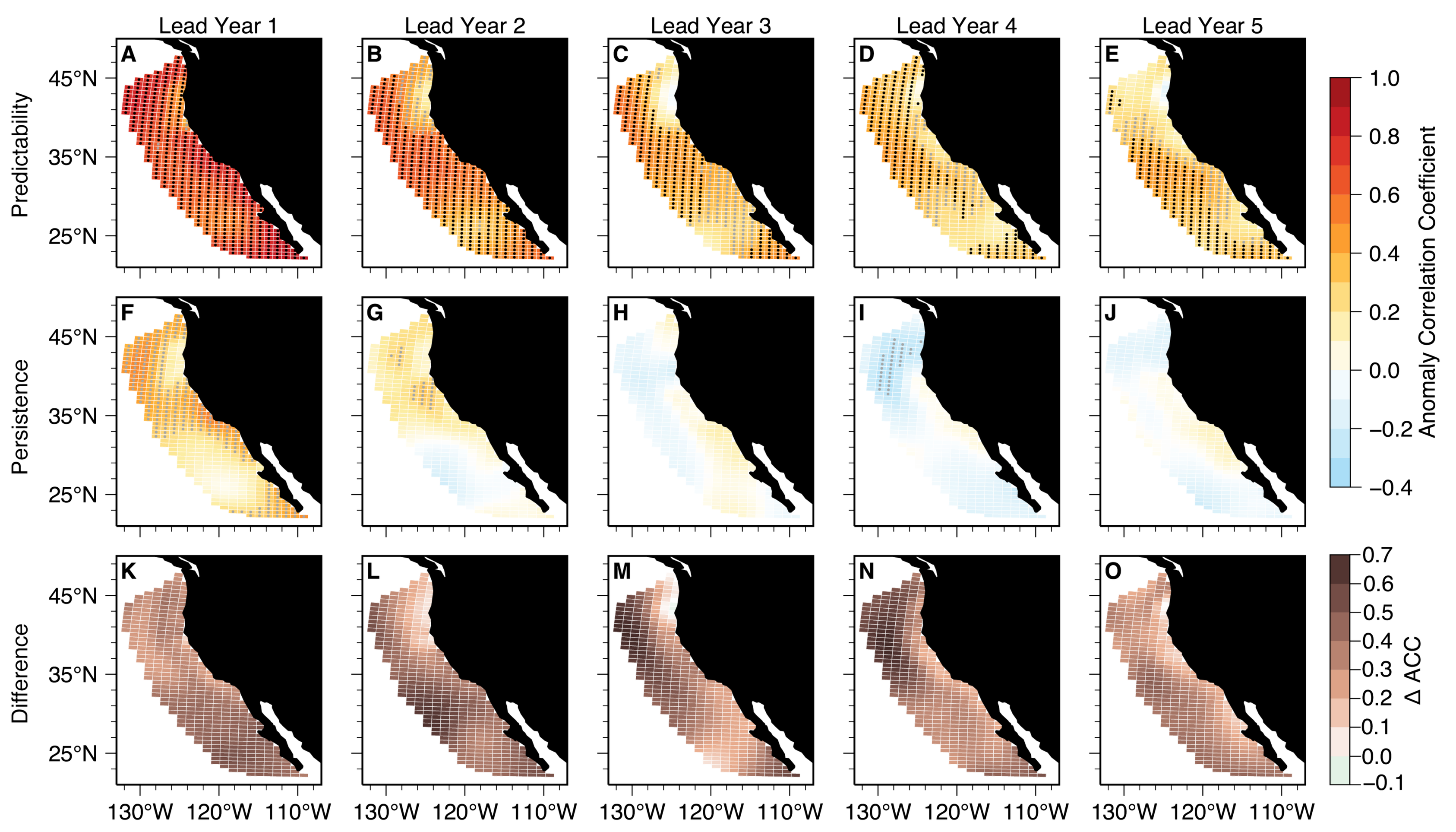


Fig 4. Potential predictability of surface pH in the CCS-LME. (**A-E**) Linear correlations between the CESM-DPLE ensemble mean forecast and the reconstruction. (**F-J**) Persistence forecast of the reconstruction. (**K-O**) Improvement in predictability by using CESM-DPLE. Black stippling indicates significant predictability over persistence at the 95% level; gray stippling indicates significant correlations at the 95% level.

Skillful Retrospective Forecasting

Because of the reconstruction's good fit to observations, potential predictability translates to true skill in retrospective forecasts of surface pH. The initialized system has significant skill over observational persistence out to four years offshore from Cape Mendocino to Baja California. At lead year 5, most skill over persistence is confined to a few hundred kilometers offshore in the southern CCS.

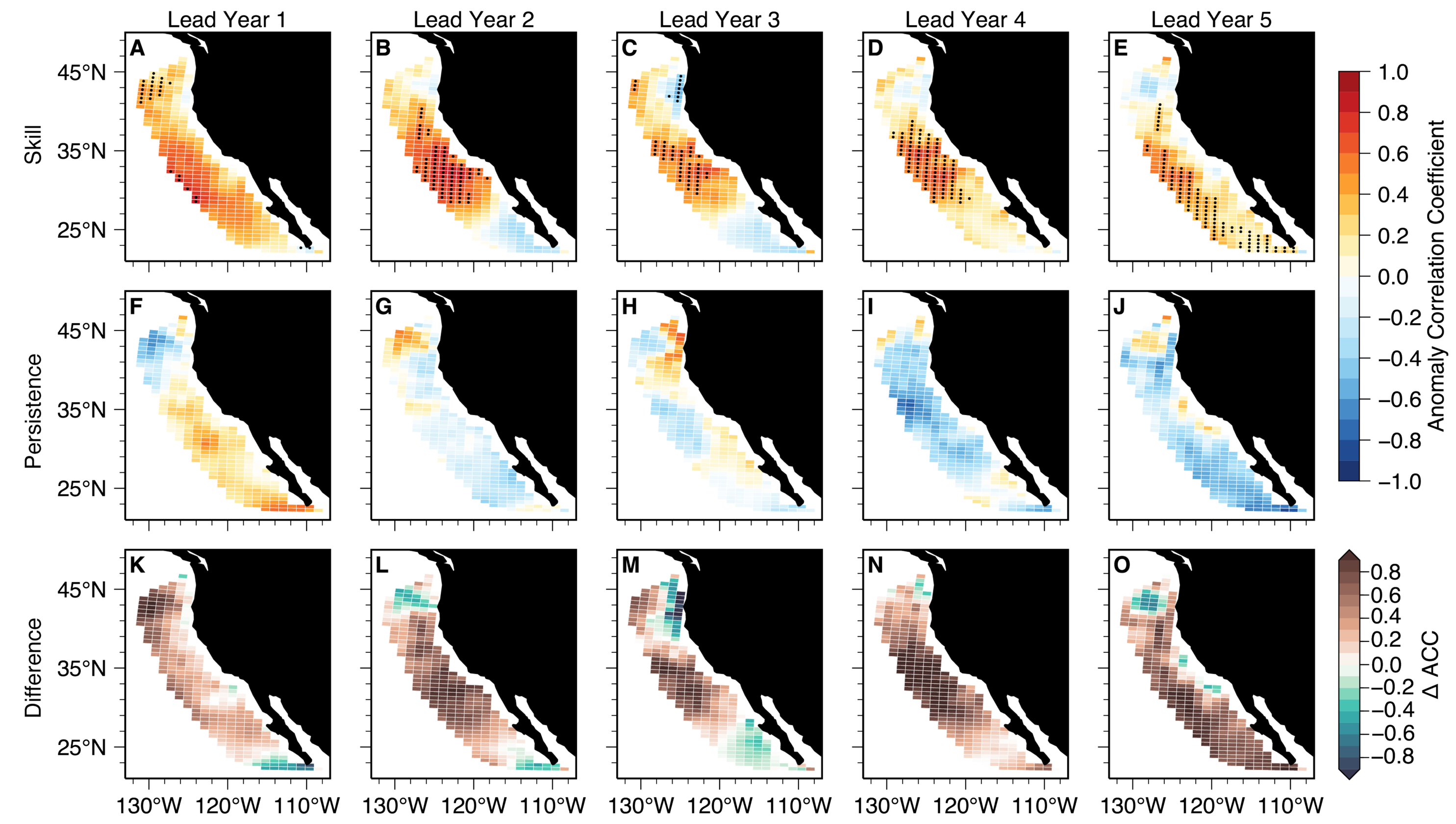


Fig 5. Predictive skill of surface pH in the CCS LME. Panels follow the same convention as Fig. 4, but in comparison to the JMA observational product. Note that only significant skill over persistence is shown by stippling here, due to the limited degrees of freedom over 1990—2005.

What drives predictability in pH?

We test the relative influence of driver variables in lending predictability to pH by scaling their potential predictability to common pH units. We find that predictability in DIC is the leading contributor to pH predictability over all lead years, while the combined predictability of SST and alkalinity is roughly equivalent to DIC over the first five lead years.

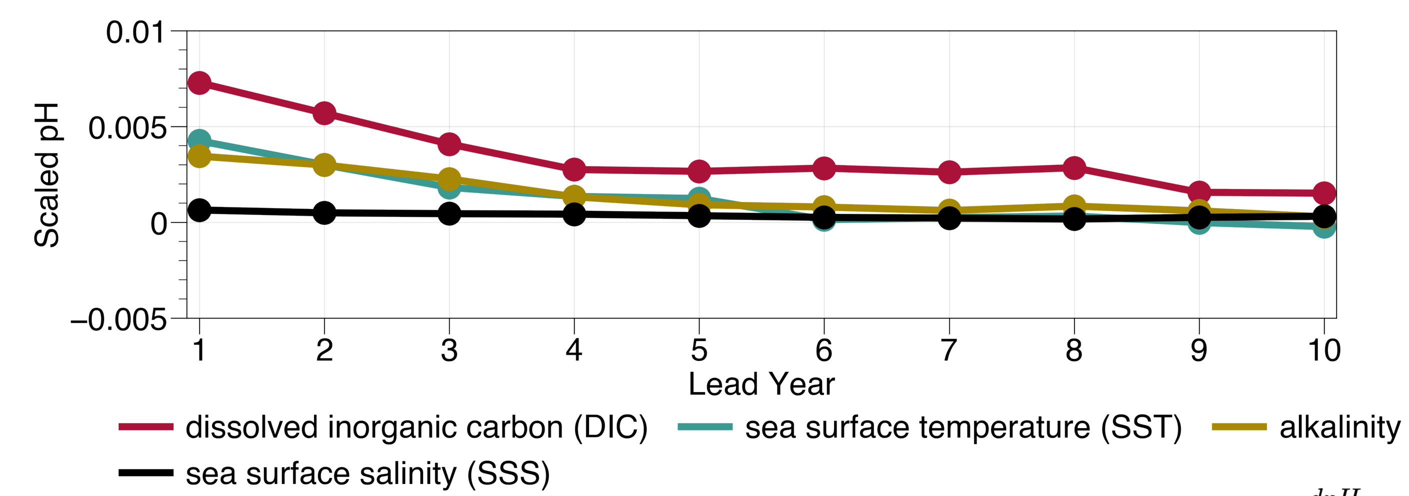


Fig 6. Scaled predictability of the driver variables of pH. This was computed via $r_x \cdot \frac{dpH}{dx} \cdot \sigma_x$, or the anomaly correlation coefficient of the driver variable forecasts multiplied by the sensitivity of pH to the driver variable and its interannual variability in the CCS.

We compute a mixed layer budget of DIC in the CCS to highlight processes that most strongly influence anomalous accumulation of DIC in the system. Total advection (vertical + lateral) is the dominant term, with high interannual variability and a correlation coefficient of 0.9 with the total DIC tendency. Thus, proper initialization of DIC anomalies and higher predictability in advective fluxes would enhance skillful forecasting of pH in the CCS.

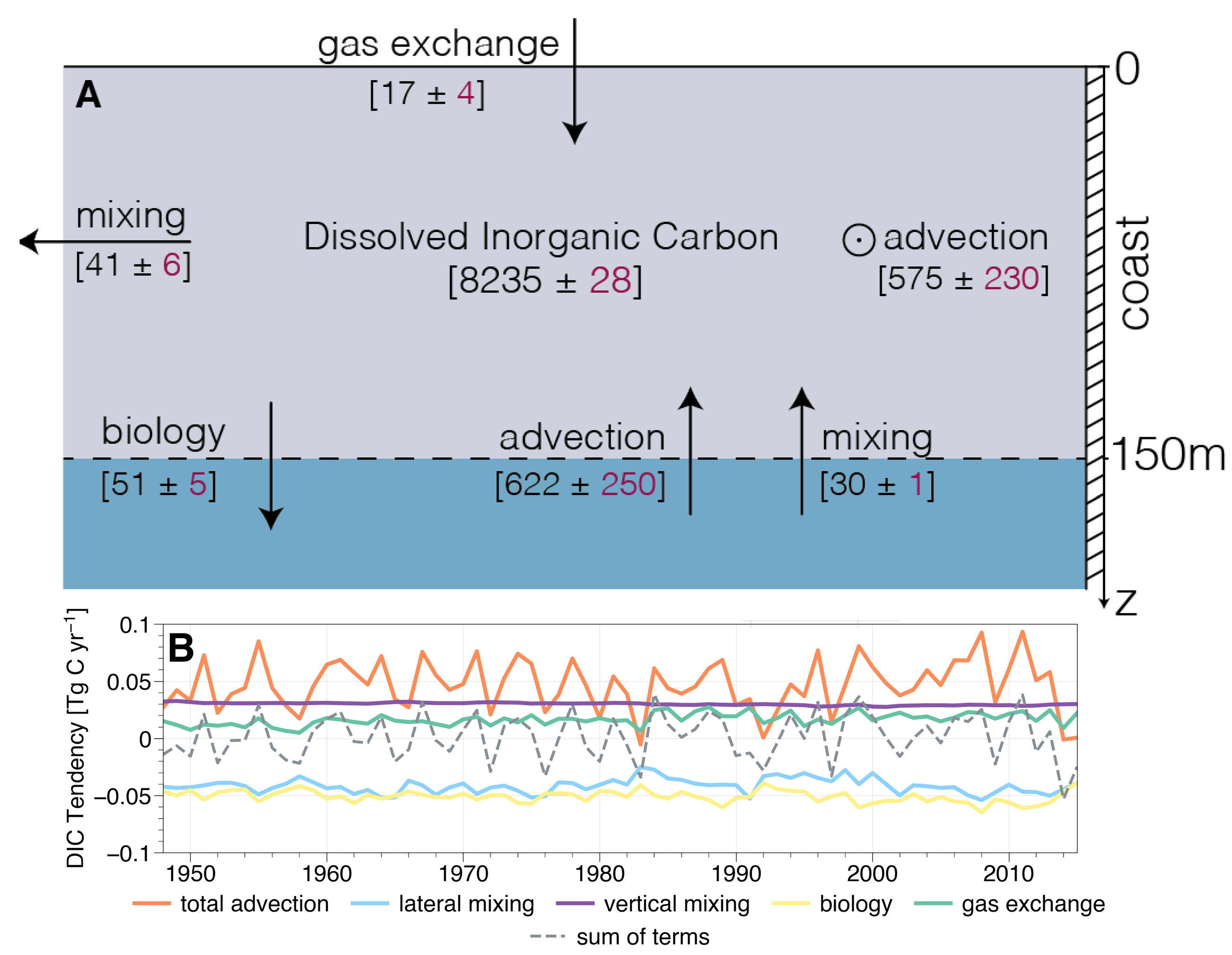


Fig 7. Volume-integrated mixed layer budget of DIC in the CCS. (**A**) Mean (black) and standard deviation (red) of annual tendencies over 1948—2015. (**B**) Annual time series of individual tendency terms. The gray dashed line represents the total DIC tendency.

Summary

- An initialized Earth System Model shows the potential to predict annual pH anomalies five years in advance.
- We can skillfully predict historical pH observations out to four years offshore from Cape Mendocino to Baja California.
- Predictability in pH is mainly engendered by predictability in dissolved inorganic carbon.
- Improved initializations and predictability in advective fluxes would enhance skillful predictions of pH in the California Current.

Ocean Biogeochemistry Research Group
Department of Atmospheric & Oceanic Sciences
Institute of Arctic & Alpine Research
UNIVERSITY OF COLORADO BOULDER

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rileyxbrady riley.brady@colorado.edu