Emerging Topics in Carbon Cycle Variability, Interactions, and Solution Spaces

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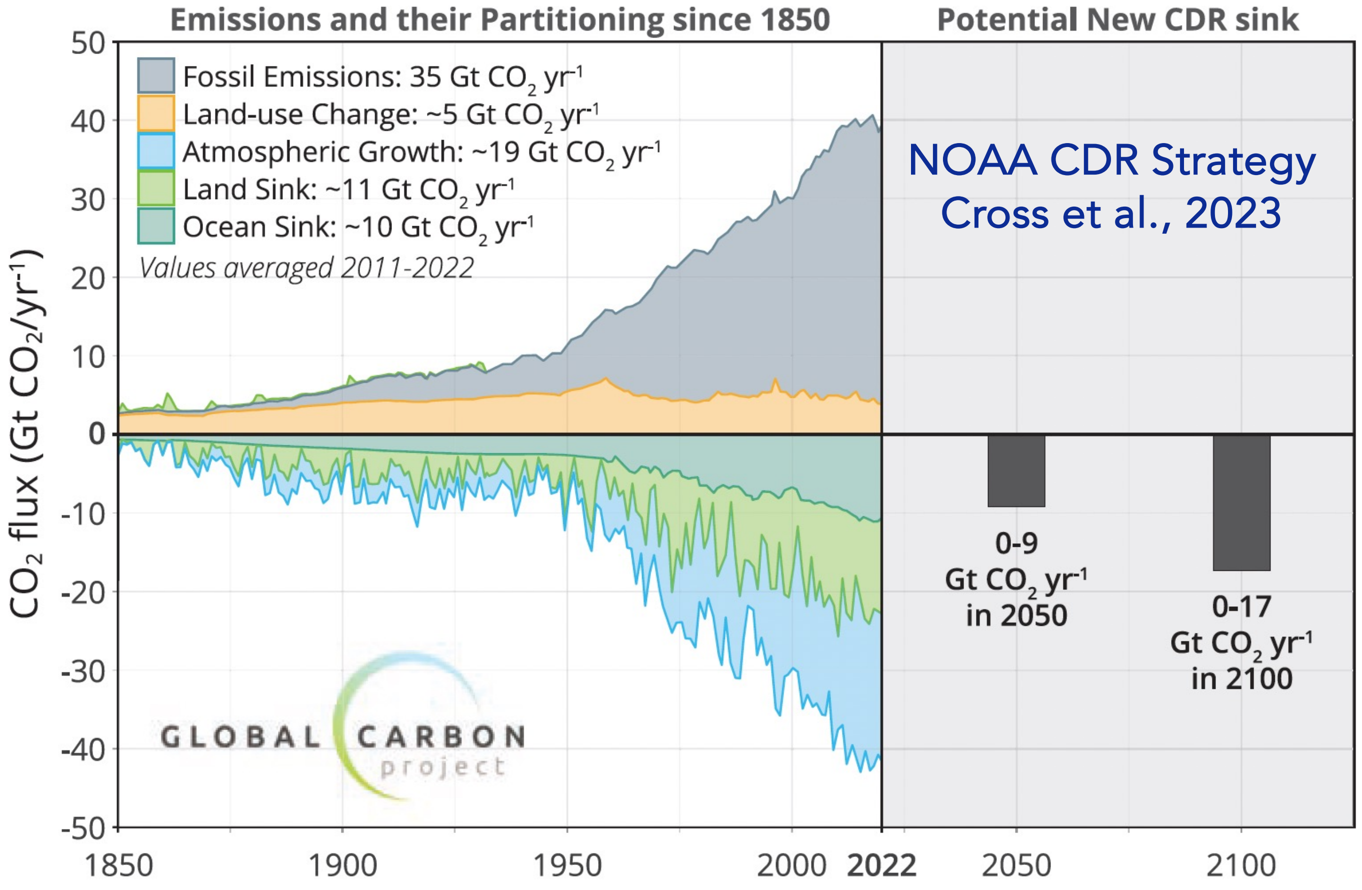
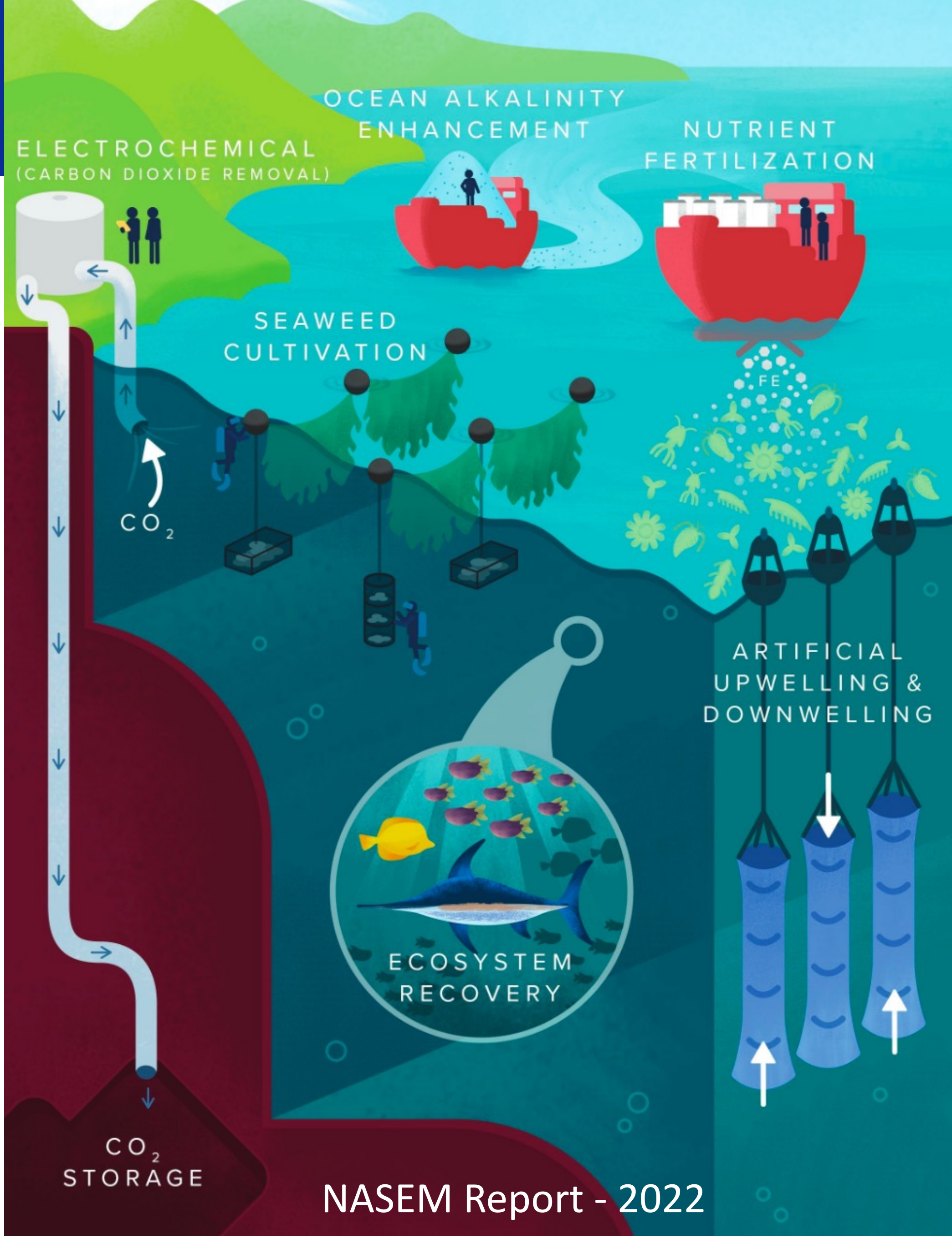
2023 US CLIVAR Summit
July 31- August 2
Phenomena, Observations, and Synthesis Panel
Interactions of the Coastal and Open Ocean in a Changing Climate

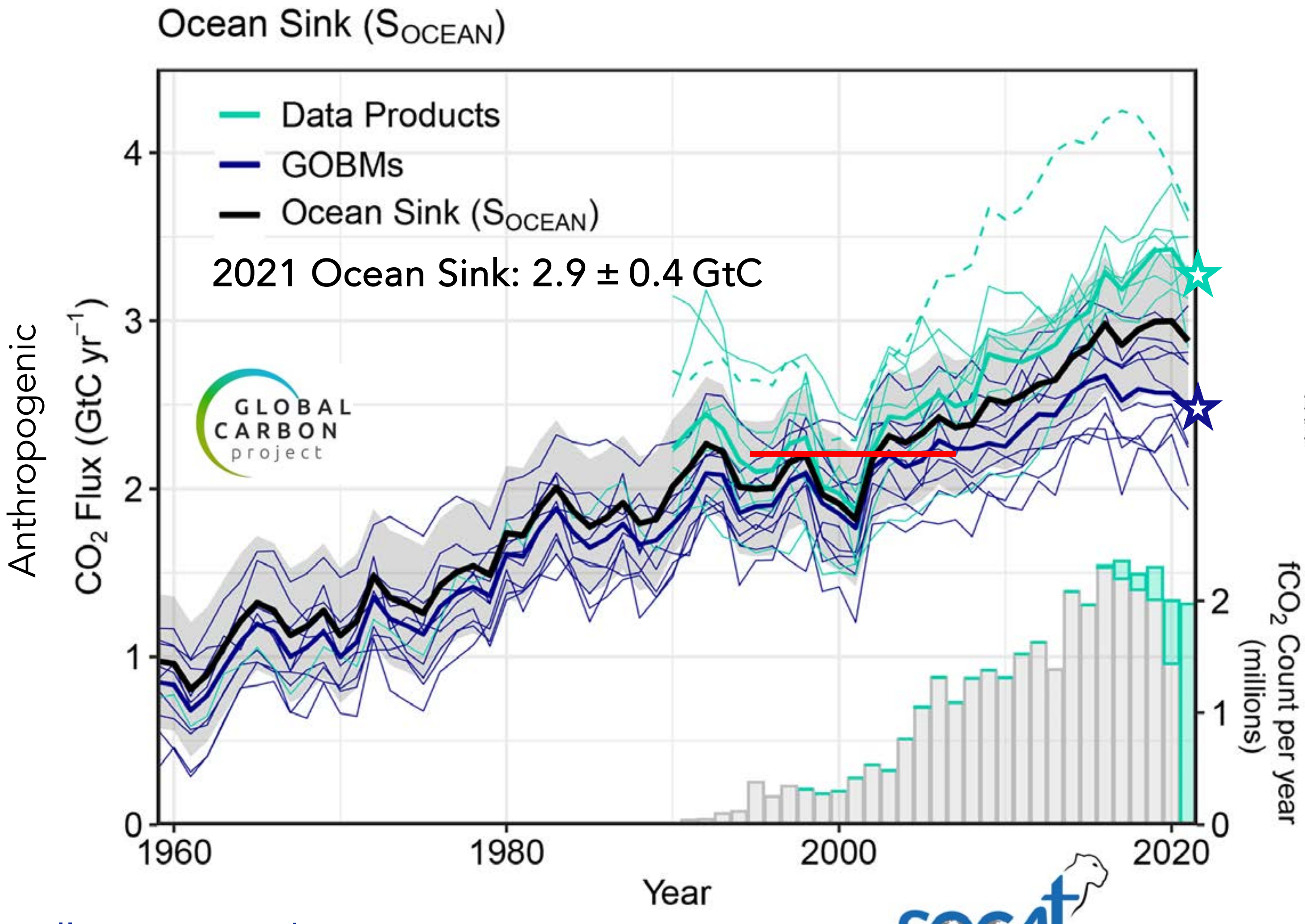
Global Carbon Budget Modification

Marine Carbon Dioxide Removal (mCDR)

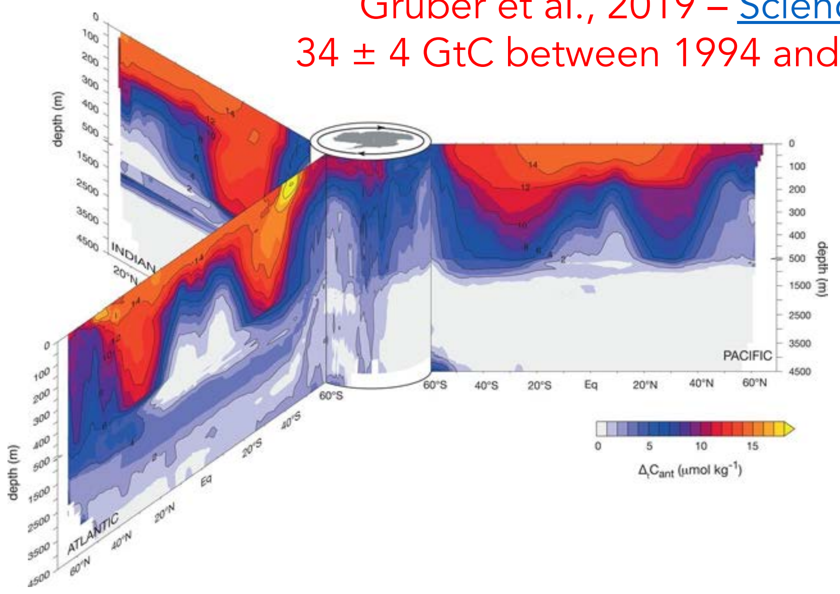




Global Carbon Budget



Friedlingstein et al., 2022 - ESSD



Gruber et al., 2019 – Science

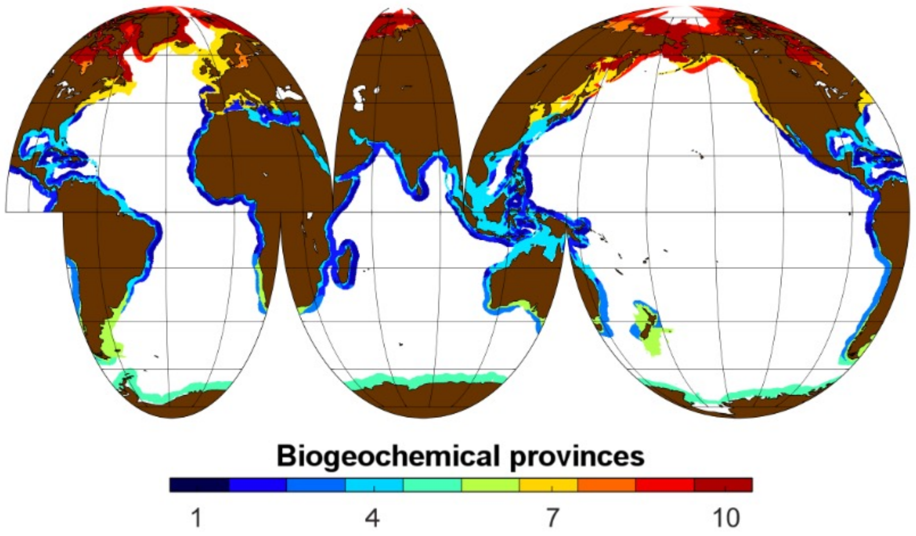
34 ± 4 GtC between 1994 and 2007

Closing the Ocean Carbon Budget

1. **G**lobal **O**cean **B**iogeochemistry **M**odels
2. *p*CO_2 Data Products
3. Repeat Hydrography

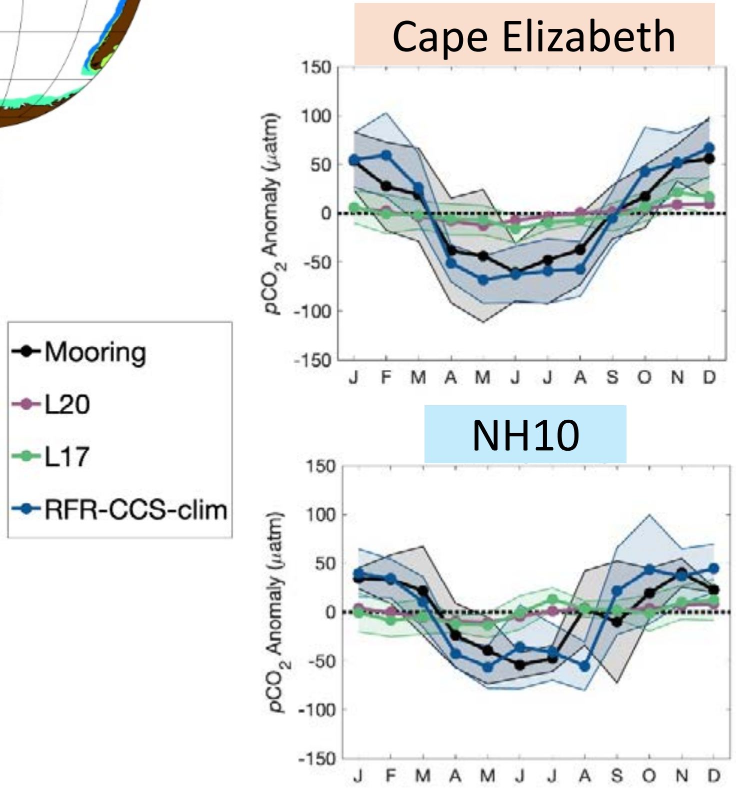
RECCAP2 ocean

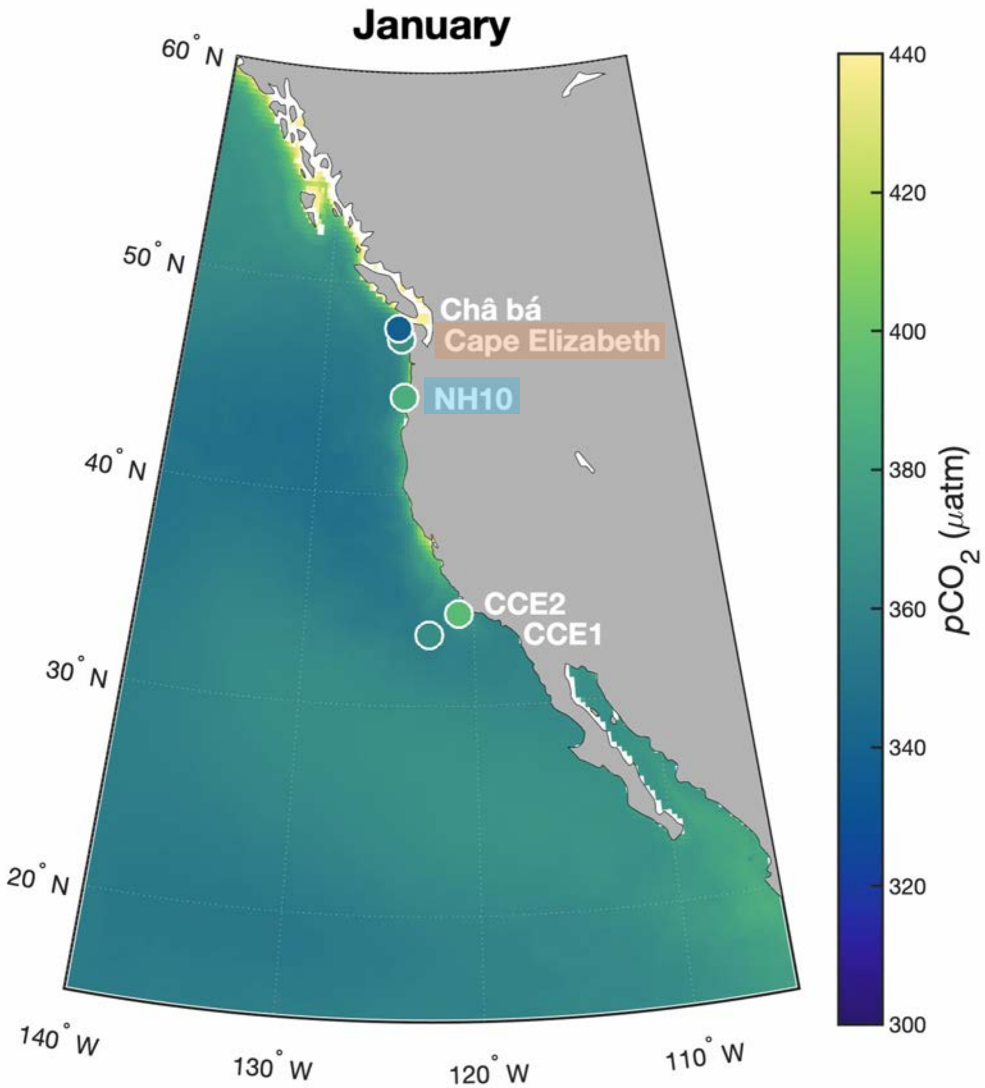
Coastal pCO_2-Based Data Products



Laruelle et al., 2017 - [ESSD]

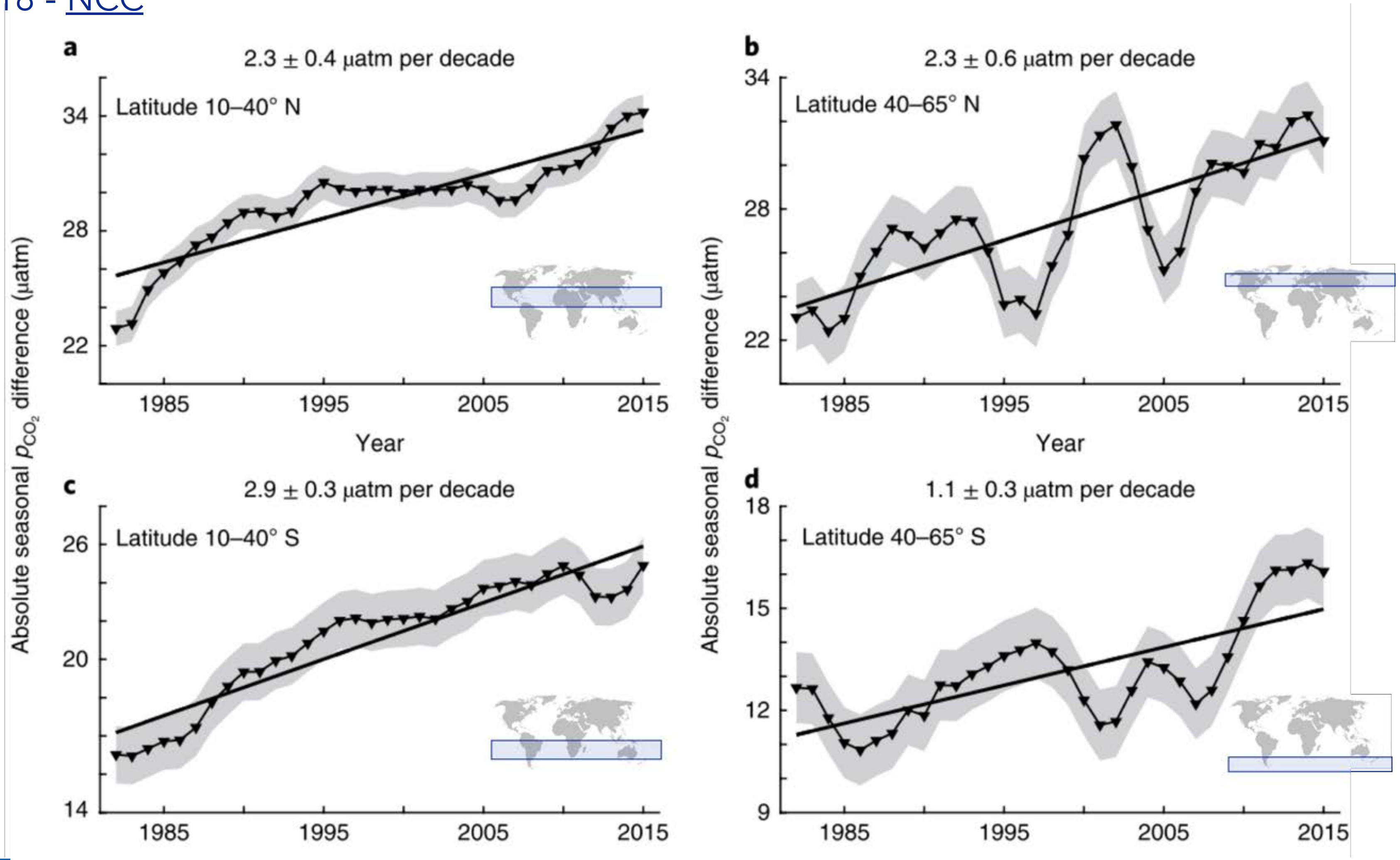
[Jonathan Sharp] et al., 2022 - [ESSD]





Changing Carbon Cycle Variability: Diel[1], Seasonal, Interannual[2]

Landschützer et al., 2018 - NCC



[1] Torres et al., 2021 - GRL

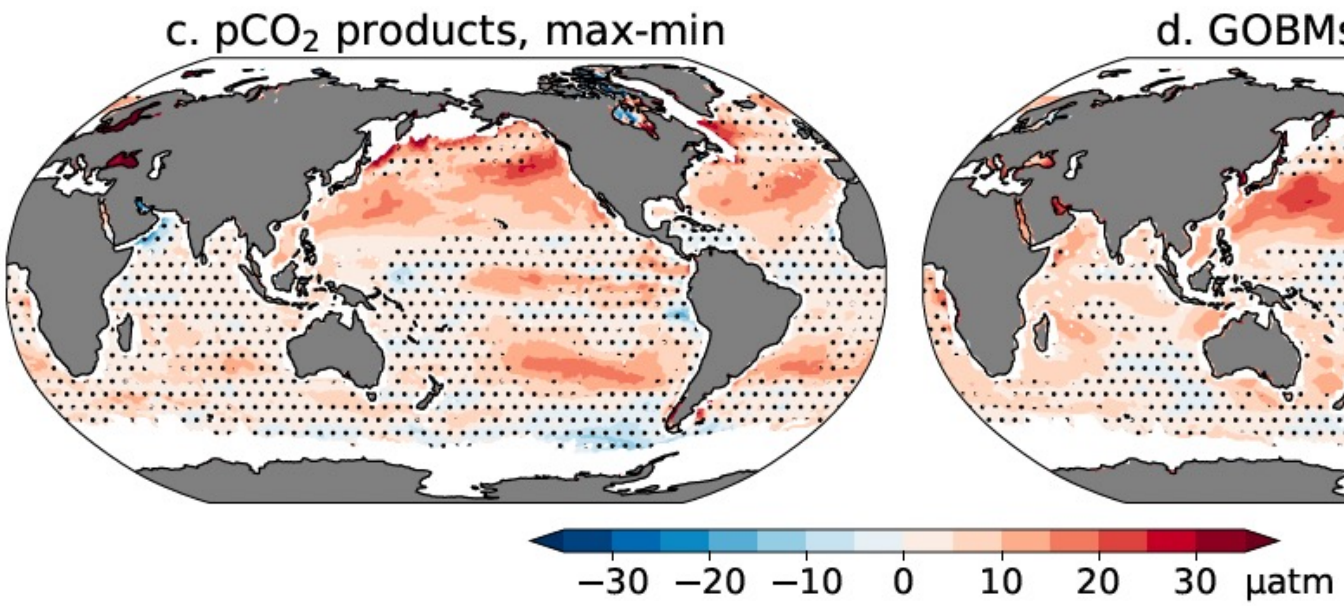
[2] Gallego et al. 2022 - GRL

Changing Carbon Cycle Variability: Consistent Seasonal Signal

RECCAP2 ocean

1985-1989 to 2014-2018 surface pCO_2 seasonal amplitude change

9 pCO_2 products and **11** GOBMs included



Rodgers et al., under review at GBC (RECCAP2 Synthesis)

Stippling: StDev of ensemble members > ensemble mean change

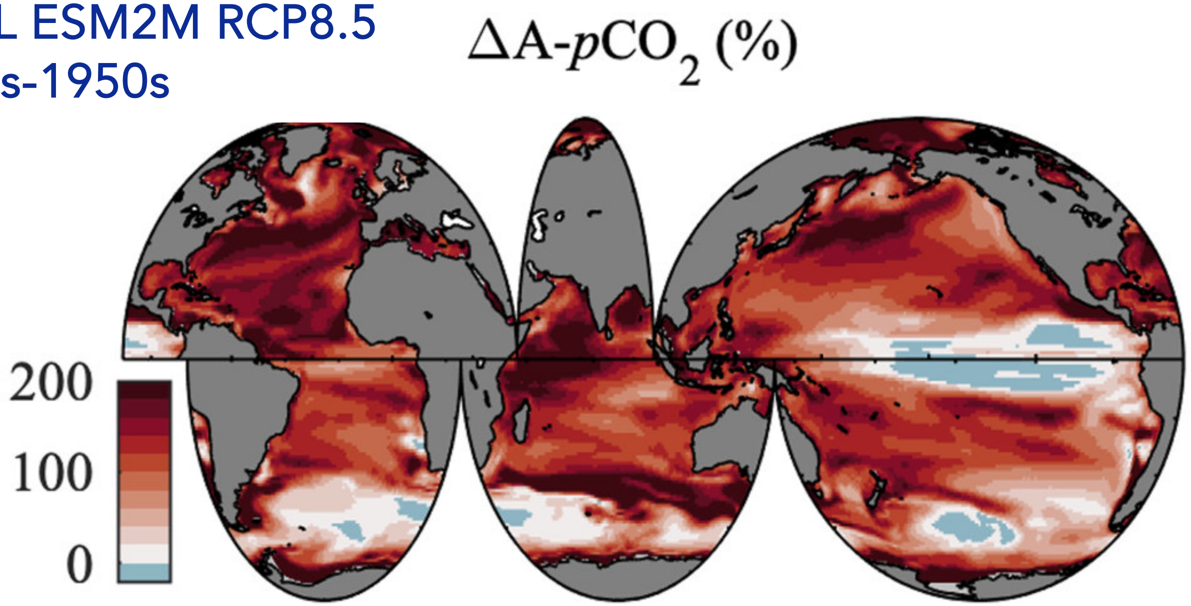
Attributing (1) observed and (2) projected seasonal changes to C_{ant} invasion:

(1) Rodgers et al., under review at GBC

(2) Joos et al., 2023 – GRL

Projected Surface pCO_2 Seasonal Amplitude Changes (ΔA)

GFDL ESM2M RCP8.5
2090s-1950s

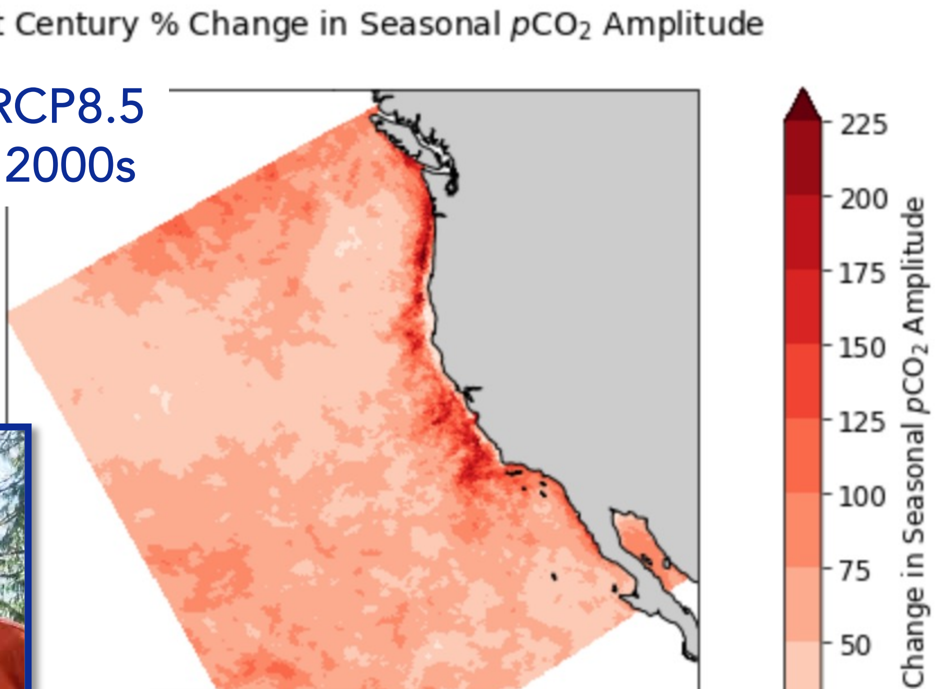


Fassbender et al., 2022 – GBC

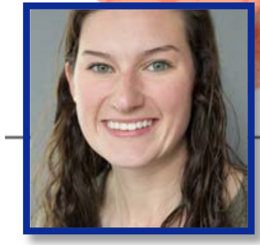
See also:
- Gallego et al., 2018 – Biogeosci.
- Goris et al., 2018 - JC

ESM2M: Dunne et al,. 2013

ROMS RCP8.5
2100s - 2000s



Hartmut Frenzel, CICOES/PMEL Research Scientist



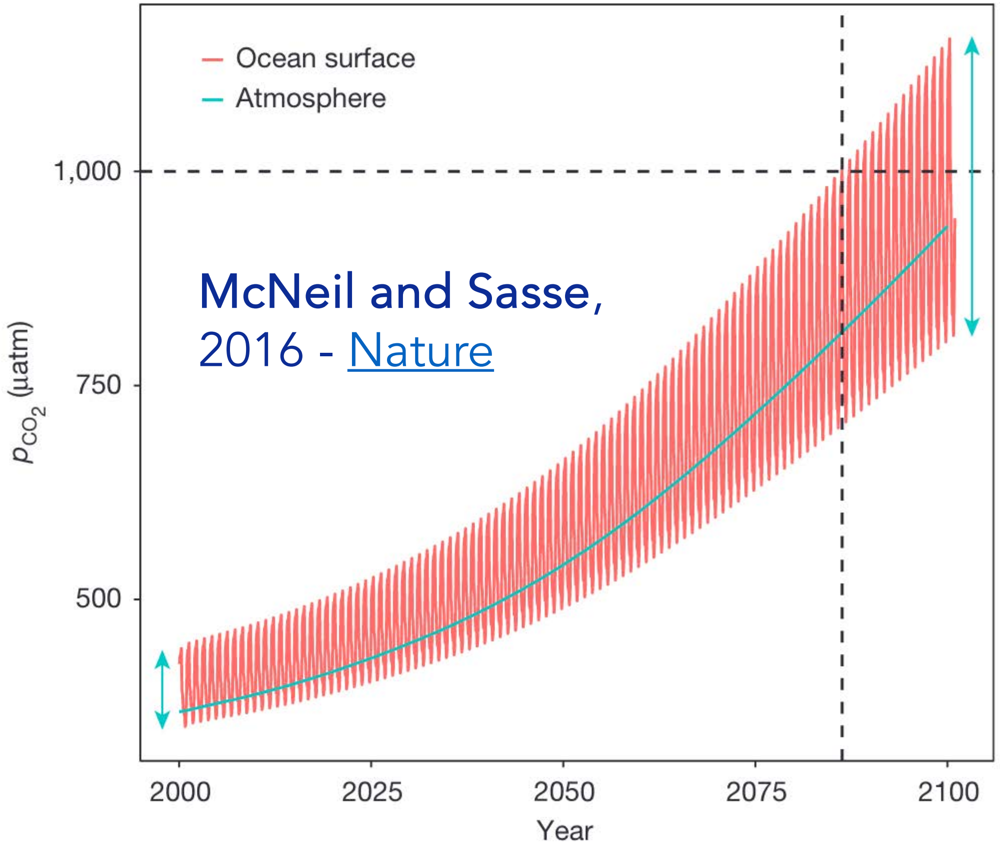
Mary Margaret Stoll, UW Grad Student

ROMS: Howard et al., 2020

Implications of Changing Upper Ocean Carbon Cycle Variability

Changes in seasonal *p*CO_2 values could alter seasonal CO_2 fluxes and impact the net ocean carbon sink

Larger *p*CO_2 variability could make it difficult to identify small mCDR-induced CO_2 flux changes, particularly in dynamic coastal regions



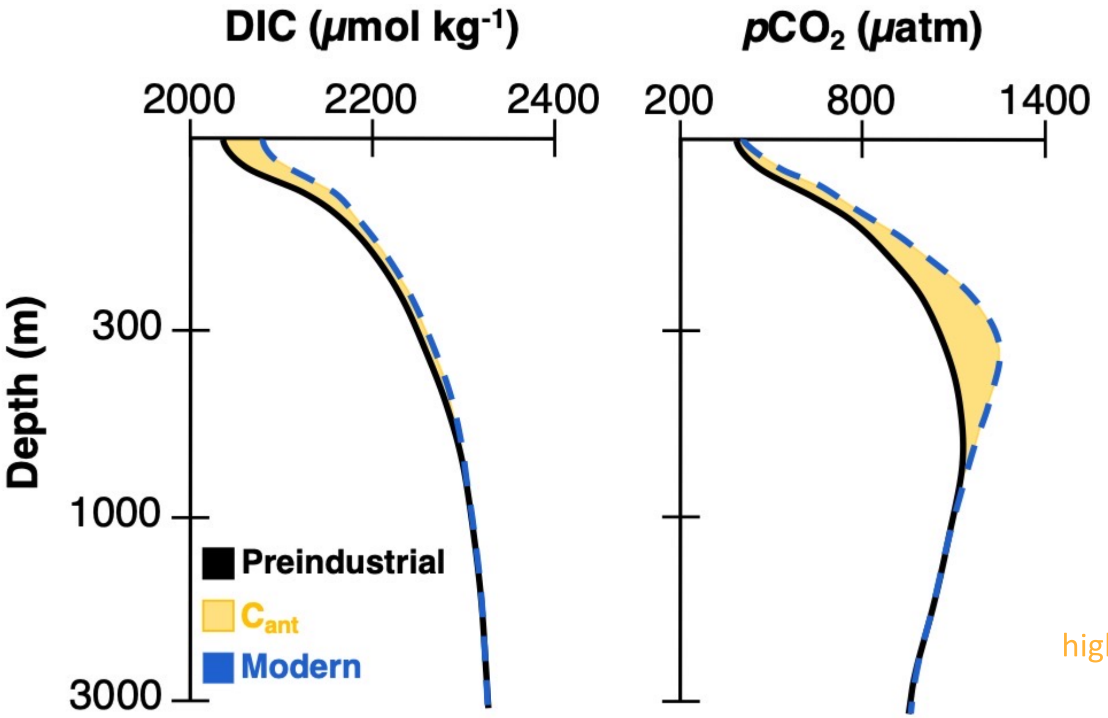
McNeil and Sasse,
2016 - Nature

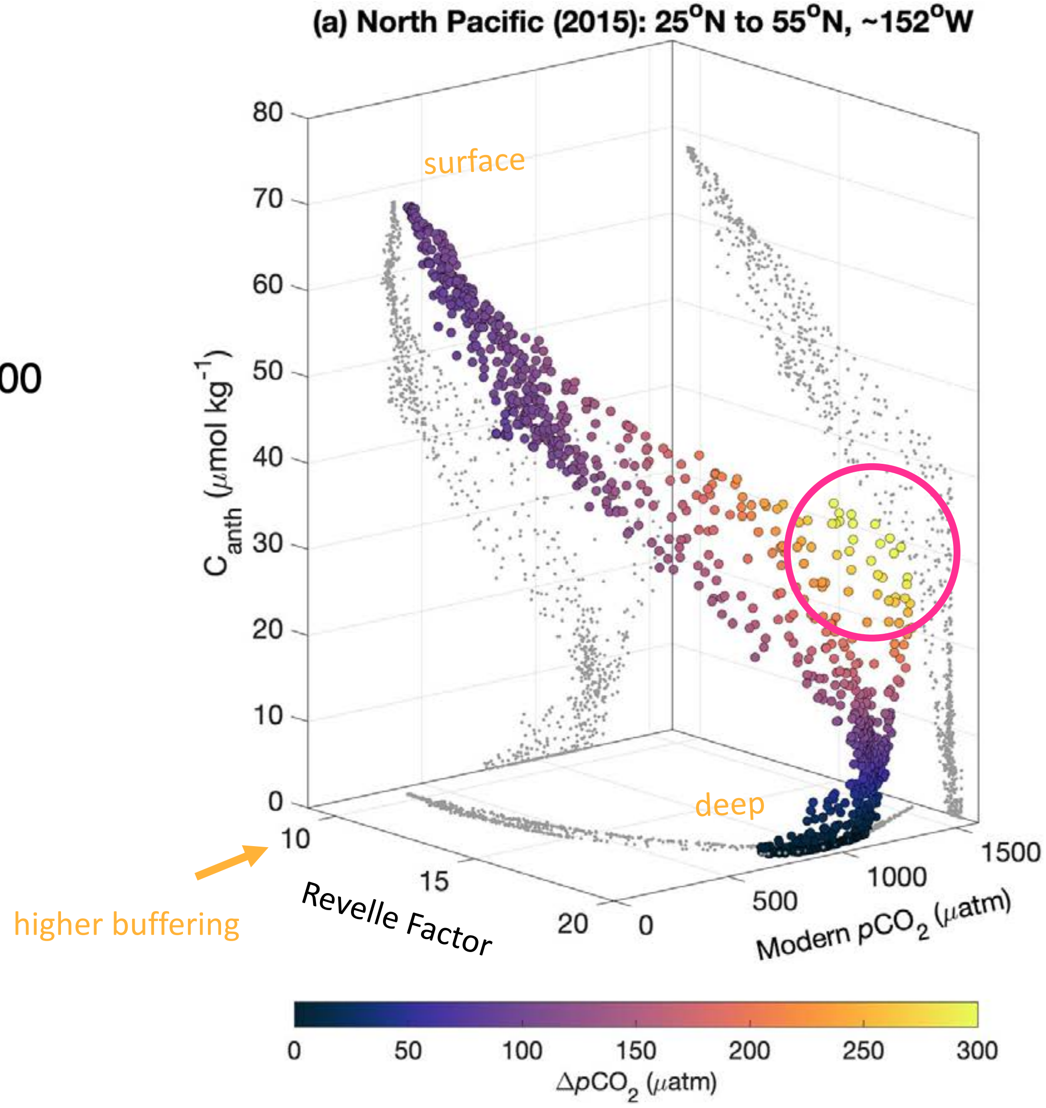
See also:

- **Fassbender** et al., 2022 - GBC
- **Gregor** et al., under review

Carbon Pool Interactions: Subsurface Amplification

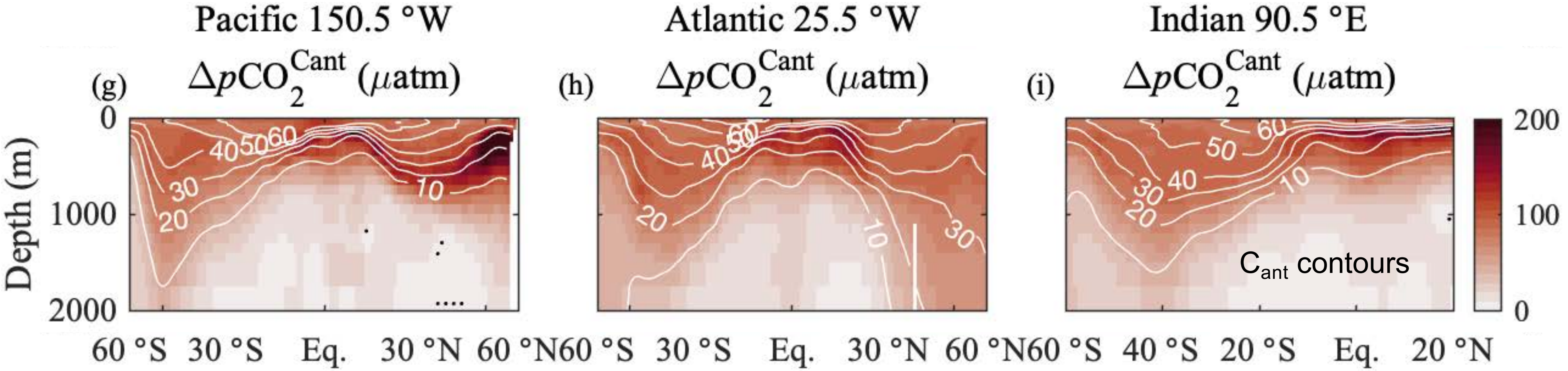
Mar Arroyo, UCSC
Grad Student





Arroyo et al., 2022 - GRL

Carbon Pool Interactions: Globally Coherent Subsurface Signal

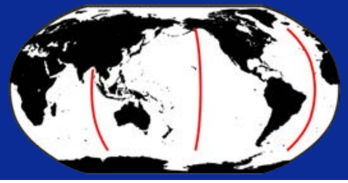


Fassbender et al., under review at GBC

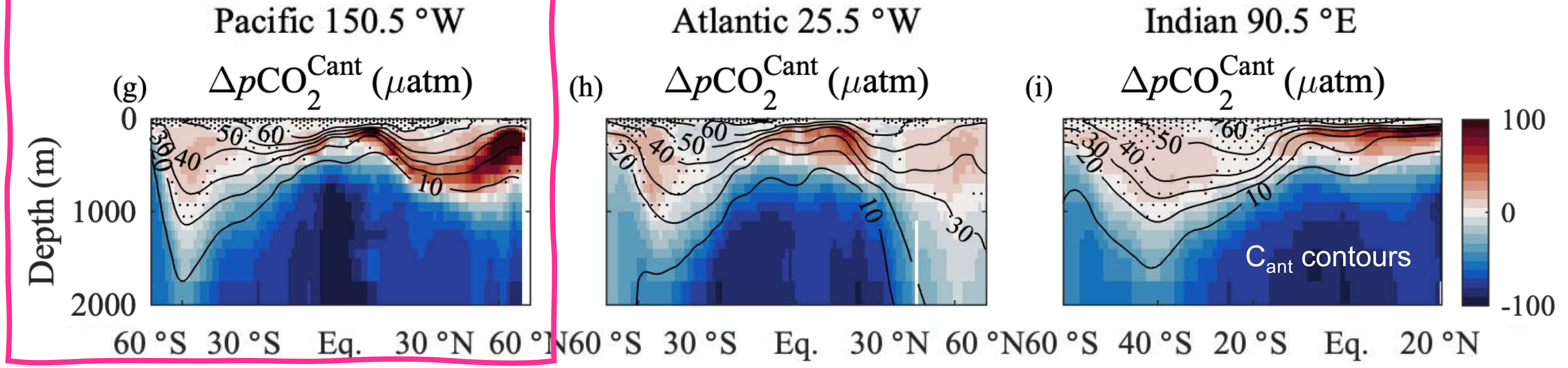
Global Ocean Data Analysis Project (GLODAP)
Gridded Product (**Lauvset** et al., 2016 – ESSD):

$\Delta pCO_2 = pCO_{2\ 2002} - pCO_{2\ \text{Preindustrial}}$

Carbon Pool Interactions: Signal Driven by Nonlinearities



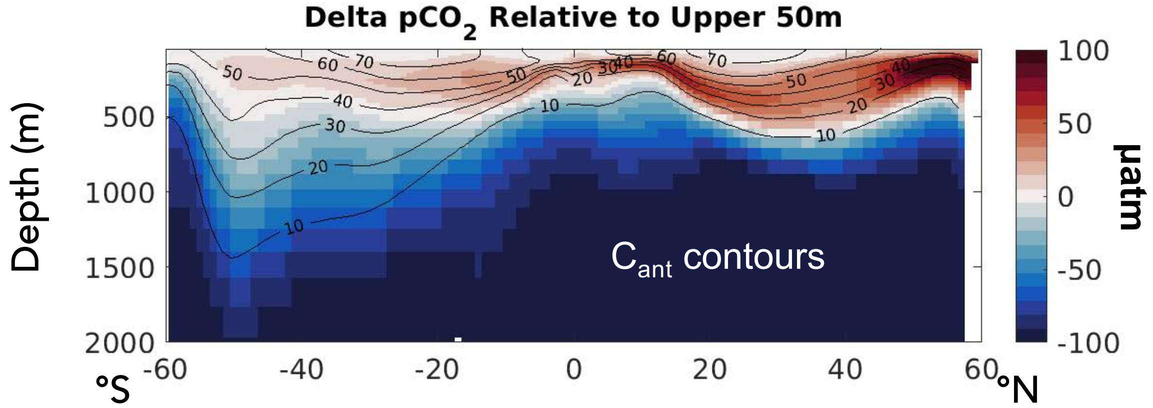
2002



changes relative to the local upper 50m

Fassbender et al., under review at GBC

GOBM: CESM ETHZ
150.5 °W (2014-2018)



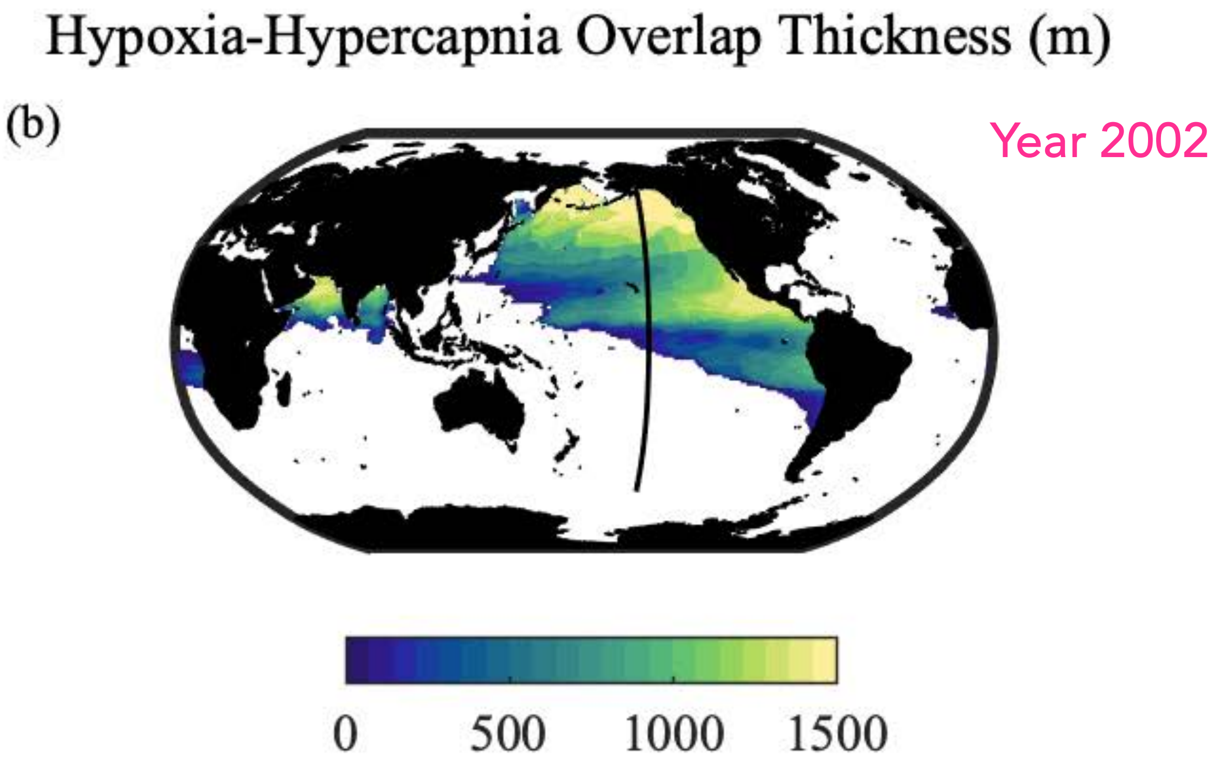
The **largest** ***p*****CO_2 changes caused by ΣCant** are occurring well **below the surface** and are **outpacing the atmospheric *p*CO_2 change** (~92 µatm in the year 2002)

Implications of Carbon Pool Interactions

Increasing the volume of water with multiple environmental stressors could cause habitat compression

Hypoxia: $O_2 \leq 60$ µmol kg^{-1}

Hypercapnia: $fCO_2 \geq 1000$ µatm

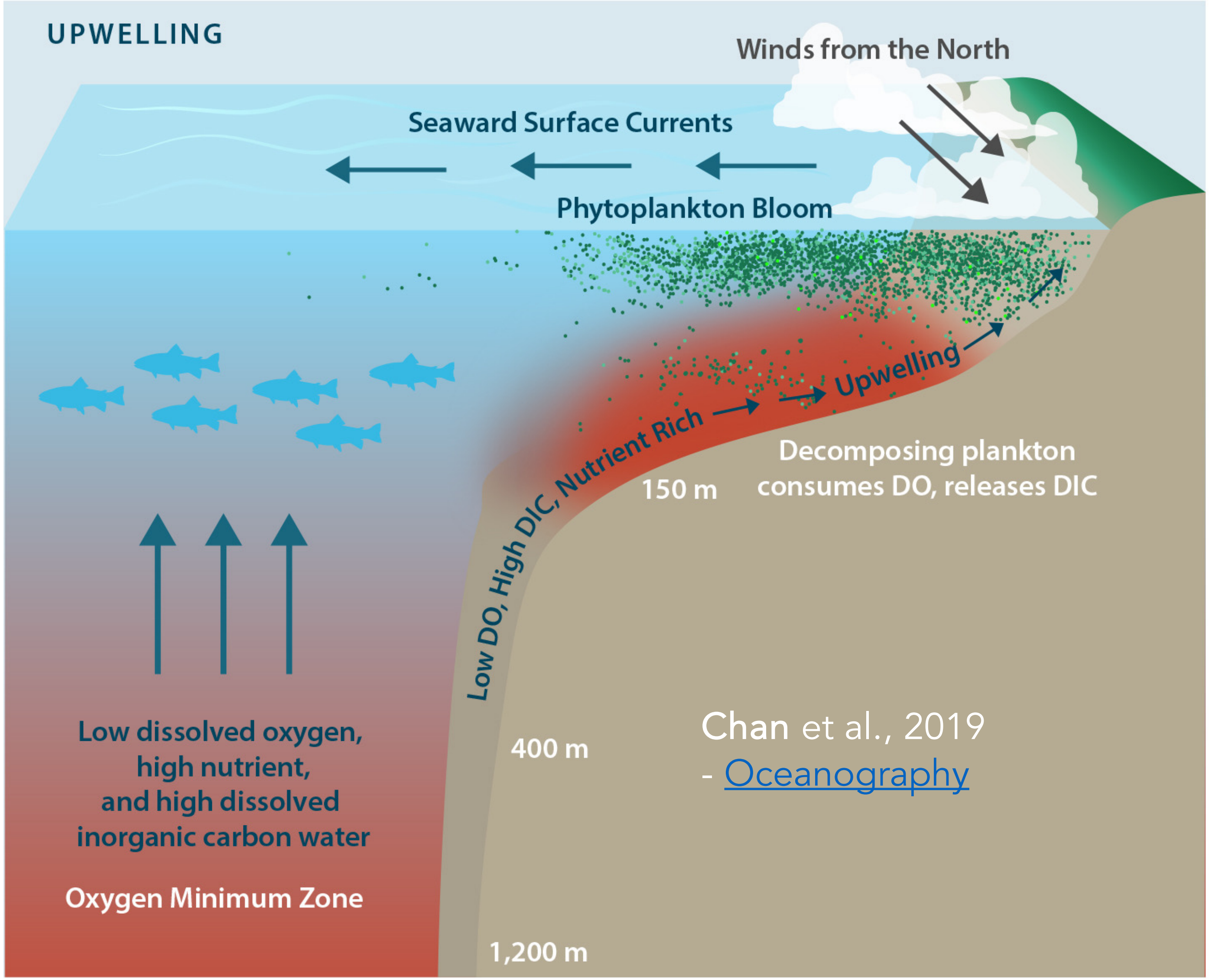


Fassbender et al., under review at GBC

Implications of Carbon Pool Interactions

Increasing the volume of water with multiple environmental stressors could cause habitat compression

Potential flaw in the hypothesis that organisms in upwelling regions are more tolerant to OA due to natural variability



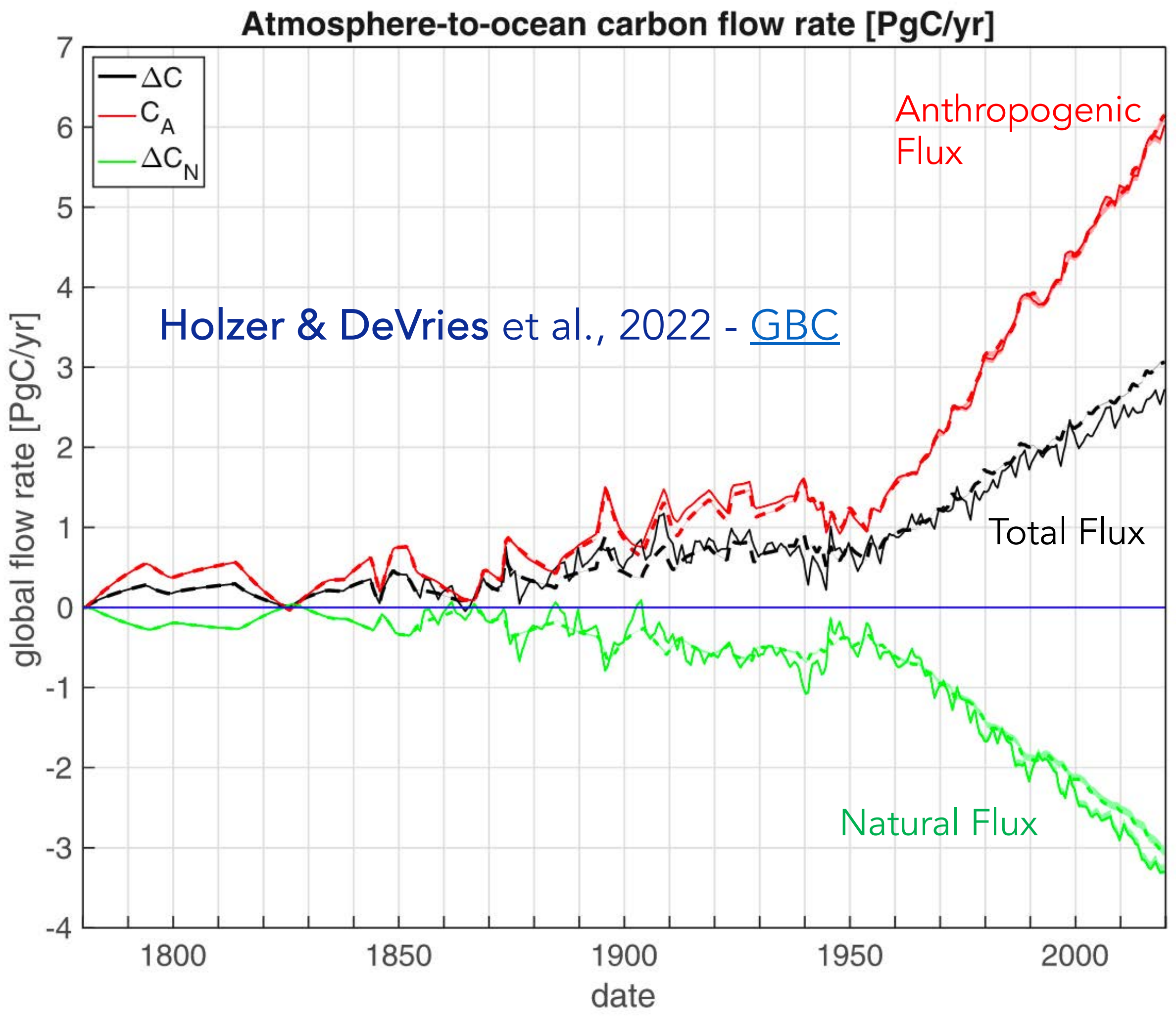
Chan et al., 2019 - Oceanography

Implications of Carbon Pool Interactions

Increasing the volume of water with multiple environmental stressors could cause habitat compression

Potential flaw in the hypothesis that organisms in upwelling regions are more tolerant to OA due to natural variability

Highly elevated $\Delta pCO_{2\ Sea\text{-}Air}$ values when waters re-emerge at the surface could impact ocean carbon storage efficiency



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Proposed Paths Forward:

Study these phenomena in models

Strategically expand the coastal carbon observing system

Grow the autonomous subsurface carbon observing system (floats)

Reduce seasonal biases in the surface carbon observing system (uncrewed systems + floats + gliders)

Prioritize the development of data assimilation models and process representation in models

Leverage our understanding to maximize efficiency and minimize impacts of viable mCDR strategies

Take advantage of high pCO_2 signal-to-noise ratios to track subsurface ecosystem changes

Test/develop ecosystem models with additional metrics of stress (pCO_2)