COLUMBIA CLIMATE SCHOOL
LAMONT-DOHERTY EARTH OBSERVATORY

LEAP

Immediate and Long-Lasting Impacts of the Mt. Pinatubo Eruption on Ocean Oxygen and Carbon

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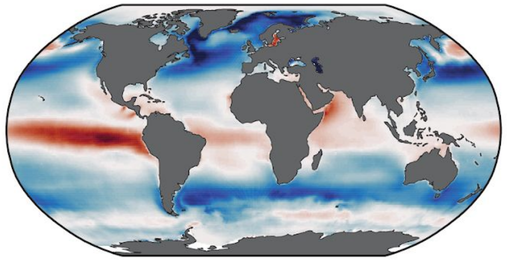
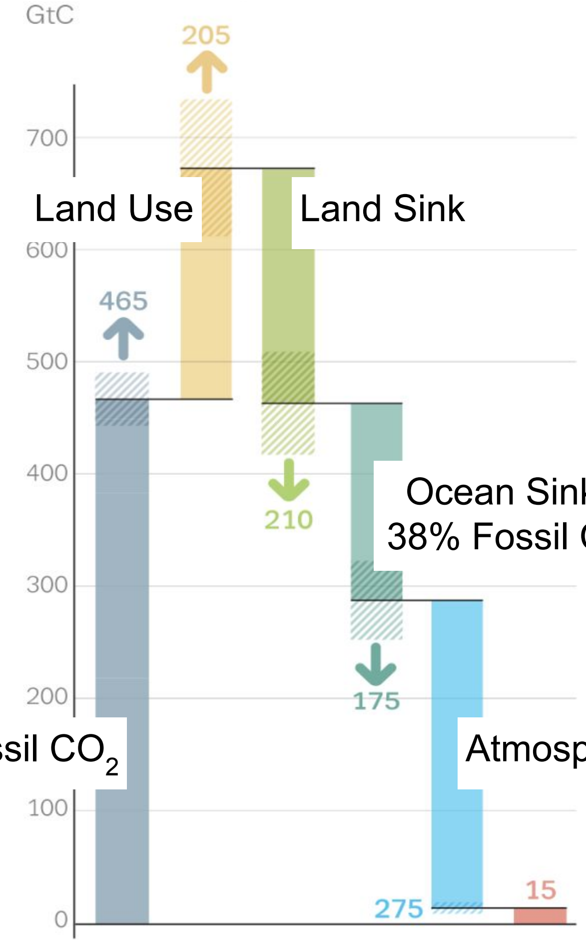
CESM Workshop, June 13, 2023

How do we quantify the the ocean carbon sink?

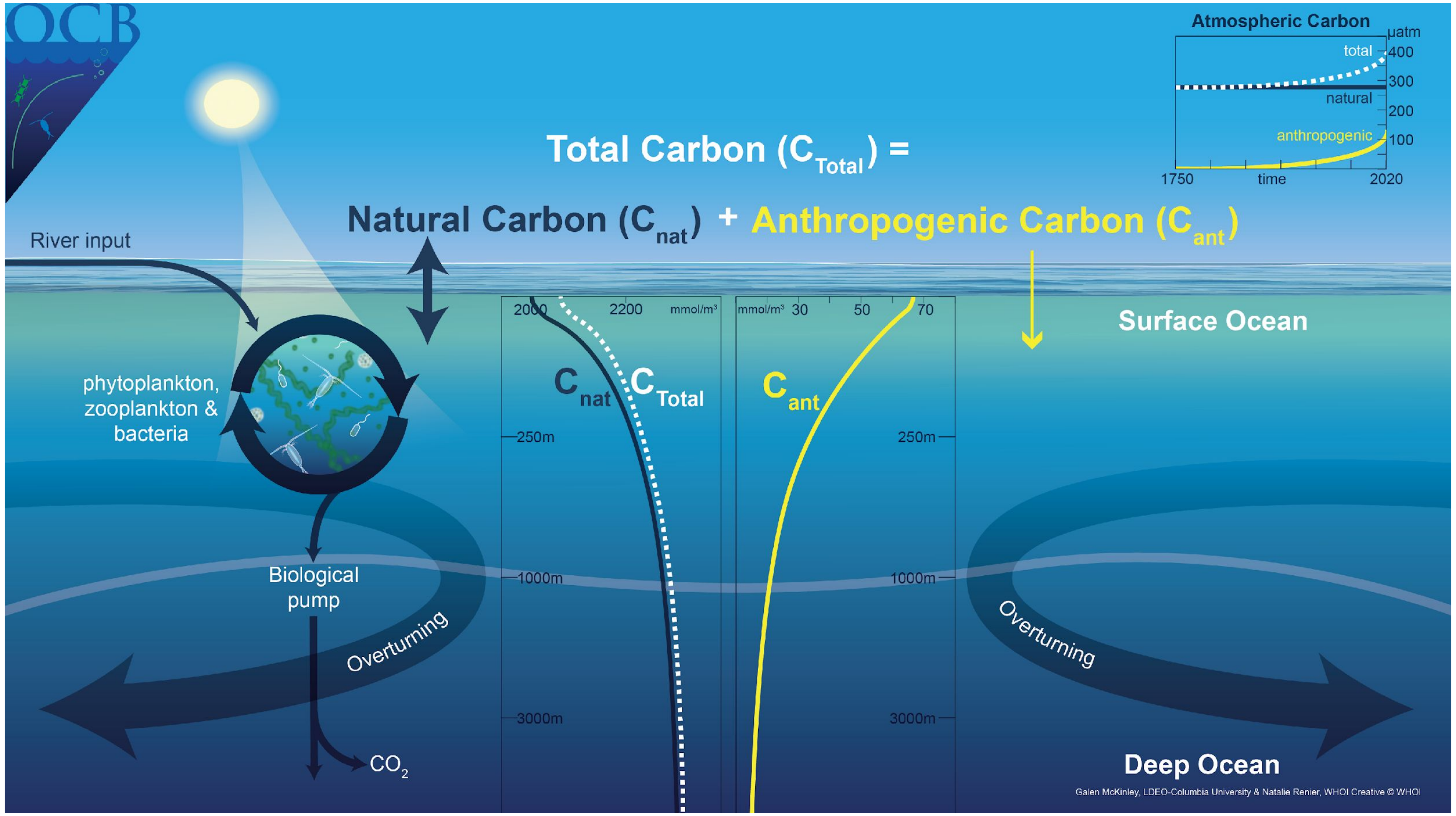


Cumulative Emissions and Sinks 1850-2021



Friedlingstein et al. 2022, ESSD

Anthropogenic sink, on top of a vigorous natural cycle

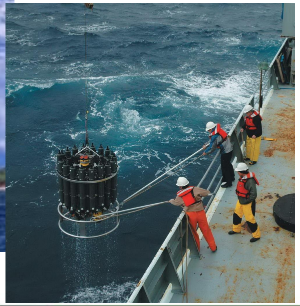


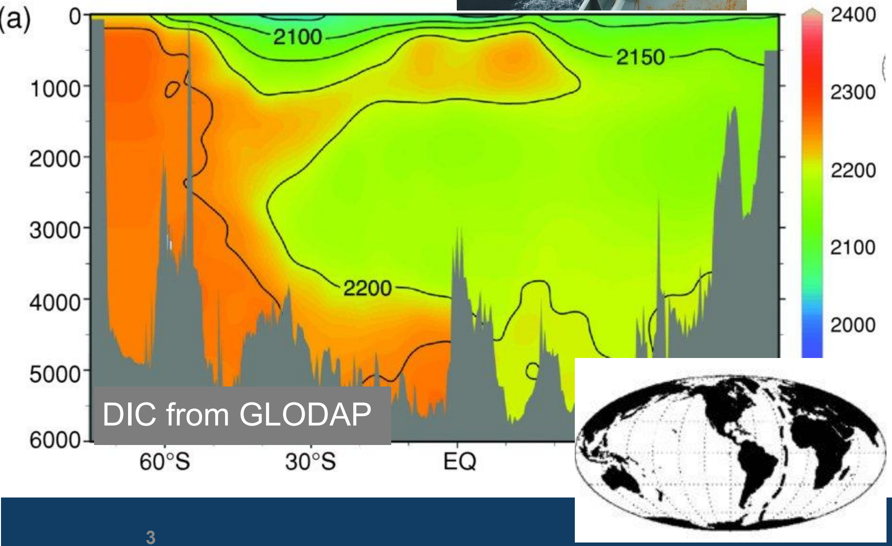
Crisp et al., 2023

Three independent approaches constrain the ocean carbon sink

1. Interior observations / products

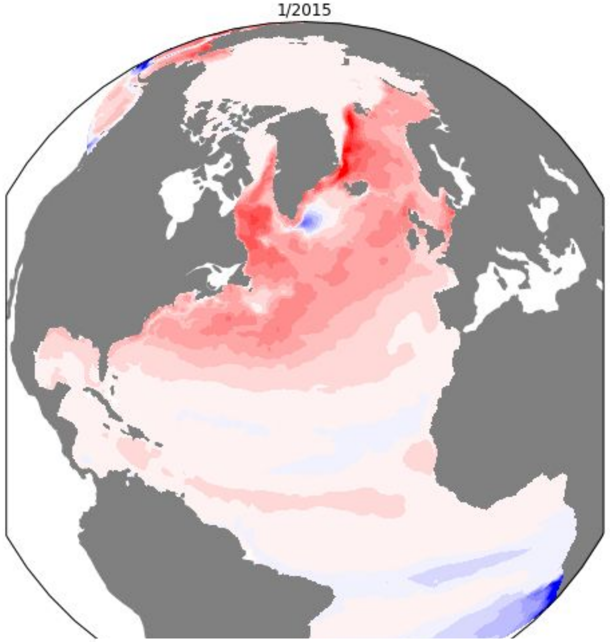
Interior carbon storage
Decadal closure of global budget
Model validation





2. Modeling

Air-sea fluxes
Mechanisms
Projections

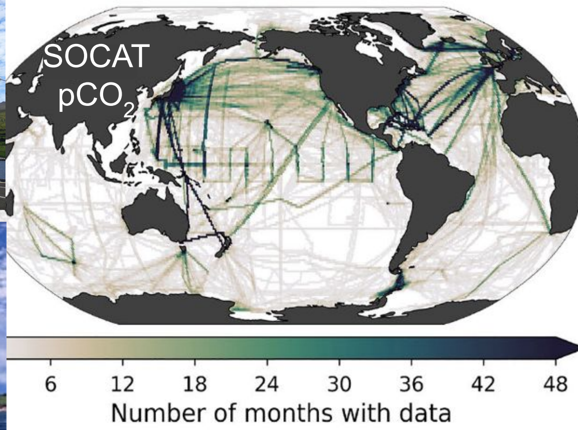


ASTE-BGC
air-sea CO_2 flux

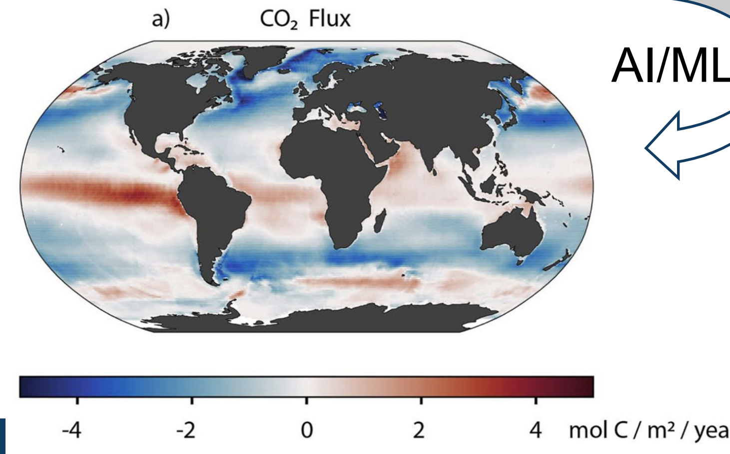
Moseley et al, in prep

3. Surface observations / products

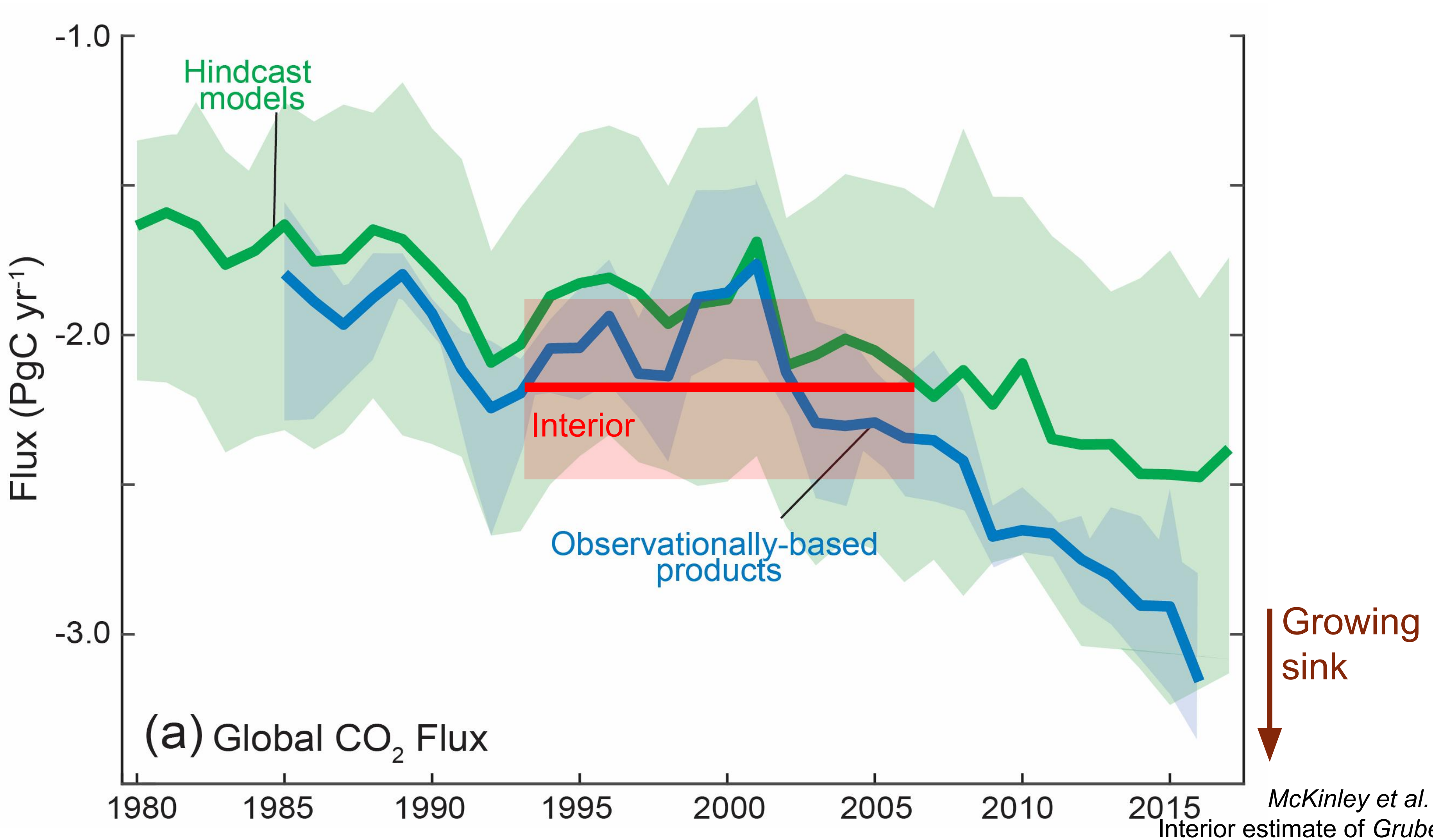
Air-sea fluxes (~monthly)
Model validation



AI/ML



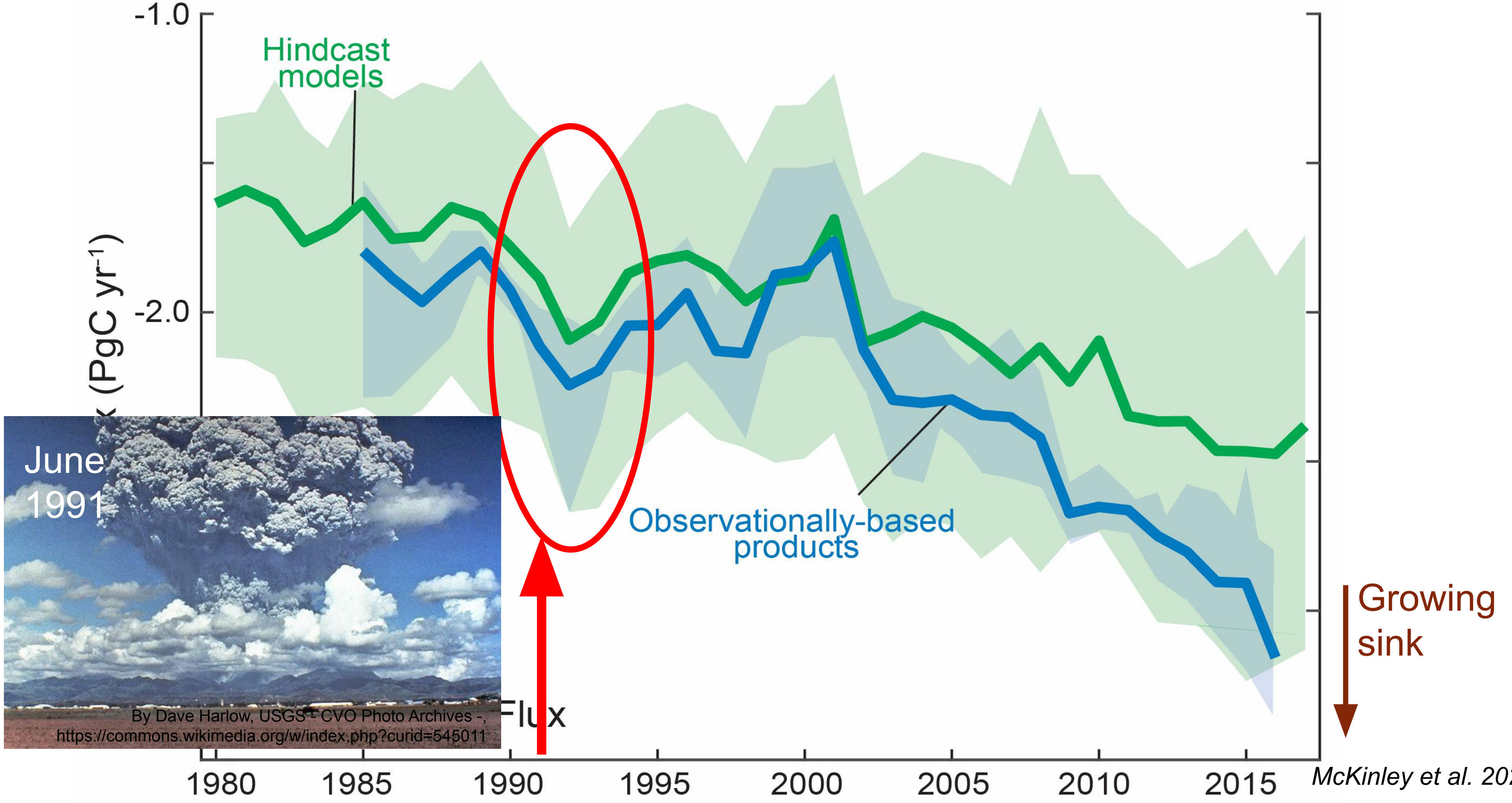
Approaches agree to first order, but uncertainties remain large



McKinley et al. 2020, AGU Advances
Interior estimate of *Gruber et al. 2019*, Science

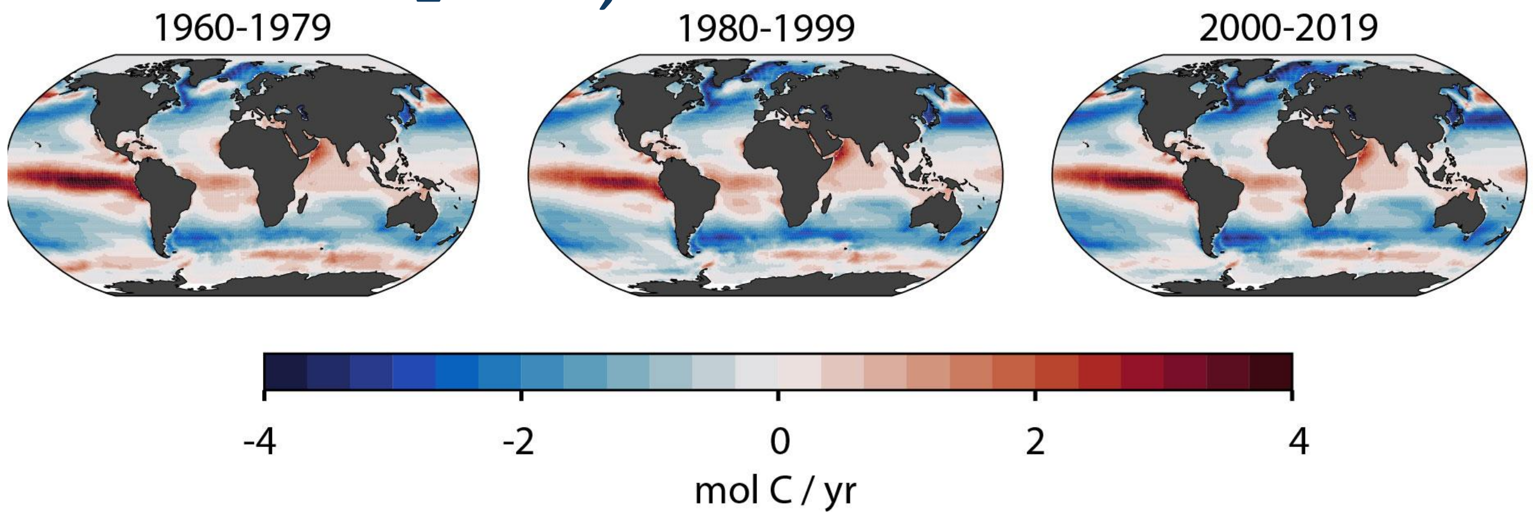
Columbia Climate School
Lamont-Doherty Earth Observatory

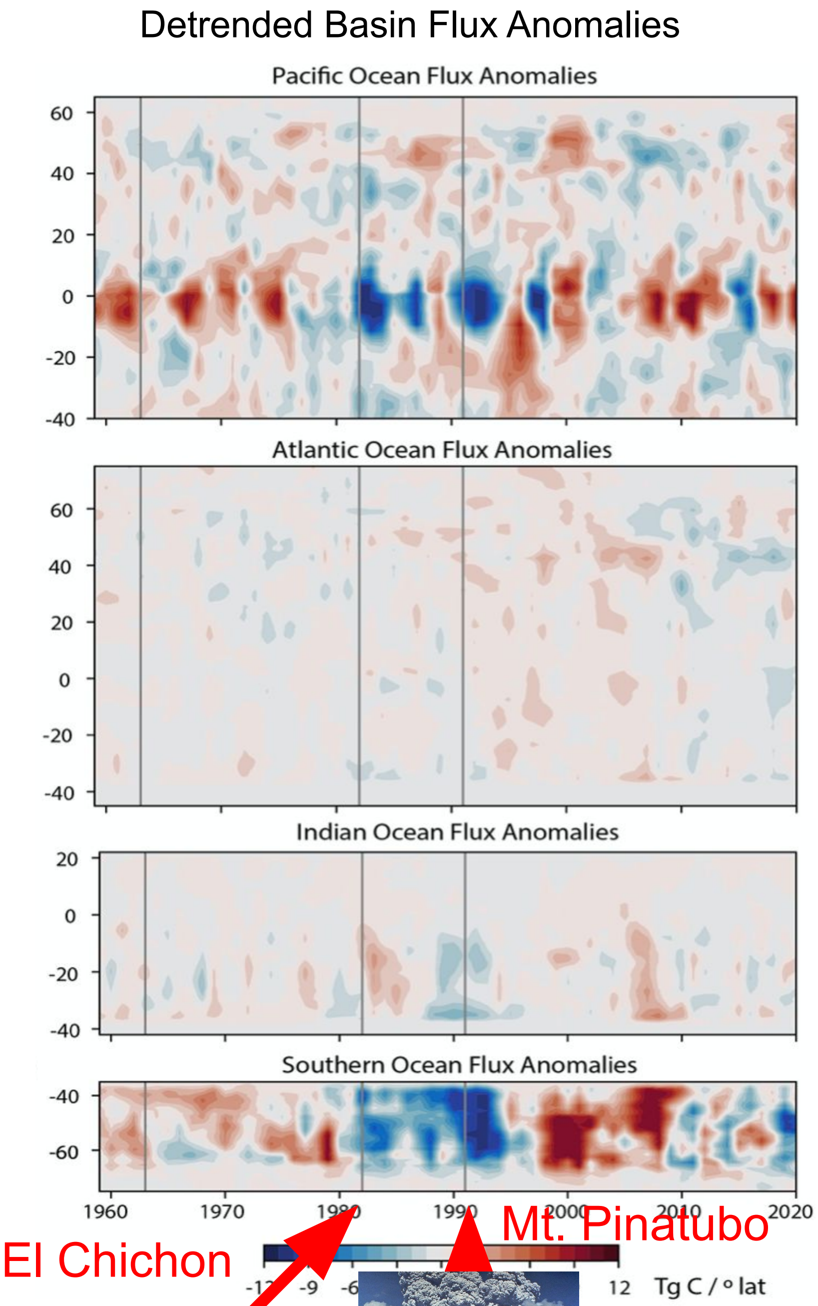
To what degree was the abrupt increase in the ocean carbon sink in the early 1990s due to the eruption of Mt. Pinatubo?



McKinley et al. 2020, AGU Advances

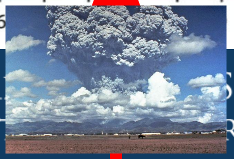
An observation-based product (LDEO-HPD) Air-sea CO_2 flux, 1959-2021





- 60 years of monthly 1x1 air-sea CO_2 fluxes from pCO_2 data / machine learning approach using hindcast models as prior
- Reveals significant decadal variations; coherent between equatorial Pacific and Southern Ocean

Bennington et al. 2022 GRL; *Wong et al*. in prep



Test the <u>externally forced</u> impact of Mt. Pinatubo on ocean carbon with CESM-Large Ensemble

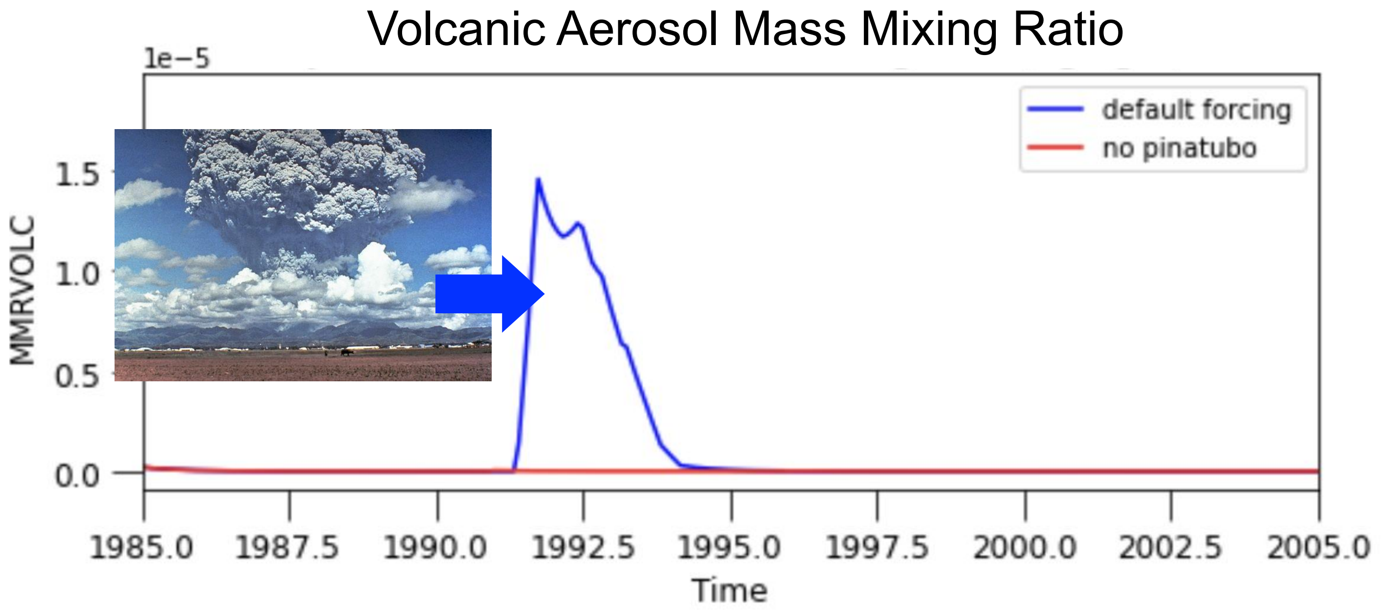
Experiment Design

CESM-LE

- CESM1-Large Ensemble (Kay et al. 2015)
- Historical / RCP8.5 Simulations
- CAM5 atmosphere and POP2 ocean

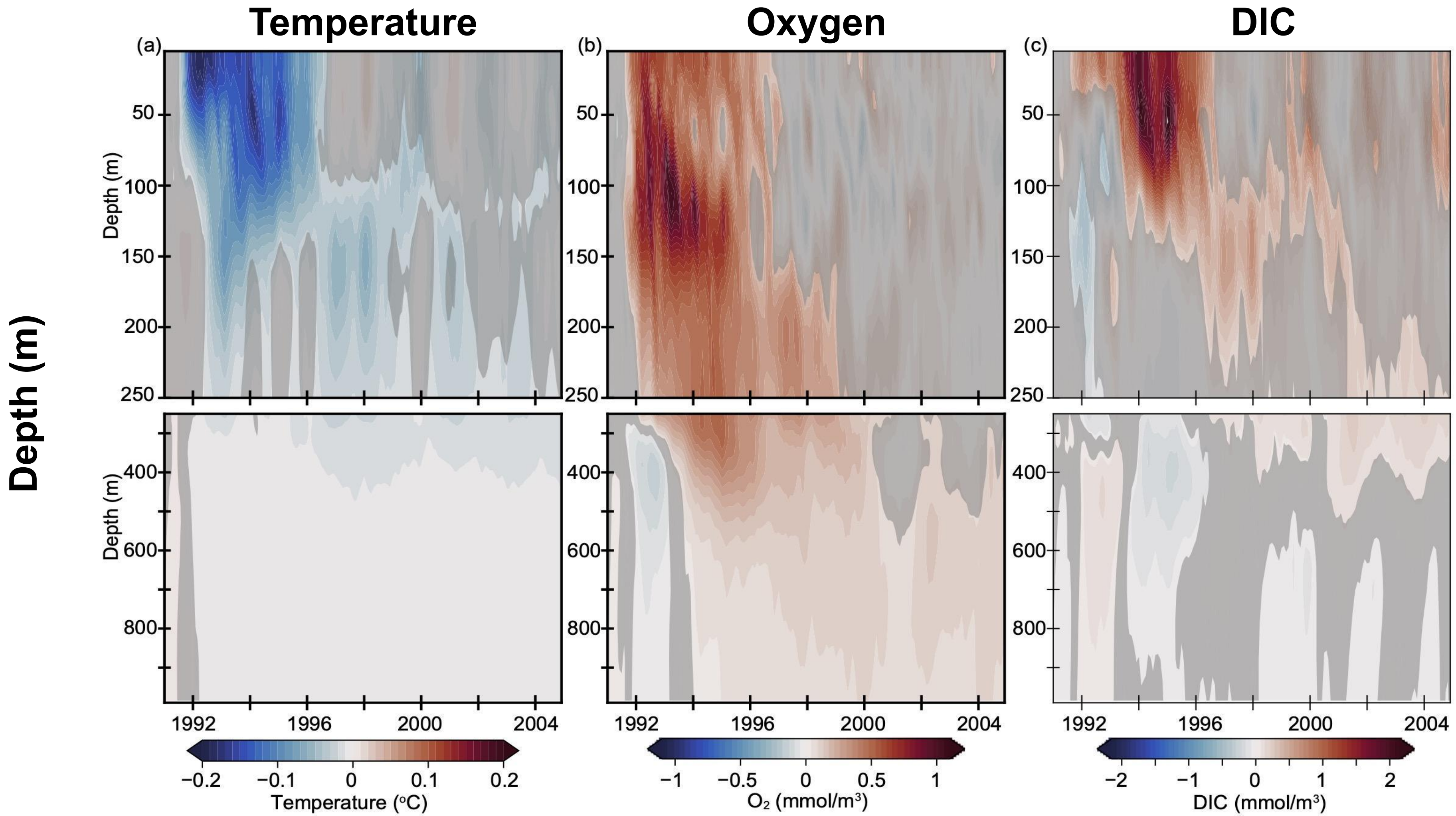
CESM1-LE, No Pinatubo

- CESM-LE, 29 ensembles
- 1991-1995 volcanic aerosol mass mixing ratio replaced with non-eruption (1986-1990 values)



Fay et al. 2023, GBC

CESM-LE minus CESM-NoPinatubo, global mean profiles



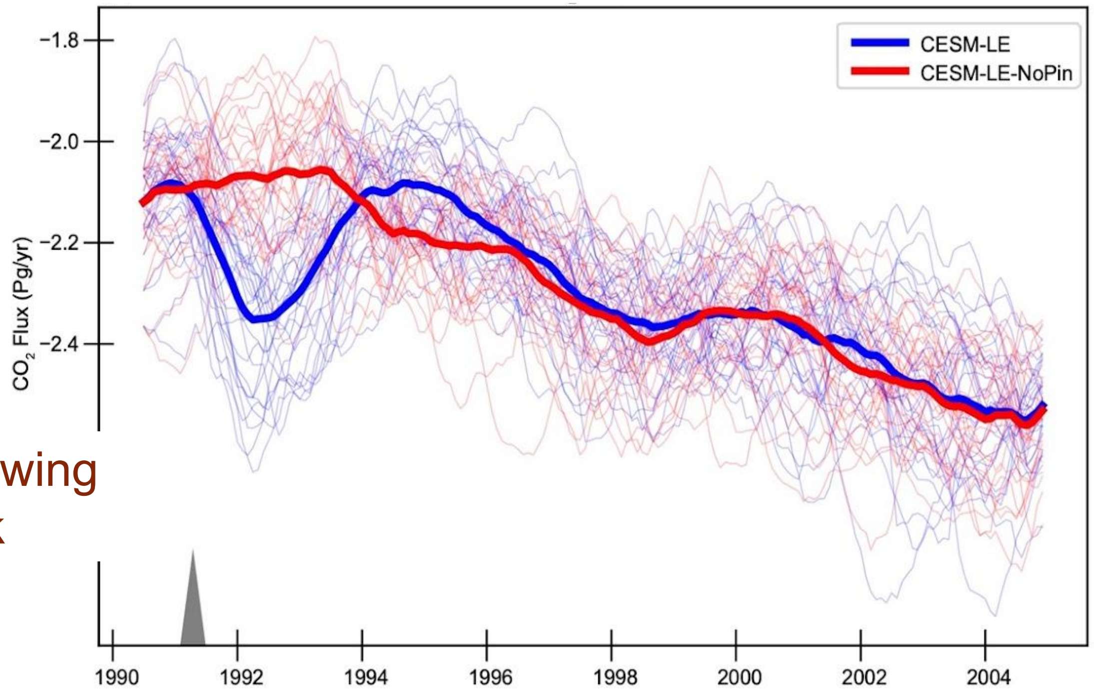
Unstippled = 95% significant given ensemble spread

Negative temperature anomalies indicate a **cooling** due to the eruption of Pinatubo

Positive oxygen and carbon anomalies indicate **greater** due to the eruption

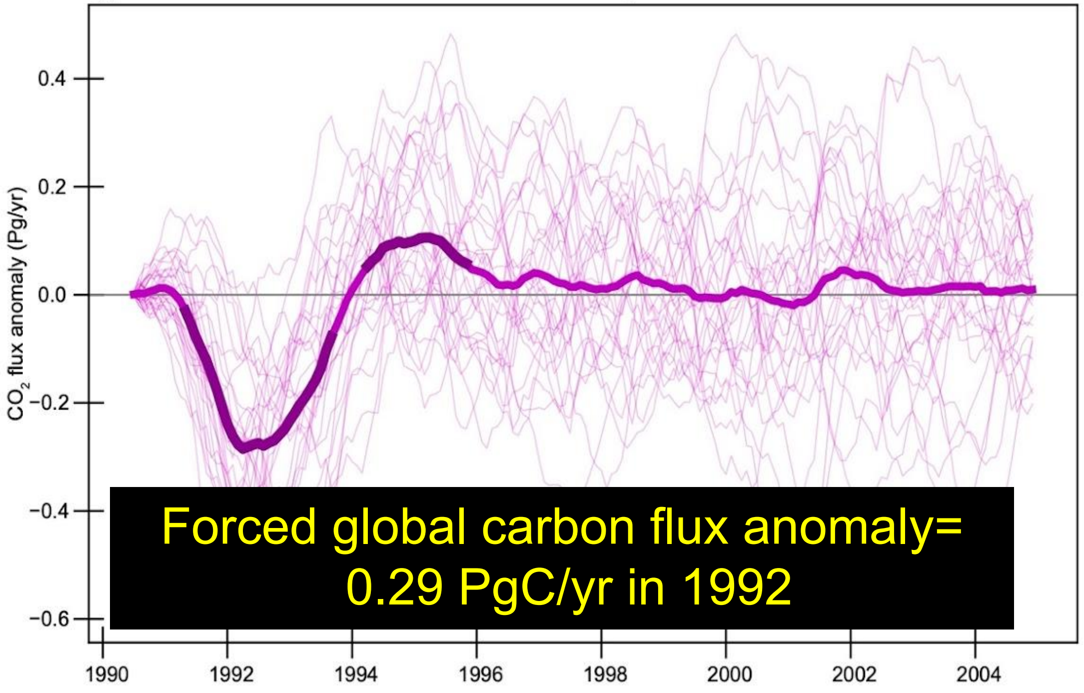
Globally integrated sea-air carbon Flux

Global CO_2 flux (**with Pinatubo**, **without**)



Growing sink

Difference (**with Pinatubo - without**)



Thin lines = 29 ensemble members, each scenario
Bold line = forced response (= ensemble mean)

Fay et al. 2023, GBC

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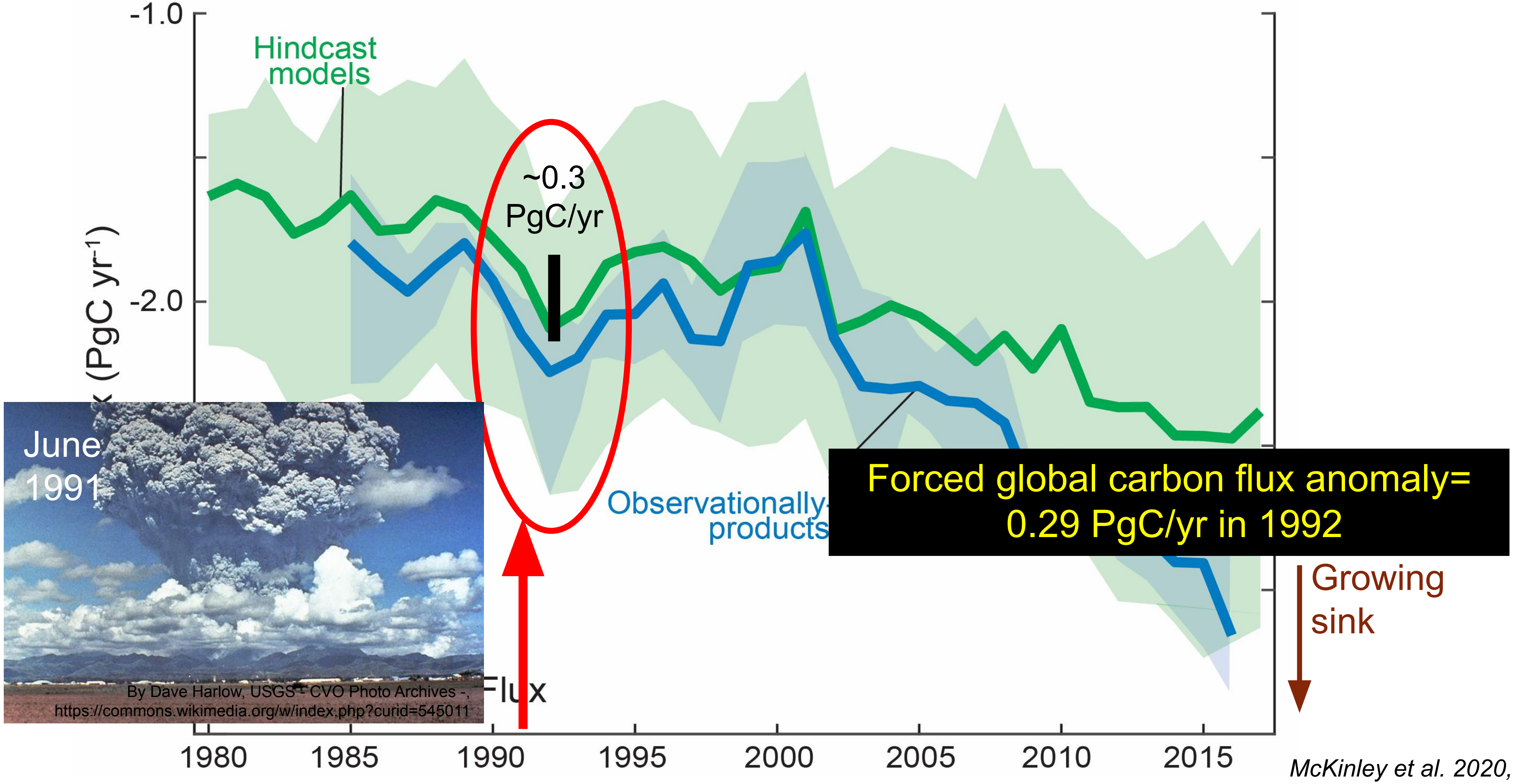


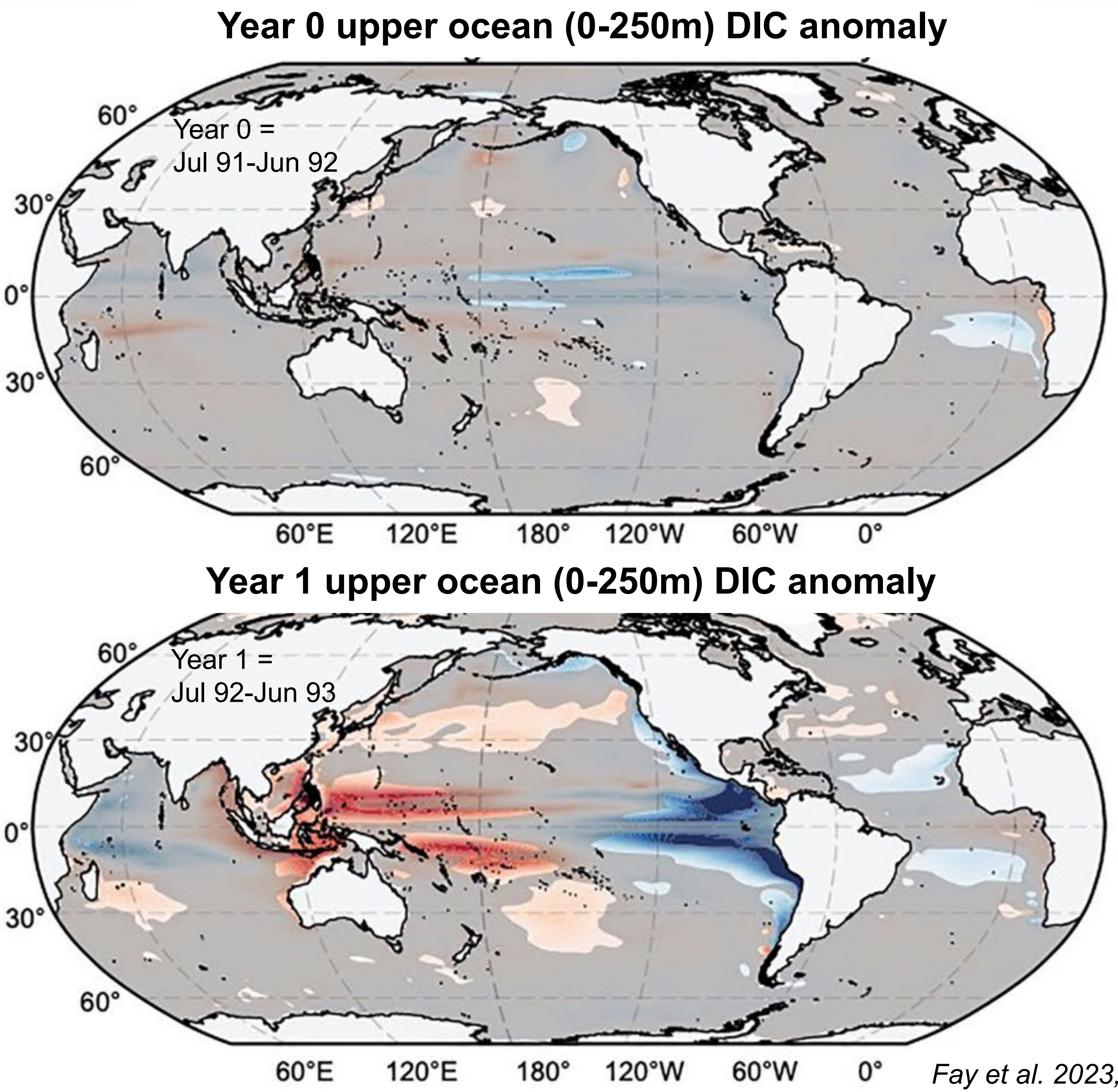
McKinley et al. 2020, AGU Advances

Where does this Mt. Pinatubo <u>forced</u> response occur?

No significant response in first year (Yr 0)

Forced El Niño (reduced outgas in E Eq Pac) and uptake anomalies in N Pacific in Yr 1-3

No significant forced response in Southern Ocean



Fay et al. 2023, GBC

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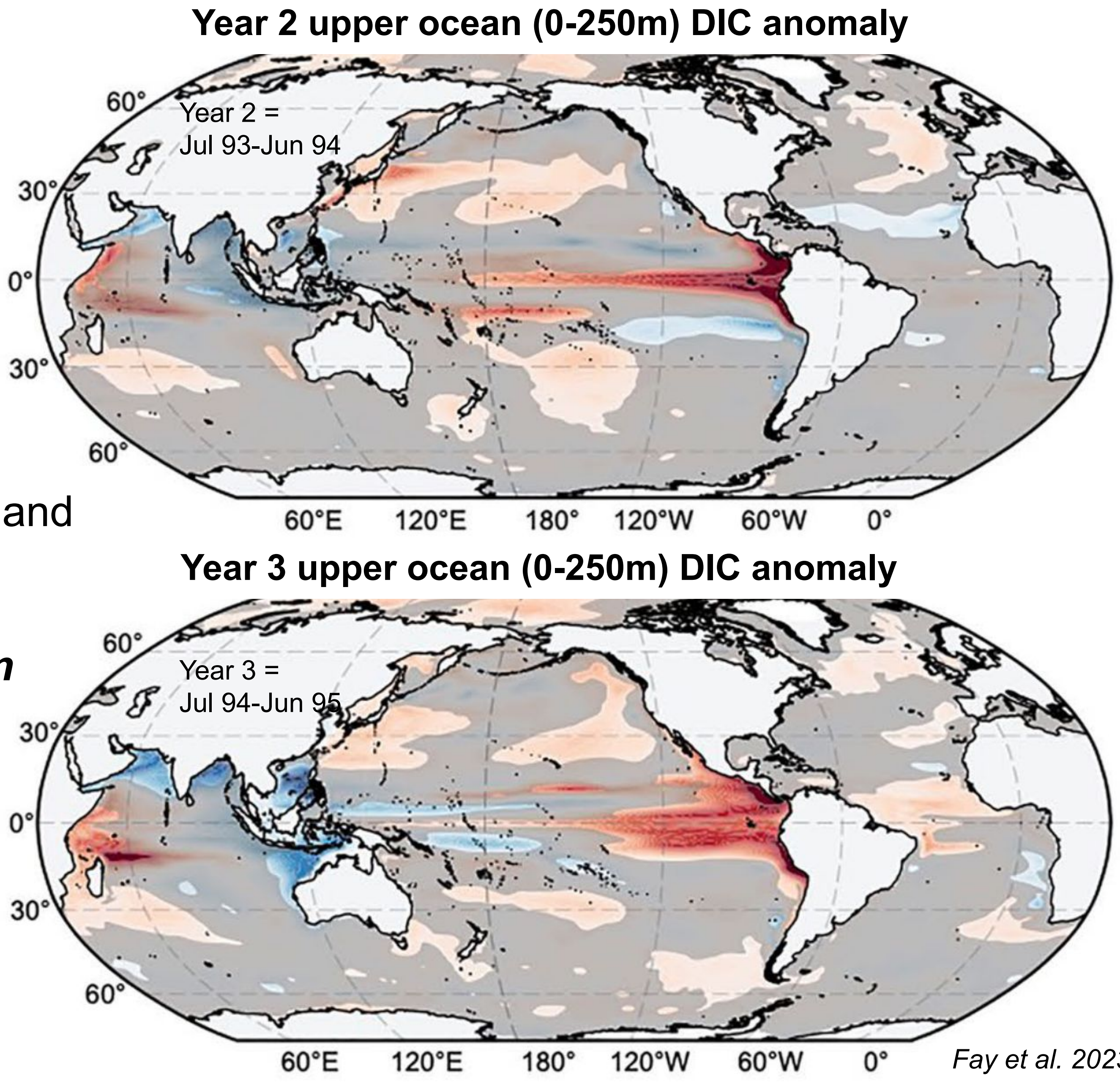
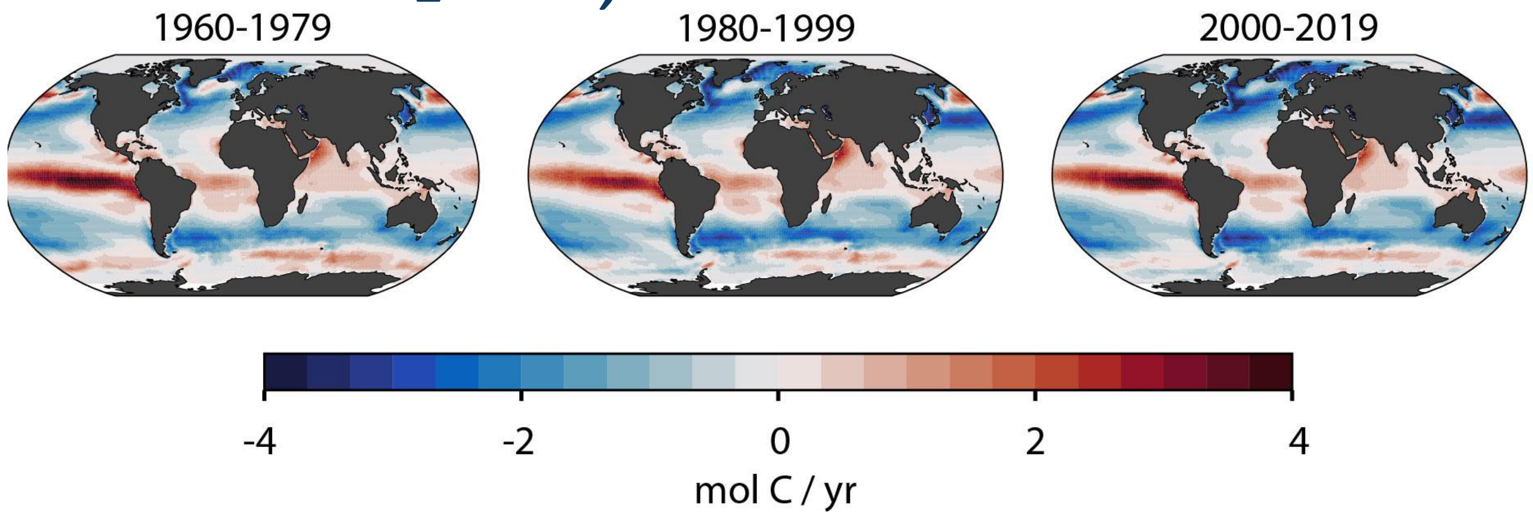
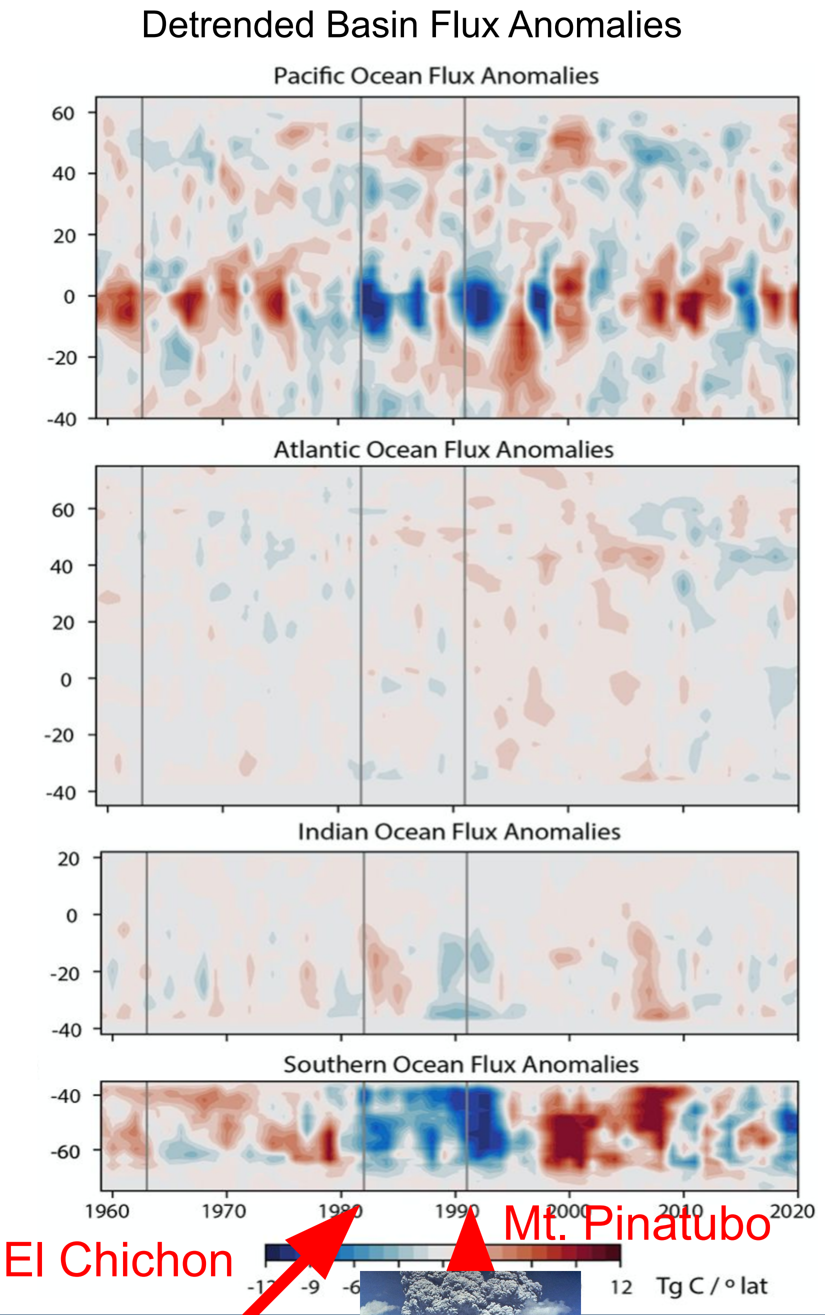


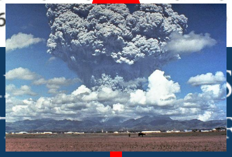
Fay et al. 2023, GBC

An observation-based product (LDEO-HPD) Air-sea CO_2 flux, 1959-2021



We do not find an externally forced response in S. Ocean. Next steps = explore internal variability with LDEO-HPD and physical reanalysis





Bennington et al. 2022 GRL; *Wong et al*. in prep

Conclusions

Fay et al. (2023) Immediate and Long-Lasting Impacts of the Mt. Pinatubo Eruption on Ocean Oxygen and Carbon, GBC, doi:10.1029/2022GB007513

- Forced SST cooling of 0.18°C
- Forced increase in global ocean carbon sink (-0.29 PgC/yr); consistent with the magnitude of observed anomalies in 1992-1993
- Interior oxygen enhanced; a temporary hiatus of deoxygenation
- Regionally, N. high latitudes, Eq. Pacific experience largest forced response

THANK YOU

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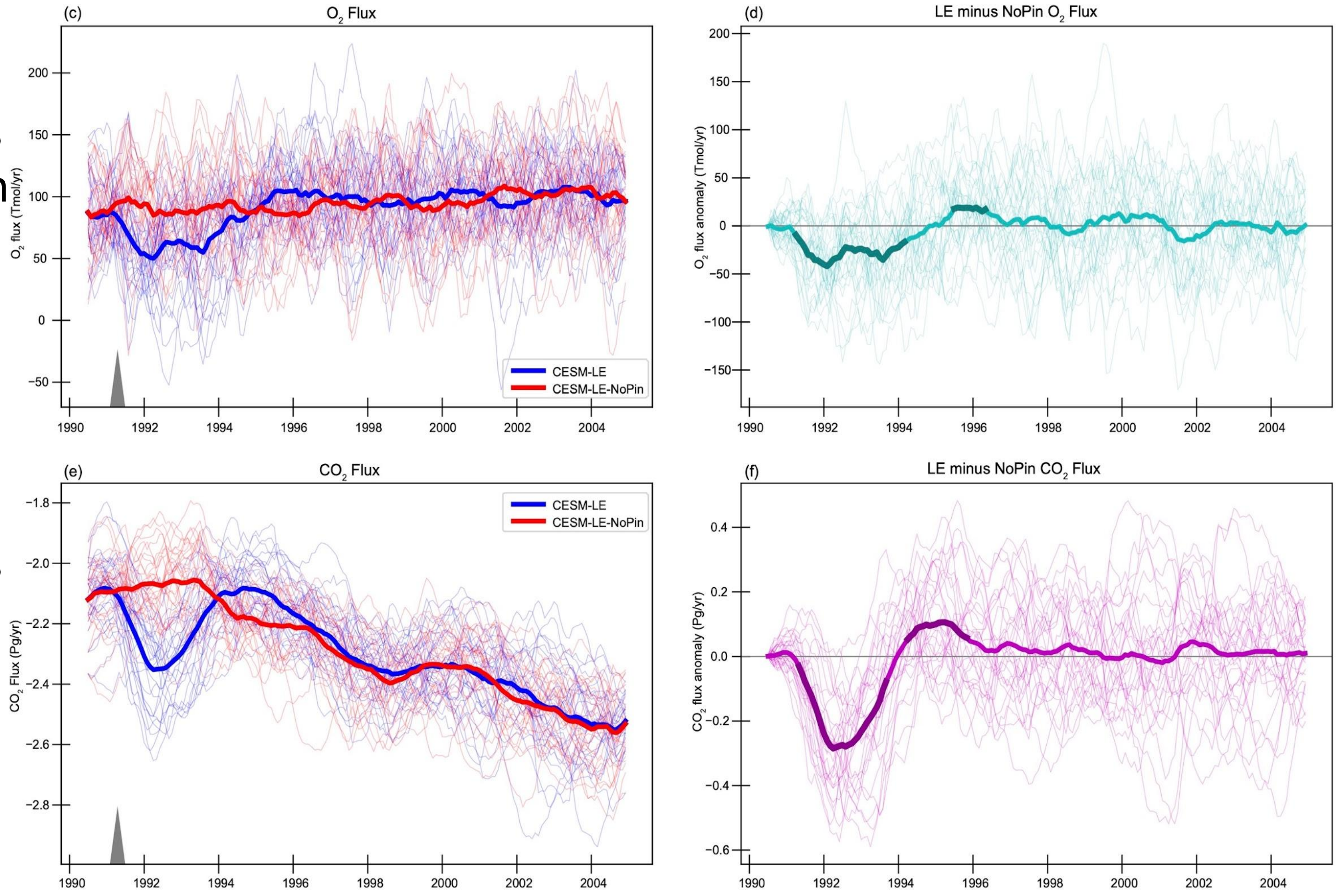
Global Mean Oxygen and Carbon Flux

Oxygen flux anomaly peaks at 42 Tmol/yr in 1992

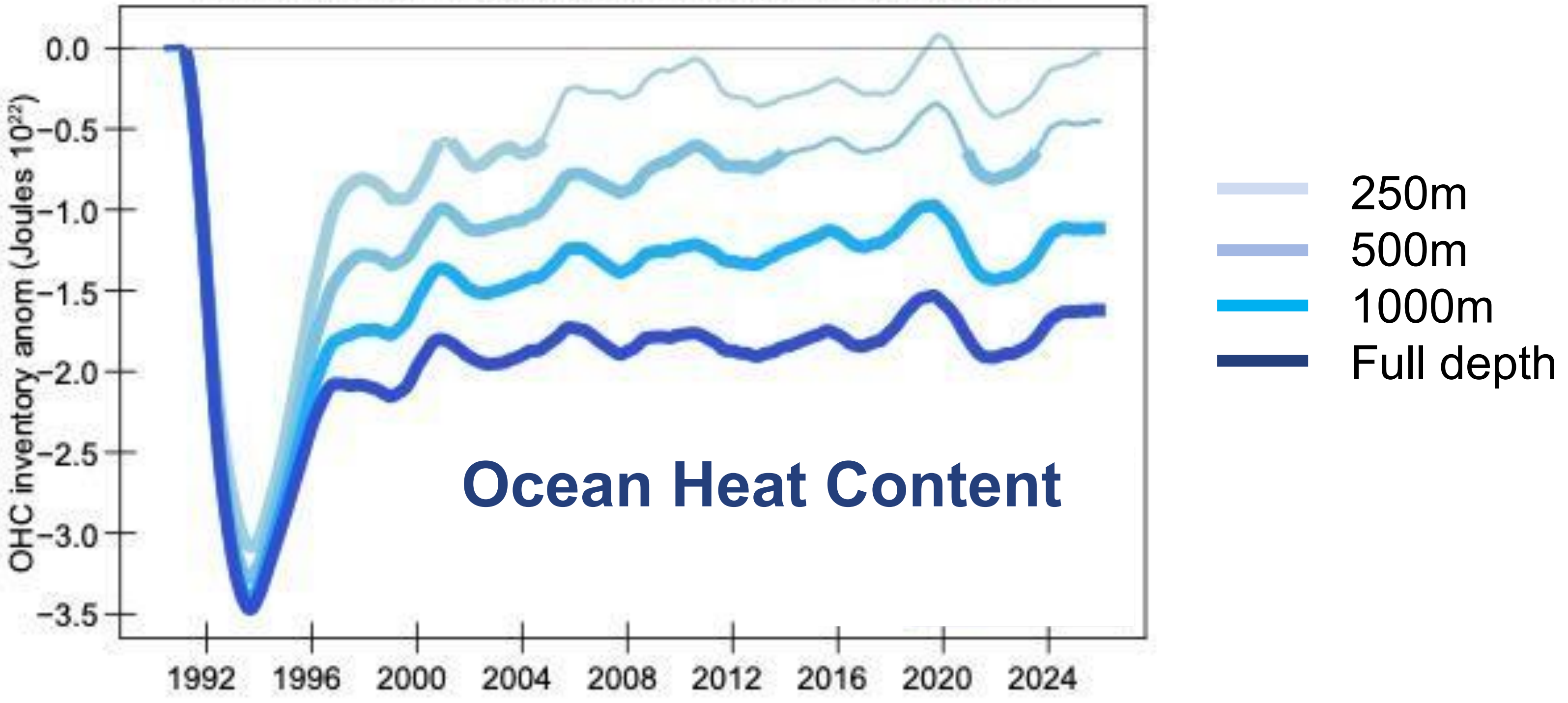
Carbon flux anomaly peaks at 0.29 PgC/yr in 1992



Negative flux indicates increase flux *INTO* the ocean.

Fay et al. 2023 GBC

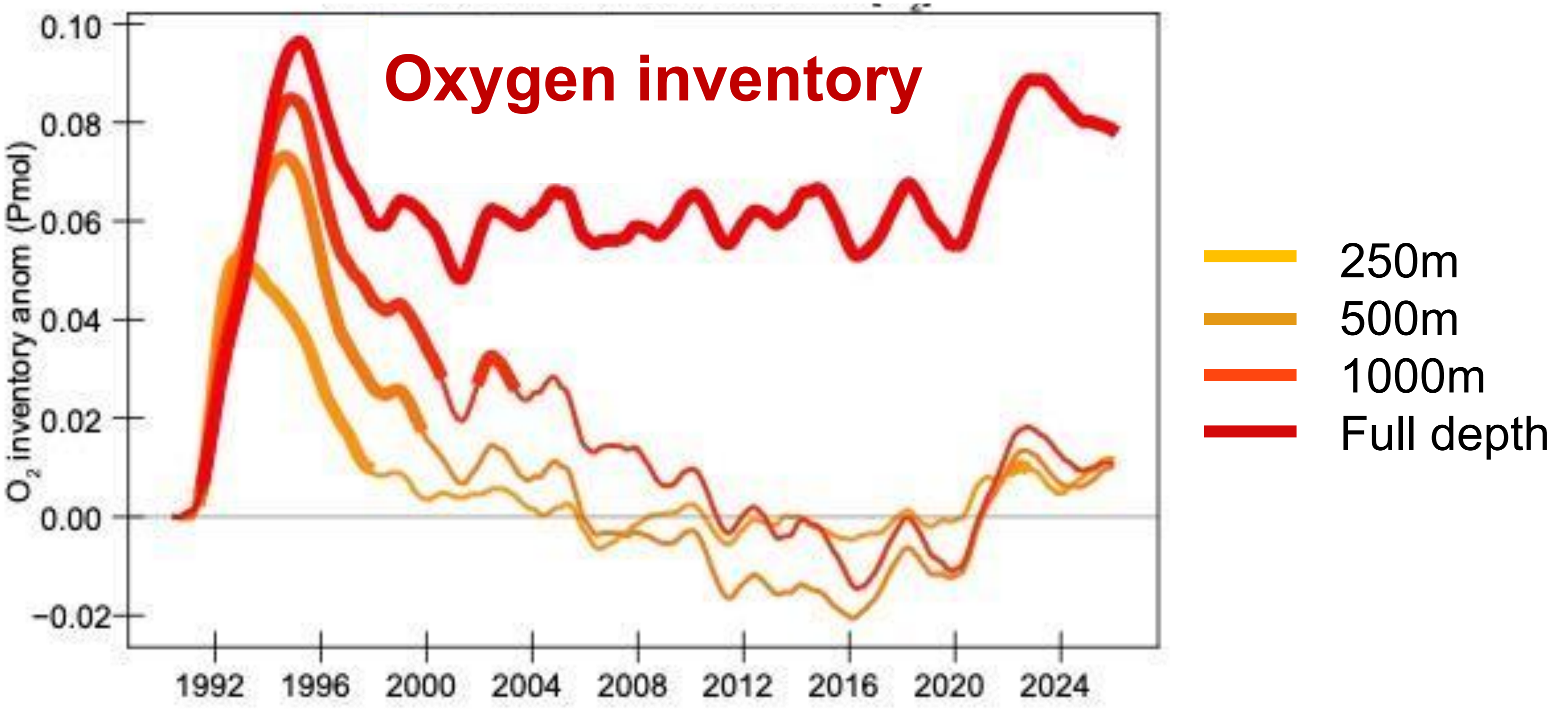
Interior inventories



- The interior inventory of heat has been significantly impacted by Mt. Pinatubo
- Anomalies between the ensemble means in 1992 are comparable to observed variability

Fay et al. 2023 GBC

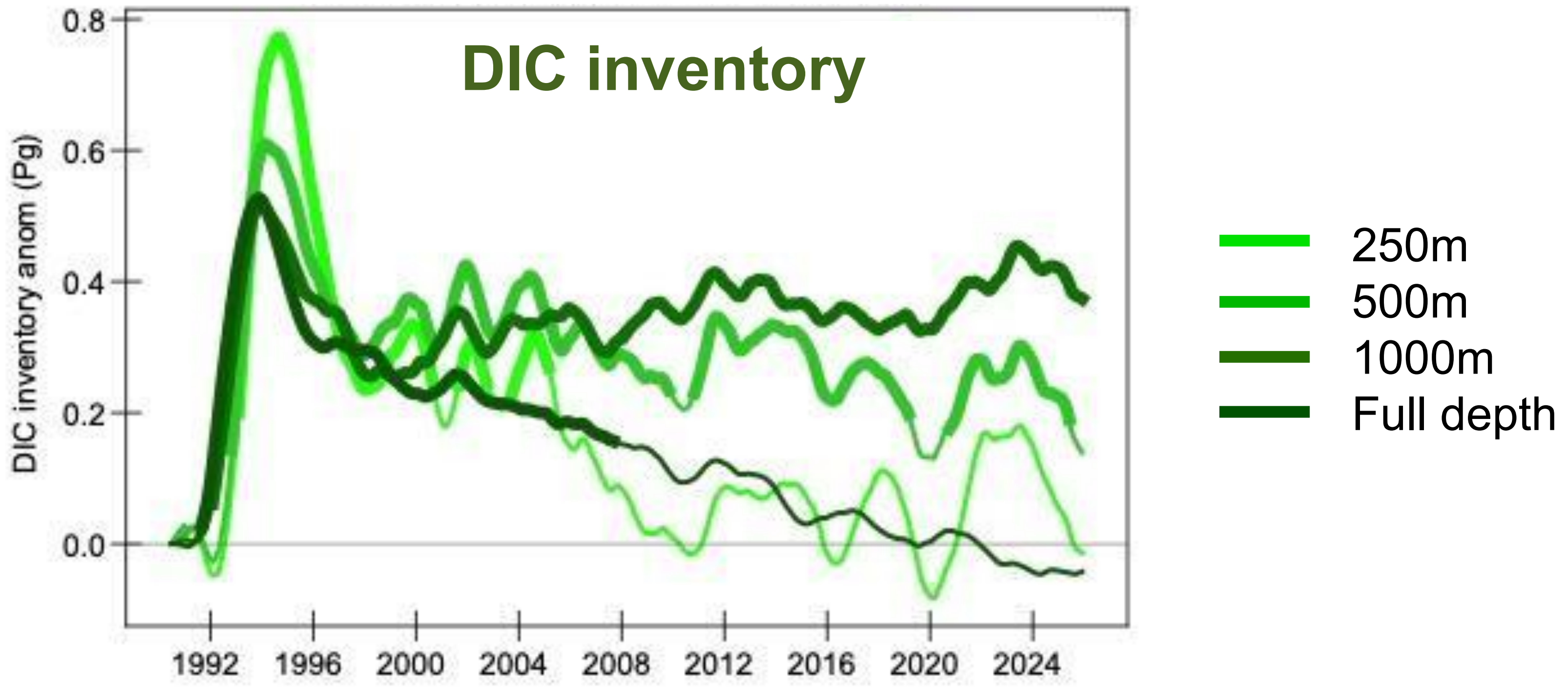
Interior inventories



- The interior inventory of oxygen has been significantly impacted by Mt. Pinatubo
- The uptake of nearly 100 Tmol of O_2 is large enough to have contributed significantly to the observed hiatus of deoxygenation trends

Fay et al. 2023 GBC

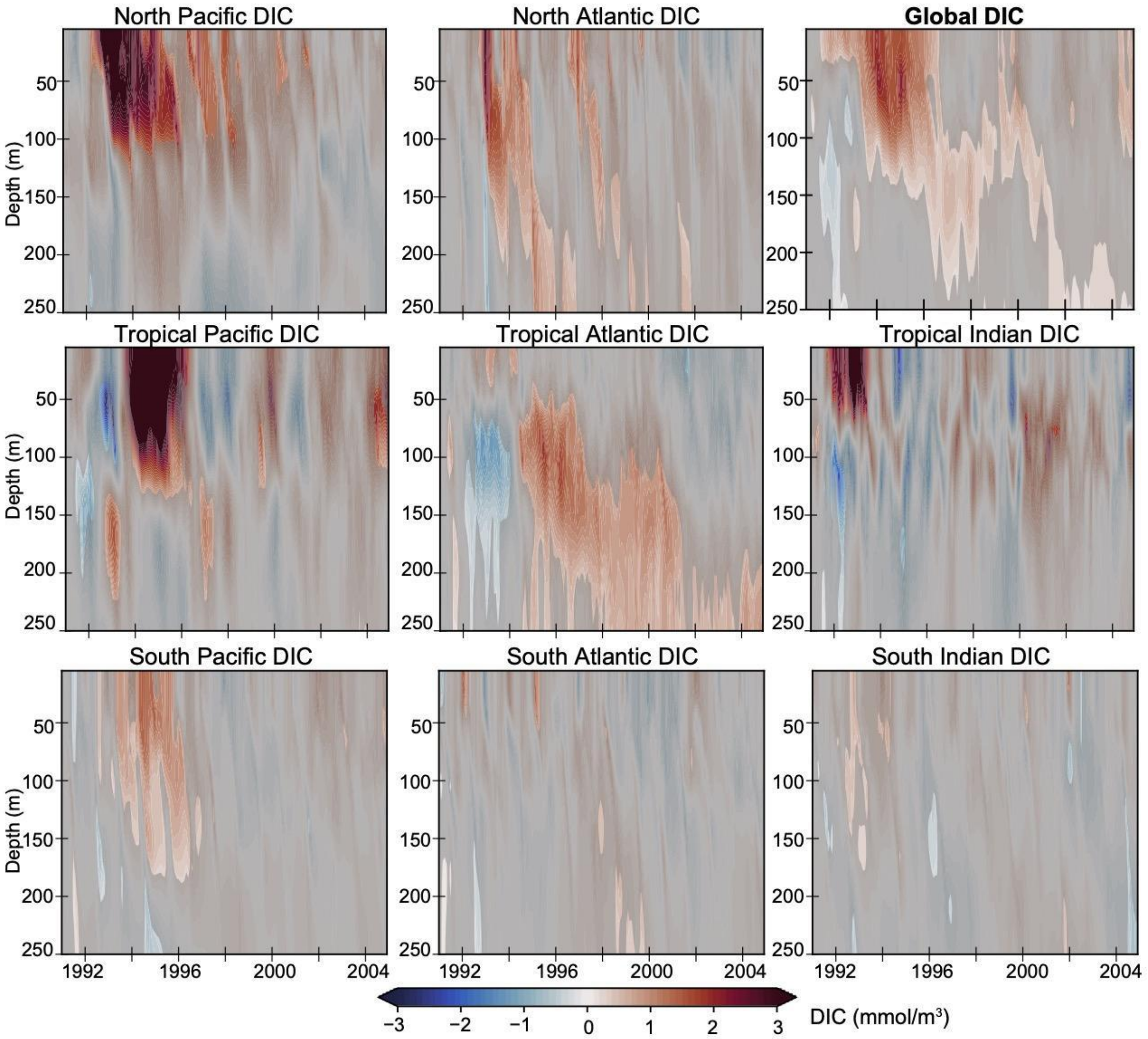
Interior inventories



- The interior inventory of carbon has been significantly impacted by Mt. Pinatubo
- Carbon anomalies are persistent in the mid-depths of the ocean column

Fay et al. 2023 GBC

Regional changes, Carbon



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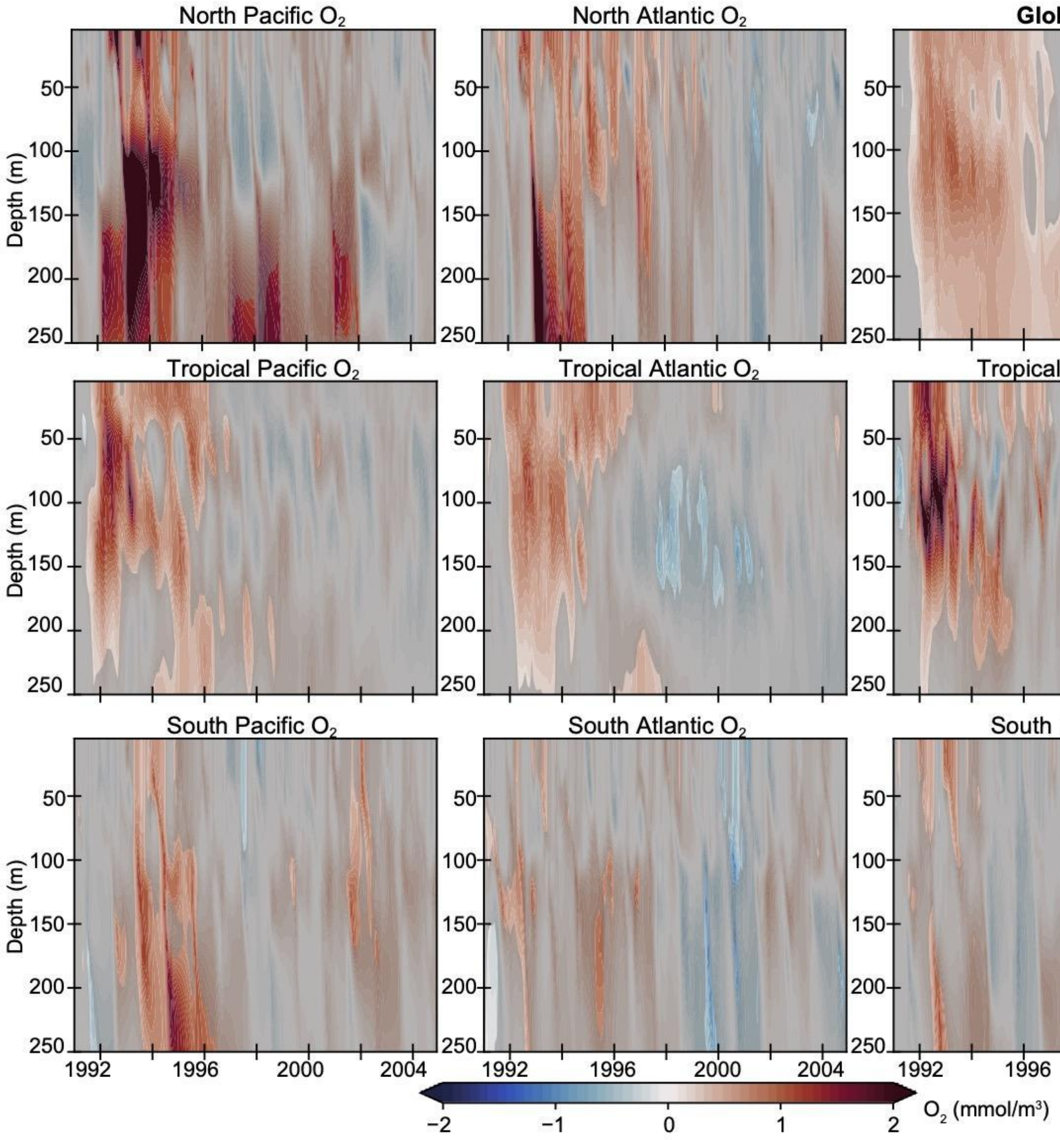
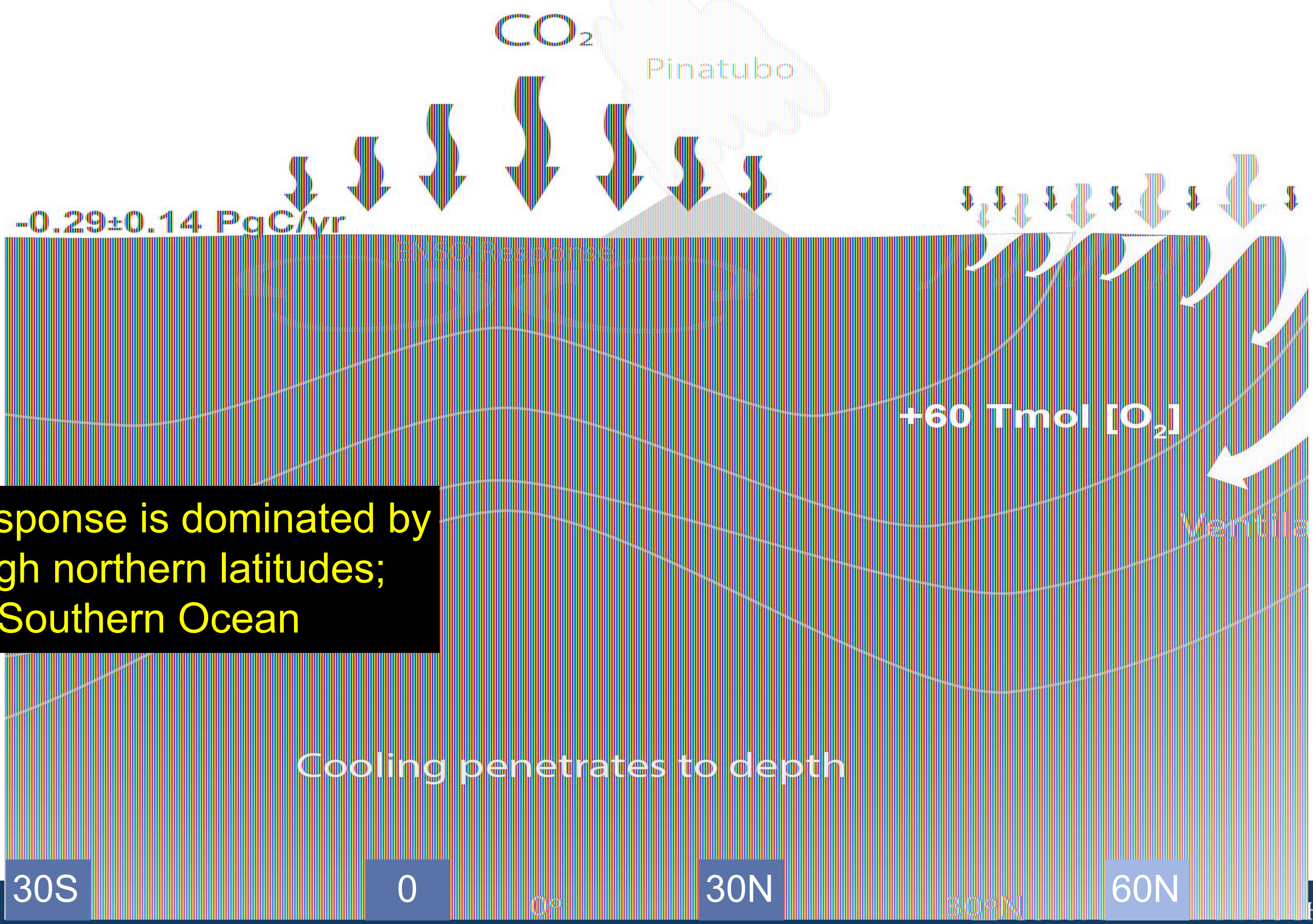
Regional changes, Oxygen



Summary of carbon and oxygen impacts forced by Mt. Pinatubo



The externally forced response is dominated by tropical Pacific and high northern latitudes; not significant in Southern Ocean

Fay et al. 2023, GBC

24

Isolating forced response from internal variability using Earth System Model Large Ensemble

- Each ESM run has its own stochastic variability ("internal") and a common "forced" response (due to volcanos, pCO_2^{atm}, etc)

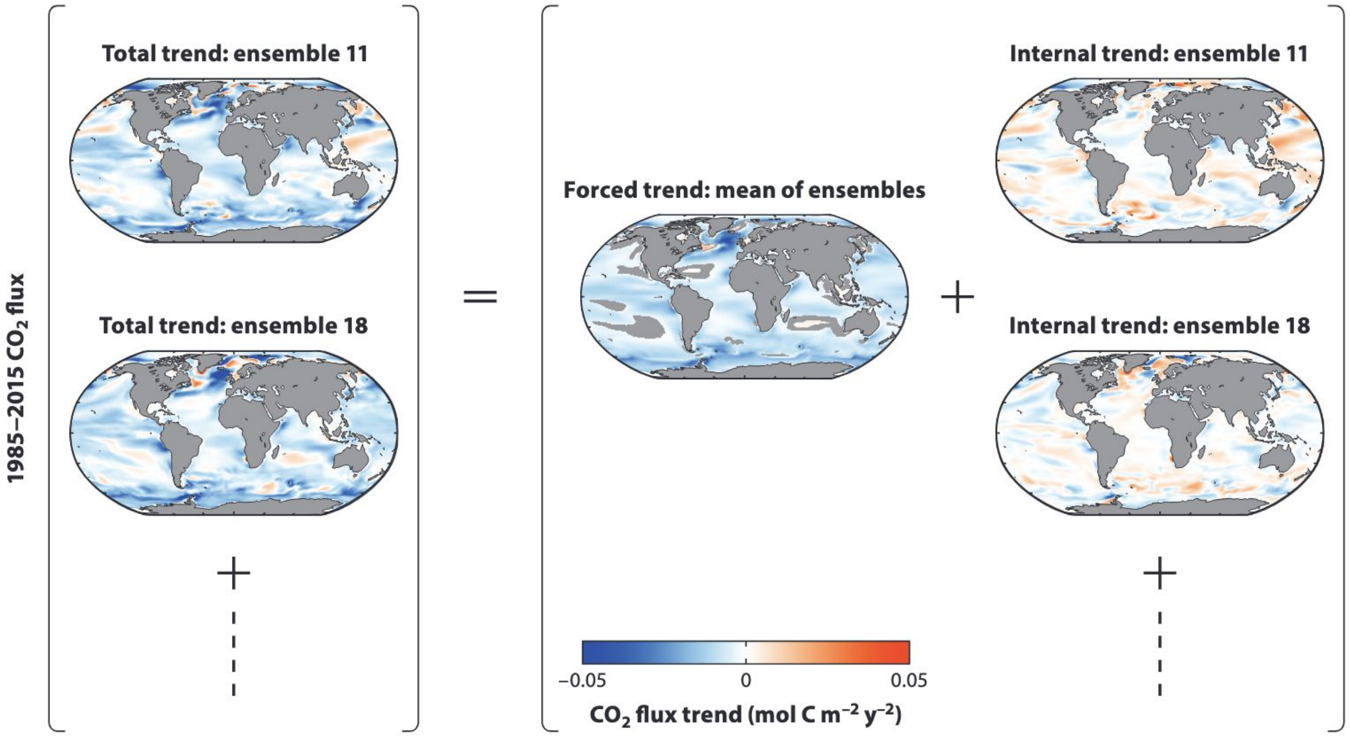
- To isolate response to external forcing, run 10s of runs; average to get what is common

  (="forced response")

- Then, for each member:

  Total – forced = internal

Example: 1985-2015 CO_2 flux trend



McKinley et al. 2017, ARMS