Attribution of space-time variability in global-ocean dissolved inorganic carbon

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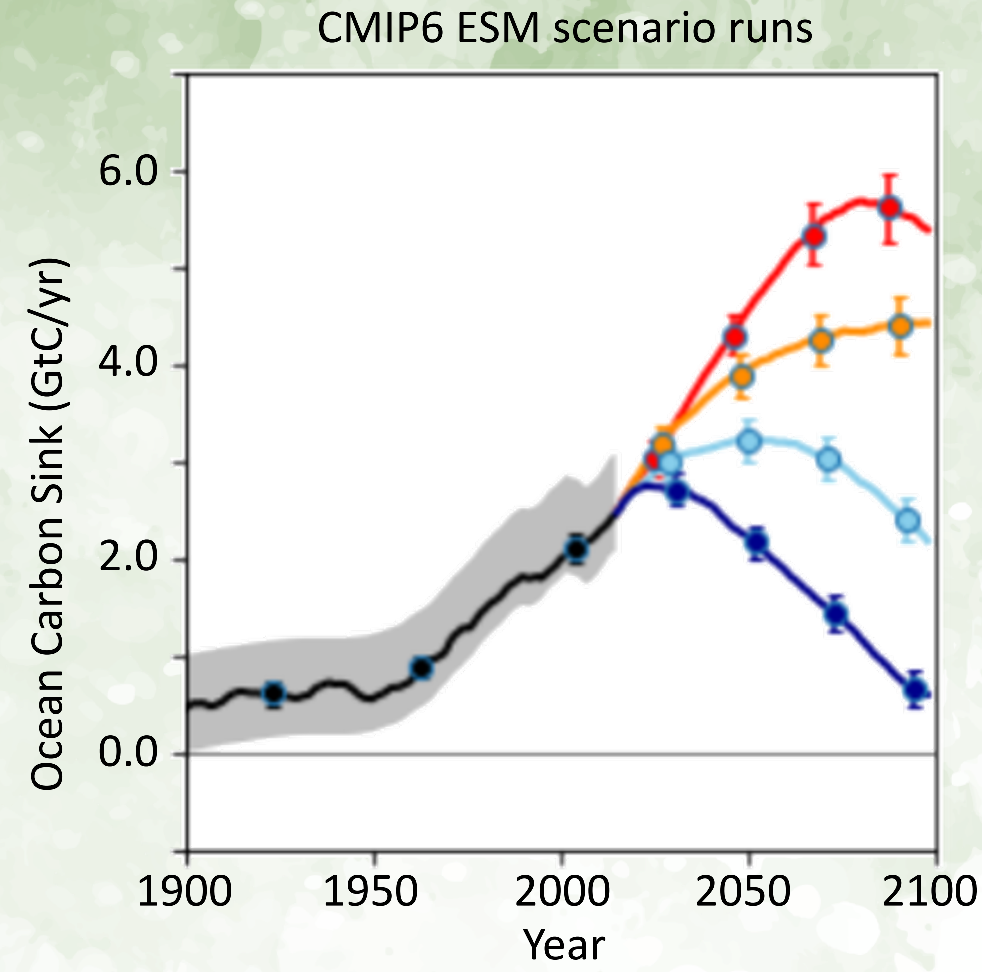
Future climate predictions are uncertain

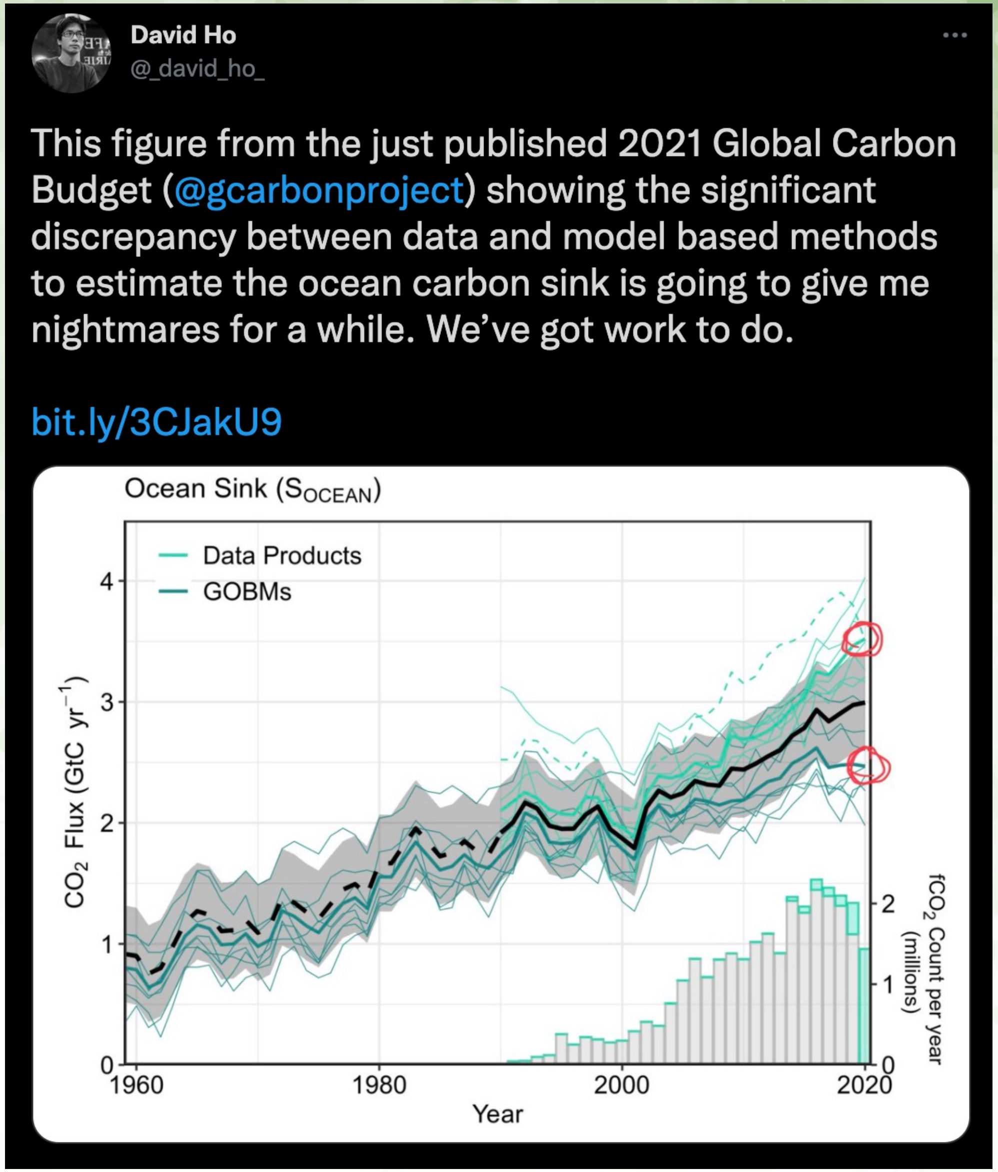
NOAA estimate of ocean net CO_2 uptake for 2019 1.4-4.1 PgC. Uncertainty of ±1.35PgC is 70% of optimistic carbon capture and storage potential in 2050.

Integrated CMIP6 ocean carbon uptake uncertainty is equivalent to total uptake in the ~1980's.



IPCC AR6 Ch.5 Fig.5.25e (Canadell *et al.,* 2021)

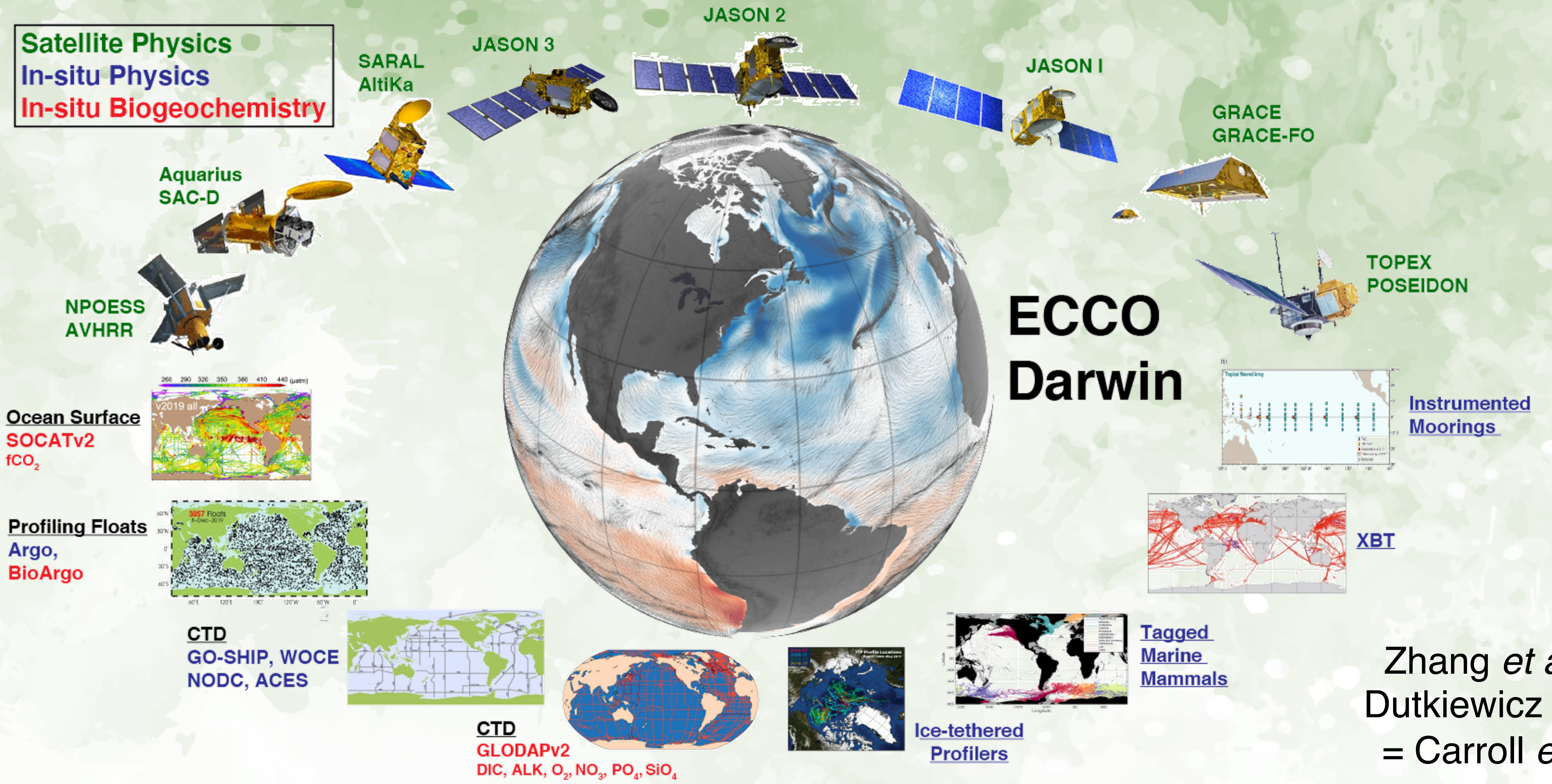
Constraining the ocean carbon sink is challenging



Providing an accurate estimate of the ocean carbon sink and its time–space variability is a critical societal and environmental challenge.

Goal: Use the Estimating the Circulation of the Climate and Ocean (ECCO) framework to address this problem.

ECCO-Darwin: the data-assimilative ocean biogeochemistry/ecosystem state estimate



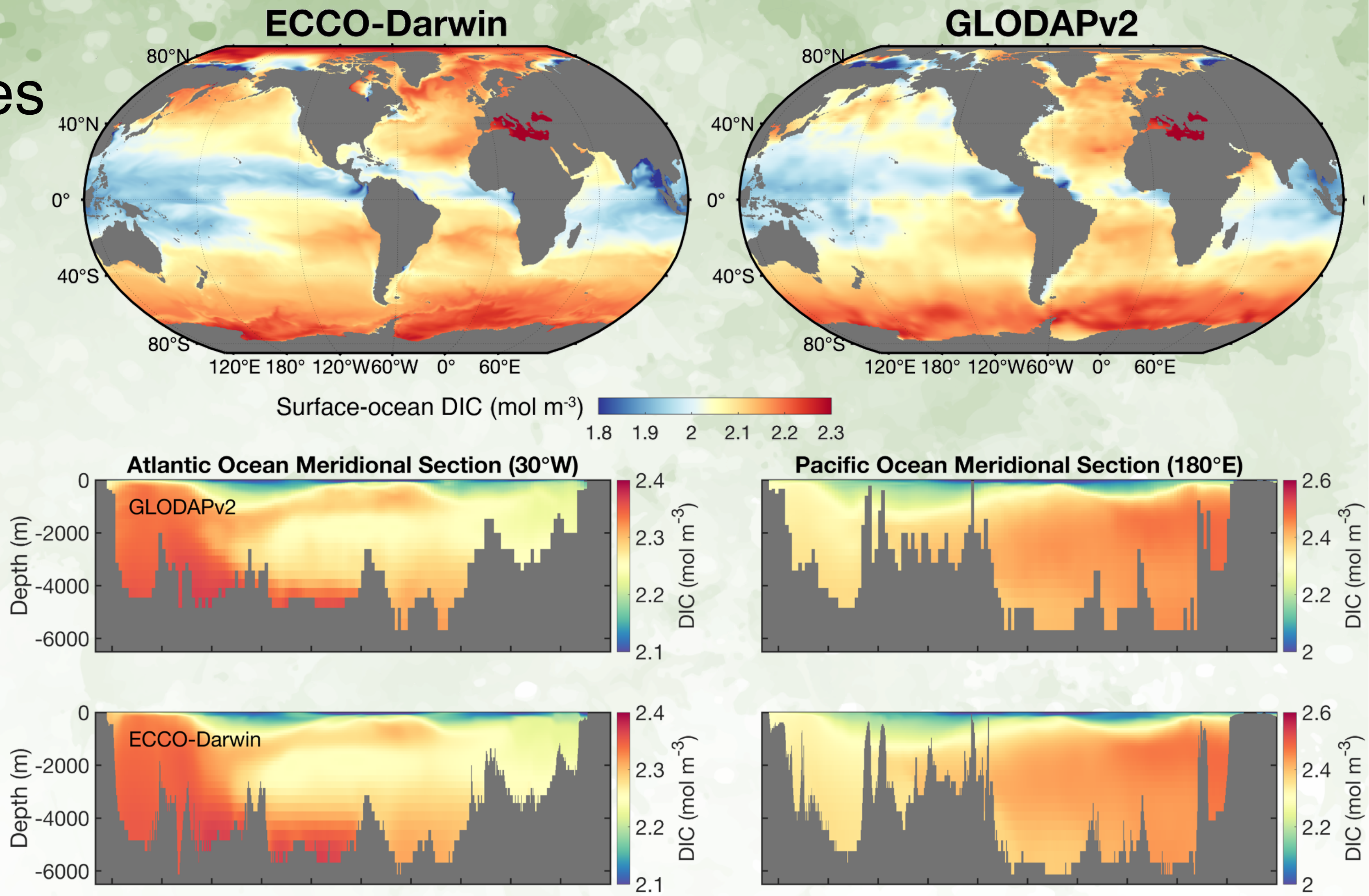
Zhang *et al.* (2018) +
Dutkiewicz *et al.* (2013)
= Carroll *et al.* (2020)

The ECCO framework is physically consistent, property-conserving data assimilation using adjoint (for physics) and Green's function (for BGC) optimization.

ECCO-Darwin Evaluation

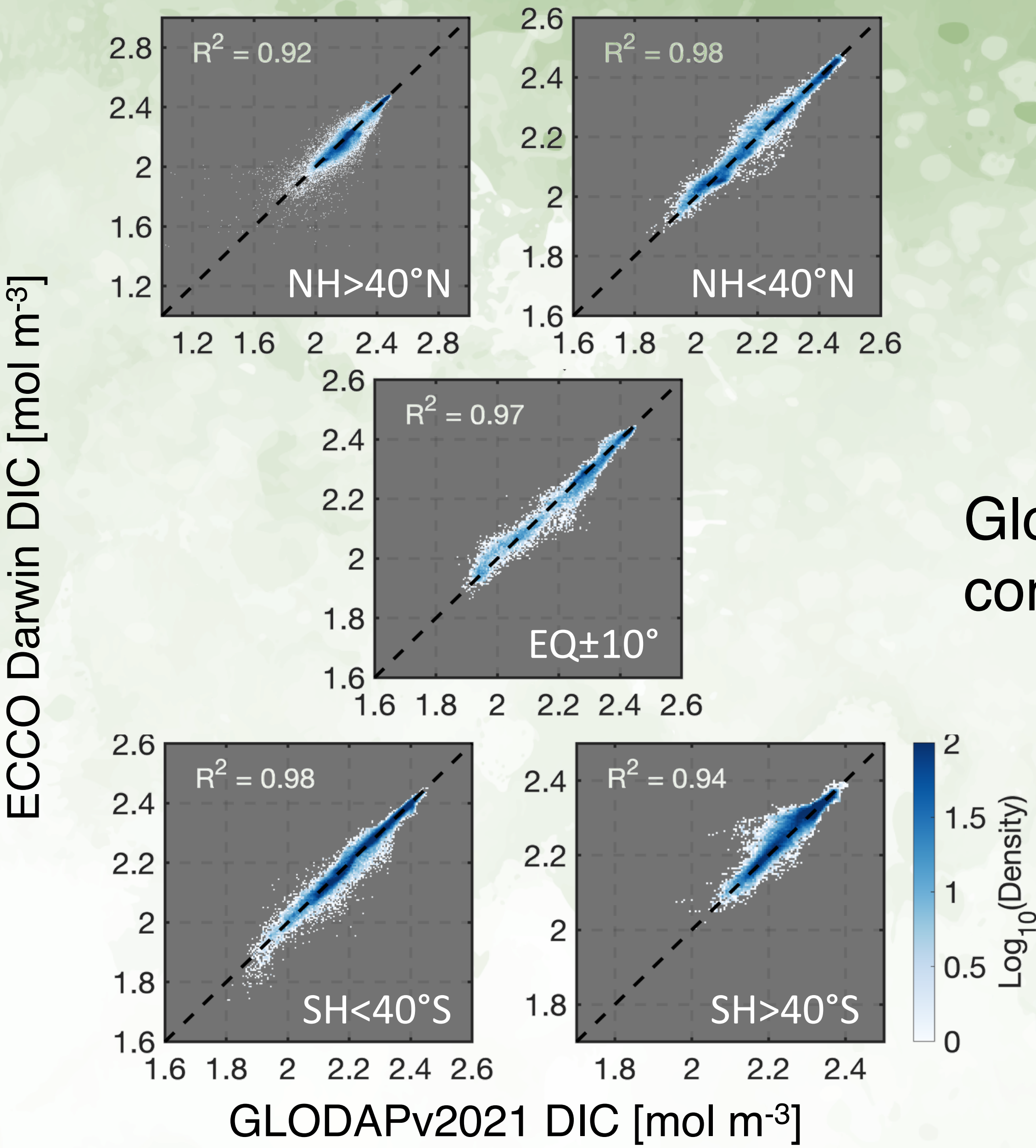
ECCO-Darwin reproduces observed gradients in surface-ocean DIC (and pCO_2) compared to obs.

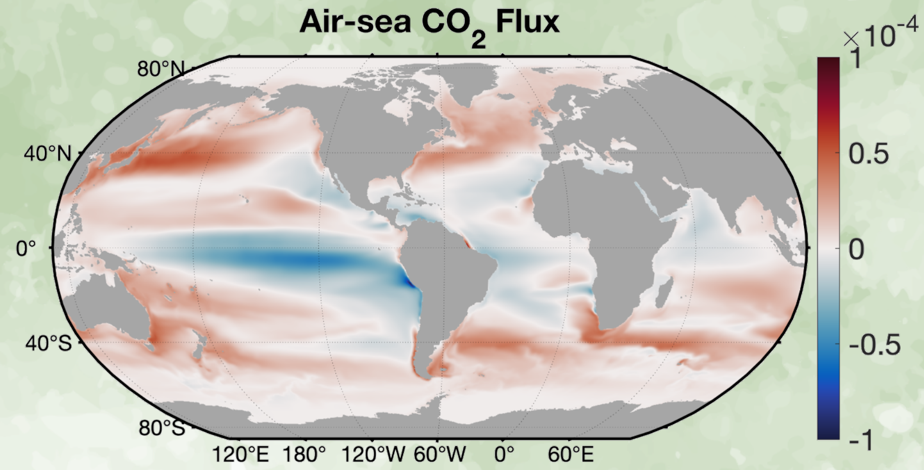
Also good large-scale agreement in the vertical structure of sections.



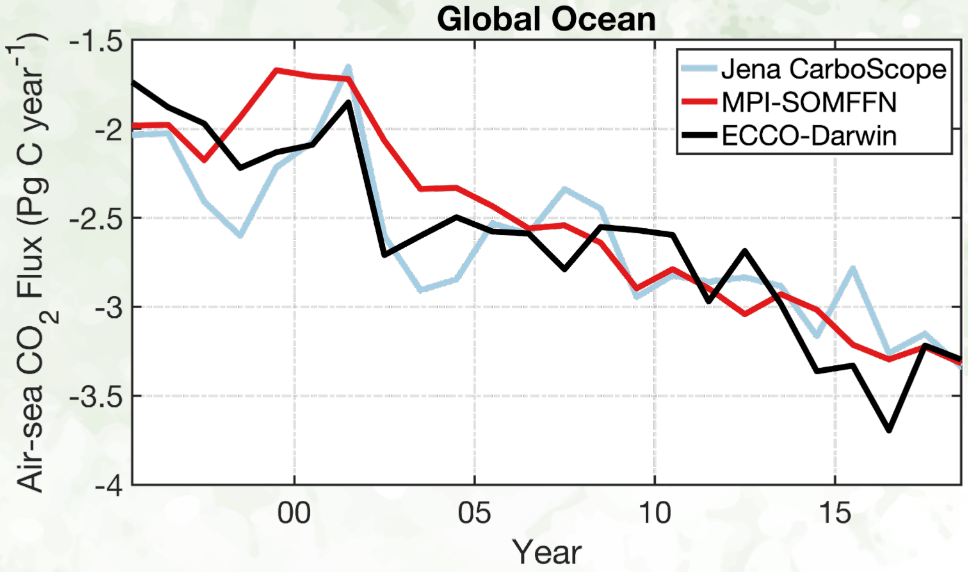
Carroll *et al.* (2022; in revision at *GBC*)

ECCO-Darwin Evaluation





Globally-integrated ECCO-Darwin air-sea CO_2 flux consistent with two observation-based estimates.



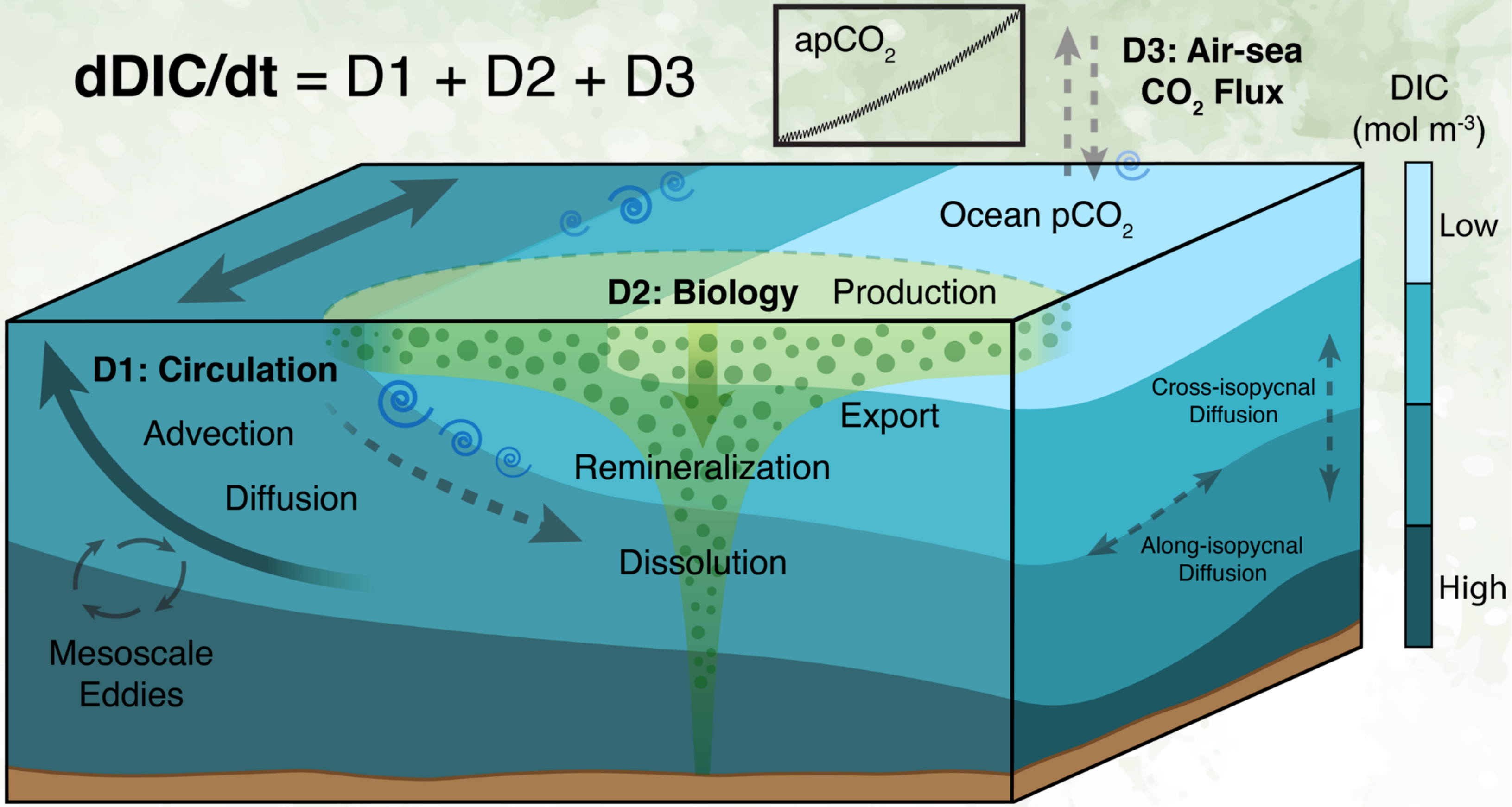
Attributing drivers of ocean DIC budget

$$\frac{dDIC}{dt} = -\nabla \cdot DIC_{\mathrm{adv}} - \nabla \cdot DIC_{\mathrm{diff}} + DIC_{\mathrm{bio}} + F_{CO_2}$$

$$DIC_{\mathrm{bio}} = Org_{\mathrm{prod}} + PIC_{\mathrm{prod}} + PIC_{\mathrm{diss}} + Org_{\mathrm{remin}}$$

Compute 3-D budgets both of the upper 100 m and full-depth ocean.

Generate monthly-mean fields from 1995–2018



DIC budget climatology (1995–2018)

Upper 100 m

DIC Tendency = 0.3 PgC yr^{-1}

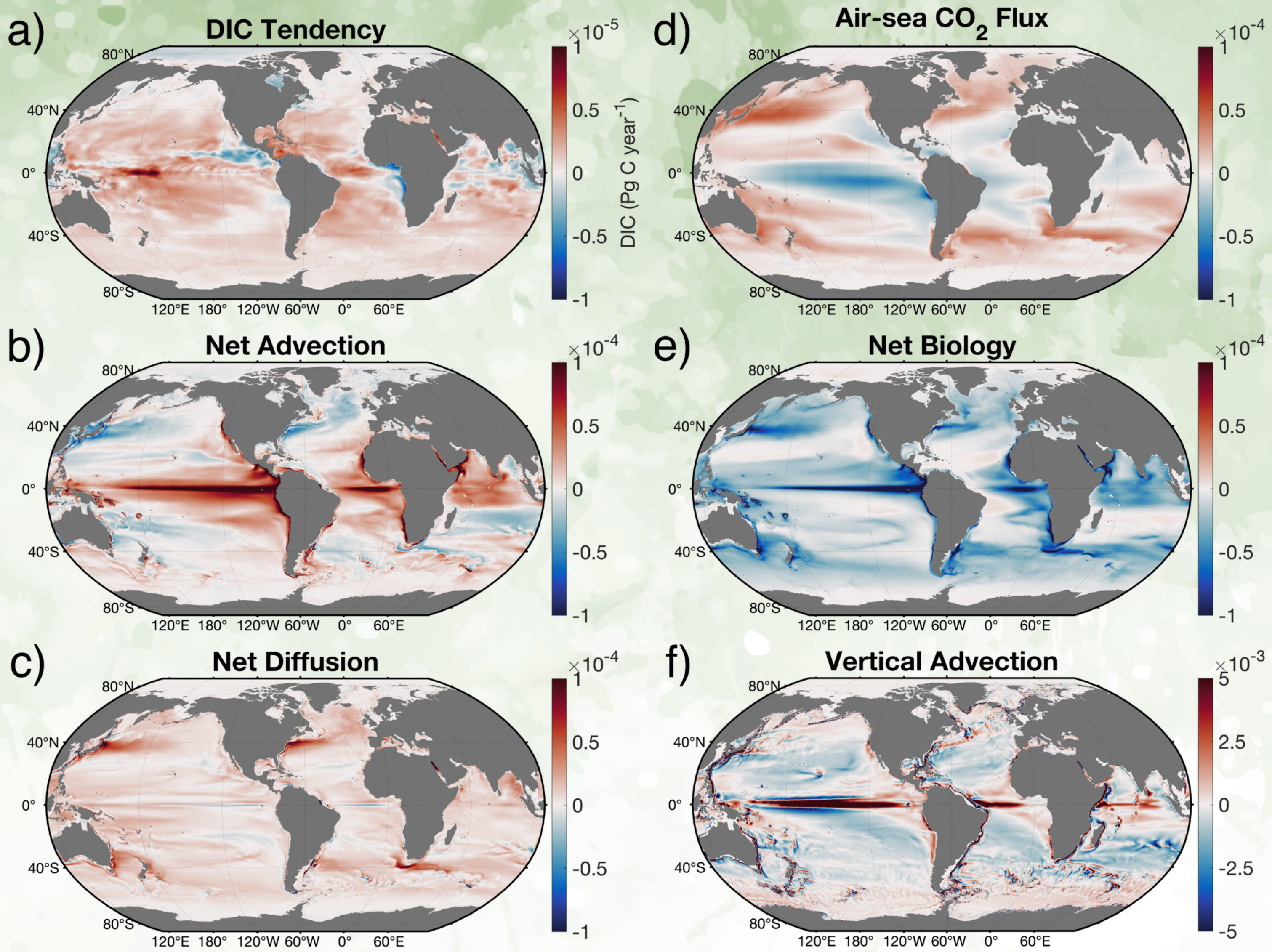
Advection = 2.9 PgC yr^{-1}

Diffusion = 3.4 PgC yr^{-1}

CO_2 Flux = 2.6 PgC yr^{-1}

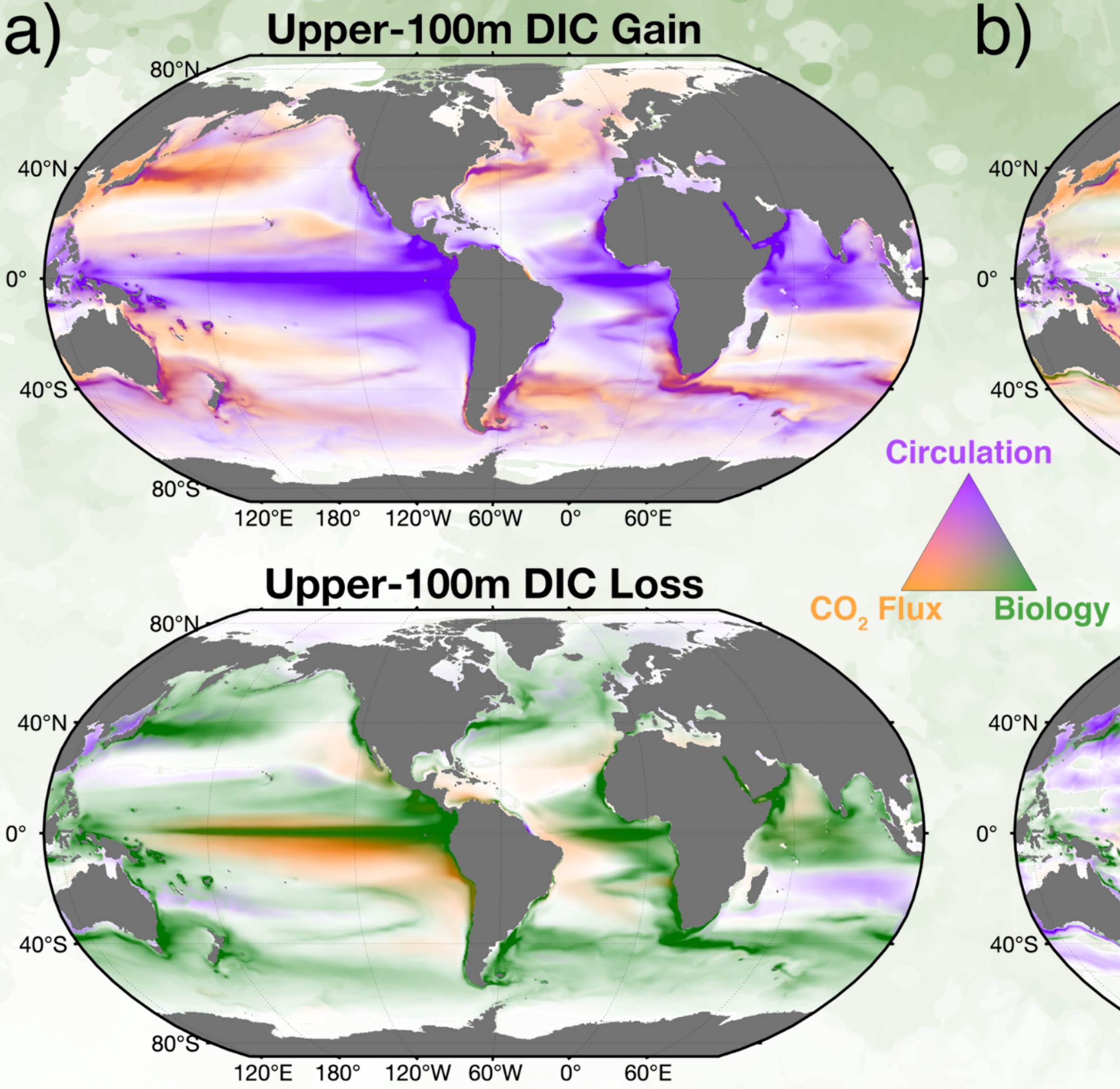
Biology = -8.6 PgC yr^{-1}

Red = gain of DIC
Blue = loss of DIC



Carroll *et al.* (2022; in revision at *GBC*)

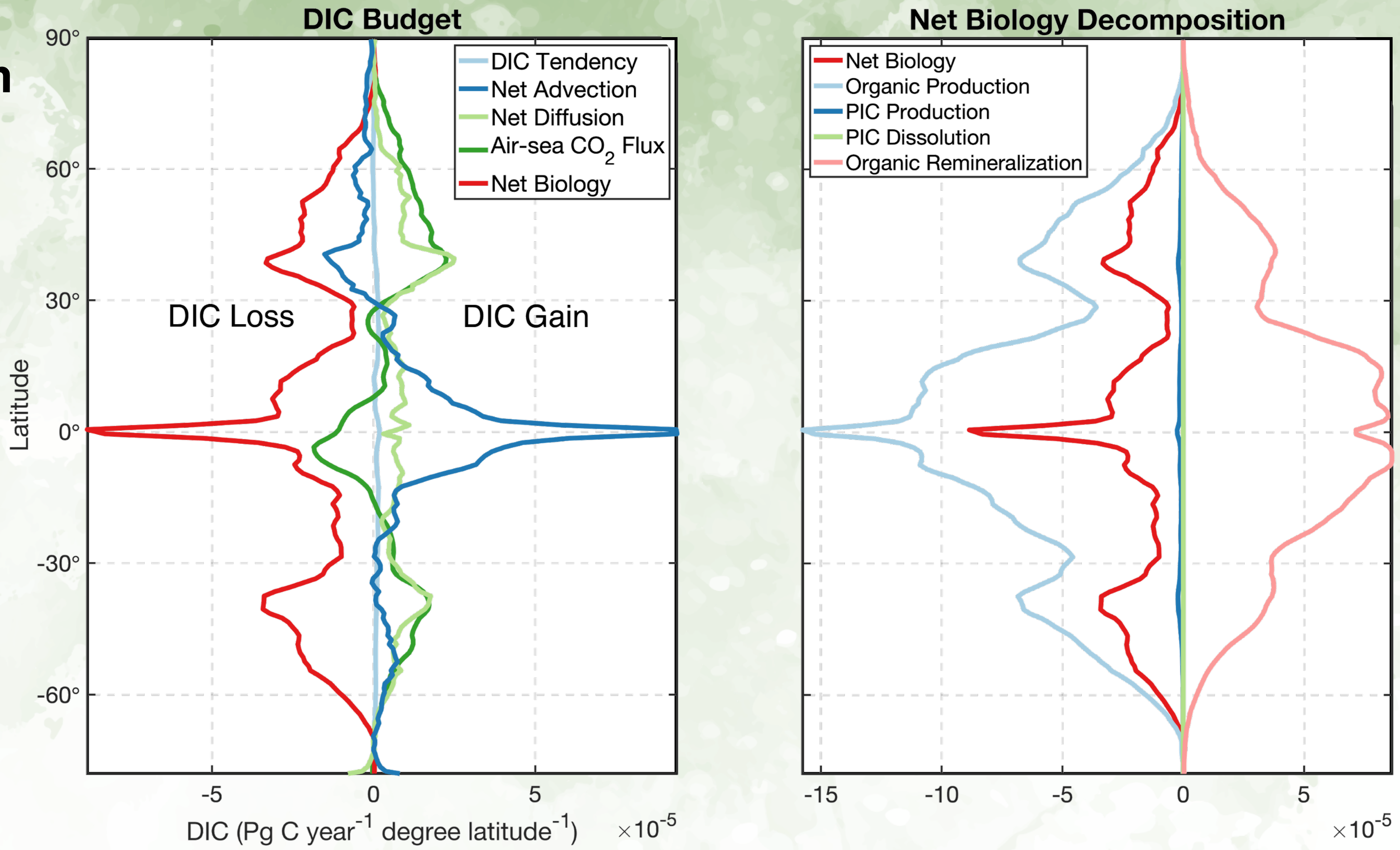
Drivers of DIC Variability (1995–2018)



Carroll *et al.* (2022; in revision at *GBC*)

Globally integrated DIC budget (1995–2018)

Upper 100 m



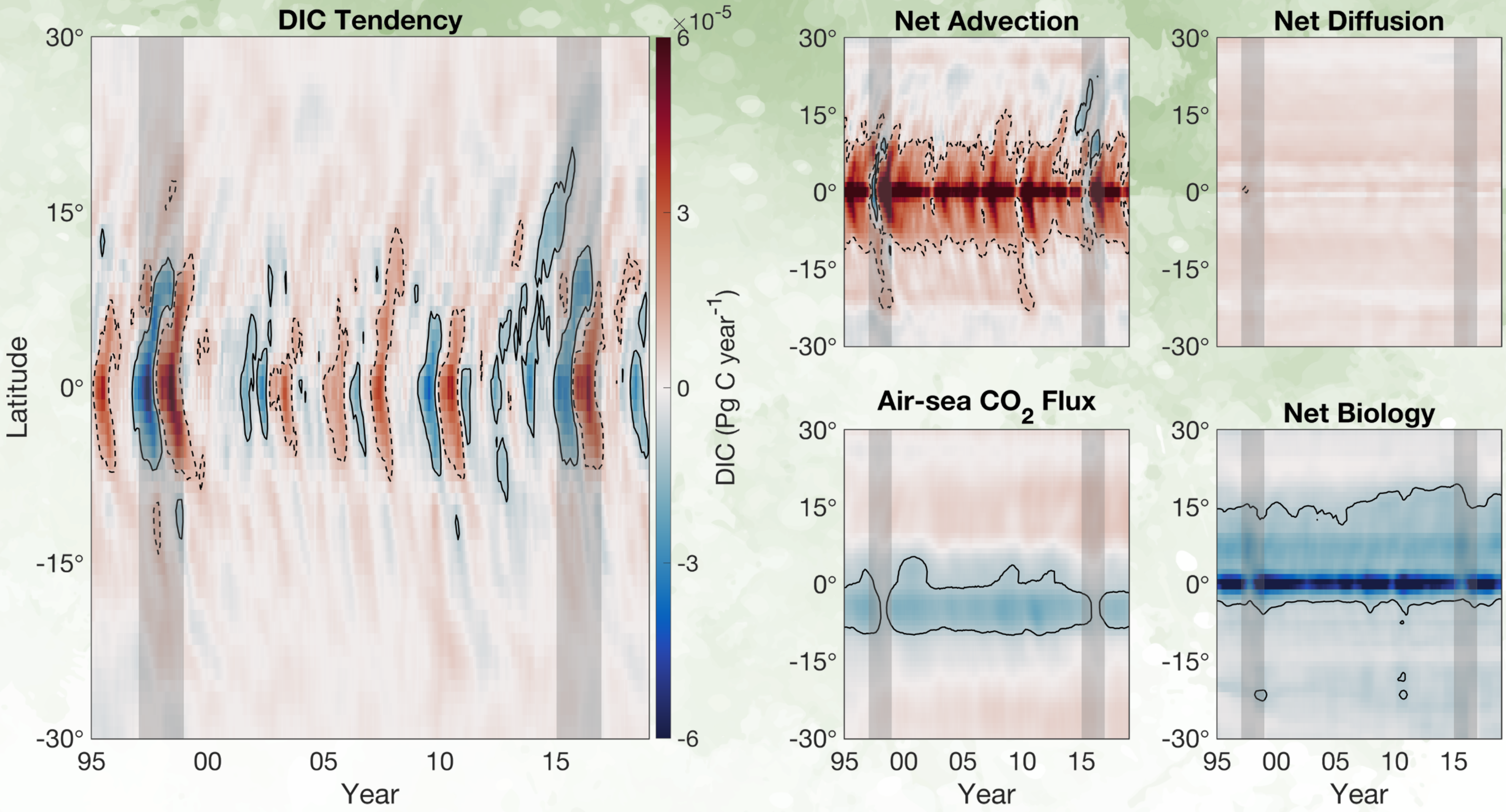
Carroll *et al.* (2022; in revision at *GBC*)

Globally integrated DIC budget (1995–2018)

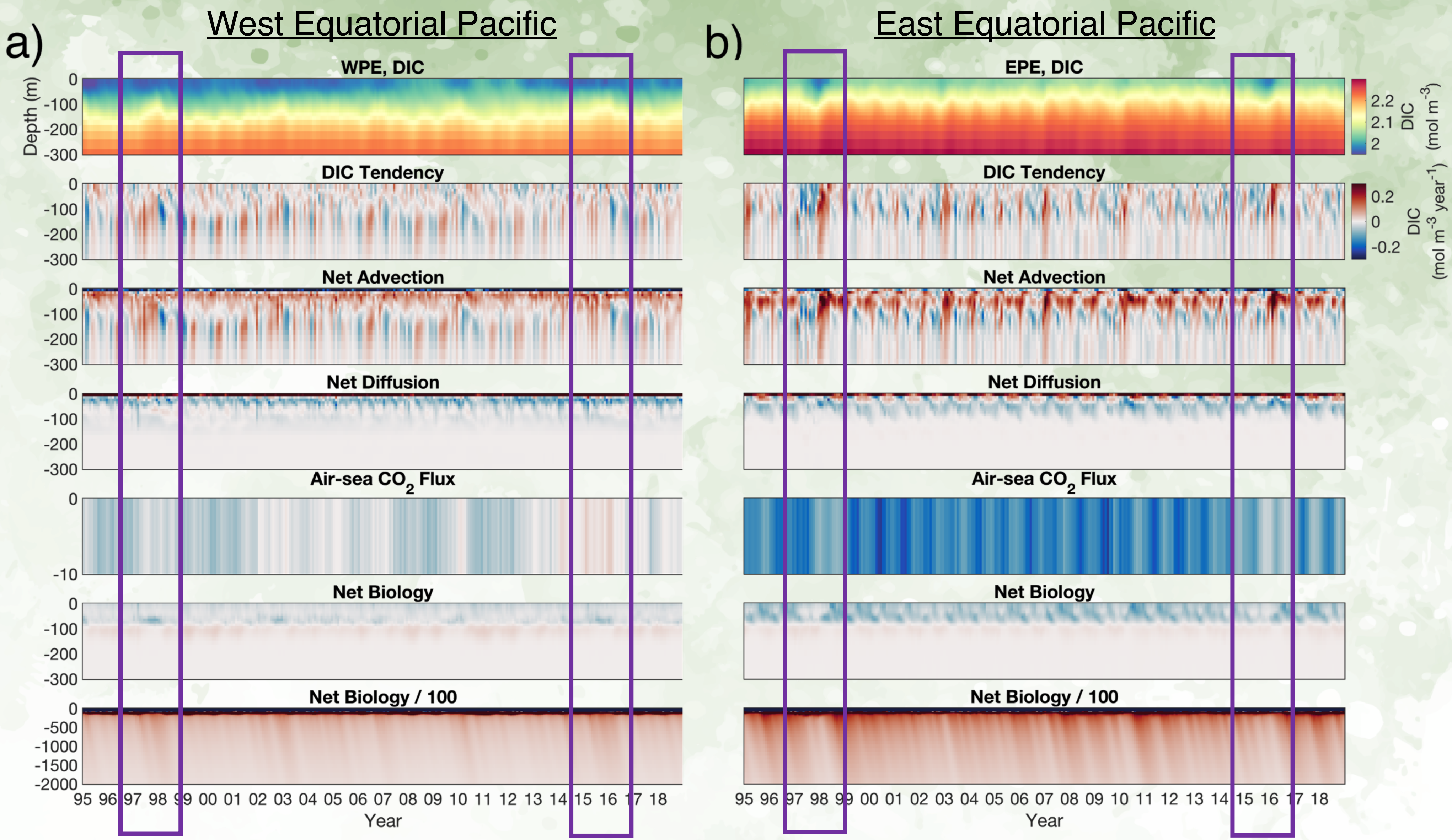
+8.1 PgC Variability driven by ENSO

+64 PgC Dominated by CO_2 flux

ECCO-Darwin neat application: ENSO Variability

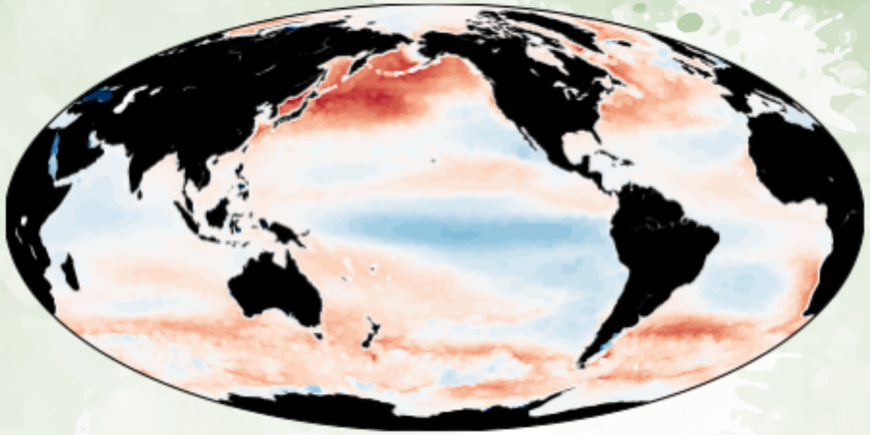


ECCO-Darwin neat application: ENSO Variability

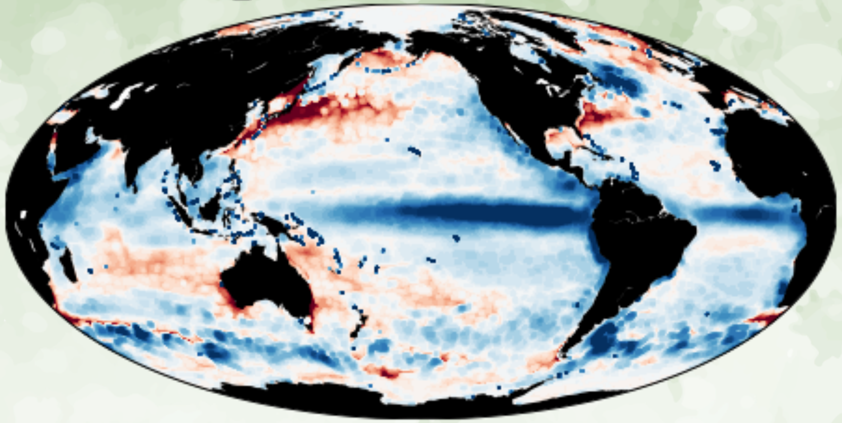


ECCO-Darwin neat application: evaluate drivers of air-sea CO_2 fluxes

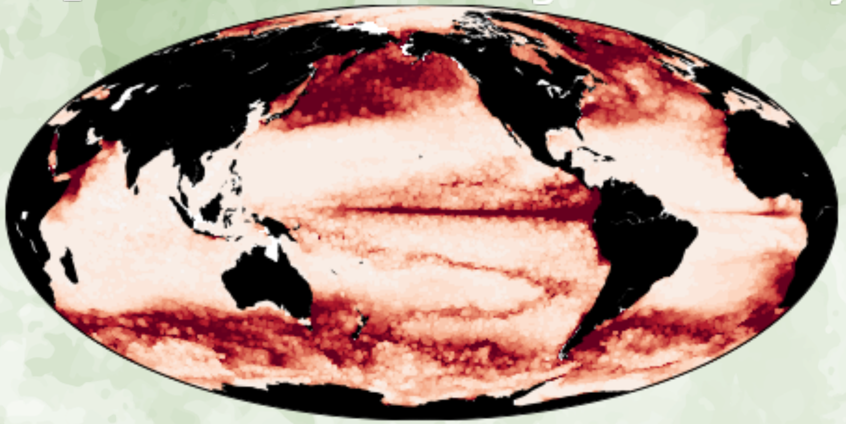
Net air-sea CO_2 flux



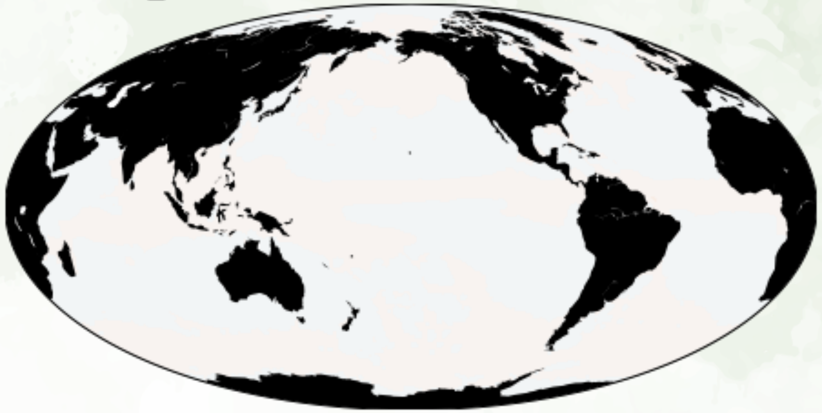
CO_2 flux due to heat



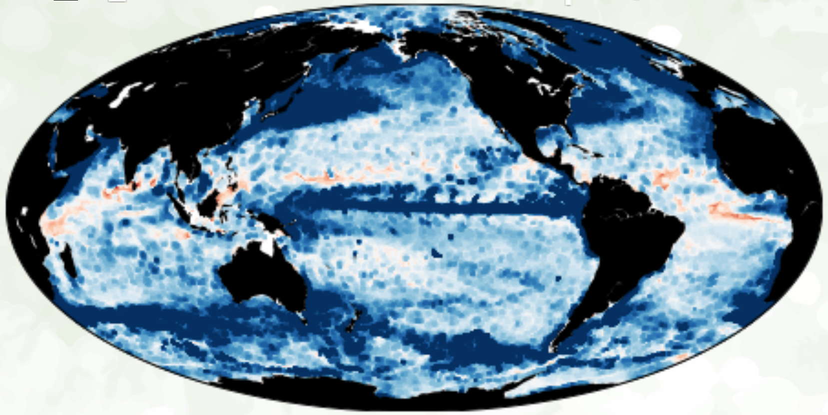
CO_2 flux due to biology



CO_2 flux due to FW

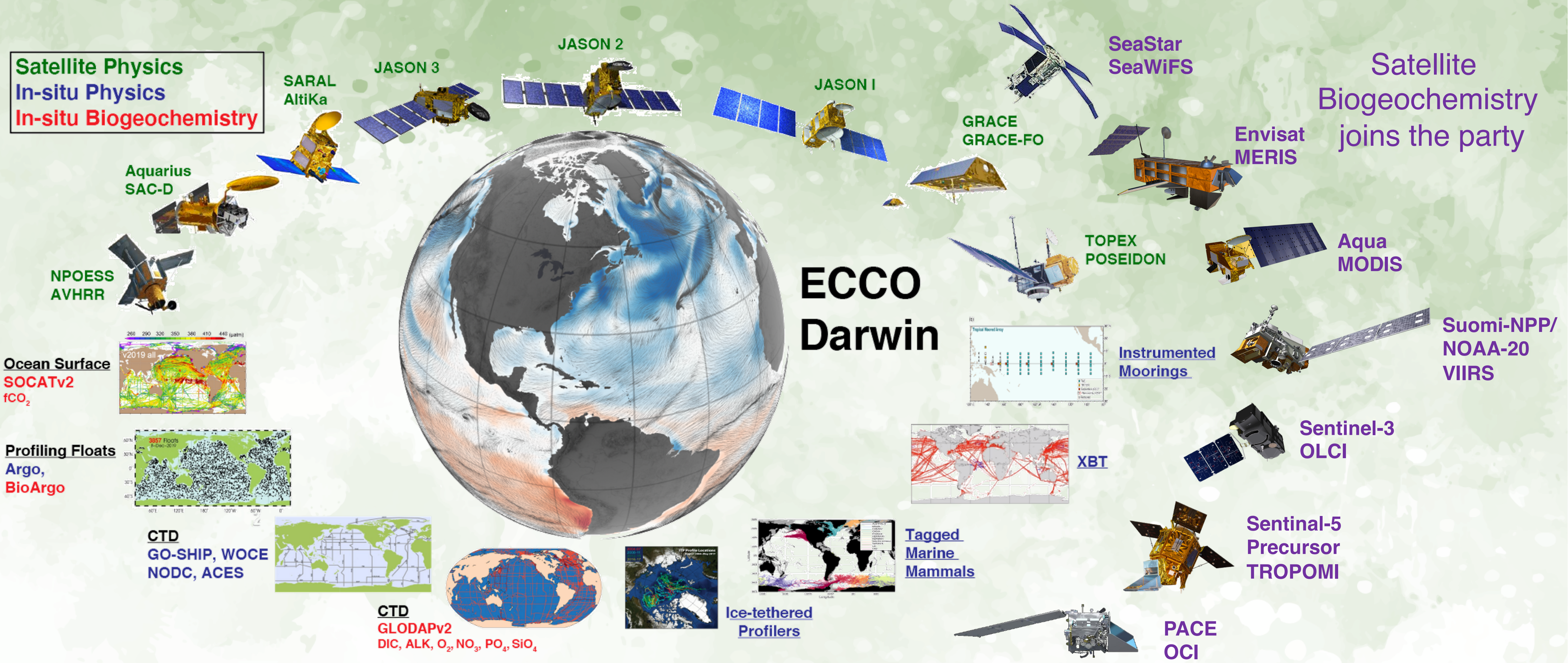


CO_2 flux due to disequilibrium



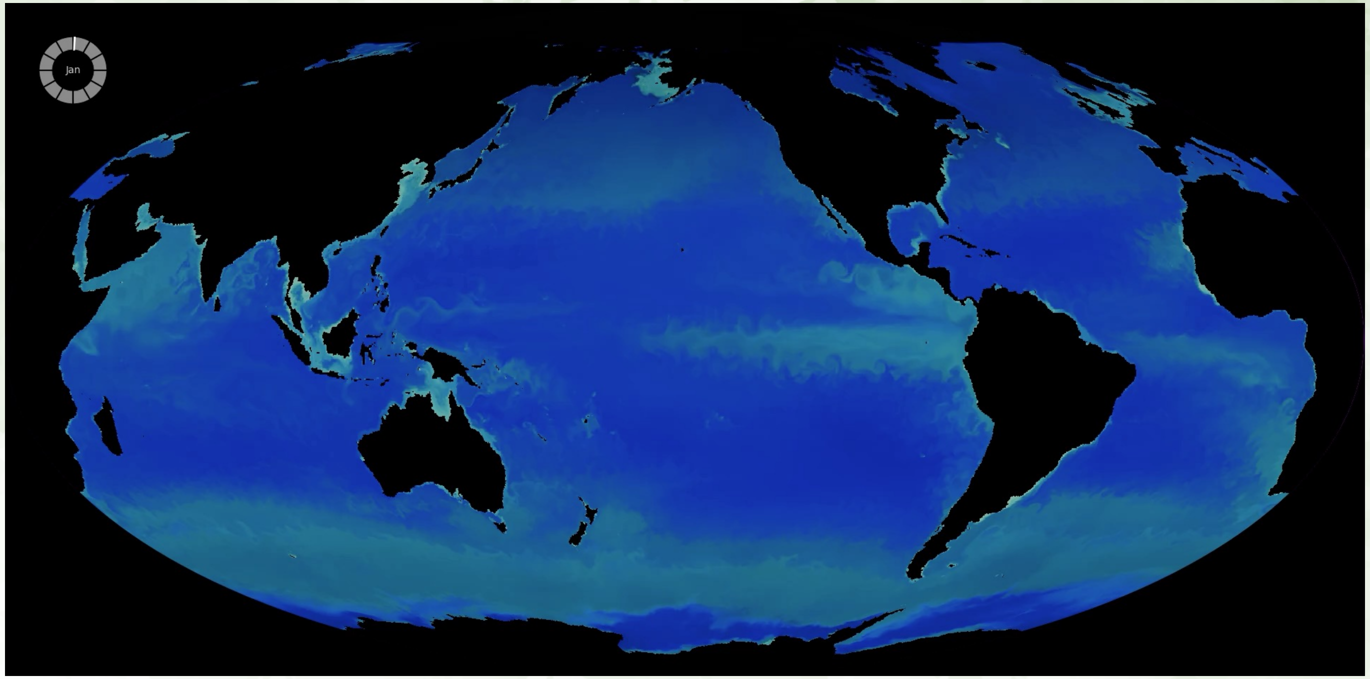
Method in Lauderdale *et al.* (2016)

Increasing the fidelity of ECCO-Darwin



Leverage continuous record of remotely sensed optical observations to help optimize ocean biogeochemistry/ecosystem properties.

Increasing the fidelity of ECCO-Darwin



“Ocean color” from Darwin’s radiative transfer model (e.g. Dutkiewicz *et al.*, 2015; 2018; 2019)

- New NASA CCS project aims to assimilate:

  Ocean color observations, particulate export fluxes.

  Can compare ECCO-Darwin to reflectance products, $R_{rs}(\lambda)$, instead of (or in addition to) satellite chlorophyll.

  Hyperspectral information about CDOM/detritus/PFT?

  Sea-state in CO_2 flux estimates?

  ML/AI parameterizations?

Summary and Conclusions

We evaluate the 3-D global DIC budget for 1995–2018 using an global-ocean biogeochemistry state estimate (ECCO-Darwin).

In the upper ocean, circulation provides the largest gain of DIC (6.3 Pg C yr^{-1}) and biological processes are the dominant loss (8.6 Pg C yr^{-1}).

Interannual variability is greatest in equatorial regions and is associated with ENSO (2.1 Pg C yr^{-1}).

ECCO-Darwin model and output are open source, fully transparent, and ready for interesting applications!

Framework is being constantly improved = better mechanistic understanding of the ocean carbon reservoir, future trajectory of its sources and sinks.

Data Availability

ECCO group website:
https://www.ecco-group.org/

Platform-independent instructions and code for running ECCO-Darwin:
https://github.com/MITgcm-contrib/ecco_darwin

ECCO-Darwin model output:
https://data.nas.nasa.gov/ecco/