ECCO-Darwin: A Data-Constrained, Global Ocean Ecology and Biogeochemistry Model

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Some key ECCO-Darwin references:

Brix et al. (2015). **Using Green's Functions to initialize and adjust a global, eddying ocean biogeochemistry general circulation model**. *Ocean Modelling*, *95*, 1–14. https://doi.org/10.1016/j.ocemod.2015.07.008

Carroll et al. (2020). **The ECCO-Darwin Data-Assimilative Global Ocean Biogeochemistry Model: Estimates of Seasonal to Multidecadal Surface Ocean p CO 2 and Air-Sea CO 2 Flux.** *Journal of Advances in Modeling Earth Systems*, *12*(10), 1–28. https://doi.org/10.1029/2019MS001888

Carroll et al. (2022). **Attribution of Space-Time Variability in Global-Ocean Dissolved Inorganic Carbon.** *Global Biogeochemical Cycles*, *36*(3), 1–24. https://doi.org/10.1029/2021GB007162

Outline

1. Motivation for a "data-constrained" ocean biogeochemistry model

2. ECCO vs GLORYS (state estimation vs reanalysis)

3. A brief history of ECCO-Darwin

4. Physics and biogeochemistry data assimilation

5. Attribution of Dissolved Inorganic Carbon (DIC) variability

6. Summary and some future directions

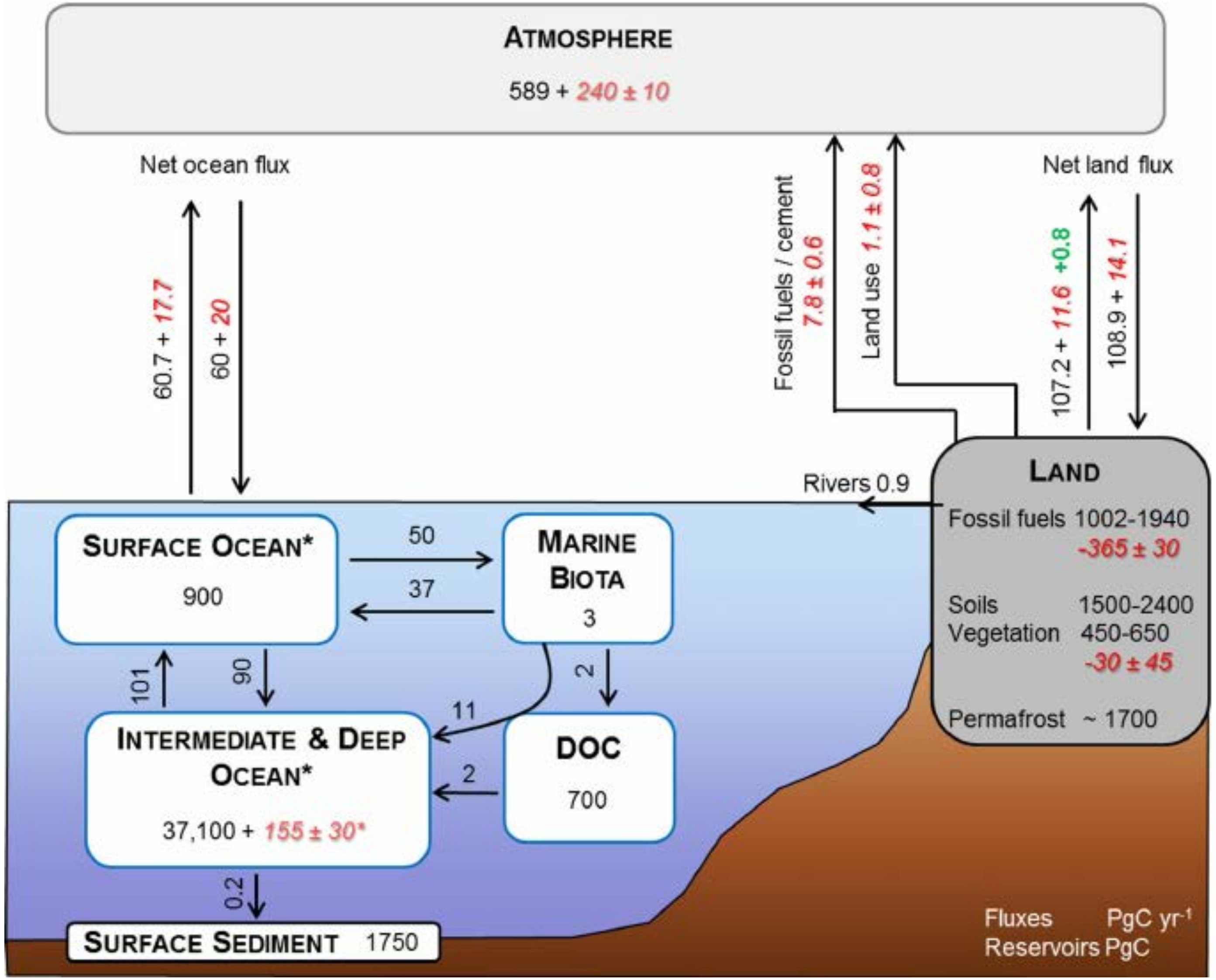
Motivation for ECCO-Darwin

The ocean is a huge reservoir of carbon, containing approximately 95% of active carbon.

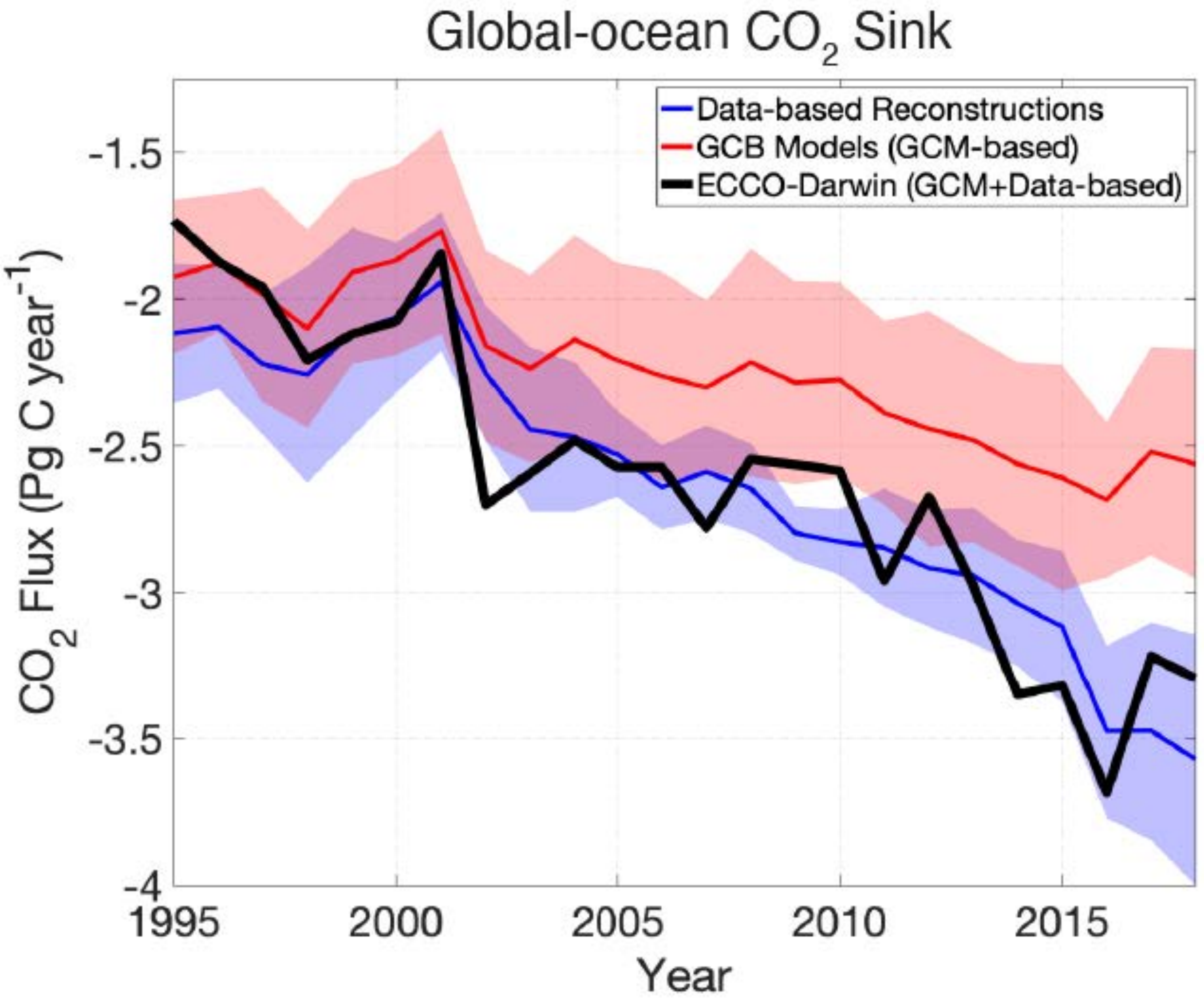
It has absorbed ~40% of fossil-fuel CO_2 emissions since beginning of industrial revolution.

Small changes in ocean absorption rate can have large consequences in peak atmospheric CO_2.

Need to understand mechanisms of air-sea exchange, transport, and storage of carbon by the ocean.



Global carbon cycle reservoirs, fluxes, and anthropogenic perturbations.



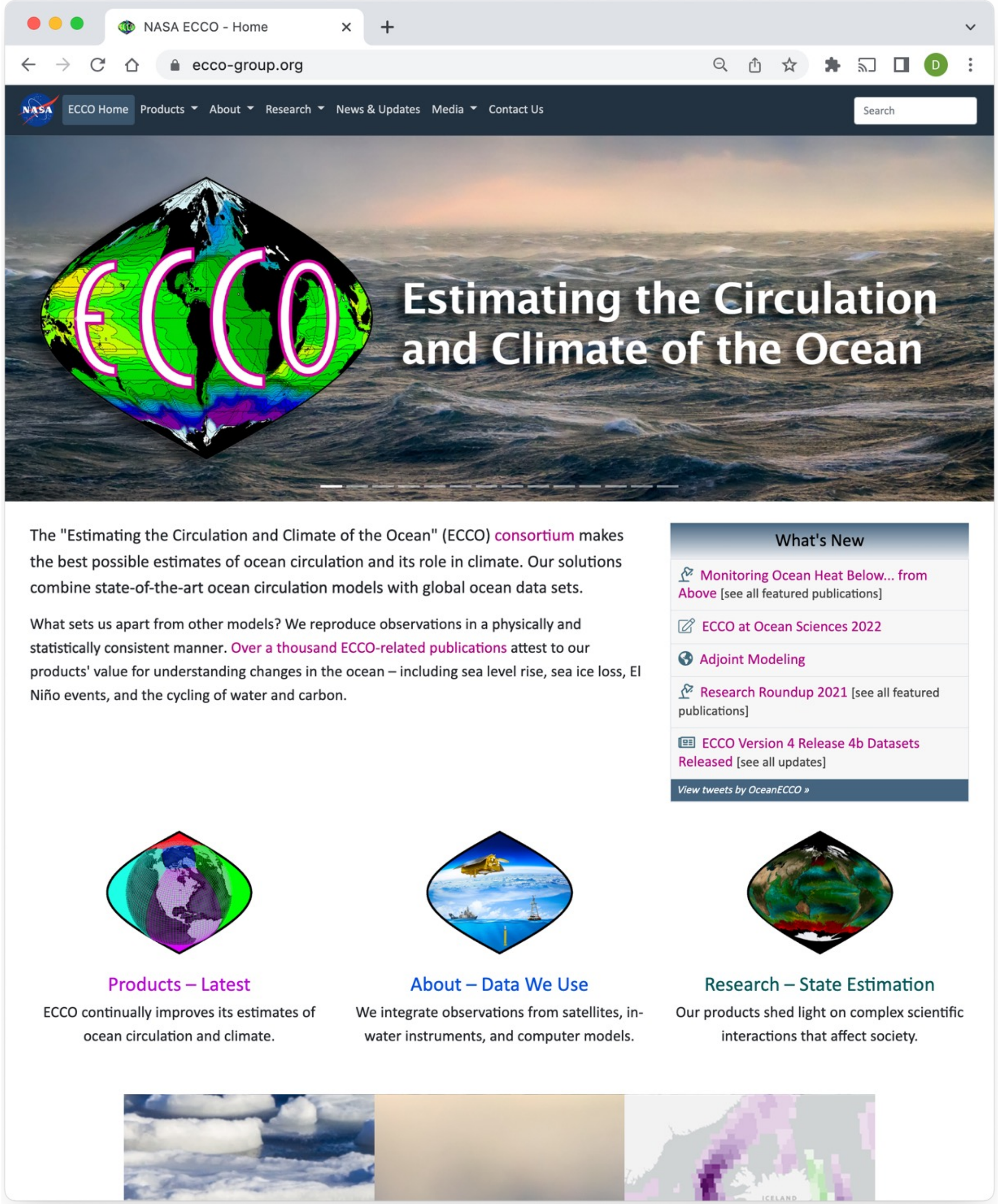
Globally-integrated air-sea CO_2 flux from 6 leading data-based reconstructions (blue), 9 Global Carbon Budget (GCB) hindcast models (red), and the ECCO-Darwin model (black).

Unlike GCB models, ECCO-Darwin assimilates physical and biogeochemical observations and hence is more consistent with data-based reconstructions.

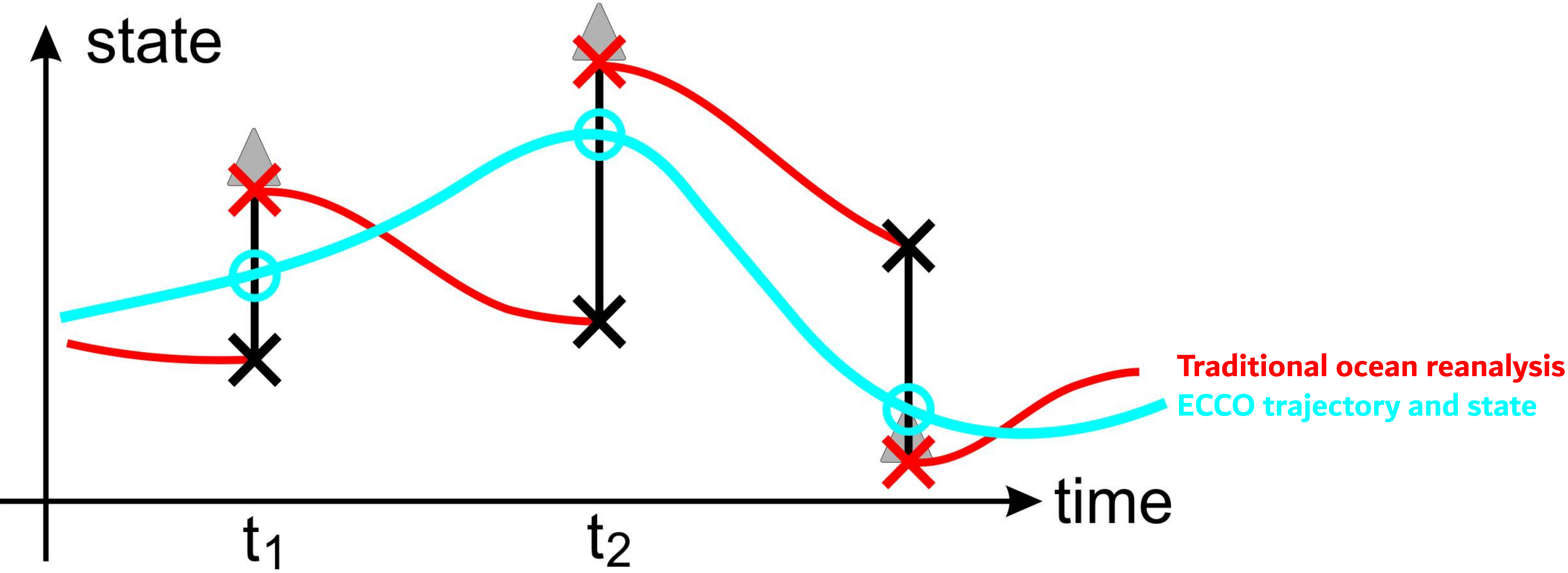
Unlike data-based reconstructions, ECCO-Darwin solutions can be used to explore the individual processes that control ocean carbon sequestration.

Diagnosing drivers of ocean carbon sources and sinks is critical for understanding the future trajectory of the ocean carbon reservoir in a perturbed climate system.

ECCO ocean state estimate vs GLORYS ocean reanalysis



ECCO state estimates are ***physically-consistent*** *solutions of free-running models that are made* ***consistent with observational data*** *and their uncertainties.*



Inverse problem solved by ECCO: Solve for a set of *model initial conditions*, *atmospheric boundary conditions*, and *ocean mixing parameters* such that residuals between the **model solution** and the **observations** are minimized in a least-squares sense.

A brief history of ECCO-Darwin

1999: Start of NOPP ECCO project (PI D. Stammer, SIO)

2000: G. McKinley discovers importance of ocean circulation estimates that do not contain discontinuities for carbon/oxygen tracer studies

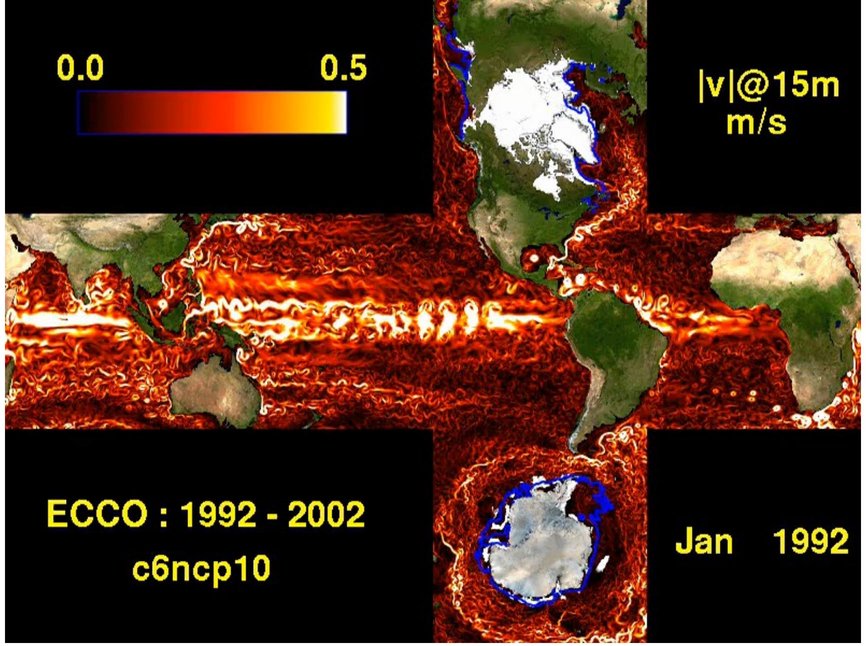
2005: ECCO participates in OCMIP-2 experiments

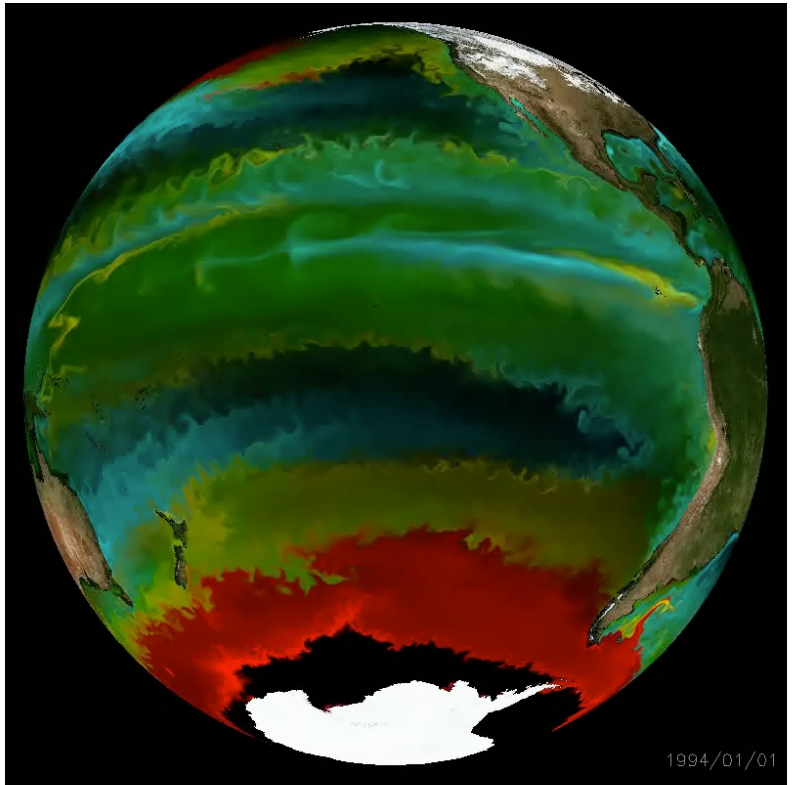
2005: M. Follows and S. Dutkiewicz start the MIT Darwin project: http://darwinproject.mit.edu

2010: ECCO + Darwin invited to participate in NASA Carbon Monitoring System (CMS) Pilot Study

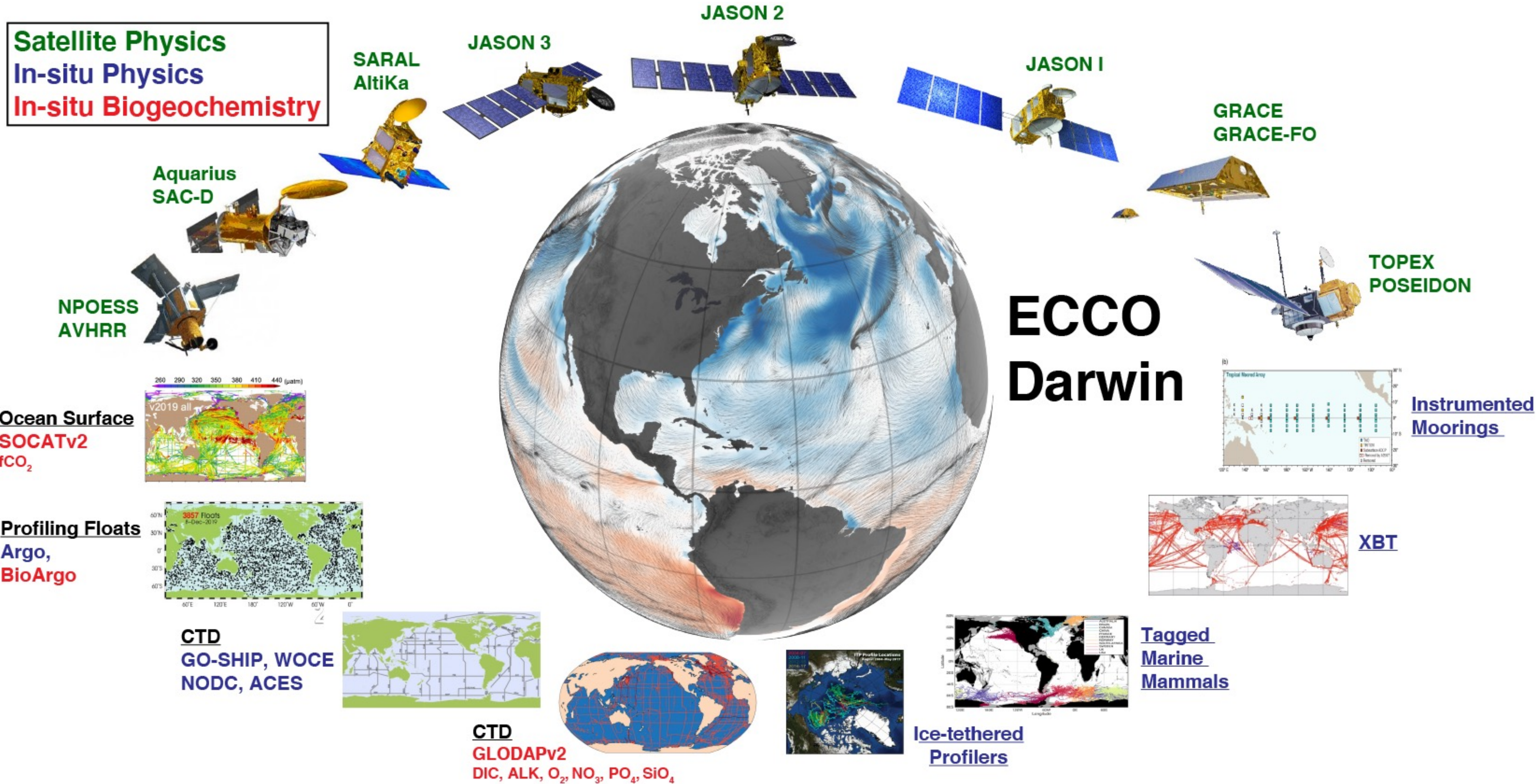
2017: Dustin Carroll joins the ECCO-Darwin team

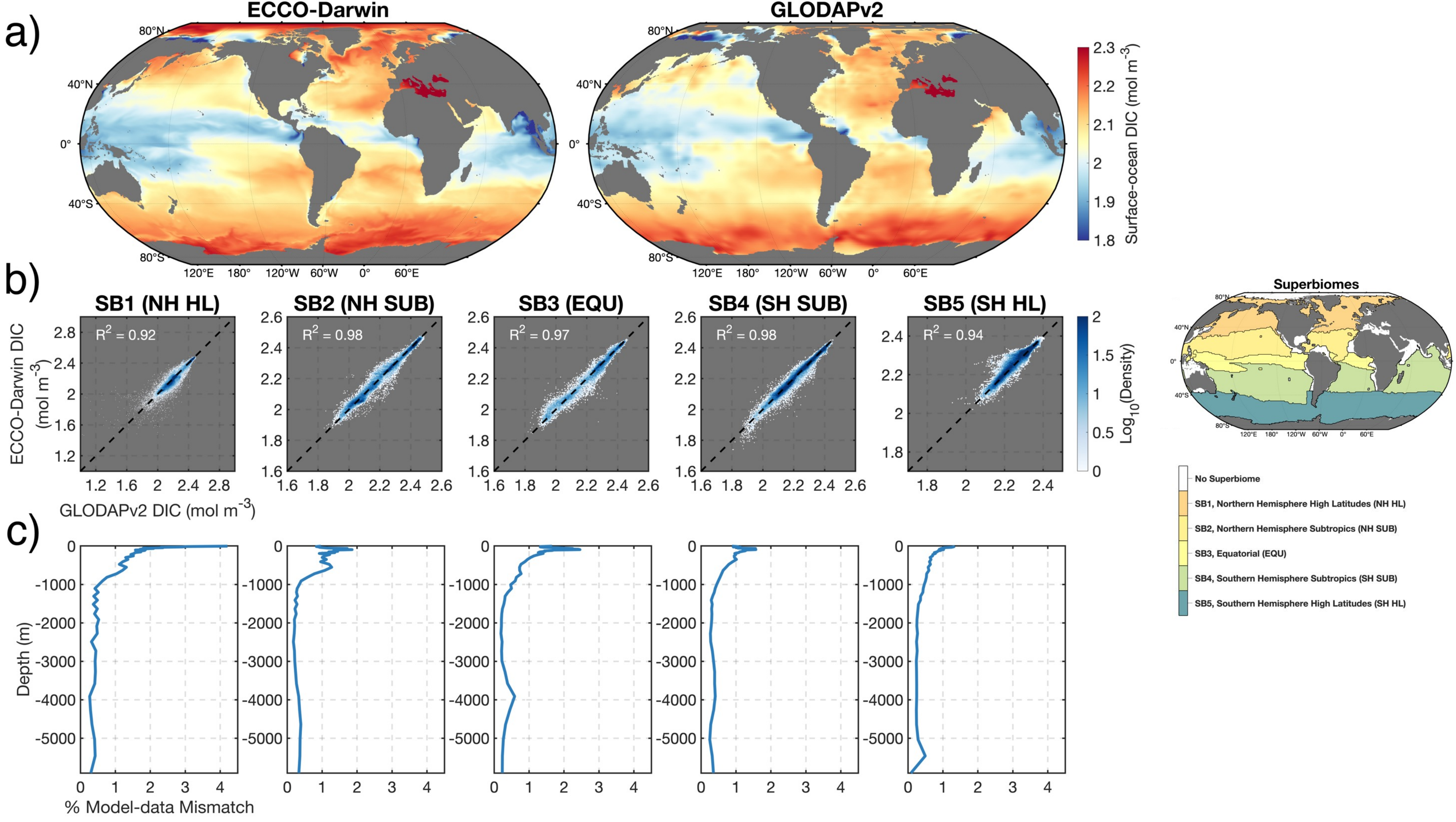
2022: Raphaël Savelli starts work on improved representation of Land-Ocean-Aquatic Continuum (LOAC) in ECCO-Darwin!





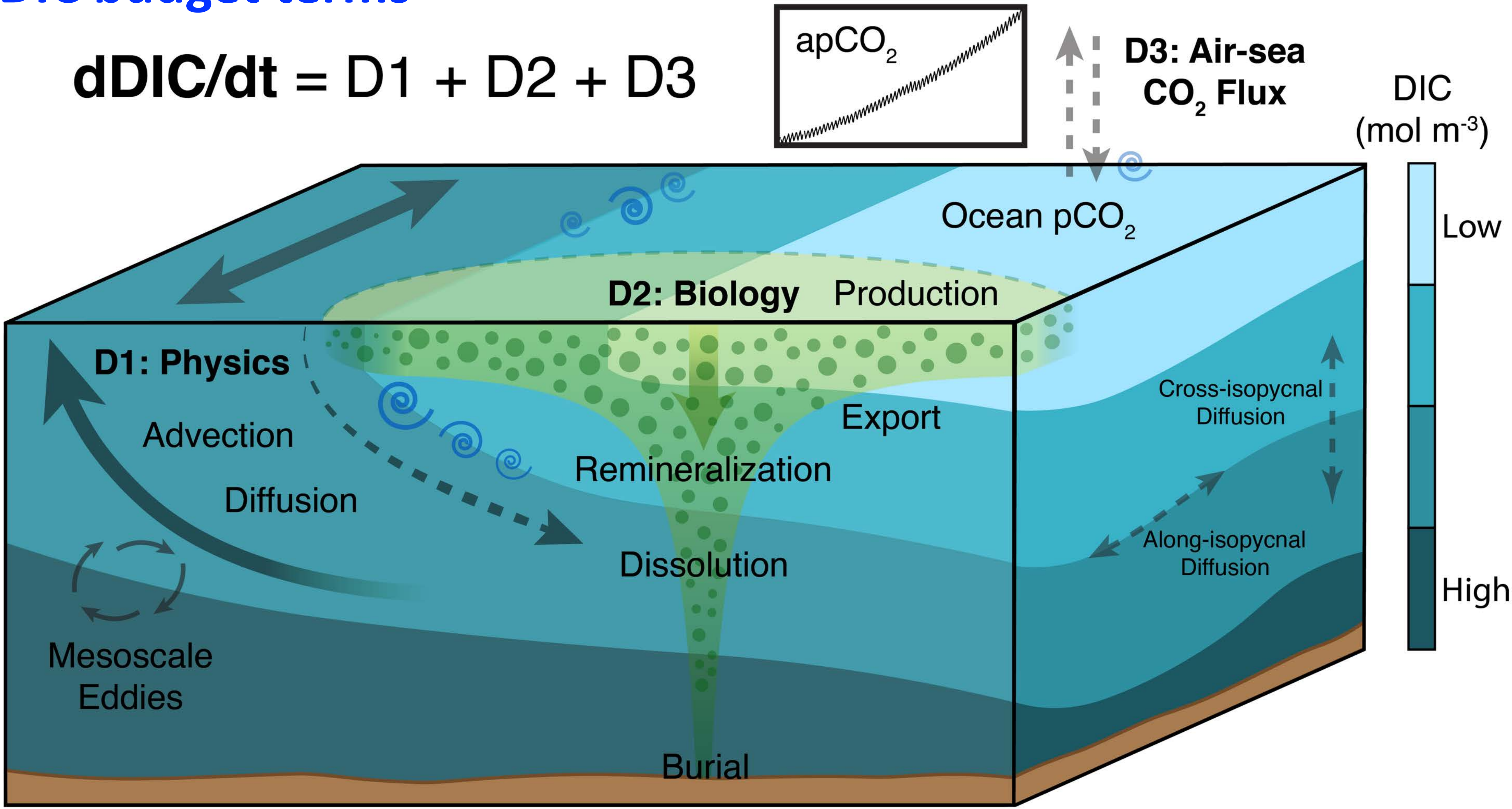
Physics and biogeochemistry data assimilation

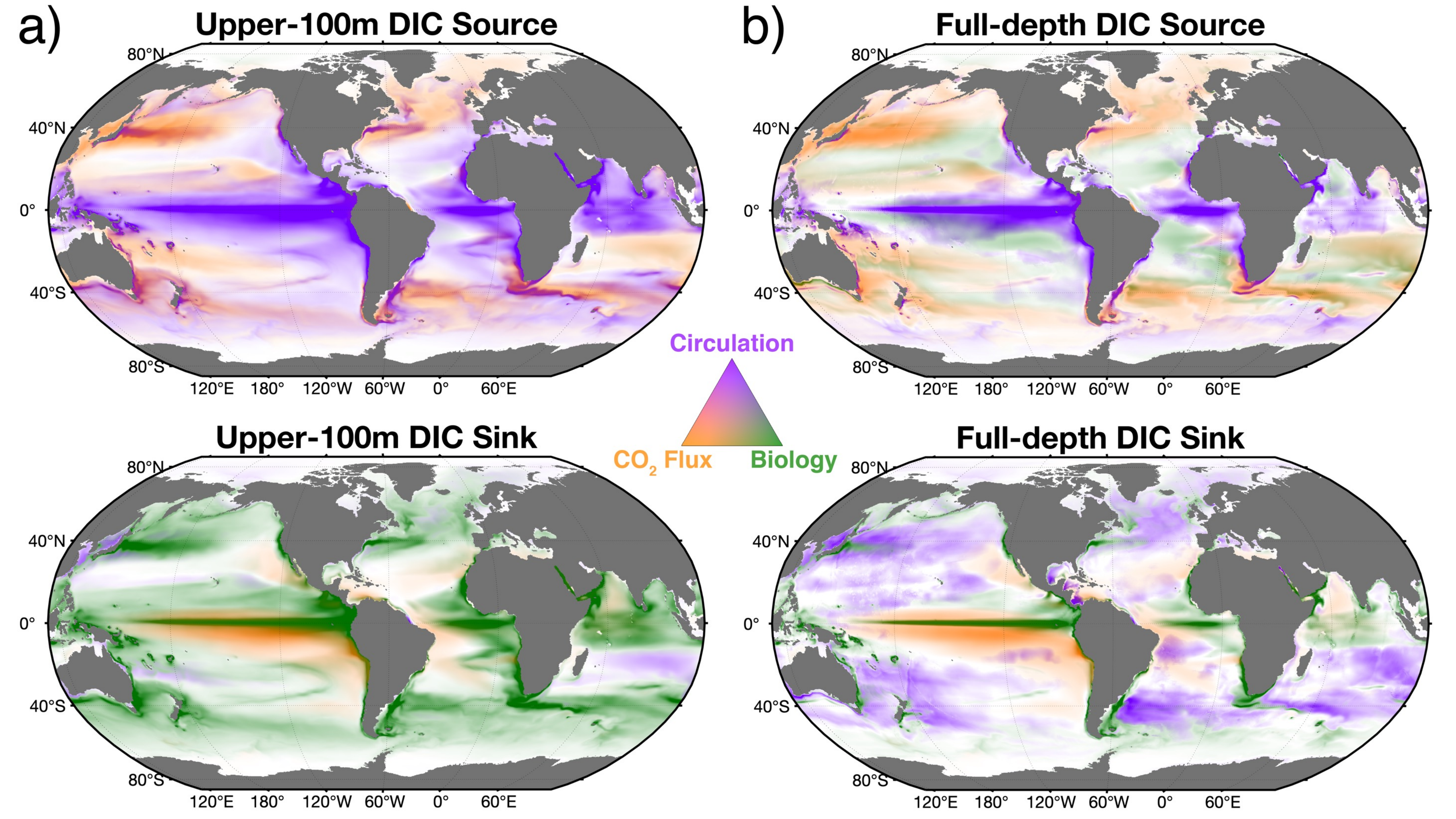



a)
ECCO-Darwin
GLODAPv2
Surface-ocean DIC (mol m^{-3})
b)
SB1 (NH HL)
SB2 (NH SUB)
SB3 (EQU)
SB4 (SH SUB)
SB5 (SH HL)
R^2 = 0.92
R^2 = 0.98
R^2 = 0.97
R^2 = 0.98
R^2 = 0.94
ECCO-Darwin DIC (mol m^{-3})
GLODAPv2 DIC (mol m^{-3})
Log_{10}(Density)
Superbiomes
No Superbiome
SB1, Northern Hemisphere High Latitudes (NH HL)
SB2, Northern Hemisphere Subtropics (NH SUB)
SB3, Equatorial (EQU)
SB4, Southern Hemisphere Subtropics (SH SUB)
SB5, Southern Hemisphere High Latitudes (SH HL)
c)
Depth (m)
% Model-data Mismatch

DIC budget terms

$$dDIC/dt = D1 + D2 + D3$$




a)
Upper-100m DIC Source
b)
Full-depth DIC Source
Upper-100m DIC Sink
Full-depth DIC Sink
Circulation
CO2 Flux
Biology
80°N
40°N
0°
40°S
80°S
120°E
180°
120°W
60°W
0°
60°E

Summary and some future directions

- By assimilating physical and biogeochemical observations, ECCO-Darwin produces air-sea CO_2 fluxes that exhibit broad-scale consistency with interpolation-based products.
- Contrary to interpolation-based products, ECCO-Darwin is less sensitive to sparse and uneven observational sampling and it permits full attribution of the inferred air-sea CO_2 flux spatiotemporal variability.
- ECCO-Darwin has been used to attribute the space-time variability of global-ocean Dissolved Inorganic Carbon (DIC) to physical, biological, and air-sea CO_2 flux drivers.
- Detailed model-data comparison (uncertainty/confidence quantification) and anthropogenic/natural carbon publications in preparation.
- Ongoing projects aim to improve representation of land-ocean-aquatic continuum, ocean ecology, carbon chemistry, bottom sediments, and ice-biology-carbon interactions in polar regions.
- ECCO-Darwin is being used to study the impact of ENSO events on the global ocean CO_2 sink, ocean acidification, ocean carbon mitigation strategies, biological ocean mixing.
- Some recently proposed applications include in-silico studies of kelp farming and sargassum lifecycle predictions.