

# **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, eddy 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<sub>2</sub> and Air-Sea CO<sub>2</sub> 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

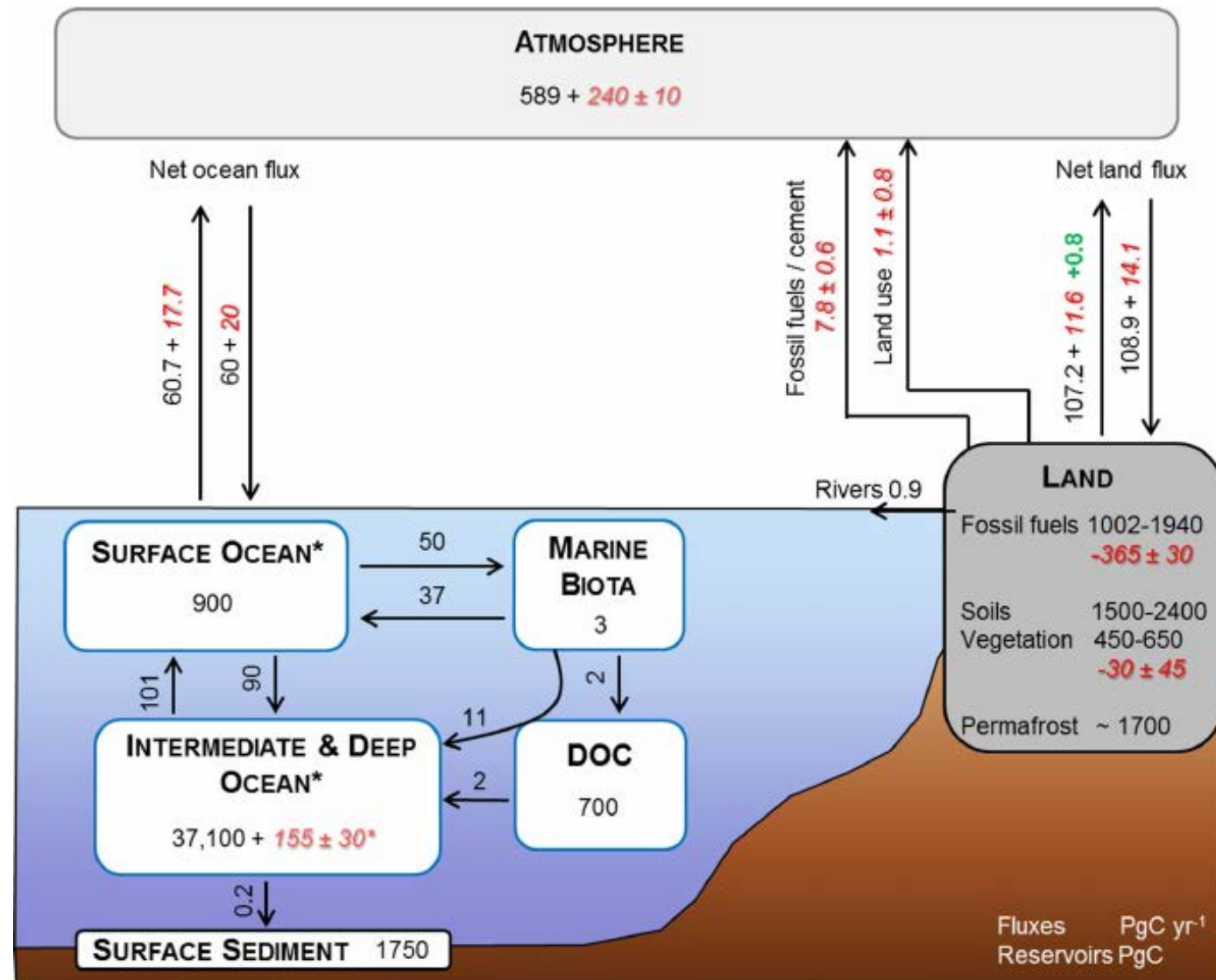
# Motivation for ECCO-Darwin

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

It has absorbed  $\sim 40\%$  of fossil-fuel  $\text{CO}_2$  emissions since beginning of industrial revolution.

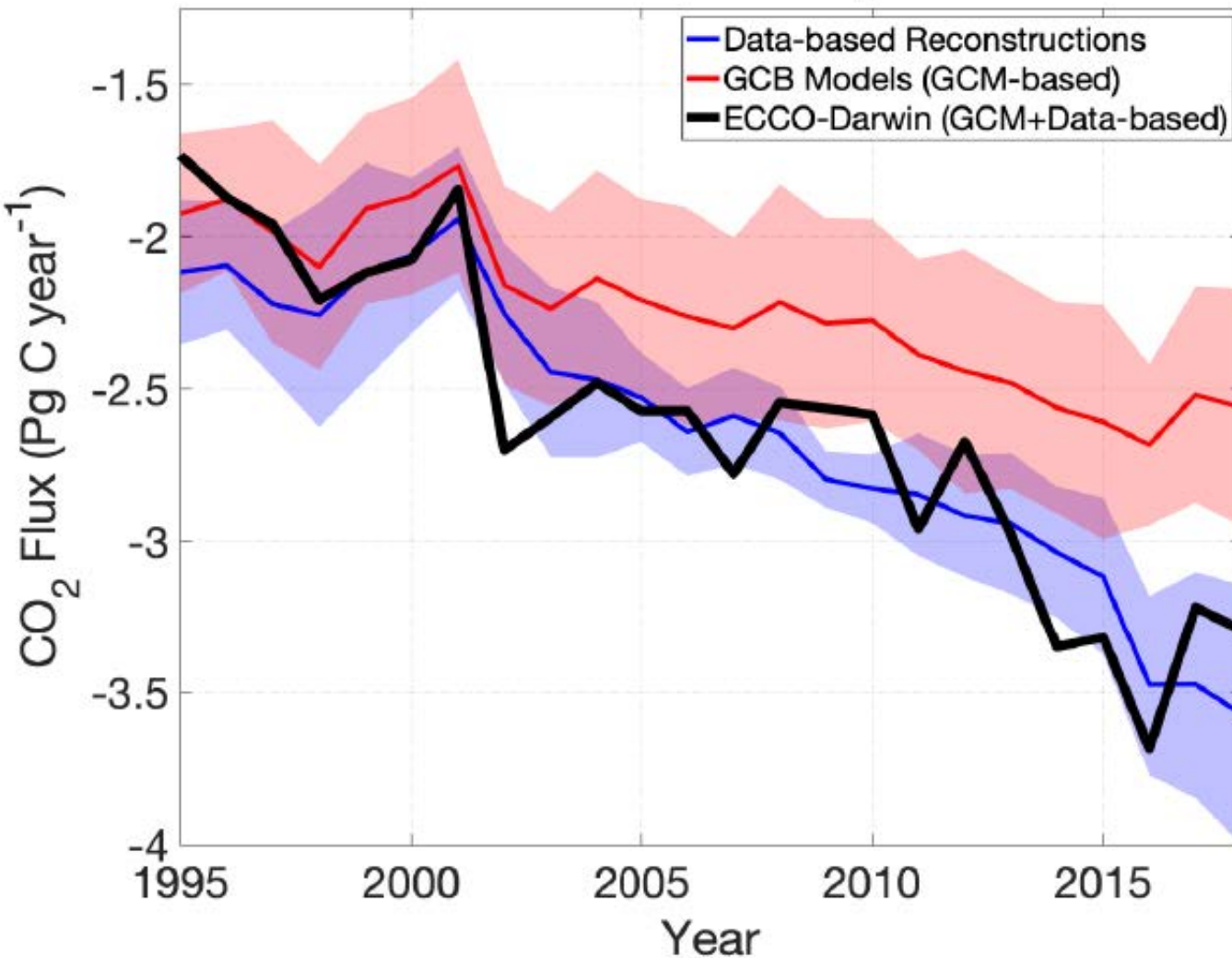
Small changes in ocean absorption rate can have large consequences in peak atmospheric  $\text{CO}_2$ .

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



**Global carbon cycle reservoirs, fluxes, and anthropogenic perturbations.**

## Global-ocean CO<sub>2</sub> Sink



Globally-integrated air-sea CO<sub>2</sub> 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.

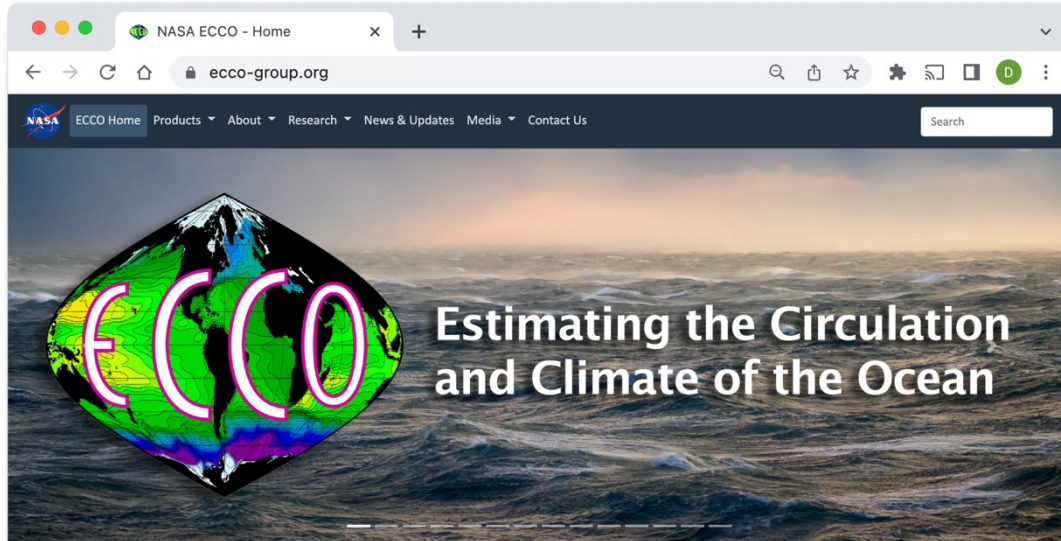
**Diagnosing drivers of ocean carbon sources and sinks** is critical for understanding the future trajectory of the ocean carbon reservoir in a perturbed climate system.



# ECCO ocean state estimate

vs


# GLORYS ocean reanalysis




The "Estimating the Circulation and Climate of the Ocean" (ECCO) **consortium** makes the best possible estimates of ocean circulation and its role in climate. Our solutions combine state-of-the-art ocean circulation models with global ocean data sets.


What sets us apart from other models? We reproduce observations in a physically and statistically consistent manner. **Over a thousand ECCO-related publications** attest to our products' value for understanding changes in the ocean – including sea level rise, sea ice loss, El Niño events, and the cycling of water and carbon.


## What's New

 **Monitoring Ocean Heat Below... from Above** [see all featured publications]

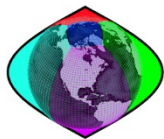
 **ECCO at Ocean Sciences 2022**

 **Adjoint Modeling**

 **Research Roundup 2021** [see all featured publications]

 **ECCO Version 4 Release 4b Datasets Released** [see all updates]

[View tweets by OceanECCO »](#)



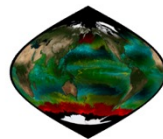
## Products – Latest

ECCO continually improves its estimates of ocean circulation and climate.



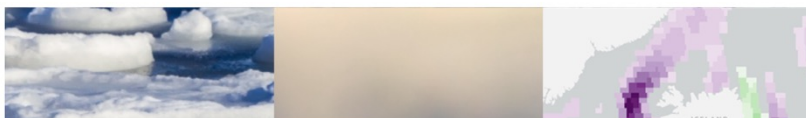
## About – Data We Use

We integrate observations from satellites, in-water instruments, and computer models.



## Research – State Estimation

Our products shed light on complex scientific interactions that affect society.



An Ocean Reanalysis is a scientific method that produces a comprehensive record of how ocean properties are changing over time. The outputs of a numerical ocean general circulation model that simulates the evolution of the ocean physical properties are combined objectively with observations to generate a synthesized estimate of the state of the ocean (here the temperature, salinity, current speed and direction, sea level and sea-ice extent, concentration and thickness).

- GLORYS produces and distributes global ocean reanalyses at eddy-permitting (1/4°) resolution that aim to describe the mean and time-varying state of the ocean circulation, including a part of the mesoscale eddy field, over recent past decades with a focus on the period since when satellite altimetry measurements of sea level provide reliable information on ocean eddies (i.e. from 1993 to present).
- GLORYS is a joint effort between Mercator Ocean operational oceanography centre in Toulouse, the academic research community represented by CNRS research scientists and engineers in Grenoble and Brest, the CORIOLIS data centre in Brest and CLS in Toulouse. The GLORYS project is supported by the French Groupe Mission Mercator Coriolis (GMMC), INSU-CNRS and the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement n°218812 (MyOcean).
- GLORYS reanalysis project is carried out in the framework the European **Copernicus Marine Environment Monitoring Service (CMEMS)**. GLORYS project also contributes to GodaeOceanview and CLIVAR international programs, the realisation of ocean reanalyses between these two programs being coordinated by the Global Synthesis and Observations Panel (GSOP).
- The numerical model used is the NEMO OGCM in the ORCA025 configuration developed within DRAKKAR consortium (global with sea-ice, 1/4° Mercator grid). The model surface boundary conditions are derived from atmospheric ECMWF reanalyses. Assimilated observations are in-situ T&S profiles, satellite SST and along track sea-level anomalies obtained from satellite altimetry. The data assimilation method is based on a reduced order Kalman filter using the SEEK formulation.

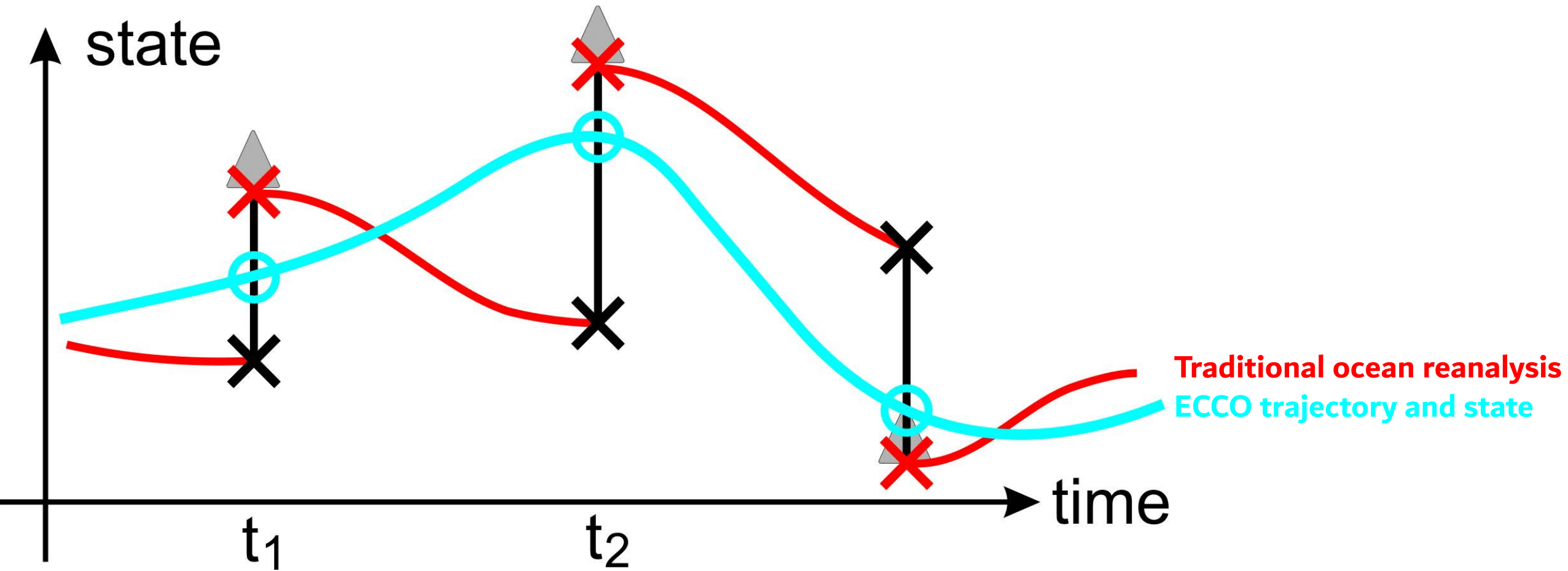


Reanalysed current speed (m/s) at 97 m depth on 3 may 2003 in GLORYS2v1

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Ok

*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

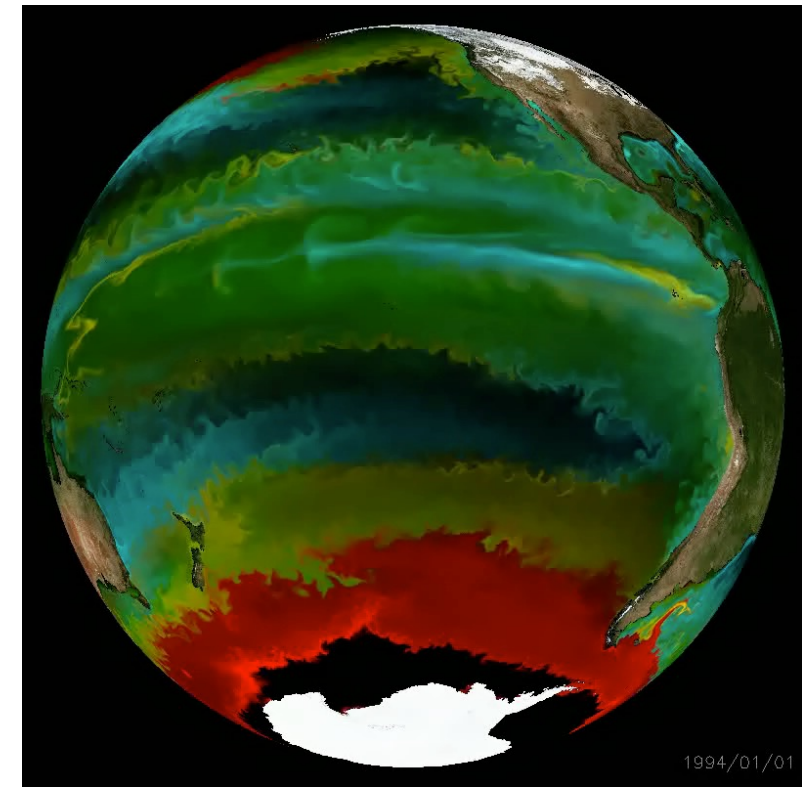
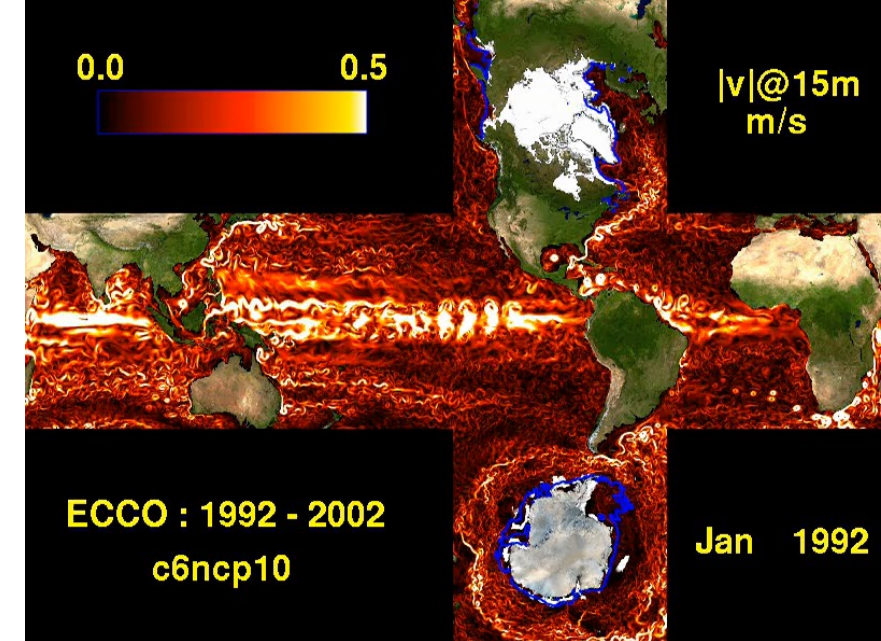
**2005:** ECCO participates in OCMIP-2 experiments

**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

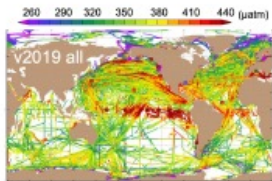
**2022:** Raphaël Savelli starts work on improved representation of Land-Ocean-Aquatic Continuum (LOAC) in ECCO-Darwin!





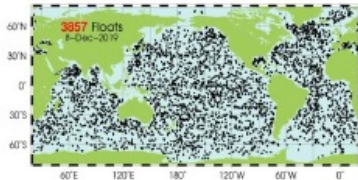
# Physics and biogeochemistry data assimilation

**Satellite Physics**  
**In-situ Physics**  
**In-situ Biogeochemistry**



**Ocean Surface**  
**SOCATv2**  
**pCO<sub>2</sub>**

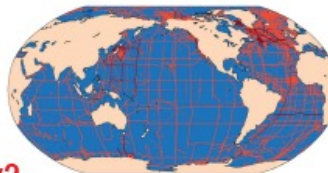
**Profiling Floats**  
**Argo,**  
**BioArgo**



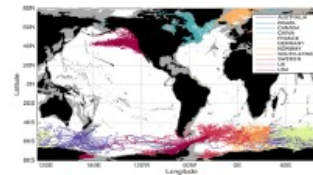
**CTD**  
**GO-SHIP, WOCE**  
**NODC, ACES**



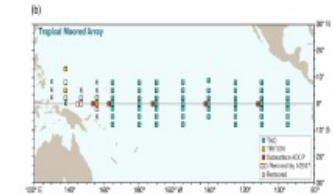
**CTD**  
**GLODAPv2**  
**DIC, ALK, O<sub>2</sub>, NO<sub>3</sub>, PO<sub>4</sub>, SiO<sub>4</sub>**



**Ice-tethered  
Profilers**



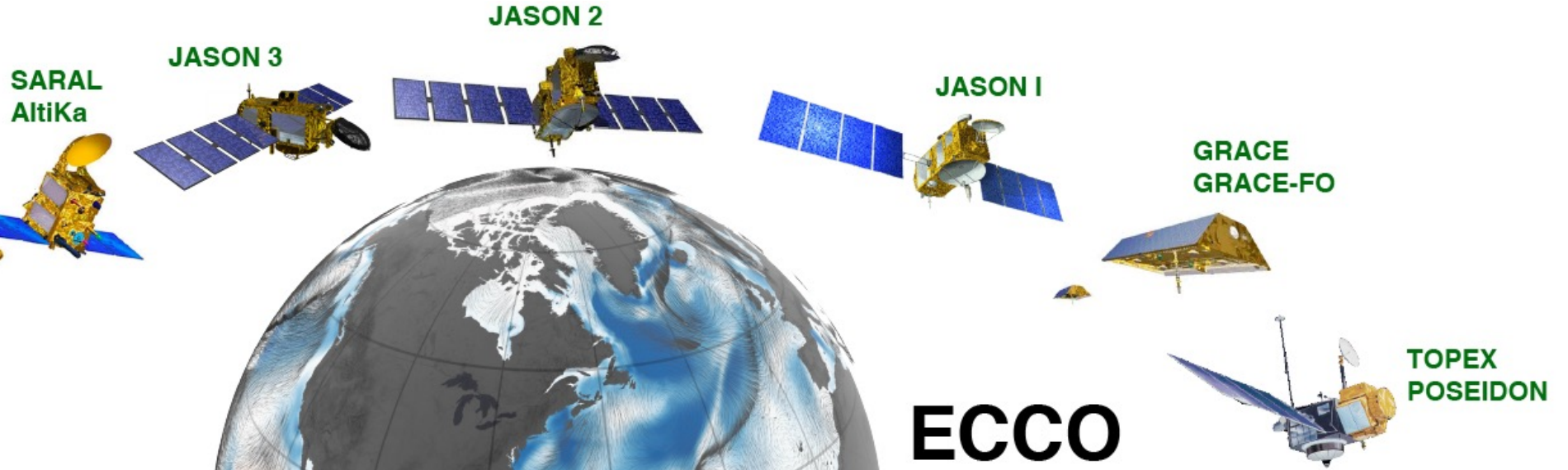
**Tagged  
Marine  
Mammals**



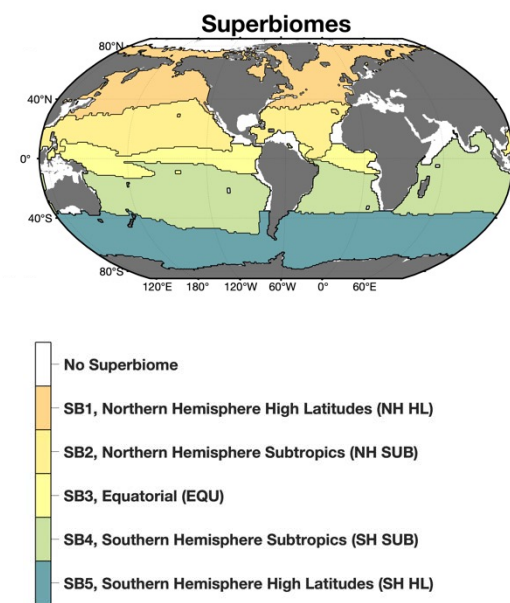
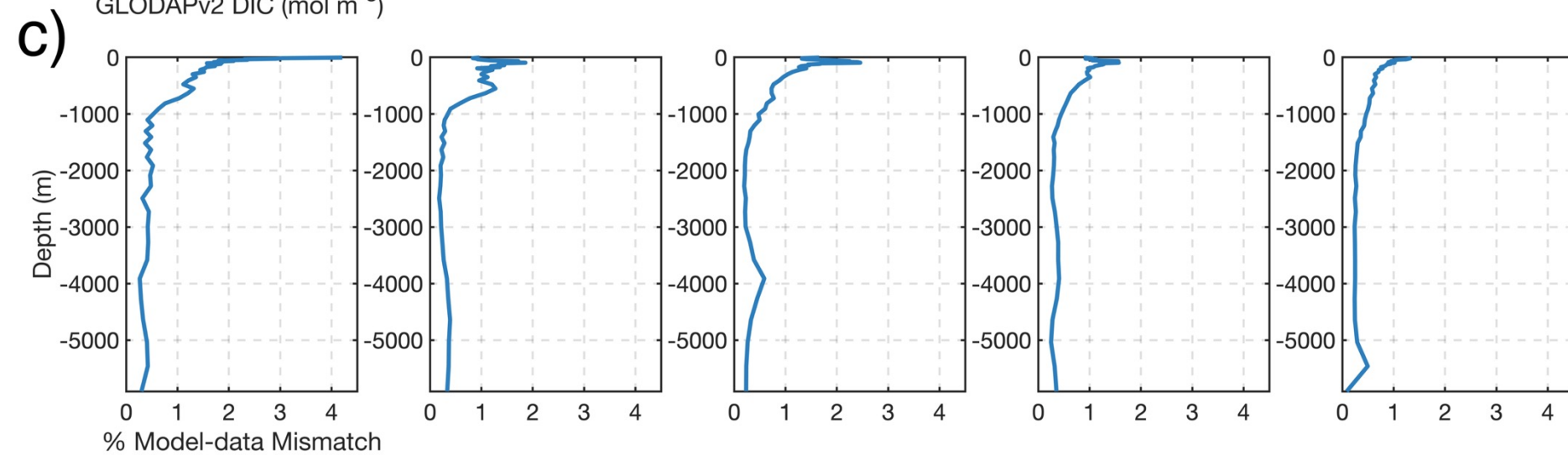
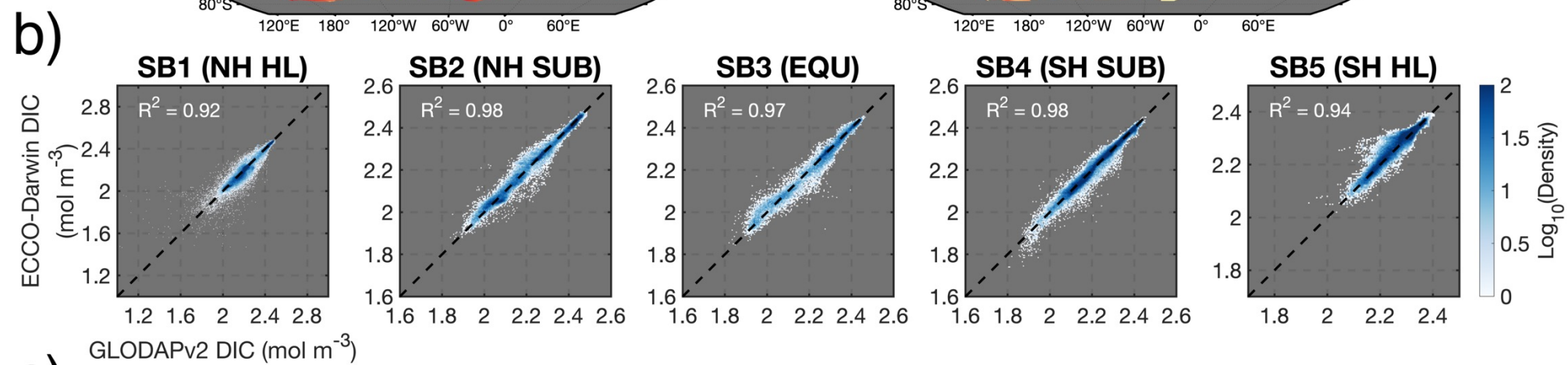
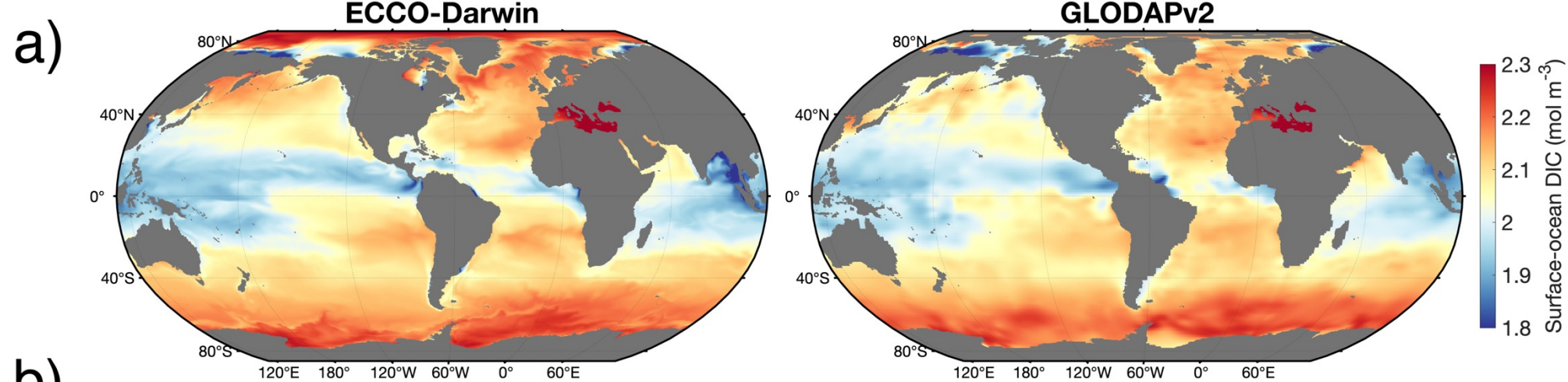
**Instrumented  
Moored**



**XBT**

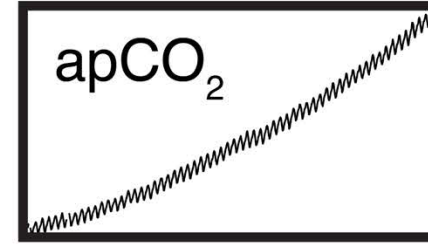






# DIC budget terms

$$d\text{DIC}/dt = D1 + D2 + D3$$

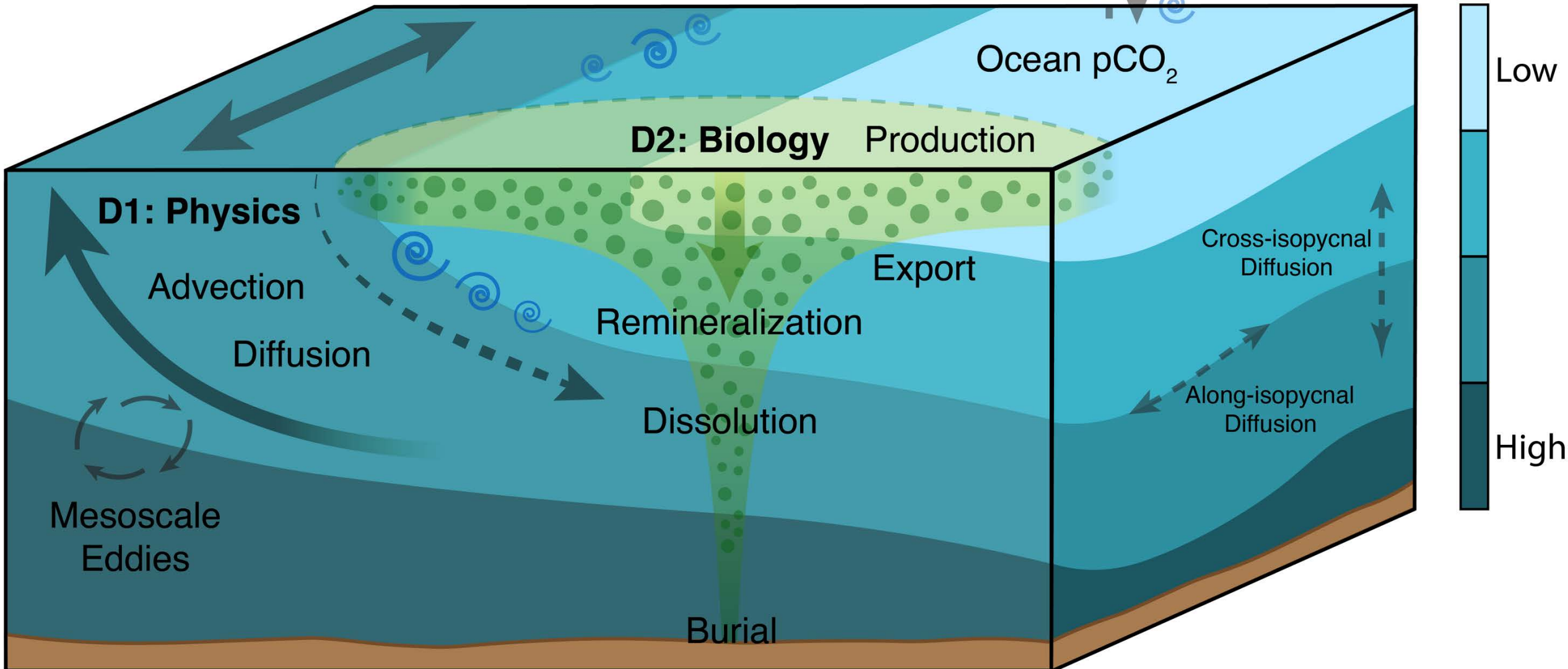


**D3: Air-sea  
CO<sub>2</sub> Flux**

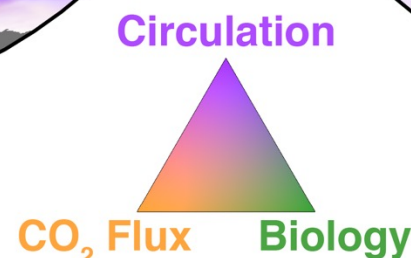
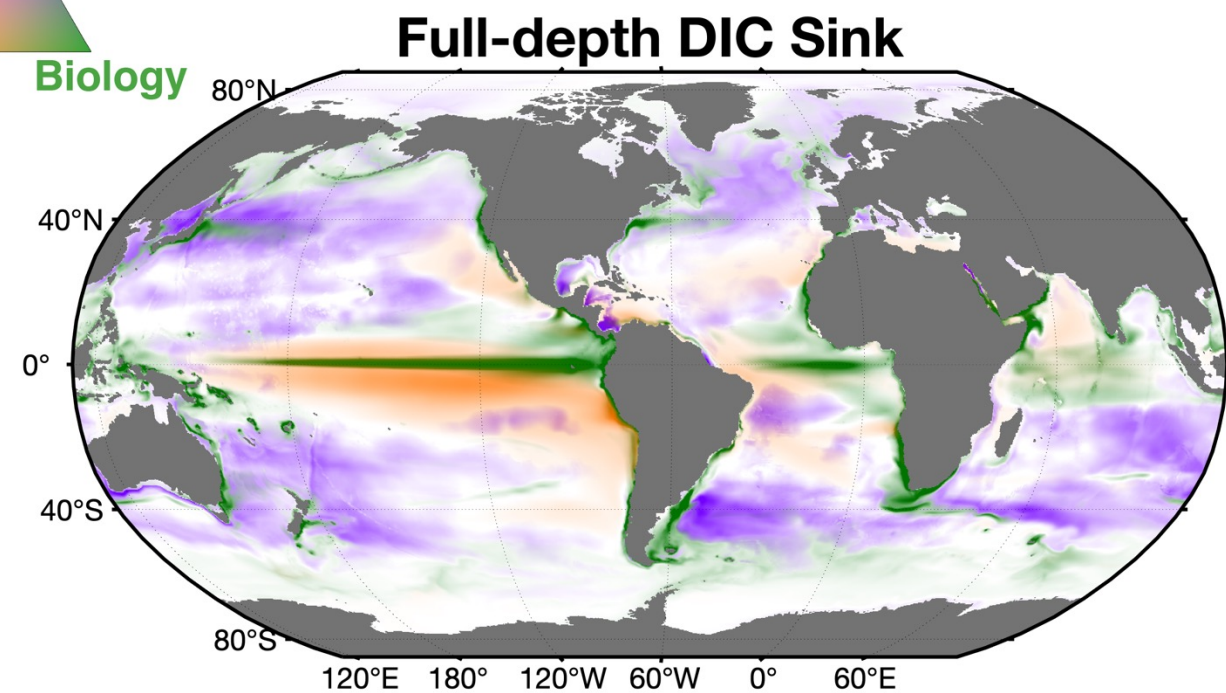
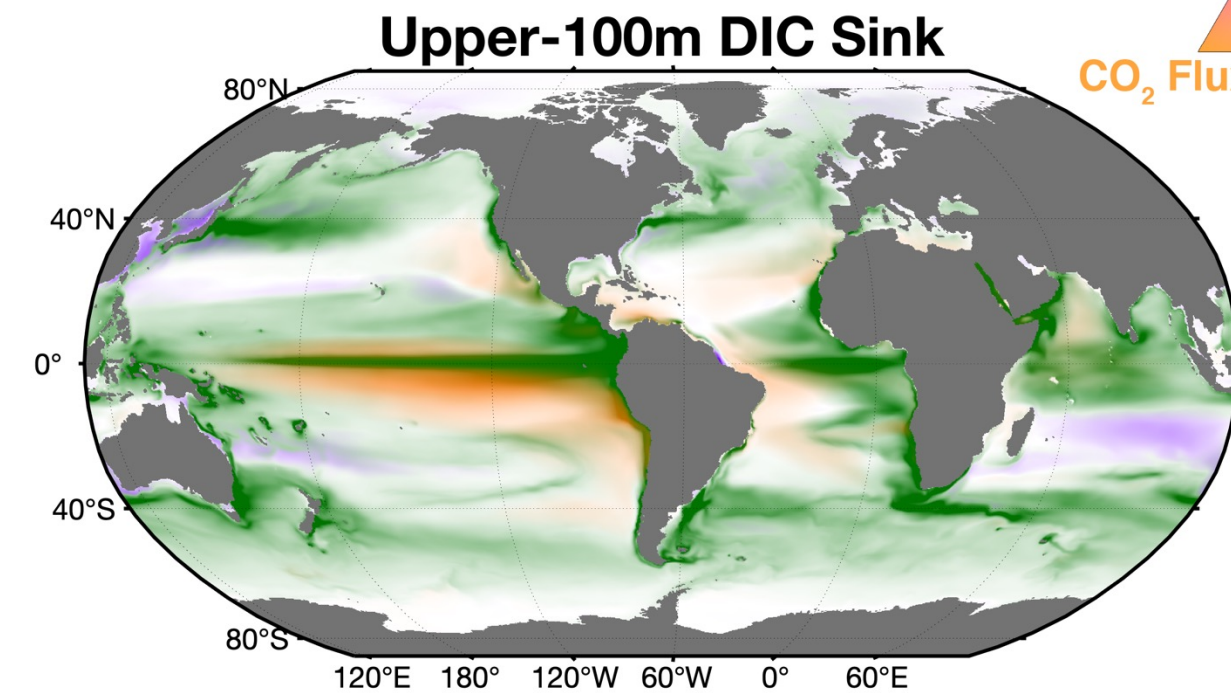
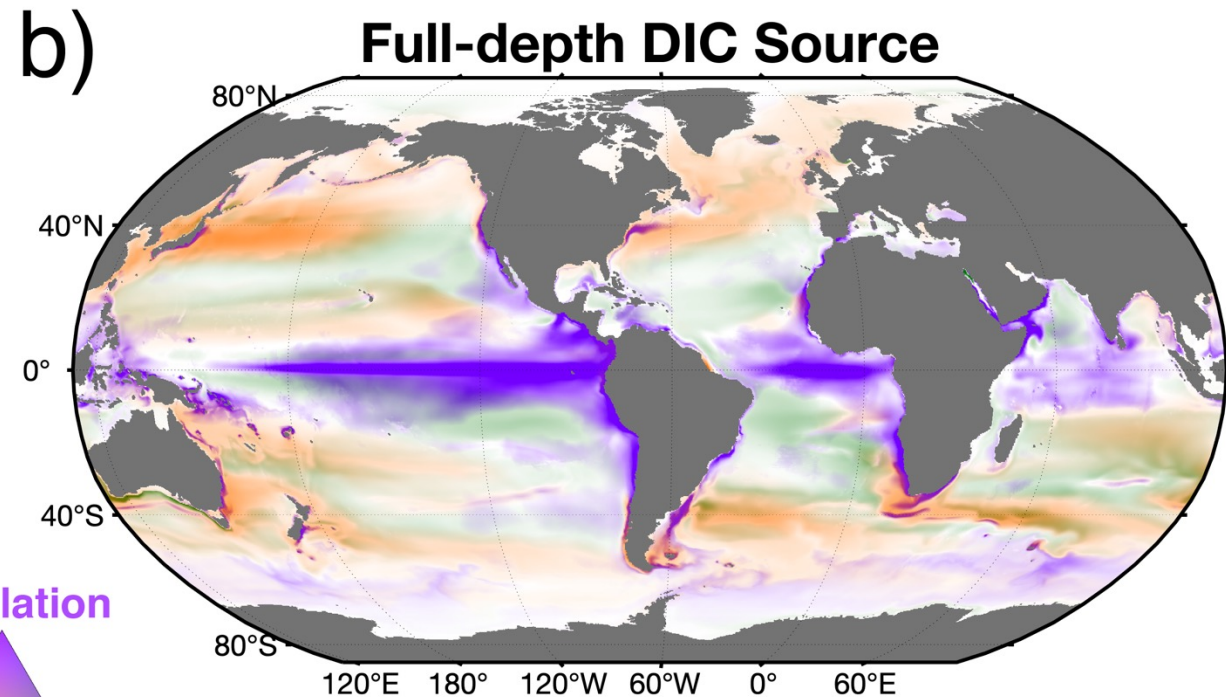
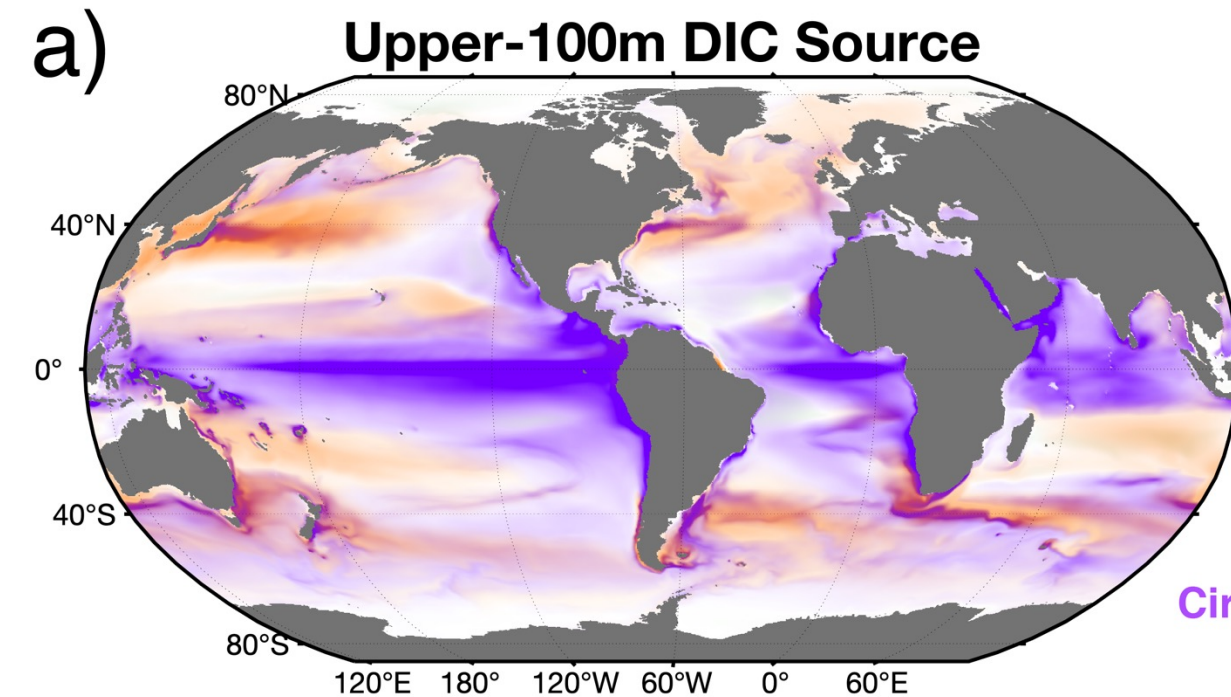
DIC  
(mol m<sup>-3</sup>)

Low

High









# Summary and some future directions

- By assimilating physical and biogeochemical observations, ECCO-Darwin produces air-sea CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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.

## Numerical modeling and remote sensing of the land-ocean aquatic continuum

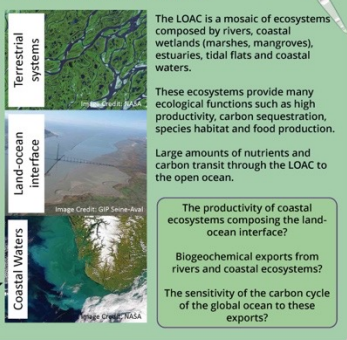
R. Savelli <sup>a</sup>, D. Menemenlis <sup>a</sup>, M. Simard <sup>a</sup>, D. Carroll <sup>b</sup>, C. Dupuy <sup>c</sup>, V. Le Fouest <sup>c</sup>



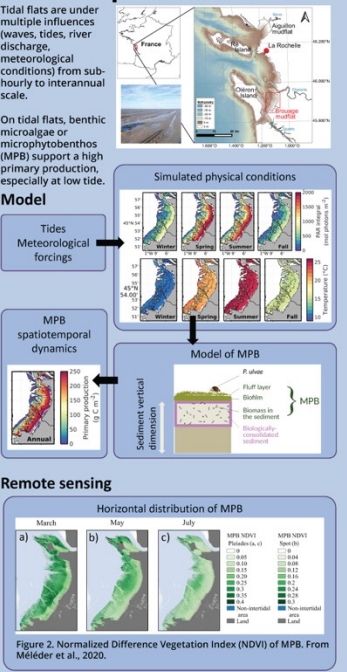
<sup>a</sup> Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA  
<sup>b</sup> Moss Landing Marine Laboratories, San José State University, Moss Landing, CA, USA  
<sup>c</sup> Littoral, Environnement et Sociétés (LIENSs), La Rochelle Université, UMR 7266, CNRS-ULR, France



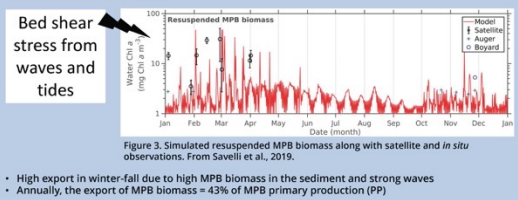
### The land-ocean aquatic continuum (LOAC)



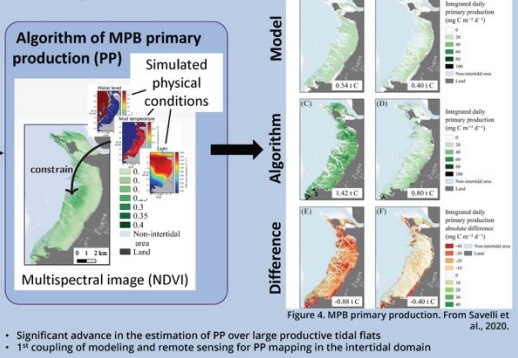
### Numerical models and remote sensing of the LOAC: the example of tidal flats



### 1D modeling of the export of MPB biomass from tidal flats



### Coupling a 3D model with space remote sensing



### Current project: what rivers and coastal wetlands bring into the global ocean ?

