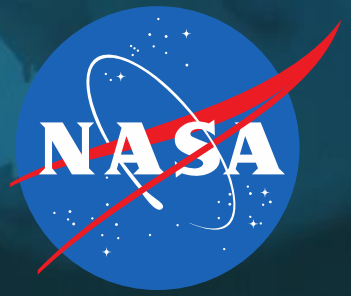
ECCO-Darwin Development Update

Dustin Carroll, Dimitris Menemenlis, Stephanie Dutkiewicz, Jonathan M. Lauderdale, Jess F. Adkins, Kevin W. Bowman, Holger Brix, Ian Fenty, Michelle M. Gierach, Chris Hill, Oliver Jahn, Peter Landschützer, Junjie Lui, Manfredi Manizza, Matt R. Mazloff, Charles E. Miller, John Naviaux, Christian Rödenbeck, David S. Schimel, Ariane Verdy, Tom Van der Stocken, Daniel B. Whitt, Hong Zhang, and many others…

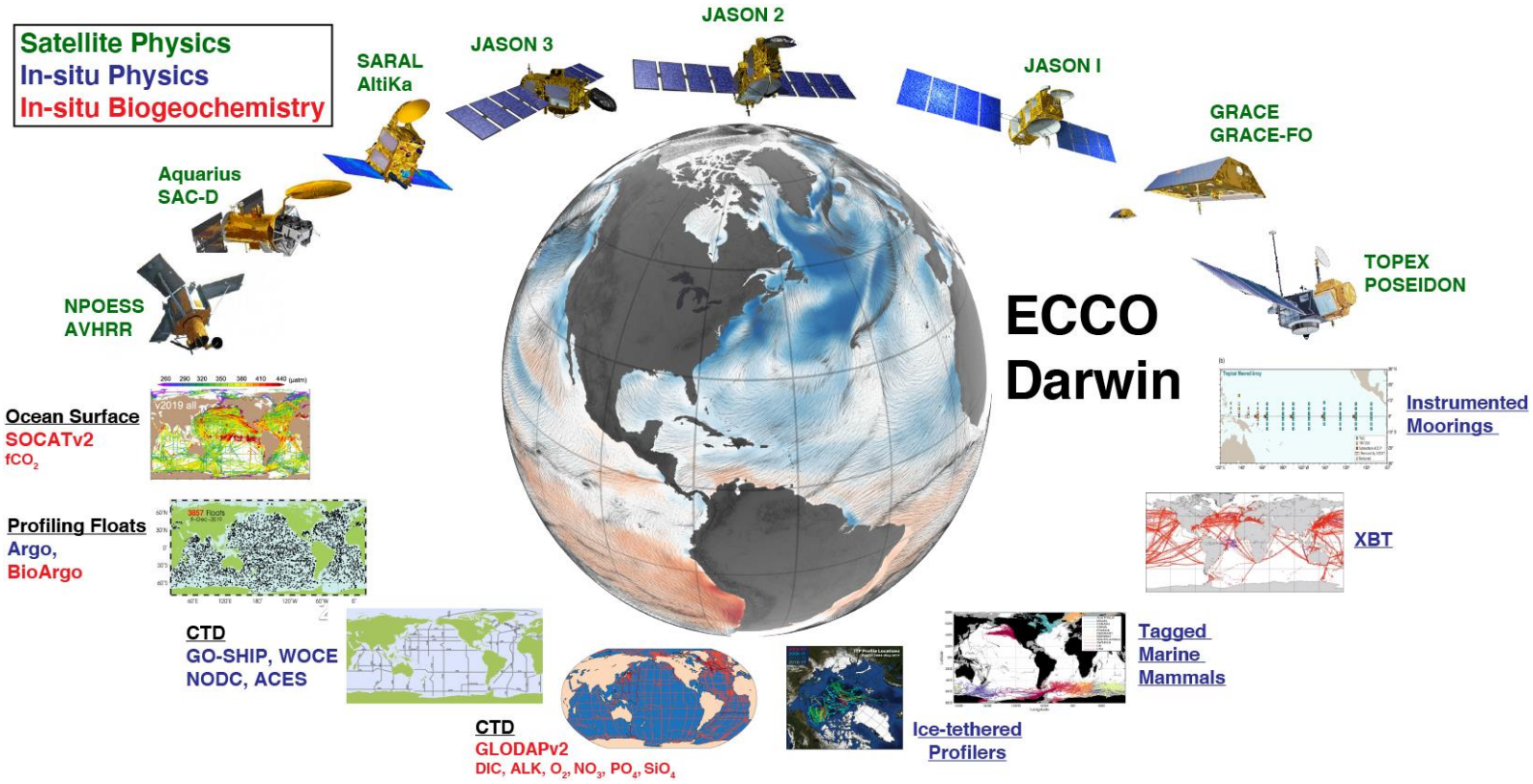
SJSU SAN JOSÉ STATE UNIVERSITY



ECCO Annual Meeting 2023

ECCO-Darwin Overview

- **ECCO-Darwin** = ocean biogeochemistry state estimate (1992–near present)
- Based on ECCO framework (physically consistent, property-conserving data assimilation)
- MIT Darwin ecology model
- Physical (adjoint method) and biogeochemical (Green's Functions) optimization



Foundational Paper #1: ECCO-Darwin Model

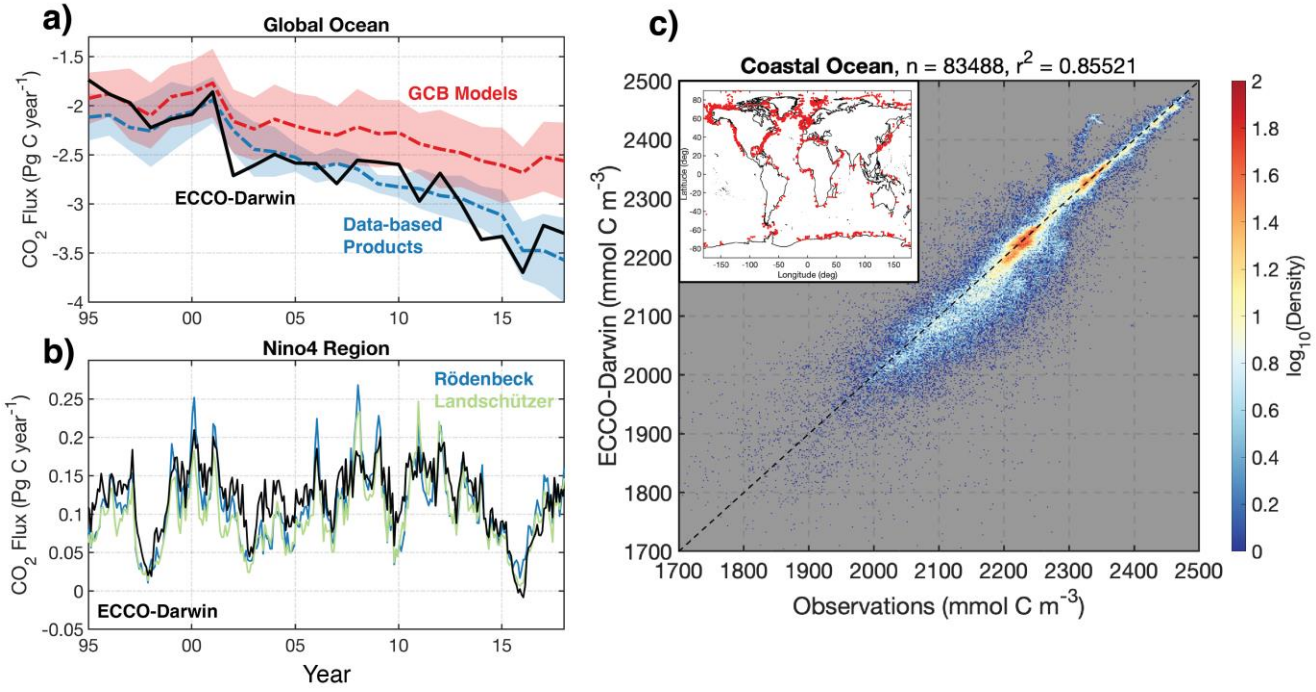
JAMES | Journal of Advances in Modeling Earth Systems

Research Article | Open Access

The ECCO-Darwin Data-Assimilative Global Ocean Biogeochemistry Model: Estimates of Seasonal to Multidecadal Surface Ocean pCO_2 and Air-Sea CO_2 Flux

D. Carroll, D. Menemenlis, J. F. Adkins, K. W. Bowman, H. Brix, S. Dutkiewicz, I. Fenty, M. M. Gierach, C. Hill, O. Jahn, P. Landschützer, J. M. Lauderdale, J. Liu, M. Manizza, J. D. Naviaux, C. Rödenbeck, D. S. Schimel, T. Van der Stocken, H. Zhang ... See fewer authors

First published: 26 July 2020 | https://doi.org/10.1029/2019MS001888



Key Deliverables:

- Multi-decadal estimate of ocean carbon sequestration (1995–2017).
- Quantification of global-ocean pCO_2 and CO_2 fluxes across a wide range of time-space scales.
- Estimate unknown ECCO-Darwin biogeochemistry and ecosystem parameters to a suite of biogeochemical ocean observations using a Green's Functions approach.

Foundational Paper #2: Carbon Budget

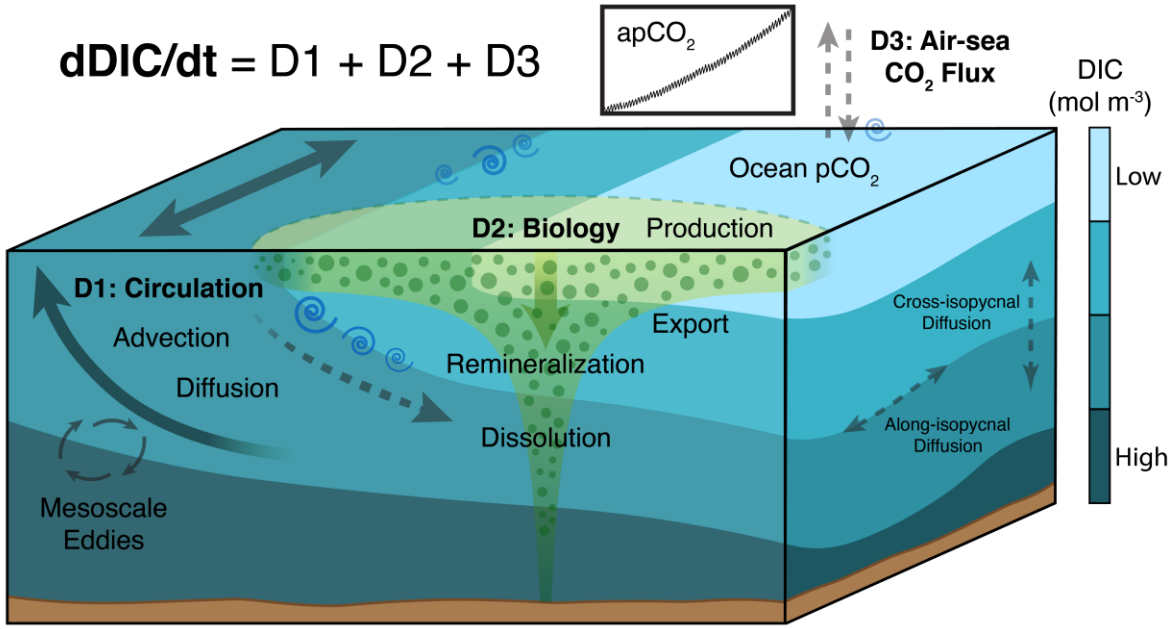
Global Biogeochemical Cycles®

Research Article | Open Access

Attribution of Space-Time Variability in Global-Ocean Dissolved Inorganic Carbon

Dustin Carroll, Dimitris Menemenlis, Stephanie Dutkiewicz, Jonathan M. Lauderdale, Jess F. Adkins, Kevin W. Bowman, Holger Brix, Ian Fenty, Michelle M. Gierach, Chris Hill, Oliver Jahn, Peter Landschützer, Manfredi Manizza, Matt R. Mazloff, Charles E. Miller, David S. Schimel, Ariane Verdy, Daniel B. Whitt, Hong Zhang ... See fewer authors

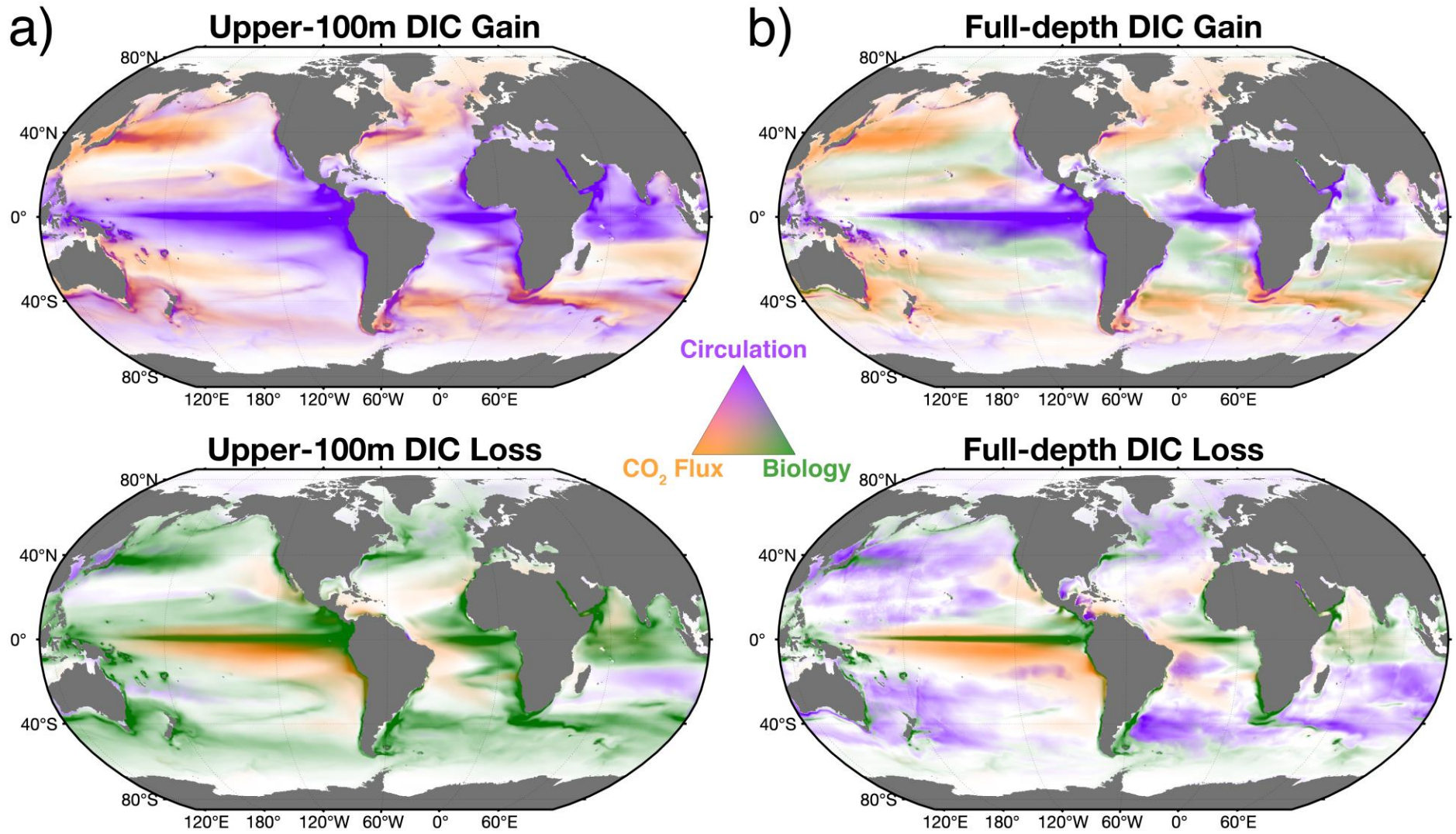
First published: 11 March 2022 | https://doi.org/10.1029/2021GB007162



Key Deliverables:

- Closed 3-D budgets and analysis for biogeochemical quantities (carbon, macro and micronutrients, plankton biomass)
- Full attribution of ocean carbon variability into circulation, air-sea flux, and biology

Foundational Paper #2: Carbon Budget



Foundational Paper #3: Model-data Evaluation

- We are currently working on a carbon/BGC **"standard analysis"** product.
- Evaluation of model solution vs. in-situ observations (SOCAT, GLODAP, BGC-Argo) over model period.
- This product will accompany future ECCO-Darwin solutions.
- Plan to publish "evaluation" white paper(s) using Zenodo, etc., as done with ECCO central production products.

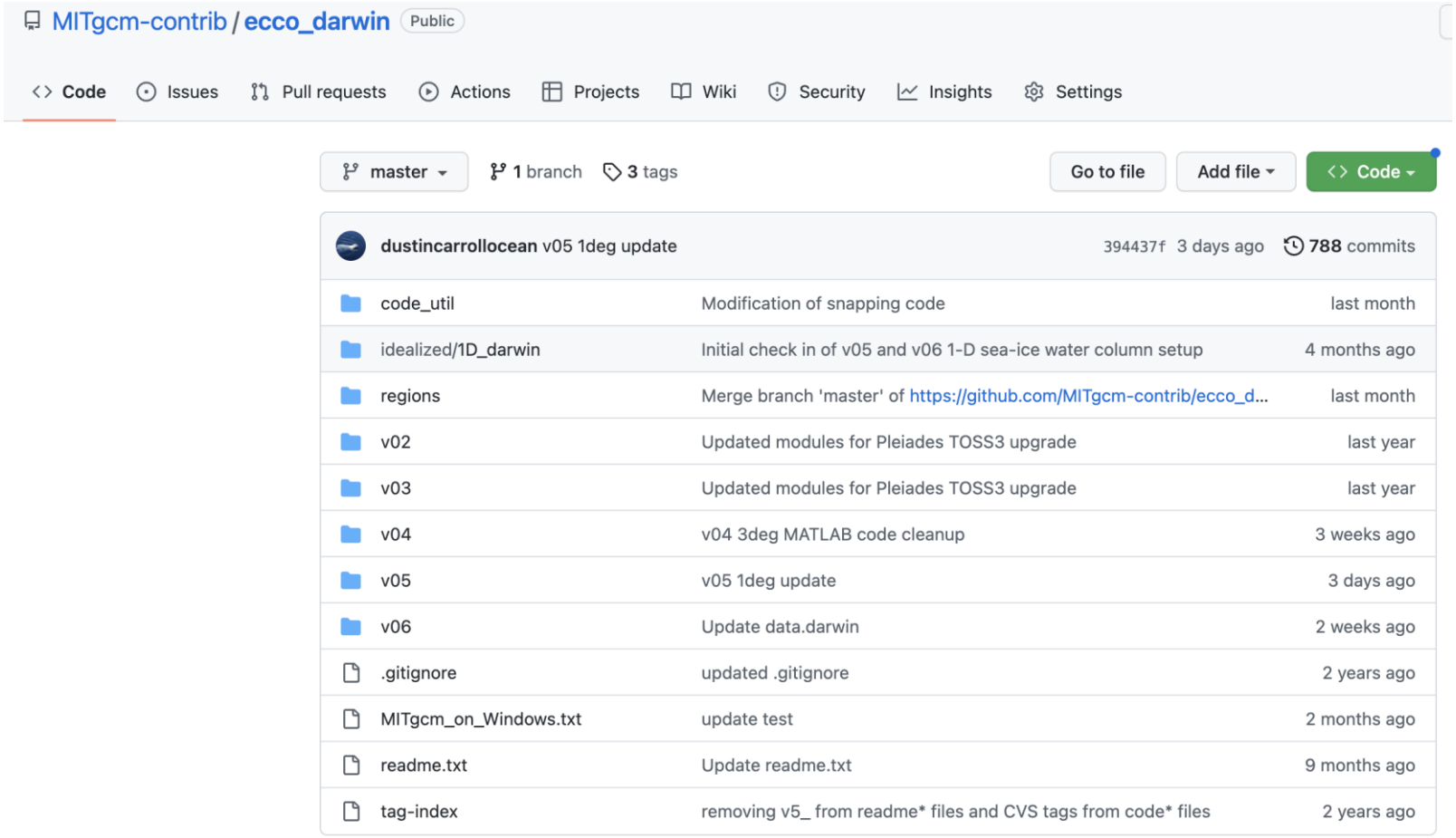
ECCO-Darwin and MITgcm-contrib GitHub Repo

- 1-D water-column simulation (for testing new Darwin ecosystems)
- 3 deg, based on verification/tutorial_global_oce_biogeo
- 1 deg, based on ECCOV4r4
- 1/3 deg, based on LLC 270
- Regional cut-outs
- Legacy simulations (including CS 510 solutions)
- All simulations include platform-independent instructions for compilating/integrating
- Example analysis scripts in MATLAB/Python

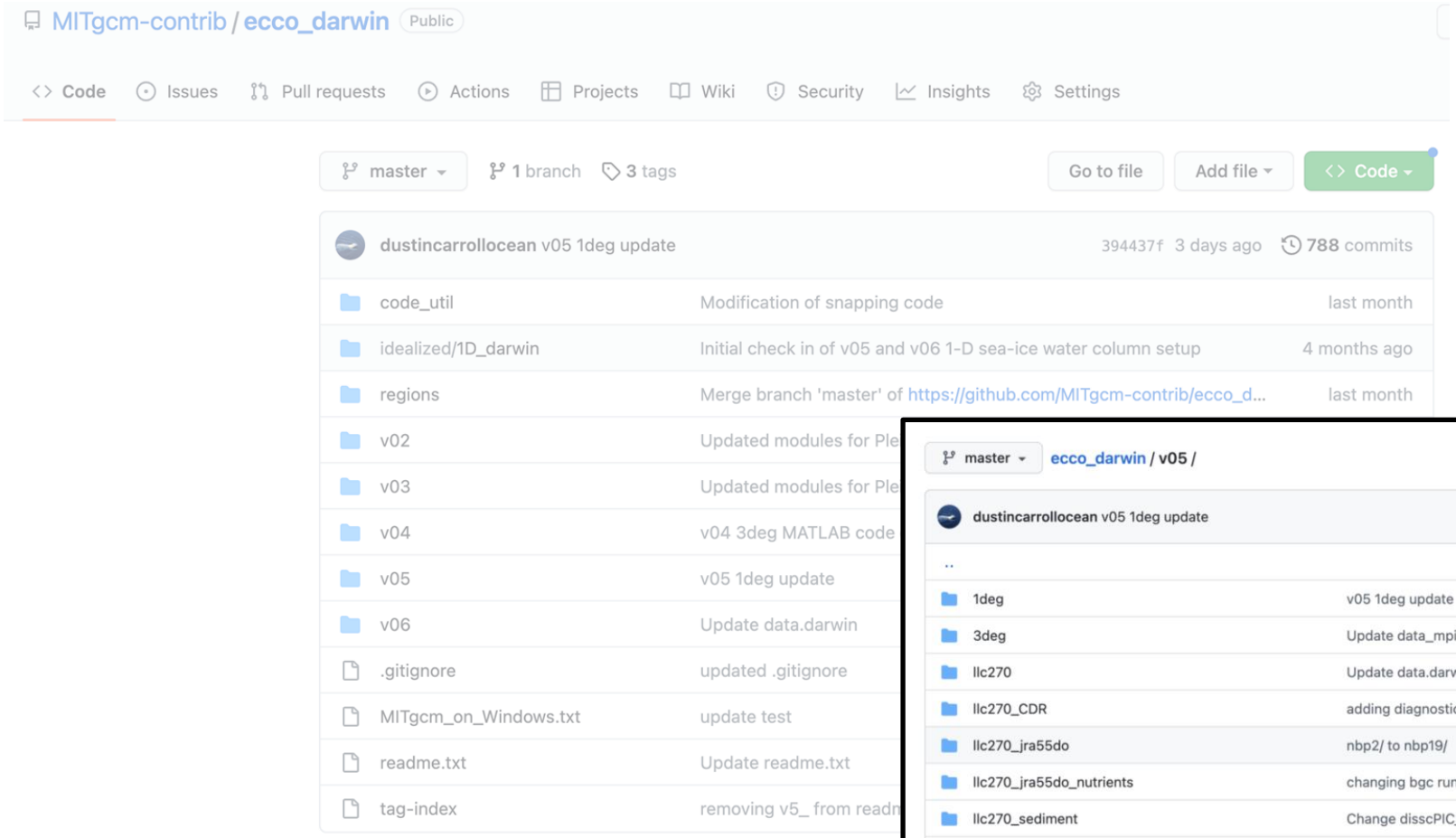
Published ECCO-Darwin model output (ECCO Data Portal):
https://data.nas.nasa.gov/ecco/

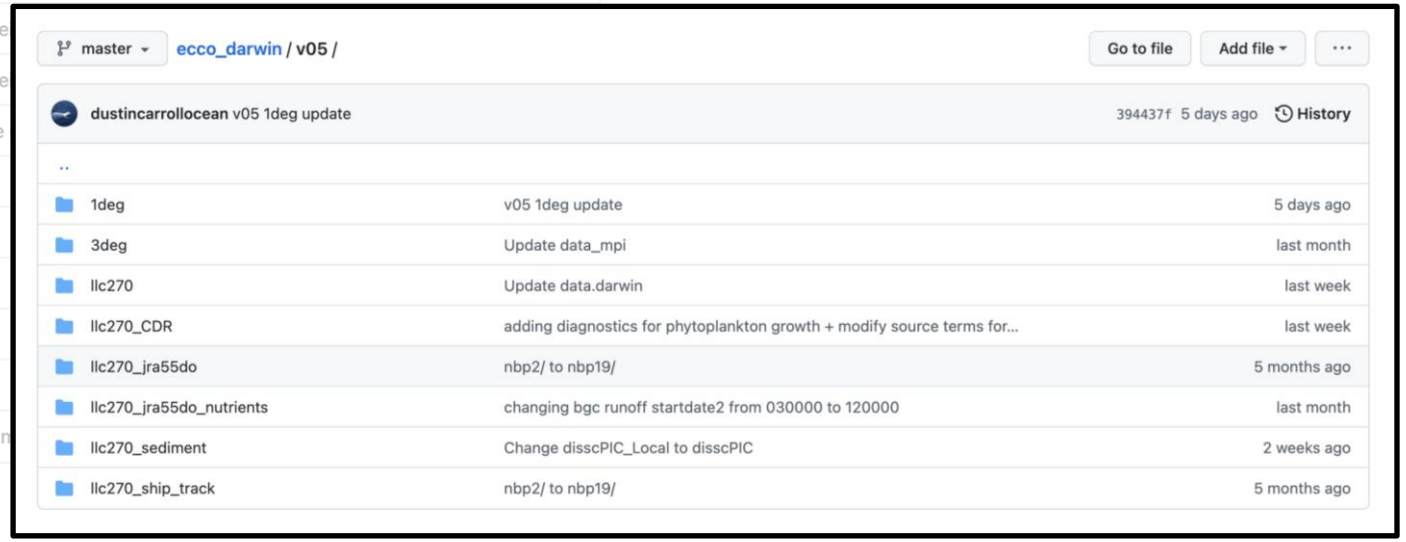
ECCO-Darwin extension to near-present (ECCO Drive):
https://ecco.jpl.nasa.gov/drive/files/ECCO2/LLC270/ECCO-Darwin_extension

ECCO-Darwin and MITgcm-contrib GitHub Repo



ECCO-Darwin and MITgcm-contrib GitHub Repo





Darwin Ecosystem Module

- Darwin is a versatile biogeochemical, ecosystem module (Darwin3 pkg).
- Cycling of C, N, P, Si, Fe, O_2, and alkalinity though inorganic and living/dead organic pools.
- Can incorporate any number (up to ~4000) plankton phenotypes: phyto-, zoo-, mixo-, heterotrophic bacteria, other non-autotrophic prokaryotes (coming soon: viruses).
- Together with **pkg/radtrans** simulates radiative transfer through water column, including upwelling irradiance — allows for a direct link to satellite ocean color products (MODIS-Aqua, SeaWiFS, PACE). Can be used without Darwin, includes spectral treatment of light.
- Code available at (a pkg of MITgcm: https://github.com/darwinproject/darwin3
- Documentation at: https://darwin3.readthedocs.io/en/latest/phys_pkgs/darwin.html

v06 ECCO-Darwin

- We are currently working on an updated version of ECCO-Darwin (v06)
- More realistic ecosystem (6 phytoplankton + 4 zooplankton)
- Will include new in-situ data constrains: dissolved iron and particle data from sediment traps
- Improved representation of river runoff, bottom sediments, water-column dissolution, and biogeochemical fluxes from hydrothermal vents
- Uses radiative transfer package and will optimize ecosystem dynamics using ocean-color observations

Extending ECCO-Darwin Back in Time

Goals: 1) Extend ECCO-Darwin back to 1985 and 2) separate anthropogenic and natural carbon

1) Set up:

Initial guess of IC for 1985/01/01 taken from 1993/01/01 of iter42 (for ECCO-Darwin)

Run to 1993/01/01 and generate new pickup, so-called "it0"

Update IC by:

% pic85_old run to generate pic93, to compare/match pic@93 of it42 (named pic42)

% delta = pic93 - pic42

% pic85_new = pic85_old - delta = pic85_old - (pic93 - pic42)

two iterations (to it2), then apply same optimized forcing as ECCO-Darwin

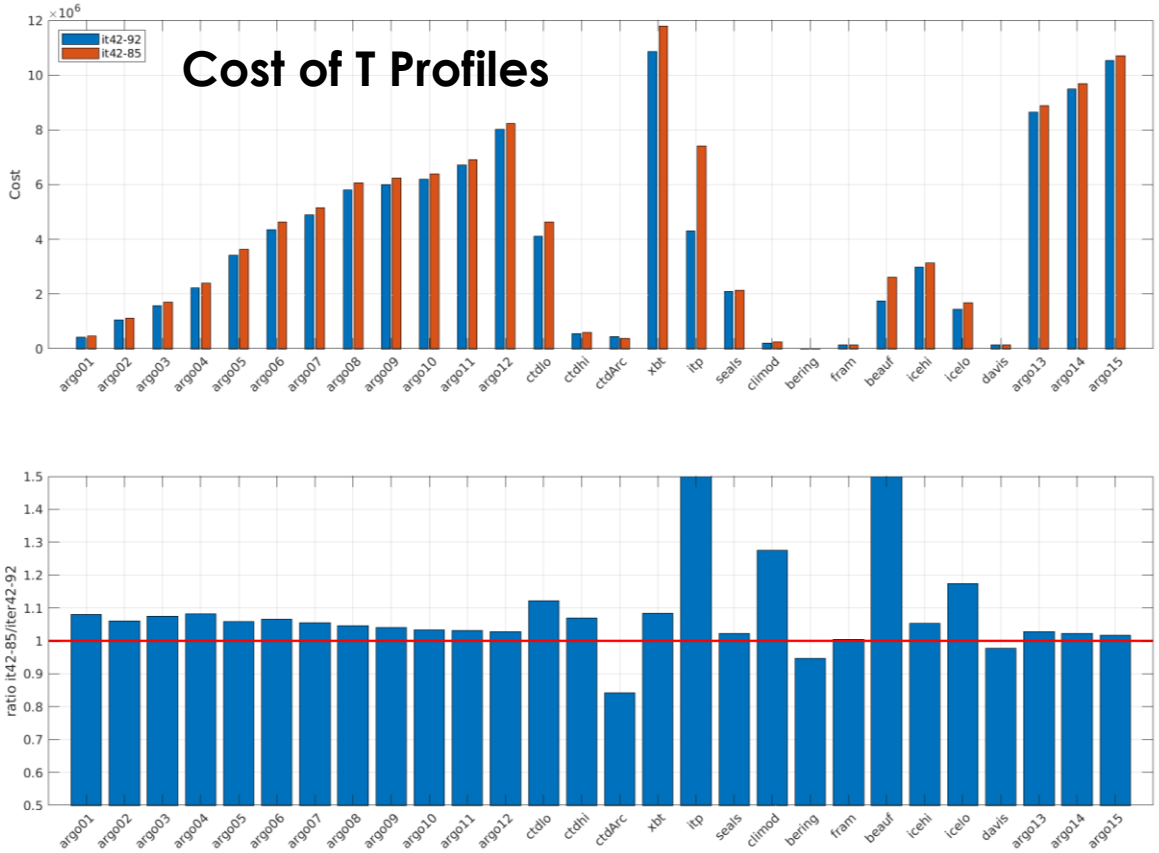
Generate carbon initial conditions by back-scaling 1992 DIC pickup by atmospheric CO_2 growth rate

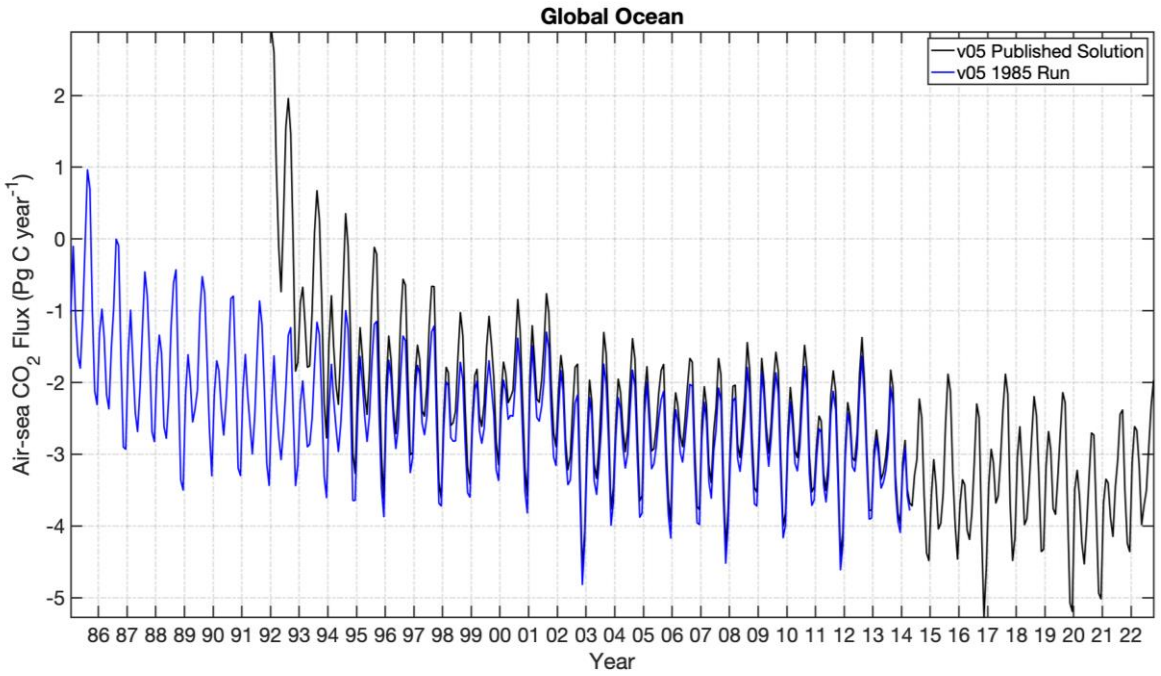
2) Assessment:

Comparison of 1985-run and ECCO-Darwin run for the common period:

1. Global-mean quantities
2. Cost of T/S profiles (ARGO, CTD, XBT, etc.)
3. Standard Analysis of volume, heat, and salt transports. Global, zonal, and regional averages, mixed layer depth fields, sea ice, and snow fields.

Extending ECCO-Darwin Back in Time





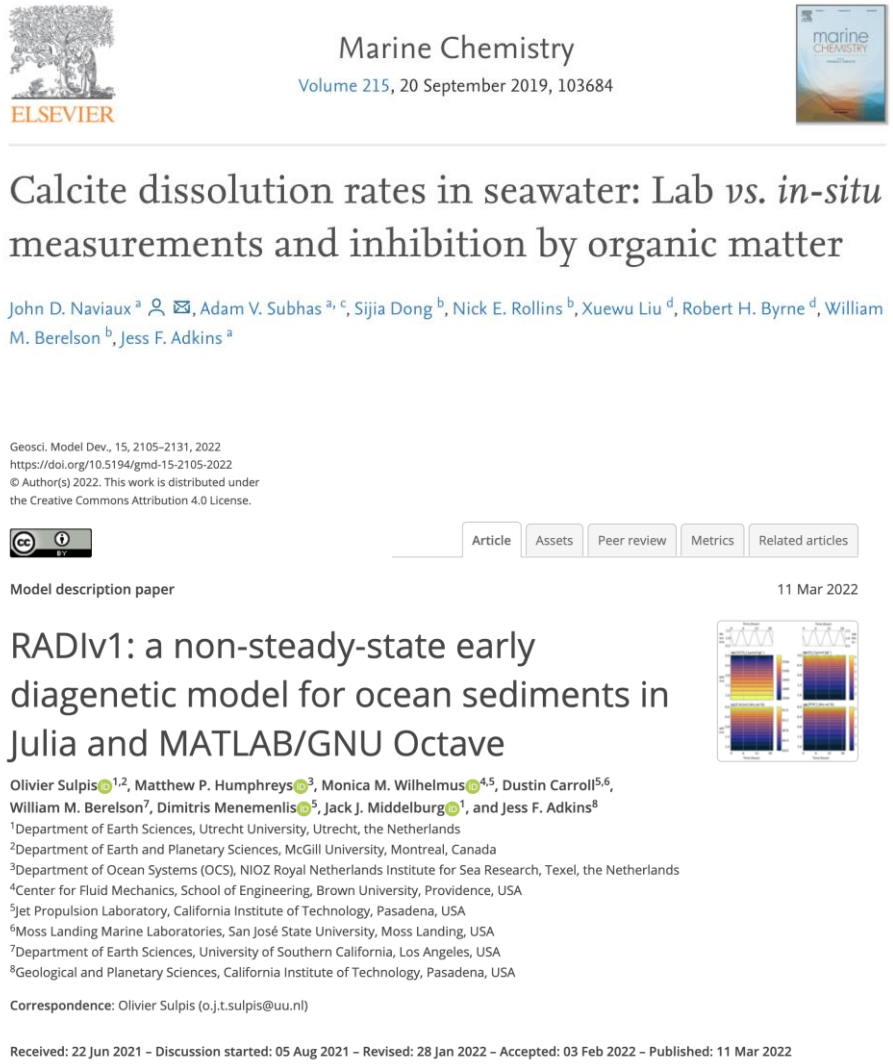
Global Air-sea CO_2 Flux

Improvements to Model Chemistry

- **Implemented nonlinear dissolution model.**
- Calcite dissolution kinetics show abrupt changes in dissolution mechanisms depending on the saturation state.

- **Implemented bottom sediment model.** Equations provide steady-state values of five sediment fluxes.
- Considered fluxes are:
  1. Alkalinity
  2. DIC
  3. O_2
  4. Buried PIC
  5. Buried POC

Outcome: improved representation of chemical processes, such as acidification and hypoxia



ELSEVIER

Marine Chemistry

Volume 215, 20 September 2019, 103684

Calcite dissolution rates in seawater: Lab *vs.* *in-situ* measurements and inhibition by organic matter

John D. Naviaux [a], Adam V. Subhas [a, c], Sijia Dong [b], Nick E. Rollins [b], Xuewu Liu [d], Robert H. Byrne [d], William M. Berelson [b], Jess F. Adkins [a]

Geosci. Model Dev., 15, 2105–2131, 2022
https://doi.org/10.5194/gmd-15-2105-2022
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Model description paper

11 Mar 2022

RADIv1: a non-steady-state early diagenetic model for ocean sediments in Julia and MATLAB/GNU Octave

Olivier Sulpis[1,2], Matthew P. Humphreys[3], Monica M. Wilhelmus[4,5], Dustin Carroll[5,6], William M. Berelson[7], Dimitris Menemenlis[5], Jack J. Middelburg[1], and Jess F. Adkins[8]

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[6]Moss Landing Marine Laboratories, San José State University, Moss Landing, USA
[7]Department of Earth Sciences, University of Southern California, Los Angeles, USA
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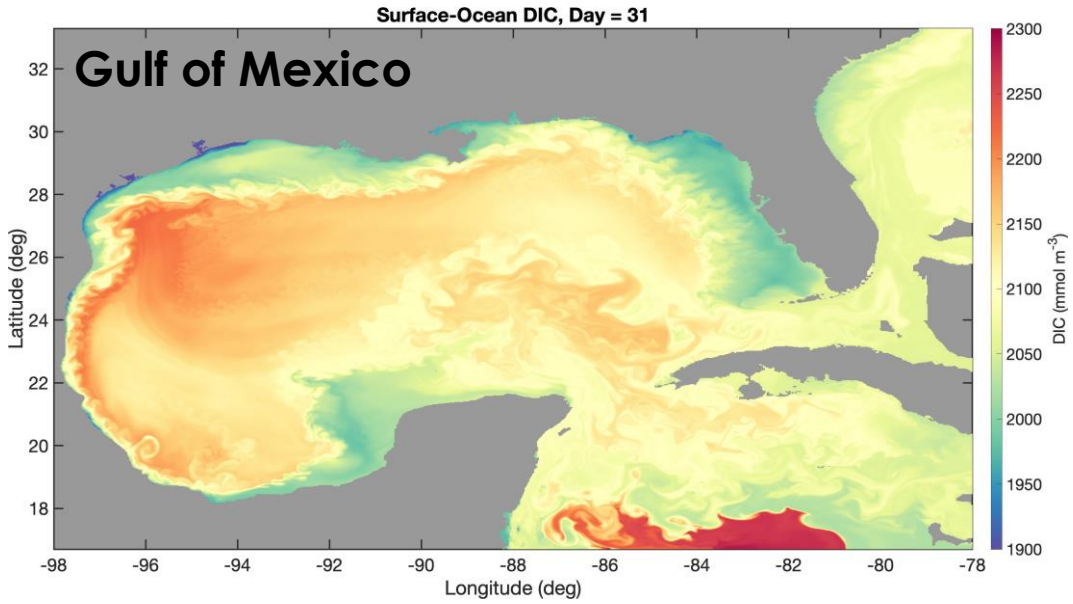
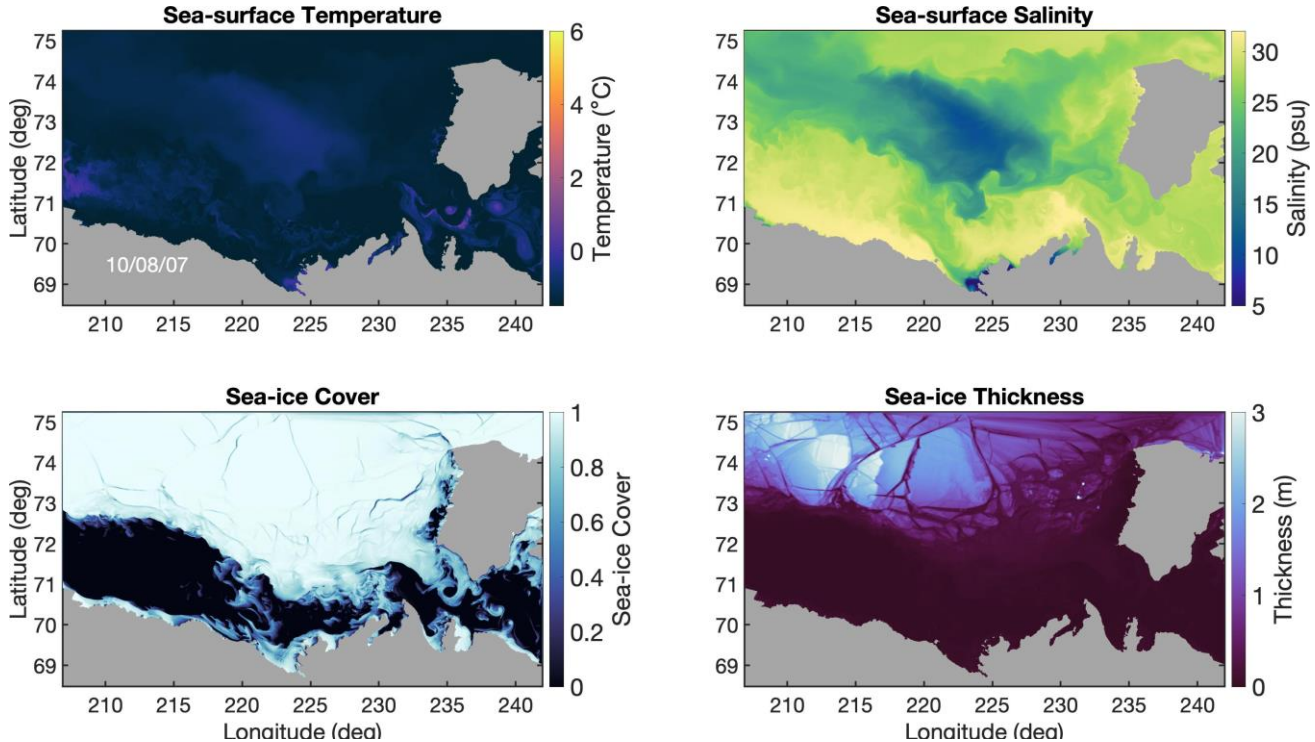
Received: 22 Jun 2021 – Discussion started: 05 Aug 2021 – Revised: 28 Jan 2022 – Accepted: 03 Feb 2022 – Published: 11 Mar 2022

Downscaling / Regional Studies

- Mackenzie Delta / Beaufort Sea
- Gulf of Mexico
- Tropical Atlantic Ocean
- West/East Greenland
- East Antarctica (Totten Ice Shelf)





Mackenzie Delta / Beaufort Sea

Marine Carbon Dioxide Removal (mCDR) Simulations

- Cargo ship track simulations w/ Jess Adkins (Caltech)
- Google (ocean alkalinity enhancement)
- Running Tide (algal platforms that drift then sink)
- The Climate Foundation (modeling kelp afforestation)

Google

RUNNING TIDE

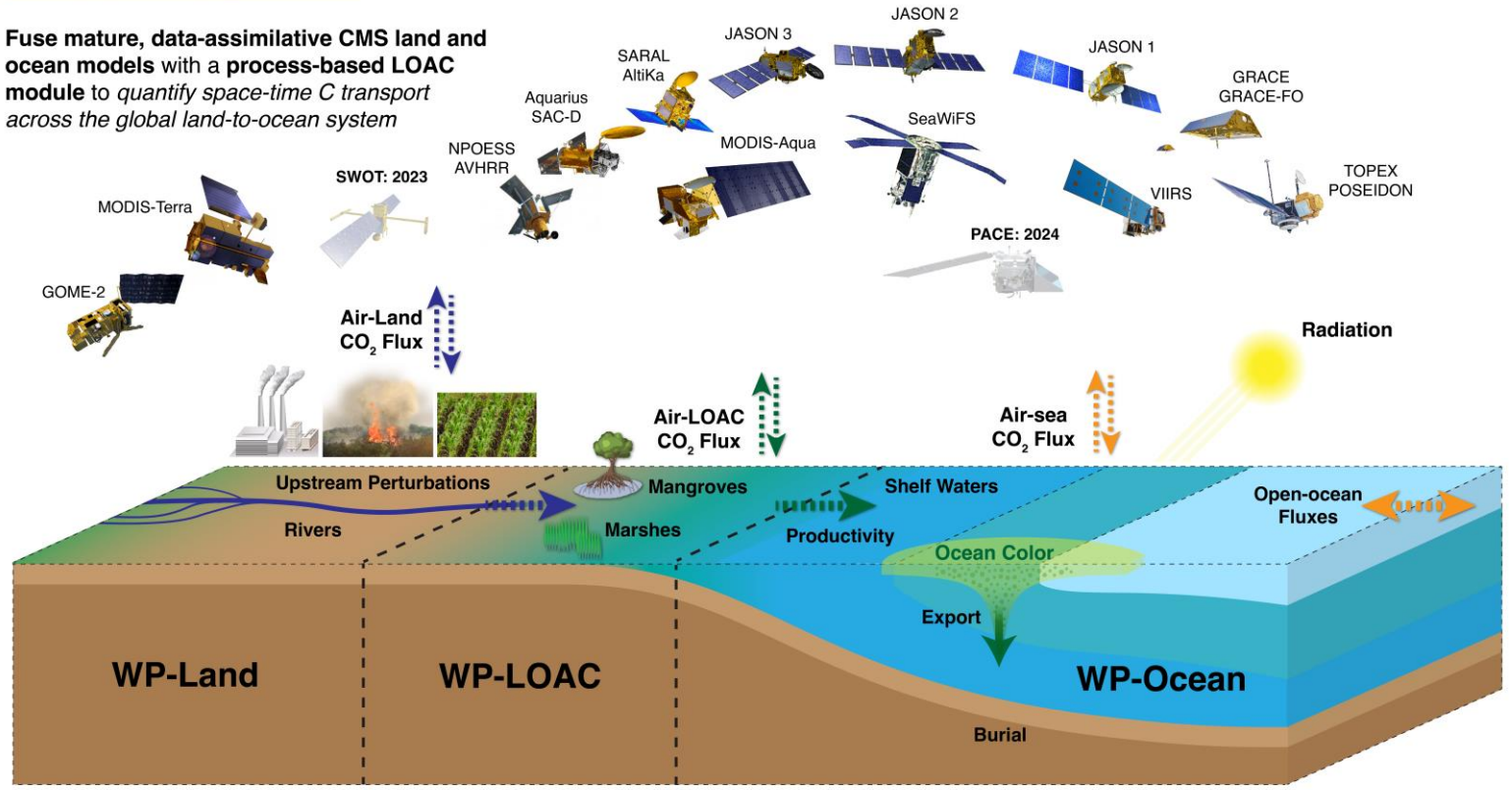
CLIMATE FOUNDATION

Land-Ocean-Aquatic-Continuum (LOAC)

§	Component
1.2	Project Goals
1.4.3	Satellite Data
	Land-to-Ocean Schematic
1.5	Work Packages
1.5.4	Time-space -resolved Deliverables
1.7 & 4	Stakeholders & Letters

EXECUTIVE SUMMARY

Fuse mature, data-assimilative CMS land and ocean models with a **process-based LOAC module** to *quantify space-time C transport across the global land-to-ocean system*



WP1 Deliverables:
Land-to-LOAC
C and Nutrient Flux

WP2 Deliverables:
Land-to-Ocean
C and Nutrient Flux

WP3 Deliverables:
– 3-D Carbon Budget and Attribution
– Sensitivity to Upstream Perturbations

USGS

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USGS Google RUNNING TIDE CLIMATE FOUNDATION

Thank you!