National Aeronautics and Space Administration

Improving our Understanding of Ocean Acidification and the Effects of Novel Carbon Sequestration Mechanisms in the Ocean Using ECCO-Darwin and new Rules for Carbonate Sequestration

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Project Objectives:

Combine JPL/Caltech in-situ and remotely-sensed observations with ECCO-Darwin ocean biogeochemistry model in order to improve understanding of ocean acidification and carbon cycle. Develop tools needed to reduce uncertainties regarding future projections of these processes.Specific objectives are to improve representation of key ocean acidification processes in ECCO-Darwin, including (1) sources of chemicals due to river runoff and other coastal processes, (2) representation of carbonate dissolution rates, and (3) sources and sinks of chemicals in ocean sediments; and use this updated ocean biogeochemistry model to study hypothetical responses of ocean biogeochemistry to (4) atmospheric carbon perturbations and (5) artificial carbon sequestration scenarios.

FY19 Results:

Successful thesis defense by John Naviaux on "Chemical and Physical Mechanisms of Calcite Dissolution in Seawater" (see references 1-6 below). Submission of second ECCO-Darwin paper (see reference 7 as well as the description of the ECCO-Darwin global-ocean biogeochemistry model in this poster.

Significance of results:

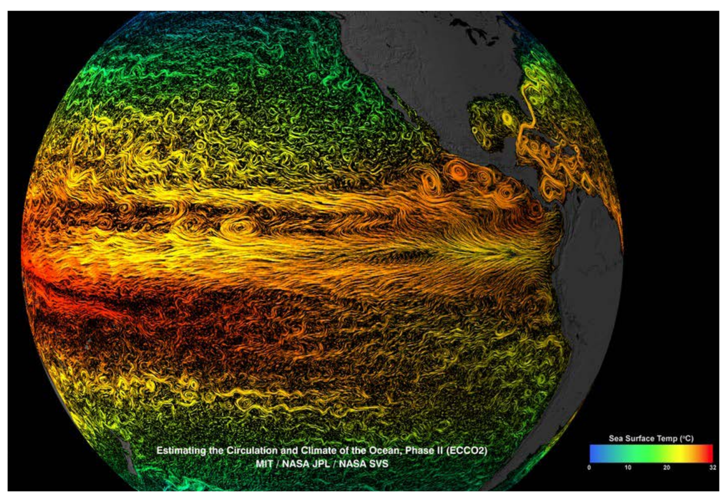
Development of unique, world-leading research capabilities, which are positioning JPL/Caltech at forefront of ocean acidification and carbon dioxide removal studies and open avenues of future funding as part of NSF's Ocean Acidification Program, NASA's Ocean Biology & Biogeochemistry Program, OCO-2 and PACE science teams, EV Suborbital and other field campaign opportunities, and private foundations.

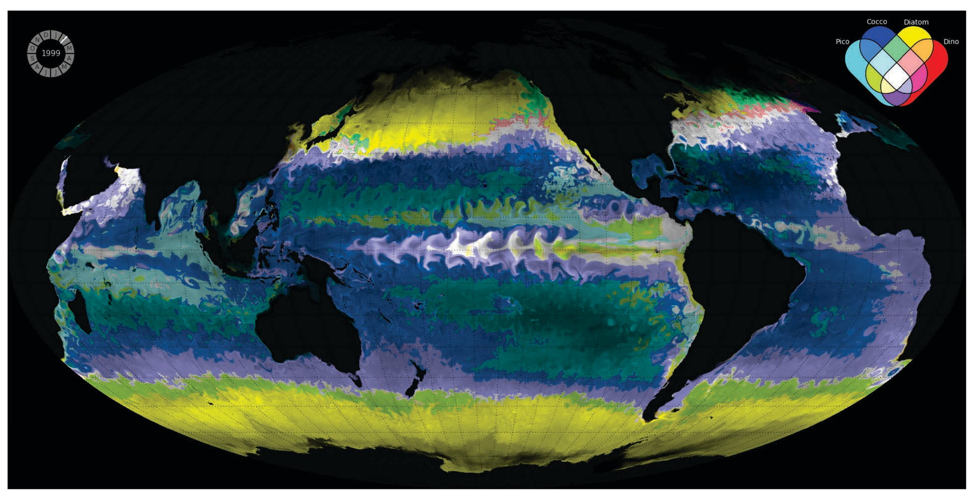
1. What is ECCO-Darwin?

ECCO-Darwin is a new data-assimilative global ocean biogeochemistry model. Here we leverage results from two well-established projects[1,2]:

Model Physics:
Estimating the Climate and Circulation of the Ocean (ECCO) Consortium

Model Ecosystem and Chemistry:
MIT Darwin Project





[LEFT] Snapshot of sea-surface temperature from the ECCO ocean state estimate. **[RIGHT]** The Darwin Project ecosystem model (35 phytoplankton species) driven by ECCO ocean circulation fields. This realistic, "survival of the fittest" ocean ecology is the basis of ECCO-Darwin, which uses a simplified ecosystem based on the most successful species in the above simulation.

<u>This model represents a major step forward as it:</u>

1) Assimilates global physical and biogeochemical observations in a property-conserving manner (i.e., without nudging or spurious sources/sinks).

2) Considers the time-varying nature of the ocean carbon sink over multi-decadal timescales.

2. ECCO-Darwin Model Setup

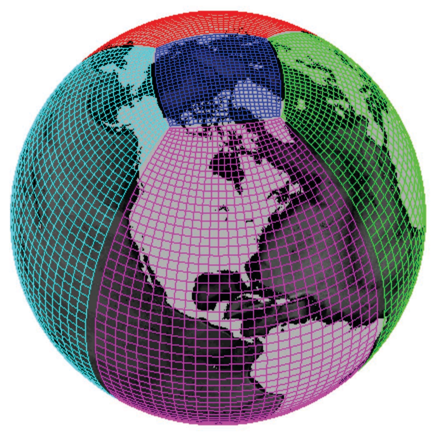
Model:
MITgcm w/ "Lon-Lat-Cap" (LLC) grid
(1/3° at Equator, ~18 km at high-latitudes)

Ocean Physics:
ECCO LLC270 (1992–2018)

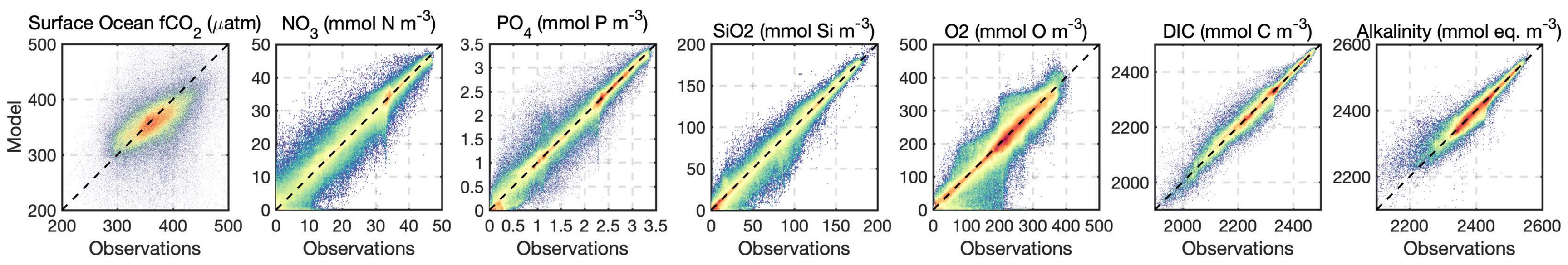
Ecosystem:
5 phytoplankton and 2 zooplankton types

Observational Constraints (n = 4038777):
SOCATv5 surface ocean fCO_2
GLODAPv2 profiles, BGC-Argo profiles

Biogeochemical Optimization:
12 Greens Functions (6 model parameters and inital conditions)

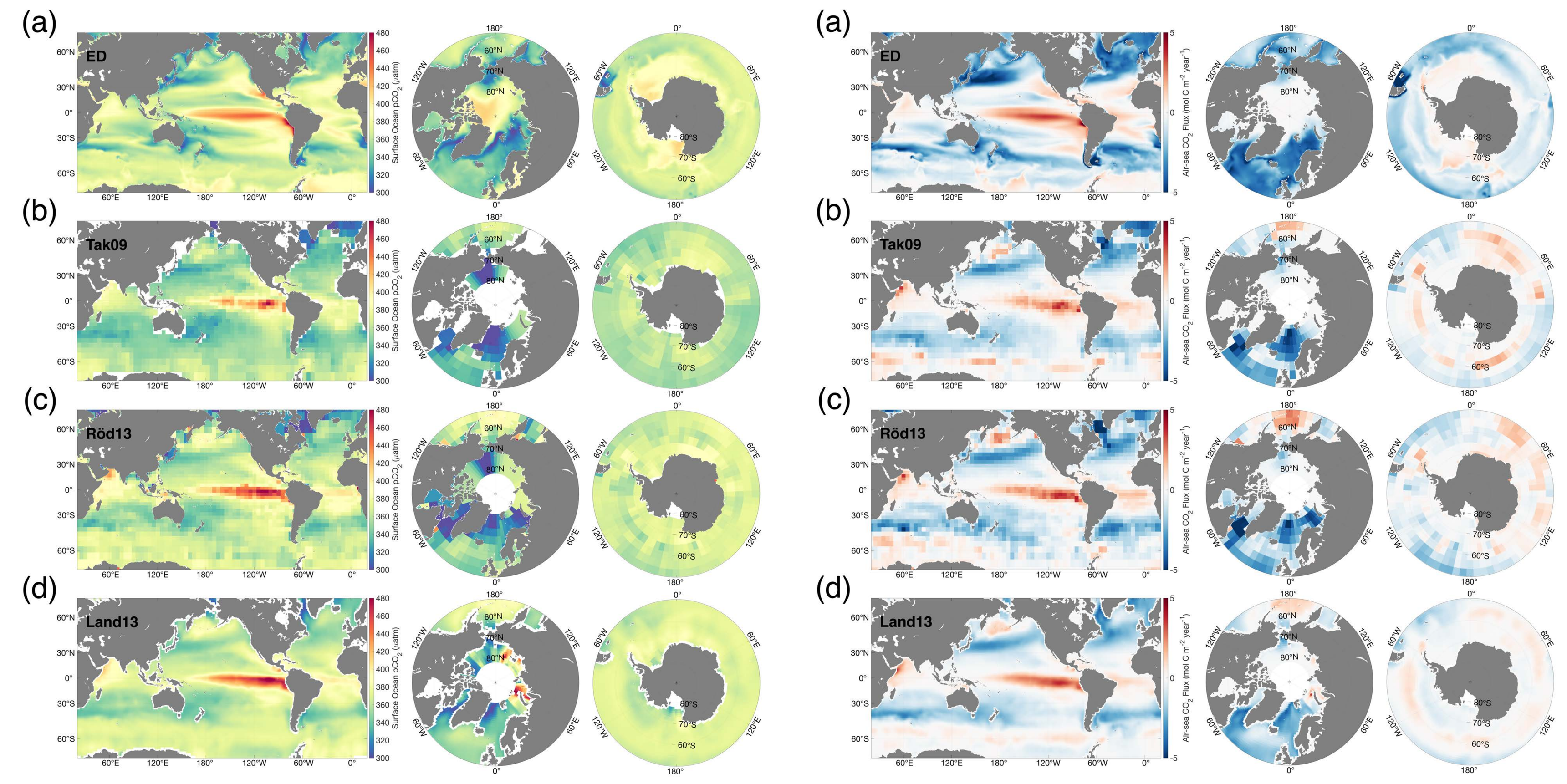


[Above] Example of the novel "Lon-Lat-Cap" horizontal grid used by ECCO-Darwin, which allows for an improved representation of the Arctic Ocean.



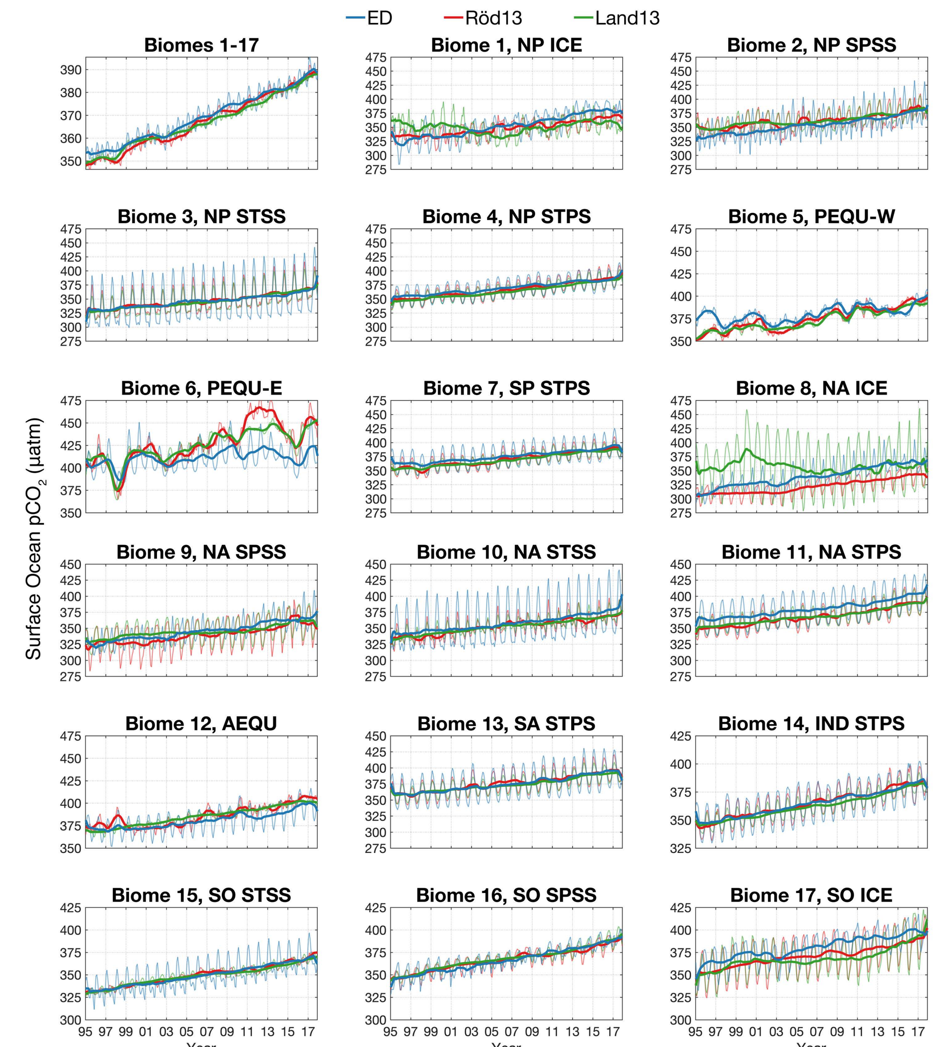
[ABOVE] Comparison of biogeochemical observations and ECCO-Darwin. X-axis shows observations and y-axis shows ECCO-Darwin at the same space-time location. Colors represent the normalized density of observation-model pairs (log scale).

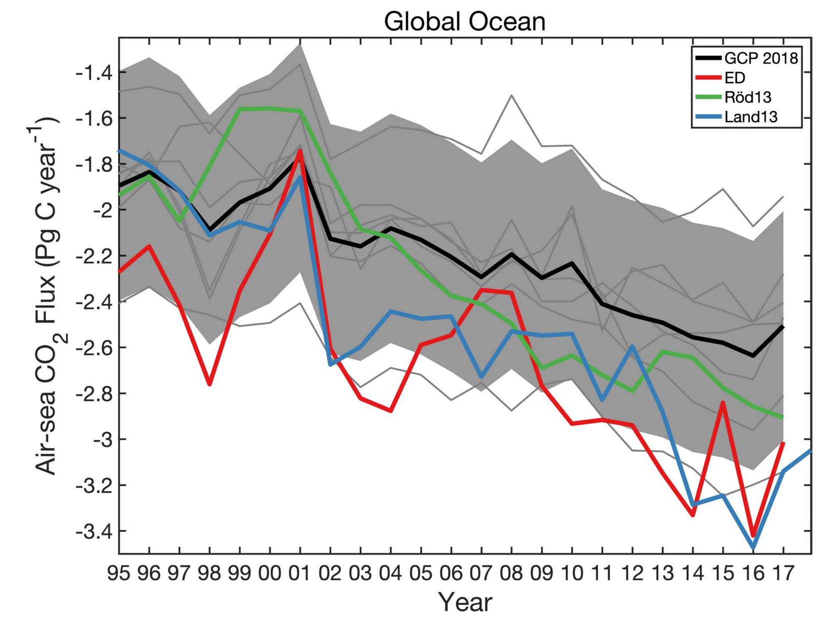
3. Climatolgical Results (1995–2017)



[LEFT] Climatological surface ocean pCO_2 for **(a)** ECCO-Darwin and **(b)** Takahashi, **(c)** Rödenbeck, and **(d)** Landschützer interpolation-based products. **[RIGHT]** Associated air-sea CO_2 fluxes.

4. Seasonal to Multi-Decadal Results



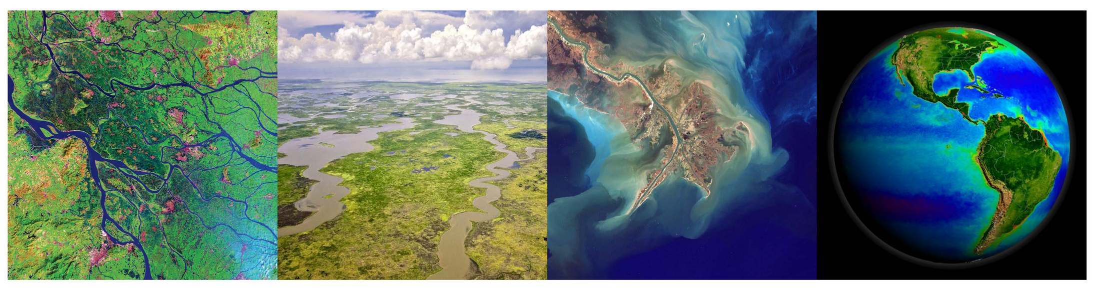


[ABOVE] Time series of globally-integrated air-sea CO_2 flux for the GCP ocean sink (black line), ECCO-Darwin (blue), Rödenbeck (red), and Landschützer (green). Thin grey lines show the individual OBMs used to compute the GCP ocean sink; gray shading shows the GCP uncertainty band.

[ABOVE] Time series of biome-scale surface ocean pCO_2 for ECCO-Darwin (blue), Rödenbeck (red), and Landschützer (green). Thin lines show monthly values and thick lines show interannual variability (12-month forward running mean).

5. Ongoing ECCO-Darwin Development

Online CO_2 flux decomposition
Non-linear dissolution rate laws
Dissolution in bottom sediments
Daily terrestrial runoff
Coastal blue carbon fluxes
Global uncertainty analysis



[ABOVE] We are actively working to improving ECCO-Darwin's representation of land-to-ocean carbon fluxes and the carbon cycle in coastal ecosystems.

References: [1]Forget et al. 2015; [2]Follows and Dutkiewicz, 2011

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Publications:

1. Naviaux, J.D., 2019. Chemical and Physical Mechanisms of Calcite Dissolution in Seawater. PhD Thesis, Caltech.
2. Dong, S., Adkins, J.F., Rollins, N.E., Subhas, A.V., Naviaux, J.D., et. al., 2019. Aragonite Dissolution Kinetics and Calcite/Aragonite Ratios in Sinking and Suspended Particles in the North Pacific. Earth Planet. Sci. Lett.
3. Dong, S., Subhas, A.V., Rollins, N.E., Naviaux, J.D., Adkins, J.F., Berelson, W.M., 2018. A kinetic pressure effect on calcite dissolution in seawater. Geochim. Cosmochim. Acta 238, 411–423.
4. Naviaux, J.D., Subhas, A.V., Dong, S., Rollins, N.E., Liu, X., Byrne, R.H., et al., 2019. Calcite dissolution rates in seawater: Lab vs. in-situ measurements and inhibition by organic matter. Mar. Chem. 215, 103684.
5. Naviaux, J.D., Subhas, A.V., Rollins, N.E., Dong, S., Berelson, W.M., Adkins, J.F., 2019. Temperature Dependence of Calcite Dissolution Kinetics in Seawater. Geochim. Cosmochim. Acta 246, 363–384.
6. Subhas, A.V., Adkins, J.F., Rollins, N.E., Naviaux, J., Erez, J., Berelson, W.M., 2017. Catalysis and chemical mechanisms of calcite dissolution in seawater. Proc. Natl. Acad. Sci. 114, 8175–8180.
7. Carroll, D., et al., 2019. Seasonal to Multi-decadal Air-sea CO2 Fluxes from the Data-constrained ECCO-Darwin Global Ocean Biogeochemistry Model, Journal of Advances in Modeling Earth Systems, submitted.

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