

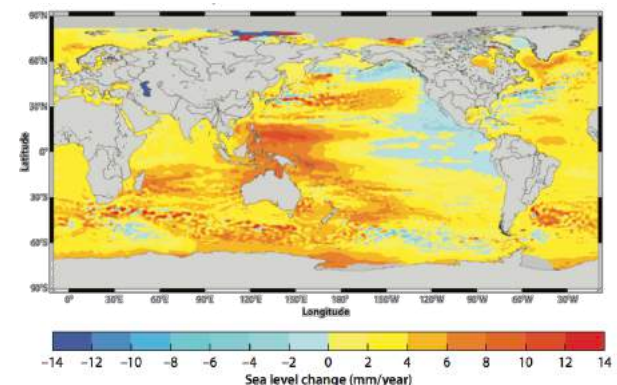
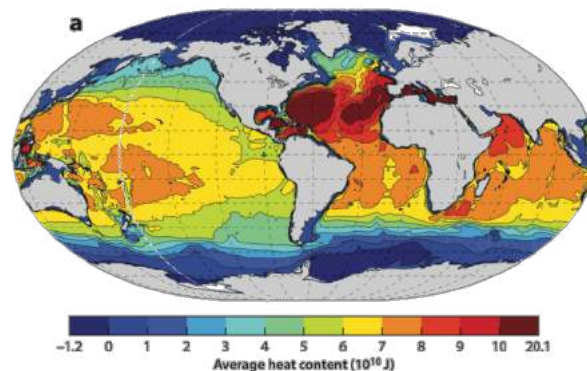
ECCO PRODUCTS AND TOOLS

- The “Estimating the Circulation and Climate of the Ocean” (ECCO) consortium endeavors to produce the best possible estimates of ocean circulation and its role in climate.
- **Solutions are obtained** by combining state-of-the-art ocean circulation models with global ocean and sea-ice data in a physically and statistically consistent manner.
- **Products are being utilized** in studies on ocean variability, biological cycles, coastal physics, water cycle, ocean-cryosphere interactions, and geodesy

$$J = \sum_{t=0}^{t_f} (y_t - \Gamma_t x_t)' P_t (y_t - \Gamma_t x_t)$$

$$L = J(x_{[0,t_f]}) + \sum_{t=0}^{t_f-1} \lambda_t' (x_{t+1} - M(p_t, x_t))$$

$$\lambda_0 = \sum_{t=1}^{t_f-1} \{A_1' A_2' \cdots A_t' G_{t+1}\} + G_1$$



ECCO Consortium



Goal: to make the best possible estimates of ocean circulation and its role in climate.

The JPL logo, consisting of the letters "JPL" in a bold, red, sans-serif font.

Jet Propulsion Laboratory
California Institute of Technology



TEXAS

The University of Texas at Austin



Massachusetts
Institute of
Technology

The aer logo, consisting of the letters "aer" in a white, sans-serif font on a blue rectangular background.

Atmospheric and
Environmental Research



Universität Hamburg

DER FORSCHUNG | DER LEHRE | DER BILDUNG

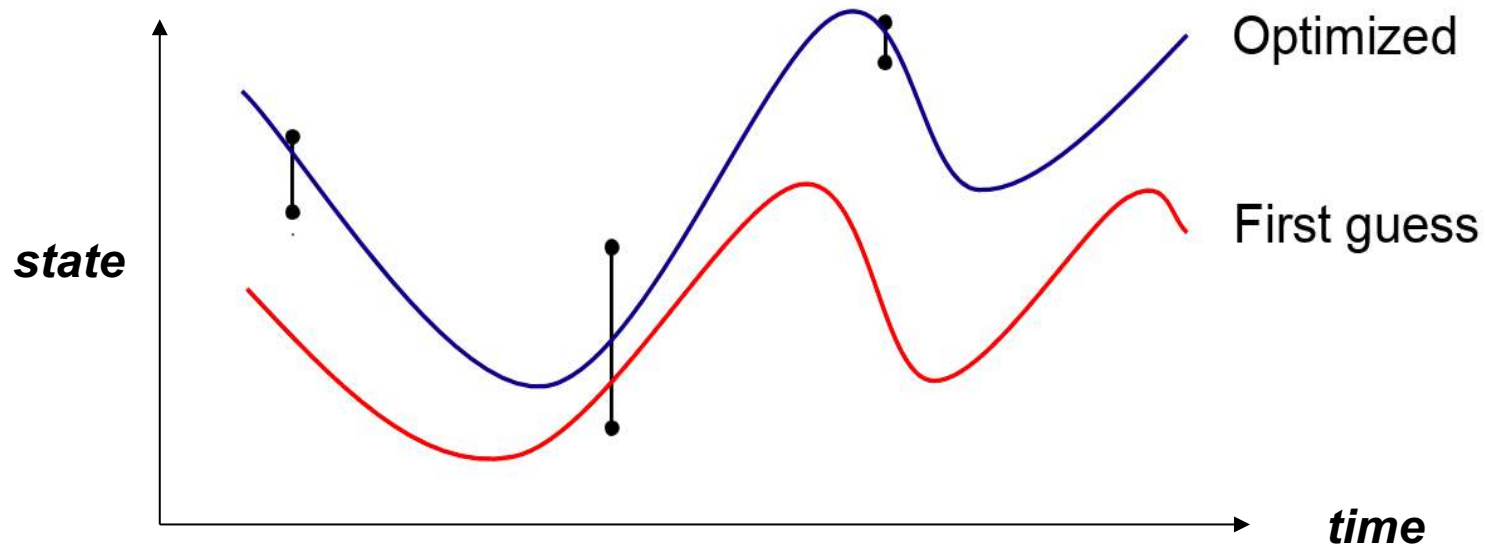


SCRIPPS INSTITUTION OF
OCEANOGRAPHY



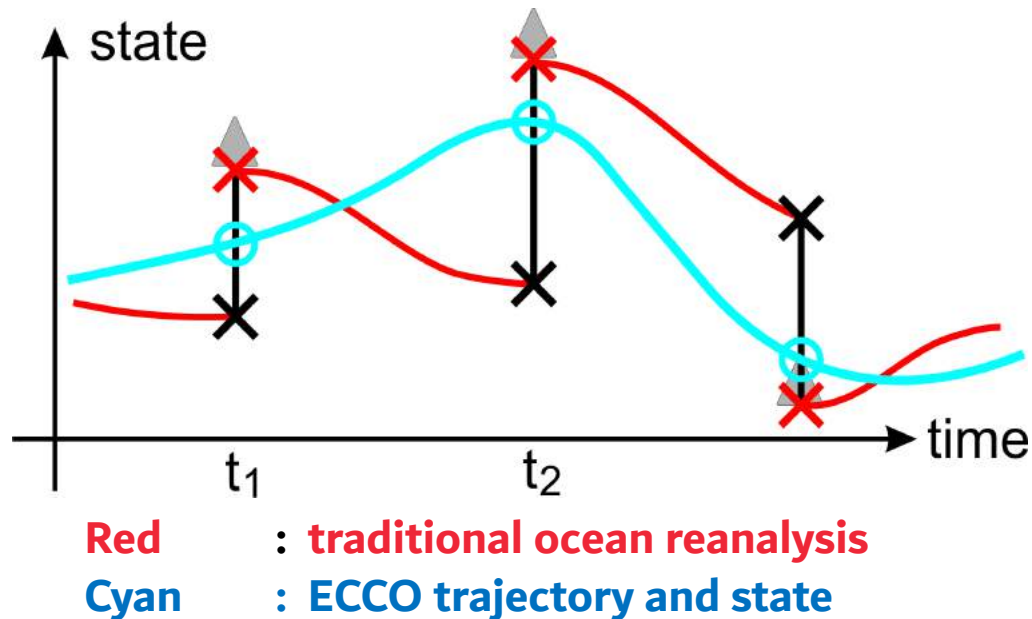
ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

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



Inverse problem: 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.

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



Inverse problem: 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.

1. ECCO Products

- ECCO Central Production
- ECCO-Darwin
- ASTE
- B-SOSE
- *other regional products*

2. Analysis tools and tutorials

1. ECCO Products

- **ECCO Central Production**
- ECCO-Darwin
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- *other regional products*

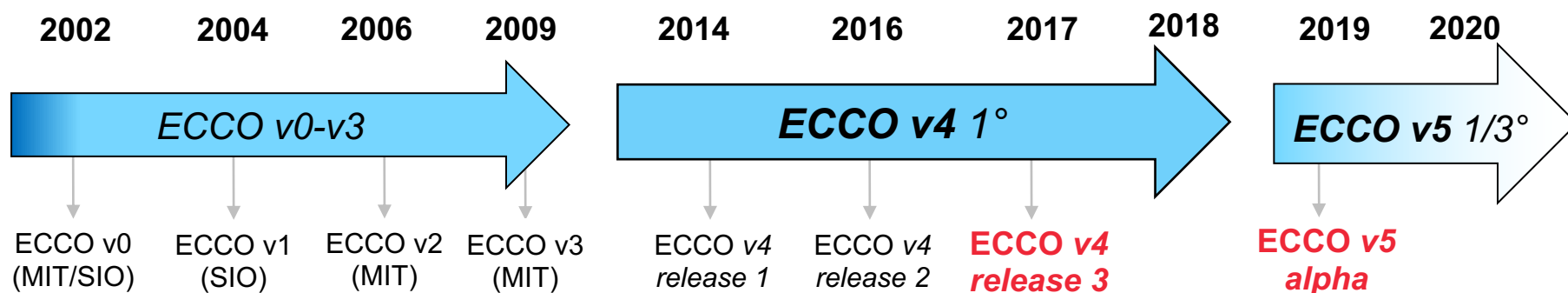
2. Analysis tools and tutorials

ECCO Central Production Timeline

ECCO v4 is our flagship ocean state estimate.

The first adjoint-based, multi-decadal global ocean and sea-ice state estimate.

> *Our best reconstruction of the global ocean.*



ECCO v4r3

A 1° resolution 4-D (space and time) **reconstruction** of the **1992-2015** global ocean and **sea-ice state**

Constrained by > 10⁸ *in situ* and satellite remote sensing observations

ECCOv4r3: Monthly and daily mean fields

Ocean + sea-ice

- $T, S, u, v, w, \eta, \rho, \Phi$
- Sea-ice and snow h and c
- Lateral and vertical fluxes of volume, heat, salt, and momentum

Atmosphere

- $T, q, |u|, \tau$, long- and radiative fluxes
- Air–sea-ice–ocean fluxes of heat, moisture, energy, and momentum

Subgrid-scale mixing parameters

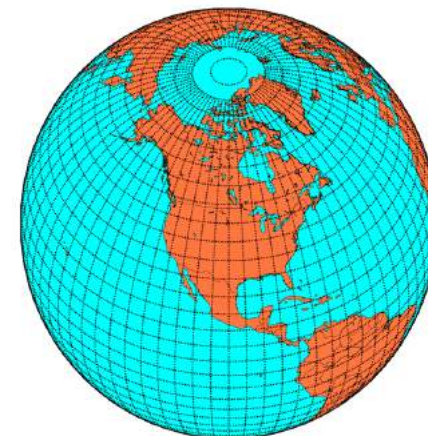
- 3D GM κ and Redi κ
- 3D vertical diffusivity

Fields are provided on two grids

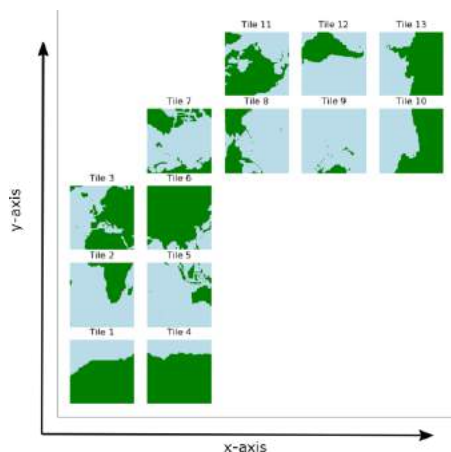
*Curvilinear Cartesian
“lat-lon-cap 90”*



*Interpolated
0.5° lat-lon*



13 tiles of 90x90x50



ECCOv4r3: Observational constraints

| Variable | Observations |
|------------------------------|--|
| Sea surface height | TOPEX/Poseidon (1993-2005), Jason-1 (2002-2008), Jason-2 (2008-2015), Geosat-Follow-On (2001-2007), CryoSat-2 (2011-2015), ERS-1/2 (1992-2001), ENVISAT (2002-2012), SARAL/AltiKa (2013-2015) |
| Temperature profiles | Argo floats (1995-2015), XBTs (1992-2008), CTDs (1992-2011), Southern Elephant seals as Oceanographic Samplers (SEaOS; 2004-2010), Ice-Tethered Profilers (ITP, 2004-2011) and other high-latitude CTDs and moorings |
| Salinity profiles | Argo floats (1997-2015), CTDs (1992-2011), SEaOS (2004-2010), and other high-latitude CTDs and moorings |
| Sea surface temp. | AVHRR (1992-2013) |
| Sea surface salinity | Aquarius (2011-2013) |
| Sea-ice concentration | SSM/I DMSP-F11 (1992-2000) and -F13 (1995-2009) and SSMIS DMSP-F17 (2006-2015) |
| Ocean bot. pressure | GRACE (2002-2014), JPL MASCON Solution |
| TS climatology | World Ocean Atlas 2009 |
| MDT | DTU13 (1992-2012) |
| GM SSH & OBP | AVISO, CSIRO, NOAA; GRACE |

ECCOv4r3: ftp://ecco.jpl.nasa.gov/Version4/Release3/



Documentation

- Summary
- Analysis plots including climatology
- Instructions for re-running the model and calculating budgets

State estimate fields (NetCDF)

Observational data

Fields required to re-run the model

- Grid geometry
- Configuration files
- Model initial conditions
- Atmospheric and hydrological boundary conditions

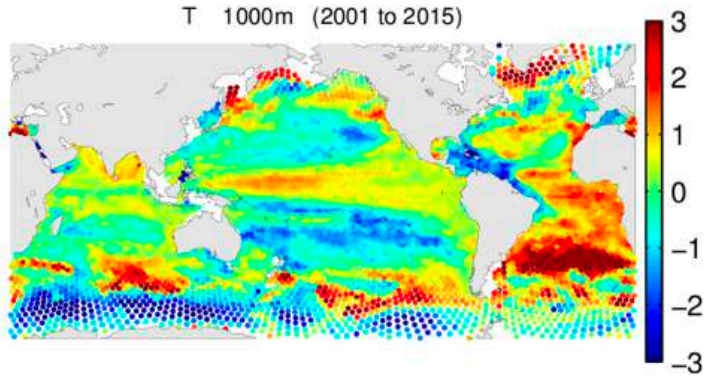
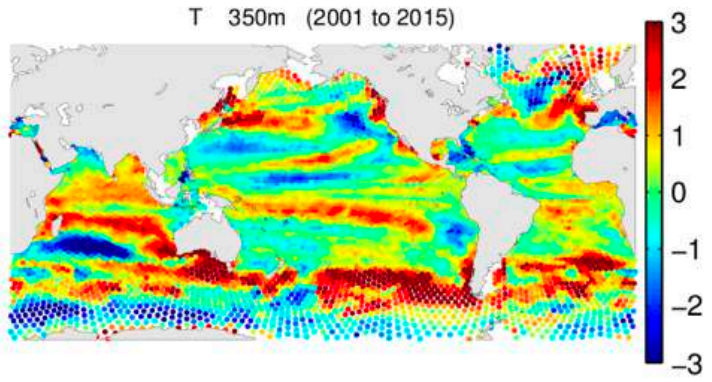
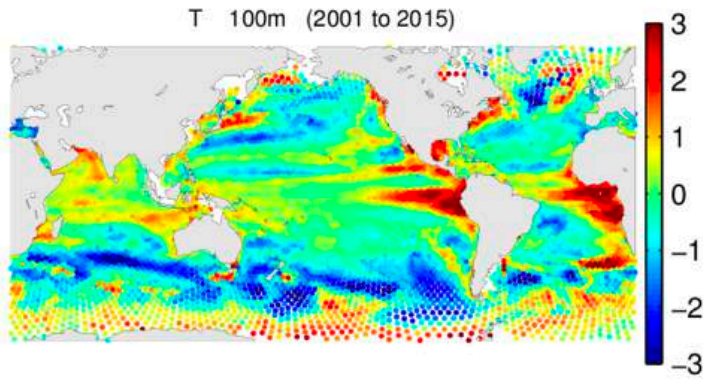
Also mirrored at

<https://web.corral.tacc.utexas.edu/OceanProjects/ECCO/ECCOv4/Release3/>

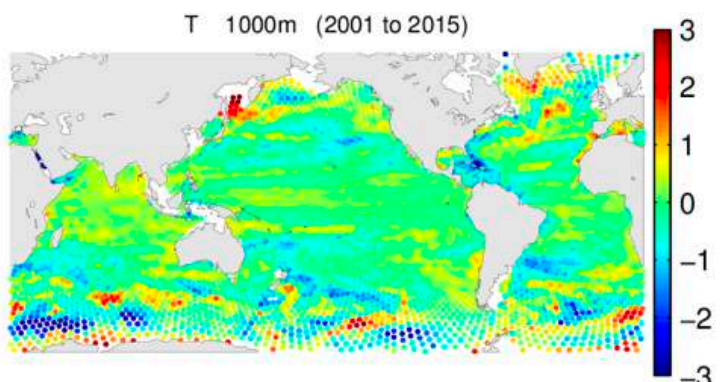
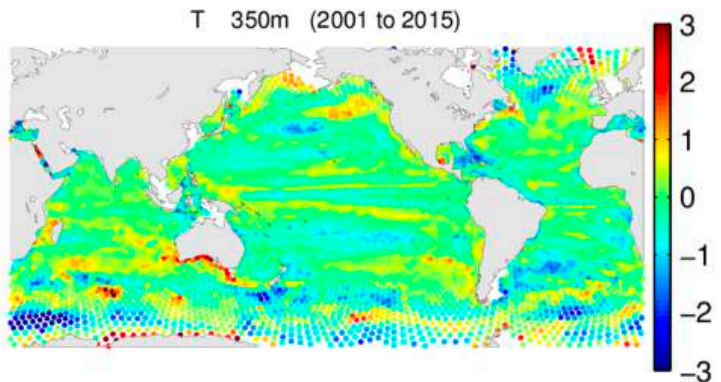
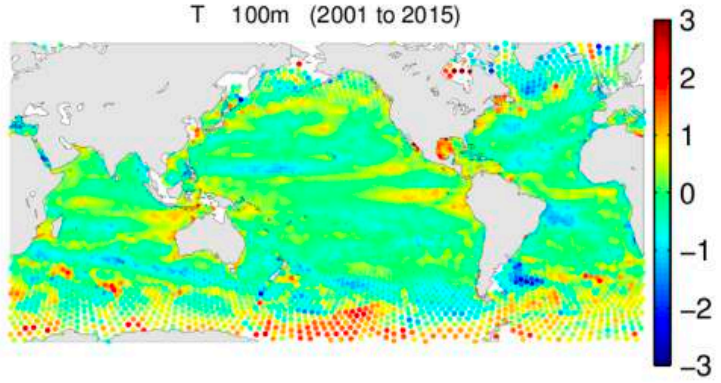
ECCOv4r3: model-data *in situ* T

$$\sum \frac{x_{ecco} - x_{obs}}{\sigma_{obs}}$$

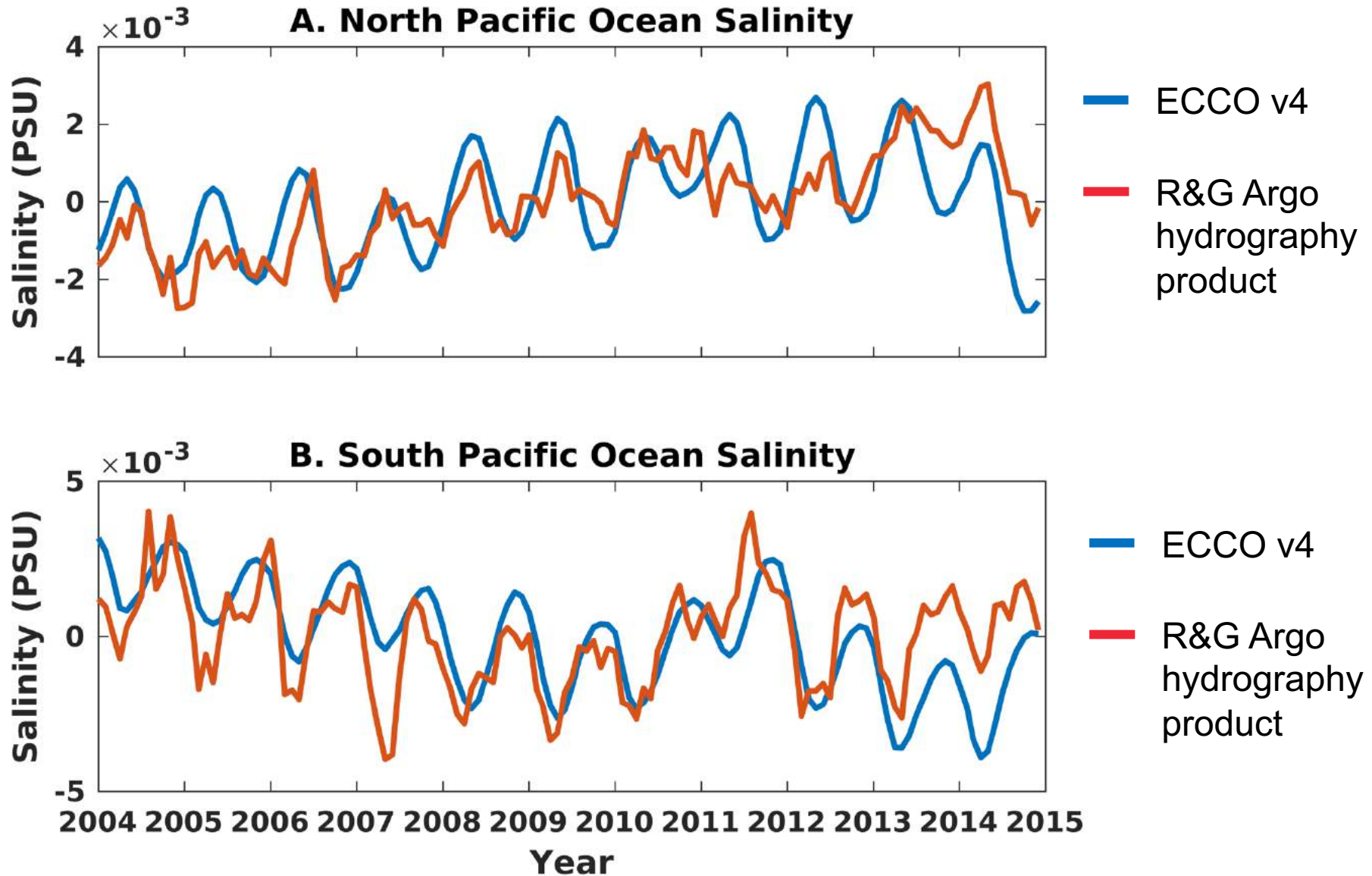
First-Guess



State Estimate



Pacific Ocean Salinity 0-2000m



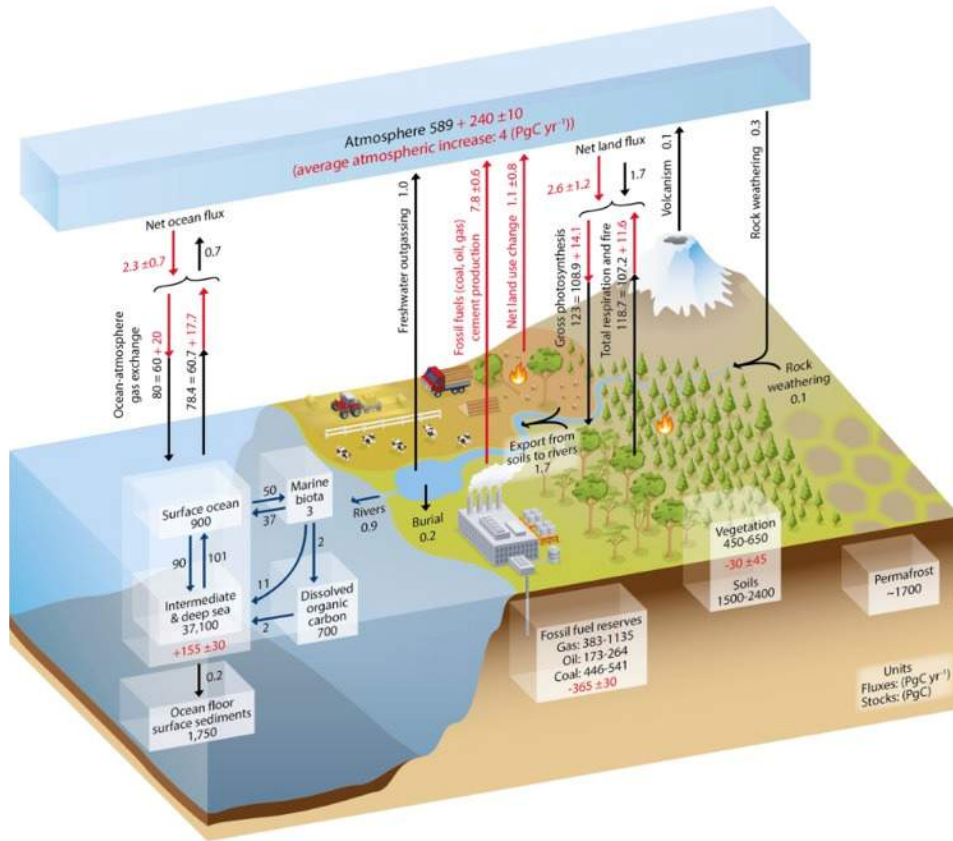
1. ECCO Products

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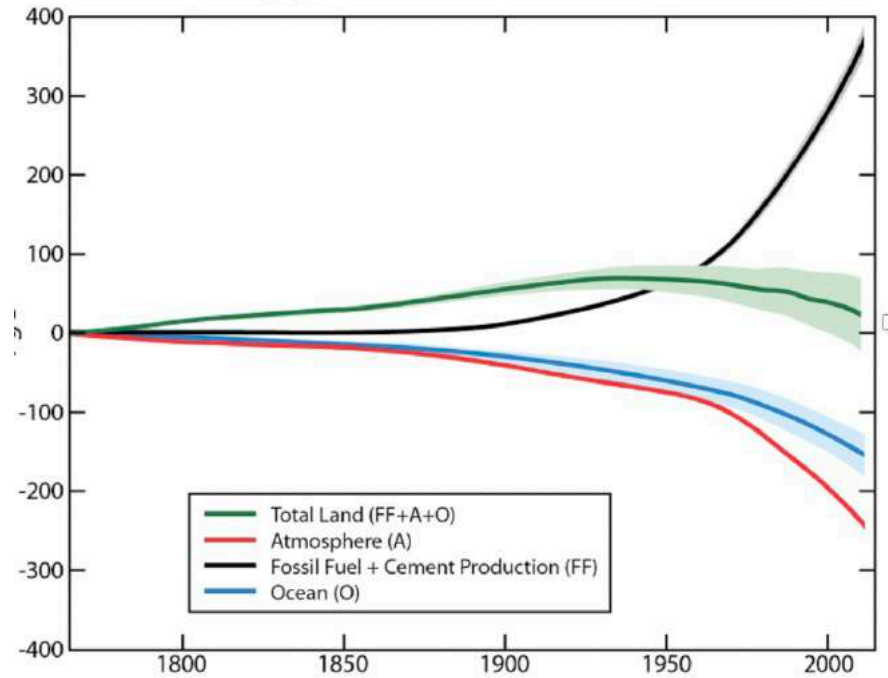
2. Analysis tools and tutorials

ECCO-Darwin

Global Carbon Budget



Temporal Evolution of Carbon Accumulation
Anthropogenic Carbon Reservoirs, 1765-2011



Khaliwala et al. *Nature* (2009); *Biogeoscience* (2013)

ECCO-Darwin

Physics: ECCO LLC 270, Jan 1992–May 2018

Biology: 5 Phytoplankton and 2 Zooplankton types

Biogeochemical ICs:

- GLODAP V2 climatology (Lauvset *et al.* 2016)
- ECCO-Darwin v2 (Brix *et al.* 2015)

Forcing:

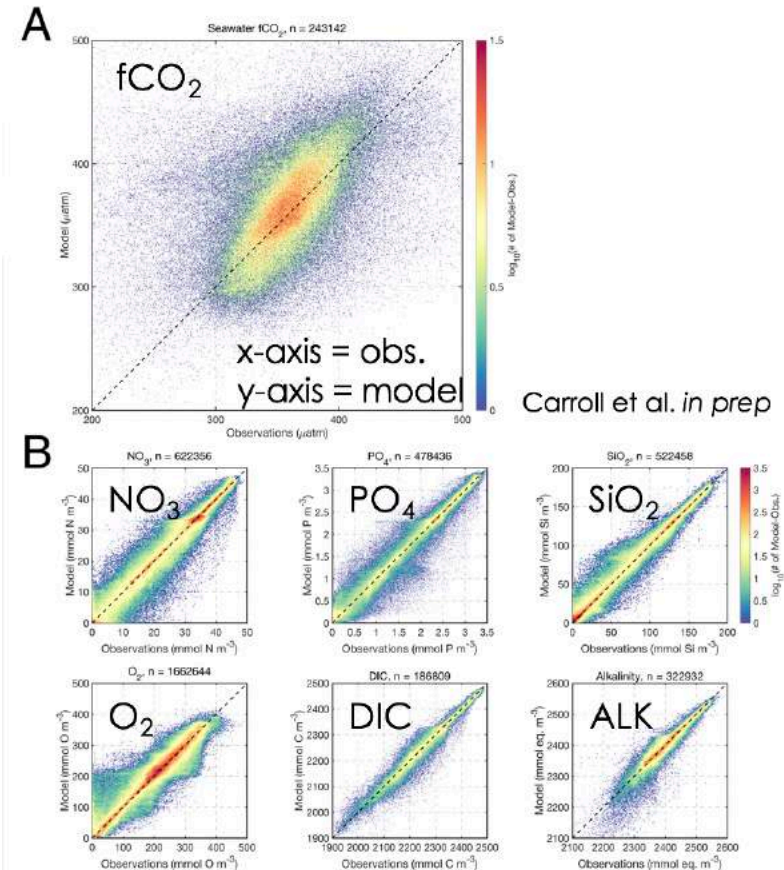
- Atmospheric $p\text{CO}_2$ forcing (NOAA MBL)
- Monthly climatological iron dust forcing (Mahowald *et al.* 2009)

Observational Constraints (n = 4038777):

- SOCAT V5 surface $f\text{CO}_2$ (Bakker *et al.* 2016)
- GLODAP V2 profiles (Olsen *et al.* 2017)
- SOCCOM BGC-Argo profiles (Riser *et al.* 2018)
- UW Argo O_2 profiles (Drucker and Riser, 2016)

Optimization:

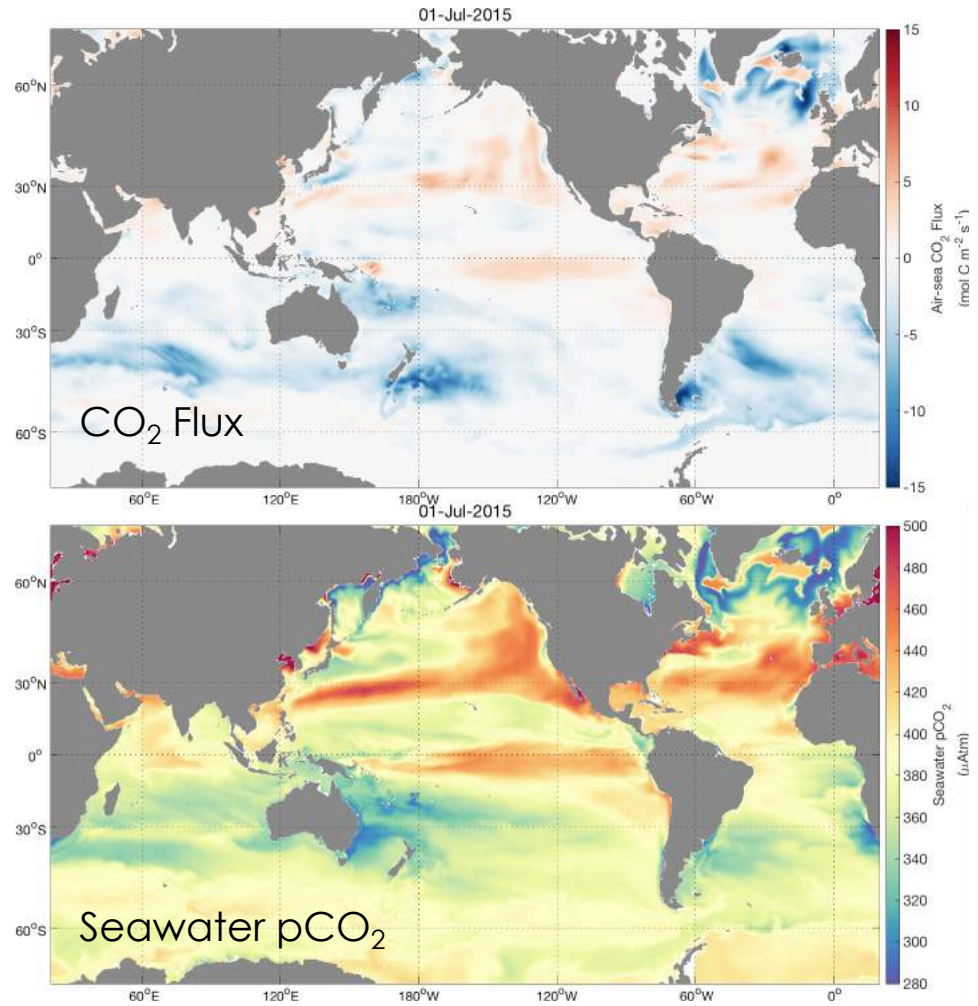
- 13 biogeochemical Green's Functions



ECCO-Darwin

CO₂ Flux

Red = CO₂ outgassing
Blue = CO₂ uptake



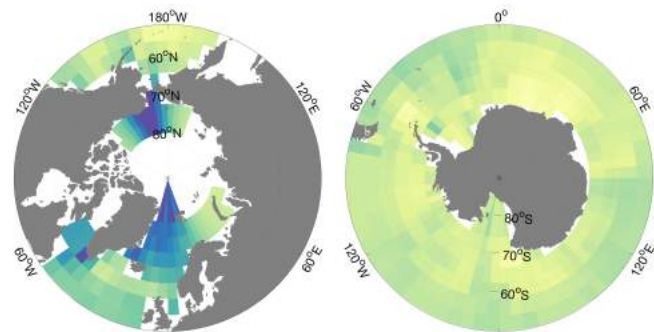
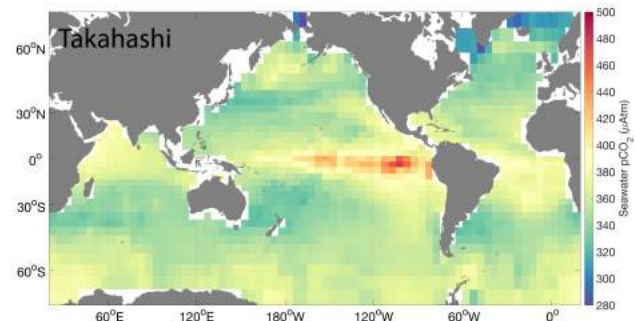
ECCO-Darwin

Seawater pCO₂ Climatology

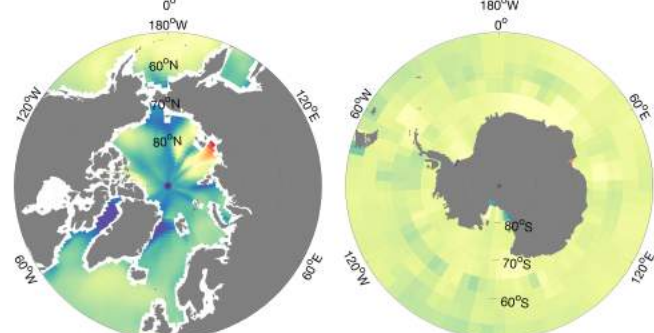
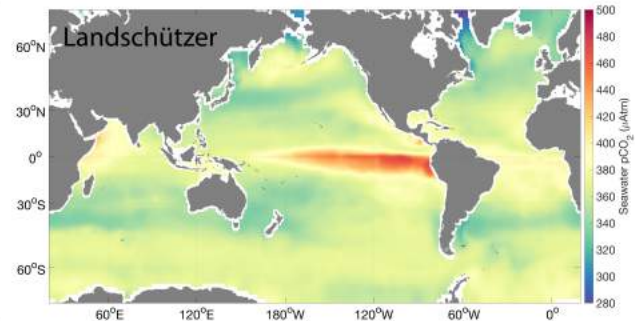
Red = High pCO₂

Blue = Low pCO₂

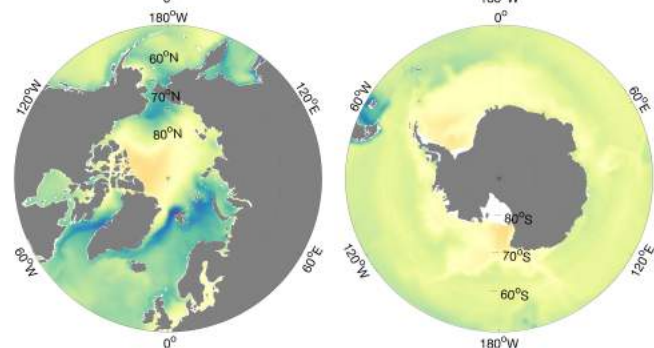
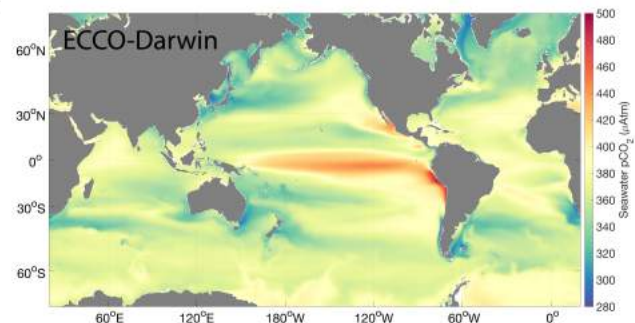
A



B



C

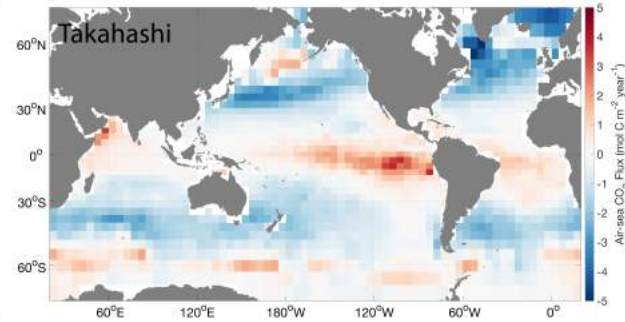


ECCO-Darwin

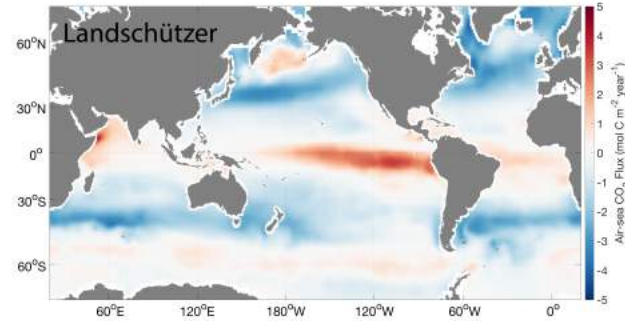
CO₂ Flux Climatology

Red = CO₂ outgassing
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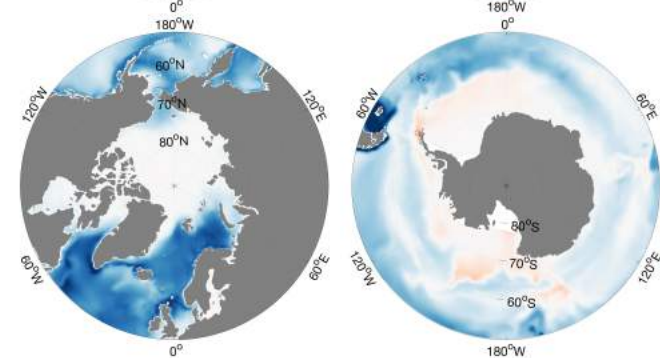
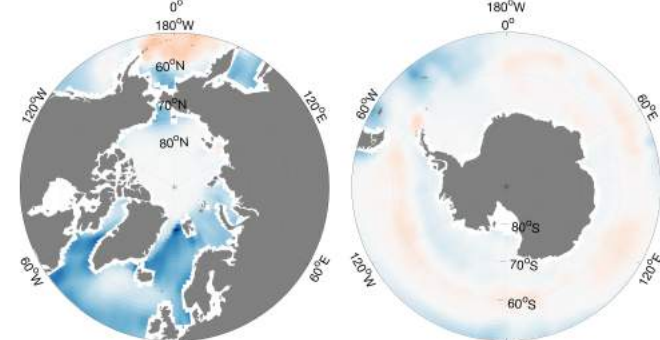
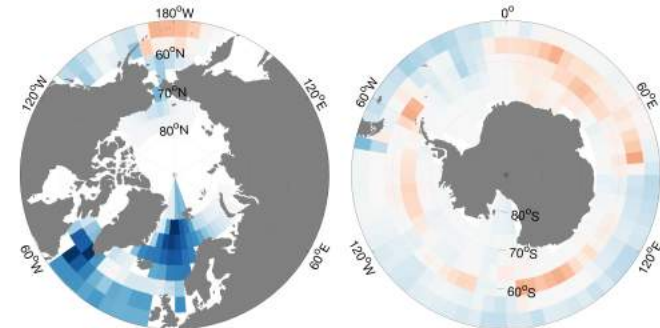
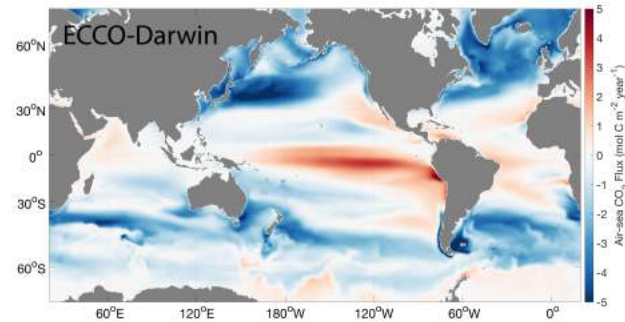
A

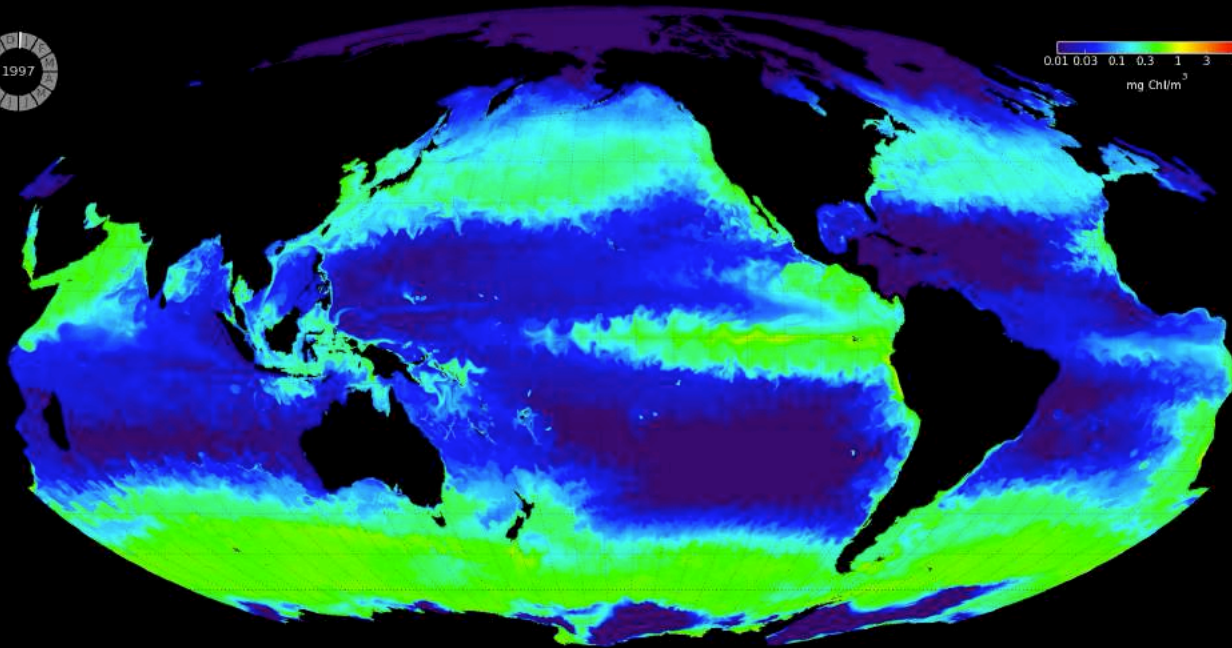
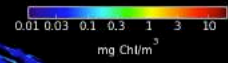
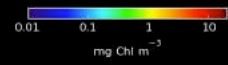


B

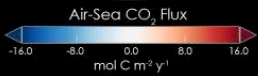
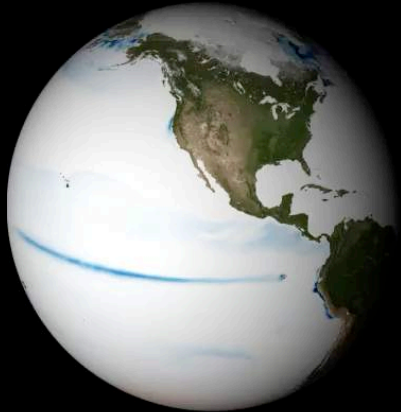


C

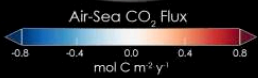
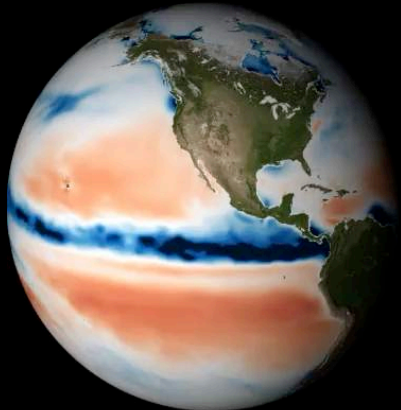




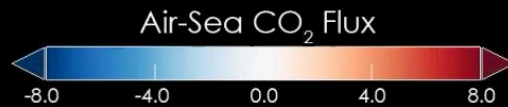
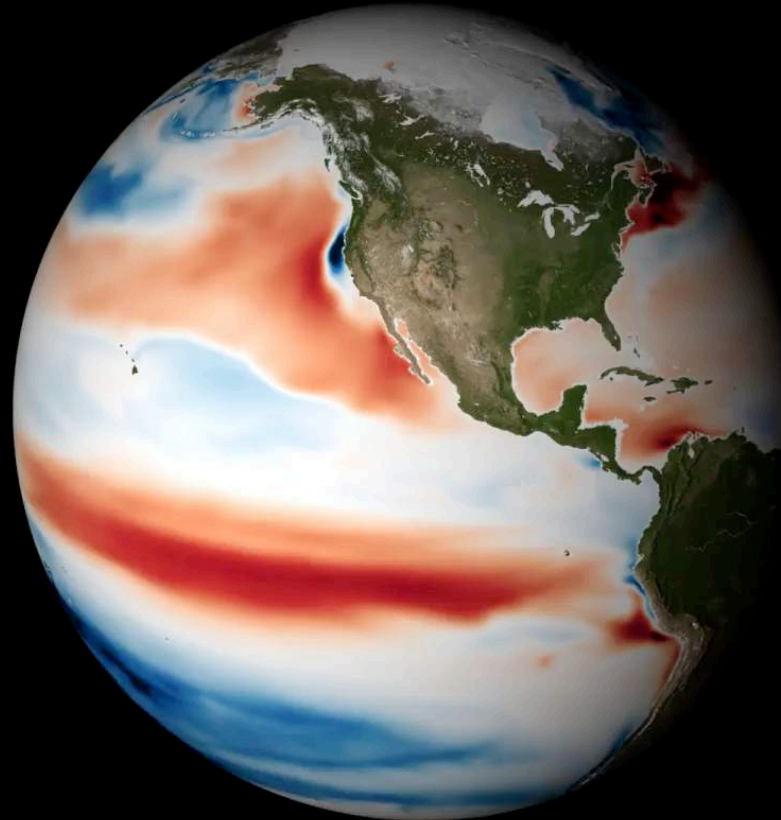
Biological CO₂ Flux



Freshwater CO₂ Flux

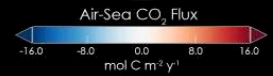
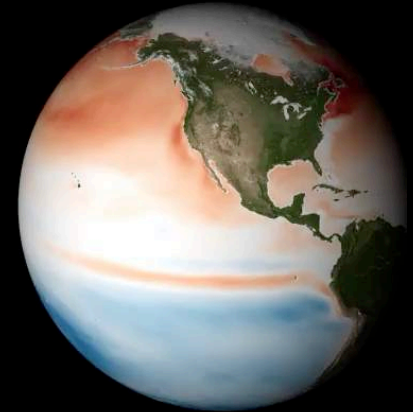


Total CO₂ Flux

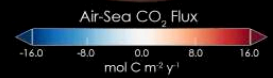
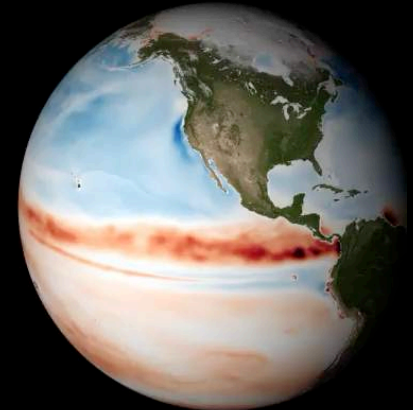


Jun 2014

Heat CO₂ Flux



Disequilibrium CO₂ Flux



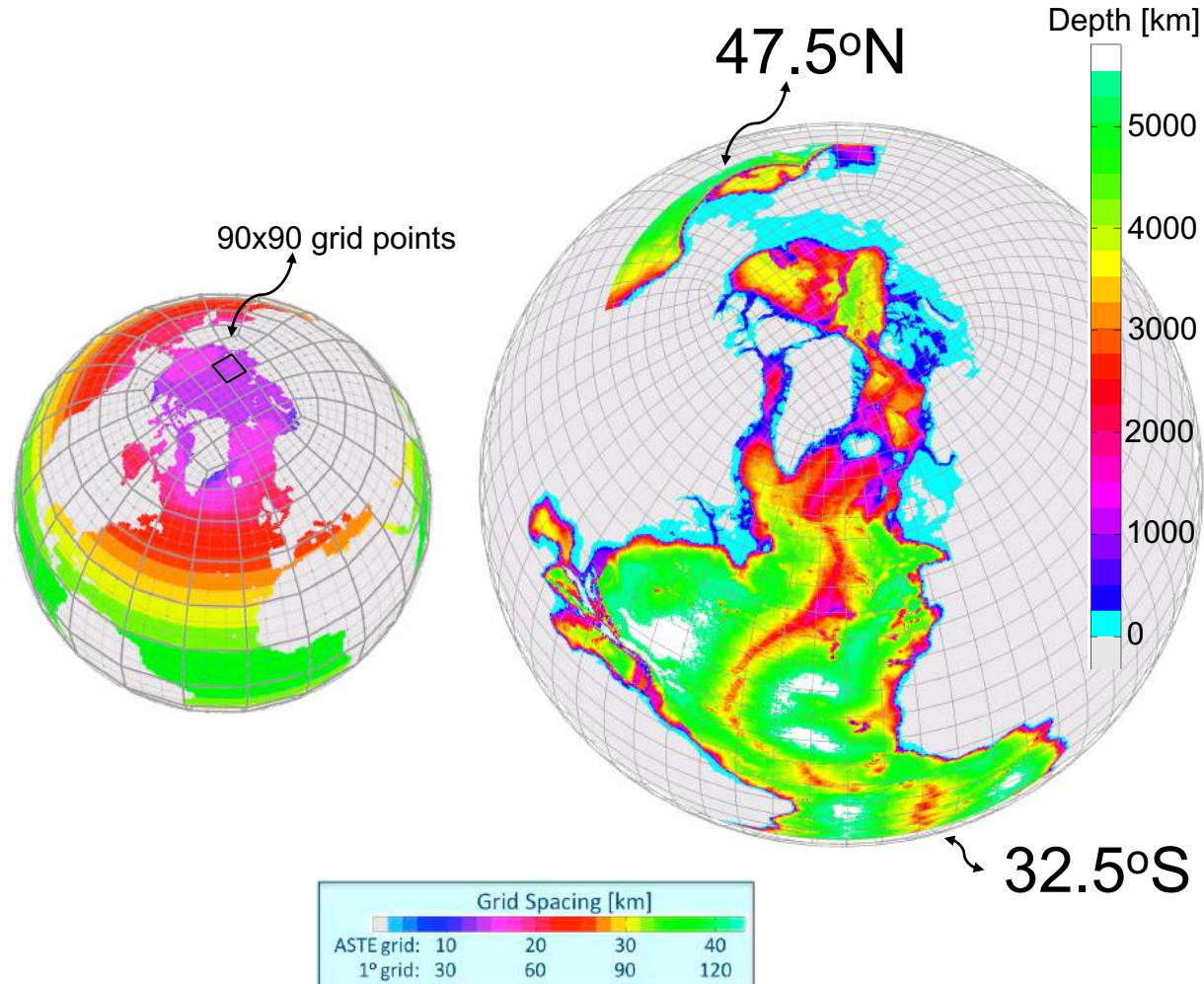
1. ECCO Products

- ECCO Central Production: v4 Release 3
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- **ASTE**
- B-SOSE
- *Other regional products*

2. Analysis tools and tutorials

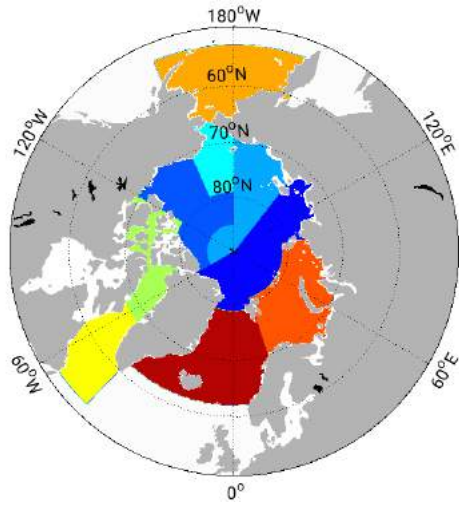
Arctic Subpolar gyre sTate Estimate (ASTE)

- Adjoint-based state estimation with high-latitudes focus
- ~1/3 degree
- Science: Arctic / SubArctic systems
- Produced and maintained at UT-Austin
- Optimization period: **2002-2017**

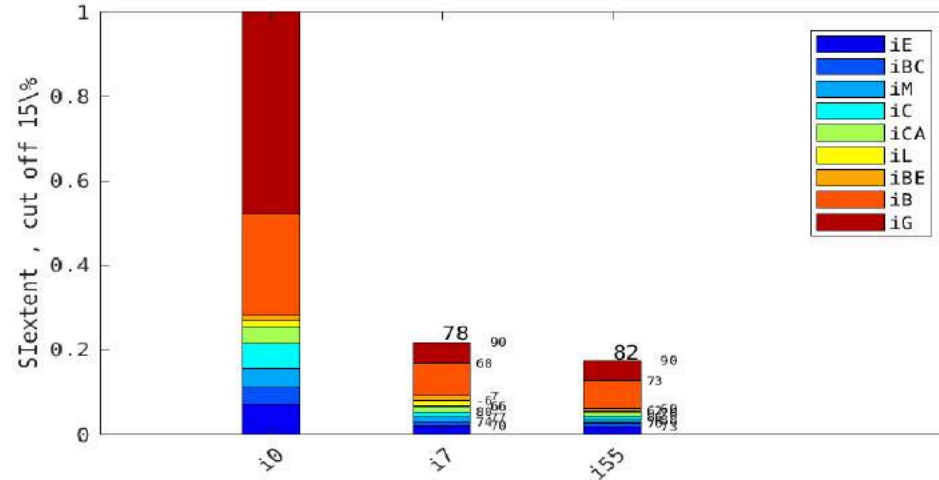


Nguyen et al., 2017;
Nguyen et al., 2019, in prep.

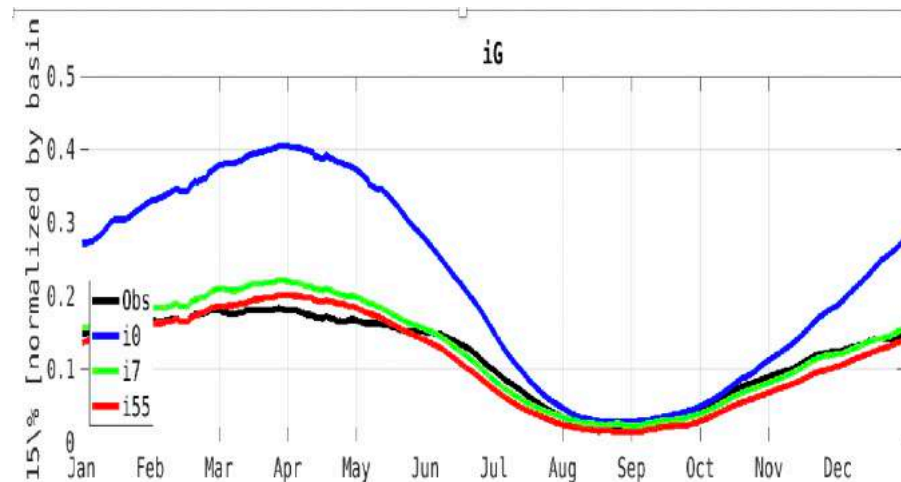
Arctic Subpolar gyre State Estimate (ASTE)



Total sea ice extent misfit

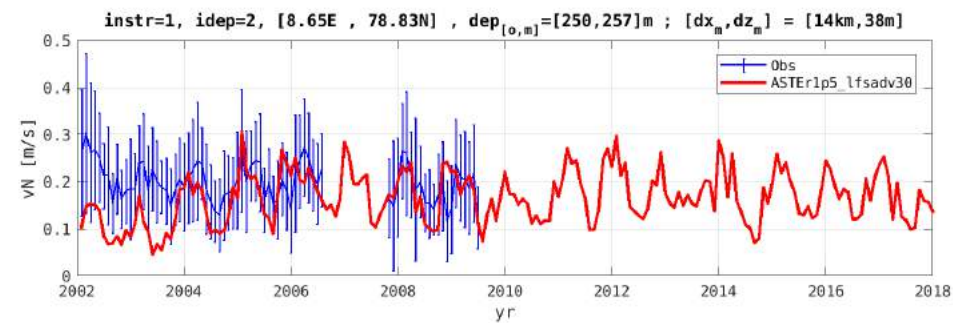
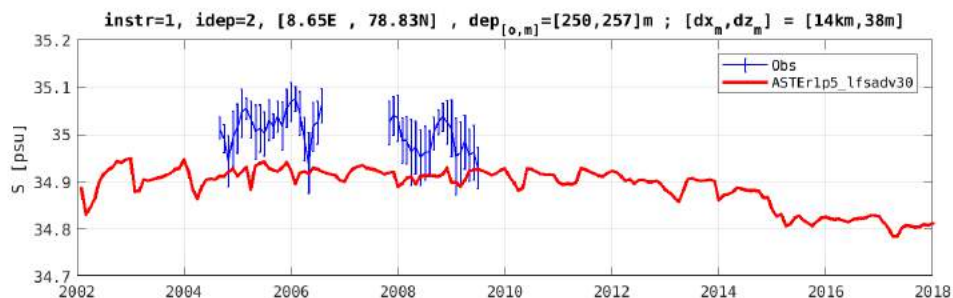
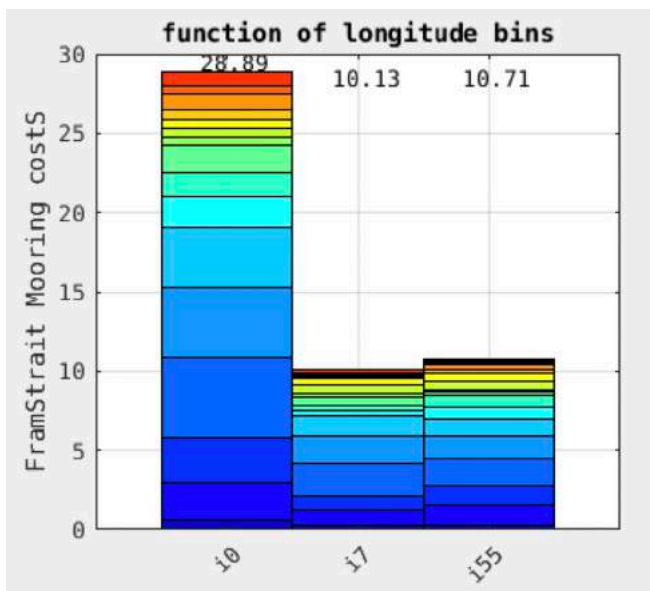
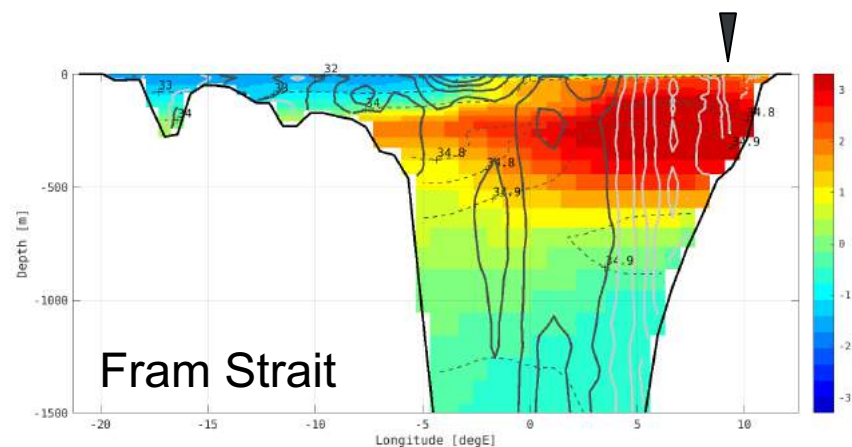


Sea ice extent climatology



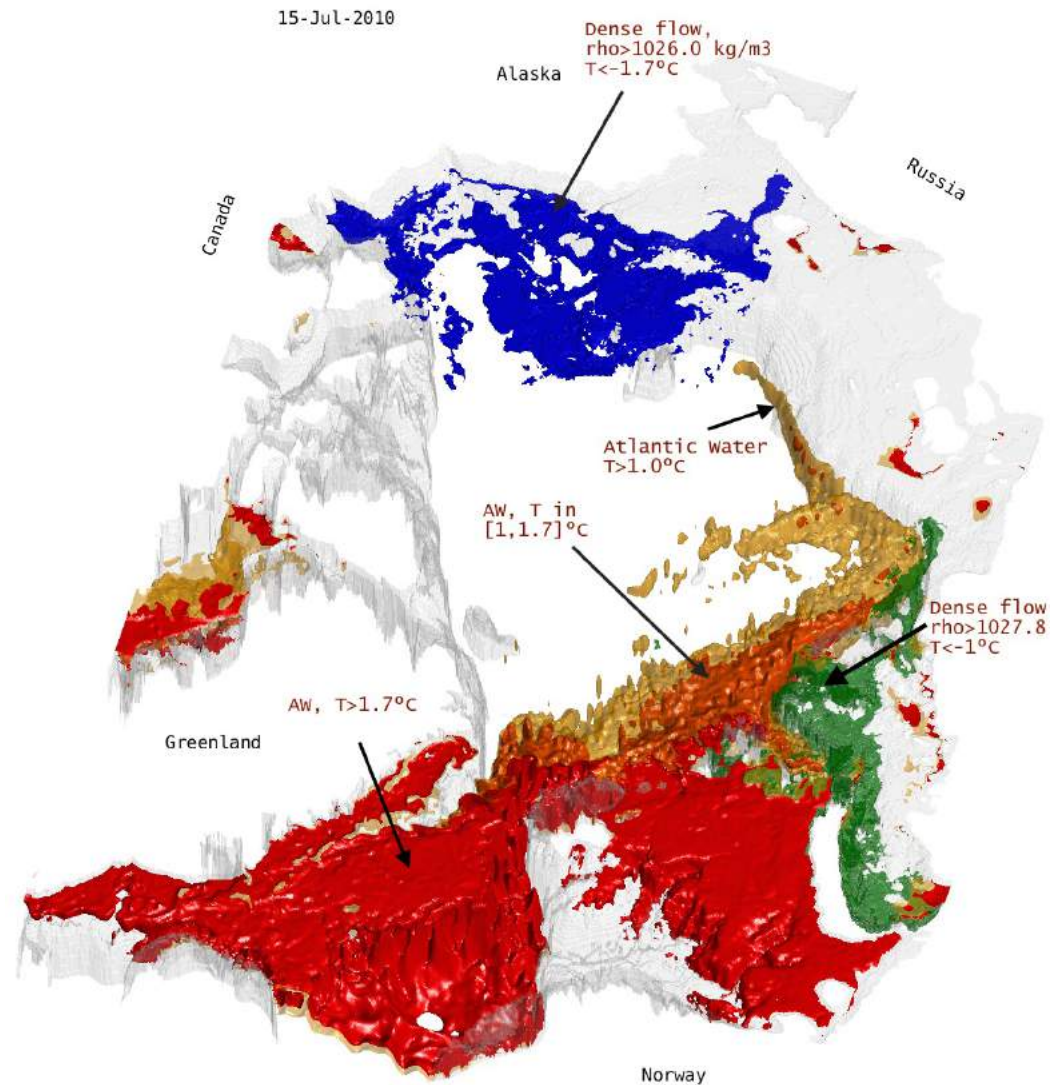
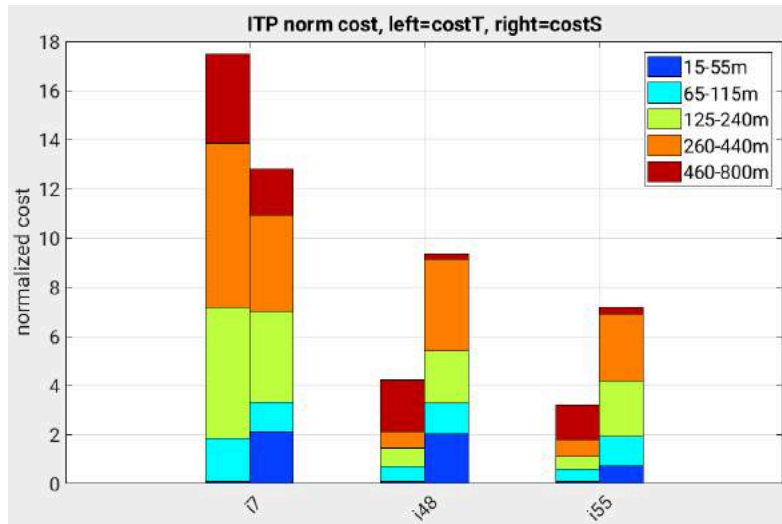
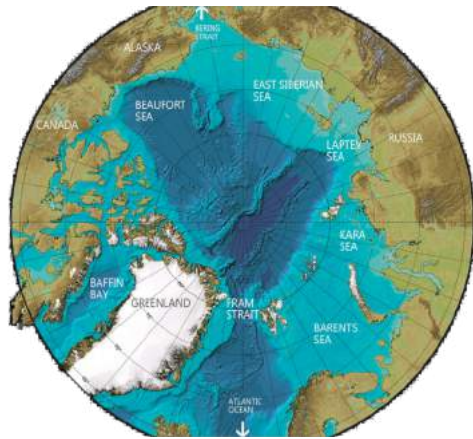
Arctic Subpolar gyre State Estimate (ASTE)

- Representation of Arctic Ocean gateway transports



Arctic Subpolar gyre sTate Estimate (ASTE)

- Representation of Arctic Ocean watermasses



Arctic Subpolar gyre sTate Estimate (ASTE)

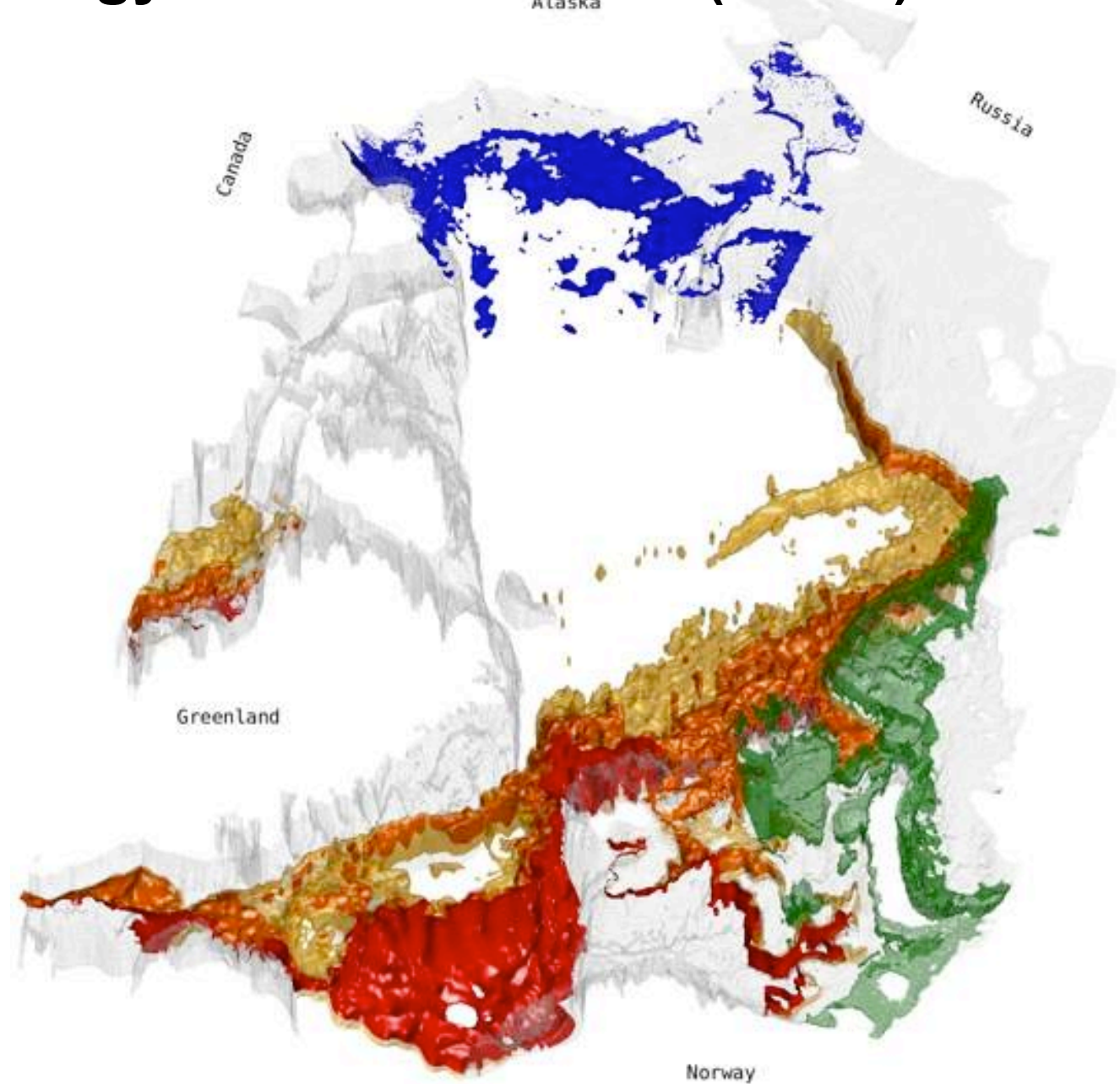
12-Mar-2012

Alaska

Canada

Russia

Watermass
production &
transformation



movie

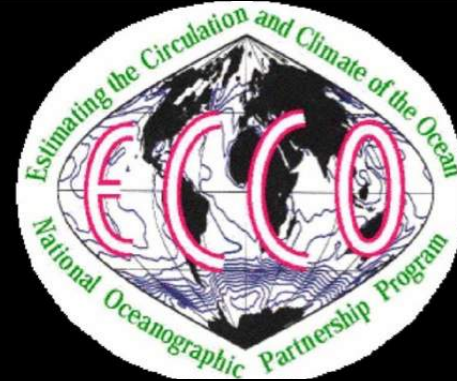
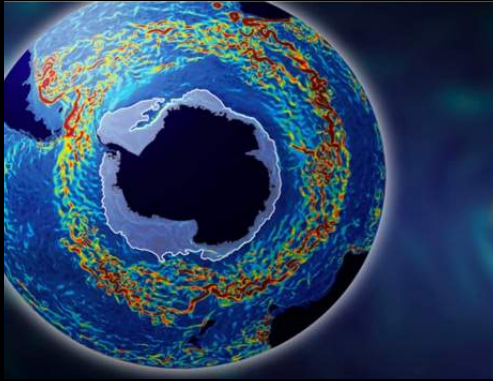
Applications / Users

- Arctic physical oceanography (WHOI, UAF, UW, URI)
- Arctic ocean-sea ice system changes (WHOI, UAF)
- Arctic – SubArctic exchange (WHOI, John Hopkins)
- Acoustic wave propagation (URI, NERSC, ARL-UT)
- Forcings and initializations (UT-Austin, NERSC)
- Coupled ASTE-BioGeoChemistry (Columbia)
- Budget analyses (UW, MIT)
- Adjoint sensitivity studies – identification of dominant control mechanism (John Hopkins, UT-Austin, UW)
- Arctic Observing System (Simulation) experiment (UW, WHOI)
- Arctic / Nordic Seas observing system assessment (NERSC)
- Arctic sea ice prediction skills (UAF, UT-Austin)

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- ASTE
- **B-SOSE + *other regional products***

2. Analysis tools and tutorials

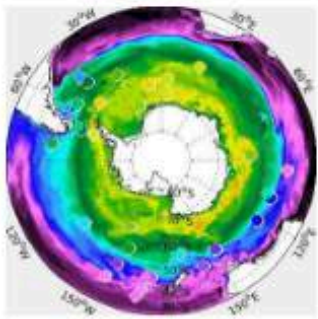


Regional state estimate efforts at SIO

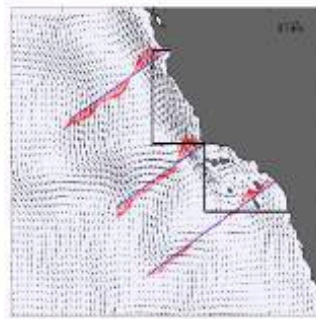
Matt Mazloff, Bruce Cornuelle, Ganesh Gopalakrishnan,
Heriberto Vazquez Peralta, Ariane Verdy, Kasia Zaba, and
others



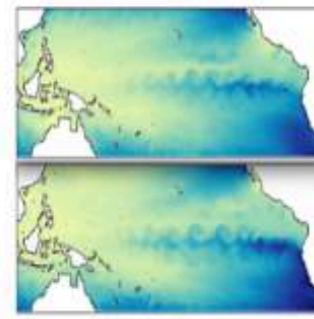
SCRIPPS INSTITUTION OF
OCEANOGRAPHY



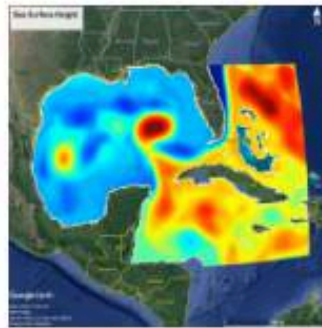
Southern Ocean State Estimate (SOSE)



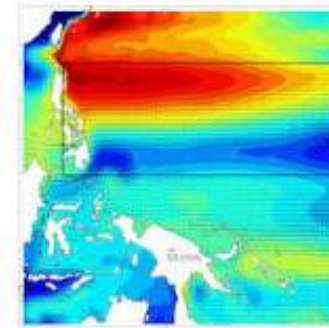
California Current System State Estimate (CASE)



Tropical Pacific Ocean State Estimate (TPOSE)



Gulf of Mexico State Estimate (GoM)



Northwest Pacific State Estimate (NWPac)

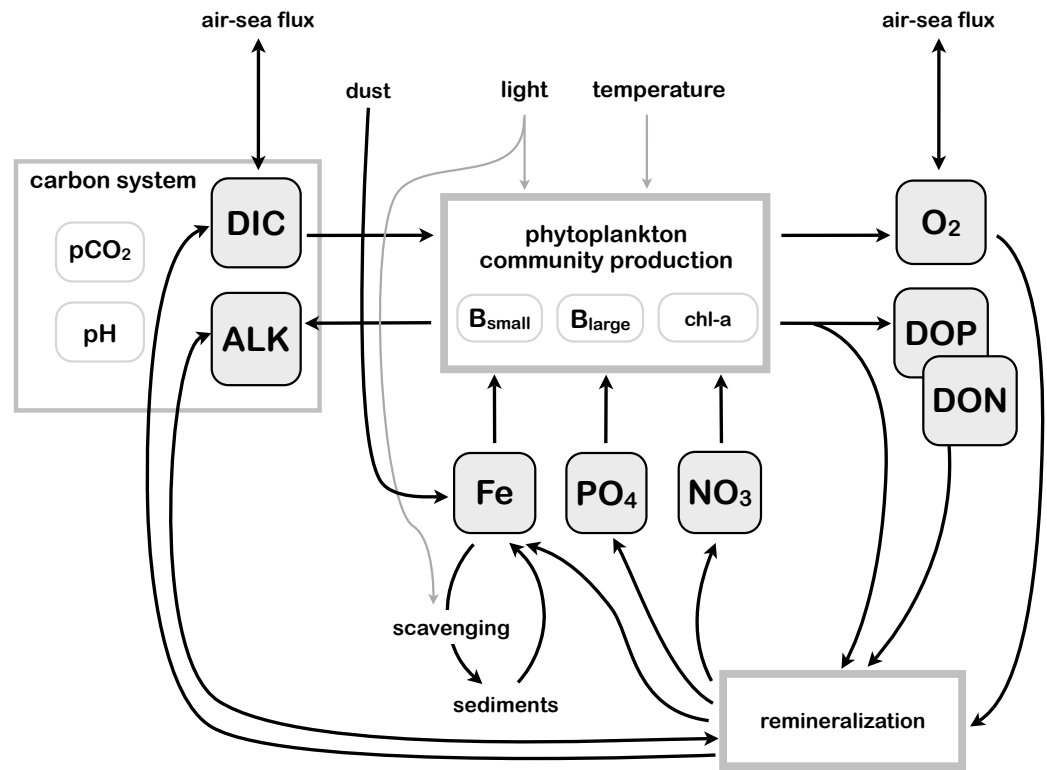
Targeted efforts for:

- Reproducing eddies
- Ocean biogeochemical processes, air-sea carbon fluxes
- Consistency in specific regions/times, or with specific obs platforms.
- Observing system design
- Forecasting: hindcasts is to provide forecast initializations

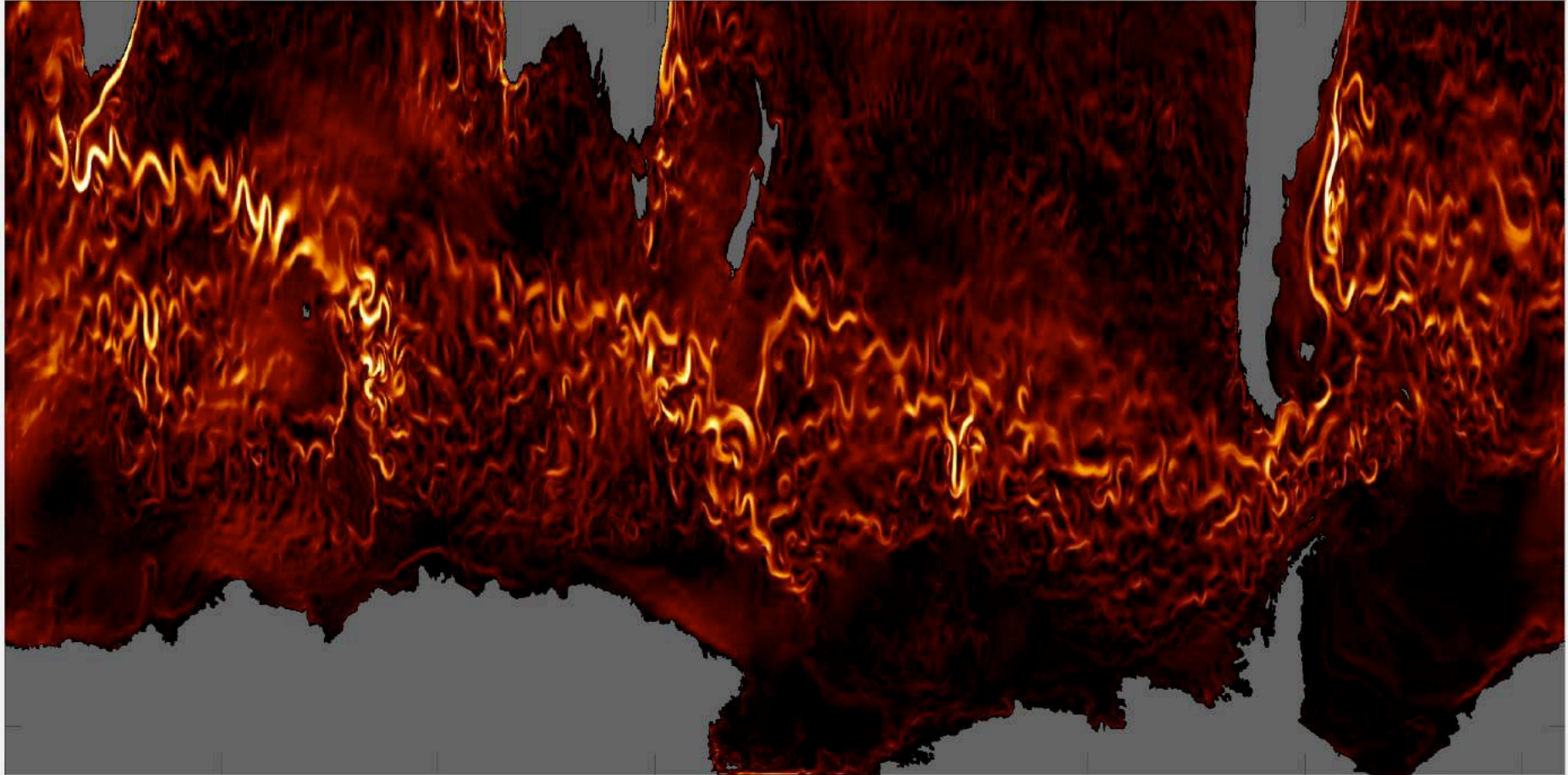
1/6° Biogeochemical-ice-ocean Southern Hemisphere model

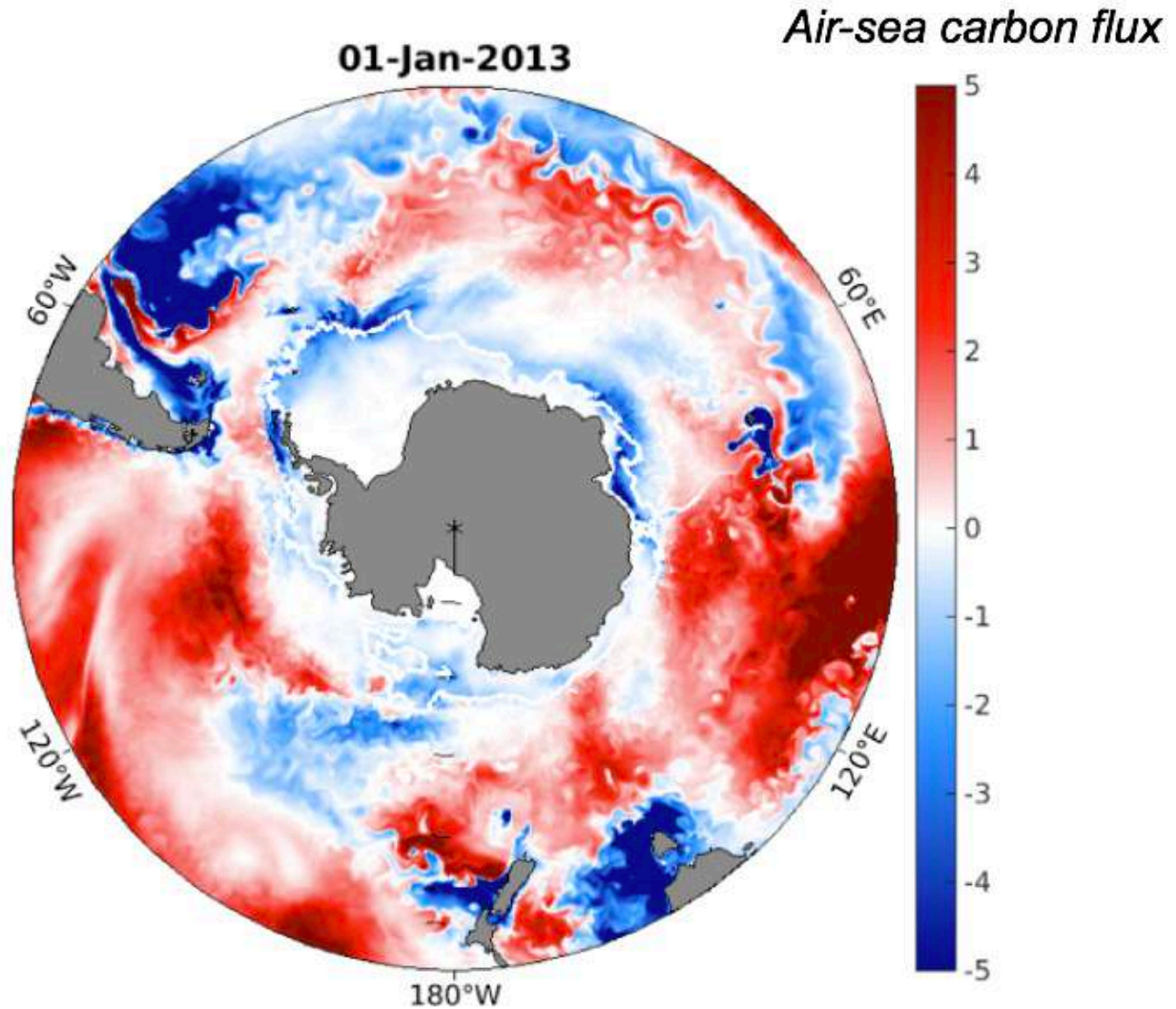
Biogeochemistry with Light, Iron, Nutrients and Gases (BLING) version 2.

State estimate uses MITgcm-ECCO adjoint machinery

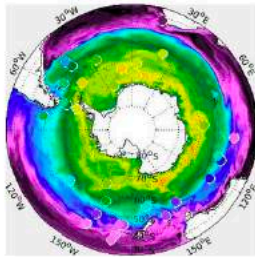


ocean surface speed



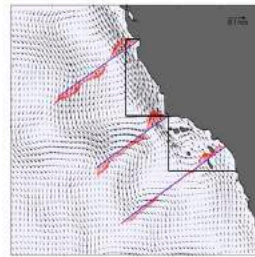


ECCO@Scripps: Our group contributes to the development and production of regional ocean state estimation using the methodology developed by the ECCO consortium (ecco.jpl.nasa.gov). The ECCO code is based on the MIT general circulation model (MITgcm) and employs automatic/algorithmic differentiation (AD) tools for generating tangent linear and adjoint code for ocean circulation and climate studies. The goal is to produce a model-observations synthesis, with consistent dynamics and closed budgets for all tracers, to be used for scientific analysis. We are currently working on:



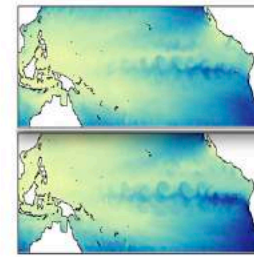
Southern Ocean State Estimate (SOSE)

The latest product, b-SOSE, is a physical-biochemical state estimate produced as part of the SOCCOM project.



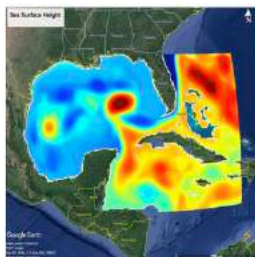
California Current System State Estimate (CASE)

Short- and long-term reanalyses synthesize observations of the California Current System.



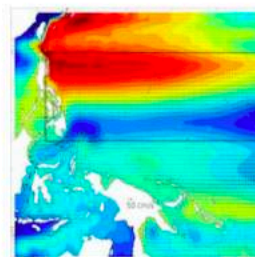
Tropical Pacific Ocean State Estimate (TPOSE)

Observations from the TPOS constrain 4-month state estimates.



Gulf of Mexico State Estimate (GoM)

Estimation and prediction of the loop current and loop current eddy separation.



Northwest Pacific State Estimate (NWPac)

State estimation and prediction in the regions of Palau and Northern Philippine Sea.

2. Analysis tools and tutorials

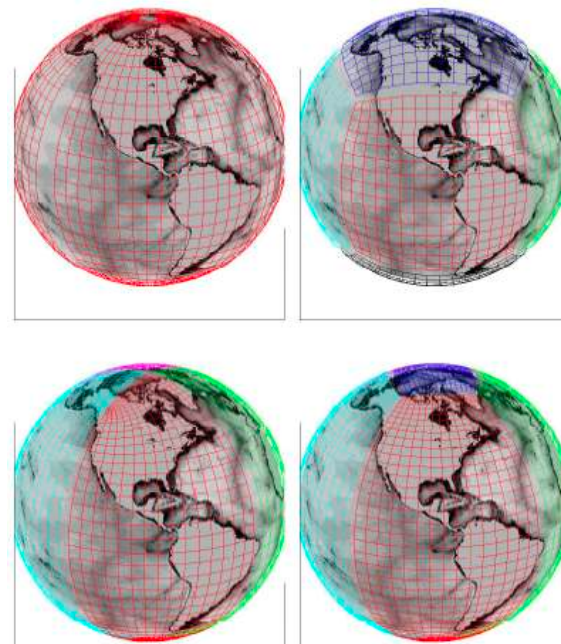
- **Matlab/Octave:** *gcmfaces*
- **Python:**
 - *ecco-v4-py* (ECCO v4 Tutorial)
 - *xmitgcm/xgcm*
 - ... *numpy, matplotlib, cartopy,*

Matlab and Octave: **gcmfaces**

gcmfaces is a toolbox to handle gridded Earth variables as sets of connected arrays.

gcmfaces allows users to write generic, compact analysis codes that readily become applicable to a wide variety of grids (including the lat-lon-cap used in ECCO version 4).

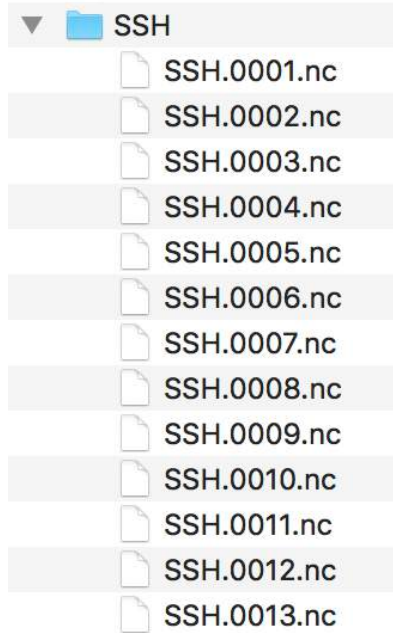
gcmfaces allows for analysis of MITgcm output on any of its familiar grids.



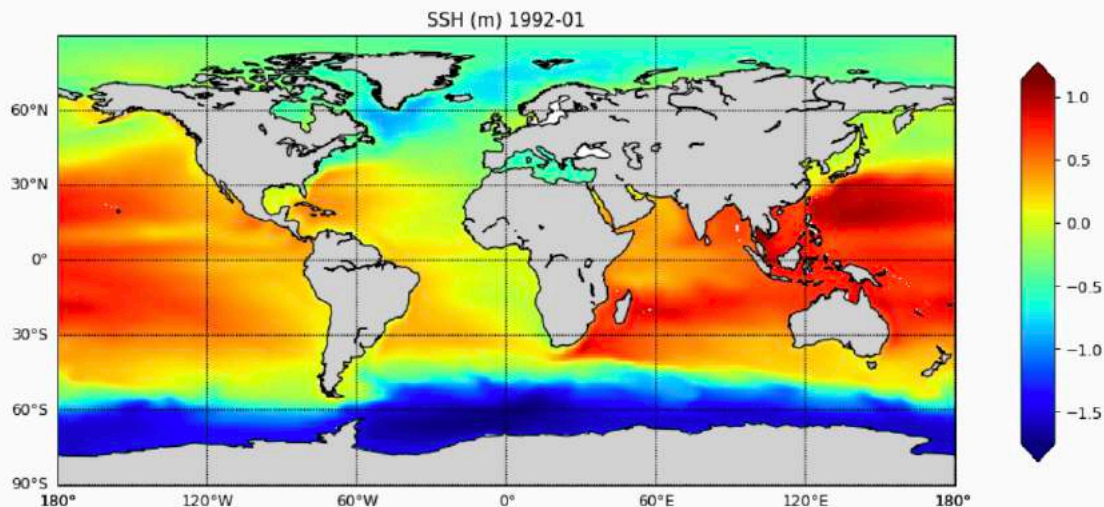
<https://gcmfaces.readthedocs.io/en/latest/index.html>

Python: ecco_v4_py

ecco_v4_py is a Python package for reading, analyzing, and plotting ECCO v4 state estimate fields.



```
plt.figure(figsize=(12,6), dpi= 90)
ecco.plot_tiles_proj(v4.XC,
                    v4.YC,
                    v4.SSH.sel(time=1),
                    cbar=True,
                    plot_type = 'pcolor',
                    projection_type = 'cyl', lon_0=180)
plt.title('SSH (m) ' + str(v4.tim[0].values)[0:7]);
```



<https://github.com/ECCO-GROUP/ECCOV4-py>

ECCO v4 Python Tutorial

🏠 ECCO Version 4 Python Tutorial

latest

Search docs

GETTING STARTED

- The ECCO Ocean and Sea-Ice State Estimate
- ECCO v4 state estimate ocean, sea-ice, and atmosphere fields
- Python and Python Packages
- How to get the ECCO v4 State Estimate
- Tutorial Overview

TUTORIAL: INPUT/OUTPUT

- The Dataset and DataArray objects used in the ECCOv4 Python package.
- A better method for loading ECCOv4 NetCDF tile files
- Loading all 13 lat-lon-cap NetCDF tile files at once
- Combining multiple Datasets
- Saving Datasets and DataArrays to NetCDF

TUTORIAL: BASIC OPERATIONS

- Accessing and Subsetting Variables

[Docs](#) » Welcome to the ECCO Version 4 Tutorial

[Edit on GitHub](#)

Welcome to the ECCO Version 4 Tutorial

This website contains a set of tutorials about how to use the ECCO Central Production Version 4 (ECCO v4) global ocean and sea-ice state estimate. The tutorials were written in Python and make use of the [ecco_v4_py](#) Python library, a library written specifically for loading, plotting, and analyzing ECCO v4 state estimate fields.

Additional Resources

The ECCO v4 state estimate is the output of a free-running simulation of a global ca. 1-degree configuration of the MITgcm. Prior to public release, the model output files model are assembled into NetCDF files. If you would like to work directly with the flat binary "MDS" files provided by the model then take a look at the [xmitgcm](#) Python package. The [xgcm](#) Python package provides tools for operating on model output fields loaded with [xmitgcm](#). If you wish to analyze the MITgcm model output using Matlab then we strongly recommend the extensive set of tools provided by the [gcmfaces](#) toolbox.

The [ecco_v4_py](#) package used in this tutorial was inspired by both the [xmitgcm](#) package and [gcmfaces](#) toolbox.

Getting Started

- [The ECCO Ocean and Sea-Ice State Estimate](#)
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- [Tutorial Overview](#)

ECCO v4 Python Tutorial

53 commits 1 branch 0 releases 2 contributors

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| File/Folder | Commit Message | Time Ago |
|--------------------------------|--------------------------------|-----------------------------------|
| ifenty readme | | Latest commit 57ce425 2 hours ago |
| Tutorials_as_Jupyter_Notebooks | tutorial | 2 days ago |
| Tutorials_as_Python_Files | restructure of tutorial layout | 2 days ago |
| doc | tutorial | 2 hours ago |
| figures | tutorial | 8 days ago |
| README.md | readme | 2 hours ago |

README.md

ECCO version 4 Python Tutorial

Content:

This repository contains a Python tutorial for using the [ECCO Central Production version 4](#) ocean and sea-ice state estimate. Directories within the repository include the ([tutorial documentation](#)) and individual lessons from the tutorial as Jupyter notebooks ([model settings ([Tutorials_as_Jupyter_Notebooks/](#)) and [Tutorials_as_Python_Files/](#)]).

The tutorials were written for ECCO version 4 release 3 but should be applicable to any ECCO v4 solution. If user support is needed, please contact ecco-support@mit.edu.

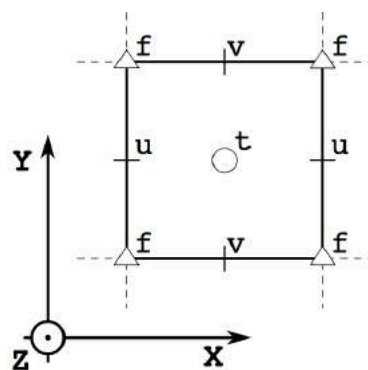
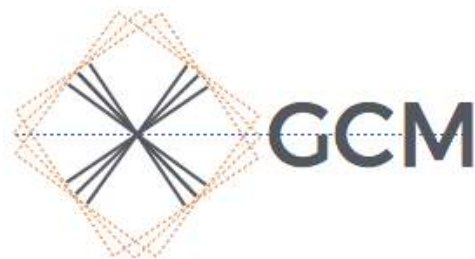
[Estimating the Circulation and Climate of the Ocean]: <http://ecco.jpl.nasa.gov>, <http://ecco-group.org>

Python Packages: **xmitgcm** and **xgcm**

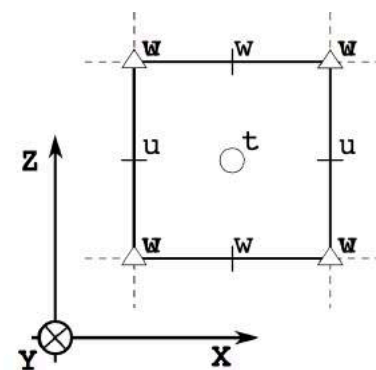
xmitgcm is a Python package for reading MITgcm model output (binary files) into Python xarray data structures

<http://xmitgcm.readthedocs.org>

xgcm is a Python package for working with the datasets produced by numerical General Circulation Models (GCMs) and similar gridded datasets that are amenable to finite volume analysis. <http://xmitgcm.readthedocs.io/en/latest/>



C-grid — horizontal view



C-grid — vertical view

More information

<https://ecco.jpl.nasa.gov>

<http://ecco-group.org>

Download the latest ECCO state estimate

<ftp://ecco.jpl.nasa.gov/Version4/Release3>

Tutorial & Tools

<http://ecco-v4-python-tutorial.readthedocs.io>

<http://eccov4.readthedocs.io>

Getting support

mailto: ecco-support@mit.edu