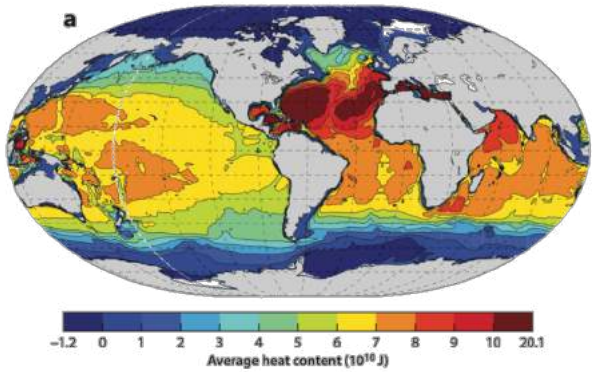
# ECCO PRODUCTS AND TOOLS

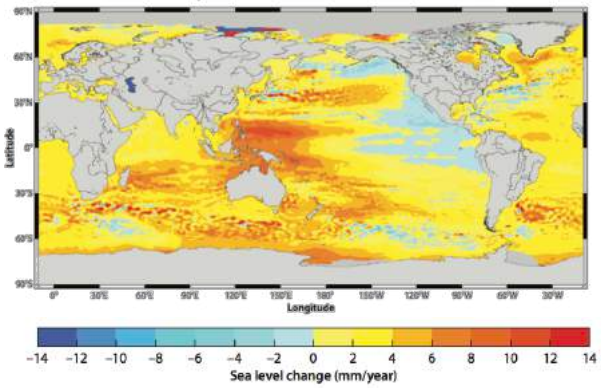
- *The "Estimating the Circulation and Climate of the Ocean" (ECCO) consortium endeavors to produce the best possible estimates of ocean circulation and its role in climate.*
- ***Solutions are obtained** by combining state-of-the-art ocean circulation models with global ocean and sea-ice data in a physically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

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

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

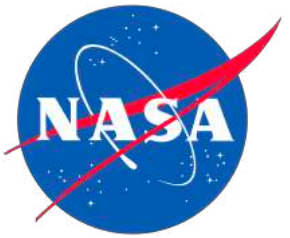
$$\lambda_0 = \sum_{t=1}^{t_f - 1} \left\{ A_1' A_2' \cdots A_t' G_{t+1} \right\} + G_1$$



# ECCO Consortium

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




JPL
Jet Propulsion Laboratory
California Institute of Technology

TEXAS
The University of Texas at Austin

Massachusetts Institute of Technology

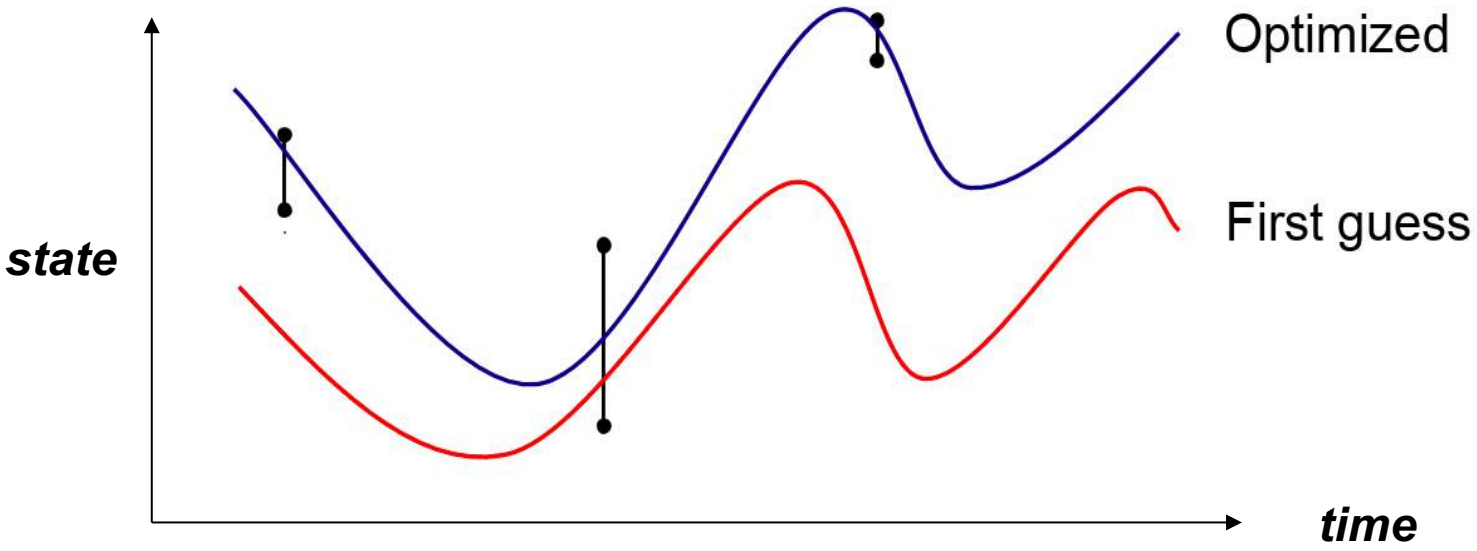
aer
Atmospheric and Environmental Research

UHH
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

SCRIPPS INSTITUTION OF OCEANOGRAPHY

AWI
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.

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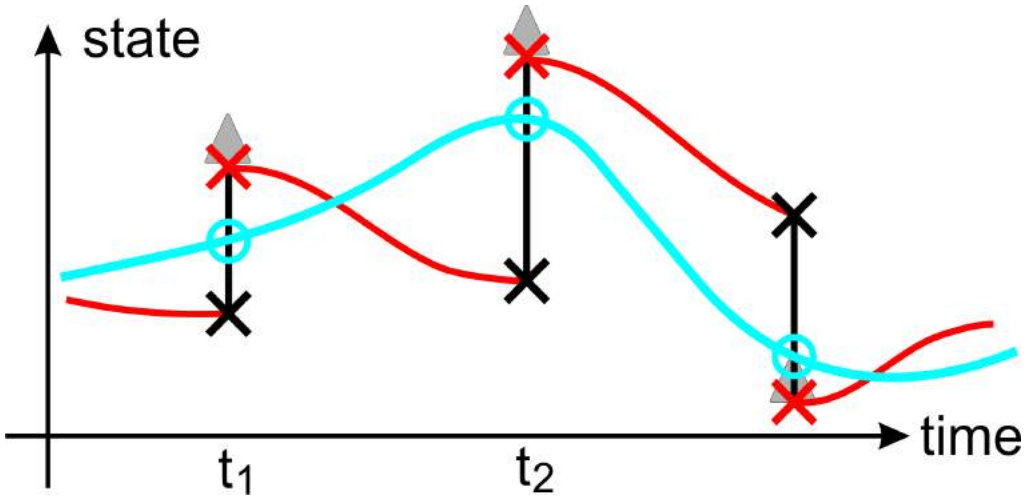


**Inverse problem:** solve for a set of *model initial conditions*, *atmospheric boundary conditions*, and *ocean mixing parameters* such that residuals between the **model solution** and the **observations** are minimized in a least-squares sense.

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

2. Analysis tools and tutorials

1. ECCO Products
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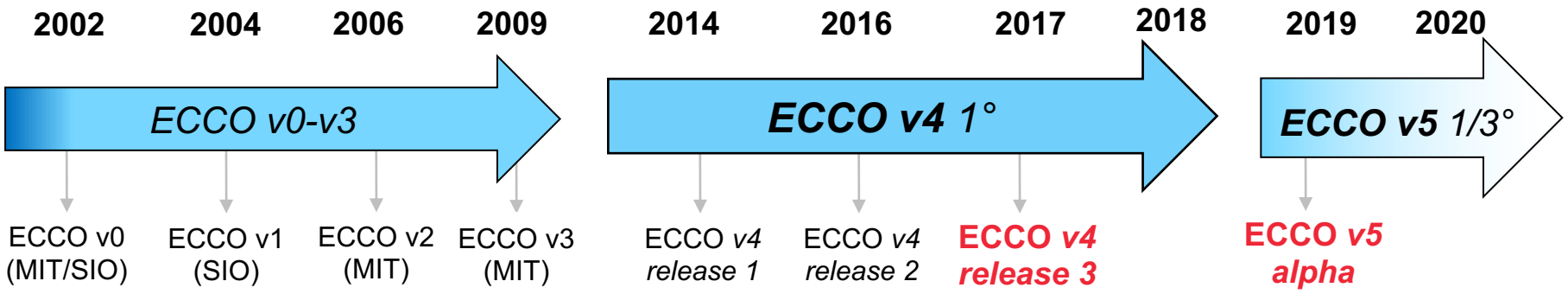
# *ECCO Central Production Timeline*

**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** > $10^8$ *in situ* and satellite remote sensing observations

# *ECCOv4r3: Monthly and daily mean fields*

## Ocean + sea-ice

- *T, S, u, v, w, η, ρ, Φ*
- Sea-ice and snow *h* and *c*
- Lateral and vertical fluxes of volume, heat, salt, and momentum

## Atmosphere

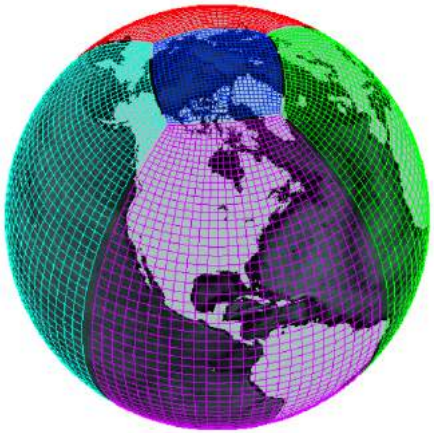
- T, q, |u|, τ, long- and radiative fluxes
- Air–sea-ice–ocean fluxes of heat, moisture, energy, and momentum

## Subgrid-scale mixing parameters

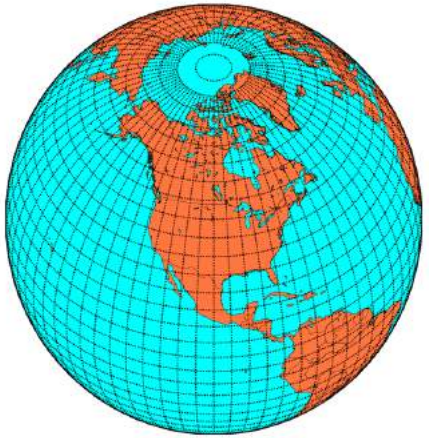
- 3D GM κ and Redi κ
- 3D vertical diffusivity

***Fields are provided on two grids***

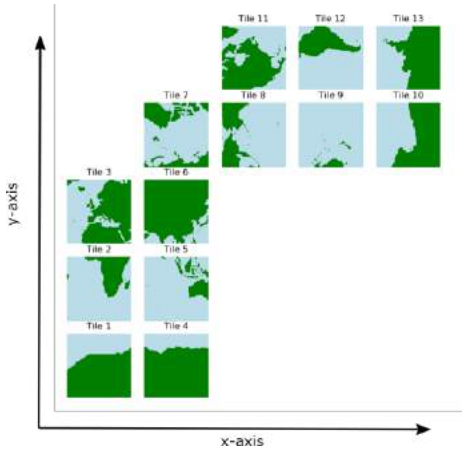
*Curvilinear Cartesian*
*"lat-lon-cap 90"*



*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**

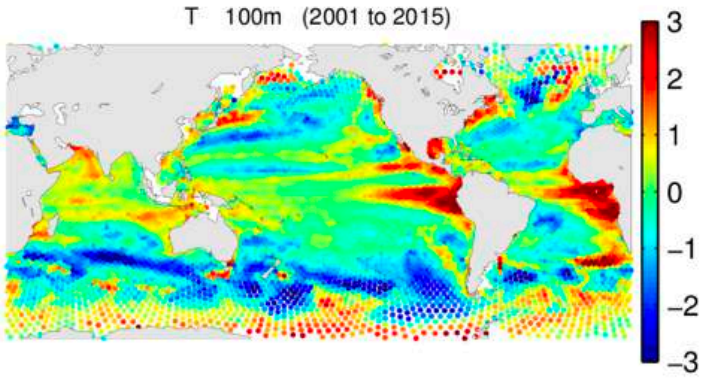
- Grid geometry
- Configuration files
- Model initial conditions
- Atmospheric and hydrological boundary conditions

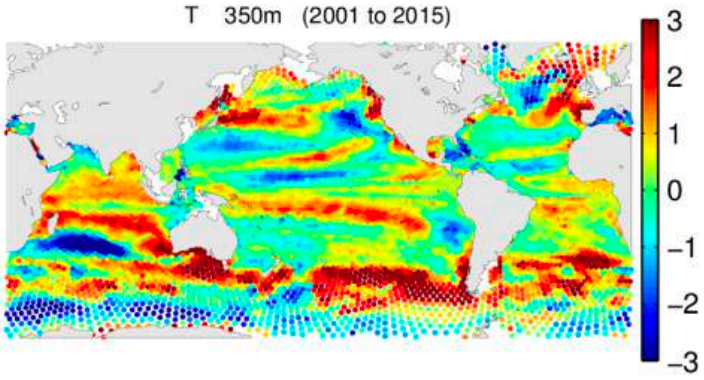
Also mirrored at
*https://web.corral.tacc.utexas.edu/OceanProjects/ECCO/ECCOv4/Release3/*

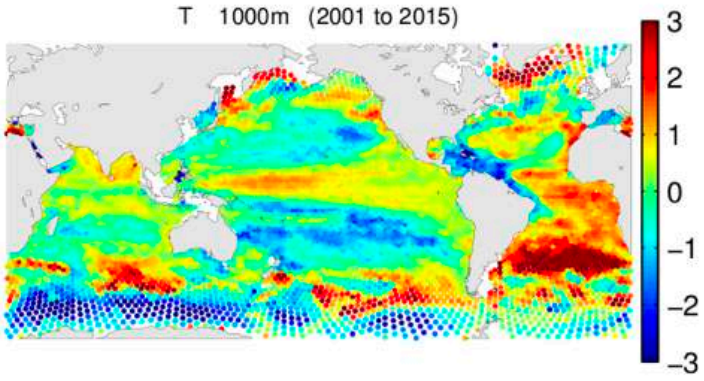
# *ECCOv4r3:* model-data *in situ* T

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

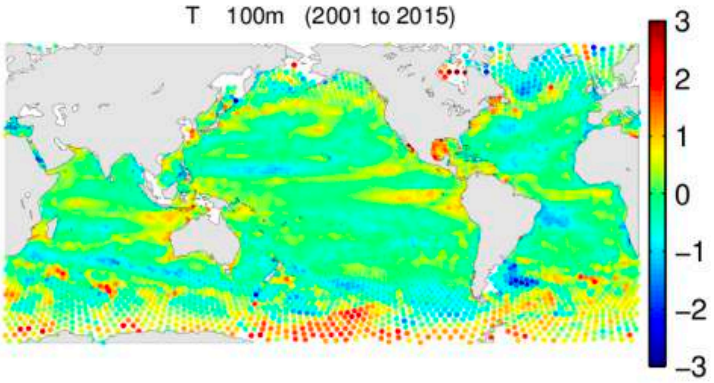
## First-Guess

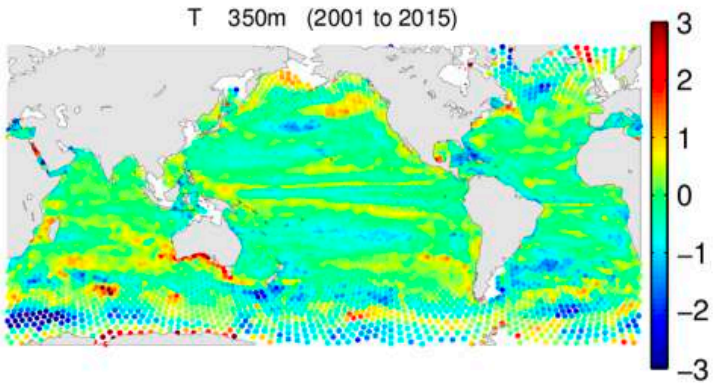


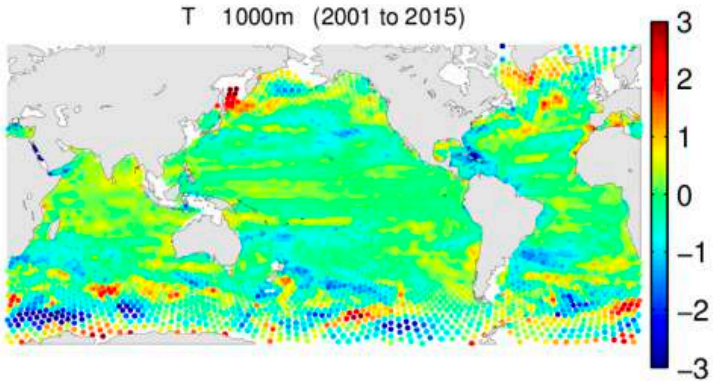



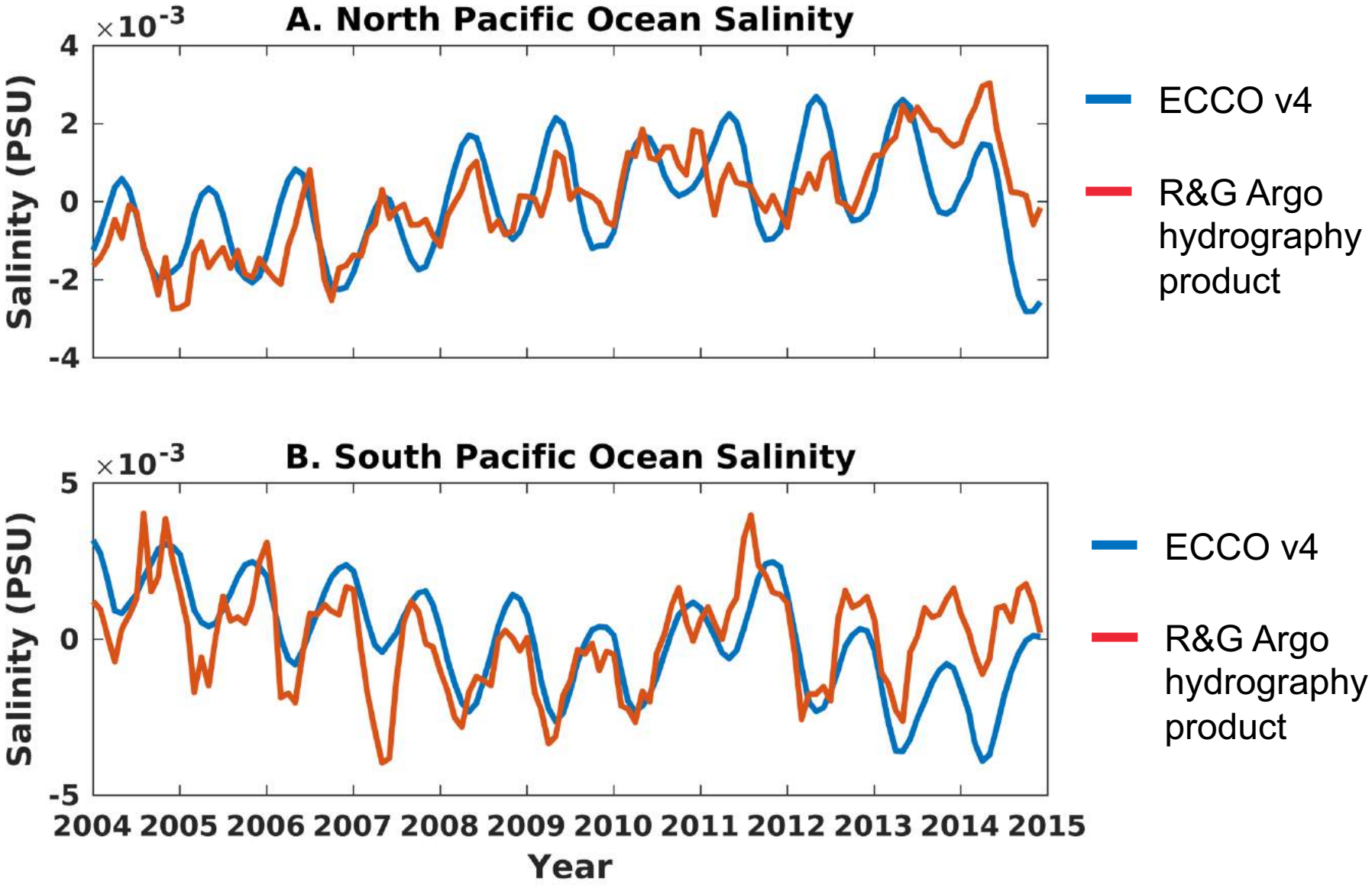

## State Estimate



# Pacific Ocean Salinity 0-2000m



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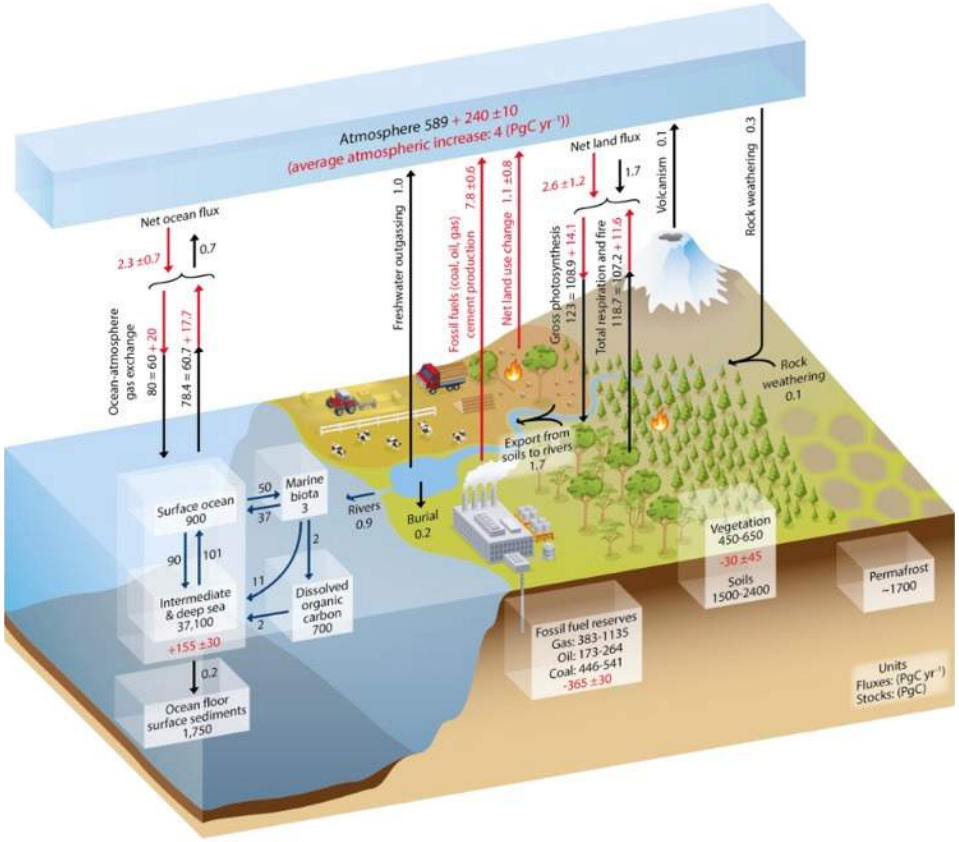
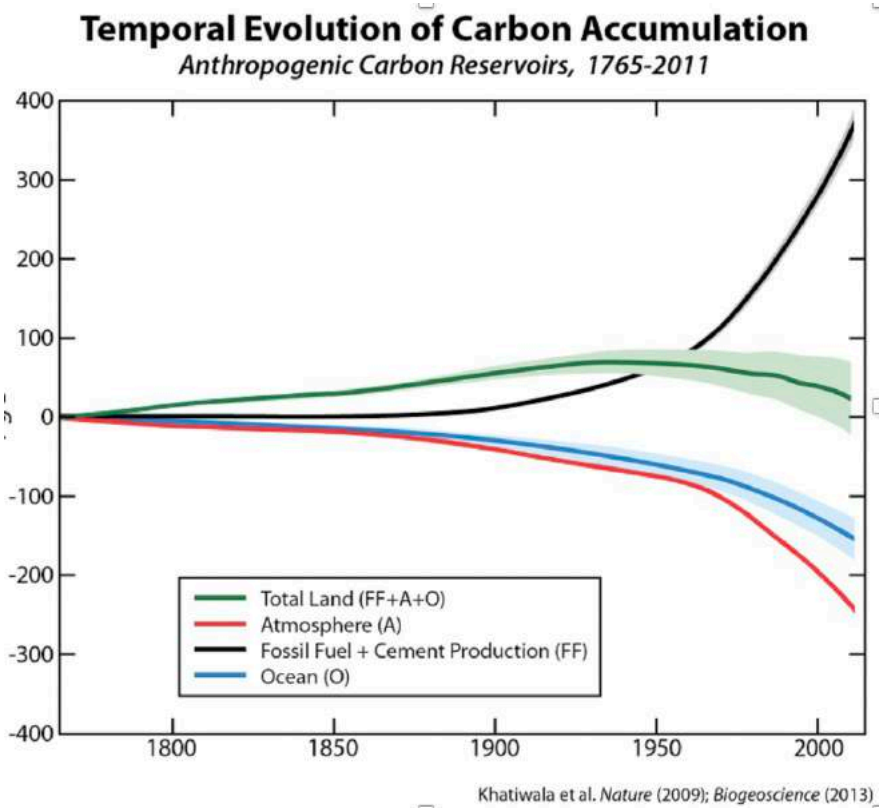
2. Analysis tools and tutorials

# ECCO-Darwin

## Global Carbon Budget



# ECCO-Darwin

**Physics:** ECCO LLC 270, Jan 1992–May 2018

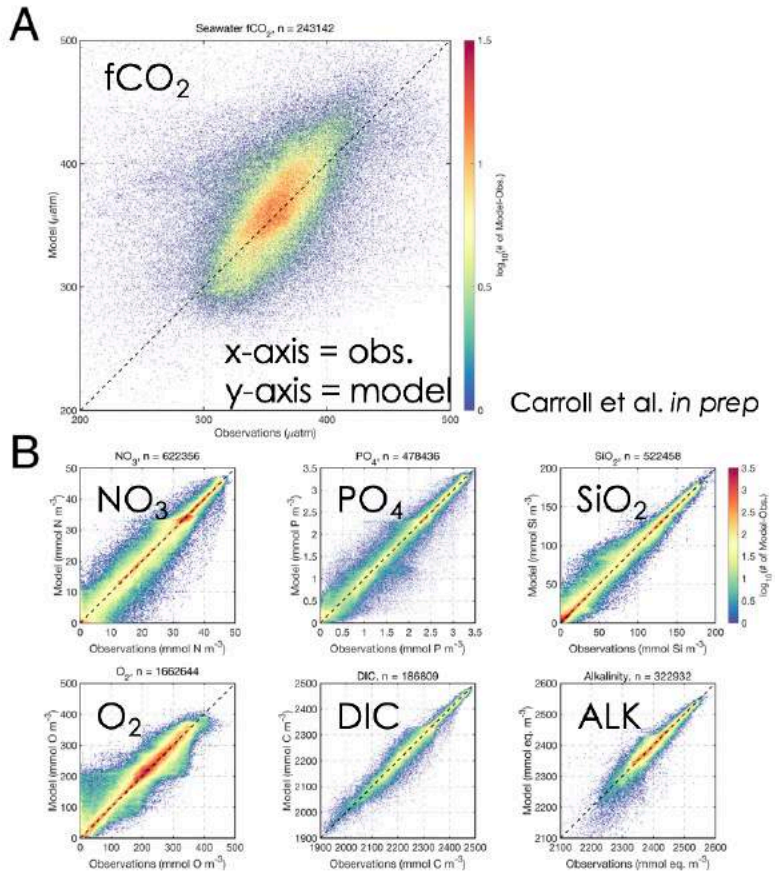
**Biology:** 5 Phytoplankton and 2 Zooplankton types

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

**Forcing:**
- Atmospheric $pCO_2$ forcing (NOAA MBL)
- Monthly climatological iron dust forcing (Mahowald *et al.* 2009)

**Observational Constraints (n = 4038777):**
- SOCAT V5 surface $fCO_2$ (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)

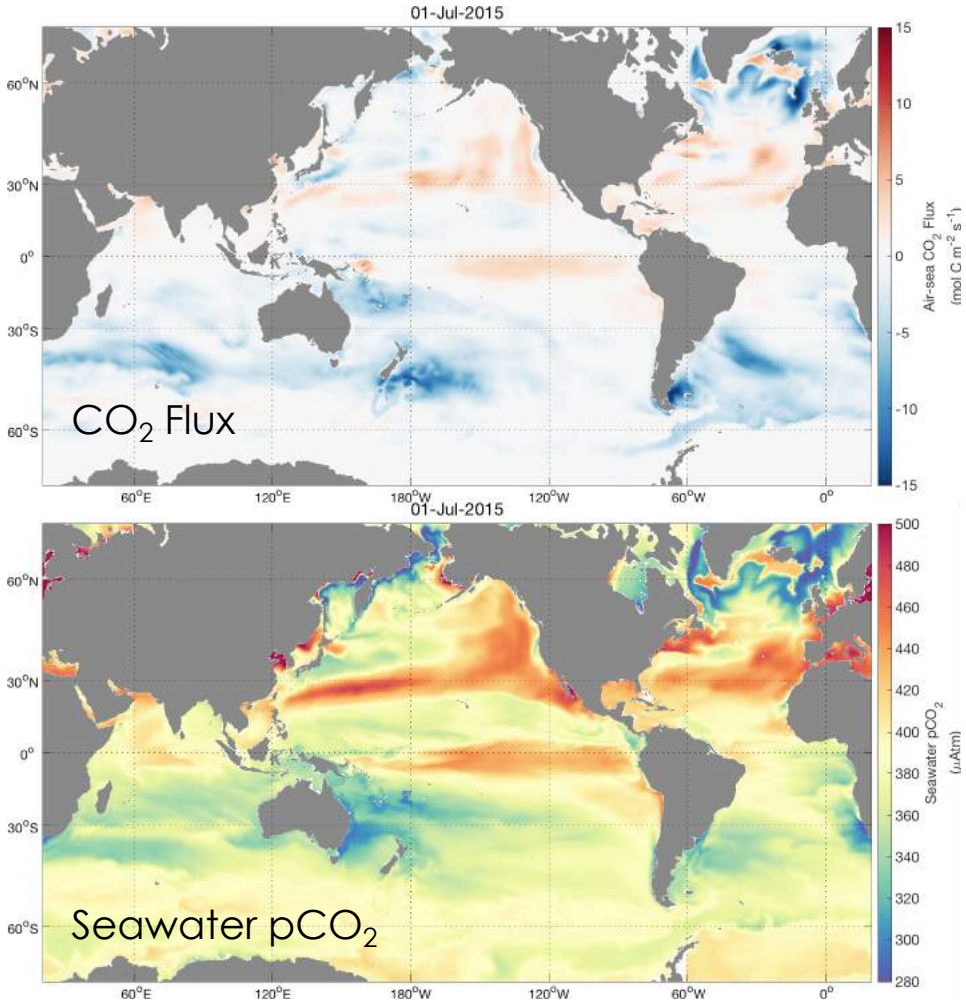
**Optimization:**
- 13 biogeochemical Green's Functions



# ECCO-Darwin

## $CO_2$ Flux

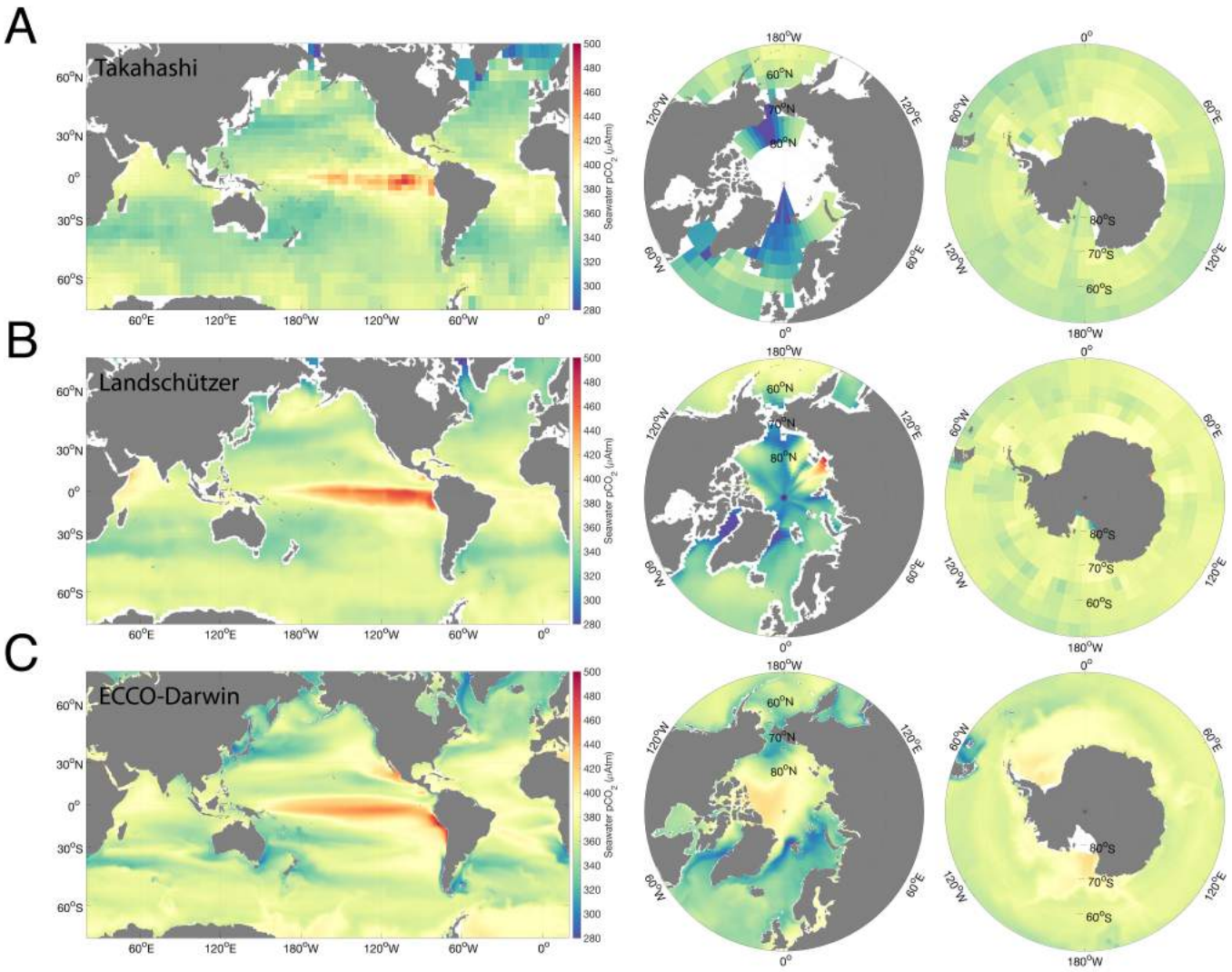
Red = $CO_2$ outgassing
Blue = $CO_2$ uptake



# ECCO-Darwin

Seawater $pCO_2$ Climatology

Red = High $pCO_2$
Blue = Low $pCO_2$



# ECCO-Darwin

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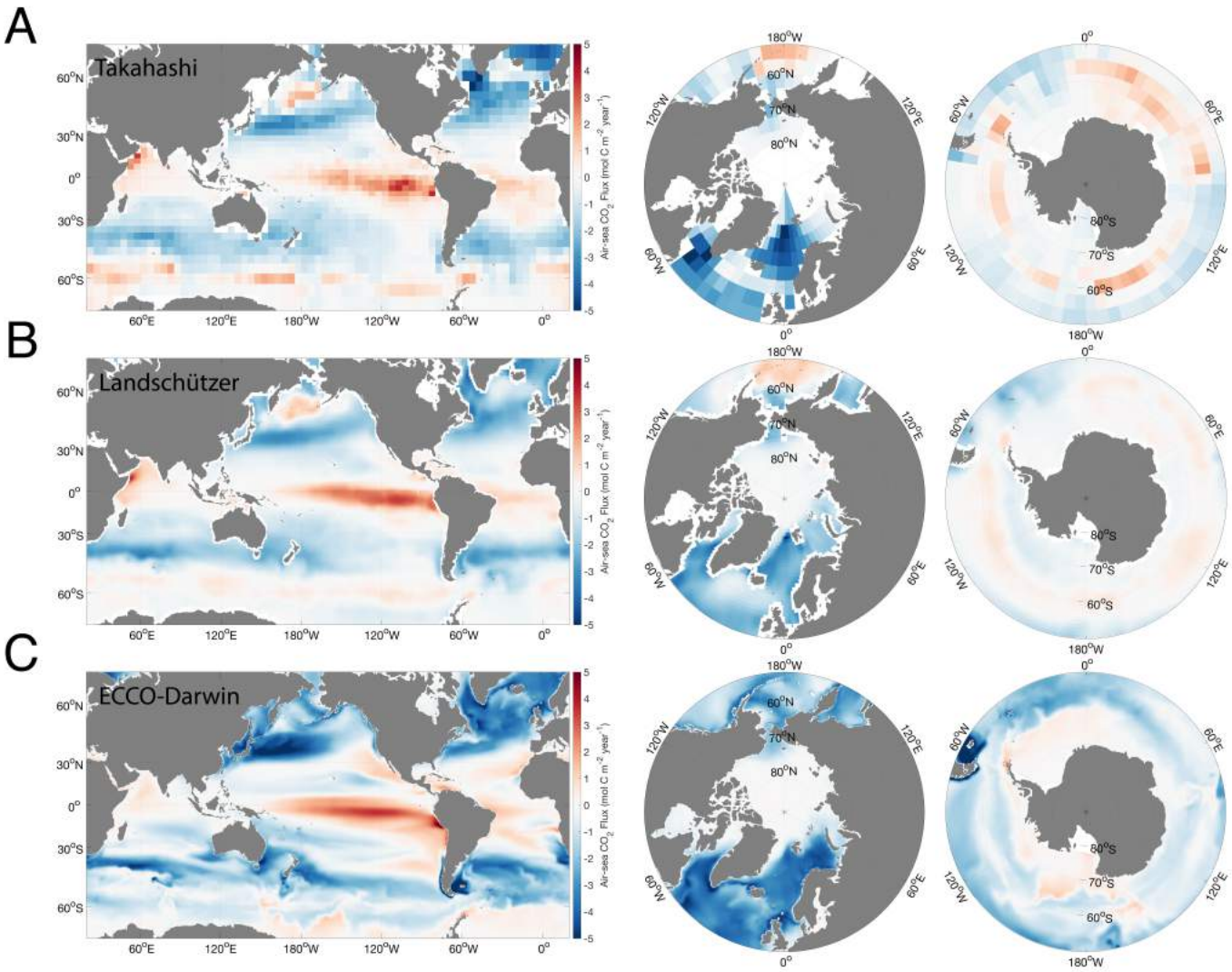
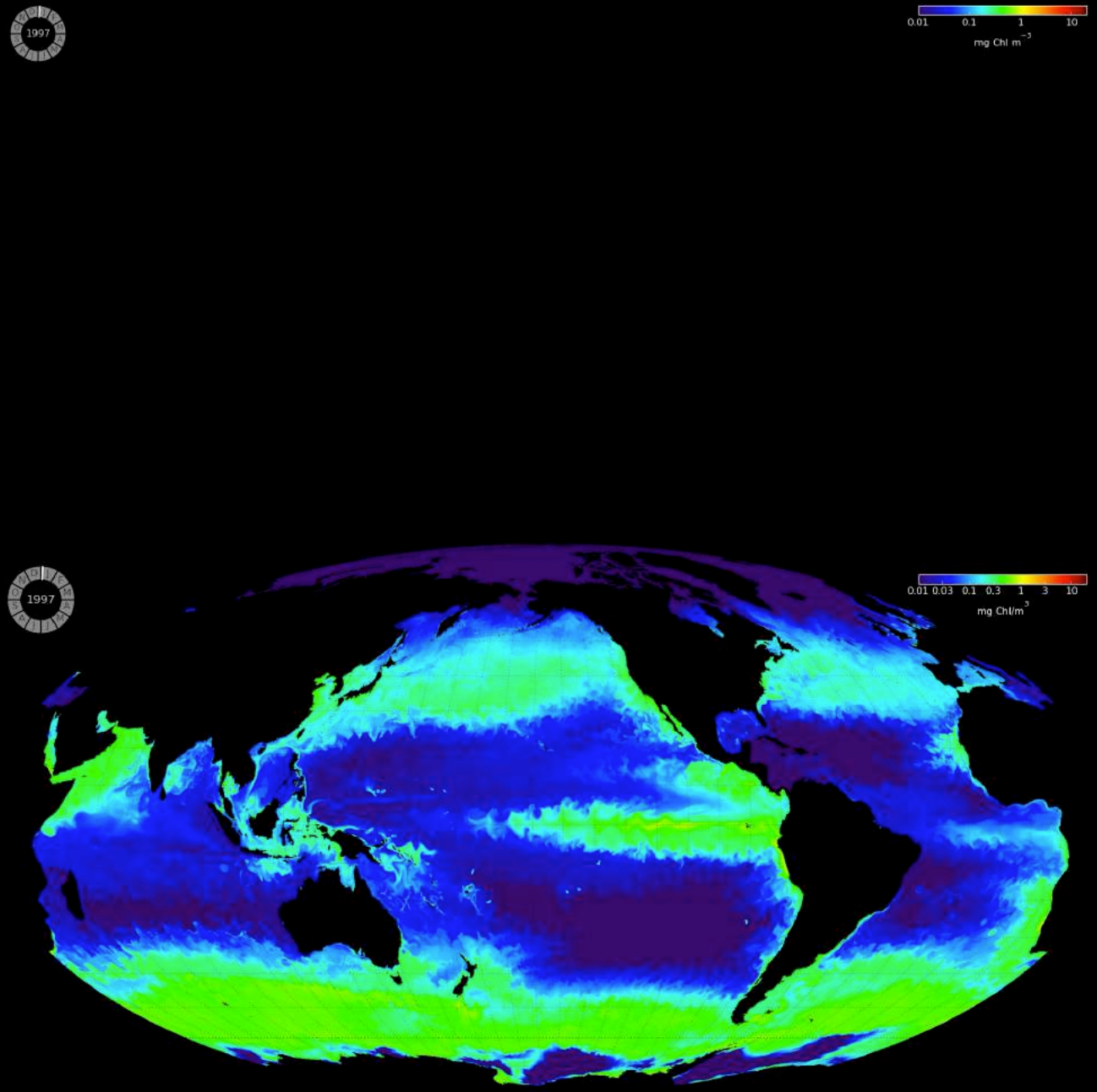
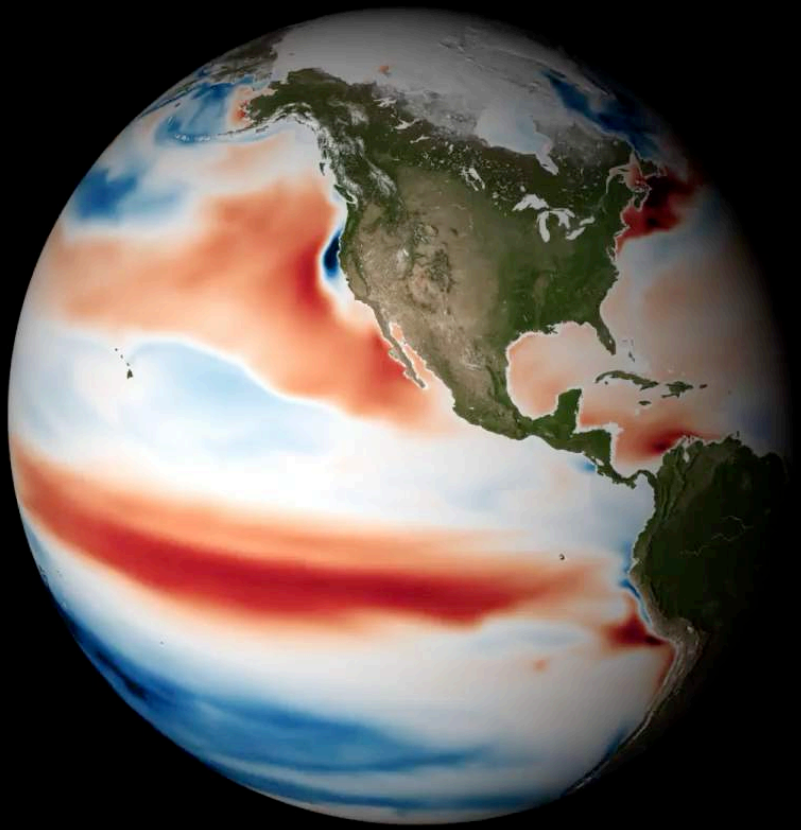



1997
0.01
0.1
1
10
mg Chl m$^{-3}$
1997
0.01 0.03 0.1 0.3 1 3 10
mg Chl/m$^{3}$

# Total $CO_2$ Flux



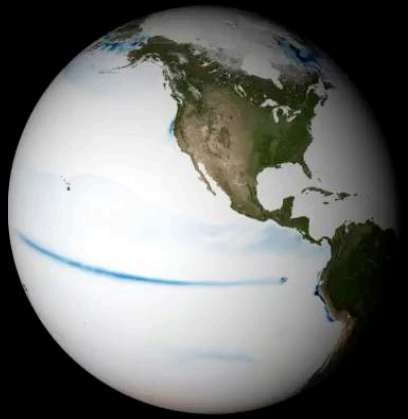
Air-Sea $CO_2$ Flux

-8.0 -4.0 0.0 4.0 8.0

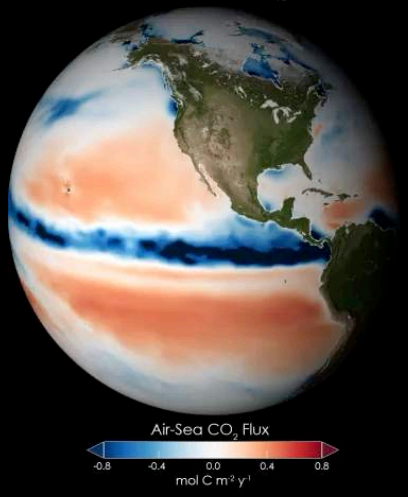
mol C $m^{-2}$ $y^{-1}$

**Jun 2014**

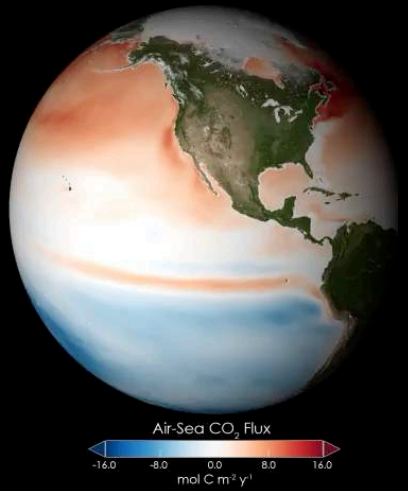
## Biological $CO_2$ Flux



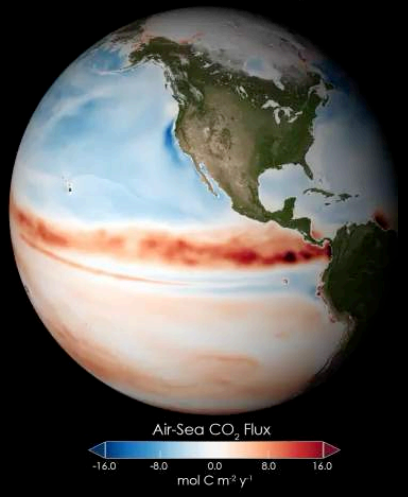

## Freshwater $CO_2$ Flux




## Heat $CO_2$ Flux




## Disequilibrium $CO_2$ Flux



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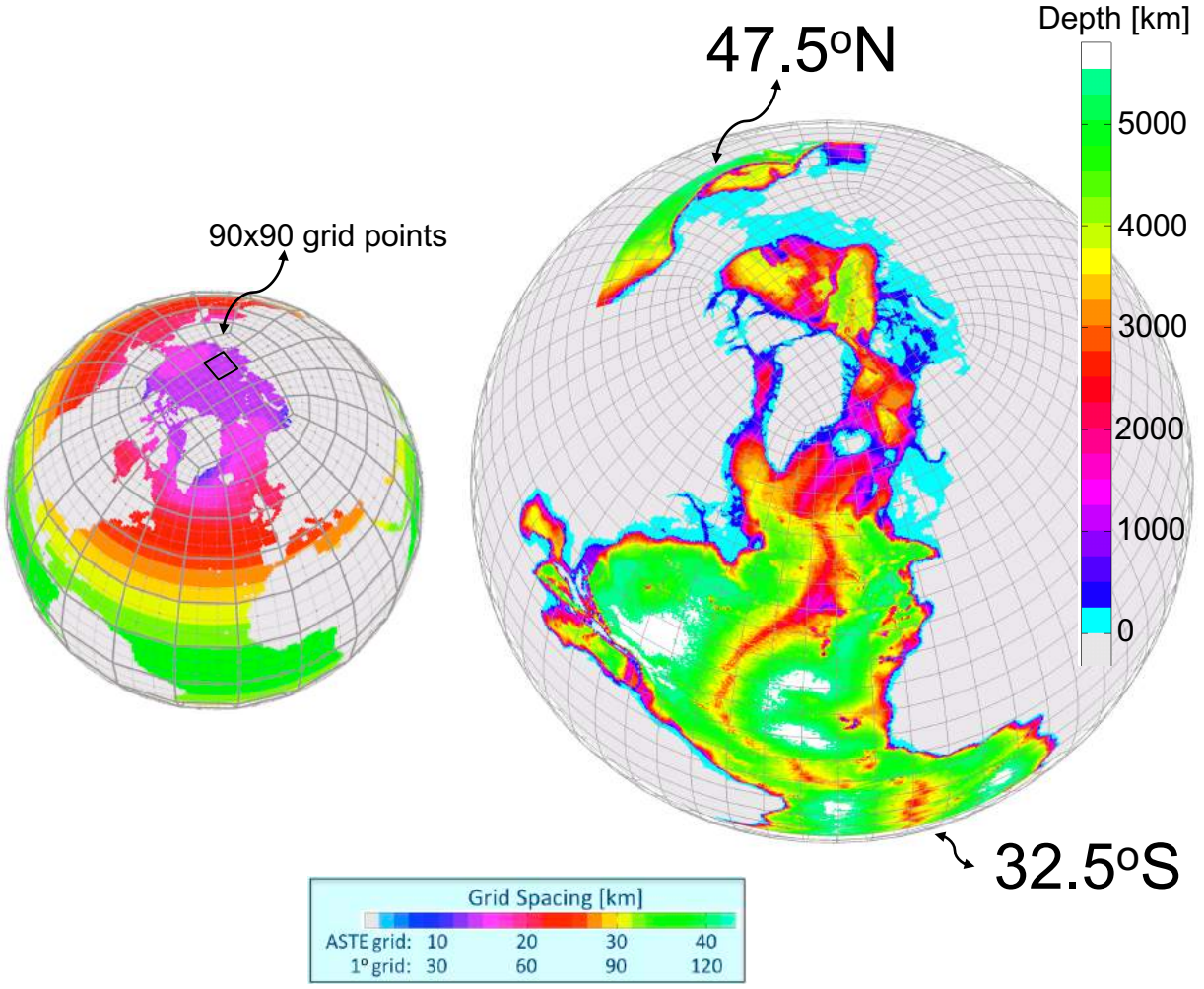
2. Analysis tools and tutorials

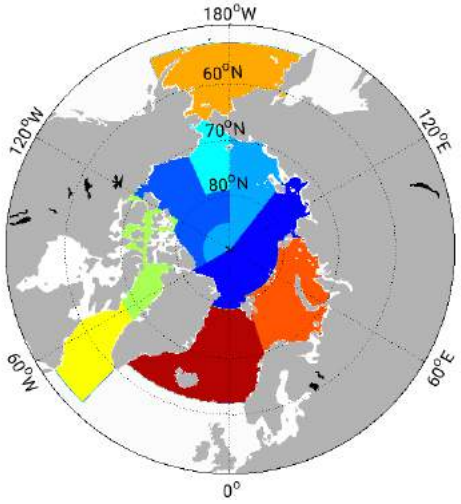
# Arctic Subpolar gyre sTate Estimate (ASTE)

- 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**

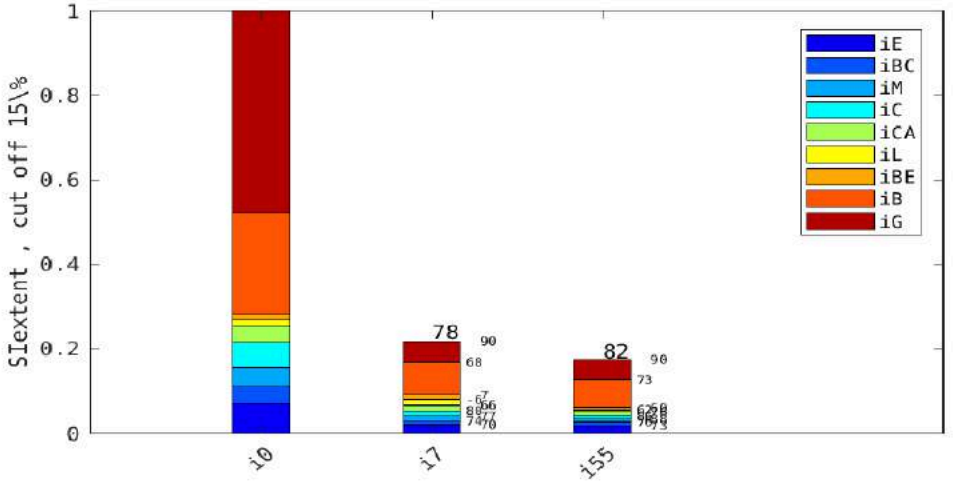



Nguyen et al., 2017;
Nguyen et al., 2019, in prep.

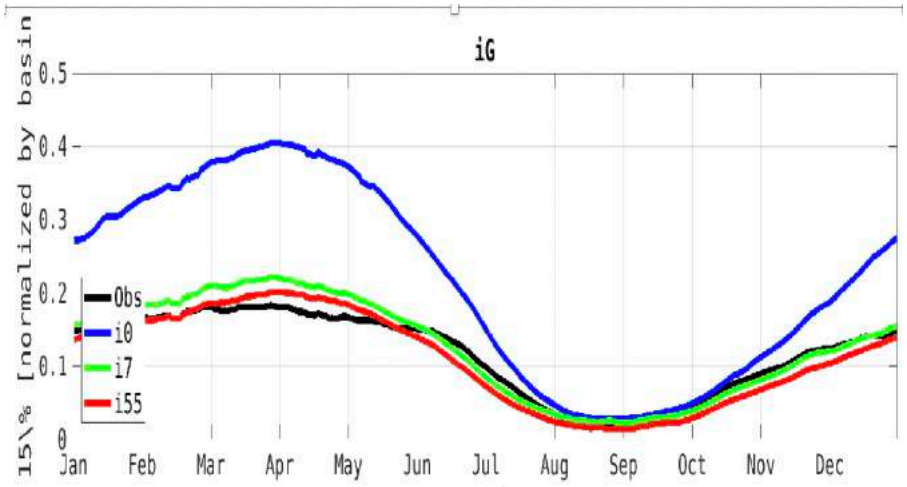
# Arctic Subpolar gyre sTate Estimate (ASTE)




## Total sea ice extent misfit

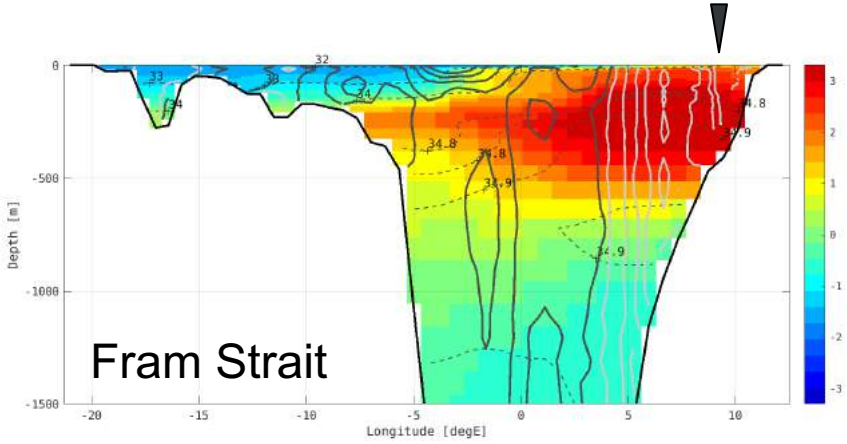


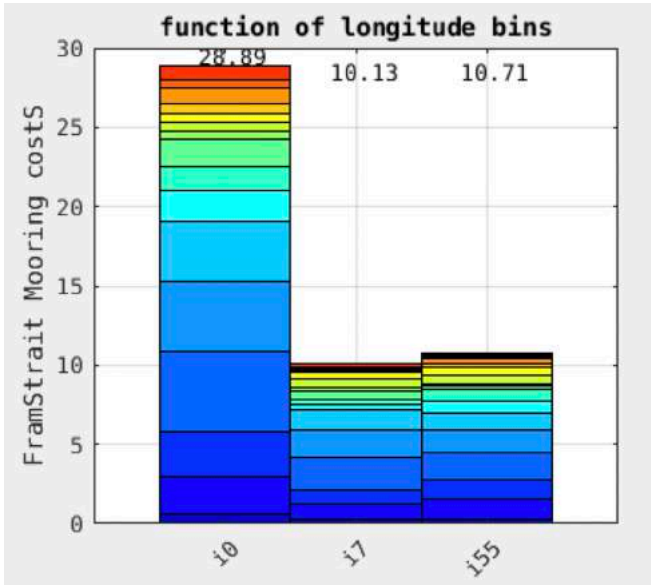

## Sea ice extent climatology



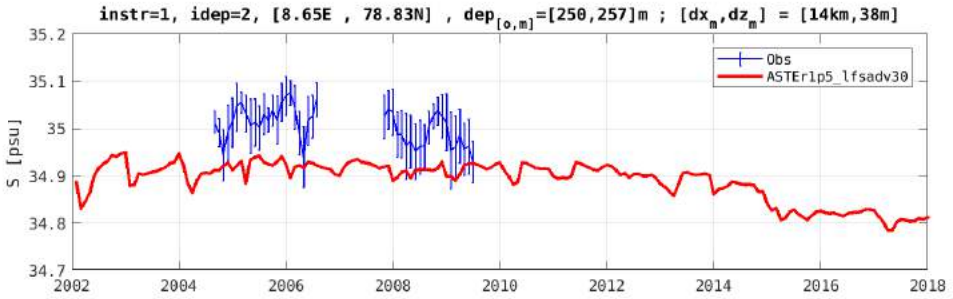
# Arctic Subpolar gyre sTate Estimate (ASTE)

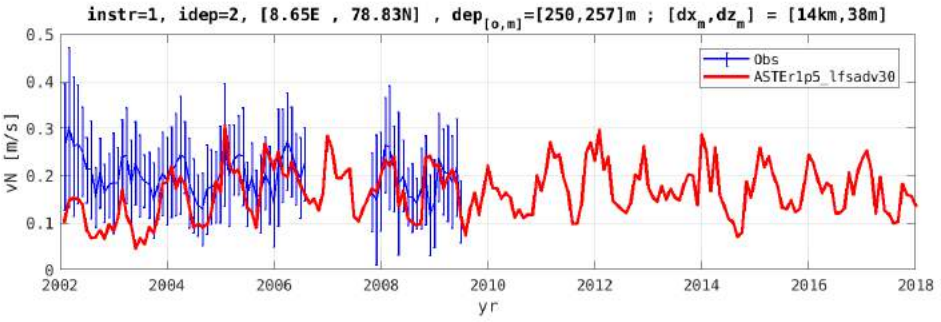
- Representation of Arctic Ocean gateway transports



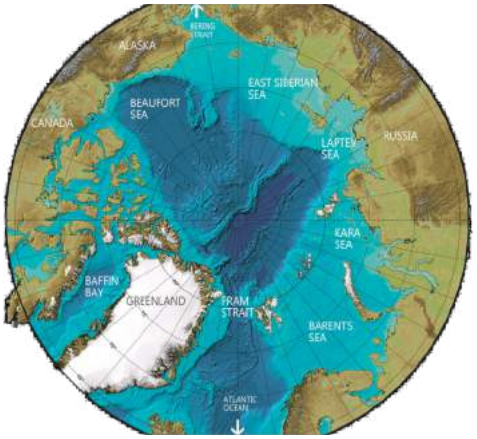


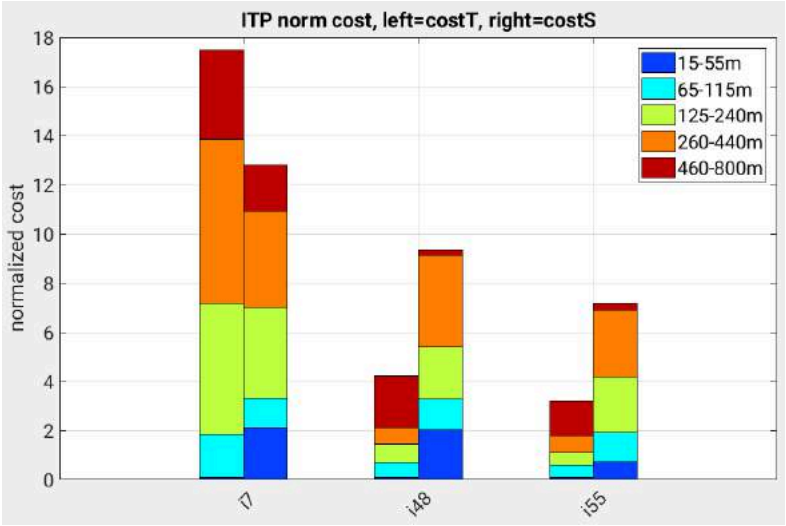


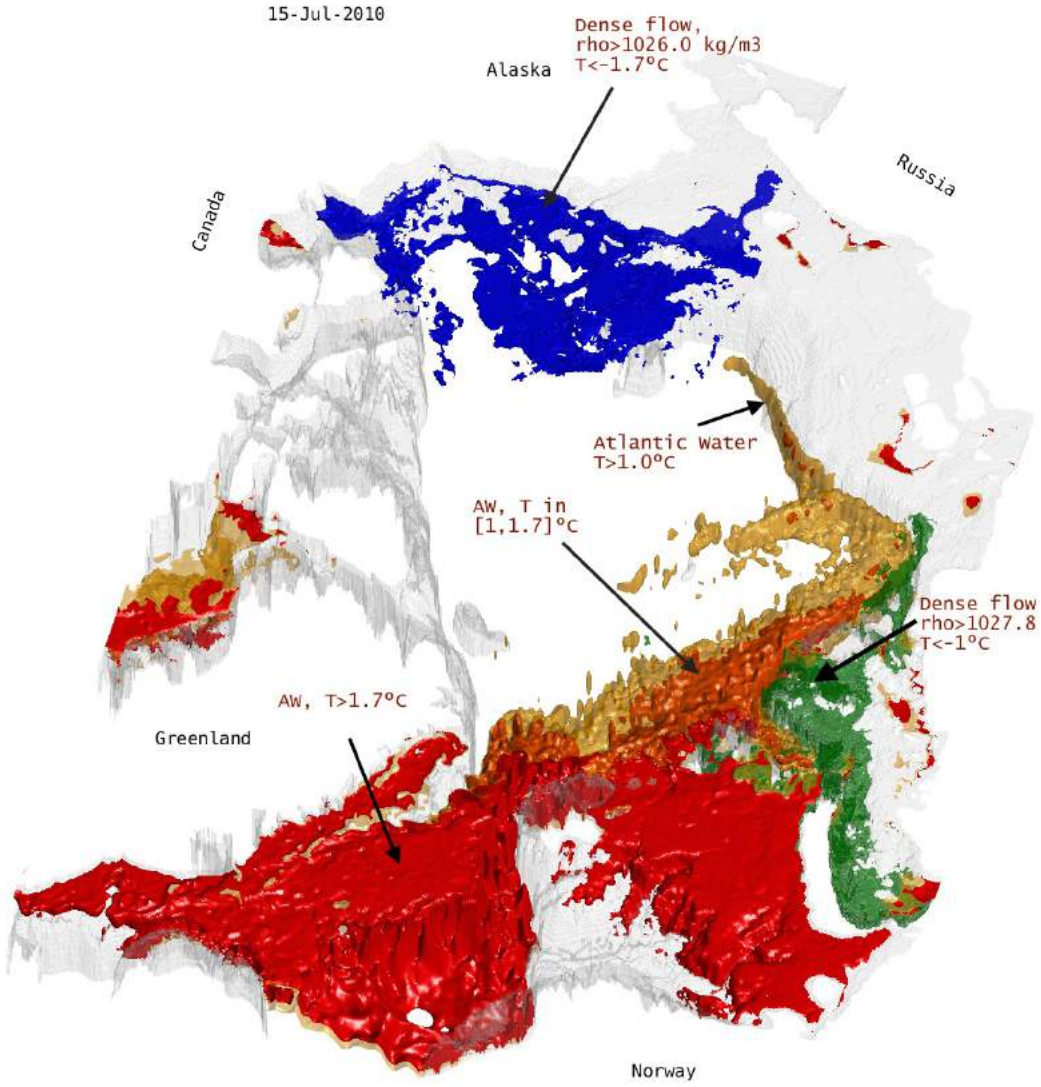



# Arctic Subpolar gyre sTate Estimate (ASTE)

- Representation of Arctic Ocean watermasses



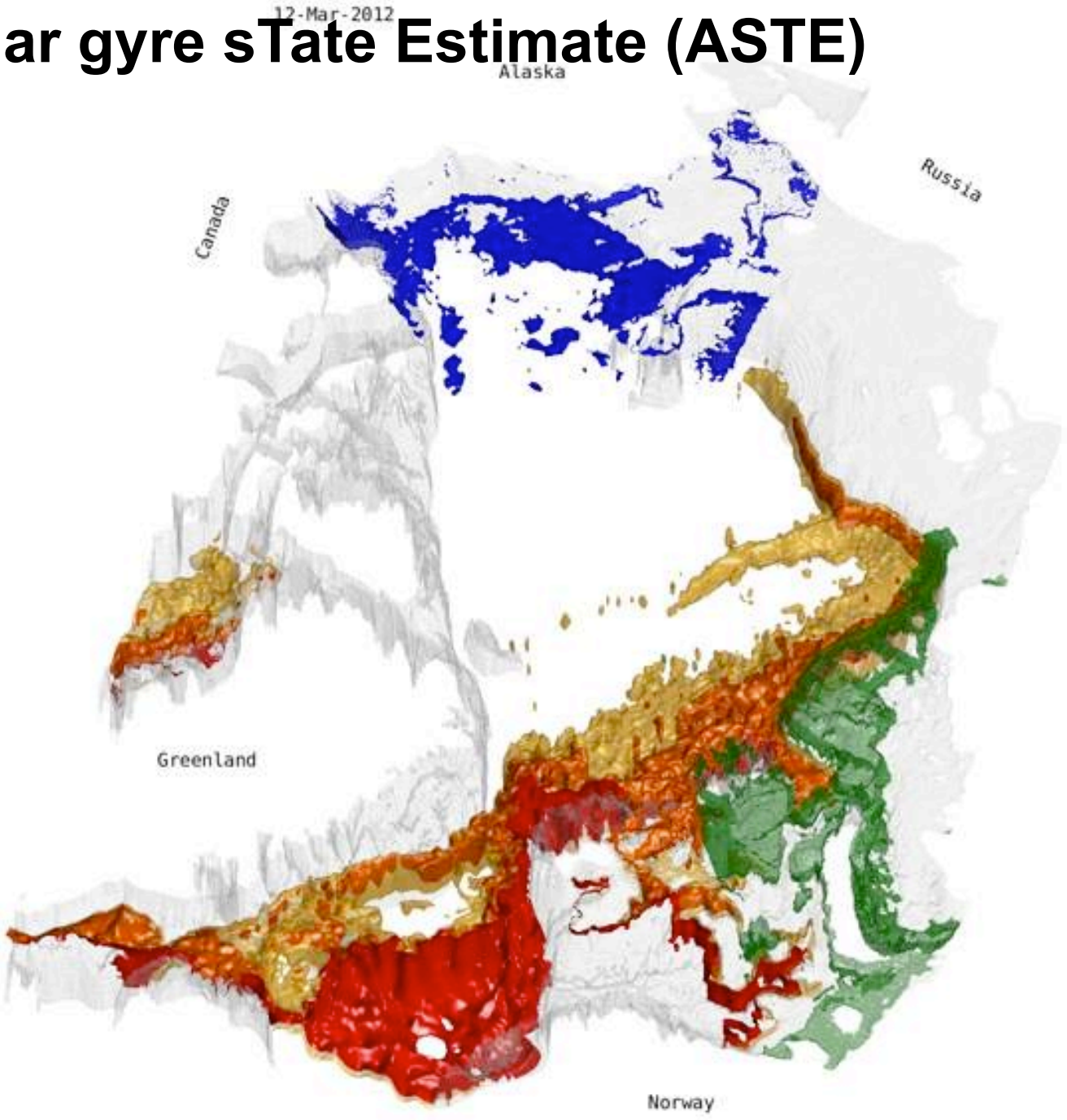



# Arctic Subpolar gyre sTate Estimate (ASTE)

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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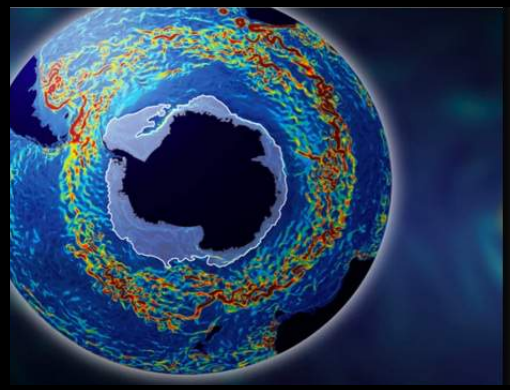
   - **B-SOSE + o*ther regional products***

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

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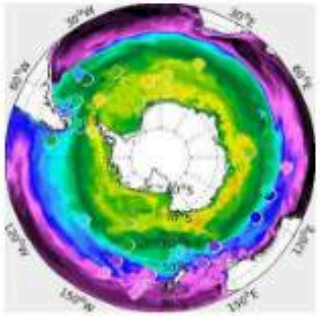
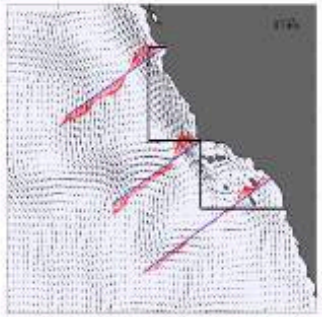
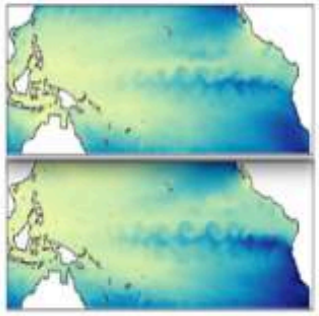


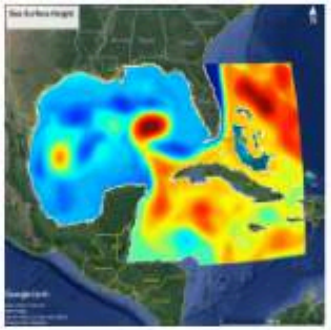
Southern Ocean State Estimate (SOSE)



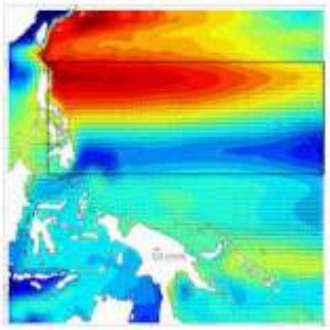
California Current System State Estimate (CASE)



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

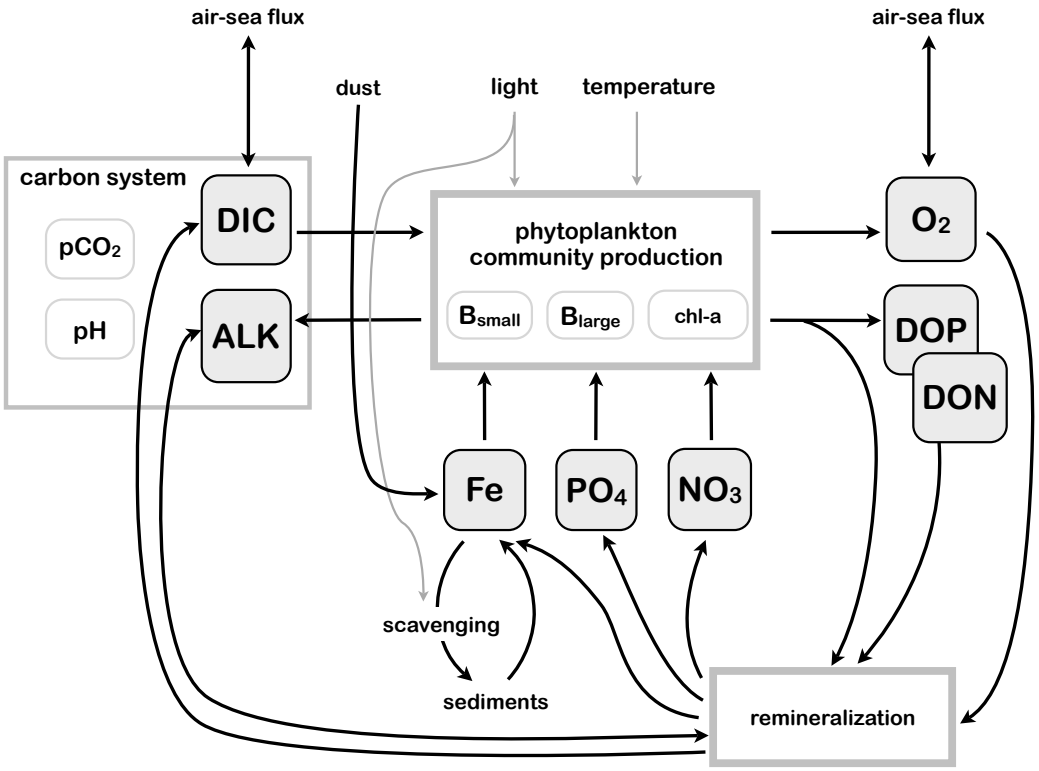
B-SOSE

Biogeochemical Southern Ocean State Estimate

# 1/6º Biogeochemical–ice–ocean Southern Hemisphere model

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

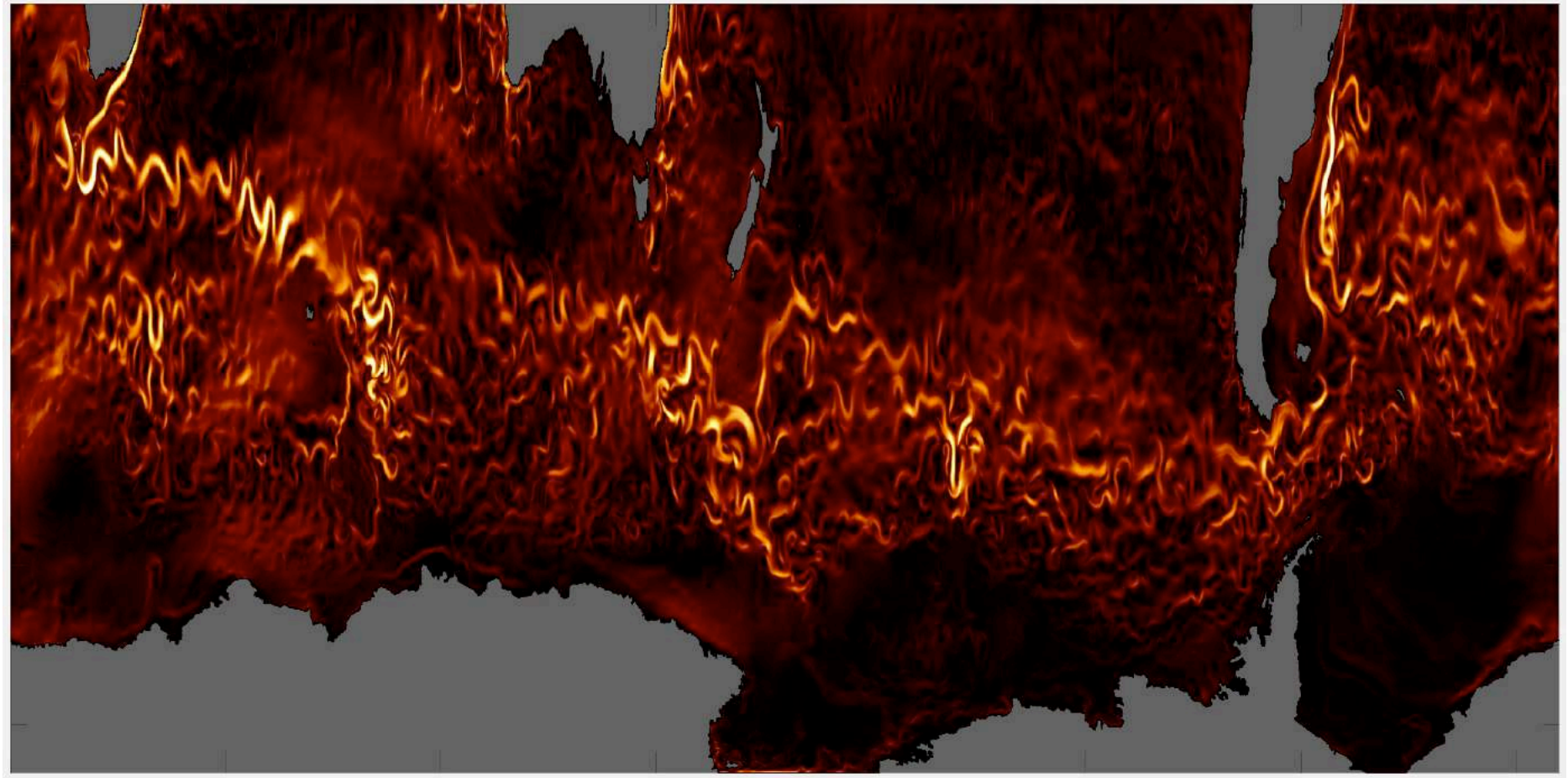
State estimate uses MITgcm-ECCO adjoint machinery



B-SOSE
Biogeochemical Southern Ocean State Estimate

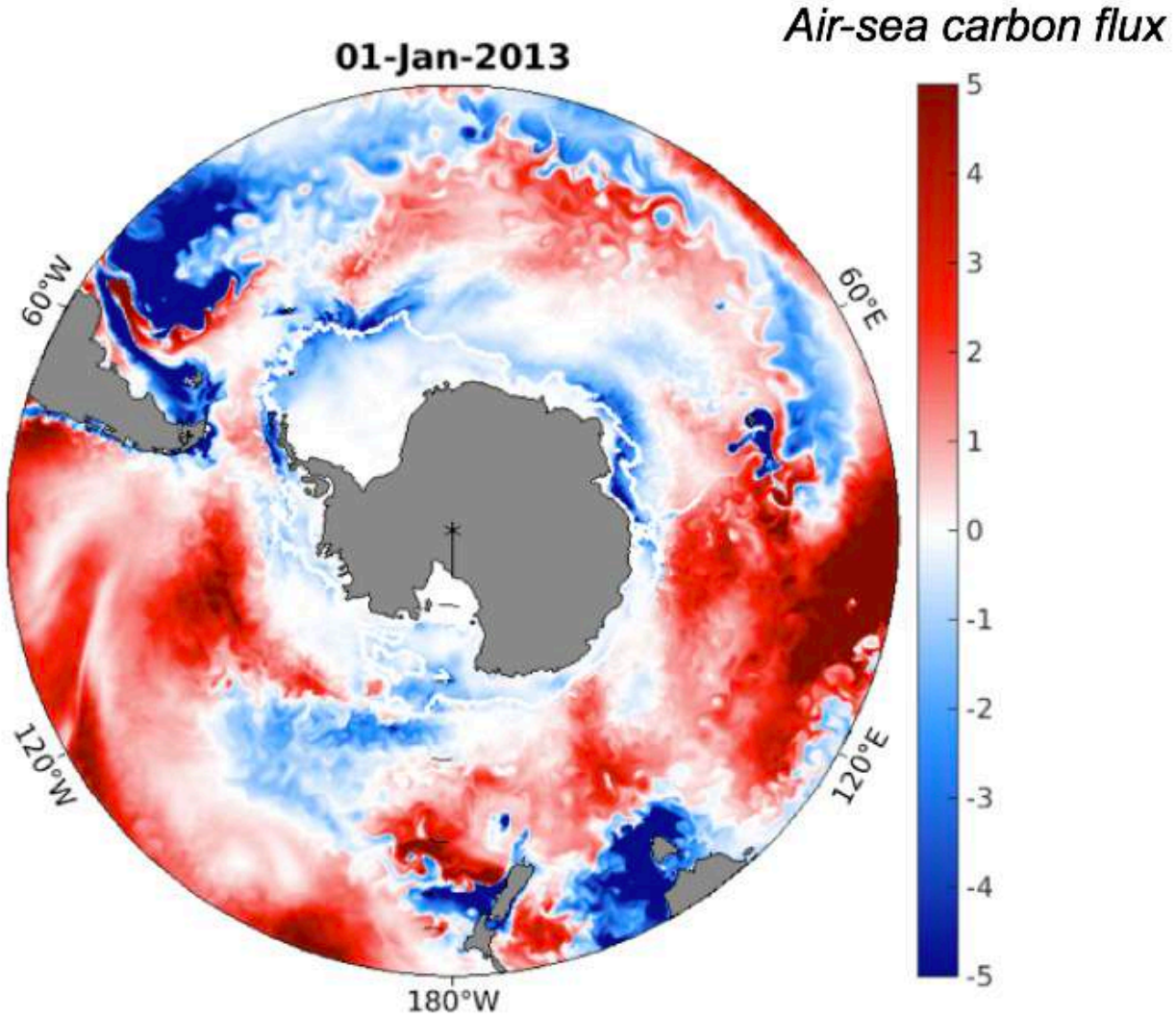
1/6° Biogeochemical–ice–ocean
Southern Hemisphere model

*ocean surface speed*



B-SOSE
Biogeochemical Southern Ocean State Estimate

# 1/6° Biogeochemical–ice–ocean Southern Hemisphere model



# Ocean State Estimation at Scripps

**http://www.ecco.ucsd.edu/**

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UC San Diego

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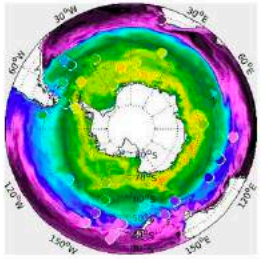
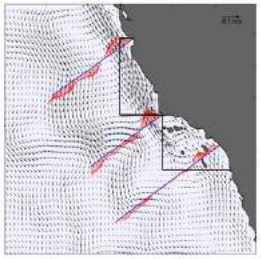
**ECCO@Scripps:** Our group contributes to the development and production of regional ocean state estimation using the methodology developed by the ECCO consortium ( ecco.jpl.nasa.gov ). The ECCO code is based on the MIT general circulation model (MITgcm) and employs automatic/algorithmic differentiation (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:



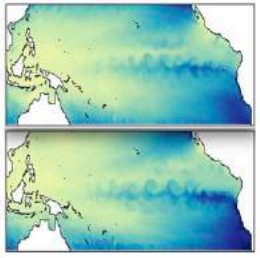
**Southern Ocean State Estimate (SOSE)**

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



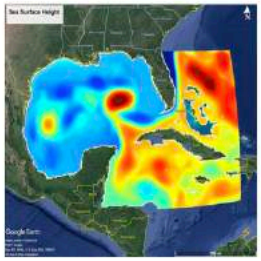
**California Current System State Estimate (CASE)**

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



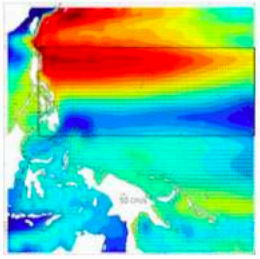
**Tropical Pacific Ocean State Estimate (TPOSE)**

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*

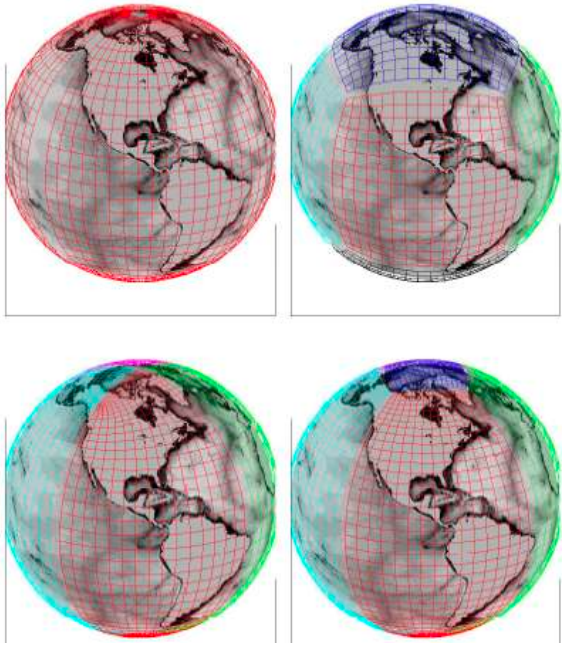
- **Python:**
  - *ecco-v4-py* (ECCO v4 Tutorial)
  - xmitgcm/xgcm
  - *… numpy, matplotlib, cartopy,*

# 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).

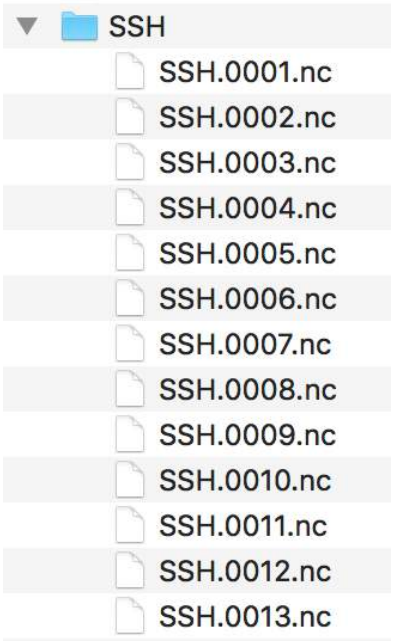
gcmfaces allows for analysis of MITgcm output on any of its familiar grids.



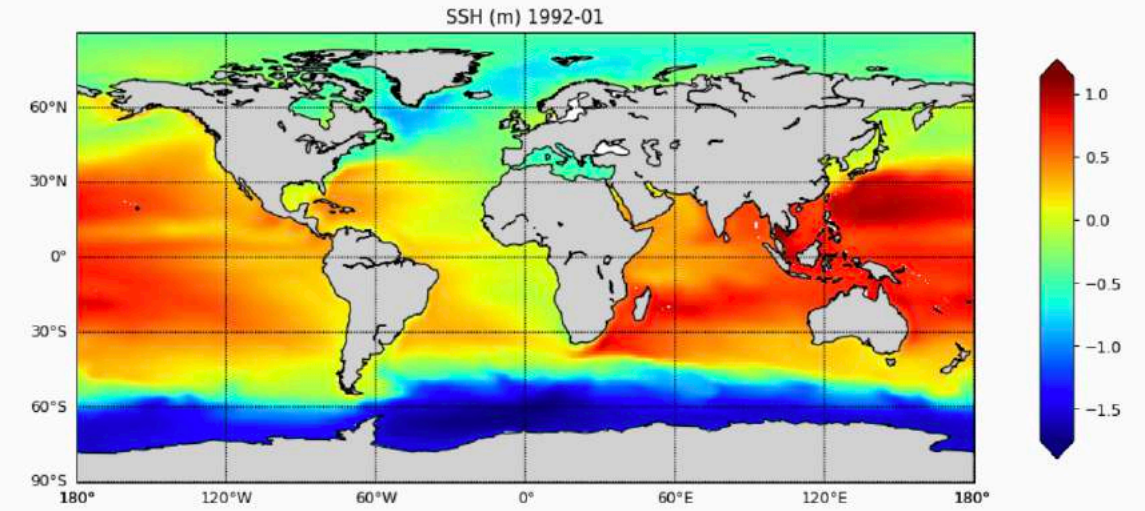
**https://gcmfaces.readthedocs.io/en/latest/index.html**

# Python: **ecco_v4_py**

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

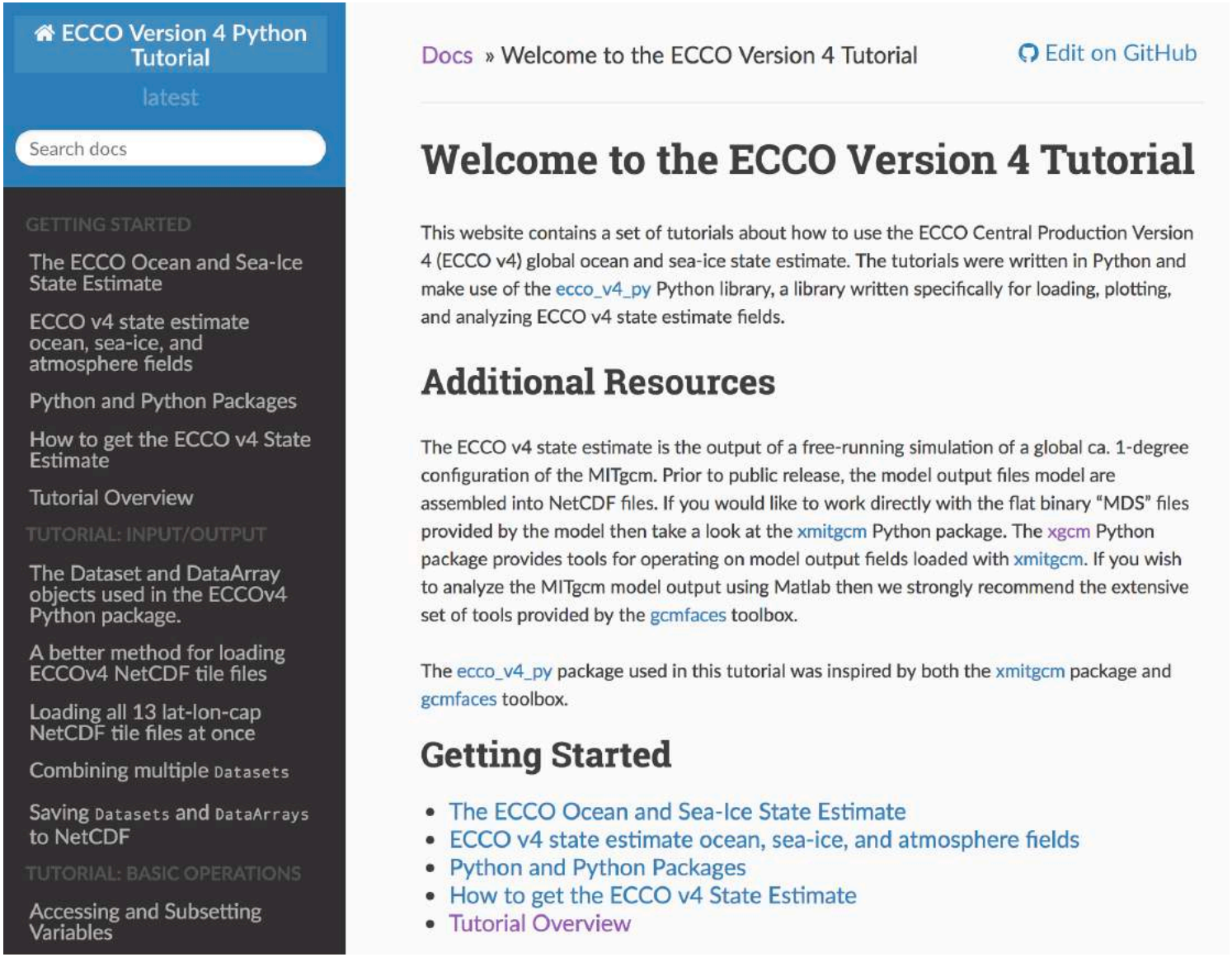



```
plt.figure(figsize=(12,6), dpi= 90)
ecco.plot_tiles_proj(v4.XC,
                     v4.YC,
                     v4.SSH.sel(time=1),
                     cbar=True,
                     plot_type = 'pcolor',
                     projection_type = 'cyl', lon_0=180)
plt.title('SSH (m) ' + str(v4.tim[0].values)[0:7]);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



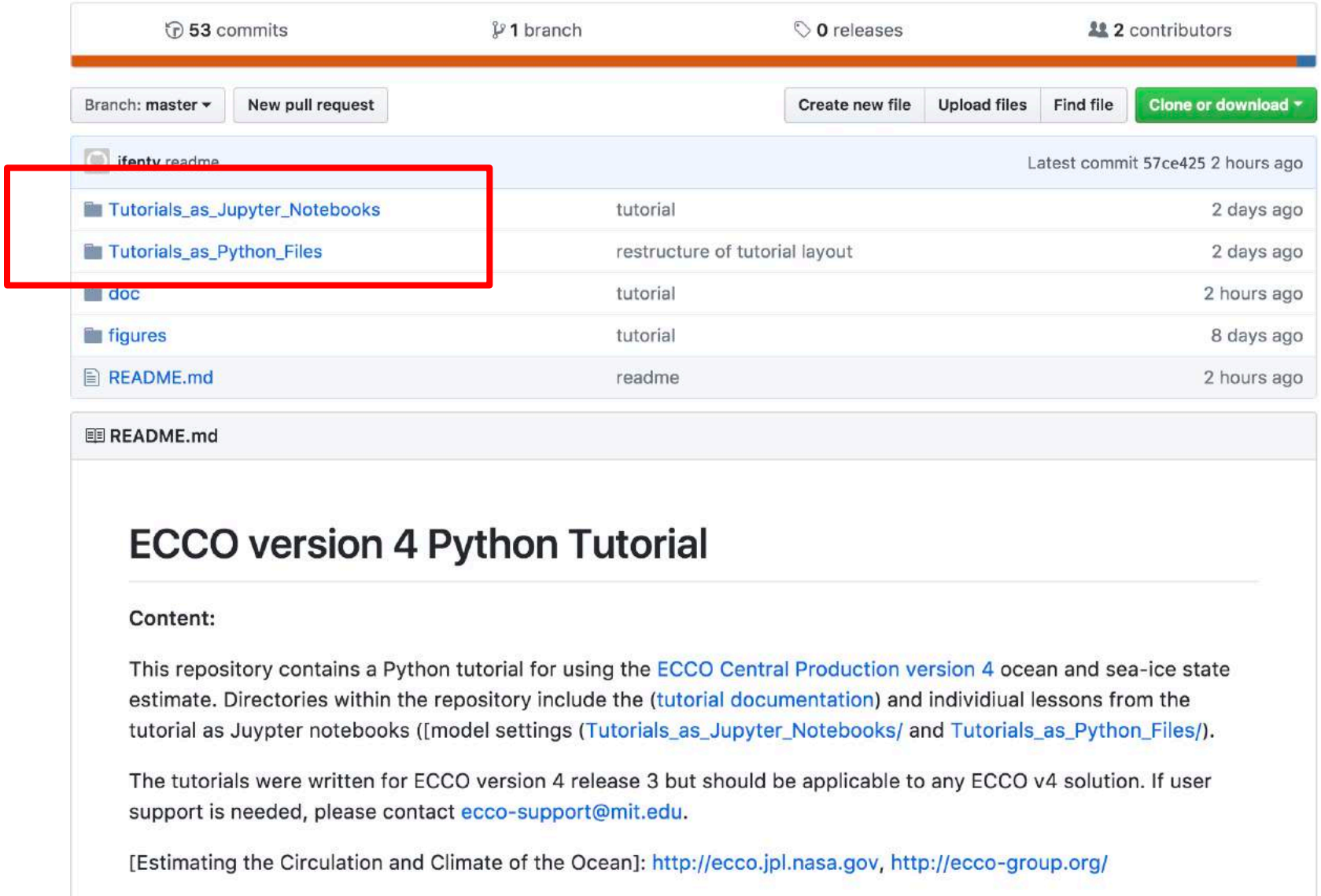

https://github.com/ECCO-GROUP/ECCOv4-py

# ECCO v4 Python Tutorial




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

# ECCO v4 Python Tutorial



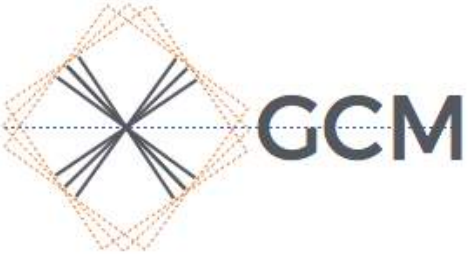

https://github.com/ECCO-GROUP/ECCO-v4-Python-Tutorial

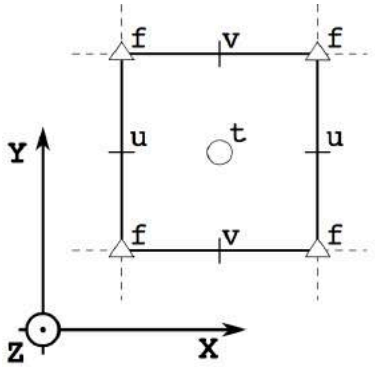
# Python Packages: **xmitgcm** and **xgcm**

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

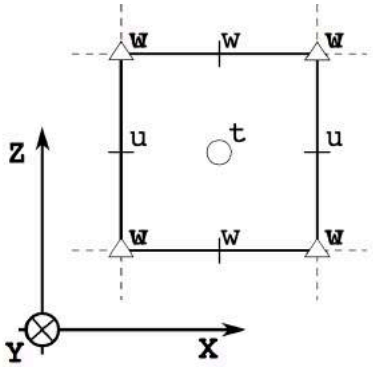
http://xmitgcm.readthedocs.org

**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*