ECCO WORKSHOP

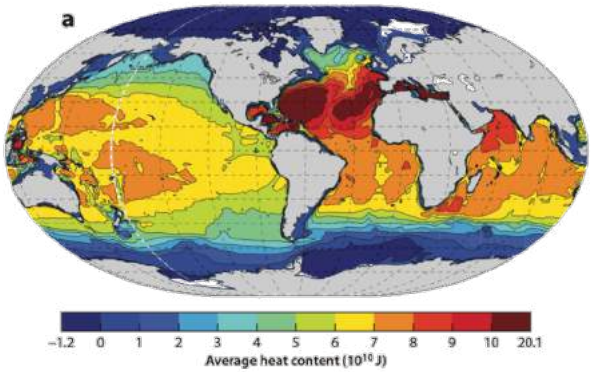
HOW TO USE THE LATEST ECCO OCEAN STATE ESTIMATE

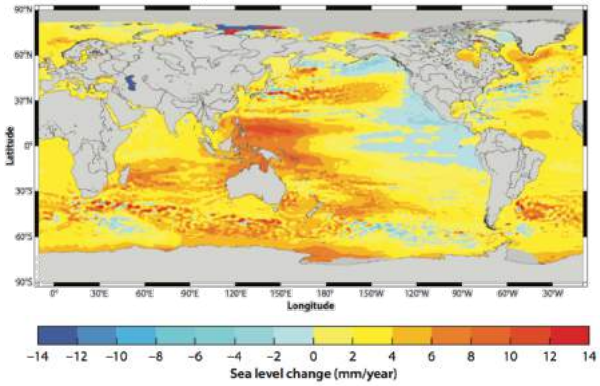
- *The "Estimating the Circulation and Climate of the Ocean" (ECCO) consortium is directed at making the best possible estimates of ocean circulation and its role in climate.*
- ***Solutions are obtained** by combining state-of-the-art ocean circulation models with nearly complete global ocean data sets 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, and are available for general applications.*

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

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

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





ECCO WORKSHOP

HOW TO USE THE LATEST ECCO OCEAN STATE ESTIMATE

1. What is ECCO?
2. What is provided in the state estimate?
3. Some comparisons to observations
4. Example applications
5. How to reproduce the state estimate
6. Analysis tools and tutorials
7. Future directions
8. Where to get help

1. What is ECCO?

ECCO Consortium

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

Jet Propulsion Laboratory
California Institute of Technology

TEXAS
The University of Texas at Austin

Massachusetts Institute of Technology

aer
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

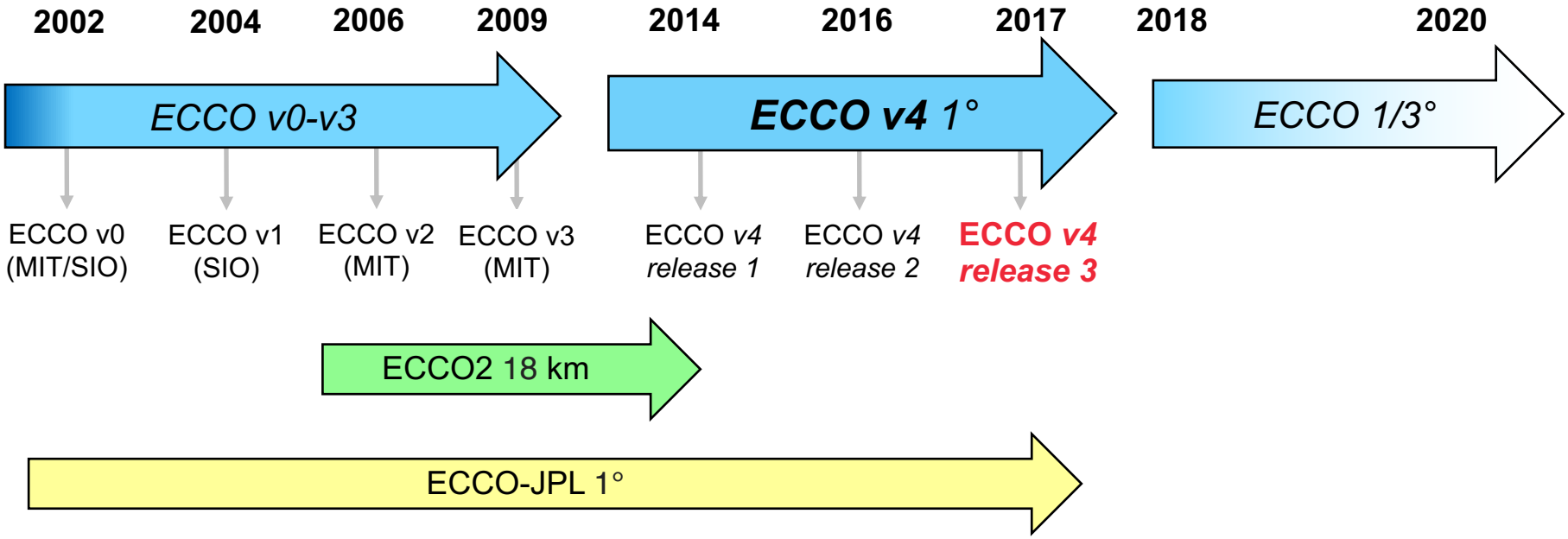
ECCO Product Timeline

ECCO Central Production *Adjoint*

ECCO2
Green's function

ECCO-JPL
Kalman filter / smoother

ECCO v4 is our **flagship product.**
The first adjoint-based, multi-decadal global ocean and sea-ice state estimate.
> Our best reconstruction of the global ocean.



ECCO2 was a global multi-decadal eddy-permitting estimate. Derived with the Green's function approach

ECCO-JPL is a 1° estimate to support near-real applications. Derived with Kalman filter/smoother.

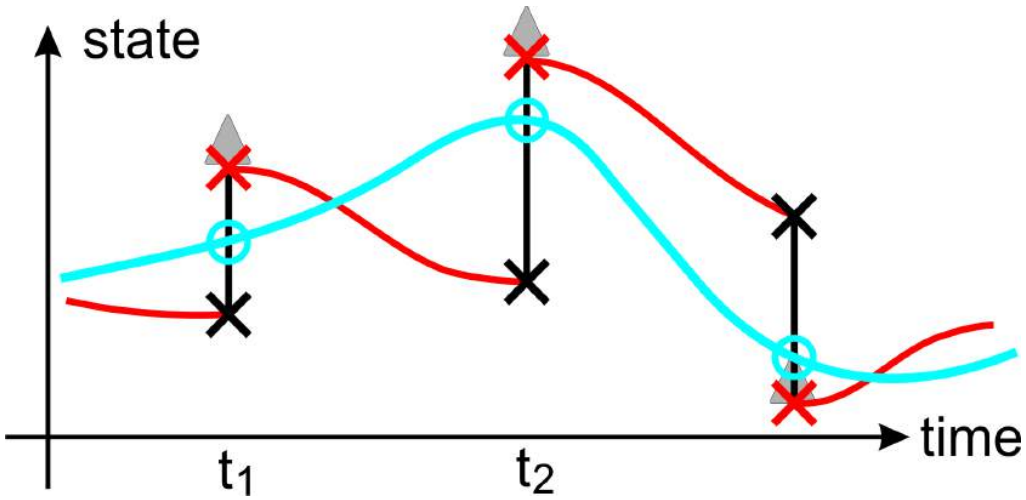
Regional higher resolution ECCO products include SOSE, B-SOSE, ASTE, California/GoM, others.

ECCO Central Production v4: Release 3

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

The reconstruction is a **synthesis** of >10^8 *in situ* and satellite remote sensing **observational data** with a coupled ocean and sea-ice general circulation **model**

The **model** is **made consistent** with the **observational data** in a least-squares sense using the model's **adjoint**.

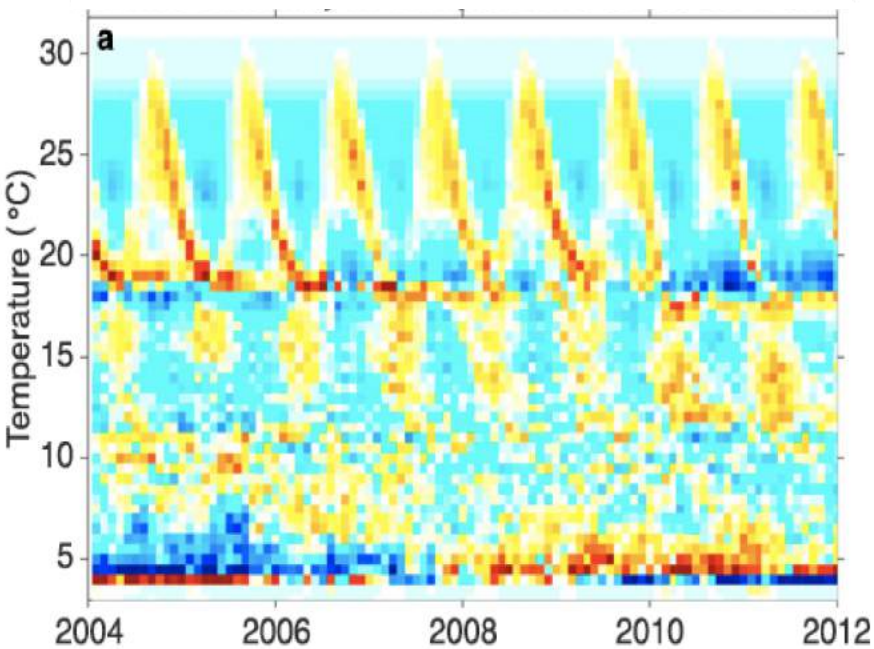


Red line : traditional ocean reanalysis
Blue : ECCO trajectory and state

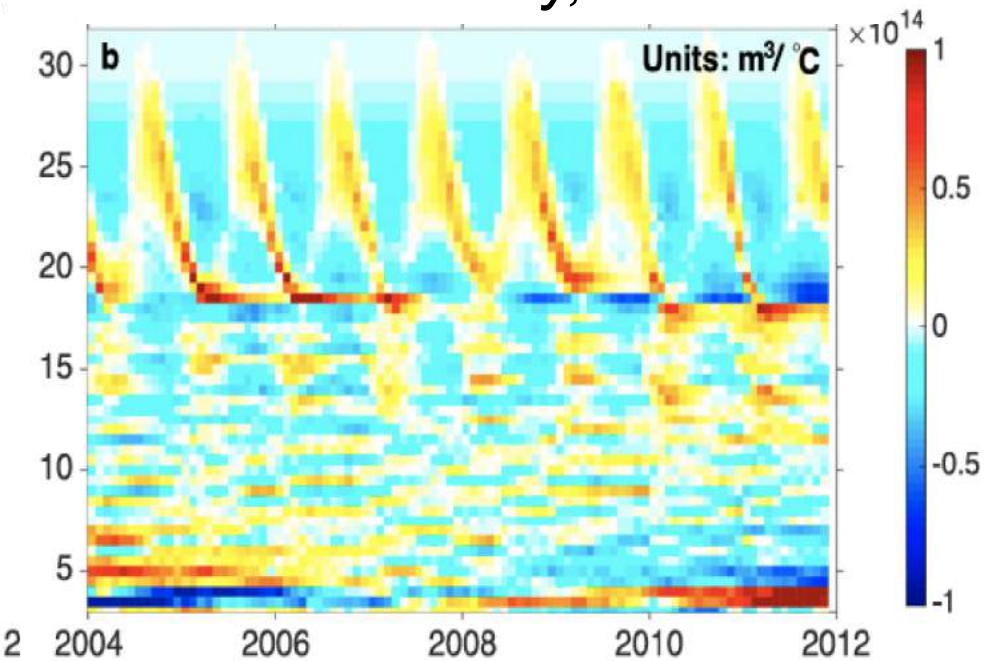
Ocean Hydrography products vs. ECCO products

*Question 1: What is the **volume** of different water temperature classes in the North Atlantic subtropical gyre (26°N – 45°N)?*

Volume anomaly, **Argo**



Volume anomaly, **ECCO**



Roemmich & Gilson, 2009
Ocean Hydrography (Argo)

ECCO version 4
(> 10^8 ocean obs)

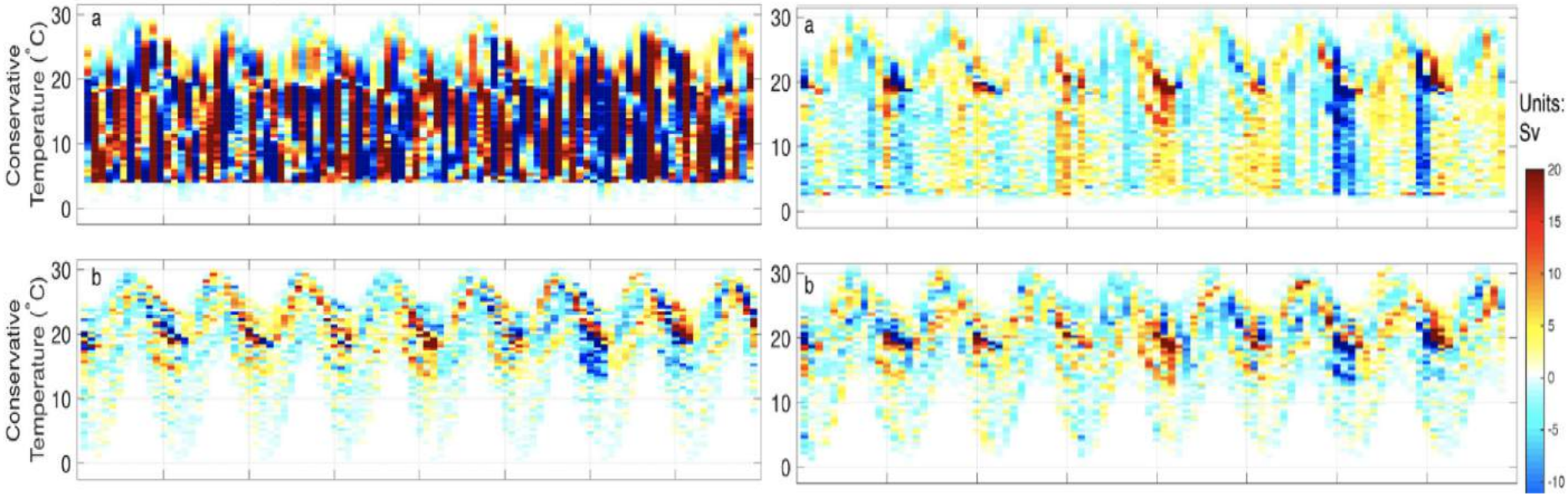
Evans, Forget, et al., JPO (2017)

Ocean Hydrography products vs. ECCO products

*Question 2: What is the **derivative of the volume** of different water temperature classes **with respect to time**?*

Total monthly ***dV/dt***, **Argo**

Total monthly ***dV/dt***, **ECCO v4**

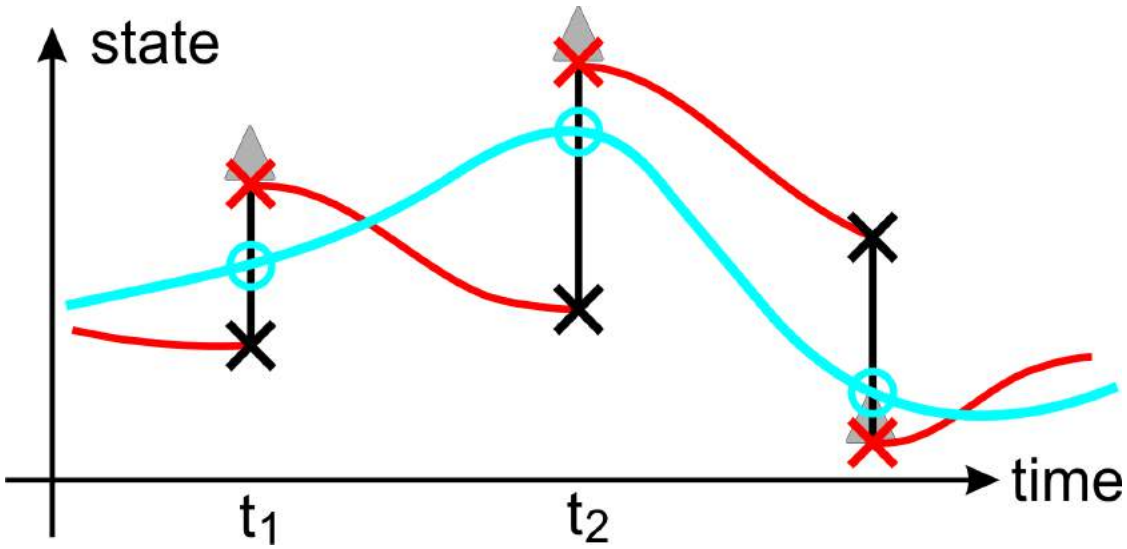


Monthly diabatic transformation due to air–sea heat fluxes
NCEP + Reynolds SST

Monthly diabatic transformation due to air–sea heat fluxes
ECCO v4

Evans, Forget, et al., JPO (2017)

Ocean Hydrography products vs. ECCO products



Red line : traditional ocean reanalysis
Blue : ECCO trajectory and state

*Unlike traditional **ocean reanalyses** and **hydrography products,** ECCO state estimates are dynamically consistent with the physics and thermodynamics of the coupled ocean and sea-ice system.*

2. What is provided in the ECCO v4 Release 3 state estimate?

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

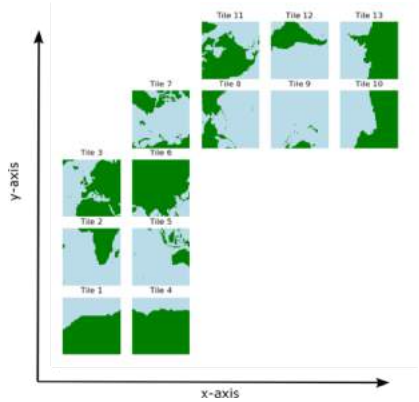
- 3D GM κ and Redi κ
- 3D vertical diffusivity

Fields are provided on two grids

Curvilinear Cartesian
"lat-lon-cap 90"

Interpolated
0.5° lat-lon

13 tiles of 90x90x50



Observational data used to constrain the model

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

New or updated items from are indicated in red.

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

- README
- doc/
- input_ecco/
- input_forcing/
- input_init/
- interp_monthly/
- nctiles_daily/
- nctiles_grid/
- nctiles_monthly/
- nctiles_monthly_snapshots/
- other/
- profiles/

Documentation

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

State estimate fields (NetCDF)

Observational data

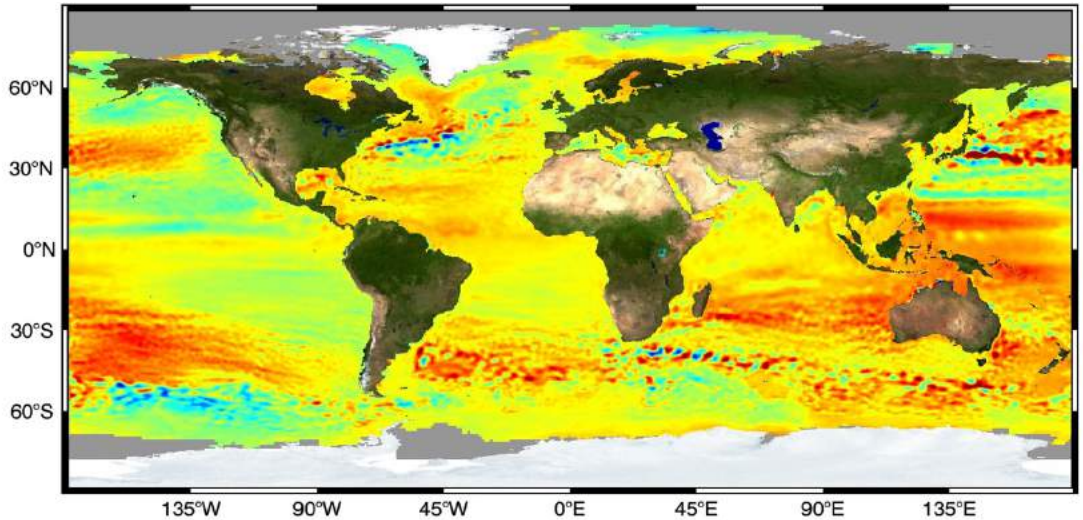
Fields required to re-run the model

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

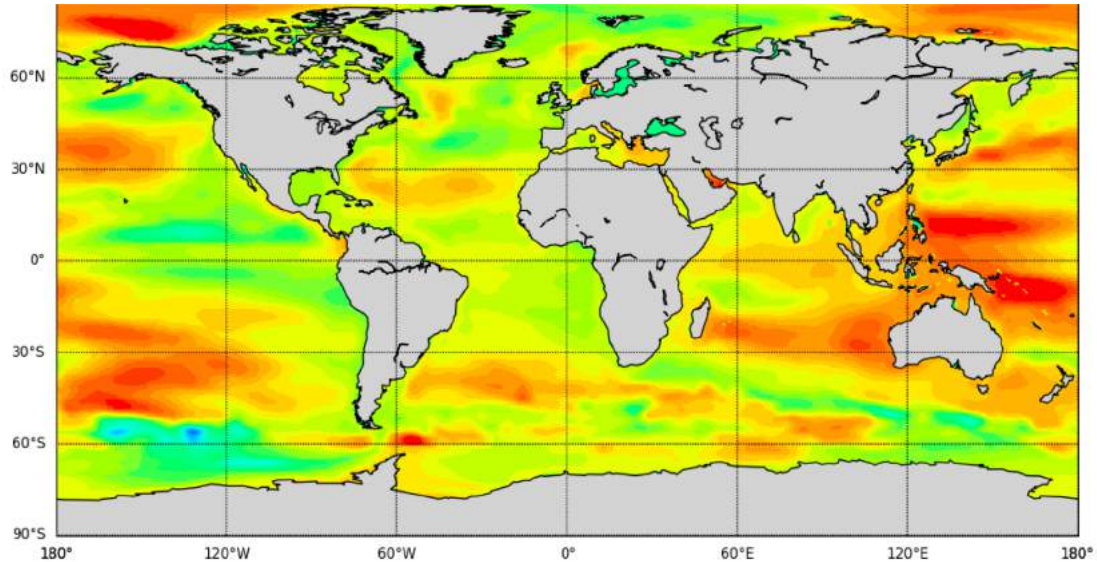
3. Some comparisons to observations

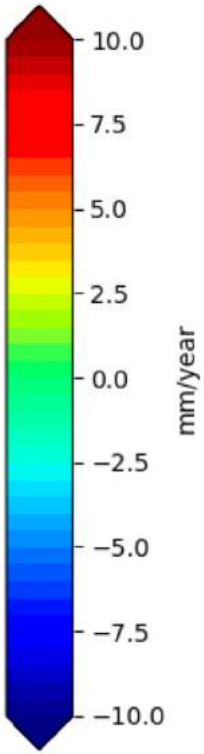
Sea Surface Height Linear Trend: 1992-2015

OBS
(NASA)

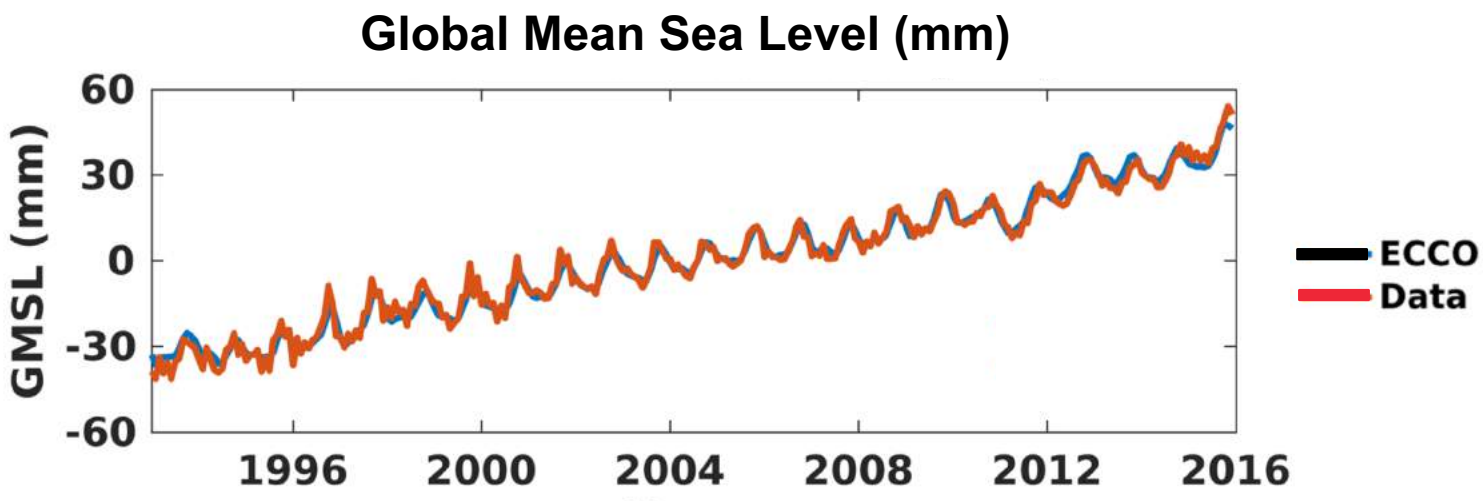


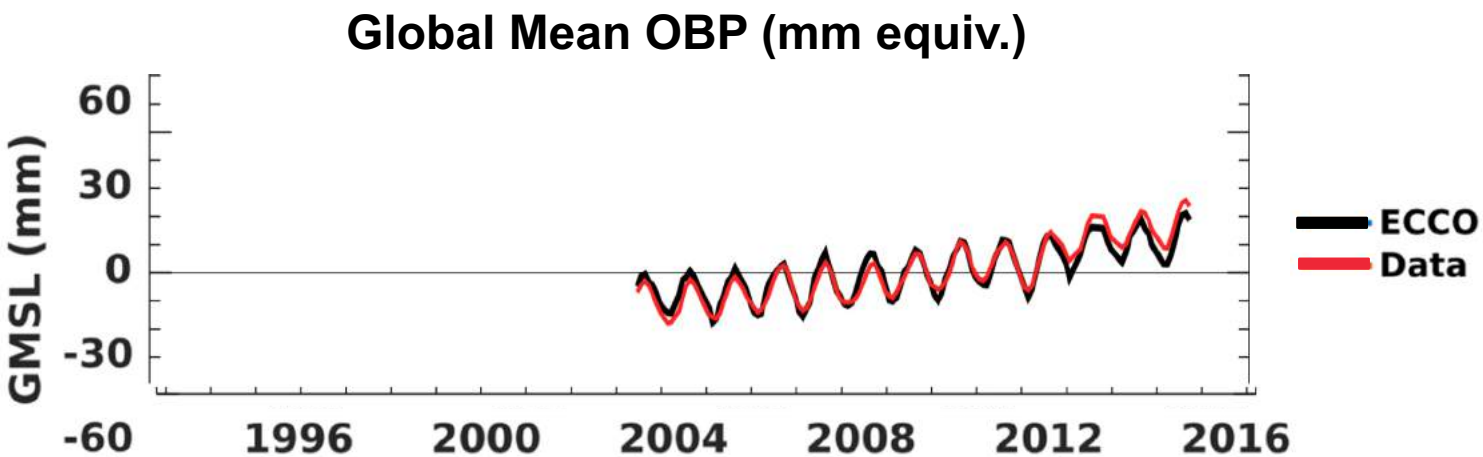
ECCO v4r3





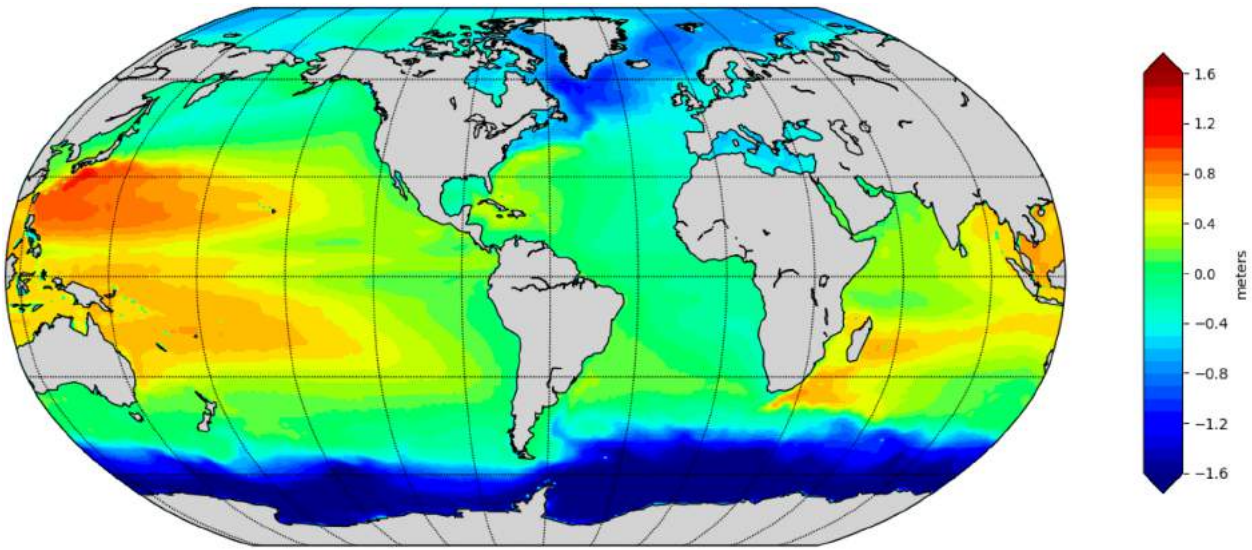
Global mean sea level and ocean bottom pressure



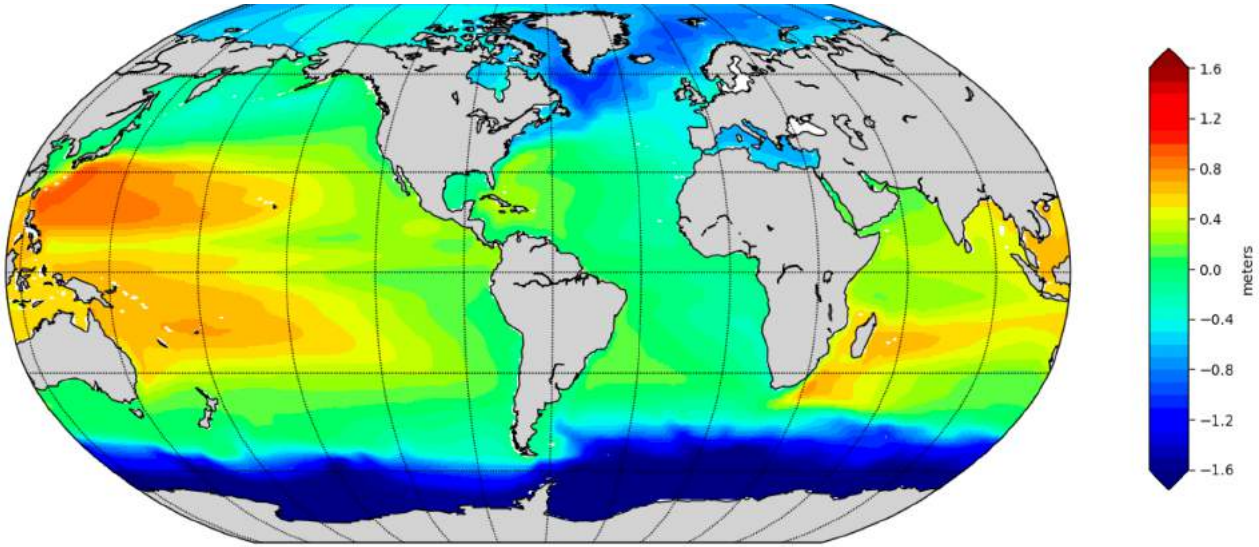


Mean Dynamic Topography

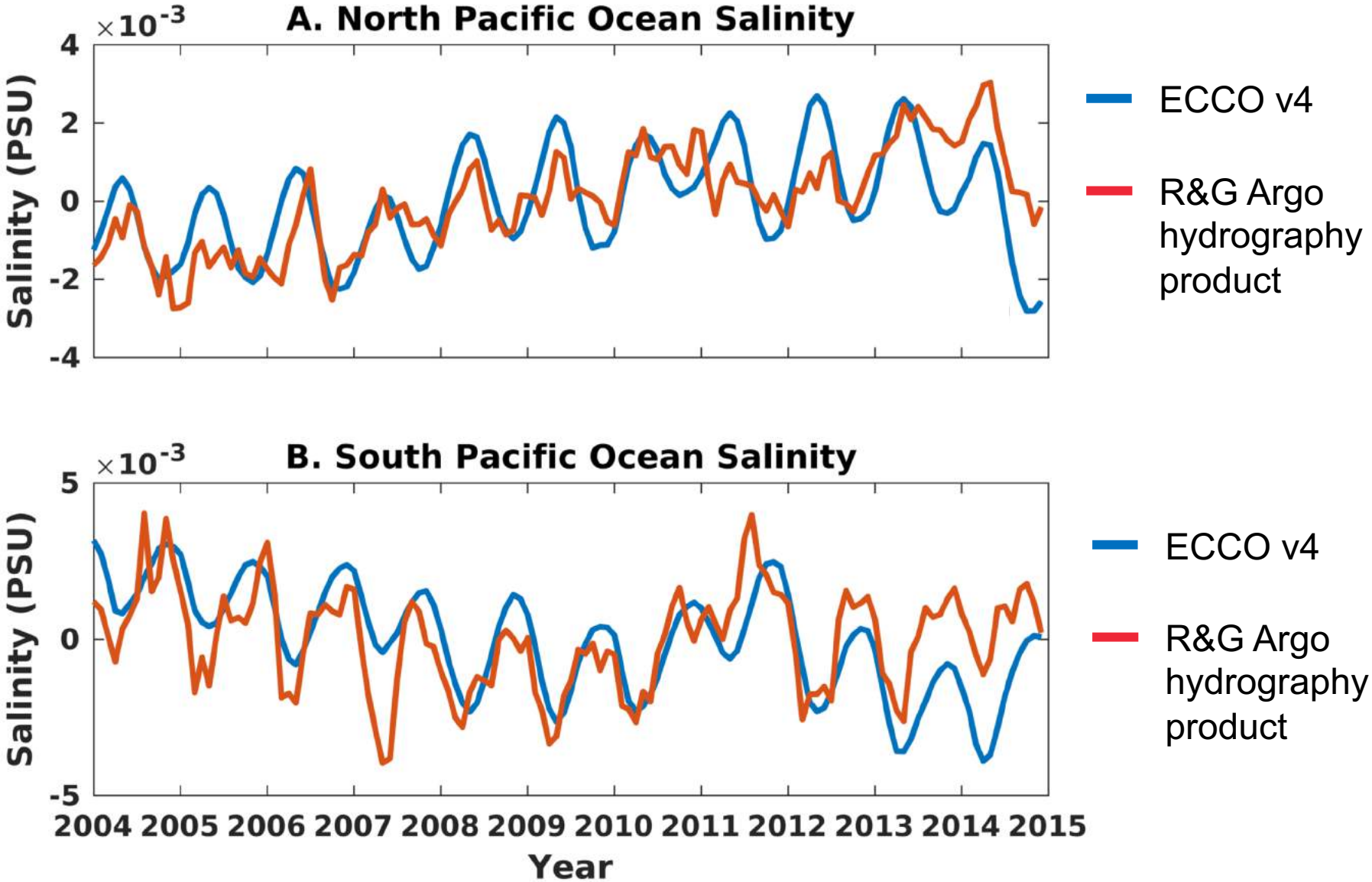
OBS
(DTU-13)



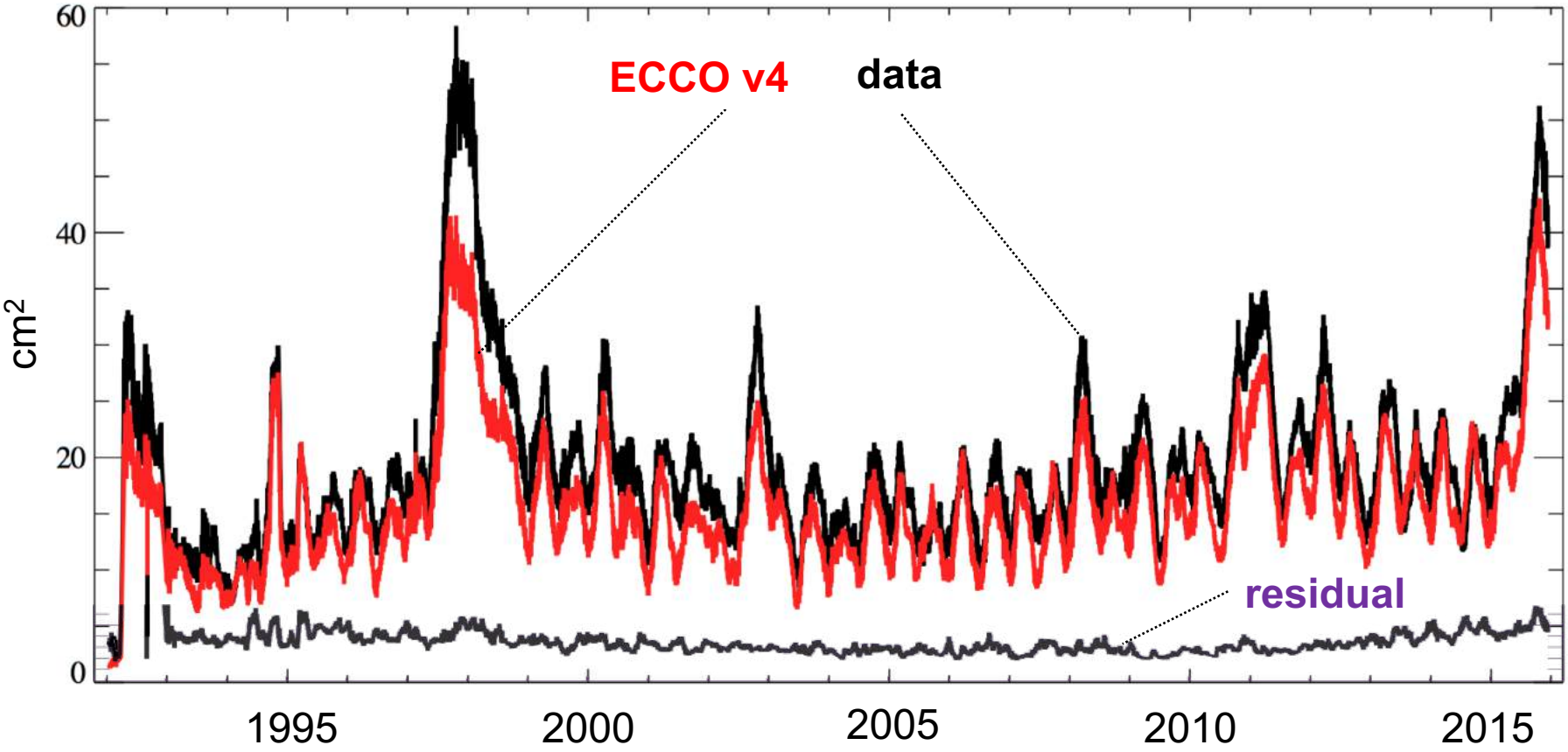
ECCO v4r3



Pacific Ocean Salinity 0-2000m



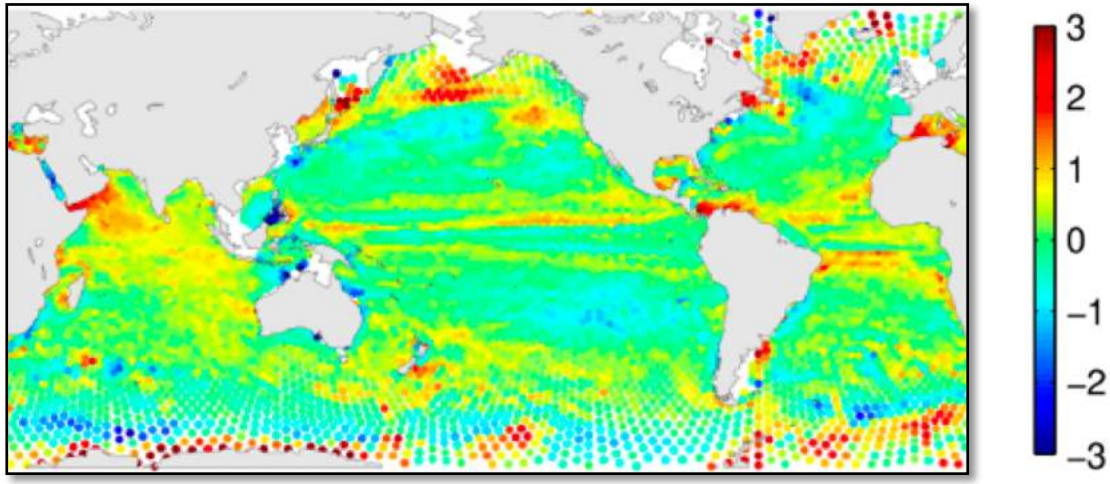
Large-scale SSH variance



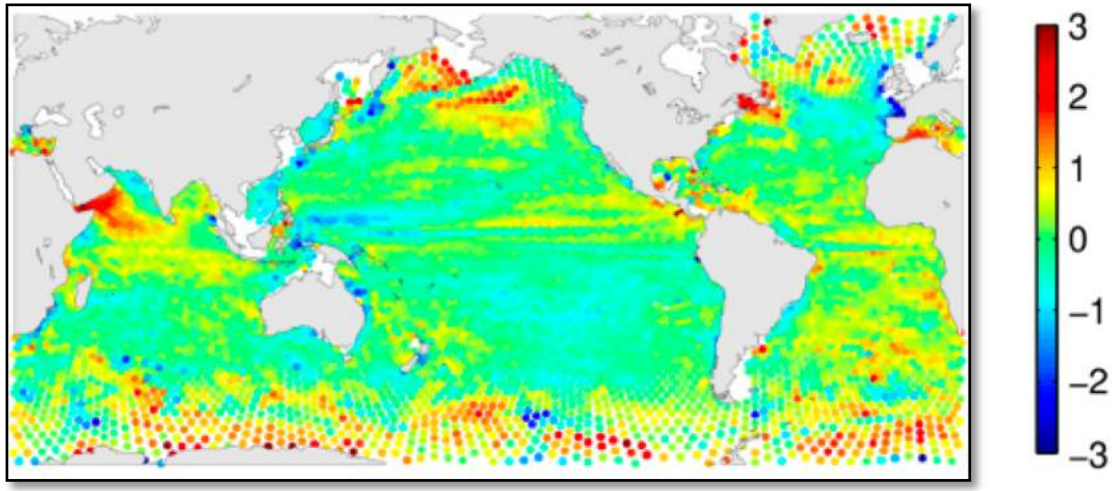
Uncertainty-normalized model-data: *in situ* T and S

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

350 m
Temperature



350 m
Salinity



4. Example applications:

Highlighted work

ECCO state estimates (**a**) faithfully reproduce a large number of in situ and satellite remote sensing ocean and sea ice observations and (**b**) satisfy the laws of physics and thermodynamics.

This makes them useful for a wide range of science investigations including:

global and regional sea level,

ocean T and S variability,

ocean-cryosphere interactions,

AMOC,

carbon cycle,

biological cycles,

coastal physics,

water cycle,

geodesy/Earth rotation,

El Niño,

+many others!

ECCO v4 at 2018 Ocean Sciences

1. PS52A-07 **Gauging the Impacts of an Observationally Derived Oceanic Diapycnal Diffusivity Increment** David S Trossman
2. HE43A-07 **Explaining the trend of Antarctic sea-ice over the past three decades** Kwok
3. IS34D-2656 **Ocean Circulation's Induced Electromagnetic Temporal Variations** Schnepf
4. AI24A-1591 **Variability of Volume and Salt Transports in the Southern Ocean** Ferster and Bulusu
5. PL14A-1767 **Scale analysis of Ocean circulation: insight into Baroclinic conversion and energy spectrum** Sadek
6. HE24C-2893 **Local and remote drivers of Nordic Seas heat anomalies** Årthun
7. HE23A-08 **Local and remote influences on the Labrador Sea: an adjoint sensitivity study** Jones
8. PL34A-1825: **Success and failure of barotropic theory in the North Atlantic using the ECCO state estimate**. Sonnewald
9. PC13A-08 **Varieties of Wind Effects on Tropical Pacific Decadal Sea-Surface Height Variability** Piecuch
10. PL44E-1924 **The subsurface transport to the mixed layer of the tropical Pacific** Gao
11. PC44C-0696 **Relationship between the Indian Ocean Warming and Upwelling in the Southeastern Arabian Sea** Nigam
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13. OM14B-2065 **The Impact of High-resolution, High-frequency Atmospheric Boundary Conditions on Ocean Model Solutions** Zhang
14. AI13A-06 **Vertical Redistribution of Global Ocean Salt Content** Liu
15. PC24C-0607 **Bidecadal Change of the Global Ocean Vertical Heat Transport and Its Implications for the Recent Surface Warming Slowdown** Liang
16. PC24C-0613 **Examining Processes Responsible for the Evolution of Global Mean Sea Surface Temperature** Ponte
17. PC14A-0540 **Causal Mechanisms of Near-Uniform Sea Level and Ocean Bottom Pressure Fluctuation of the Antarctic Continental Shelf** Fukumori

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Ocean Circulation's Induced Electromagnetic Temporal Variations

Neesha R. Schnepf, M. Nair, N. P. Thomas & A. Kuvshinov [S34D-2656]

Science Question:

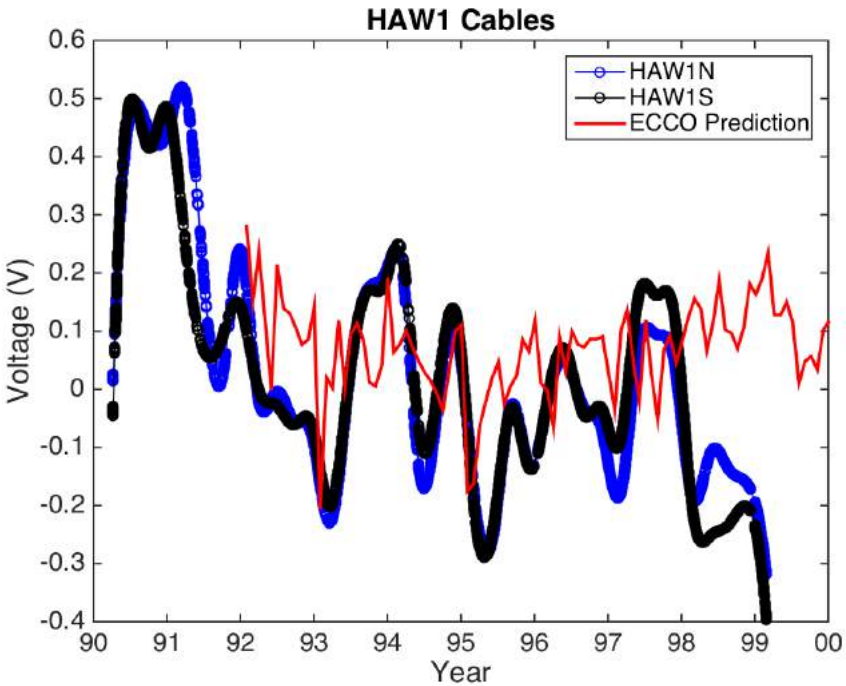
Can basin-scale ocean circulation be inferred using seafloor cables that can measure its induced EM fields?

Why ECCO?

"*ease of access and documentation*", "*recommendation to us from various physical oceanographers*"

Results:

Positive correlation found between measured (blue/black) and predicted (red) voltages.



Gauging the Impacts of an Observationally Derived Oceanic Diapycnal Diffusivity Increment

David S Trossman et al. [PO12A-01]

Science Question:

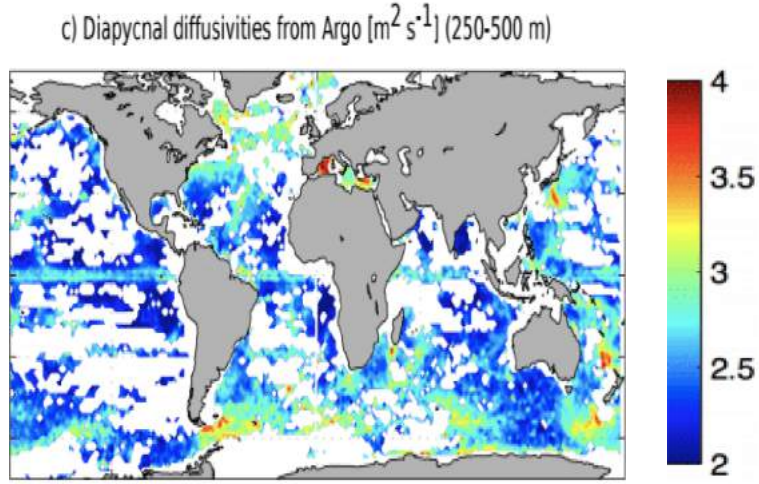
How well do ocean mixing parameters (κ_{GM}, κ_{Redi}, κ_h) estimated by ECCO compare with those derived from Argo data alone?

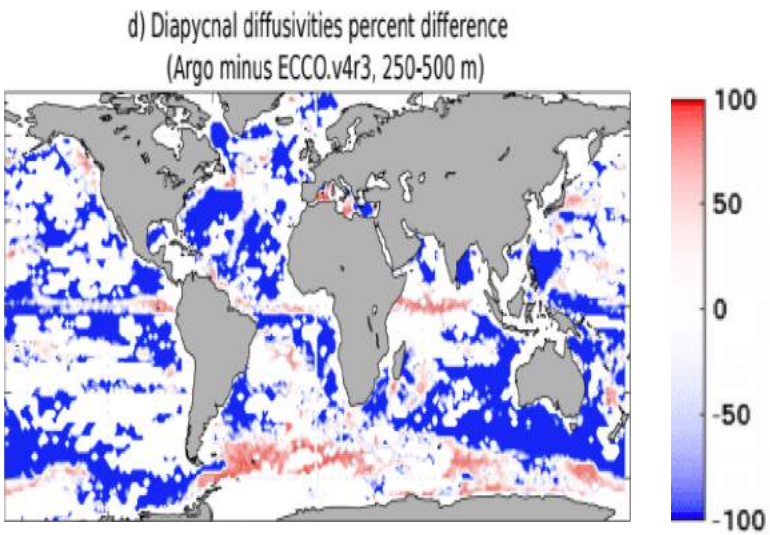
Why ECCO?

"ECCO is one of the few models that estimate and use spatially-varying subgrid-scale mixing parameters."

Results:

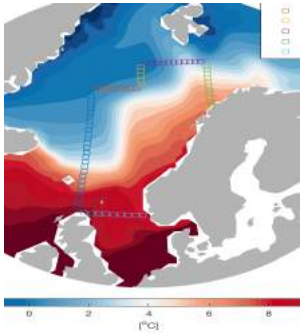
ECCO and Argo-derived products agree within a factor 10. Use of Argo-derived parameters changes upper ocean oxygen concentrations.





Local and remote drivers of Nordic Seas heat anomalies

H. Asbjørnsen, M. Årthun, T. Eldevik, et al. [HE24C-2893]



Science Question:

Why drives upper-ocean ocean heat content variability in the Nordic Seas?

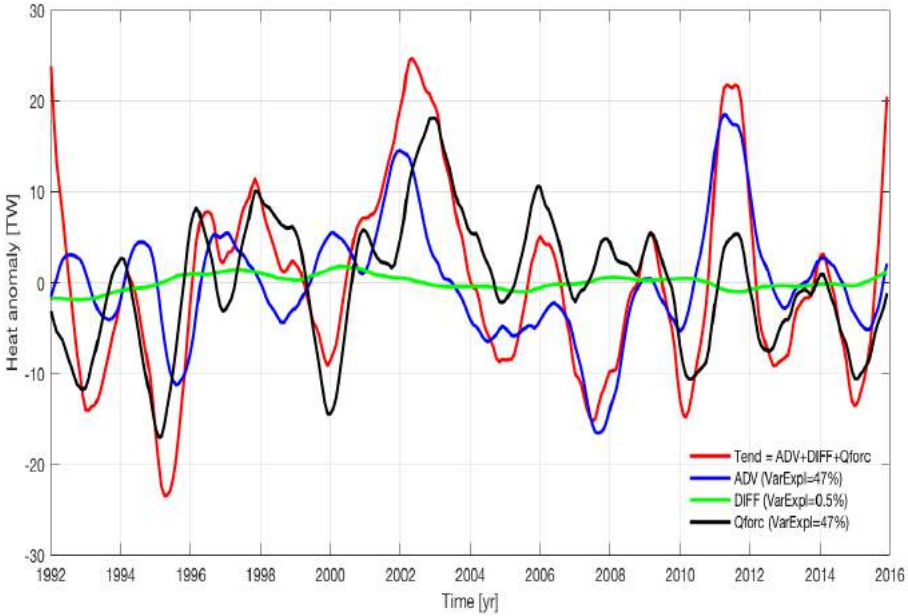
Why ECCO?

"ECCOv4 r3 is deal for heat budget analysis"

Results:

Advective heat convergence dominates the heat budget. Dominated by Eulerian advective fluxes through the western (Atlantic) boundary.

Depth-integrated heat budget for the Norwegian Sea.



Success and failure of barotropic theory in the North Atlantic using the ECCO state estimate

Maike Sonnewald, Carl Wunsch, and Patrick Heimbach [PL34A-1825]

$$0 = \nabla \cdot (f\mathbf{U}) + \frac{1}{\rho_0}\nabla p_b \times \nabla H + \frac{1}{\rho_0}\nabla \times \tau + \nabla \times \mathbf{A} + \nabla \times \mathbf{B}$$

Science Question:

Can we classify the ocean into regions based on the relative importance of different terms in the barotropic vorticity equation?

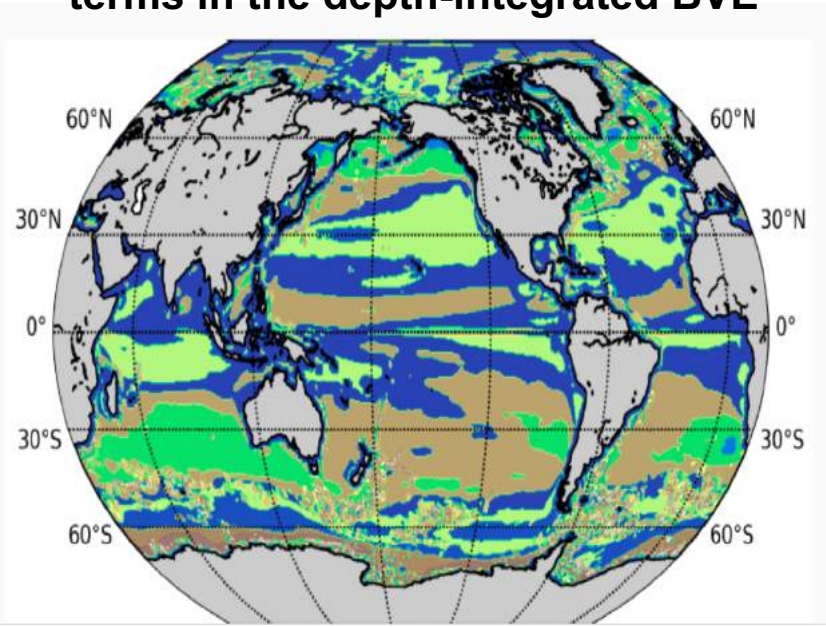
Why ECCO?

ECCO products have closed dynamical budgets.

Results:

Dynamically-distinct regions can be identified and key regions have significant contributions from non-linear terms

Regions of different balances of the terms in the depth-integrated BVE



Causal Mechanisms of Near-Uniform Sea Level and Ocean Bottom Pressure Fluctuation of the Antarctic Continental Shelf

Ichiro Fukumori, et al. [PC14A-0540]

Science Question:

What drives coherent bottom pressure variations on the Antarctica continental shelf on seasonal to interannual timescales?

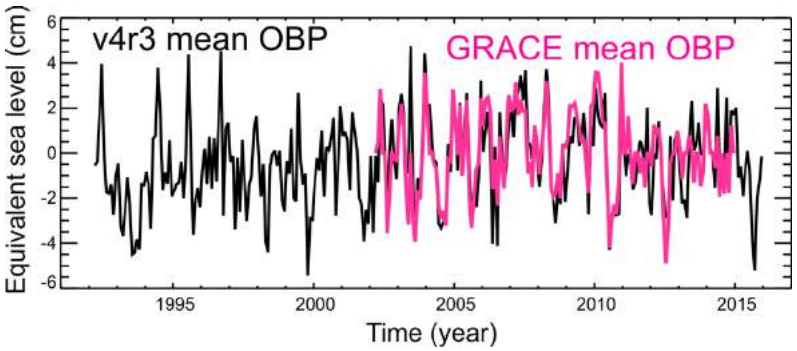
Why ECCO?

ECCO's adjoint–derived sensitivities can reveal causal mechanisms.

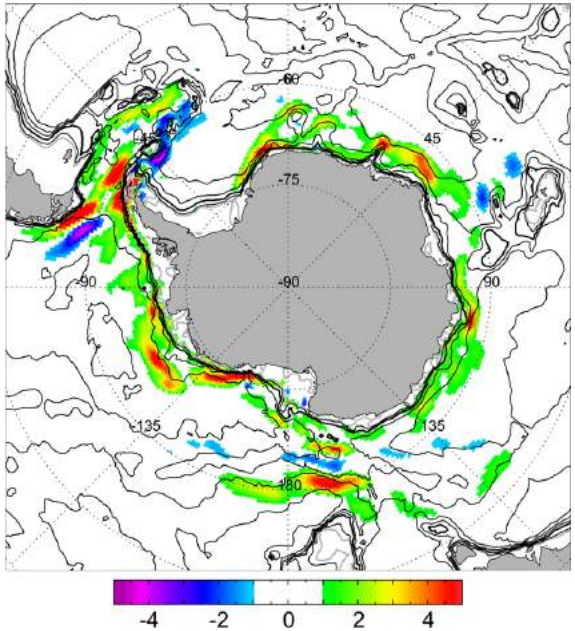
Results:

ECCO reproduces the observed OBP variations (and temperatures too!) These variations are largely driven *by winds along the Antarctic continental slope*.

Mean OBP on the Antarctic shelf.



Explained variance of winds driving *coherent bottom pressure variations* (% per km^2×10^5)



5. Running the forward and adjoint model (Gael Forget)

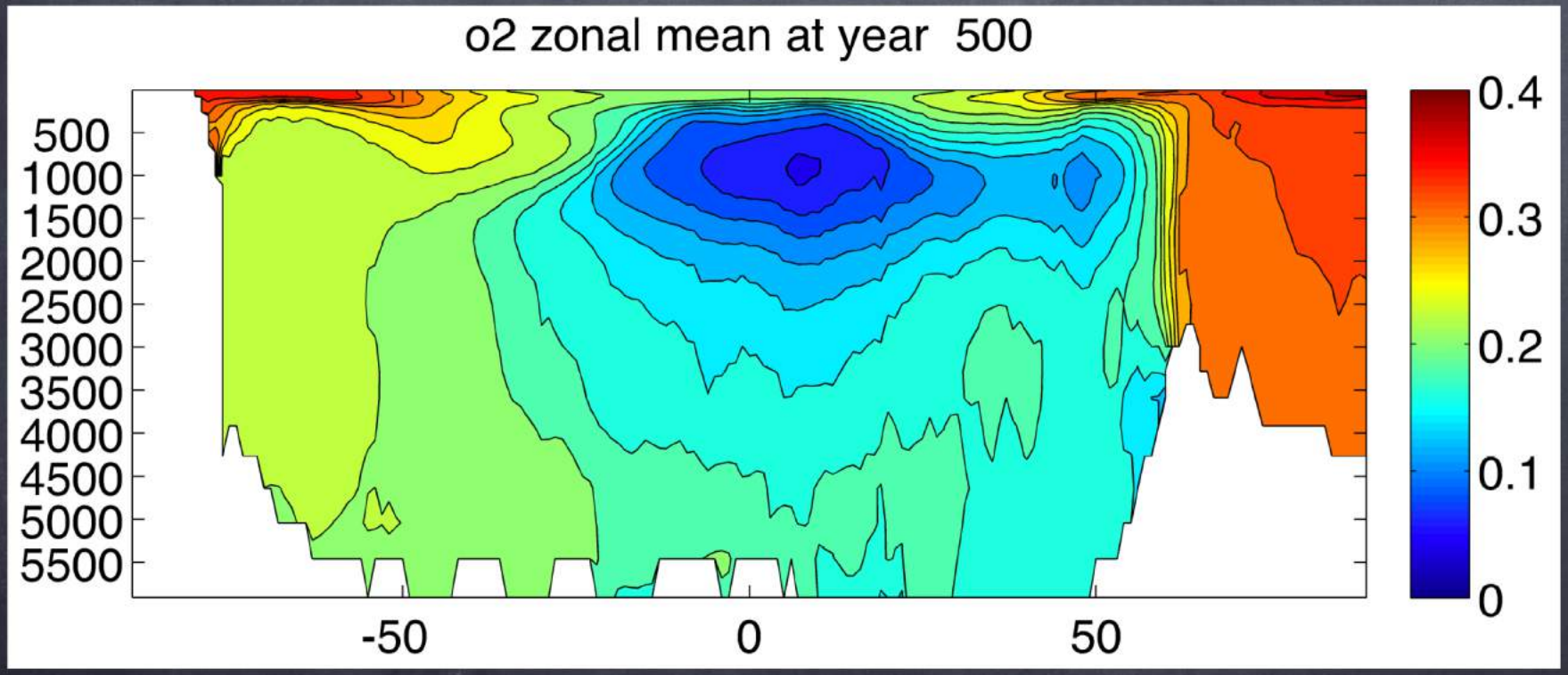
- Why?
- How?

Why would you want to run the model?

To generate original output and results!

For example:
- output not available online
- longer model integrations
- experiment with solutions

ps: this is pretty easy, fast, and inexpensive



Forget, Ferreira, Liang 2015 doi.org/10.5194/os-11-839-2015

Why would you want to run the adjoint model?

Because it is a great tool to help understand observed signals!

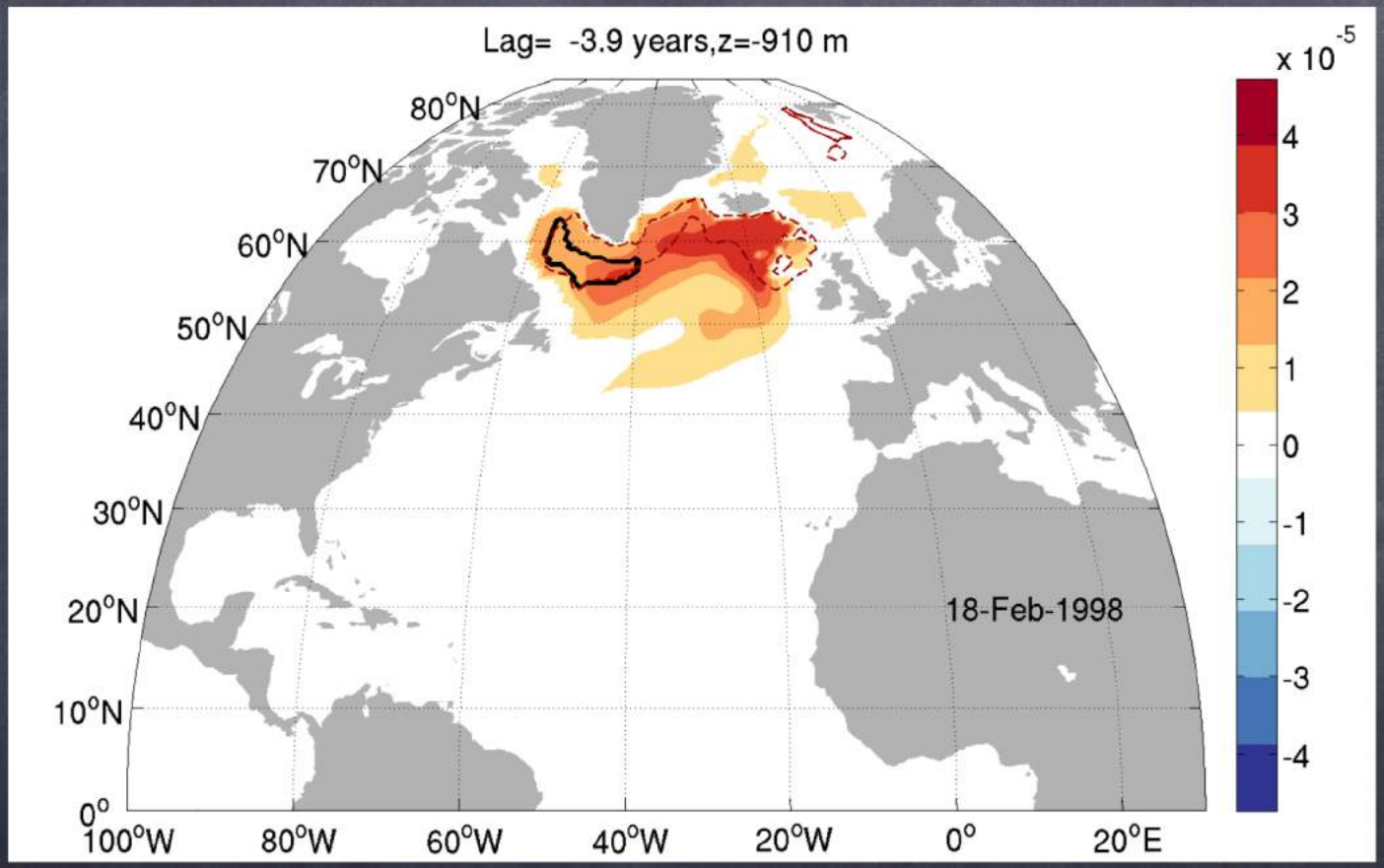
$$J(T,\tau) = \int_{wtp} H(x,y,T,\tau)\ dxdy - \int_{etp} H(x,y,T,\tau)\ dxdy$$

$$\mathcal{G}(x,y,t-T) = \frac{\partial J}{\partial \tau}(t-T) \text{ from the adjoint model}$$

$$K(T,\tau) = \int_{-\infty}^{T} \int_{glo} \mathcal{G}(x,y,t-T) \cdot \tau'(x,y,t)\ dxdy\ dt$$

ps: this is also easy, although not as inexpensive as the forward model

For example



Jones, Forget, Sinha, Josey, Boland, Meijers, Shuckburgh (under review)

1) rerun an ECCO solution
2) customize model settings
3) analyze the output

go to eccov4.readthedocs.io and mitgcm.readthedocs.io for guidance

install MITgcm + configuration

```
git clone https://github.com/MITgcm/MITgcm
git clone -b release3 https://github.com/gaelforget/ECCOv4
mkdir MITgcm/mysetups
mv ECCOv4 MITgcm/mysetups/.
```

compile the MITgcm config.

```
cd MITgcm/mysetups/ECCOv4/build
../../../tools/genmake2 -mods=../code -optfile \
     ../../../tools/build_options/linux_amd64_gfortran -mpi
make depend
make -j 4
cd ..
```

download input files

```
cd MITgcm/mysetups/ECCOv4
wget --recursive ftp://mit.ecco-group.or
wget --recursive ftp://mit.ecco-group.or
mv mit.ecco-group.org/ecco_for_las/versi
mv mit.ecco-group.org/ecco_for_las/versi
```

setup the run directory

```
cd MITgcm/mysetups/ECCOv4
mkdir run
cd run
ln -s ../build/mitgcmuv .
ln -s ../input/* .
ln -s ../input_init/* .
ln -s ../input_forcing/* .
```

run the model

```
mpiexec -np 96 ./mitgcmuv
```

(from ECCOv4r3_mods.md; see eccov4.readthedocs.io)

6. Analysis tools and tutorials

- Gcmfaces
- ECCO v4 Python tutorial
- Python Packages
  - *ecco_v4_py*
  - *xmitgcm*
  - *xgcm*

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

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

New ECCO v4 Python Tutorial

53 commits | 1 branch | 0 releases | 2 contributors

Branch: master | New pull request | Create new file | Upload files | Find file | Clone or download

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 individiual lessons from the tutorial as Juypter notebooks ([model settings (Tutorials_as_Jupyter_Notebooks/ and Tutorials_as_Python_Files/).

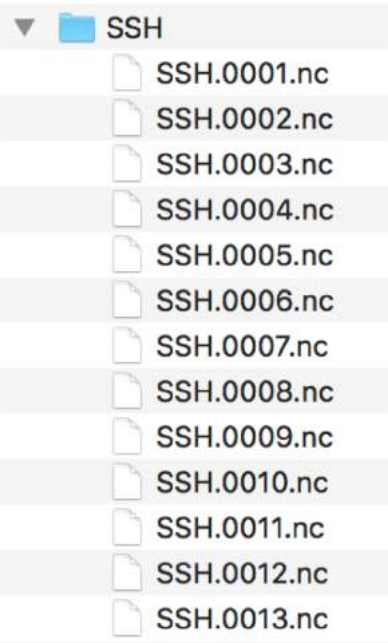
The tutorials were written for ECCO version 4 release 3 but should be applicable to any ECCO v4 solution. If user support is needed, please contact ecco-support@mit.edu.

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

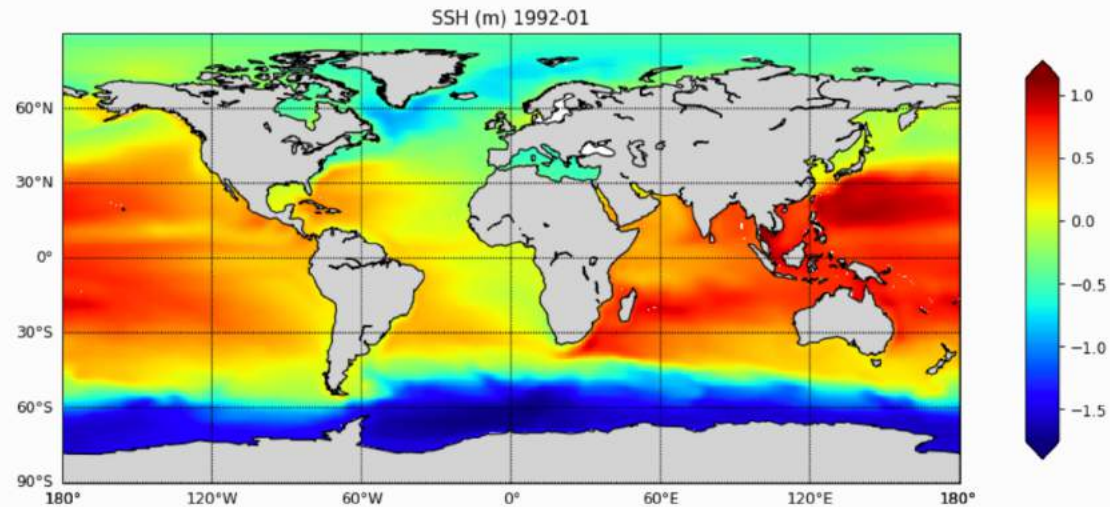
https://github.com/ECCO-GROUP/ECCO-v4-Python-Tutorial

ecco_v4_py Python Package

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]);
```



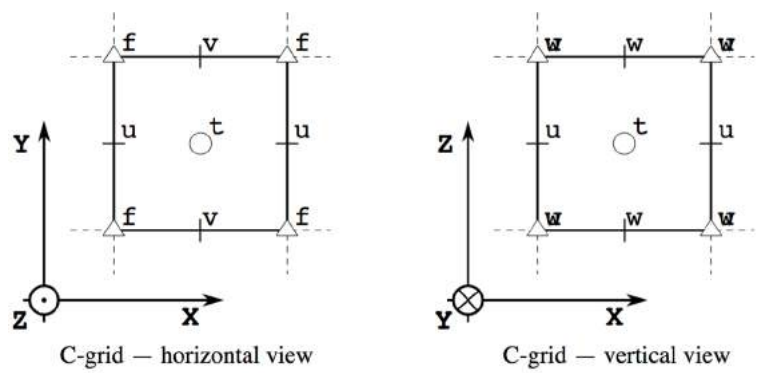
https://github.com/ECCO-GROUP/ECCOv4-py

xmitgcm and xgcm Python Packages

xmitgcm is a Python package for reading MITgcm binary MDS files into 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/



New ECCO website!

Jet Propulsion Laboratory
California Institute of Technology

ECCO

Home About Products Data Knowledge Research

Latest Product

All Products

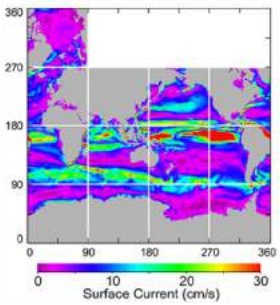
ECCO-V4r3

Authors: Fukumori, Ichiro; Wang, Ou; Fenty, Ian; Forget, Gael; Heimbach, Patrick; Ponte, Rui M.

Description:

Version 4 Release 3 (V4r3), covering the period 1992-2015, represents ECCO's latest ocean state estimate. This product is an updated edition to that described by Forget et al. (2015, Geosci. Model Dev.). Version 4 is the first multi-decadal ECCO estimate that is truly global, including the Arctic Ocean. The Release 3 edition includes improvements in time-period (1992-2015), model (e.g., sea-ice), observations (e.g., GRACE, Aquarius), and constraints (e.g., correlated errors).

[*Image at right*]Speed (cm/s) of 1992-2015 time-mean current at 5m depth. The figure combines into a global image, V4r3's thirteen tiles, each a 90-by-90 grid delineated by white lines.



Download Product

Overview

Period:	Jan 1992 - Dec 2015
Grid & Resolution:	LLC90 (1 deg)
Domain:	Global
Variable:	Ocean State (temperature, salinity, velocity, sea level, bottom pressure), Fluxes (temperature, salt, volume)
Temporal Resolution:	Monthly, Daily, Hourly
Data Used:	Satellite Altimetry, ARGO, GRACE, Aquarius, CTD, XBT
Type of Estimation:	Adjoint
Data Format(s):	NetCDF, Binary
Version:	Release 3
Contact Person:	Ian Fenty, Ichiro Fukumori, Ou Wang
Last Updated Date:	October 15, 2017

Have your work highlighted on the new ECCO website!

https://ecco.jpl.nasa.gov
https://ecco-group.org

7. Future directions

ECCO Future Directions

Modeling and Estimation	Ice shelves and tidewater glaciers packages
	New cryosphere observations (e.g., sea ice thickness), ice shelf basal ocean melt rates
	New controls (e.g., time-variable ocean mixing parameters)
	Higher spatial resolution 1/3° 10–25km grid (llc270)
Modeling Tools	Online passive tracer tool
	Open-source algorithmic differentiation and generic adjoint
Community Program	Annual ECCO Meeting and Community Workshop
	20th year Symposium 2019
	20th year Special Issue 2019
	ECCO Summer School, May/June 2019 (tentative)

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