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.

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

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

\[
\lambda_0 = \sum_{t=1}^{t_f-1} \left\{ A_1 A_2 \cdots A_t G_{t+1} \right\} + G_1
\]
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.
**ECCO Product Timeline**

**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.

- **ECCO v0-v3** (2002-2009)
- **ECCO v4** (2014-2017)
- **ECCO 1/3°** (2018-2020)
- **ECCO2 18 km**
- **ECCO-JPL 1°**

**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/smooth.

Regional higher resolution ECCO products include SOSE, B-SOSE, ASTE, California/GoM, others.
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)
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**
- $T$, $S$, $u$, $v$, $w$, $\eta$, $\rho$, $\Phi$
- 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 $\kappa$ and Redi $\kappa$
- 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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity profiles</td>
<td>Argo floats (1997-2015), CTDs (1992-2011), SEaOS (2004-2010), and other high-latitude CTDs and moorings</td>
</tr>
<tr>
<td>Sea surface temp.</td>
<td>AVHRR (1992-2013)</td>
</tr>
<tr>
<td>Sea surface salinity</td>
<td>Aquarius (2011-2013)</td>
</tr>
<tr>
<td>Ocean bot. pressure</td>
<td>GRACE (2002-2014), JPL MASCON Solution</td>
</tr>
<tr>
<td>TS climatology</td>
<td>World Ocean Atlas 2009</td>
</tr>
<tr>
<td>MDT</td>
<td>DTU13 (1992-2012)</td>
</tr>
<tr>
<td>GM SSH &amp; OBP</td>
<td>AVISO, CSIRO, NOAA; GRACE</td>
</tr>
</tbody>
</table>

New or updated items from are indicated in red.

- 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

Global Mean Sea Level (mm)

Global Mean OBP (mm equiv.)
Mean Dynamic Topography

OBS (DTU-13)

ECCO v4r3
Pacific Ocean Salinity  0-2000m

A. North Pacific Ocean Salinity

B. South Pacific Ocean Salinity

- Salinity (PSU)
  - Salinity (PSU)
  - Year

ECCO v4
R&G Argo hydrography product

Large-scale SSH variance

ECCO v4 data
residual
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!
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
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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 ($\kappa_{GM}$, $\kappa_{Redi}$, $\kappa_h$) 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.

David S Trossman et al. [PO12A-01]
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.
Success and failure of barotropic theory in the North Atlantic using the ECCO state estimate

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

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

- Why?
- How?
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
Because it is a great tool to help understand observed signals!

\[
J(T, \tau) = \int_{wtp} H(x, y, T, \tau) \, dx\,dy - \int_{etp} H(x, y, T, \tau) \, dx\,dy
\]

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

\[
K(T, \tau) = \int_{-\infty}^{T} \int_{glo} G(x, y, t - T) \cdot \tau'(x, y, t) \, dx\,dy \, dt
\]

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

```bash
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.

```bash
cd MITgcm/mysetups/ECCOv4/build

```
```bash
../.../tools/genmake -mods=../code -optfile \
../.../tools/build_options/linux_amd64_gfortran -mpi
make depend
make -j 4
cd ..
```

download input files

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

setup the run directory

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

run the model

```bash
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`
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

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.


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.

![SSH map](image)

```python
plt.figure(figsize=(12.6, 9))
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.t[0].values[0:7]));
```

[GitHub Repository](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](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/](http://xmitgcm.readthedocs.io/en/latest/)
New ECCO website!

Have your work highlighted on the new ECCO website!

https://ecco.jpl.nasa.gov
https://ecco-group.org
7. Future directions
## ECCO Future Directions

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

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

Download the latest ECCO state estimate

Tutorial & Tools

http://ecco-v4-python-tutorial.readthedocs.io
http://eccov4.readthedocs.io

Getting support

mailto: ecco-support@mit.edu