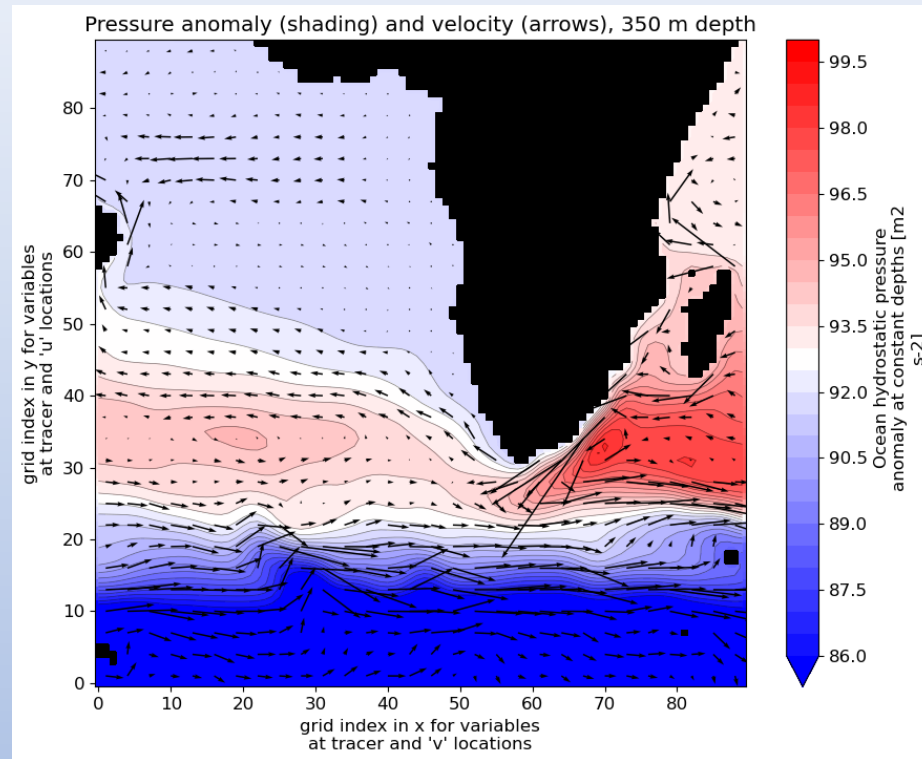


Introducing ECCO to the Next Generation of Oceanographers:

Illustrating Fundamental PO Concepts using the ECCO State Estimate



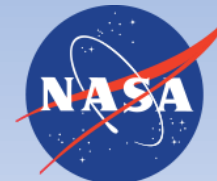
Andrew Delman^{1,2}, Ian Fenty²

¹Joint Institute For Regional Earth System Science & Engineering (JIFRESSE), University of California Los Angeles, Los Angeles, CA, USA

²Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA



ECCO Meeting
January 2023



Jet Propulsion Laboratory
California Institute of Technology

Introducing ECCO to the Next Generation of Oceanographers

Outline

- ECCO Python Tutorials
- Updating ECCO access in the transition to NASA Earthdata Cloud
- Intro to PO Tutorials
 - The motivation and “vision”
 - Walkthrough of a tutorial
 - Planned Tutorials

ECCO Python Tutorials

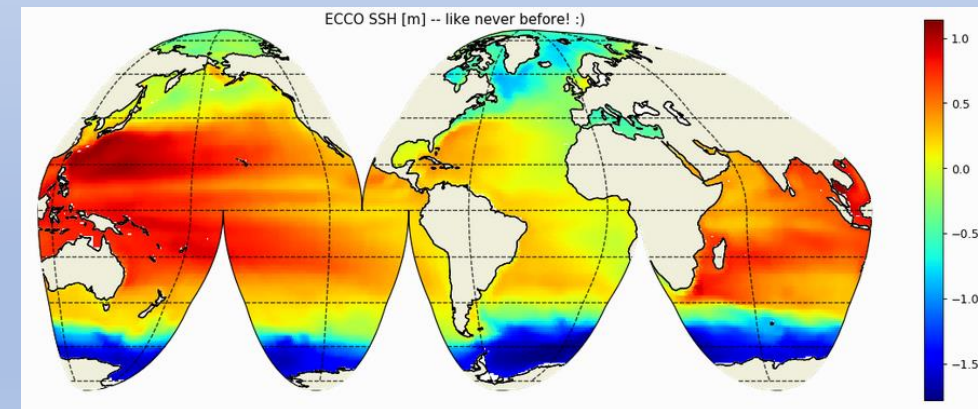
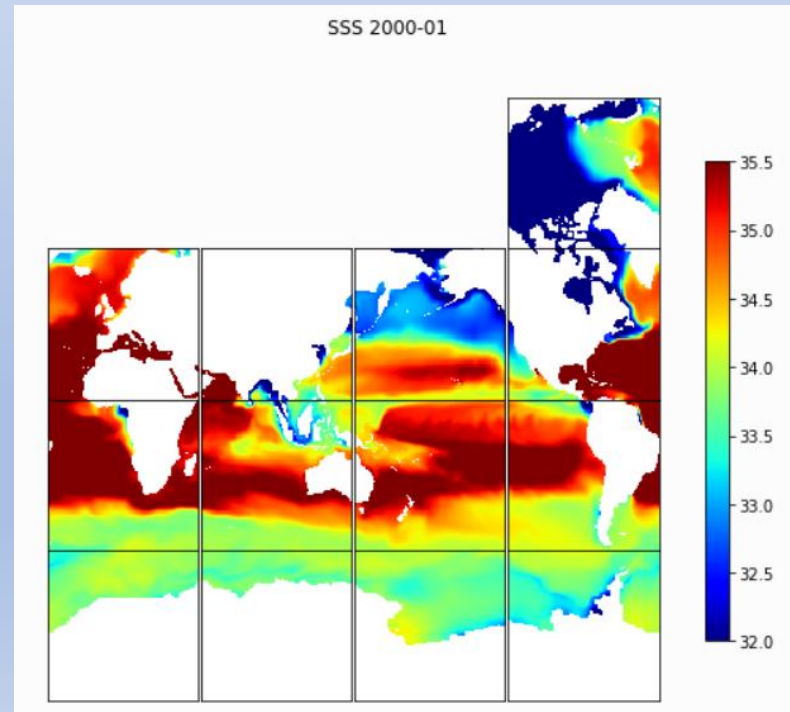
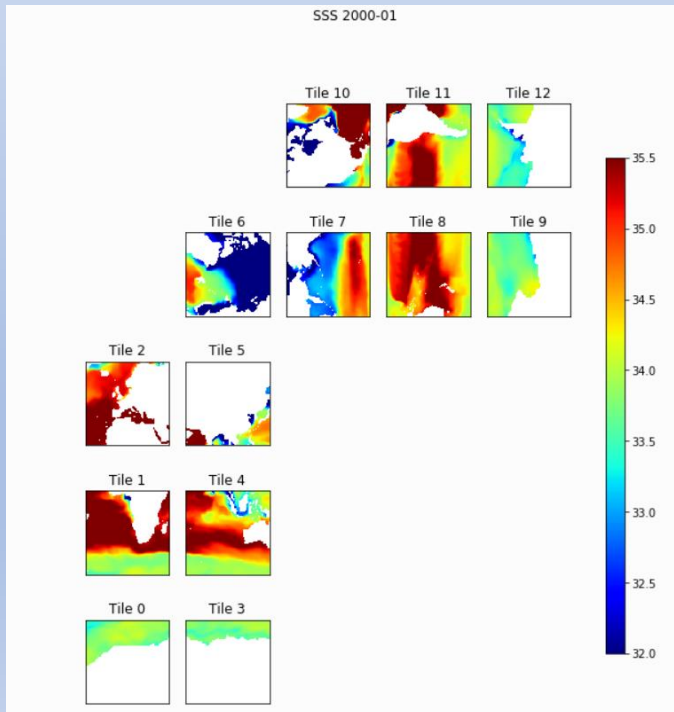
- Tutorials website (by Ian Fenty et al.) to provide oceanographers with demos and code for ECCO analysis
- Comprised mostly of Jupyter notebooks that can be downloaded or git cloned to user's machine
- <https://ecco-v4-python-tutorial.readthedocs.io>

The screenshot shows the homepage of the ECCO Version 4 Python Tutorial website. The URL is <https://ecco-v4-python-tutorial.readthedocs.io>. The page features a navigation menu on the left with sections like 'GETTING STARTED', 'ECCO DATA STRUCTURES', and 'INPUT/OUTPUT, DATA STRUCTURE MANIPULATION'. The main content area has a 'Welcome to the ECCO Version 4 Tutorial' heading and a paragraph explaining the site's purpose. Below this is an 'Additional Resources' section and a 'Getting Started' section with a list of links.

The screenshot shows a tutorial page titled 'Compute meridional heat transport'. The URL is https://ecco-v4-python-tutorial.readthedocs.io/ECCO_v4_Example_MHT.html. The page includes a table of contents on the left and two heat transport plots on the right. The top plot is 'Global time mean meridional heat transport' and the bottom plot is 'Atlantic time mean meridional heat transport'. Both plots show depth (0 to 4000 m) versus latitude (-60 to 40). The global plot has a color scale from -0.3 to 0.3 PW, and the Atlantic plot has a color scale from -0.08 to 0.08 PW.

ECCO Python Tutorials

- Tutorials website (by Ian Fenty et al.) to provide oceanographers with demos and code for ECCO analysis
- Comprised mostly of Jupyter notebooks that can be downloaded or git cloned to user's machine
- <https://ecco-v4-python-tutorial.readthedocs.io>
- Also associated with the `ecco_v4_py` Python package, with support for analyzing and plotting ECCO output in a number of formats



Updating Tutorials and ECCO Access

- The tutorials have been oriented around ECCOv4 release 3 output, accessed via ECCO Drive
- But we have release 4 now (with release 5 on the way), and ECCO Drive/PO.DAAC Drive are being decommissioned...

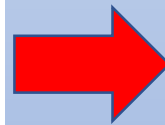
...in favor of NASA Earthdata Cloud, accessed via Earthdata Search

ECCO Drive

Back to WebDAV Credentials

Current Location:
files / Version4 / Release3 / nctiles_monthly /

Name	Last Modified	Size
Parent Directory	-	-
ADVr_SLT	2018-04-07 00:21:00	-
ADVr_TH	2017-04-21 23:32:24	-
ADVx_SLT	2017-04-21 23:15:28	-
ADVx_TH	2017-04-21 22:46:23	-
ADVxHEFF	2017-04-20 22:46:55	-
ADVxSNOW	2017-04-20 22:47:31	-
ADVy_SLT	2017-04-21 23:23:07	-
ADVy_TH	2017-04-21 22:54:26	-
ADVyHEFF	2017-04-20 22:47:05	-
ADVySNOW	2017-04-20 22:47:40	-
DFrE_SLT	2017-04-24 16:20:25	-
DFrE_TH	2017-04-21 23:43:24	-
DFrI_SLT	2017-04-24 16:27:51	-
DFrI_TH	2017-04-21 23:50:18	-
DFxE_SLT	2017-04-21 23:01:49	-
DFxE_TH	2017-04-21 22:25:57	-



EARTHDATA SEARCH

Find a DAAC

temperature

90 Matching Collections

Showing 60 of 90 matching collections

ECCO Ocean Density, Stratification, and Hydrostatic Pressure - Daily Mean llc90 Grid (Version 4 Release 4)
9,497 Granules 1992-01-01 to 2018-01-01
Earthdata Cloud
This dataset provides daily-averaged ocean density, stratification, and hydrostatic pressure on the native Lat-Lon-Cap 90 (LLC90) model grid from th...
GEOSS • ECCO L4 DENS STRAT PRESS LLC0090GRID DAILY V4R4 V4R4 - NASA/JPL/PODAAC

ECCO Sea-Ice and Snow Concentration and Thickness - Daily Mean llc90 Grid (Version 4 Release 4)
9,497 Granules 1992-01-01 to 2018-01-01
Earthdata Cloud
This dataset provides daily-averaged sea-ice and snow concentration, thickness, and pressure loading on the native Lat-Lon-Cap 90 (LLC90) model grid from th...
GEOSS • ECCO L4 SEA ICE CONC THICKNESS LLC0090GRID DAILY V4R4 V4R4 - NASA/JPL/PODAAC

ECCO Ocean Temperature and Salinity - Monthly Mean llc90 Grid (Version 4 Release 4)
312 Granules 1992-01-01 to 2018-01-01
Earthdata Cloud
This dataset provides monthly-averaged ocean potential temperature and salinity on the native Lat-Lon-Cap 90 (LLC90) model grid from the ECCO Versio...
GEOSS • ECCO L4_TEMP_SALINITY LLC0090GRID_MONTHLY V4R4 V4R4 - NASA/JPL/PODAAC

v1.185.1 • Search Time: 1.4s • NASA Official: Stephen Bernick • FOIA • NASA Privacy Policy • USA.gov

Earthdata Access: A Section 508 accessible alternative

Updating Tutorials and ECCO Access

- The tutorials have been oriented around ECCOv4 release 3 output, accessed via ECCO Drive
- But we have release 4 now (with release 5 on the way), and ECCO Drive/PO.DAAC Drive are being decommissioned...

...in favor of NASA Earthdata Cloud, accessed via Earthdata Search

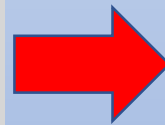
ECCO Drive

Current Location:
files / Version4 / Release3 / nctiles_monthly /

Name	Last Modified	Size
[Folder]	-	-
[Folder]	2018-04-07 00:21:00	-
[Folder]	2017-04-21 23:32:24	-
[Folder]	2017-04-21 23:15:28	-
[Folder]	2017-04-21 22:46:23	-
[Folder]	2017-04-20 22:46:55	-
[Folder]	2017-04-20 22:47:31	-
[Folder]	2017-04-21 23:23:07	-
[Folder]	2017-04-21 22:54:26	-
[Folder]	2017-04-20 22:47:05	-
[Folder]	2017-04-21 23:50:18	-
[Folder]	2017-04-21 23:01:49	-
[Folder]	2017-04-21 22:25:57	-

Annotations:

- Temporal resolution (points to a folder)
- Variable (points to a folder)
- Ilc Tile or Year (points to a grid icon)



Earthdata Search

temperature | 90 Matching Collections

Showing 60 of 90 matching collections

ECCO Ocean Density, Stratification, and Hydrostatic Pressure - Daily Mean Ilc90 Grid (Version 4 Release 4)

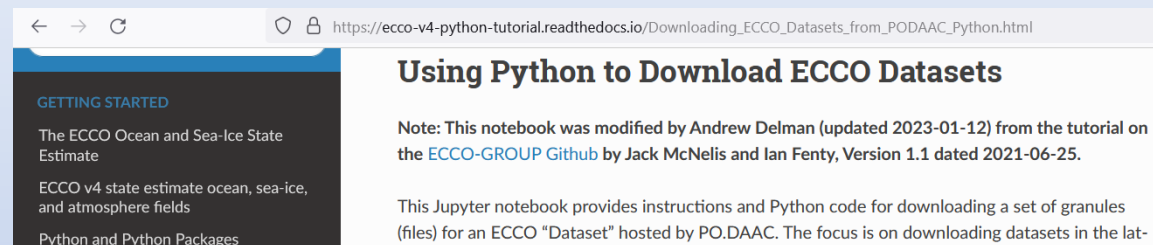
9,497 Granules 1992-01-01 to 2018-01-01

Annotations:

- Dataset (group of related variables) (points to a folder icon)
- Granule (single time entry) (points to a grid icon)

Updating Tutorials and ECCO Access

- Now the ECCO Python Tutorials include a tutorial on how to download ECCOv4 release 4 output from the cloud



- AND an `ecco_download.py` module that can be imported and called from a Python shell or Jupyter notebook

```
ECCO Version 4: Fourth Release (1992-2017) [ECCO v4r4]

These are the variables in the ECCO v4r4 output that can be downloaded as daily averages from the PO.DAAC cloud storage.

ShortName      Variable Name      Description (units)
ECCO_L4_SSH_LLC0090GRID_DAILY_V4R4
SSH            Dynamic sea surface height anomaly. Suitable for comparisons with altimetry.
SSHIBC        The inverted barometer correction to sea surface height due to atmospheric pressure.
SSHNOIBC      Sea surface height anomaly without the inverted barometer correction.
ETAN          Model sea level anomaly, without corrections for global mean decrease in sea level.

ECCO_L4_ATM_STATE_LLC0090GRID_DAILY_V4R4
EXFatemp      Atmosphere surface (2 m) air temperature (degK)
EXFaqh        Atmosphere surface (2 m) specific humidity (kg/kg)
EXFuwind      Wind speed at 10m in the model +x direction (m/s)
EXFvwind      Wind speed at 10m in the model +y direction (m/s)
EXFwspeed     Wind speed (m/s)
EXFpsp        Atmosphere surface pressure (N/m^2)

ECCO_L4_STRESS_LLC0090GRID_DAILY_V4R4
EXFtaux       Wind stress in the model +x direction (N/m^2)
EXFtauy       Wind stress in the model +y direction (N/m^2)
oceTAUX       Ocean surface stress in the model +x direction, due to wind and waves.
oceTAUY       Ocean surface stress in the model +y direction, due to wind and waves.

ECCO_L4_HEAT_FLUX_LLC0090GRID_DAILY_V4R4
EXFh1         Open ocean air-sea latent heat flux (W/m^2)
EXFhs         Open ocean air-sea sensible heat flux (W/m^2)
EXFlwdn       Downward longwave radiative flux (W/m^2)
```

```
[21]: from ecco_download import *

ecco_podaac_download(ShortName="ECCO_L4_SSH_LLC0090GRID_DAILY_V4R4",
                     StartDate="2000-01-09", EndDate="2000-01-14", download_root_dir=None,
                     n_workers=6, force_redownload=False)

created download directory C:\Users\adelman\Downloads\ECCO_V4r4_PODAAC\ECCO_L4_SSH_LLC0090GRID_DAILY_V4R4
{'ShortName': 'ECCO_L4_SSH_LLC0090GRID_DAILY_V4R4', 'temporal': '2000-01-09,2000-01-14'}

Total number of matching granules: 7

=====
total downloaded: 41.48 Mb
avg download speed: 1.9 Mb/s
```

Intro to PO Tutorials

Motivation

- The ECCOv4 state estimate is unique in that it **assimilates data** AND maintains **physical conservation laws**
- This makes it a valuable **teaching tool** for graduate students and others learning about physical oceanography & GFD

Vision

- ECCO tutorials to demonstrate core concepts in physical oceanography
 - Jupyter notebooks for classroom demonstrations or problem sets
- Students can enhance Python coding skills while analyzing and plotting NASA datasets
- Use open source tools that encourage transparency, accessibility, and reproducibility

Intro to PO Tutorials: An Example

- Three new PO Tutorials have been completed...more on the way!
- They have a common format...let's look at **Part 1: Geostrophic Balance**

Objectives listing tasks/skills that the user will practice in the tutorial

Part 1: Geostrophic balance

Andrew Delman, updated 2023-01-13.

Objectives

To use ECCO state estimate output to illustrate the concept of geostrophic balance; where it does and doesn't explain oceanic flows well.

By the end of the tutorial, you will be able to:

- Download ECCO fields and query their attributes using `xarray`
- Plot ECCO fields on a single tile
- Carry out spatial differencing and interpolation on the ECCO native model grid
- Compare the two sides of the geostrophic balance equations
- Compute geostrophic velocities
- Apply masks in 2-D spatial plots
- Use the `ecco_v4_py` package to plot global maps of ECCO fields
- Use a statistical measure (normalized difference) to assess the latitude and depth dependence of geostrophic balance

Introduction

The tutorials in this series use output from the ECCO version 4 release 4 (v4r4) state estimate to illustrate foundational concepts in the physics of the ocean (physical oceanography or PO for short). These tutorials are written as Jupyter notebooks; this format allows the concepts, code, and results of running the code to be viewed together in one document.

While these notebooks can be read online, it is strongly recommended to download them, and the ECCO output needed to run them, in order to allow users to interact with the data themselves. You can even tinker with the notebooks yourself to look at different regions or perform different calculations, that's part of the fun!

We'll start by visualizing one of the most basic concepts in fluid dynamics on a rotating reference frame: geostrophic balance.

Intro to PO Tutorials: An Example

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- They have a common format...let's look at **Part 1: Geostrophic Balance**

Objectives listing tasks/skills that the user will practice in the tutorial

Introduction briefly discussing relevant theory as in a textbook (with references to established textbooks)

P

$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} = -\frac{1}{\rho} \nabla p + \nu \nabla^2 \mathbf{u} + g \hat{\mathbf{k}} - 2\boldsymbol{\Omega} \times \mathbf{u} + \mathbf{F}_f$$

And

Of those last three terms:

O

1. Gravity $g\hat{\mathbf{k}}$ effectively only applies to vertical momentum, and can be neglected in the horizontal momentum equations
2. The Coriolis force $-2\boldsymbol{\Omega} \times \mathbf{u}$ can be approximated by its vertical component, $2\Omega \sin \theta (\hat{\mathbf{i}} - u\hat{\mathbf{j}})$ where Ω is the rotation rate of Earth in radians and θ is latitude
3. Friction \mathbf{F}_f from wind and topography is negligible in the ocean interior.

To

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To simplify, f is defined as $f \equiv 2\Omega \sin \theta$. So using subscript notation for derivatives (u_t is the derivative of u with respect to t) the two horizontal components of momentum conservation are:

$$u_t + \mathbf{u} \cdot \nabla u = -\frac{1}{\rho} p_x + \nu \nabla^2 u + fv$$

$$v_t + \mathbf{u} \cdot \nabla v = -\frac{1}{\rho} p_y + \nu \nabla^2 v - fu$$

Geostrophic balance

In

The two horizontal momentum equations still have a number of terms, but in the global oceans most of the flow is explained by a balance between just two terms. In steady state (or for very slowly-varying ocean features) the time derivatives u_t , v_t are negligible, and at the large scales of major ocean currents viscosity is relatively small as well (inviscid approximation). This leaves three terms. The 2nd term on the left-hand side is usually negligible at large scales as well (we'll return to this later), so large-scale ocean flows generally follow **geostrophic balance**:

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$$fv = \frac{1}{\rho} p_x$$

$$fu = -\frac{1}{\rho} p_y$$

If you've looked at weather maps that show the clockwise or counter-clockwise flow of winds around areas of high or low pressure, you've encountered

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Introduction briefly discussing relevant theory as in a textbook (with references to established textbooks)

Open and view contents of ECCO file(s) needed for the calculation

Out[8]: xarray.DataArray 'RHOAnoma' (time: 1, k: 50, tile: 13, j: 90, i: 90)

dask.array<chunksize=(1, 50, 13, 90, 90), meta=np.ndarray>

Coordinates:

Variable	Dimensions	dtype	Values
i	(i)	int32	0 1 2 3 4 5 6 ... 84 85 86 87 88 89
j	(j)	int32	0 1 2 3 4 5 6 ... 84 85 86 87 88 89
k	(k)	int32	0 1 2 3 4 5 6 ... 44 45 46 47 48 49
tile	(tile)	int32	0 1 2 3 4 5 6 7 8 9 10 11 12
time	(time)	datetime64[ns]	2000-01-16T12:00:00
XC	(tile, j, i)	float32	dask.array<chunksize=(13, 90, 90), meta=np.nd...
YC	(tile, j, i)	float32	dask.array<chunksize=(13, 90, 90), meta=np.nd...
Z	(k)	float32	dask.array<chunksize=(50,), meta=np.ndarray>

Attributes:

```

long_name : In-situ seawater density anomaly
units : kg m-3
coverage_cont... : modelResult
valid_min : -18.81316375732422
valid_max : 25.540061950683594
comment : In-situ seawater density anomaly relative to the reference density, rhoConst. rhoCo
nst = 1029 kg m-3

```

Note the attribute "comment" at the bottom. The density anomaly is relative to a constant value, 1029 kg m-3. So if we need the actual density value, we add 1029 to the density anomaly.

In [9]: rhoConst = 1029.

Attributes:

```

long_name : In-situ seawater density anomaly
units : kg m-3
coverage_cont... : modelResult
valid_min : -18.81316375732422
valid_max : 25.540061950683594
comment : In-situ seawater density anomaly relative to the reference density, rhoConst. rhoCo
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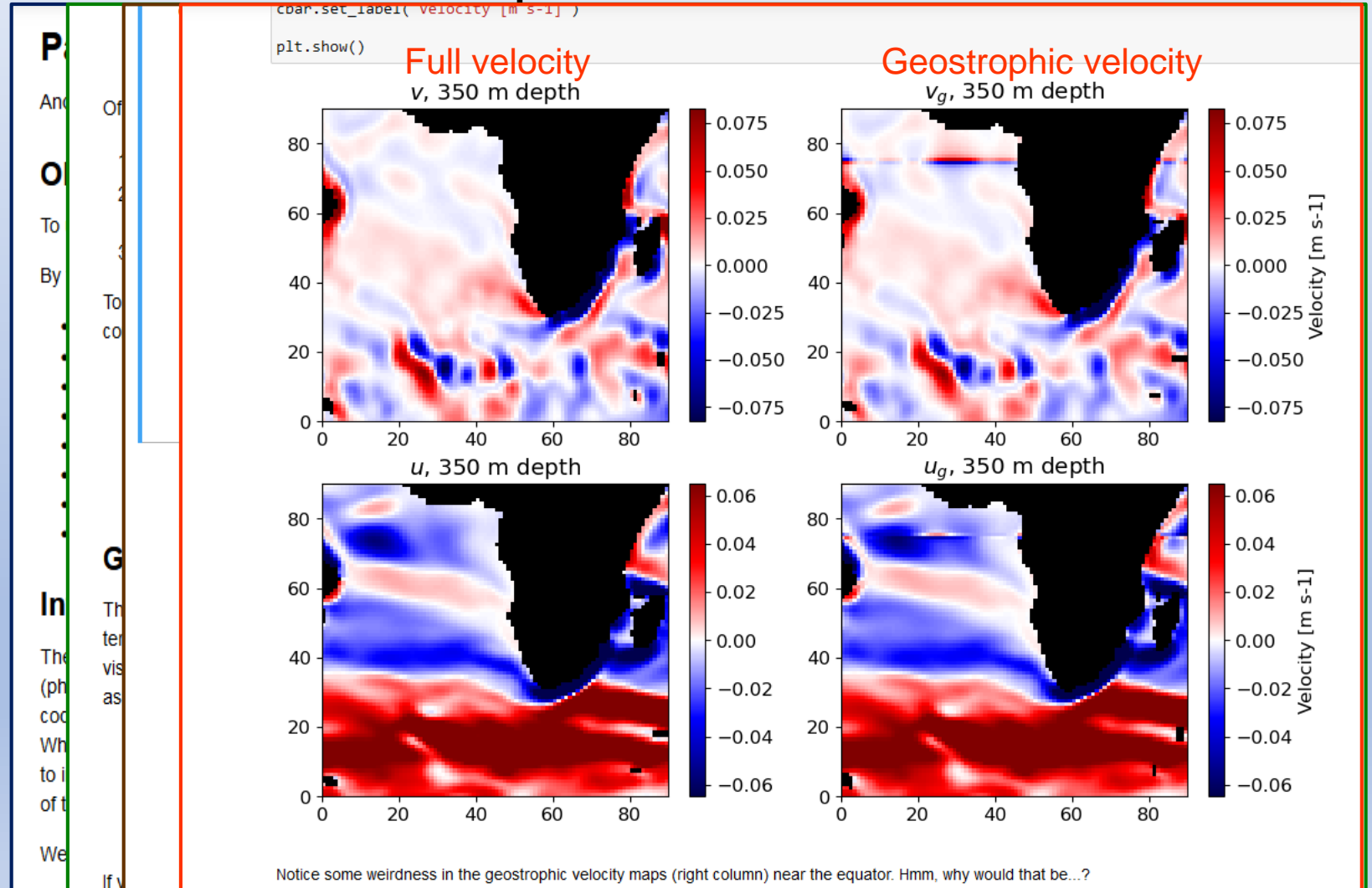
- Three tutorials have been completed...more on the way!
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Open and view contents of ECCO file(s) needed for the calculation

Compute the quantity or balance (in this case geostrophic balance)



Intro to PO Tutorials: An Example

- Three tutorials have been completed...more on the way!
- They have a common format...let's look at **Part 1: Geostrophic Balance**

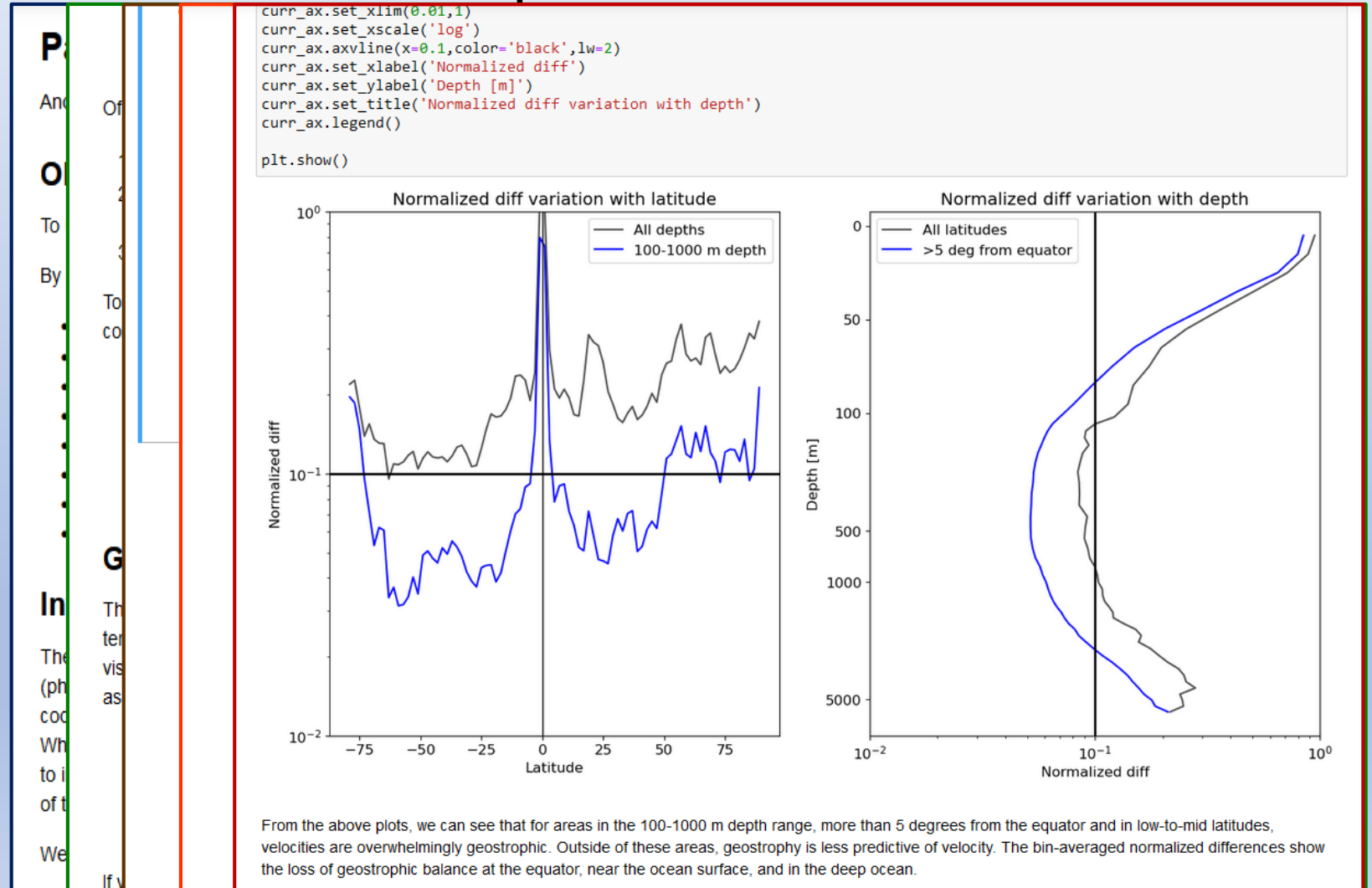
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Open and view contents of ECCO file(s) needed for the calculation

Compute the quantity or balance (in this case geostrophic balance)

Assess the concept's usefulness in application to the "real" ocean



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Assess the concept's usefulness in application to the "real" ocean

Exercises for students to do on their own

Part 1: Geostrophic Balance

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Objectives

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Exercises

Having made it to the end of the tutorial, you're now ready to try tweaking some of the code above to explore the ECCO data on your own. Here are a couple of suggested exercises, or you can develop your own ideas!

1. All of the mapping we just did was with monthly data for January 2000, but we also downloaded daily files for 1999-12-31 and 2000-01-01. Repeat the calculations and plots that we did, but this time with the daily files for one of those dates. How does geostrophic balance on daily timescales compare with monthly timescales? Why might they be different?
2. You probably noticed that geostrophic balance does not seem to be as good of an approximation for the flow in the Arctic as in other ocean basins. Focus on the monthly data in the Arctic tile (`tile=6`). Where is geostrophic balance the least effective, after masking out the smallest velocities? You'll probably need to change a few parameters to get informative plots in this region of lower velocities. Pick a grid cell (i,j) where there are high normalized differences (preferably one where the ocean is >500 m deep), and make a plot comparing the depth profiles of geostrophic and actual u and v. For extra credit, also plot the depth profile of the *angle* of difference between the geostrophic and actual velocity vectors.

Tip: make a copy of this notebook before you edit it, so that you can try your own innovations while being able to easily return to the original notebook for comparison.

For future use

ecco_po_tutorials module

There are some functions used in this tutorial that it will be helpful to have access to for future tutorials (or your own analysis with ECCOv4). Hence these functions have been put into a `ecco_po_tutorials` module (a Python file) that will be imported in future tutorials. This module also includes a function to compute geostrophic velocities quickly, given the file containing density and pressure anomalies.

[ecco_po_tutorials module](#)

I recommend downloading it to the same directory where your tutorials are located. Some functions from this module may also be incorporated into the `ecco_v4_py` package in the future.

References

Kundu, P.K. and Cohen, I.M. (2008). *Fluid Mechanics* (4th ed.). Elsevier.

Vallis, G.K. (2006). *Atmospheric and Oceanic Fluid Dynamics*. Cambridge University Press.

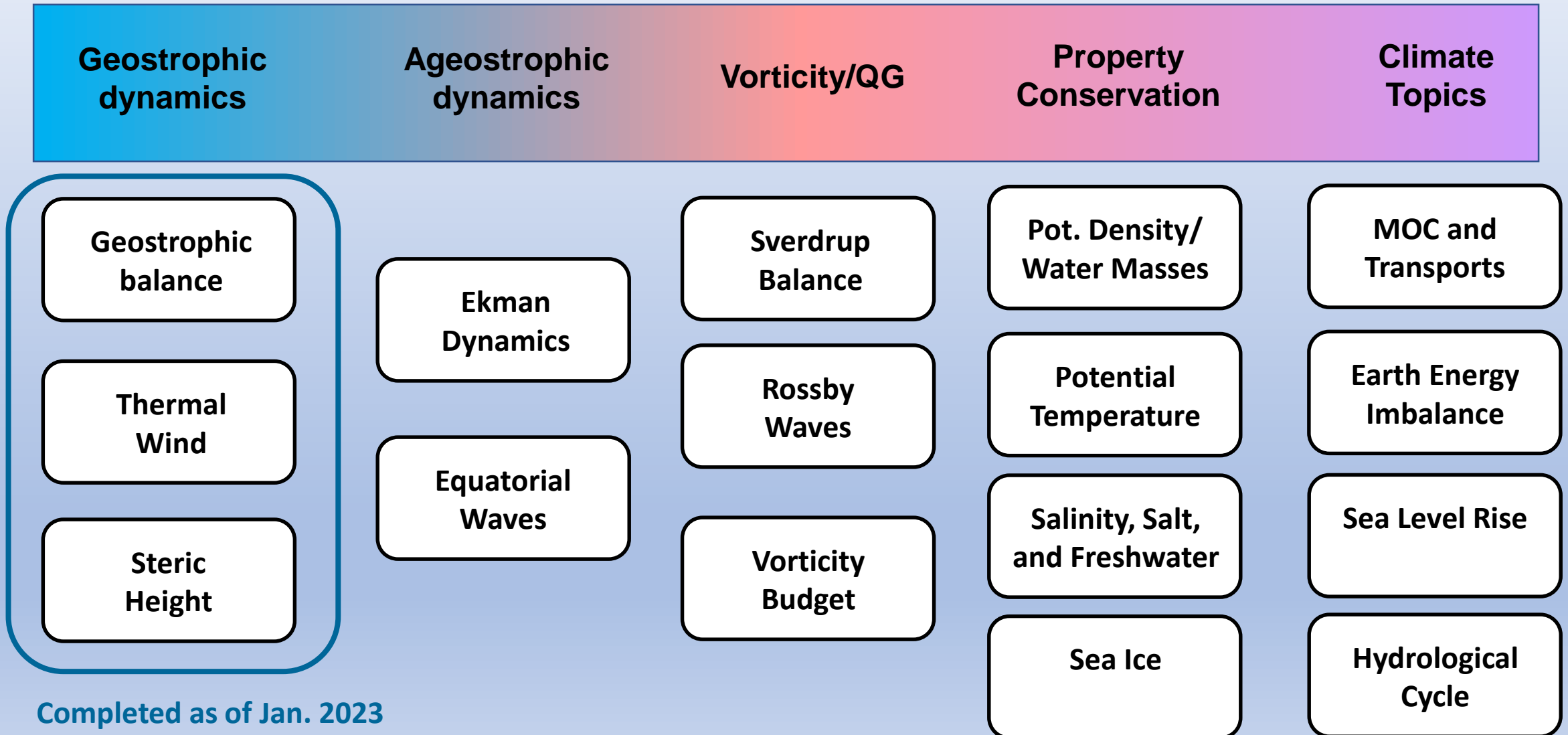
Normalized diff

From

vel

the

Intro to PO Tutorials: Planned



Completed as of Jan. 2023

In conclusion...

- The Intro to PO Tutorials are currently in development, and we are very open to ideas for concepts to cover, as well as suggestions for improvement!
 - Especially if you teach a class that could make use of them
- If you are new to Python...these tutorials will not teach you **everything** you need to know, but they are a great way to get more comfortable with computations and plotting
- Here's the URL again: <https://ecco-v4-python-tutorial.readthedocs.io>
 - Can also be accessed through the ECCO Group website under Products -> Analysis Tools