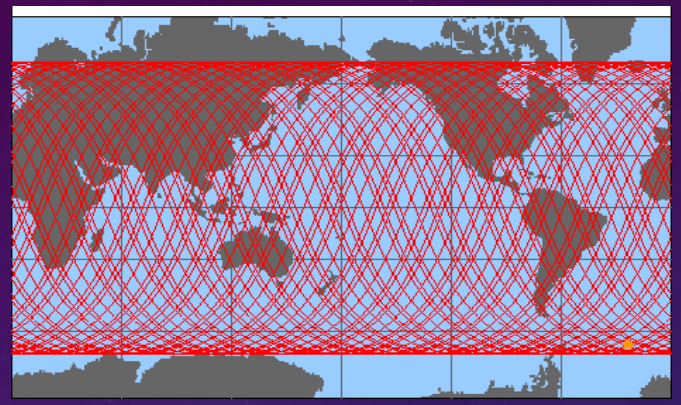

ECCO
SUMMER
SCHOOL

Estimating the Circulation and Climate of the Ocean (ECCO)

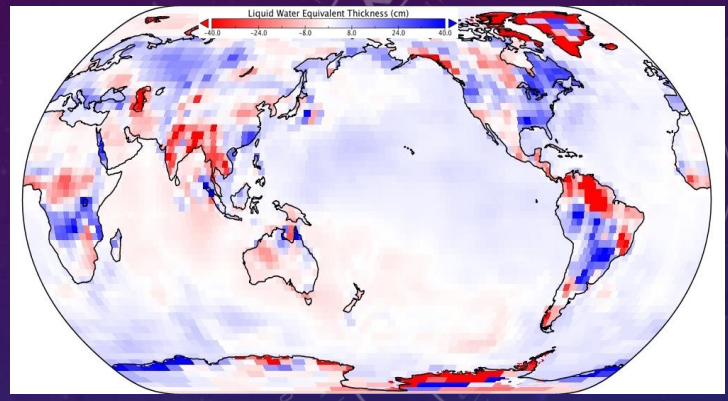
The scientific goal of the ECCO project is to understand, describe, and forecast the global general circulation of the oceans and its role in climate.

Despite global coverage, global ocean observations are **sparse in space and time relative to many dynamical scales of scientific interest**.

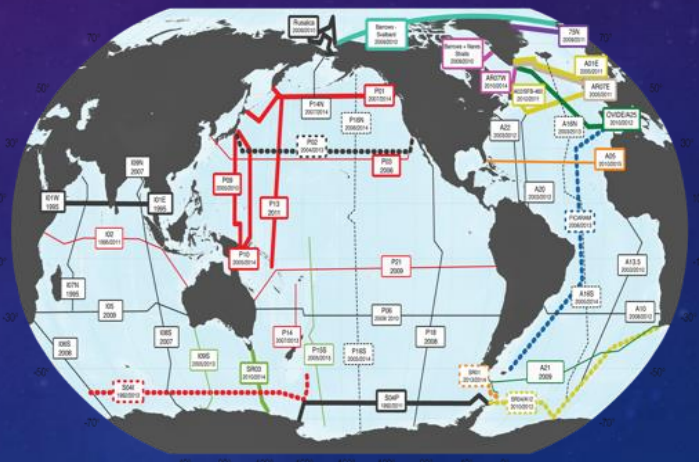
Combining ocean observations with physical models yields an estimate of the time-varying ocean that is consistent with observed ocean conditions and ocean physics, which is more complete and better than either alone.



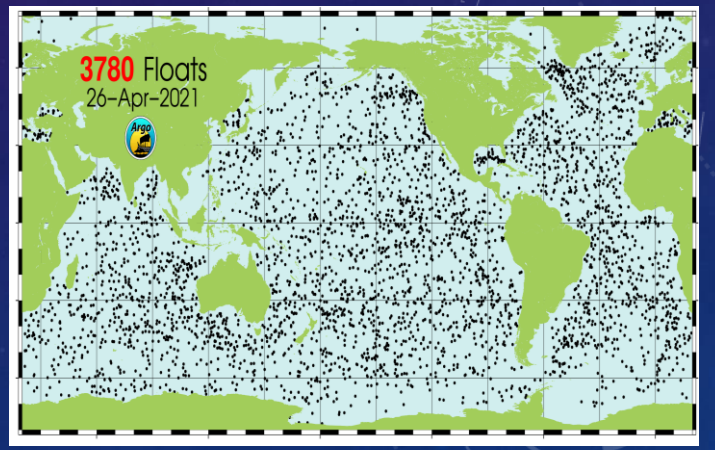
Satellite altimetry reference missions; 10d global coverage, orbital inclination: 66°



Satellite gravimetry GRACE/GRACE FO; 1m global coverage



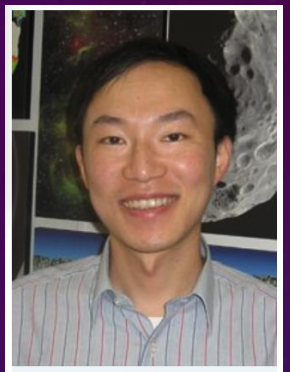
Global ocean ship surveys tracks (WOCE/GO-SHIP) annual-biennial campaigns



Argo autonomous profiling floats
10-day cycles, 2000 m depth


WELCOME

ESS25 Staff


Ou Wang


An Nguyen

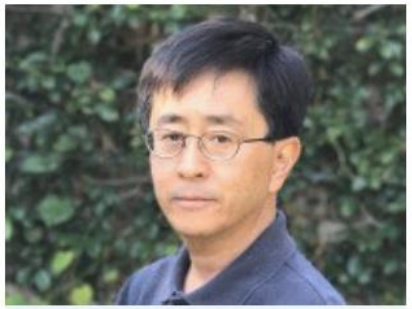

Sarah Purkey


Galen McKinley


Matthew Mazloff


Ian Fenty

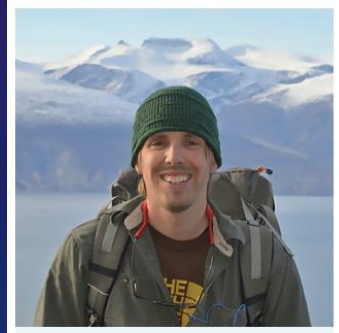

Gaël Forget


Ichiro Fukumori


Paola Cessi


Dimitris Menemenlis


Helen Pillar


Dustin Carroll

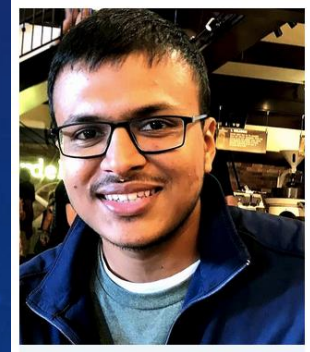

Severine Fournier


Chris Hill

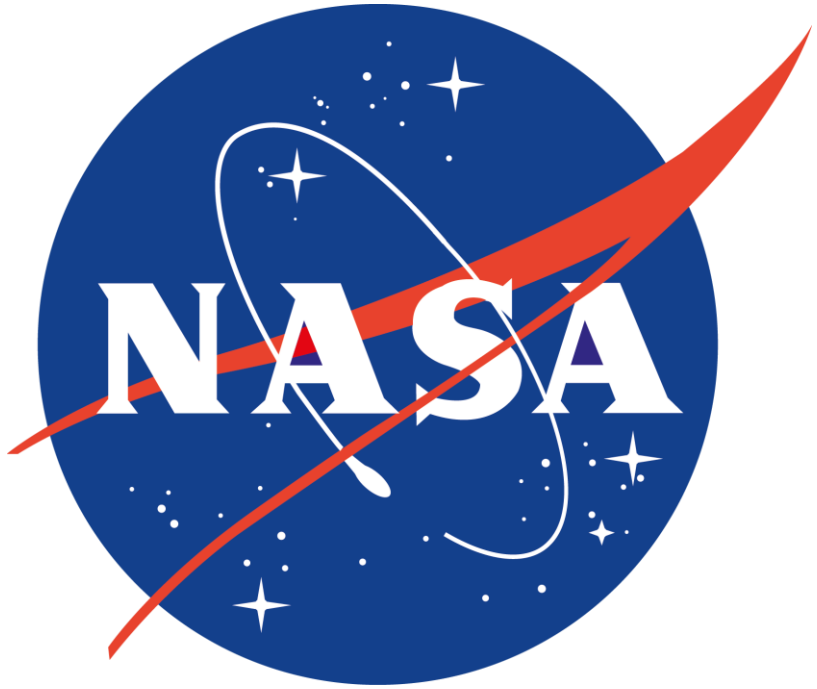

Chris Piecuch


Mike Wood


Jean-Michel Campin


Shreyas Gaikwad

Institutional Support



NASA Program Offices:
Physical Oceanography
Modelling Analysis and Prediction
Cryosphere

A NASA Research and Development center focusing on robotic space exploration, planetary exploration (especially Mars), Earth Science, and astronomy.

Corporate Sponsor

R&D company specialized in data assimilation, inverse modelling, parameter estimation, sensitivity analysis, and satellite data processing.

Provides “Transformation of Algorithms in Fortran” (TAF) commercial software, a source-to-source translator for Fortran code to evaluate derivatives in forward mode (tangent linear) or reverse mode (adjoint).

Purpose and Vision of the Summer School

WHY A SUMMER SCHOOL?

Over 20+ years, an active community has contributed to the ECCO Project in many ways:

- Developing the ocean model
- Advancing the state estimation techniques
- Producing the state estimates and high-resolution model simulations
- Developing tools and educational materials
- Using ECCO products and tools to advance our scientific understanding of the oceans' role in climate

Knowledge and expertise about ECCO is distributed across the community, which can make it challenging for new scientists to learn how ECCO products and tools can support their research.

Our goal for the summer school is to support you in learning about ECCO; no matter where you're starting from. We're here to make the process easier and more engaging, so you can build on your knowledge, both during these two weeks and beyond.

Meet the Participants

What's your name?

Where are you from?

How long have you worked with ECCO?

What do you want to learn this week?

What could you teach someone about ECCO?

Let's get to know each other

30 seconds each

Two-Week Program Flow and Learning Philosophy

	May Sun-18	Day 1 Mon-19	Day 2 Tue-20	Day 3 Wed-21	Day 4 Thu-22	Day 5 Fri-23	Day 6 Sat-24
7 AM							
:30		Breakfast: Seascape	Breakfast: Woodlands	Breakfast: Seascape	Breakfast: Woodlands	Breakfast: Woodlands	Breakfast: Woodlands
8 AM	**Breakfast served every day 7:30-9 am lunch/dinner room**						
:15		Registration @ Kiln	Office Hours	Office Hours	Office Hours	Office Hours	Open Project Time
:30							
:45			Daily Kick-Off & Recap	Daily Kick-Off & Recap	Daily Kick-Off & Recap	Daily Kick-Off & Recap	
9 AM		Summer School Kick-Off					
:15			**State Estimation**	**Adjoint Applications**	**Ocean Modelling**	**ECCO Budgets**	
:30			*Ichiro Fukumori*	*Ichiro Fukumori* *Ian Fenty*	*Jean-Michel Campin*	*Helen Pillar*	
:45							
10 AM							
:15							
:30		Coffee Break	Coffee Break	Coffee Break	Coffee Break	Coffee Break	
:45		**ECCO Overview**	**ECCO Analysis Hands-On**	**Algorithmic Differentiation**	**Running the ECCO model & adjoint**	**Closing ECCO Budgets**	
11 AM							
:15		*Ichiro Fukumori* *Ian Fenty*	*Ian Fenty* *Ou Wang*	*Shreyas Gaikwad* *Ian Fenty*	*Ian Fenty* *Ou Wang*	*Helen Pillar*	
:30							
:45							
12 PM							
:15							
:30	Lunch: Croker Dining Hall	Lunch: Seascape	Lunch: Seascape	Lunch: Seascape	Lunch: Woodlands	Lunch: Woodlands	Lunch: Woodlands
:45							
1 PM							
:15							
:30		**ECCO History & Science Applications**	**General Circulation**	**Climate Change and Ocean Warming**	**Ocean Observing Systems**	**Sea Level**	Open Project Time
:45							
2 PM		*Fukumori, Piecuch* *Fenty, Wunsch*	*Paola Cessi*	*Sarah Purkey*	*Severine Fournier*	*Chris Piecuch*	
:15							
:30							
:45		Coffee Break	Coffee Break	Coffee Break	Coffee Break	Coffee Break	
3 PM		**ECCO Analysis Tools**	Project Pitches	**ECCO Modeling Utilities (EMU)**	Open Project Time	**Sea Level Policy in Carmel-by-the Sea**	
:15		*Ian Fenty*		*Ichiro Fukumori*		*Chip Rerig*	
:30		*Ichiro Fukumori*	Project Team Organization	*Ou Wang*			
:45		*Gael Forget*				Open Project Time	
4 PM	Begin Hotel Check-In	**Cloud Compute & Data Access**	*Github*	Open Project Time			Whale Watch
:15		*Ian Fenty*					
:30		*Ou Wang*					
:45							
5 PM		Daily Wrap-Up	Daily Wrap-Up	Daily Wrap-Up	Daily Wrap-Up	Daily Wrap-Up	
:15							
:30							
:45							
6 PM	*Dinner: Seascape*	Dinner & Reception until 9 pm: Seascape	*Dinner: Woodlands*	*Dinner: Seascape*	*Dinner: Woodlands*	*Dinner: Woodlands*	
:30							
7 PM							
:30							

	May Sun-25	Day 8 Mon-26	Day 9 Tue-27	Day 10 Wed-28	Day 11 Thu-29	Day 12 Fri-30	Day 13 Sat-31
7 AM							
:30		*Breakfast: Seascape*	*Breakfast: Seascape*	*Breakfast: Seascape*	*Breakfast: Seascape*	*Breakfast: Seascape*	
8 AM	**Breakfast served every day 7:30-9 am lunch/dinner room**						*Breakfast: Woodlands*
:15		Office Hours	Office Hours	Office Hours	Office Hours	Office Hours	
:30							
:45	Open Project Time	Daily Kick-Off & Recap	Daily Kick-Off & Recap	Daily Kick-Off & Recap	Daily Kick-Off & Recap	Daily Kick-Off & Recap	
9 AM							
:15		**Advanced Topics in General Circulation**	**Ocean Biology and Biogeochemistry**	**Regional State Estimation at SIO**	**Regional State Estimation at UT Austin**	**Project Repositories & Project Posters**	
:30		*Paola Cessi*	*Galen McKinley*	*Matthew Mazloff*	*An Nguyen*	*Ian Fenty*	
:45							
10 AM							
:15							
:30		Coffee Break	Coffee Break	Coffee Break	Coffee Break	Coffee Break	
:45		**Ice Sheet & Ocean Interactions**	**ECCO Darwin and B-SOSE**	**Climate Data Assimilation and Earth System Reanalysis**	Open Project Time	Open Project Time	Hotel Check-Out
11 AM							
:15		*Mike Wood*	*Matt Mazloff* *Dustin Carroll*	*Detlef Stammer*			
:30							
:45							
12 PM							
:15							
:30	*Lunch: Woodlands*	*Lunch: Seascape*	*Lunch: Seascape*	*Lunch: Seascape*	*Lunch: Seascape*	*Lunch: Seascape*	
:45							
1 PM							
:15							
:30	Open Project Time	Open Project Time	**Oceanography and the U.S. Navy**	**High-Res Ocean Modelling & Coupling**	**Heat Pathways in a Warming Ocean**	Project Presentations 1	
:45							
2 PM			*Peter Chu*	*Chris Hill* *Dimitris Menemenlis*	*Gael Forget*		
:15							
:30							
:45		Coffee Break	Coffee Break	Coffee Break	Coffee Break	Coffee Break	
3 PM		Open Project Time	Open Project Time	**ECCO Story Map Making**	Open Project Time	Project Presentations 2	
:15				Annette deCharon			
:30				Open Project Time			
:45							
4 PM							
:15							
:30							
:45							
5 PM						Summer School Close	
:15		Daily Wrap-Up	Daily Wrap-Up	Daily Wrap-Up	Daily Wrap-Up		
:30							
:45							
6 PM	*Dinner: Woodlands*	*Dinner: Seascape*	*Dinner: Seascape*	*Dinner: Seascape*	*Dinner: Seascape*	*Dinner: Seascape*	
:30							
7 PM							
:30							

SPECIAL GUESTS

FRIDAY MAY 23

City of Carmel-by-the-Sea

- City Council Member Jeff Baron
- City Public Works Director Ken Wysocki
- City Environmental Programs Manager Mary Bilse
- City Environmental Analyst Valerie Gaino
- City Consultants:
    - Matt Jamieson, Senior Scientist
    - Davide Revell, Ph.D.

TUESDAY MAY 27

Dr. Peter C. Chu

Distinguished Professor and Chair
Department of Oceanography
Naval Postgraduate School
Monterey, California

Team Projects

TEAM PROJECTS

- Students will define their own project questions and form small teams
- Mentors will be available, but projects are student-led
- Final presentations at the end of the program: a chance to synthesize and share
- Projects may lead to collaborations or publications—take them seriously, but have fun

SOME ELEMENTS TO CONSIDER IN YOUR PROJECT

- **Data Exploration**
  - Gain familiarity with ECCO state estimates via exploratory analysis with visualization of key ocean parameters
- **Tool Use and Development**
  - Use and/or extend existing model or analysis codes; add new capabilities to the model or analysis libraries
- **Case Study**
  - Investigate the drivers of a specific event or type of interannual ocean variability
  - Consider replicating or revisiting a published study using ECCO & ECCO tools
- **Comparison with Observations**
  - How well does ECCO compare with the available observations? At what temporal and spatial scales?
- **Collaborative Documentation**
  - Work together to document your project and share your materials for the community, putting ”open science” ideas to practice
- **Step out of your comfort zone**
  - Take this opportunity try something different. Did you learn something that you can use later? Do you have a better sense of how ECCO can help your future research?

2024 HACKWEEK

https://ecco-group.org/hackweek2024.htm

Team Projects

Exploring Sensitivity Patterns and RESponses in the Southern Ocean (ESPRESSO)

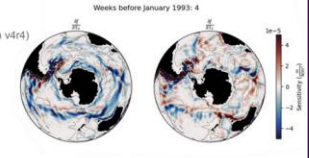
ECCO HACK WEEK

Marie Zahn @mjzahn | Noah Rosenberg @noahrosen | Odilon Houndegnonto @ojhoundegnonto

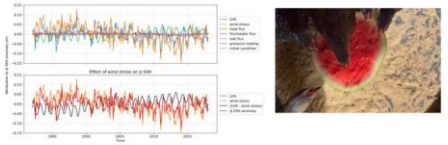
APPROACH

- Define *QoI J = (SSH @ Southern tip of Chile) - (SSH @ West Antarctic Peninsula)*: Represents geostrophic transport through Drake Passage (r = 0.78 wrt total transport in v4r4)
- Run adjoint targeting J(January 1993) with weekly lags back to January 1992

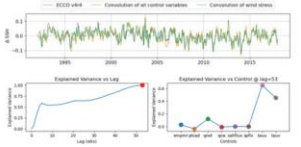
Adjoint



Attribution



Convolution



CONCLUSIONS

- EMU tools recover similar large scale features of sensitivity to wind stress forcing compared to those from a high resolution adjoint (Mazloff 2012)
- Identified bugs in EMU (running transport masks)
- Open questions: Why does EV increase at lags up to 52 weeks? Why is sensitivity to zonal wind negative?

Vorticity Budget Closure of ECCO

Team (Spinners): Basil Darby[1], Fernando Eder Campos Gonzales[2], Jonathan Aparco Lara[2]

[1]San Jose State University | SJSU · Moss Landing Marine Laboratories

[2]Ensenada Center for Scientific Research and Higher Education | CICESE · Department of Physical Oceanography

"Vorticity In = Vorticity Out"

Vorticity budget equations (depth-integrated momentum equations)

Tools used:
-ECCO V4r5
-OSS
-xmitgcm
-xgcm
-Ecco_v4_py
-PCluster
-Mitgcm

Bottom pressure torques — In Progress

Nonlinear torques — In Progress

Challenges:
-Access to correct data
-Grid face connections

Planetary vorticity flux

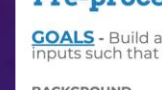
$$0 = \nabla \cdot (f\mathbf{U}) + \frac{1}{\rho_0}\nabla p_b \times \nabla H + \frac{1}{\rho_0}\nabla \times \tau + \nabla \times \mathbf{A} + \nabla \times \mathbf{B}$$

Viscous stress torques

Each should cancel to give us small residuals

Wind stress forcing

Knowledge and skills:
-Basil learned spanglish*
-Calculating gradients between grid faces using xgcm



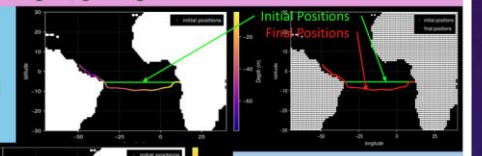
Drifters

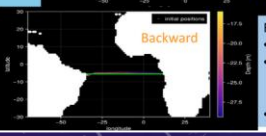
ECCO HACK WEEK

Lagrangian particle tracking starting from 6° S across the Atlantic for 250 days.

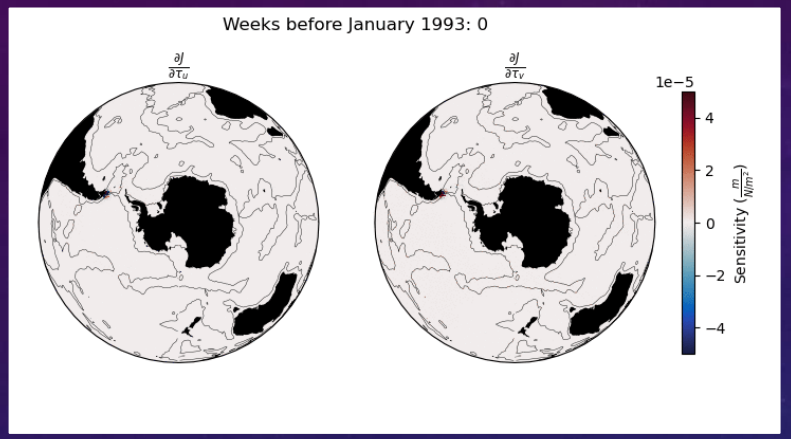
Ciara Pimm @ciarapimm, Kylie Kinne @kykinne, Yuanyuan Song @YuanyuanSong99, Gael Forget @gaelforget

Goals:
- Learn basics of Julia ✅
- Learn basics of git ✅
- Run short particle tracking experiments ✅
- Plot particle tracking experiments on map ✅
- Create movie showing how particles move horizontally and with depth ✅





Future Plans:
- Do the same on the ECCO grid
- Be able to track more particles properties e.g. temperature, salinity, velocity
- Heat budget!



Pre-processing for pkg/profiles and pkg/obsfit

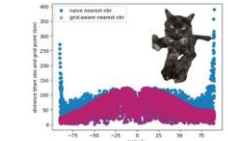
ECCO HACK WEEK

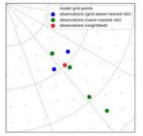
GOALS - Build a publicly available Python package which pre-processes observational inputs such that that are compatible with pkg/profiles & pkg/obsfit

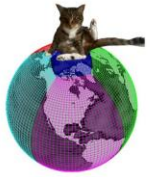
BACKGROUND

Need to perform nearest neighbor on a sphere and calculate bi/trilinear interpolation weights for observations

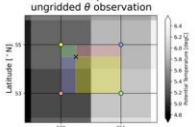
Options are:
- MeshArrays.jl
- MITprof
- ECCO-obs-pipeline
- **Pudding.py**







Bilinear interpolation of ungridded θ observation



RESULTS

Input: ungridded observation coordinates
Output: grid interpolation fields and interpolation weights in xarray/netCDF

NEXT STEPS

- Add documentation to MITgcm readthedocs and ECCO-Group github repo
- Improve weight calculation in python
- Enhance file pipeline

AUTHORS Goldberg, M., Griffin, C, & Reich, S.

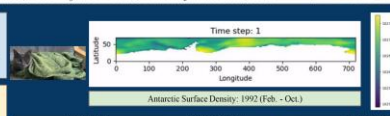
ECCO Representation of Water Masses

Isba Keshwani, Sarah Zhang

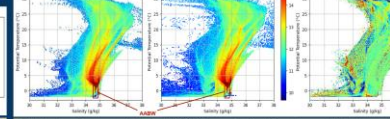
WMW: water-mass women, women of mode waters, women of water mass, etc…

ECCO HACK WEEK

Overview
Understanding how ECCO represents water masses, specifically Antarctic Bottom Water (AABW), and whether recent Antarctic extremes are captured in ECCO.



Products, Resources Used
- ECCO V4r4: density, temperature, salinity, grid products
- ecco_v4_py (and Ian), ecco_access
- ECCO hack week tutorials, OSS

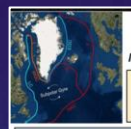


AABW ranges from θ = -0.8 °C to 2 °C and salinity of 34.6 to 34.7 g/kg. We calculated the volume of ocean water within this range from our volumetric TS plot. Then, repeated the calculation from 1992 to 2017.

Global volumetric temperature & salinity: 1992-2017 averages in March, September, and March subtracted from September, respectively. Volumes (m^3) are represented in log scale.

Challenges Faced
- Calculating/understanding volume of ocean using MITgcm grid
- Identifying where AABW waters were
- Calculating AABW volume by constraining temp and salinity

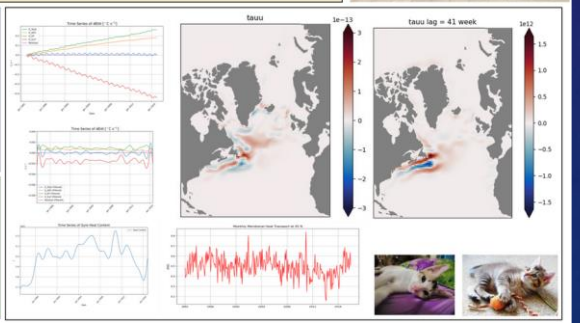
Future Work
- Plot the ECCO temperature, salinity along an ocean transect (ex. recreate WOCE A16)
- Validate AABW volume derivations with observations/other model outputs
- Explore High Salinity Shelf Water production using ECCO



Team: SPGECCO

Members: margaretmurakami, MaceKuailv, AshfaqAhmed40, prajvala-ocean

We investigated the heat content in the subpolar gyre and its influences



Accomplishments:
1. ID'd subpolar gyre.
2. Surface forcing is the largest contribution to heat budget
3. Heat content increased during 1993-2011 and decreased during 2011-16
4. Attribution to zonal wind stress **may* cause expansion of subtropical gyre.

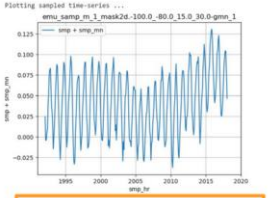
Future Outlook:
1. More work is needed on long-term implications of anomalous events.
2. Correlation between the SPG and the poleward Ocean Heat Transport requires further investigations.

ECCO HACK WEEK

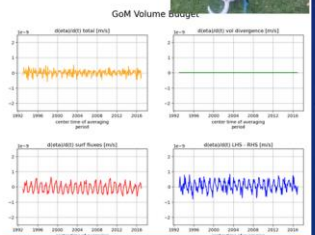
Closing the volume budget of the Gulf of Mexico

J. Zaiss - JPL | git: @jzaiss

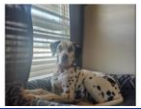
What drives interannual dead zone variability?



ECCO provides an excellent opportunity to explore dead zone dynamics



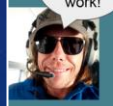
How well does ECCO capture GoM fluxes → are they balanced?



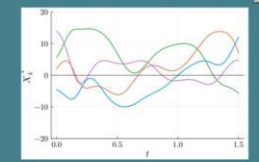
Toy ECCO: AD Tool Intercomparisons

Shreyas Gaikwad, Max Trostel, Ellen Davenport, Gaël Forget

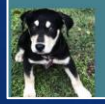
Get back to work!



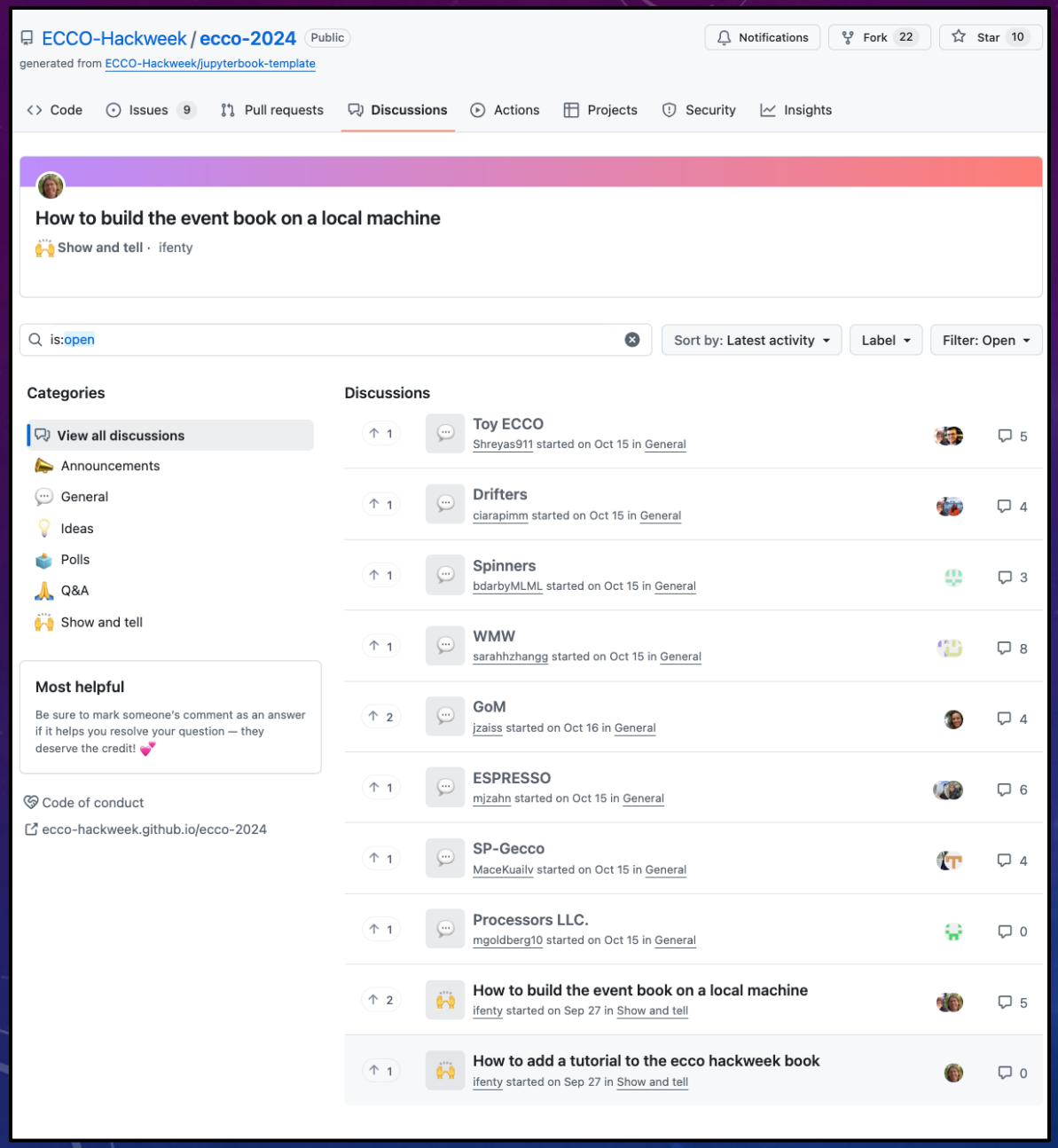
	EXF bulk formulae	Mountain Glacier	L96
JAX		X	X
PyTorch		X	X
Enzyme	X		X
Tapenade		X	
Julia	X	X	X
Python		X	X
Fortran	X	X	
Optimization	X		X

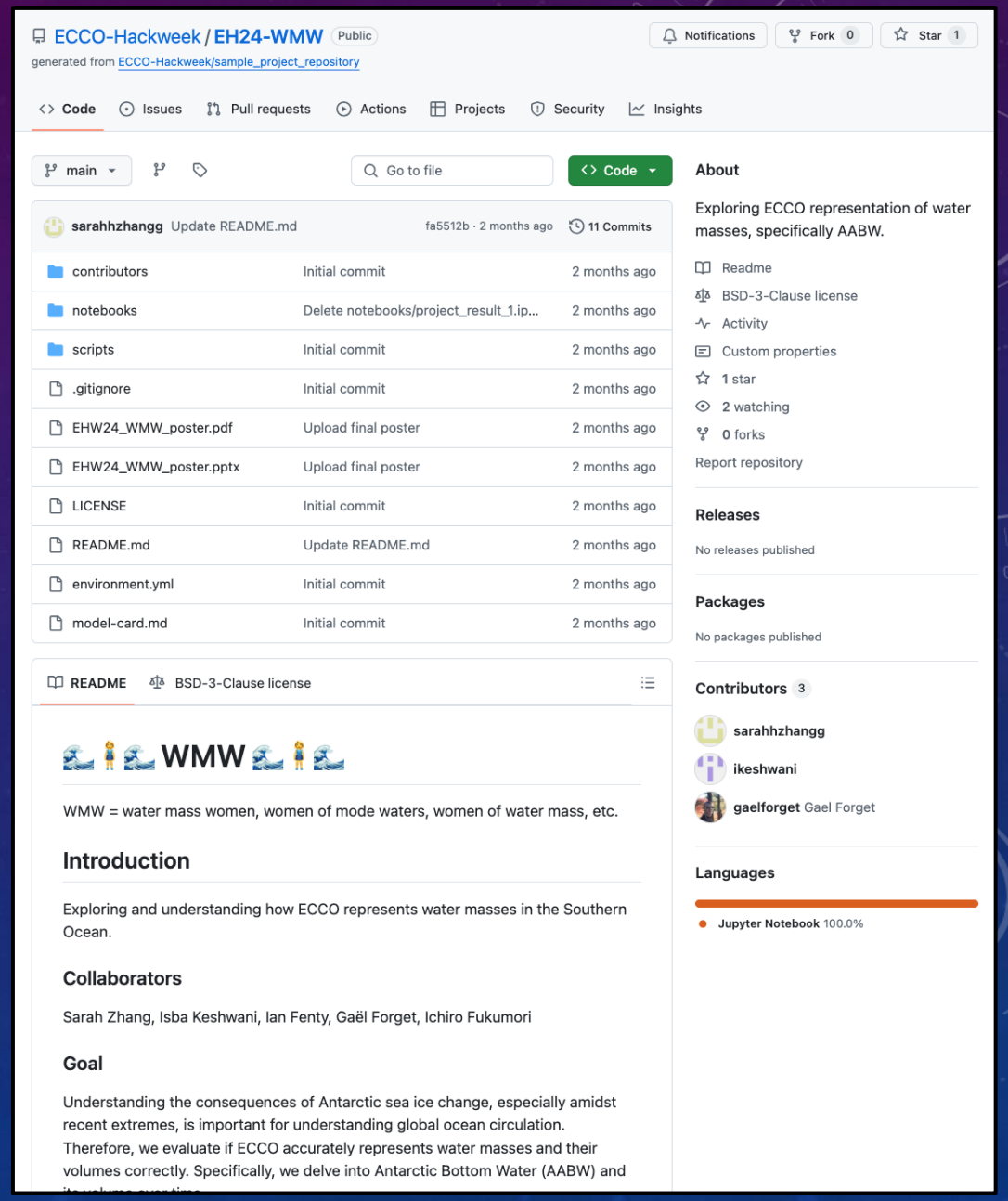


- 3 languages (Python, Julia, Fortran)
- 4 AD tools (Enzyme, PyTorch, JAX, Tapenade)
- 3 Algorithms (bulk formulae, L96, mountain glacier)
- 16 toy problem experiments!!!!!



	EXF bulk formulae	Mountain Glacier	L96	With compile -> pre-compiled
JAX		400s	17s	Time to run forward + adjoint
PyTorch		790s	0.60s	
Enzyme	x		27s -> 0.0025s	
Tapenade		0.52s		
Julia	x	7.7s	0.15s -> 0.000056s	Time to run foward
Python		1.5s	0.22s	
Fortran	x	0.14s		
Optimization	x		x	





Team Projects

PROJECT PITCHES & TEAM FORMATION

- Tomorrow 3:00-3:45 pm (or longer if there are a lot of ideas)
  - Up to 5-minutes per pitch
- Anyone can pitch an idea (staff + students)
- What to include:
  - High-level overview
  - Why you think it's cool
  - What tools/resources would be used?
  - What knowledge or skills would be gained at the end?
  - How would the community benefit from your project?
- Brainstorm your ideas with other students and staff between now and tomorrow
- Following pitch, team formation

5 REASONS TO COLLABORATE WITH OTHERS DURING THE EHW

- Access to Diverse Expertise
- Focused problem-based learning
- Co-Learning & Teaching
- Professional Networking and Collaboration Opportunities
- Accelerated Project Development

FINAL PRESENTATIONS

- 10-minutes + 5 minute questions
- High level summary
- What product/tools/resources did you use?
- What new knowledge did you learn?
- What new skills did you acquire?
- What were some challenges?
- If you had another week, how would you continue your project?