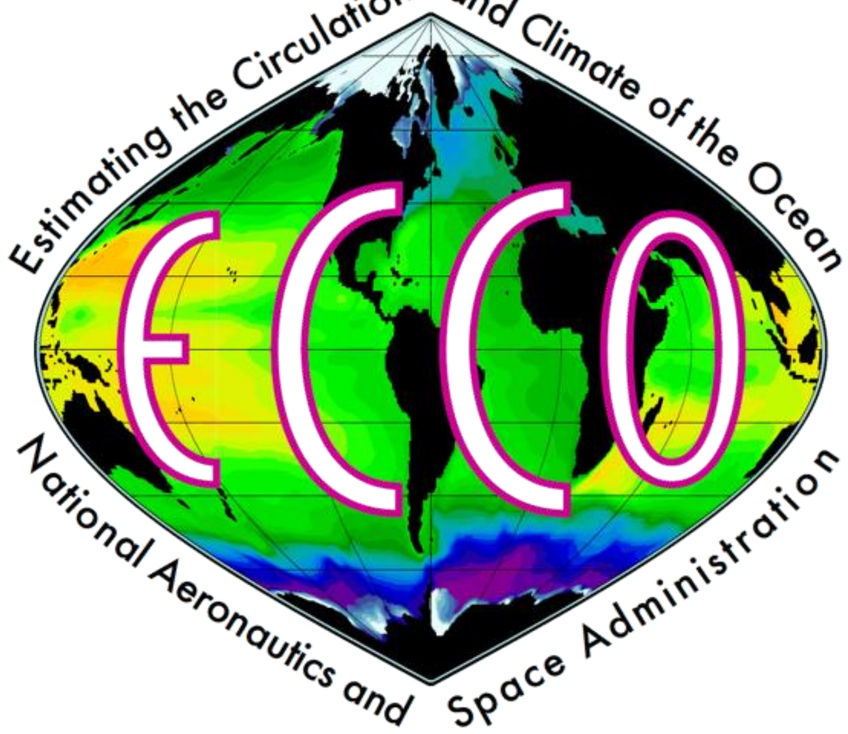


Ian Fenty, Ichiro Fukumori, Eric Larour, Dimitris Menemenlis:
Jet Propulsion Laboratory, California Institute of Technology
Patrick Heimbach, An Nguyen, Helen Pillar: *UT Austin*
Gael Forget, Christopher Hill: *MIT*
Rui Ponte: *Atmospheric and Environmental Research, Inc.*
Dustin Carroll: *MLML, San Jose State University*

Physical Oceanography
Cryosphere
Modelling, Analysis, and Prediction
High-End Computing

Jet Propulsion Laboratory
California Institute of Technology

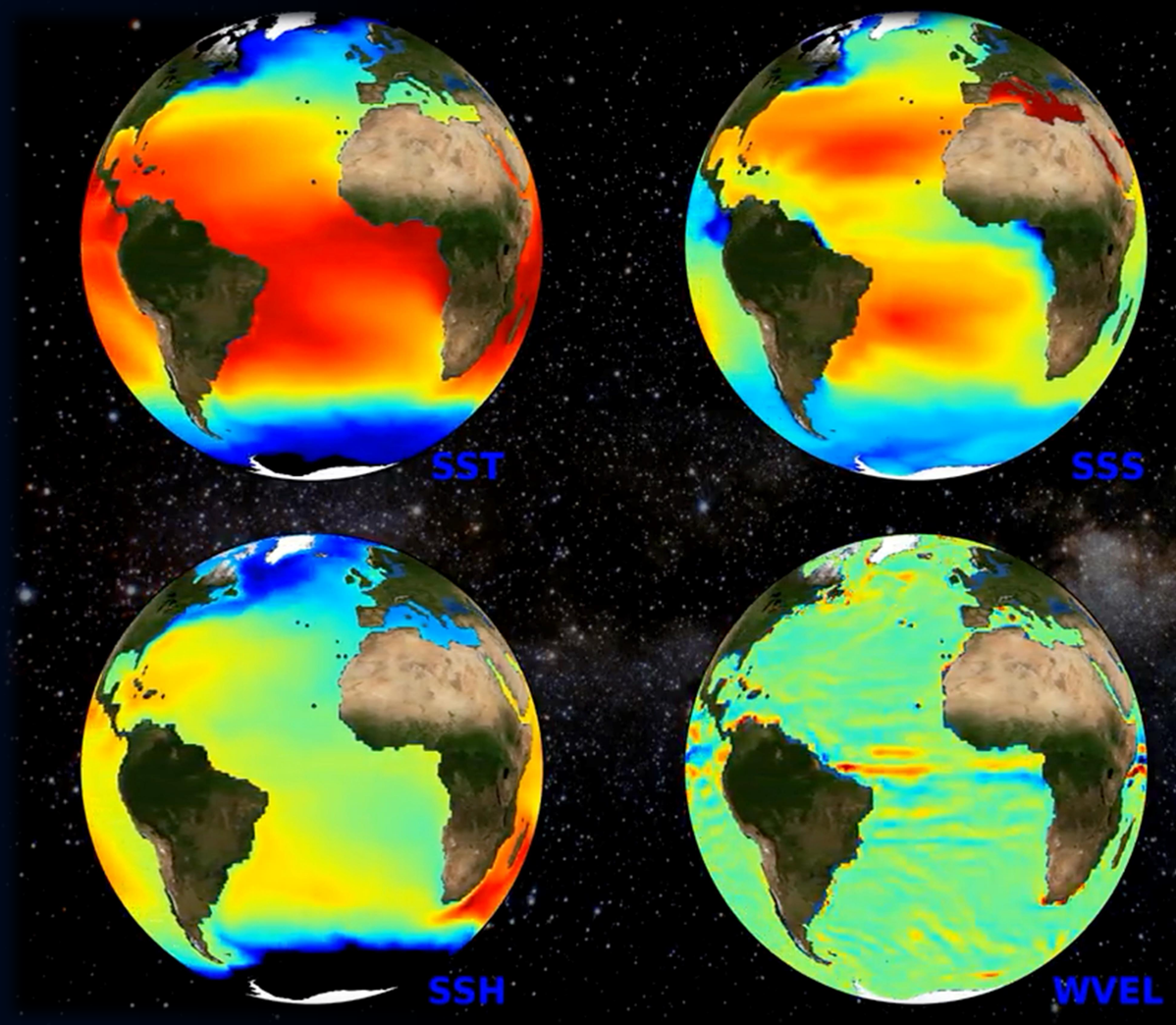
The scientific goal of ECCO is to understand and describe the general circulation of the ocean and its role in climate.

Support and Partners

- Supported by **Physical Oceanography**, **Modeling Analysis and Prediction** (MAP), and **Cryosphere** programs
- Add'l NASA support: **OBB, CMS**
- Key U.S. partnerships: MIT, UT Austin, Atmospheric and Environmental Research (AER), SJSU/Moss Landing Marine Laboratory, UCSD/Scripps Institute of Oceanography

Two Cornerstone Applications

- *State Estimates:* complete, physically-consistent, multi-decadal reconstructions of the full-depth, time-evolving global ocean, understanding ocean climate change:
- *High-Resolution Simulations*: cutting-edge ocean and coupled atm/ocean simulations that push technological and computational limits, process studies, S2S forecasting, mission formulation



Select fields from the 1-degree ECCO Central Estimate
http://www-ecco-group.org

ECCO: Connections

Connecting NASA Ocean, Cryosphere, and Biogeochemistry Data to Support National Climate Policy

Project Objectives

- Over the next five years, **we will extend the ECCO project to maximize the relevance, utility, and accessibility of ECCO products and tools to the scientific research community and policymakers on the national level.**
- To achieve these goals, we will engage in **research and technology development** to advance our adjoint ocean optimization machinery and **expand the scope of our state estimation** work to incorporate novel ocean, **cryosphere**, and **biogeochemical datasets** in partnership with domain experts in those communities.
- We will also make critical investments to expand and facilitate **discoverability**, **access**, **analysis**, and **reproducibility** of ECCO products in support of NASA Open Science Priorities.

ECCO: Connections High-level Goals

Connecting NASA Ocean, Cryosphere, and Biogeochemistry Data to Support National Climate Policy

Central State Estimates

- extend the start time back from 1992 (present) to 1980
- increase horizontal spatial resolution 1° (present) to 1/6°.
- include biogeochemical tracers and fluxes, including CO2 fluxes
- provide uncertainty estimates for our solutions.
- increase the cadence and reduce the latency of new solutions
- add astronomical tidal forcing and gravitational attraction and loading

Ocean/Cryosphere Coupling

- parameterize ocean melt of Greenland marine-terminating glaciers
- add time-varying freshwater fluxes from Greenland ice melt
- parameterize accumulation of “marine ice” within ice-shelf cavities
- create novel state estimates of time-evolving polar ice-sheets and ocean coupling

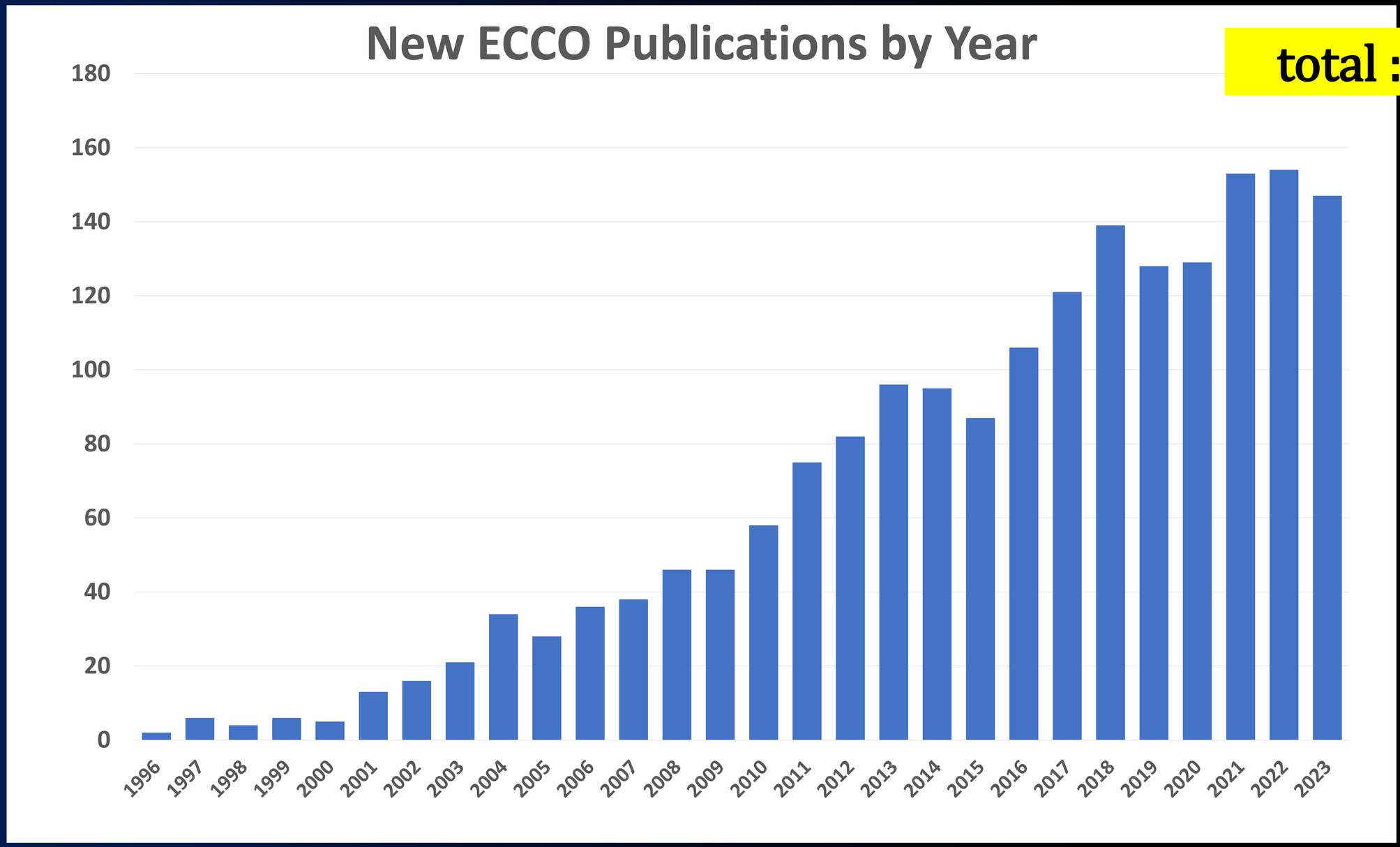
Climate Prediction

- investigate how ECCO can contribute to S2S2D prediction using MITgcm/GEOS

NASA Open Science: Transparent + Accessible + Inclusive + Repoducible

- continue development of online tutorials and code libraries
- add new high-level climate datasets for NASA public-facing websites
- develop new tools for analyzing the ECCO model and its adjoint
- host educational events to engage students, early-career scientists, and others.

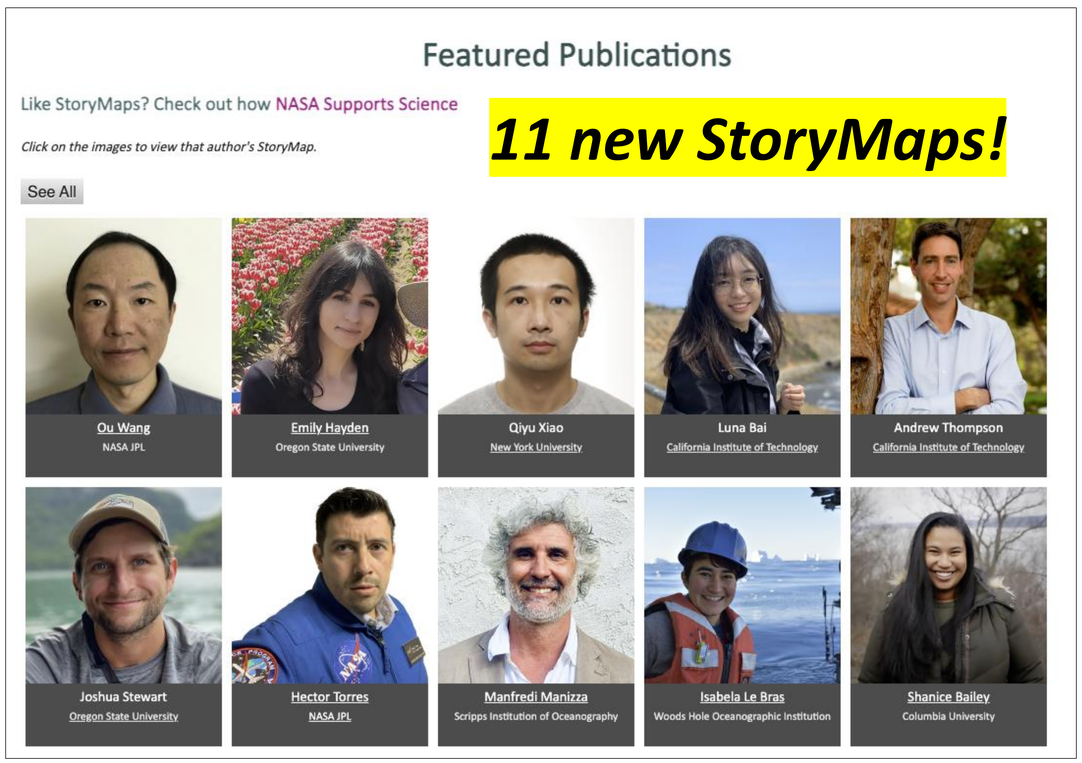
Rate of new ECCO publications continues to increase



ECCO is being used across an increasingly diverse range of research topics including ocean physics, geodesy, sea level and ocean mass variability, ocean temperature variability, meridional overturning, paleoclimate, coupled ocean/sea-ice; ocean/ice-sheet; and ocean/atmosphere interaction, and ocean biogeochemistry

Community Outreach and Engagement

ecco-group.org

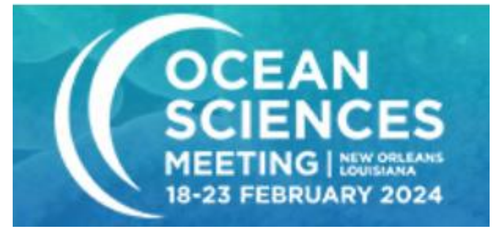


https://ecco-group.org/publications-featured.htm

https://ecco-group.org/storymaps.htm?id=95

Community Outreach and Engagement

30+ ECCO Talks at 2024 AGU Ocean Sciences



- AI31A-02 Determining dominant atmospheric drivers of ocean variability using ocean model adjoints with an application to the North Atlantic
- CC14D-1229 A New Observation-Based Water Mass Transformation Benchmark for the North Atlantic and its Application to Model-Observation Comparison
- CC14D-1233 Temperature and salinity stratification and the subpolar North Atlantic overturning
- CC14D-1229 A New Observation-Based Water Mass Transformation Benchmark for the North Atlantic and its Application to Model-Observation Comparison
- CC44F-1410 Examining the Temporal Sensitivity of Mixed Layer Salinity Budget Around the Global Ocean With Unsupervised Machine Learning
- CC53A-07 Regional Earth Energy Imbalance and Marine Heat Waves in the Sunlit Ocean Layer
- DS21A-02 Assessing the Potential of SMART Subsea Cables for Monitoring Essential Ocean Variables
- RH24A-0288 Sea Level Variability Prediction and Attribution Using the ECCO Ocean State Estimation Framework
- HE11A-08 Modelling the carbon cycle across the Arctic land-ocean continuum: a case study of the Southeastern Beaufort Sea
- HE13A-04 Seasonal Hydrography and Unique Plume Signatures from Moorings at Northwest Greenland Glacier Fronts
- HE13A-08 Decadal-scale evolution of upwelling plumes and productivity from Greenland's largest glacier using downscaled ocean models and observations
- HE31A-01 Icebergs, Right Ahead?: Implications for Future Ice Shelf-Ocean Interactions in the Changing Icescape Environment at West Ice Shelf, East Antarctica
- HE31B-06 The variability of Atlantic-origin water and impacts on Western Greenland
- HE44E-2744 Variability and Pathways of Subantarctic Mode Water Property Anomalies in the South Pacific
- OB11B-05 Multidecadal variations of the Arctic Ocean CO2 uptake inferred from models and data products
- OB23B-02 Reconstructing the spatiotemporal evolution of the global interior ocean's anthropogenic carbon sink using deep learning
- OP31F-03 Passive Ocean Color Retrievals of Zooplankton Biomass and Diel Vertical Migration via Extrapolation of the Particle Size Distribution
- OT14A-1442 Group for High Resolution Sea Surface Temperature's 0.09 degree, level 4, globally gridded dataset (GHRSST-MWIR) comparison to the Arctic Great Rivers Observatory (Ar-GRO) Yukon River volumetric discharge dataset in the Gulf of Alaska from 2003–2020, and modelling outputs from the 'Estimating the State and Climate of the Ocean (ECCO)' model.
- OT14B-1471 Extraction of the Ocean Circulation's Contribution to the Magnetic Field and Its Physical Oceanographic Applications
- PL13A-06 Using Data-Constrained Modeling to Examine the Drivers of Central Labrador Sea Oxygen Variability
- PL24A-2259 Deep Ocean Variability Forced by ENSO Cycles in the Eastern South Pacific
- PL24A-2268 Topography Effects on the Seasonal Variability of Ocean Bottom Pressure in the North Pacific Ocean and North Atlantic Ocean
- PL44A-2284 The origin and fate of Bering Strait throughflow
- PS11A-06 Ocean Eddy Splitting and the Associated Vertical Transport: Insights from Numerical Modeling
- PS23A-02 Understanding the Generation and Dynamics of Internal Tides in the Bay of Bengal using ECCO salinity and observations
- RH52A-06 What Forcing Mechanisms Affect the Co-variability of Interannual Sea Level Variations Between the Northeast and Southeast Coasts of the United States?
- RH53A-05 Identification of Forcing Mechanisms Driving Interannual Sea Level Variations along the US West Coast
- RH53A-06 Seasonal Forecasting of U.S. East Coast Sea Level Anomalies: Advantages Using a Global Simulation of Ocean-Dynamic Persistence

ECCO Central Production Status

ECCO Version 5

- **Resolution**: ~1/3 degree, llc270 grid.
- **Time period**: 1992-2023 (for now)
- **Method**: multi-grid adjoint

Goal

- Produce state estimates with higher resolution ocean models that are capable of explicitly resolving eddy mixing and other mesoscale processes

Challenge

- Our conventional adjoint method is not computationally feasible for multi-decadal simulations with high resolution models that require small time steps.

Solution

- Hybrid “multi-grid adjoint” approach: misfits are calculated on high-resolution forward simulation and adjoint gradients are calculated using an optimized “ECCO V4” model trajectory (e.g., V4r5).

Current Status

- R&D in 2023 resulted in successful demonstration of the multi-grid adjoint approach for llc270:llc90.
- We achieved model-data misfits that were **comparable** with our best llc90 V4 solutions after < 10 iterations and **significantly improved** the existing “V5 alpha” solution
- Numerous technical challenges were identified and solved.
- Satellite and in-situ observations have all been updated through the end of 2023
- Atmosphere forcing (MERRA-2) has been downloaded and prepared for use in the llc270 model (OI mapping)
- Ready to restart MG optimization
  - 1992-2023
  - V4r5 atmosphere adjustments + MERRA-2
  - V5 alpha optimized initial conditions and mixing parameters
  - All new observations

ECCO “Quick-look” Extensions Status

ECCO Version 4-EXT

- **Resolution**: ~1 degree, llc90 grid.
- **Time period**: 2020-2024 (for now)
- **Method:** apply climatology atmosphsere adjustments

Goal

- Regularly extend our state estimates to the present day with no more than 2 month lag for “quick-look” applications that require low-latency and can afford larger model-data misfits. Deliver high-level metrics to a special page on the ECCO website

Challenge

- We have not traditionally worked in an operational mode so workflows need to be adjusted and automated to the extent possible.

Solution

- Adjust workflow so that every month we now advance solutions forward in time and identify opportunities for automation

Current Status

- New atmosphere forcing is now automatically downloaded every month
- Solution extended through the end of January 2024.
- Ocean biogeochemical tracers included in the solution (thanks to Hong and Dustin)
- Codes to calculate high-level metrics from the quick-look extension are in development
- Annette has prototyped a special section for the ECCO website to host high-level metrics
- Expect a first version will come online by mid-April
- Feedback welcome

Questions?