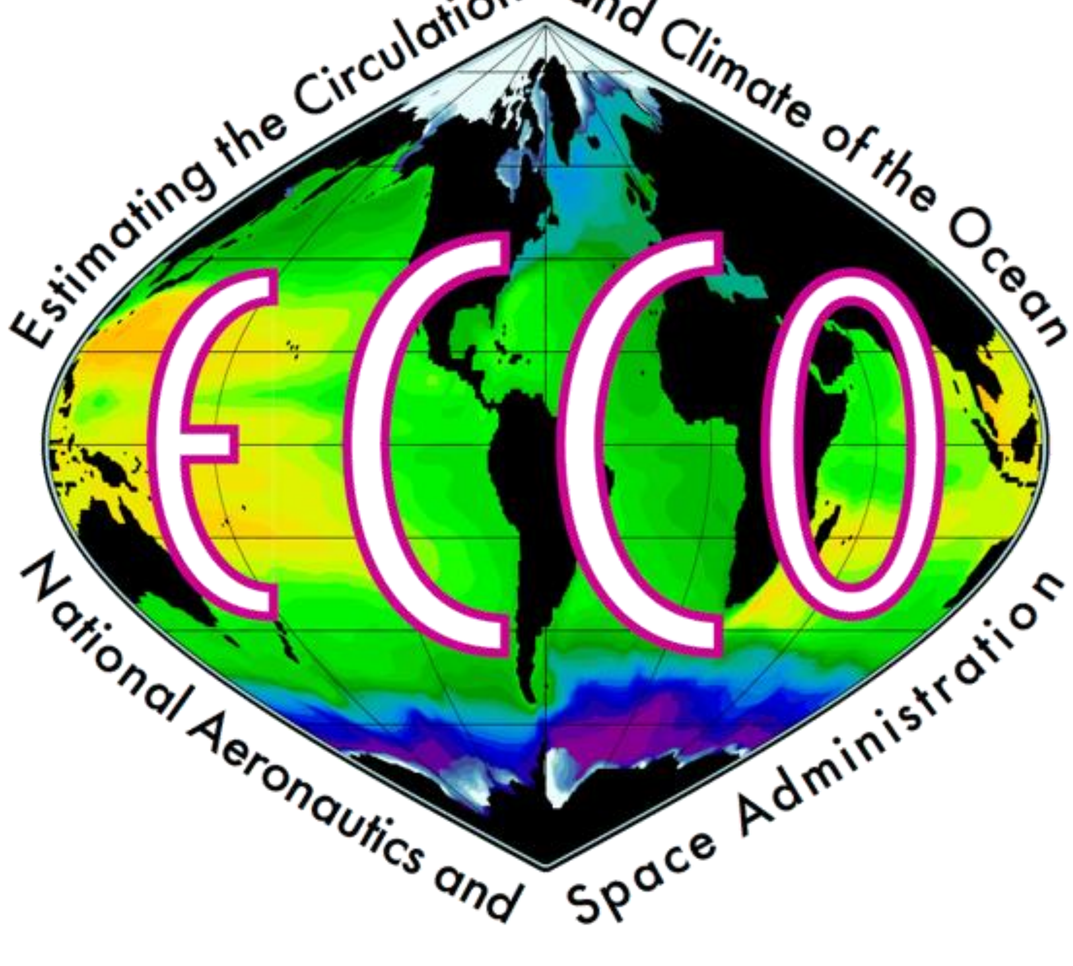


Ian Fenty, Ichiro Fukumori, Eric Larour, Dimitris Menemenlis: *NASA Jet Propulsion Laboratory*

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

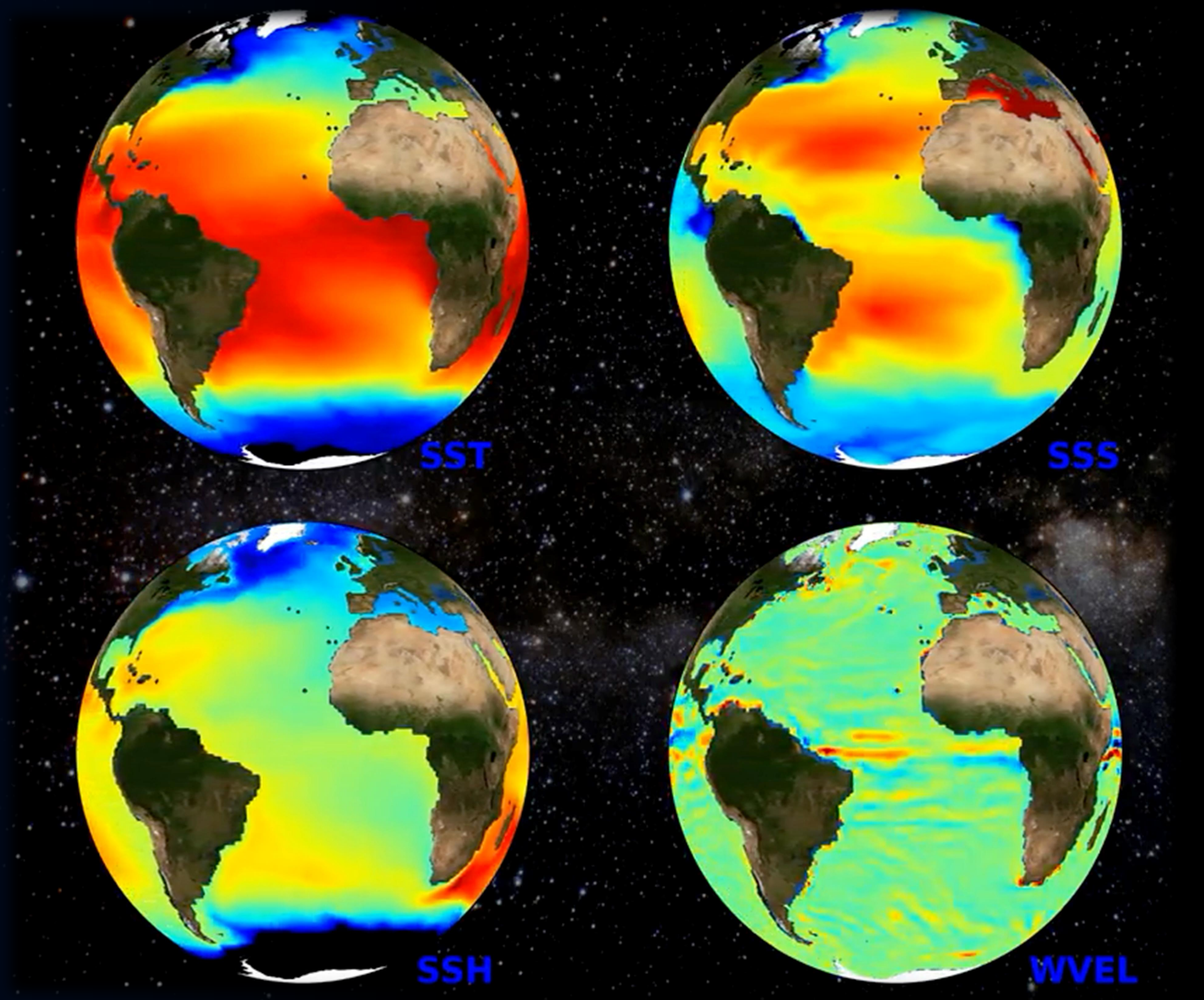
The scientific goal of ECCO to understand and describe the general circulation of the ocean and its role in climate.

Heritage, Support, and Partners

- Initiated in 1999 via the National Ocean Partnership Program (NOPP)
- Supported by NASA **Physical Oceanography, Modeling Analysis and Prediction** (MAP), and **Cryosphere** Programs
- Key U.S. partners include JPL, MIT, UT Austin, AER, SIO, and SJSU/MLML

Two Methodological Uses

- *State Estimates:* complete, physically-consistent, multi-decadal reconstructions of the full-depth, time-evolving coupled global ocean, sea-ice, ice-sheet, and biogeochemical system
- *High-Resolution Simulations*: cutting-edge numerical simulations to support fundamental ocean physics research and to support NASA science mission objectives including mission formulation.



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

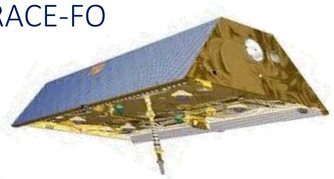
NASA's ECCO state estimates are *multi-platform, multi-instrument, multi-variable* synthesis products that integrate satellite and in-situ ocean observations with ocean climate models

JASON 1,2, 3

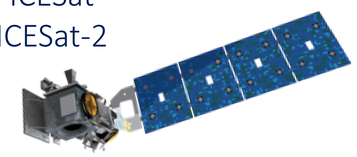
Sentinel-6
Michael Freilich

TOPEX/Poseidon

GRACE
GRACE-FO

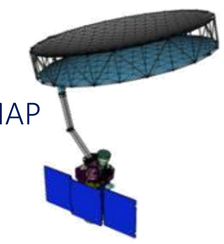


ICESat
ICESat-2



Aquarius
SAC-D

SMAP

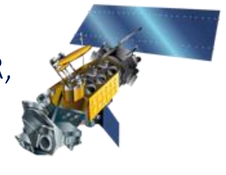


Cryosat-2

SMOS

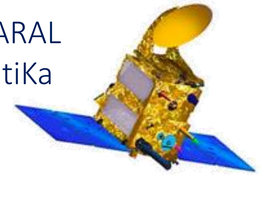
ERS 1,2

DMSP
SMMR,
SSM/I
SSMIS

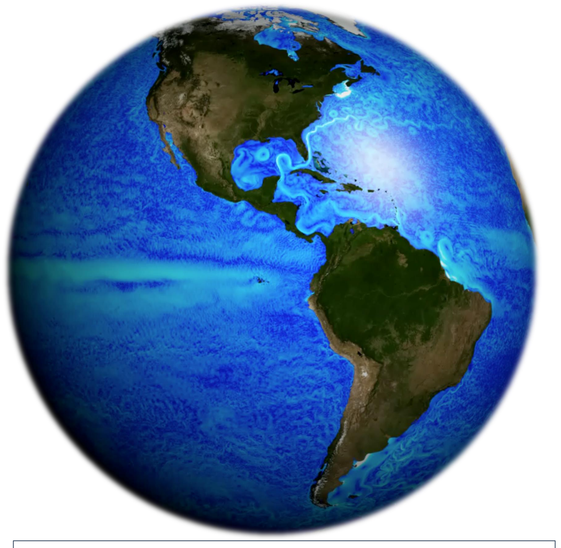


AVHRR

SARAL
AltiKa



Ocean Climate Model



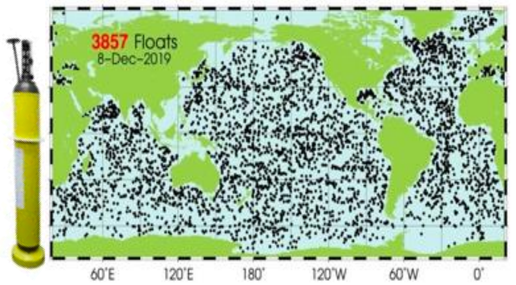
$$\frac{\partial \boldsymbol{v}}{\partial t} + (f+\zeta)\hat{\boldsymbol{k}} \times \boldsymbol{v} + \nabla_{z^*}\mathrm{KE} + w\frac{\partial \boldsymbol{v}}{\partial z} + g\nabla_{z^*}\eta + \nabla_h\Phi' = \boldsymbol{D}_{z^*,\boldsymbol{v}} + \boldsymbol{D}_{\perp,\boldsymbol{v}} + \mathcal{F}_{\boldsymbol{v}},$$

$$\frac{\partial \Phi'}{\partial z} = g\frac{\rho'}{\rho_c},$$

$$\frac{1}{H}\frac{\partial \eta}{\partial t} + \nabla_{z^*}(s^*\boldsymbol{v}) + \frac{\partial w}{\partial z^*} = s^*\mathcal{F},$$

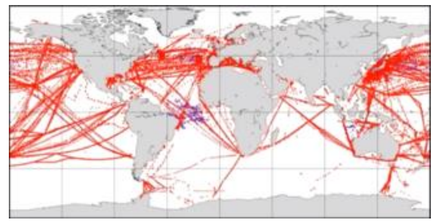
$$\frac{\partial (s^*\theta)}{\partial t} + \nabla_{z^*}(s^*\theta \boldsymbol{v}_{\mathrm{res}}) + \frac{\partial (\theta w_{\mathrm{res}})}{\partial z^*} = s^*(\mathcal{F}_\theta + D_{\sigma,\theta} + D_{\perp,\theta}),$$

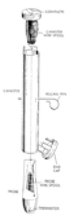
$$\frac{\partial (s^*S)}{\partial t} + \nabla_{z^*}(s^*S\boldsymbol{v}_{\mathrm{res}}) + \frac{\partial (Sw_{\mathrm{res}})}{\partial z^*} = s^*(\mathcal{F}_S + D_{\sigma,S} + D_{\perp,S}),$$



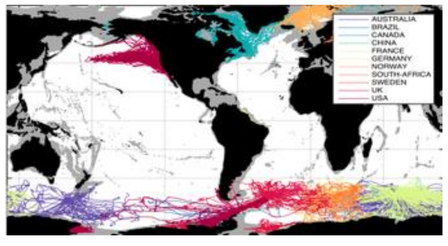
Argo Profiling Floats

CTD
•GO-SHIP
•WOCE
•others

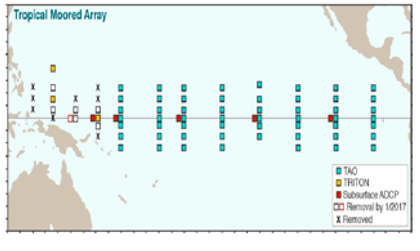




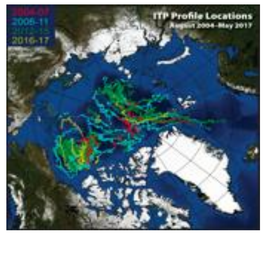
XBT



Instrumented marine mammals



Instrumented moorings



Ice-tethered profilers

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 solutions in support of NASA Open Science Priorities.

ECCO: Connections

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

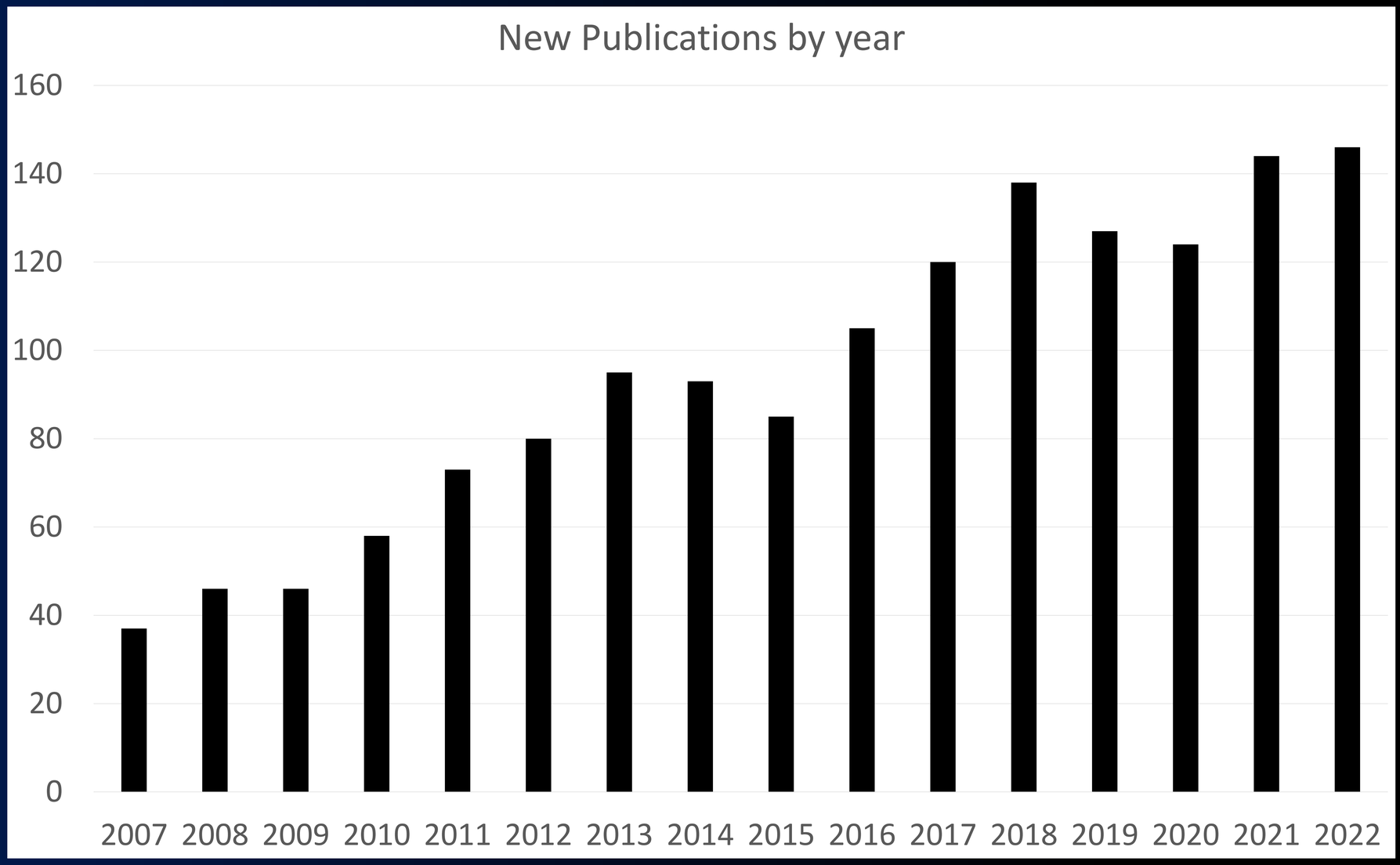
Climate Prediction

- 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 ECCO model and its adjoint, including on the cloud
- 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

What recent developments are you excited about?

1. Rapid advancements in our ability to estimate biogeochemical parameters relevant for climate including air/sea carbon fluxes
2. First multi-decadal global ocean estimate with coupled sea-ice and thermodynamic ice-shelves (V4r5)
3. New coupled, high-resolution GEOS-ECCO simulations and coupled, coarse-resolution GEOS-ECCO optimization
4. Progress towards improving the representation of land-to-ocean aquatic continuum (LOAC) including more realistic river runoff and nutrient discharge
5. New tools to empower the community to use ECCO's powerful adjoint
6. Exploring how to analyze ECCO "in the cloud" with PO.DAAC and NASA EIS
7. New studies demonstrating how ECCO state estimates and ECCO adjoints can explain causal mechanisms, including for sea level
8. Technology development of multi-grid adjoint optimization
9. Novel applications of the ECCO adjoint for sea-level prediction
10. Successful proof-of-concept state estimate of time-evolving ice-shelf
11. Use of ECCO and ECCO state estimation technology to support NASA missions and mission development including SWOT