ECCO: Estimating the Circulation and Climate of the Ocean

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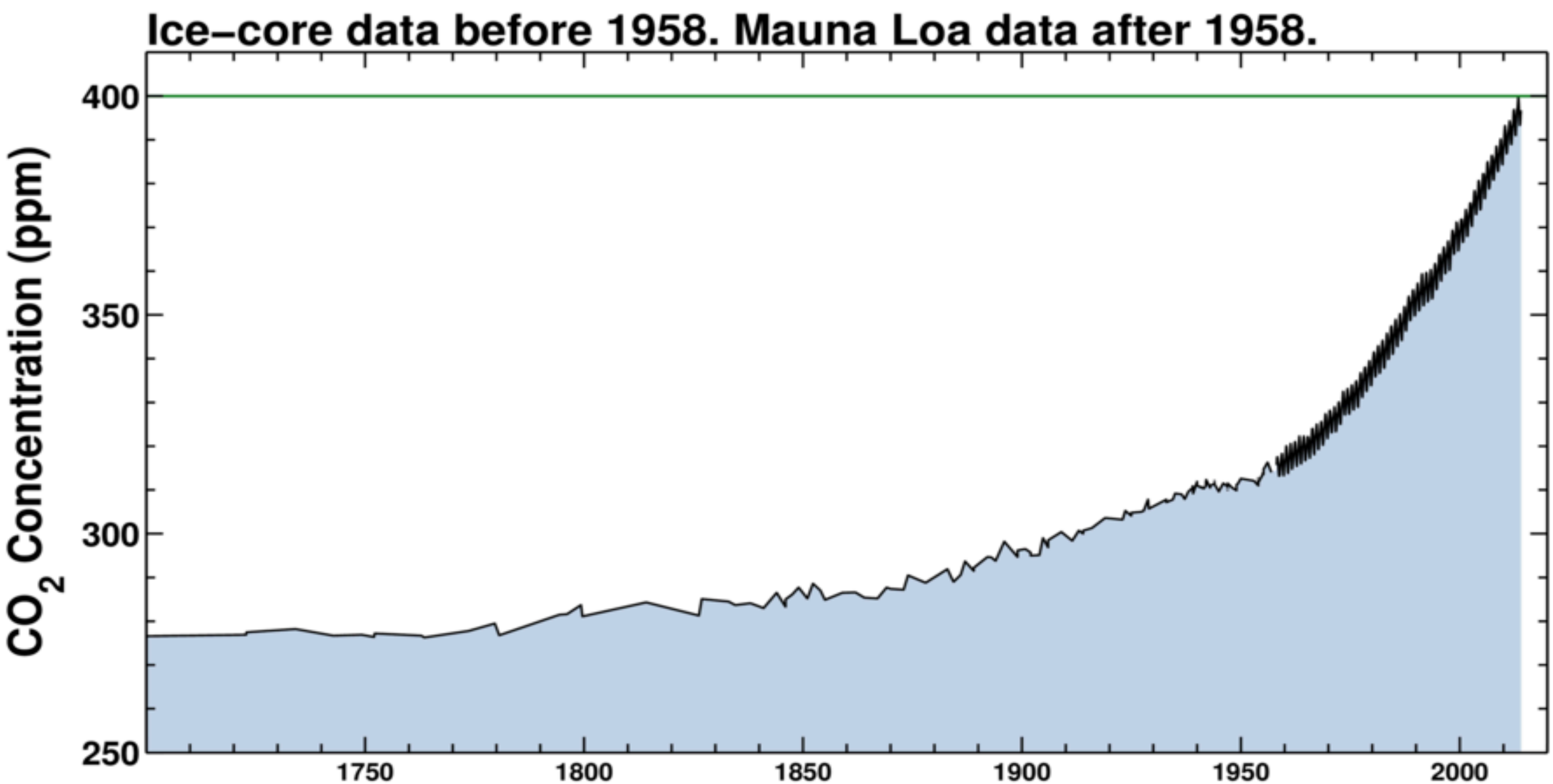
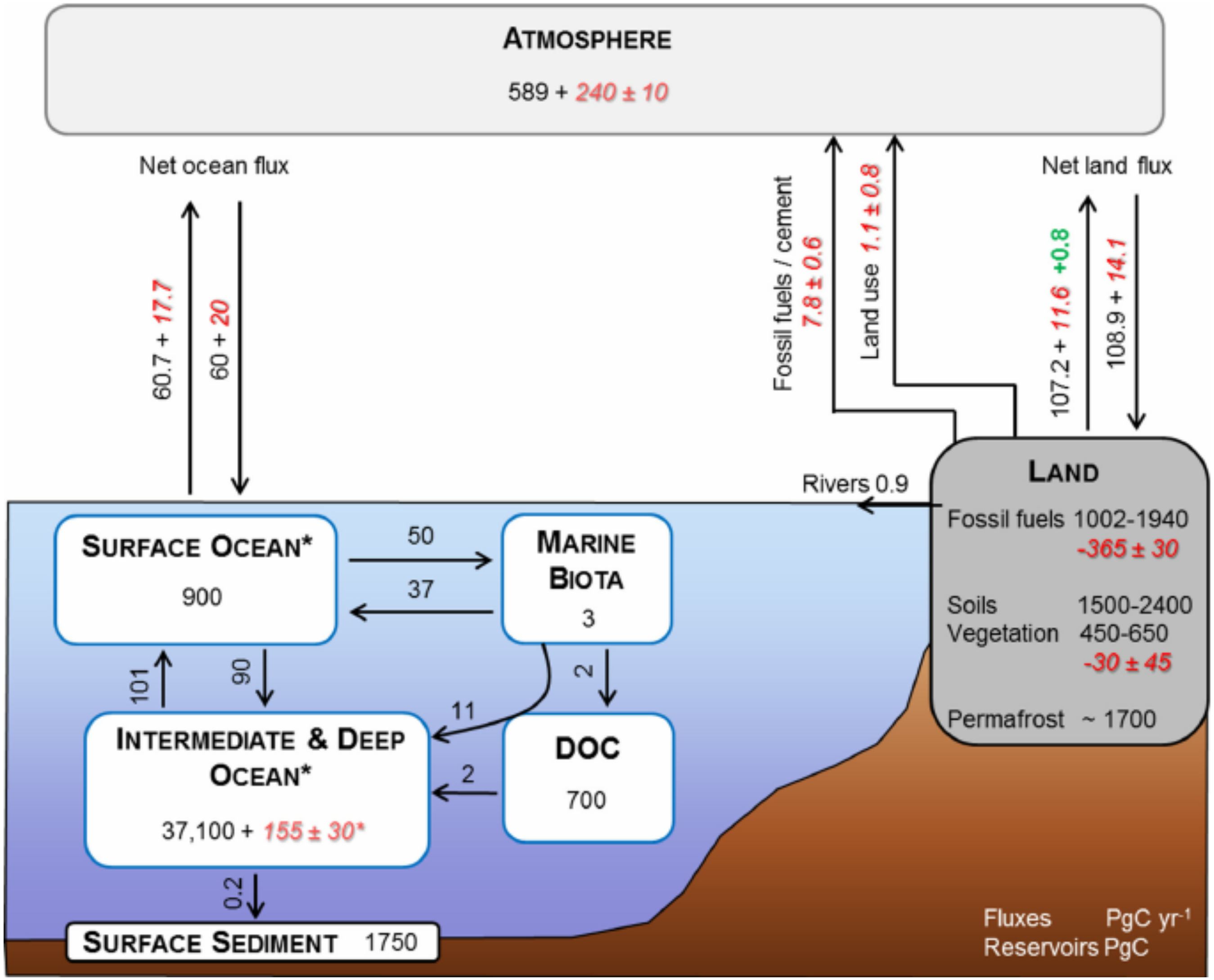
OUTLINE

- **Why study ocean circulation and climate?**
- **Strengths and limitations of observations**
- **Strengths and limitations of numerical models**
- **The ECCO project combines observations and models to obtain improved estimates of ocean properties and circulation**
- **Example applications of ECCO**

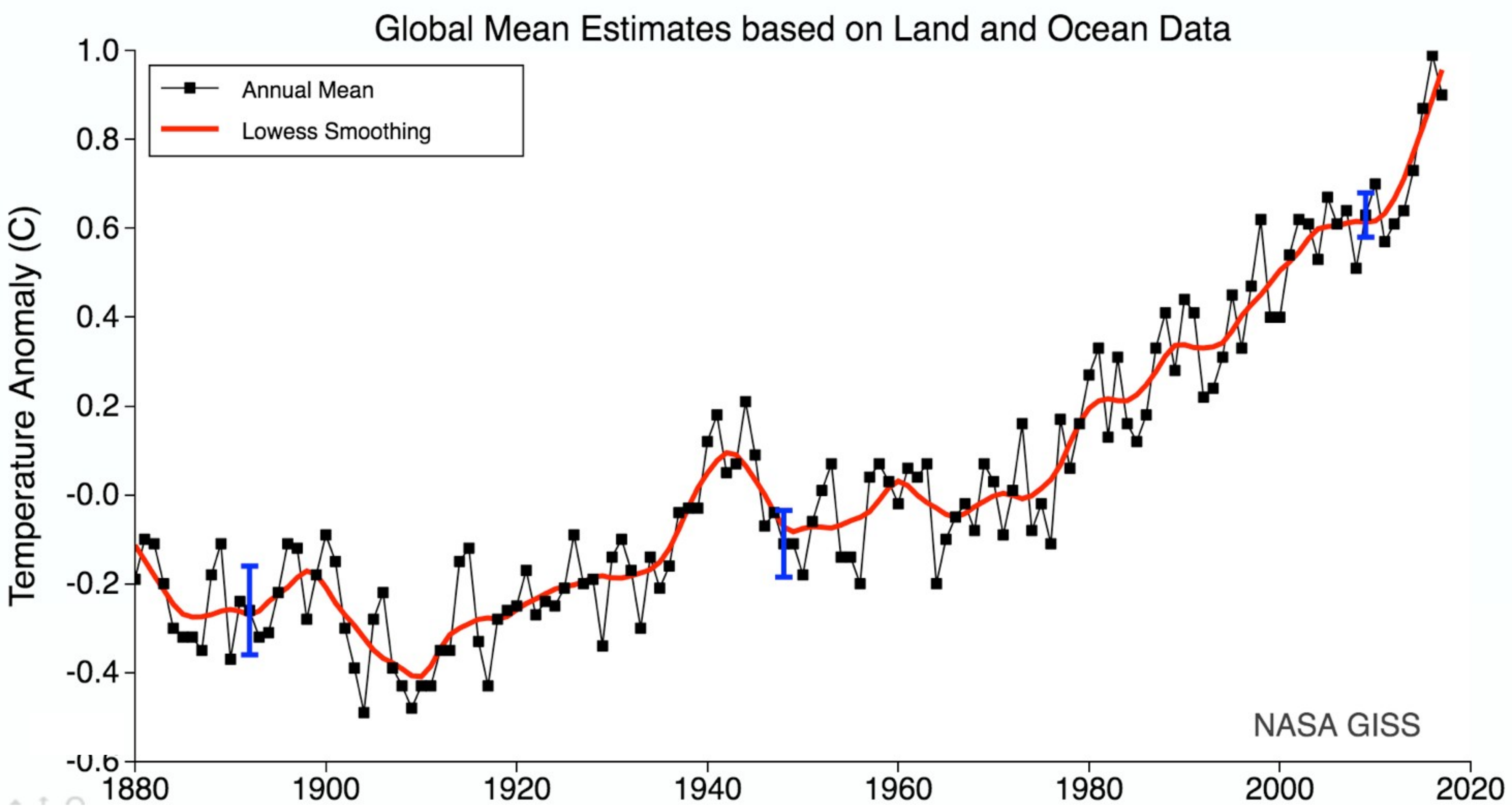
Atmospheric carbon dioxide increase since industrial revolution



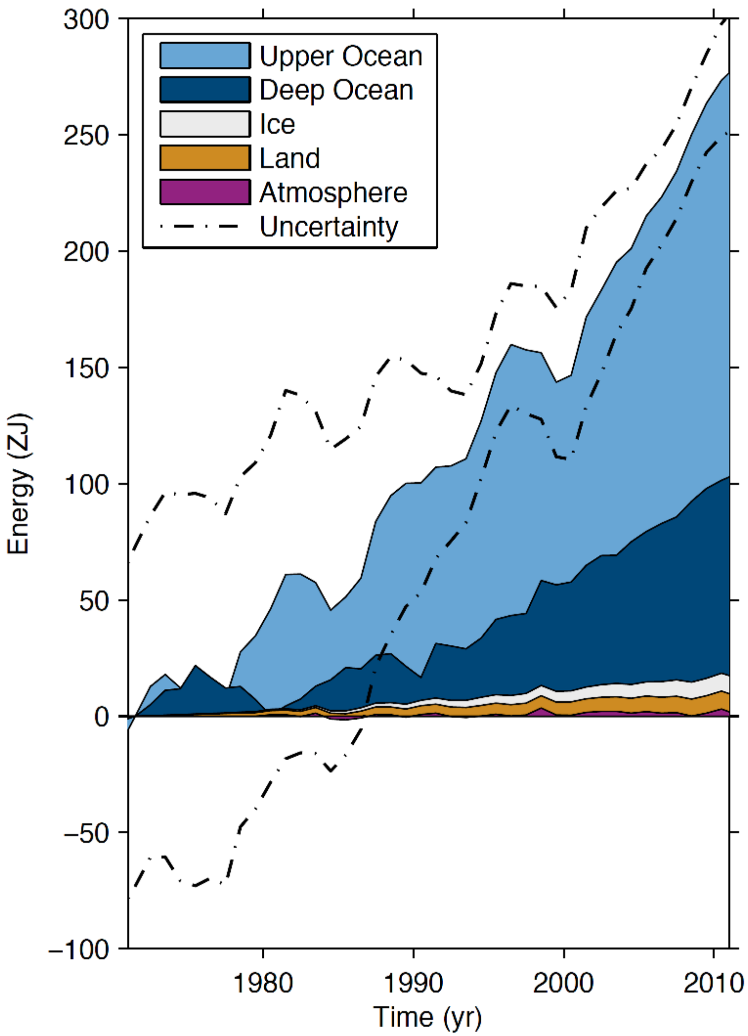
The ocean is largest active reservoir of carbon



Atmospheric surface temperature increase since industrial revolution



The ocean is the climate's reservoir of heat



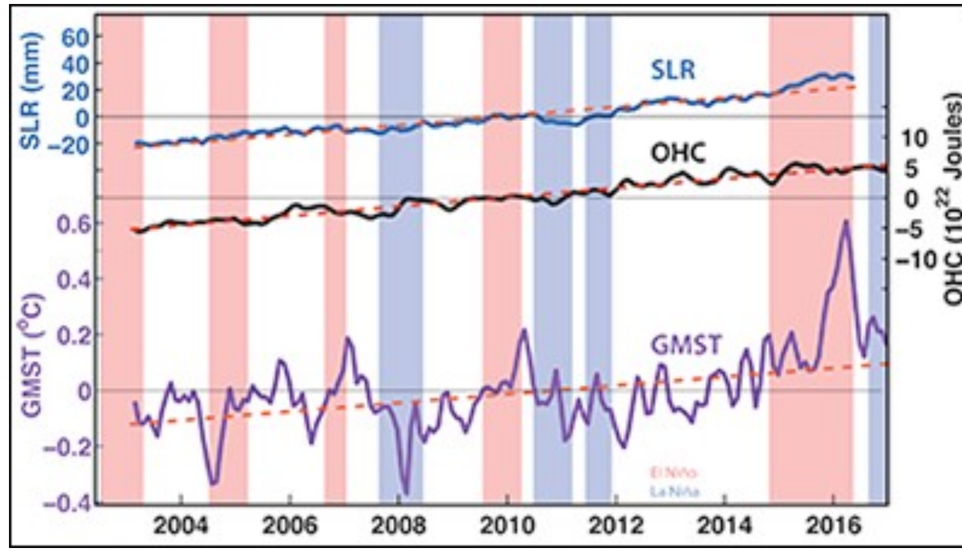
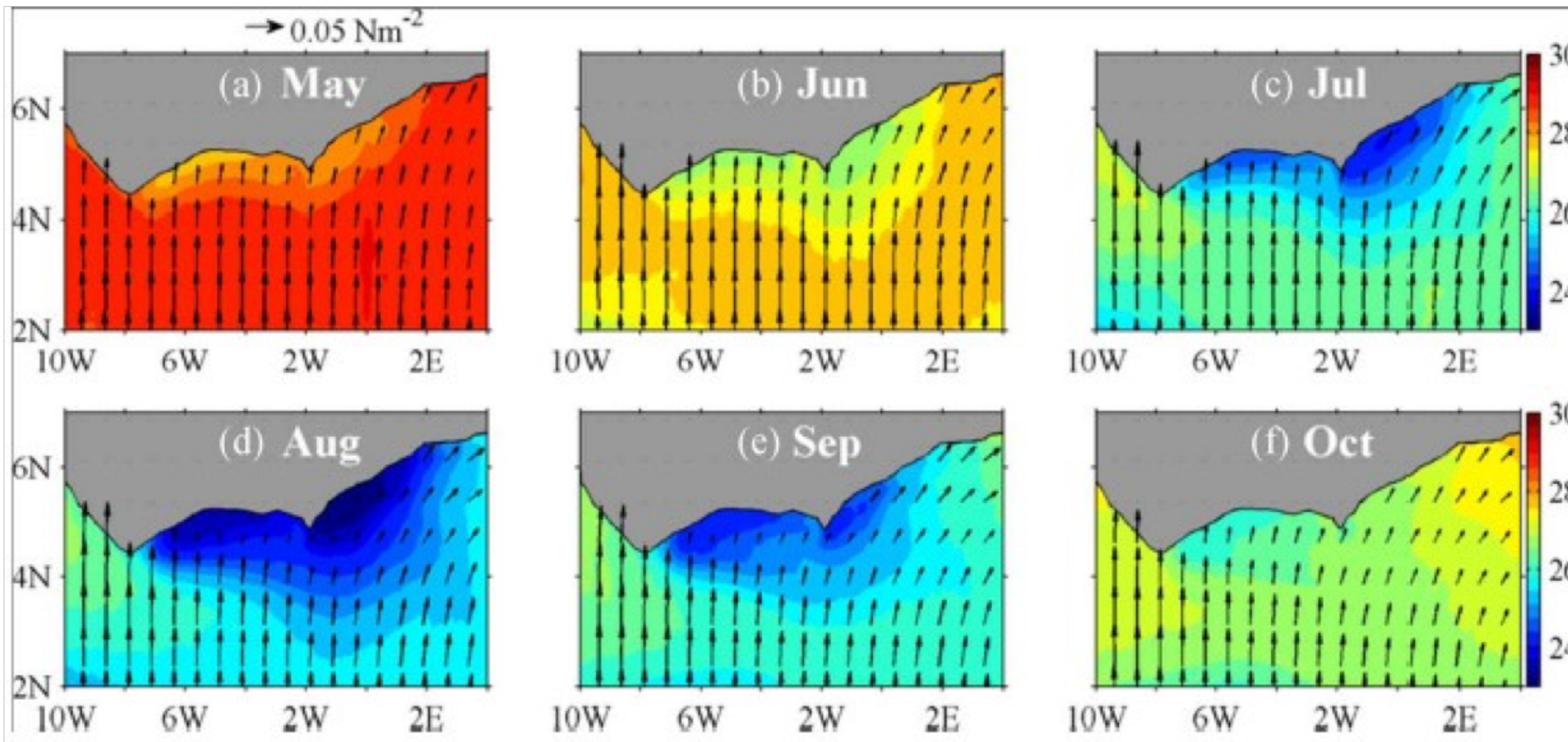


Table 1. The Linear Trend (with 95% Confidence Level) for the Three Key Climate Indicators: Global Mean Surface Temperature (GMST), Ocean Heat Content (OHC), and Sea Level Rise (SLR)[a]

	Linear Trend	σ	S/N (1/years)	Time (years)
GMST	0.016°C ± 0.005°C/yr	0.110°C/yr	0.14	27
OHC	$0.79 \pm 0.03 \times 10^{22}$ J/yr	0.77×10^{22} J/yr	1.03	3.9
SLR	3.38 ± 0.10 mm/yr	3.90 mm/yr	0.87	4.6

The ocean impacts regional climate, …

Satellite Observations of Upwelling in Gulf of Guinea



(slide from Stephan Howden's Coastal Dynamics lecture)

fisheries, …

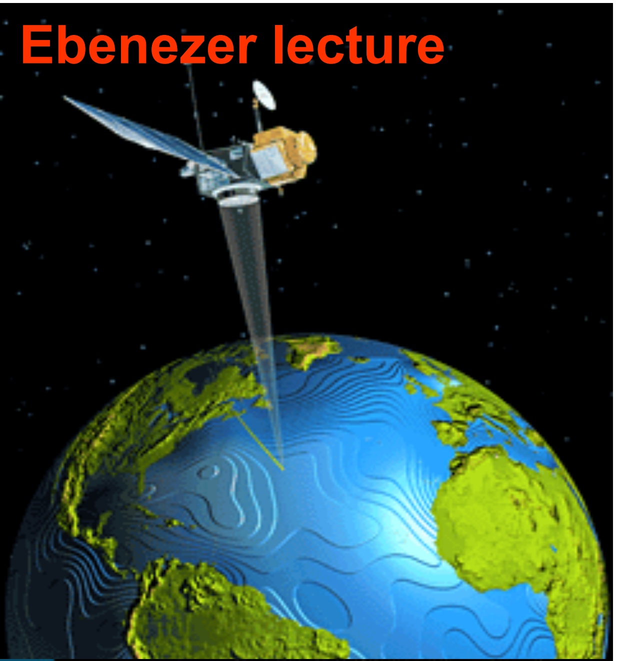
transportation, …

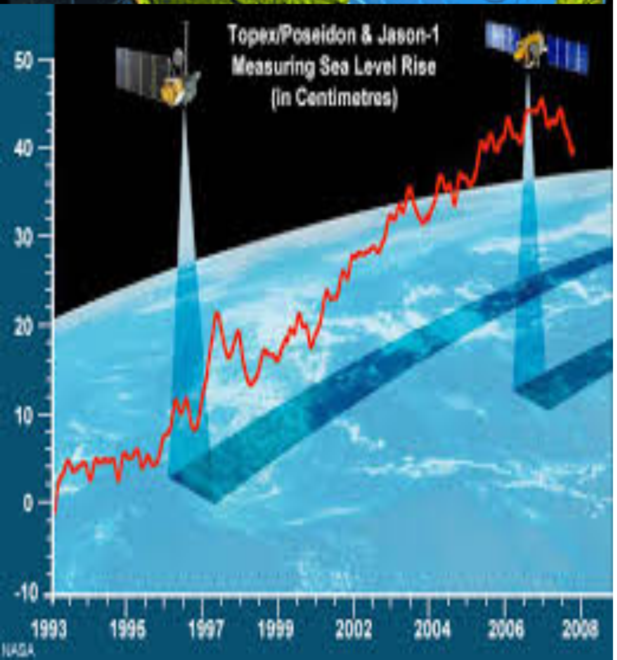
pollution, …

Strengths and limitations of in-situ observations

- **Closest to ocean truth ☺**
- **… but very limited spatiotemporal coverage ☹**
  - point measurement in time and space is not necessarily representative of large-scale, long-period average
  - contamination by geophysical and instrument noise
  - possibility of aliasing

Strengths and limitations of satellite observations



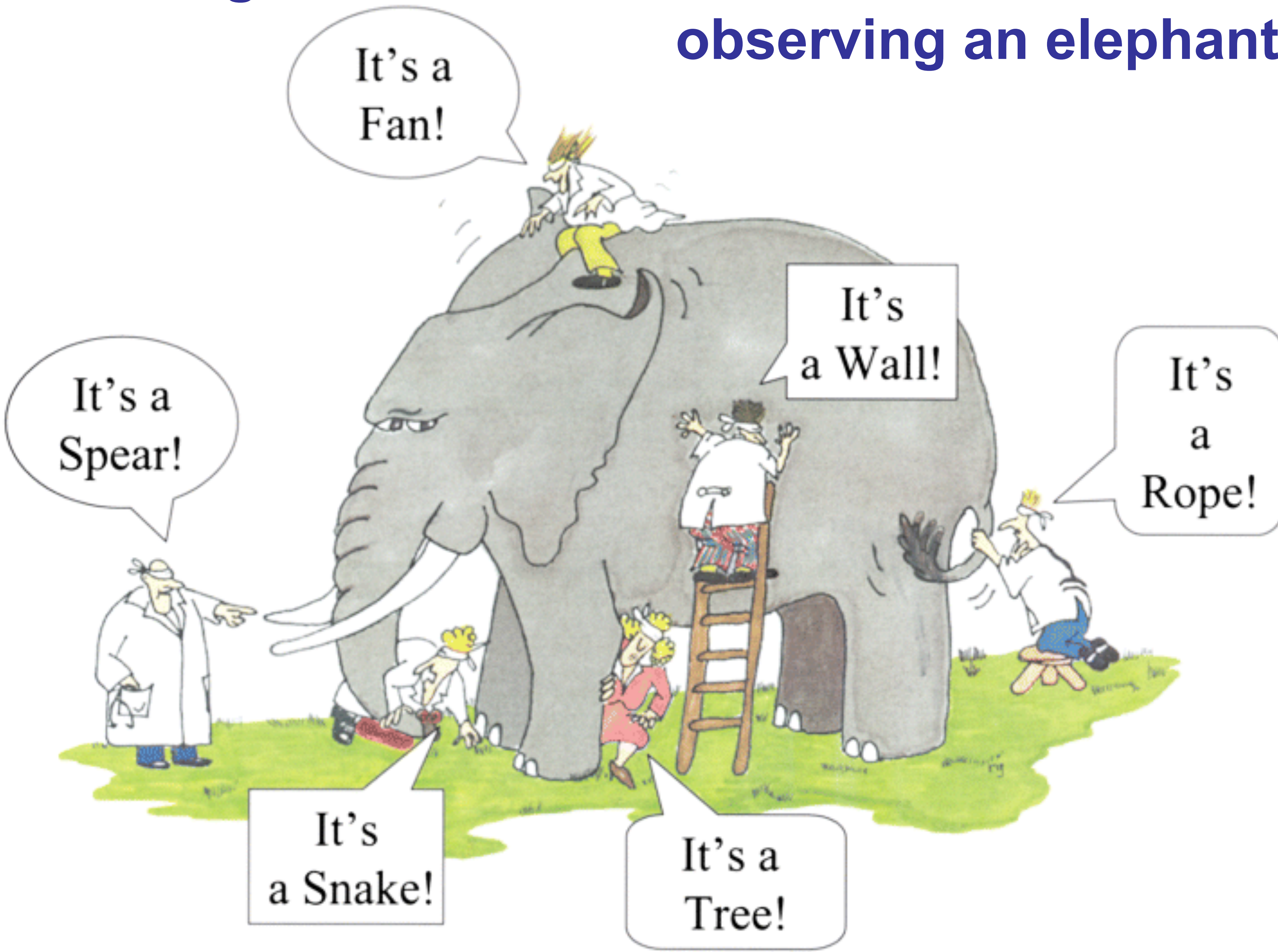


- **Global coverage ☺**

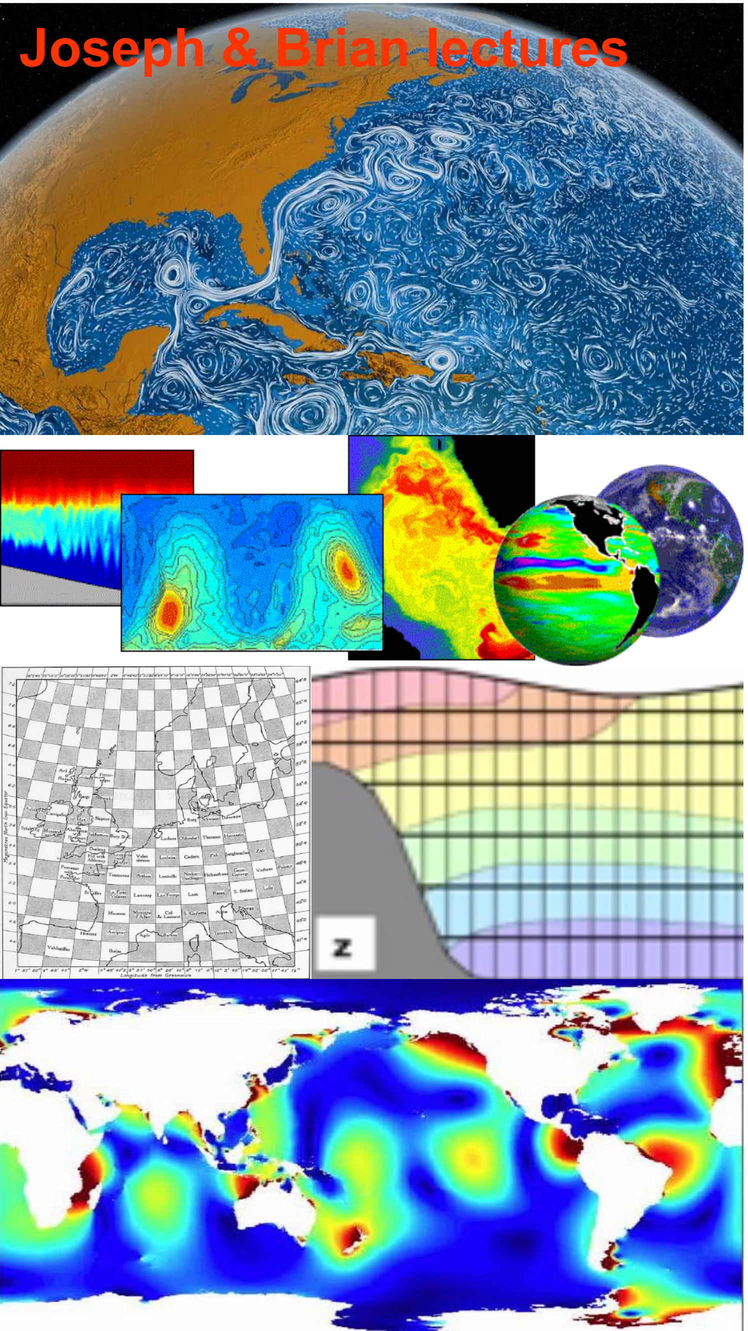
- **… but indirect observation of limited oceanographic variables ☹**

    - limited to near-surface or depth-integrated observables
    - errors due to, e.g., atmospheric variability and retrieval algorithms
    - sampling issues due to, e.g., footprint size and episodic sampling

Observing the ocean is like blind men observing an elephant.



Strengths and limitations of numerical models



- ❖ **Complete space-time description ☺**
- ❖ **… but imperfect representation of truth ☹**
  - ➢ discretization errors
  - ➢ subgrid-scale parameterization errors
  - ➢ boundary condition errors

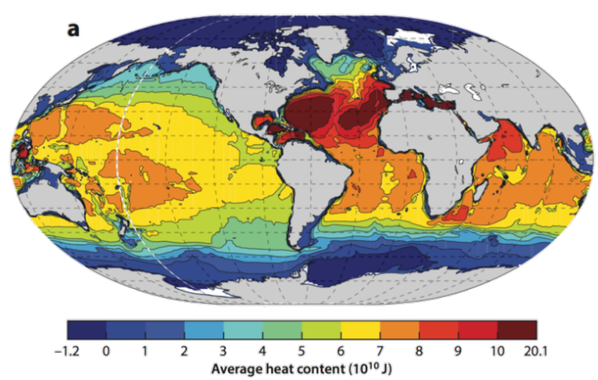
HOW CAN WE GET A DESCRIPTION OF GLOBAL OCEAN CIRCULATION THAT IS AS COMPLETE AND AS CLOSE TO TRUTH AS POSSIBLE?

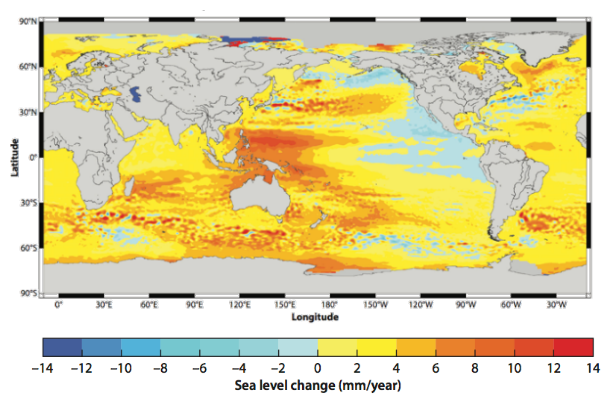
- *The "Estimating the Circulation and Climate of the Ocean" (ECCO) consortium is directed at making the best possible estimates of ocean circulation and its role in climate.*
- ***Solutions are obtained** by combining state-of-the-art ocean circulation models with nearly complete global ocean data sets 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.*

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

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

$$\lambda_0 = \sum_{t=1}^{t_f-1} \{A_1' A_2' \cdots A_t' G_{t+1}\} + G_1$$



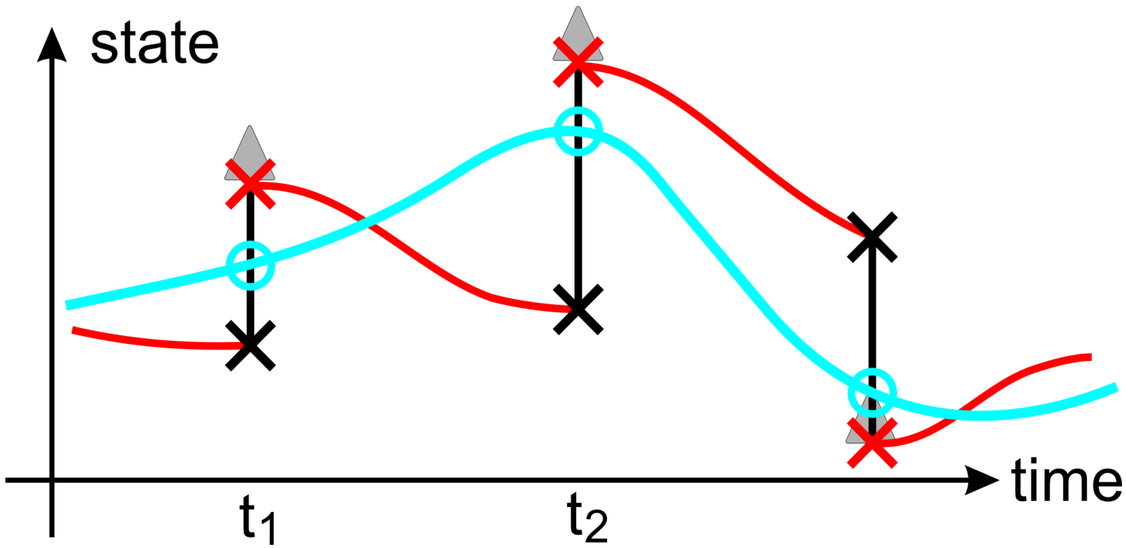


Observational data used to constrain the model

Variable	Observations
Sea surface height	TOPEX/Poseidon (1993-2005), Jason-1 (2002-2008), Jason-2 (2008-2015), Geosat-Follow-On (2001-2007), CryoSat-2 (2011-2015), ERS-1/2 (1992-2001), ENVISAT (2002-2012), SARAL/AltiKa (2013-2015)
Temperature profiles	Argo floats (1995-2015), XBTs (1992-2008), CTDs (1992-2011), Southern Elephant seals as Oceanographic Samplers (SEaOS; 2004-2010), Ice-Tethered Profilers (ITP, 2004-2011) and other high-latitude CTDs and moorings
Salinity profiles	Argo floats (1997-2015), CTDs (1992-2011), SEaOS (2004-2010), and other high-latitude CTDs and moorings
Sea surface temp.	AVHRR (1992-2013)
Sea surface salinity	Aquarius (2011-2013)
Sea-ice concentration	SSM/I DMSP-F11 (1992-2000) and -F13 (1995-2009) and SSMIS DMSP-F17 (2006-2015)
Ocean bot. pressure	GRACE (2002-2014), JPL MASCON Solution
TS climatology	World Ocean Atlas 2009
MDT	DTU13 (1992-2012)
GM SSH & OBP	AVISO, CSIRO, NOAA; GRACE

New or updated items from are indicated in red.

Ocean Hydrography products vs. ECCO products



Red line : traditional ocean reanalysis
Blue : ECCO trajectory and state

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.*

ECCO output: monthly and daily mean fields

Ocean + sea-ice

- *T, S, u, v, w, η, ρ*, *Φ*
- Sea-ice and snow *h* and *c*
- Lateral and vertical fluxes of volume, heat, salt, and momentum

Atmosphere

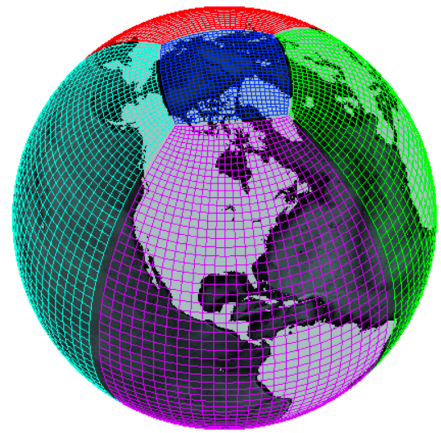
- T, q, |u|, τ, long- and radiative fluxes
- Air–sea-ice–ocean fluxes of heat, moisture, energy, and momentum

Subgrid-scale mixing parameters

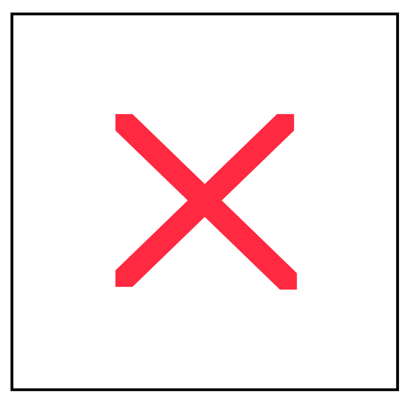
- 3D GM κ and Redi κ
- 3D vertical diffusivity

Fields are provided on two grids

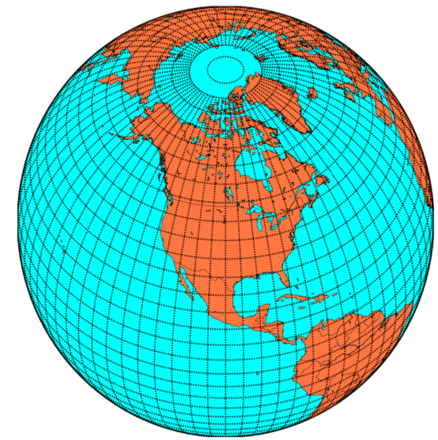
Curvilinear Cartesian
"lat-lon-cap 90"



13 tiles of 90x90x50



Interpolated
0.5° lat-lon



ftp://ecco.jpl.nasa.gov/Version4/Release3/

- 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

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!

ECCO v4 at 2018 Ocean Sciences

2018 OCEAN SCIENCES MEETING

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
8. PL34A-1825: **Success and failure of barotropic theory in the North Atlantic using the ECCO state estimate**. Sonnewald
9. PC13A-08 **Varieties of Wind Effects on Tropical Pacific Decadal Sea-Surface Height Variability** Piecuch
10. PL44E-1924 **The subsurface transport to the mixed layer of the tropical Pacific** Gao
11. PC44C-0696 **Relationship between the Indian Ocean Warming and Upwelling in the Southeastern Arabian Sea** Nigam
12. PL24A-1791 **Sensitivity of the Subtropical AMOC to Variability in the Subpolar North Atlantic** Kostov
13. OM14B-2065 **The Impact of High-resolution, High-frequency Atmospheric Boundary Conditions on Ocean Model Solutions** Zhang
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

Ocean Circulation's Induced Electromagnetic Temporal Variations

Neesha R. Schnepf, M. Nair, N. P. Thomas & A. Kuvshinov [S34D-2656]

Science Question:

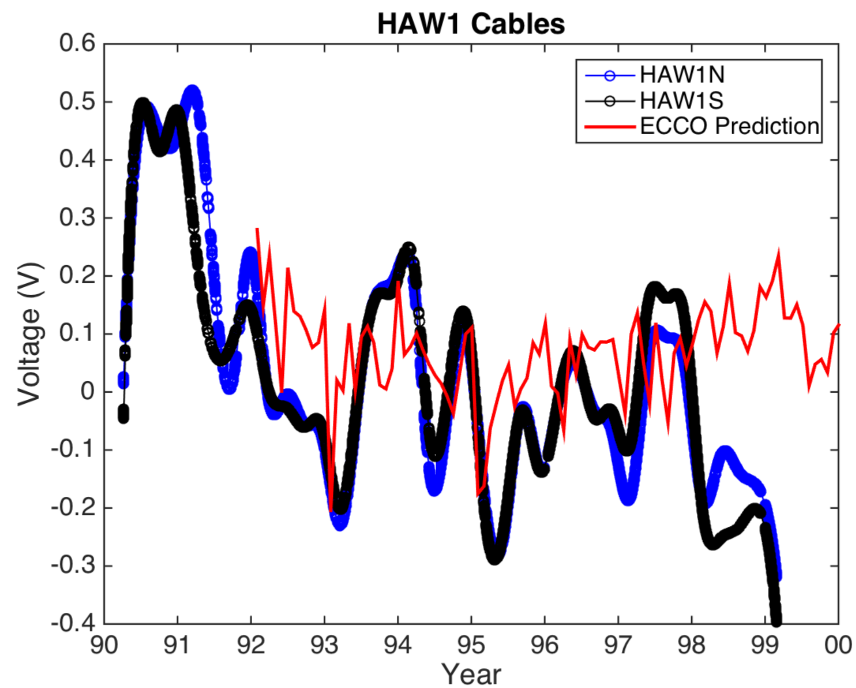
Can basin-scale ocean circulation be inferred using seafloor cables that can measure its induced EM fields?

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.



2018 OCEAN SCIENCES MEETING

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 (κ_{GM}, κ_{Redi}, κ_h) estimated by ECCO compare with those derived from Argo data alone?

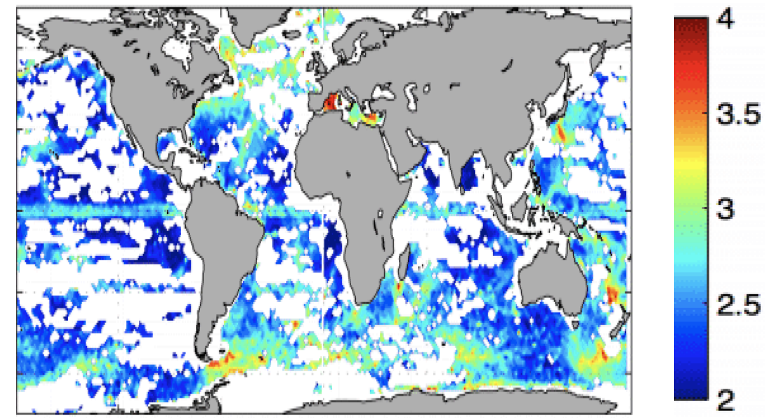
Why ECCO?

“ECCO is one of the few models that estimate and use spatially-varying subgrid-scale mixing parameters.”

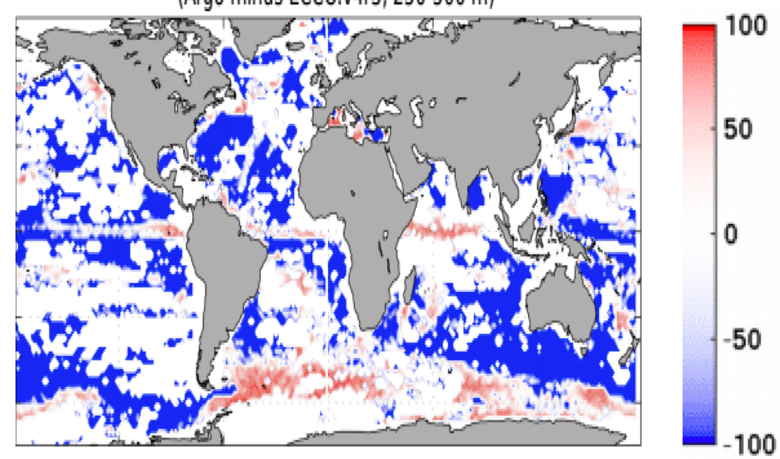
Results:

ECCO and Argo-derived products agree within a factor 10. Use of Argo-derived parameters changes upper ocean oxygen concentrations.

c) Diapycnal diffusivities from Argo [$m^2 s^{-1}$] (250-500 m)

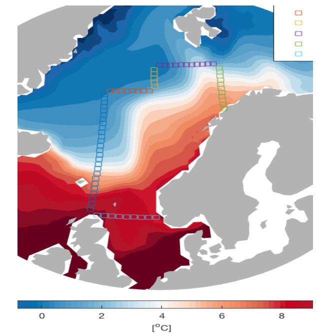


d) Diapycnal diffusivities percent difference (Argo minus ECCO.v4r3, 250-500 m)



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?

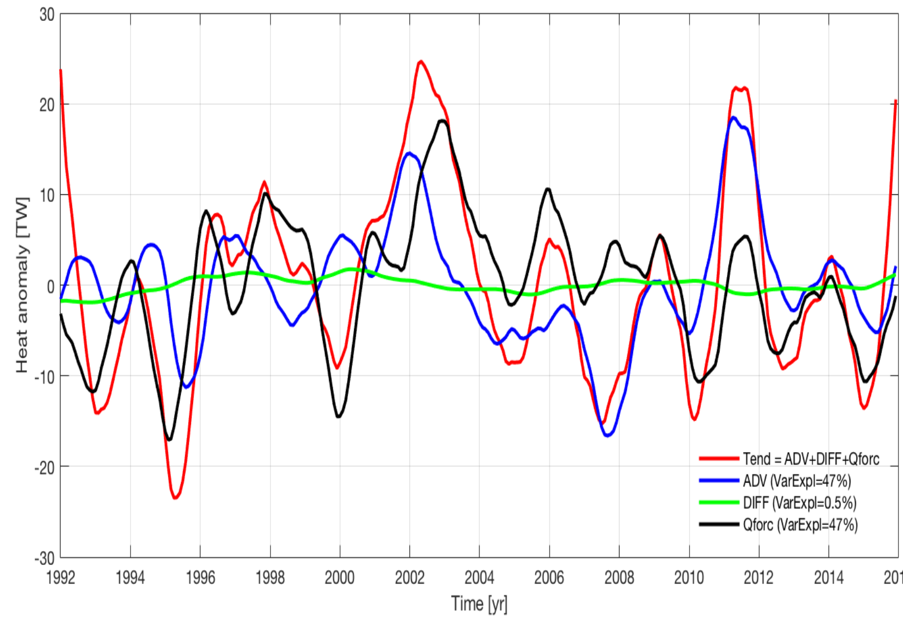
Why ECCO?

"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.

Depth-integrated heat budget for the Norwegian Sea.



Success and failure of barotropic theory in the North Atlantic using the ECCO state estimate

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

2018 OCEAN SCIENCES MEETING

Science Question:

Can we classify the ocean into regions based on the relative importance of different terms in the barotropic vorticity equation?

Why ECCO?

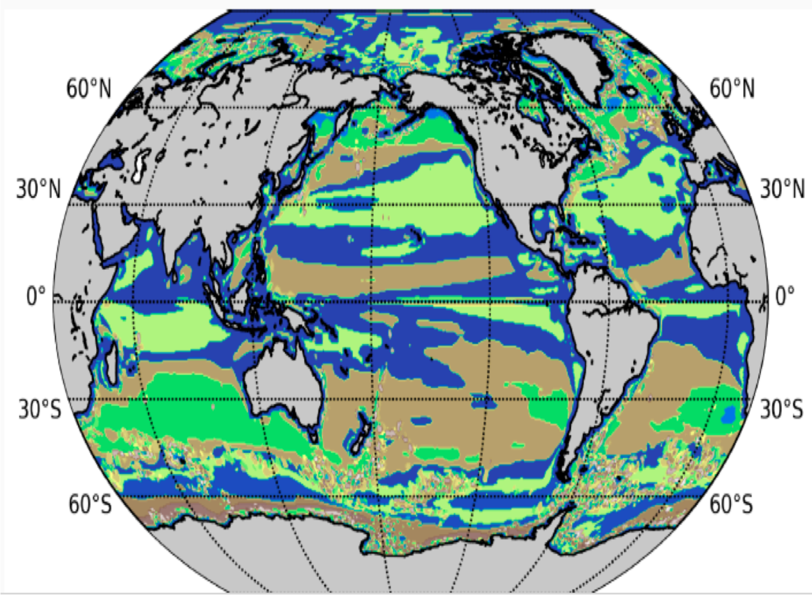
ECCO products have closed dynamical budgets.

Results:

Dynamically-distinct regions can be identified and key regions have significant contributions from non-linear terms

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

Regions of different balances of the terms in the depth-integrated BVE



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?

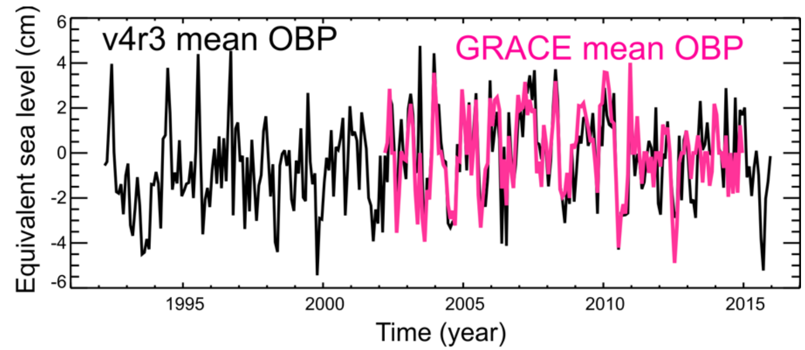
Why ECCO?

ECCO's adjoint–derived sensitivities can reveal causal mechanisms.

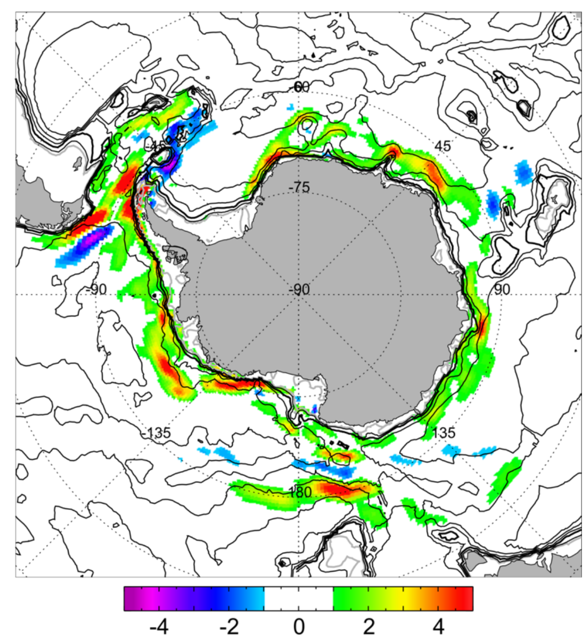
Results:

ECCO reproduces the observed OBP variations (and temperatures too!) These variations are largely driven *by winds along the Antarctic continental slope*.

Mean OBP on the Antarctic shelf.



Explained variance of winds driving *coherent bottom pressure variations* (% per km^2×10^5)



SUMMARY

- **The ocean is climate's largest reservoir of carbon dioxide and heat. It impacts regional climate, transportation, pollution, etc.**

- **Ocean observations are closest to ocean truth but have limited spatio-temporal coverage.**

- **Ocean models provide complete space-time description but imperfect representation of truth.**

- **ECCO uses observations to improve the models, leading to circulation estimates that can be used for diverse global and regional studies.**