Adjoint sensitivities to ocean mixing parameter assimilation

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ECCO meeting
October 29, 2018

Research questions

Our goals

- How well do the ocean mixing parameters of an ocean-sea ice state estimate agree with those inferred from observations?
- How does the model respond differently to adjustments in each of the ocean mixing parameters (T, S, cost, adjoint sensitivities)?

Ocean-sea ice model

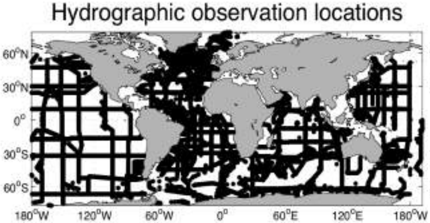
Model utilized (ECCO version 4 release 3, or ECCO.v4r3; *Fukumori et al.*, 2017):

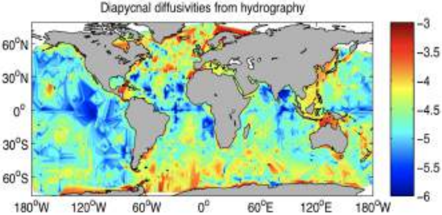
- MITgcm on LLC90 (global nominally 1^o) grid with 50 z-levels
- Time period: 1992-2015

Observations utilized:

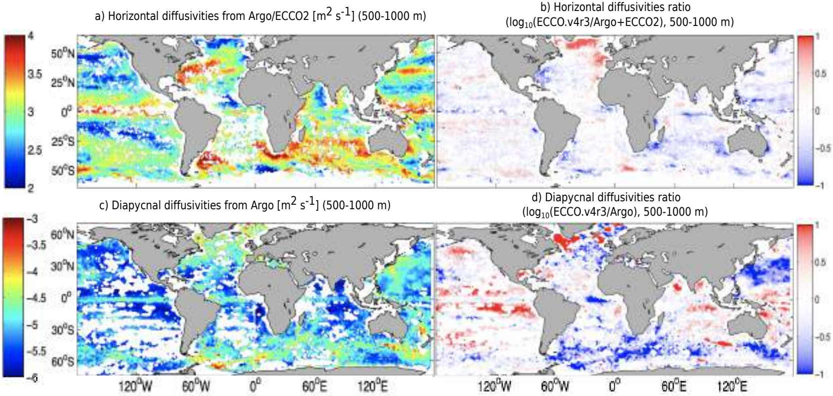
- **Diapycnal diffusivity** component of vertical diffusivity field are set to be a combination of three different data sources: Argo (*Whalen et al.*, 2015), hydrography (*Kunze*, 2017), and microstructure (*Waterhouse et al.*, 2014)
- **Along-isopycnal tracer and thickness diffusivity** field between 0-2000 meters are set to be from Argo (for the mixing length scale)/ECCO2 (for the characteristic velocity scale of the eddy field) (*Cole et al.*, 2015)

Hydrography-inferred diapycnal diffusivities (*Kunze*, 2017)


Hydrographic observation locations


Diapycnal diffusivities from hydrography

Argo- and ECCO2-derived Redi coefficients (*Cole et al.*, 2015), Argo-derived diapycnal diffusivities (*Whalen et al.*, 2015), and ECCO.v4r3-derived ones



a) Horizontal diffusivities from Argo/ECCO2 [$m^2\ s^{-1}$] (500-1000 m)

b) Horizontal diffusivities ratio ($\log_{10}$(ECCO.v4r3/Argo+ECCO2), 500-1000 m)

c) Diapycnal diffusivities from Argo [$m^2\ s^{-1}$] (500-1000 m)

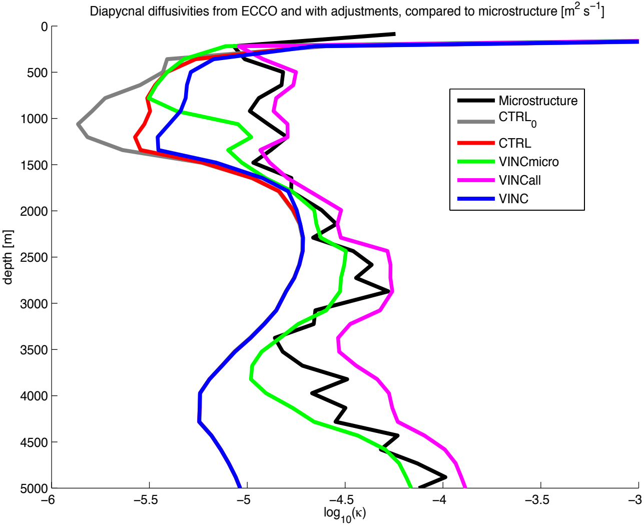
d) Diapycnal diffusivities ratio ($\log_{10}$(ECCO.v4r3/Argo), 500-1000 m)

Model configurations

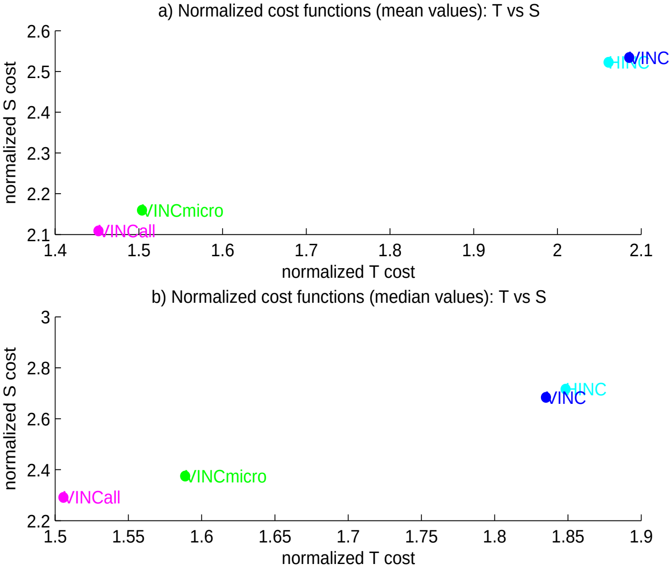
ECCO.v4r3 re-run experiments:

- **CTRL** - control ECCO.v4r3 re-run: vertical as well as along-isopycnal tracer and thickness diffusivities are overridden with those from the ECCO.v4r3 solution
- **VINC** - same as CTRL, except with diapycnal diffusivity component of vertical diffusivities nudged to Argo-derived product (*Whalen et al.*, 2015) and hydrography-derived product (*Kunze*, 2017) at available locations
- **VINCmicro** - same as VINC, except diapycnal diffusivities have been nudged to globally averaged microstructure-derived product (*Waterhouse et al.*, 2014)
- **VINCall** - both diapycnal diffusivity increments from VINC and VINCmicro
- **HINC** - same as CTRL, except with Redi coefficient nudged to Argo- and ECCO2-derived product (*Cole et al.*, 2015) at available locations

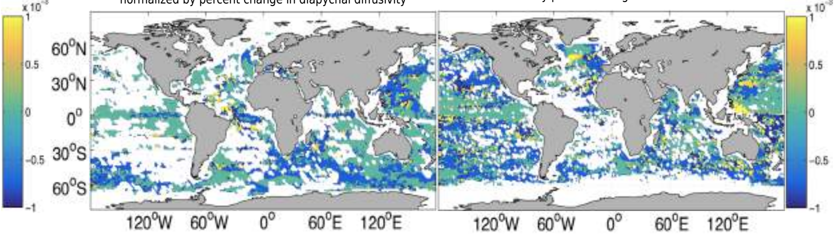
Globally averaged profiles of diapycnal diffusivities adjusting the ECCO.v4r3 estimate, relative to microstructure-inferred diapycnal diffusivities (*Waterhouse et al.*, 2014)



Misfit cost functions for temperature (T) and salinity (S), normalized by CTRL, for each experiment (mean and median) suggest VINCall is the most realistic ocean mixing product



Model is more sensitive to changes in diapycnal diffusivities than Redi coefficients in some locations, the opposite is true in other locations



a) Depth-averaged change in temperature (VINC-CTRL), normalized by percent change in diapycnal diffusivity

b) Depth-averaged change in temperature (HINC-CTRL), normalized by percent change in Redi coefficient

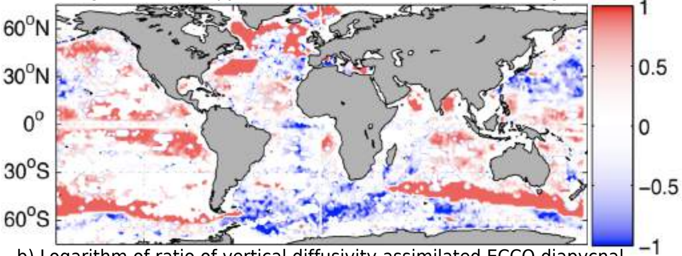
Extra assimilation simulations

ECCO.v4r3 adjoint-based experiments:

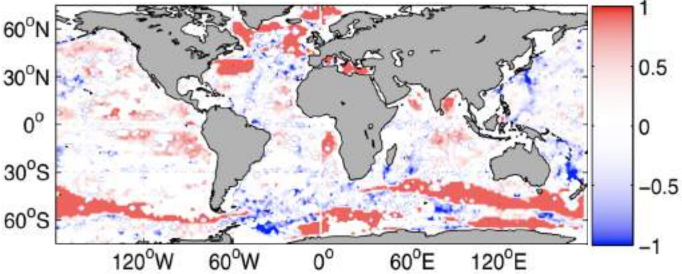
- Out-of-the-box adjoint run
- Diapycnal diffusivities from Argo-derived product (*Whalen et al.*, 2015), hydrography-derived product (*Kunze*, 2017), and ITP-derived produce (*Hayley Dosser*, personal communication) at available locations (plus vertical component of along-isopycnal diffusivities) assimilated with new term in cost function (zero weight to all other control variables)
- Redi coefficients from Argo- and ECCO2-derived product (*Cole et al.*, 2015) at available locations assimilated with new term in cost function (zero weight to all other control variables)

Improvements in simulated diapycnal diffusivities relative to Argo-inferred diapycnal diffusivities when assimilated

a) Logarithm of ratio of optimized ECCO diapycnal diffusivities to Argo-inferred diapycnal diffusivities (250-2000 m average)

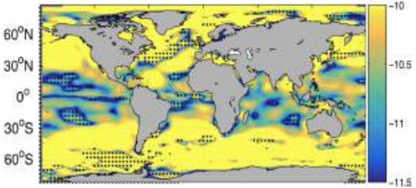


b) Logarithm of ratio of vertical diffusivity-assimilated ECCO diapycnal diffusivities to Argo-inferred diapycnal diffusivities (250-2000 m average)

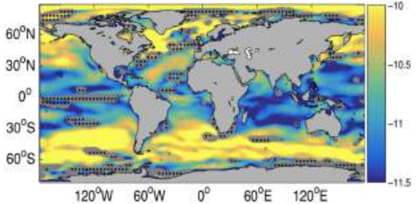


Large-scale patterns in base-10 logarithms of adjoint sensitivities to Redi coefficients (scaled by volume of each grid cell)

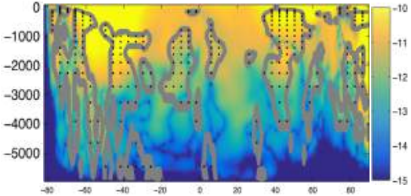
a) Adjoint sensitivities for Redi coefficient at surface



b) Adjoint sensitivities for Redi coefficient between 0-2000 m



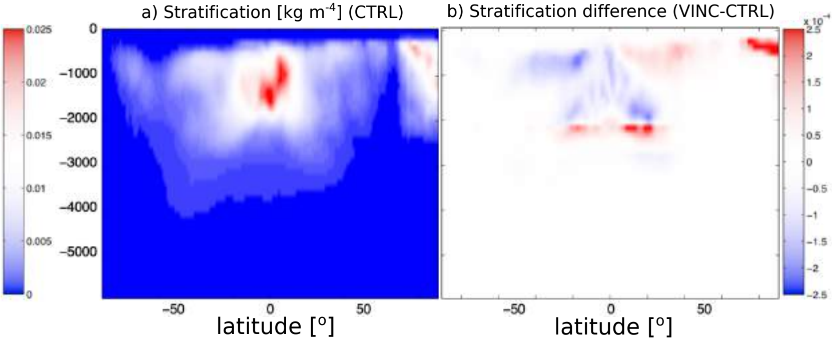
c) Adjoint sensitivities for Redi coefficient zonally averaged



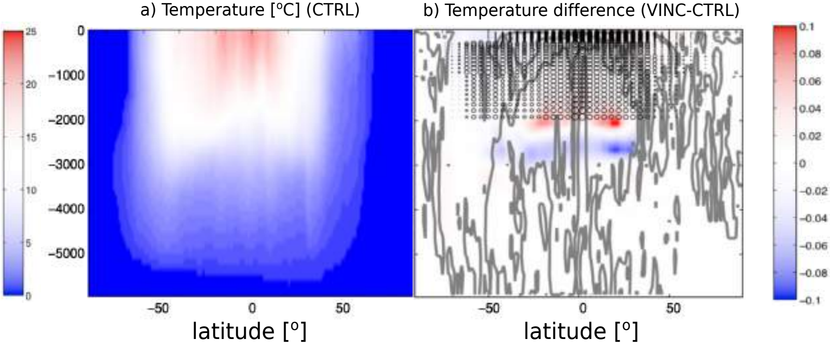
Summary

- Ocean mixing parameters from an ocean-sea ice state estimate have biases with large-scale spatial patterns, and are often an order of magnitude different from observations
- Least cost increase in vertical diffusivity override re-runs occurs in simulation guided by all available diapycnal diffusivity observations
- The model is more sensitive to changes in diapycnal diffusivities than to changes in Redi coefficients in some places, but not others
- Arctic Ocean has large adjoint sensitivities to Redi coefficients, despite no available observations there; adjoint sensitivities are mostly negative upstream of where Redi coefficients need to be increased
- Assimilation of vertical diffusivities reduces the disagreement with Argo-inferred diapycnal diffusivities

Zonally averaged stratification response is a few percent and is largest in the tropics and Arctic Ocean



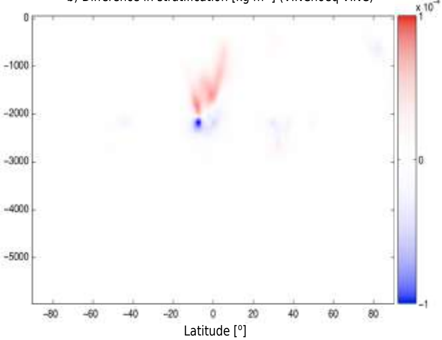
Zonally averaged temperature response is greatest where there are artificial vertical heat transports (from discontinuities in observational coverage)



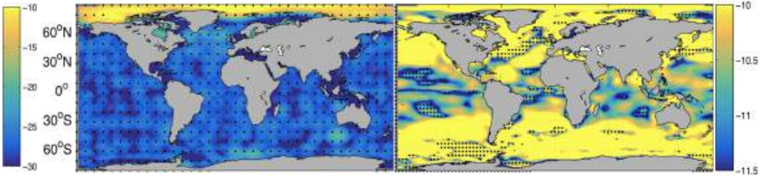
Fidelity of diapycnal diffusivity estimates near the equator (5^oS to 5^oN) matters

a) Difference in meridional heat flux [W] averaged over all Argo observation depths (VINCnoeq-VINC)

b) Difference in stratification [kg m^{-4}] (VINCnoeq-VINC)

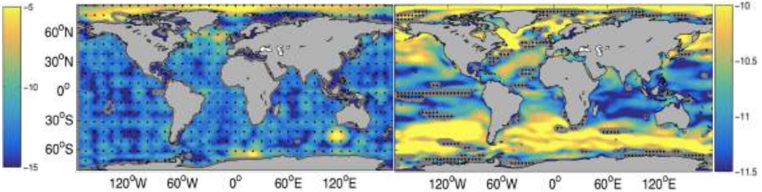


Large-scale patterns in base-10 logarithms of adjoint sensitivities to vertical diffusivities and Redi coefficients (scaled by volume of each grid cell), assimilating one mixing parameter at a time



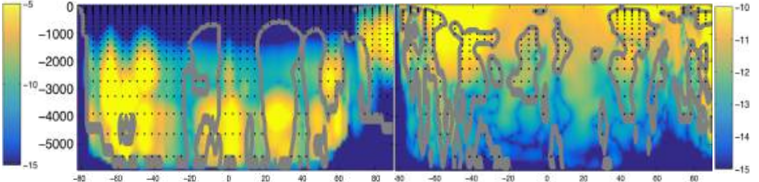
a) Adjoint sensitivities for vertical diffusivity at surface

b) Adjoint sensitivities for Redi coefficient at surface



c) Adjoint sensitivities for vertical diffusivity between 250-2000 m

d) Adjoint sensitivities for Redi coefficient between 0-2000 m



e) Adjoint sensitivities for vertical diffusivity zonally averaged

f) Adjoint sensitivities for Redi coefficient zonally averaged

Meridional overturning streamline changes are usually, but not always, parallel to the control simulation's streamlines