Fast to slow impacts of turbulent mixing

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- Internal wave-driven turbulence
- Homogenisation of properties (gradient erosion)
- Intermittent in time and space
- Small scale with global scale implications

Outline
- Mixing and MOC (centennial to millennial)
- Mixing and tracers (decadal to longer)
- Mixing and BGC (annual to longer)
Without deep mixing, the ocean would turn, within a few thousands years, into a stagnant pool of cold salty water with equilibrium maintained locally by near-surface mixing and with very weak convectively driven surface-intensified circulation. (Wunsch & Munk, 1998)
Turbulent mixing and the Meridional Overturning Circulation

- Topographically-induced mixing (ACC impinging on rough topography)
- Role of water masses sharp interfaces in modulating mixing

Baker et al., 2023
Turbulent mixing and the Meridional Overturning Circulation

- Net upwelling VS local up/downwelling (over rough topography)

Ferrari et al., 2016
See also: de Lavergne et al., 2016

Cimoli et al., 2019
Turbulent mixing and the Meridional Overturning Circulation

Boundary Layer Turbulence (BLT) project: observational proof of along-boundary tracer upwelling

Wynne-Cattanach et al., 2024 (in review)

Boundary Layer Turbulence (BLT) project: results from realistic numerical simulations

Drake et al., 2022
Turbulent mixing and the Meridional Overturning Circulation
Turbulent mixing and tracers

Implications for Southern Ocean pathways

Cimoli et al., 2023

Marshall et al., 2014

Armour et al., 2016
Both idealised and realistic simulations confirm rapid effect of mixing on tracer distribution.

- Realistic simulations: Mixing-driven changes to CO2 flux up to 40% over 6-year simulation.
- Fast and slow timescales.
Turbulent mixing and BGC

A. Phosphate concentration

B. Eddy meridional

C. Diapycnal

Gupta et al., 2022
Observing and modeling turbulent mixing

Observations

- ArgoMix
- Tracer release experiments

Scaling up in space & time

State estimates

Challenge: Combine (1) incomplete diverse observations with (2) an imperfect model to provide our best, dynamically-consistent estimate of the ocean state for climate research.

How can we improve mixing representation in ECCO (better observationally-constrained global models for regional downscaling)?

Can we use ECCO to provide meaningful large-scale estimates of ocean mixing (filling in the data gaps)?

Modeling

Le Boyer et al., 2023
Observing and modeling turbulent mixing

**Observations**
- ArgoMix
- Tracer release experiments

**Scaling up in space & time**
- ArgoMix
- Tracer release experiments

**State estimates**
- How can we improve mixing representation in ECCO (better observationally-constrained global models for regional downscaling)?
- Can we use ECCO to provide meaningful large-scale estimates of ocean mixing (filling in the data gaps)?

**Modeling**

**Observations**
- Data Assimilation
- Scaling up in time & space
- Validation and statistics

**Numerical Models**
- Increasing resolution

**Integrated System**
- Observation-constrained downscaling
Observations

Data

Assimilation

Scaling up in time & space

Validation and statistics

Ecosystem Integrated system

Numerical Models

Increasing resolution

Observations - constrained downscaling

Data assimilation

Timescales

Mixing

MOC

Tracers

BGC

Mixing

Tracers

BGC

MOC

Timescales

Mixing

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BGC

MOC

Timescales