A Data-Driven Approach for the Submesoscale Parameterization

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Laure Zanna

M²LInES

NYU

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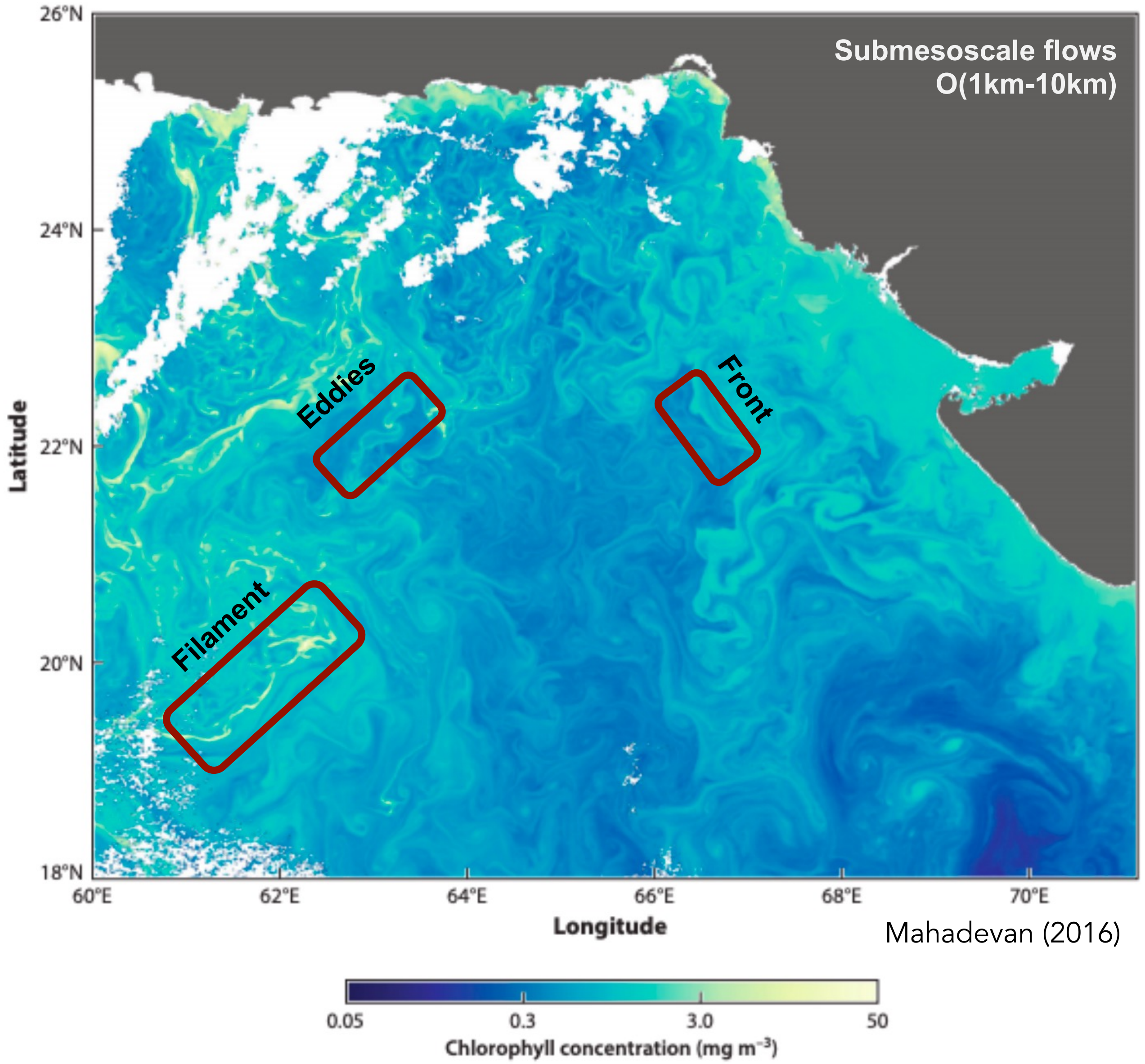


Mahadevan (2016)

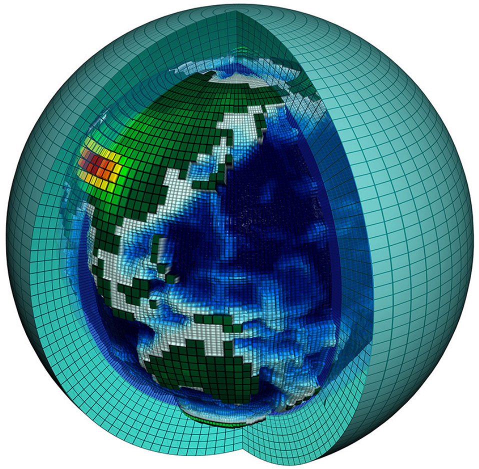
Ocean Mixed Layer

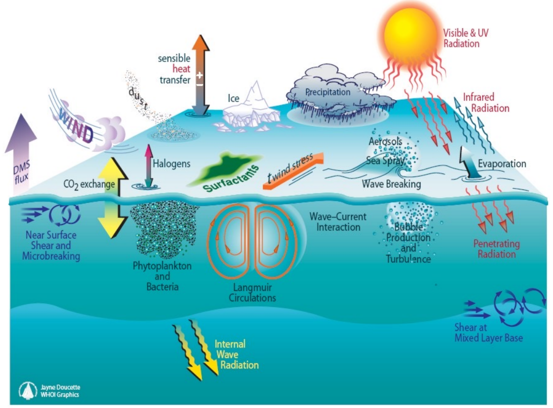
- Mixing and turbulence controls atmosphere-ocean interactions
- Accurate representation of fluxes is crucial for climate simulations
- Small, fast and complex processes
- Unresolved in General Circulation Models

Buoyancy equation

$$\frac{\partial \bar{b}}{\partial t} + \nabla \cdot (\bar{\mathbf{u}}\bar{b}) = \nabla \cdot (\overline{\mathbf{u}'b'})$$

subgrid fluxes of b' (parameterizations)





Processes in the upper ocean mixed layer

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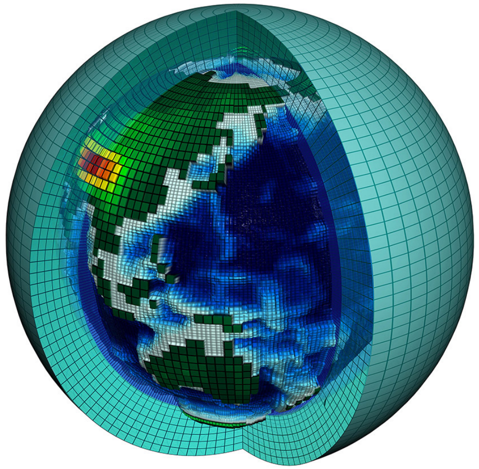

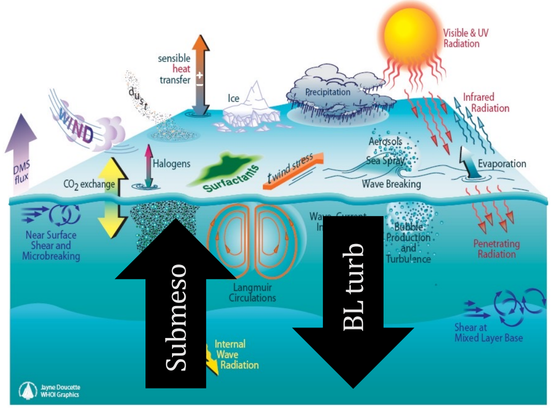

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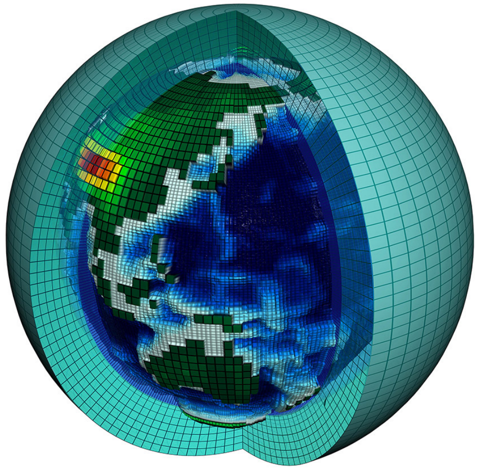
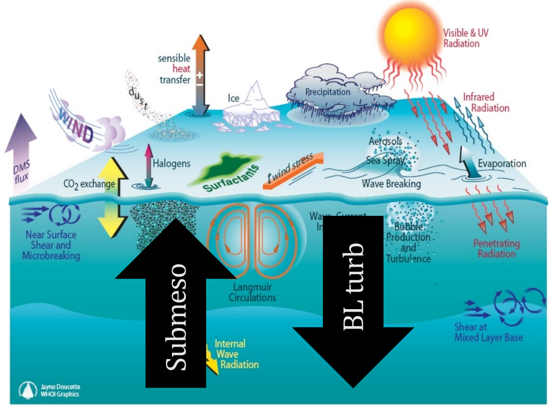


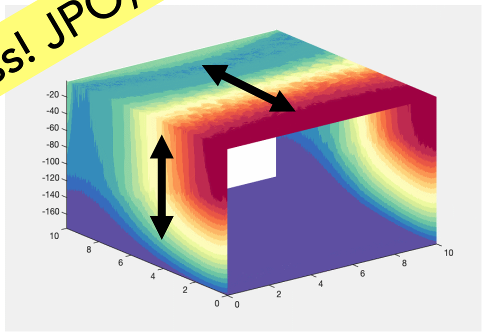


Processes in the upper ocean mixed layer

Physics-based

Buoyancy equation
$$\frac{\partial \bar{b}}{\partial t} + \nabla \cdot (\bar{\mathbf{u}}\bar{b}) = \boxed{\nabla \cdot (\overline{\mathbf{u}'b'})}$$
subgrid fluxes of b'
(parameterizations)

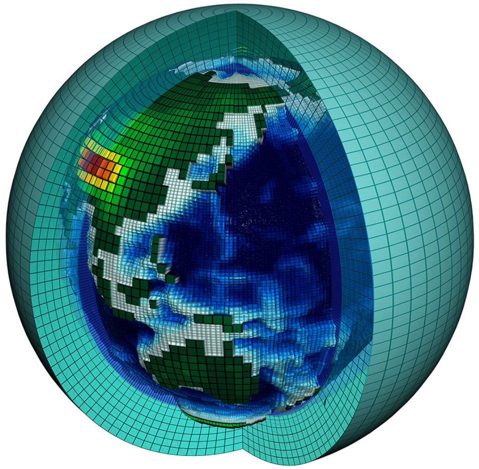
Hot off the press! JPO, Jan 2023



Modifying the Mixed Layer Eddy Parameterization

$$L_f = C_f \cdot \frac{(m_* u_*^3 + n_* w_*^3)^{\frac{2}{3}}}{f^2} \cdot \frac{1}{h}$$

Ocean Mixed Layer



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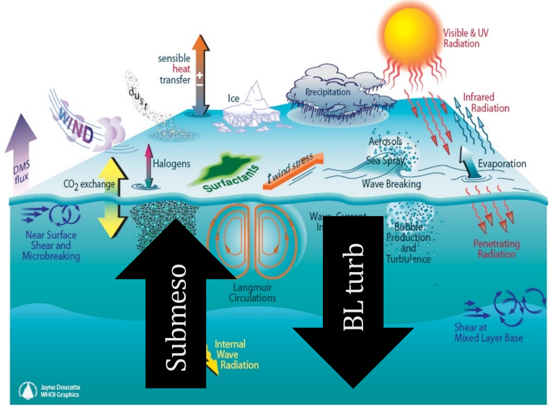

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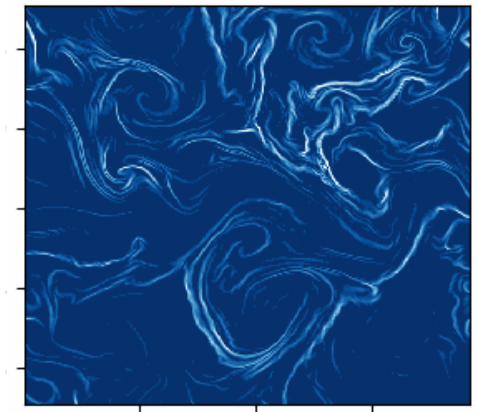

Data-Driven

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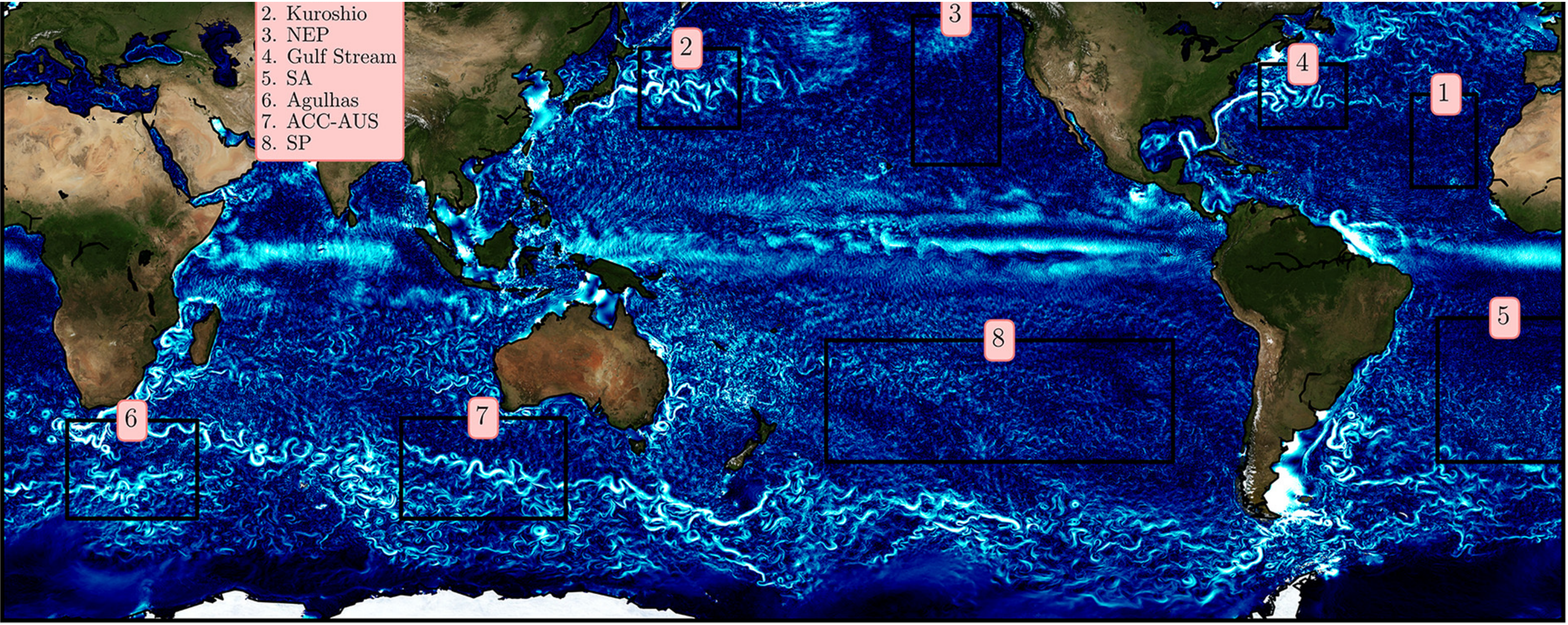
Data from submesoscale permitting simulation

MITgcm-llc4320 (horizontal resolution $1/48^o$ ~2km)



Torres et al (2018)

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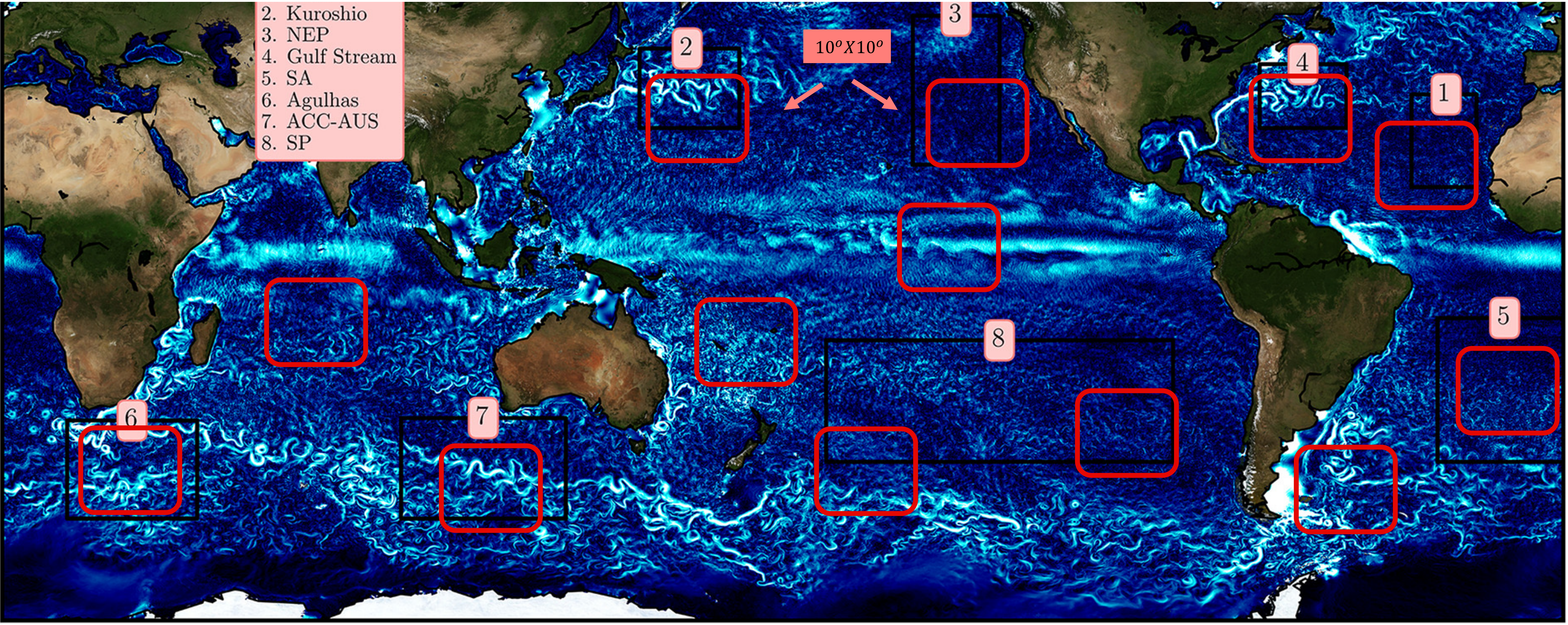


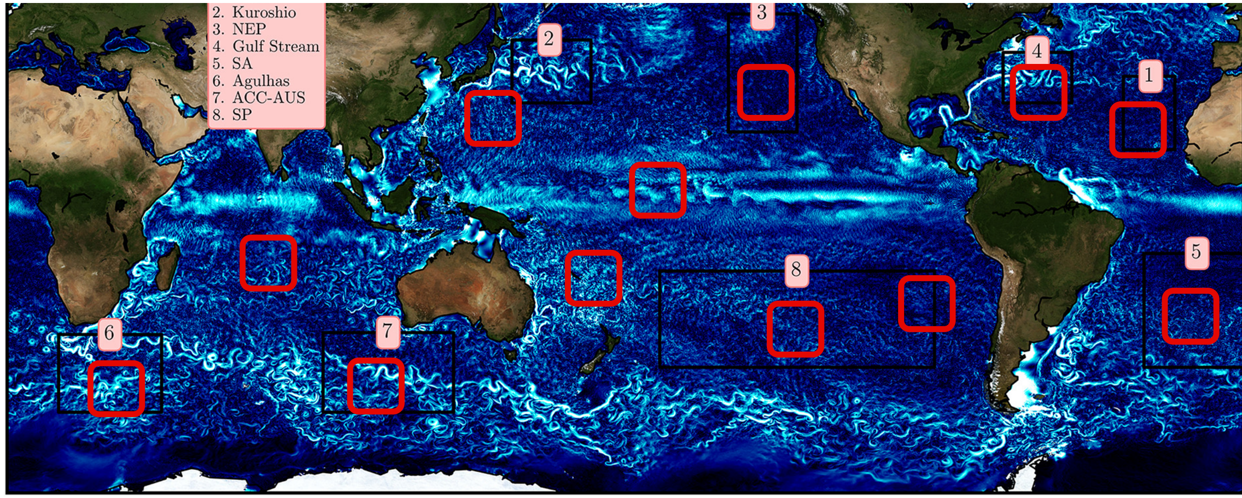
Made possible by the xmitgcm llcreader package

Torres et al (2018)

Data from submesoscale permitting simulation

- $1/48^o$ ~2km horizontal resolution
- Select $10^o X 10^o$ domains from global simulation
- Total of 14 months of hourly data, downsampled to 12 hours
- Train Neural Network to predict submesoscale-induced vertical fluxes

MITgcm-llc4320



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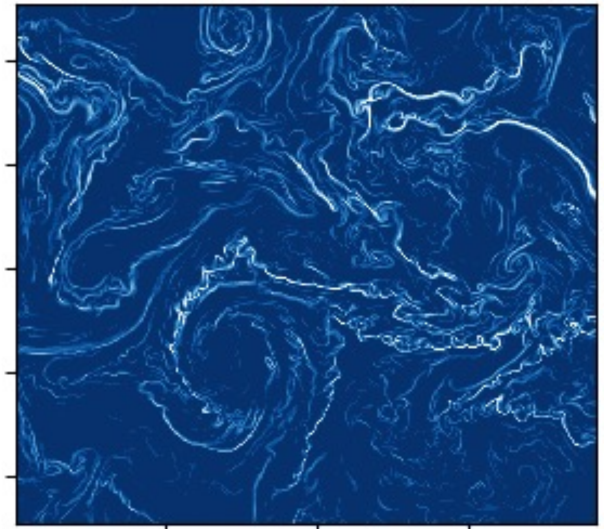

$$\Psi = \frac{\overline{w'b'}^z}{\overline{|\nabla b|}^z}$$

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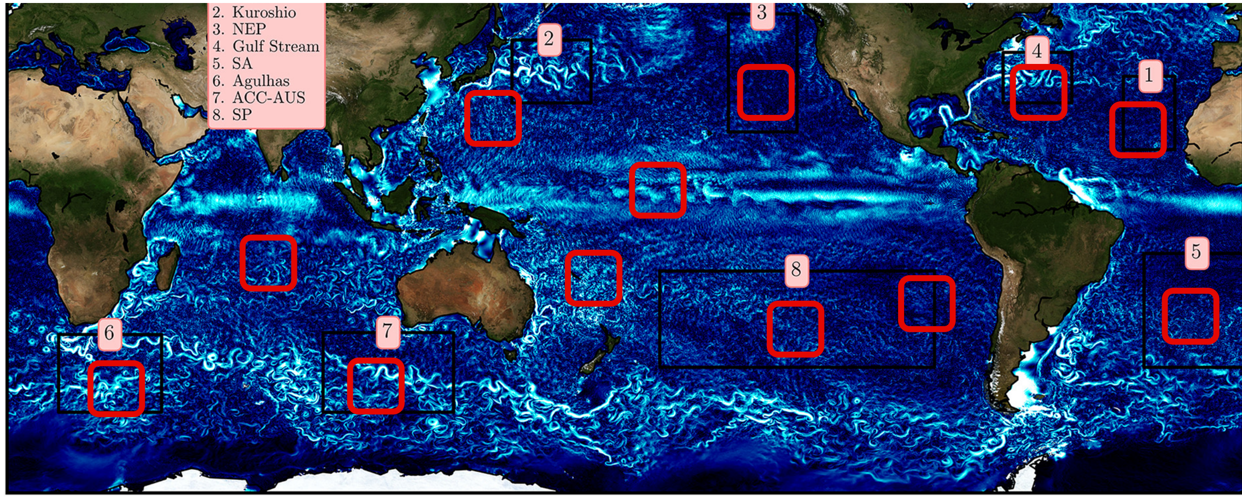

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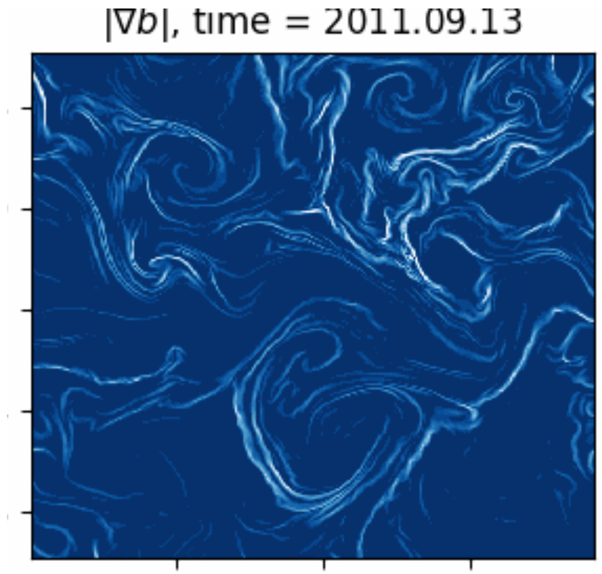

Data from submesoscale permitting simulation

MITgcm-llc4320

- **Inputs** ($1/4^o$ resolution):

  Mixed layer depth, boundary layer depth,
  wind stress, surface heat flux,
  Coriolis, MLD-averaged buoyancy gradient,
  MLD-averaged stratification

$$\Psi = \frac{\overline{w'b'}^z}{\overline{|\nabla b|}^z}$$

- **Target** ($1/4^o$ resolution): :

  MLD-averaged vertical buoyancy flux

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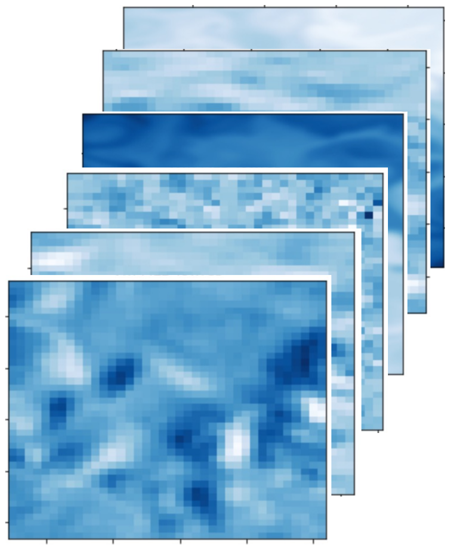
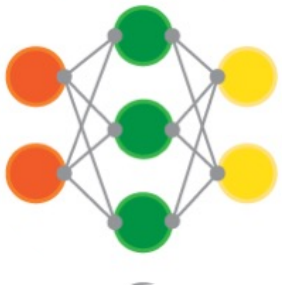
Inputs (resolved by GCM):

$H_{ML},\ h_B,$

$\tau,\ Q^*, f$

$\overline{|\nabla b|}^z, N^2$

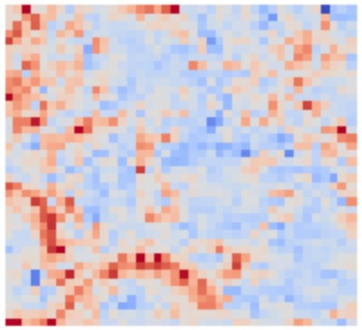




Convolutional Neural Network

Target

Subgrid submesoscale vertical buoyancy fluxes



$\overline{w'b'}^z$

Offline Training Results

- Fully Convolutional Neural Network
  (7 hidden layers, kernel 5x5)

- ~10,000 samples: 90% train, 10% test

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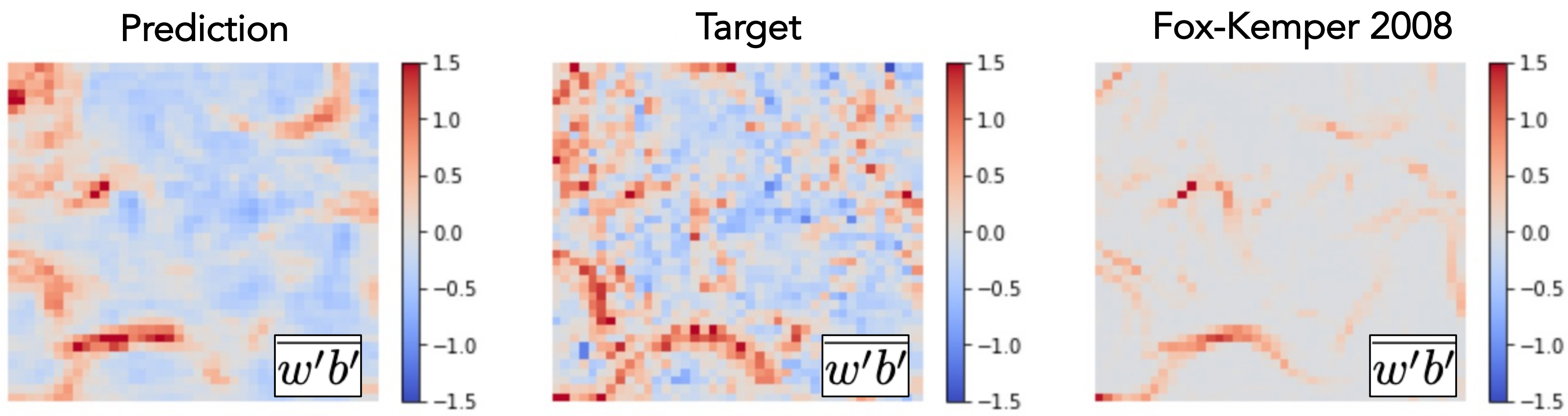
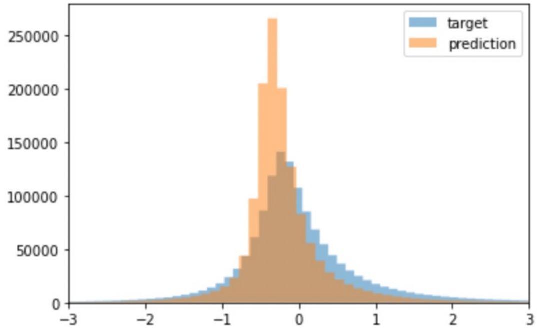


$$\propto \frac{H_{ML}\overline{|\nabla_H B|}^{z\,2}}{|f|}$$

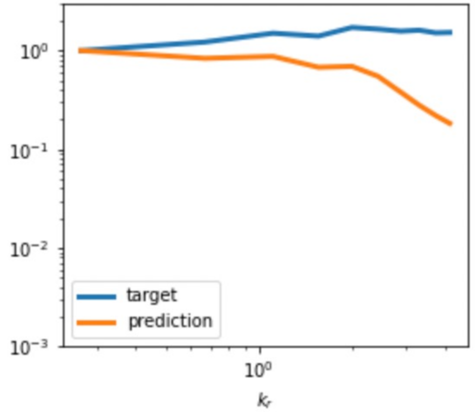
Offline Training Results

- Fully Convolutional Neural Network (7 hidden layers, kernel 5x5)
- ~10,000 samples: 90% train, 10% test
  - Prediction is a smoothed version of target
  - Spectral properties match at large scales but taper off at small scales
  - PDFs of prediction are also skewed

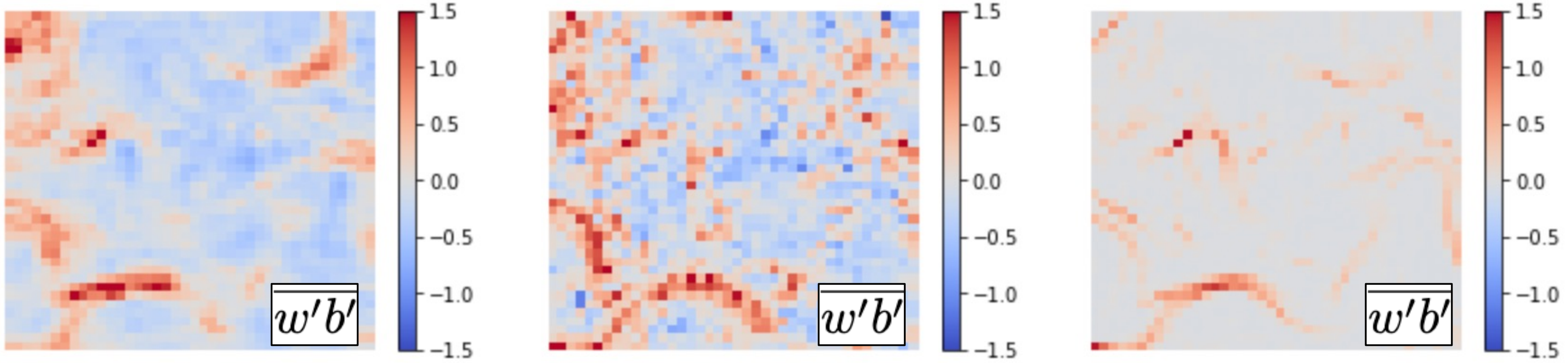
$\overline{w'b'}$ PDFs



$\overline{w'b'}$ Spectra

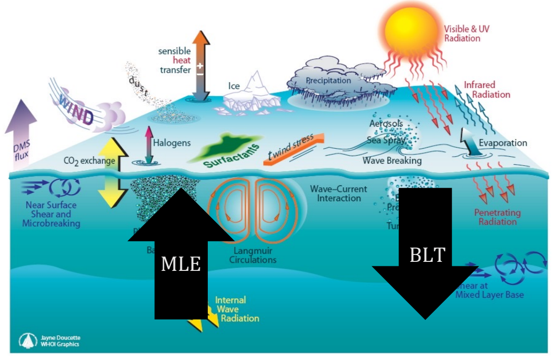


Prediction | Target | Fox-Kemper 2008



$\propto \dfrac{H_{ML}\overline{|\nabla_H B|}^{z\,2}}{|f|}$

Ocean Mixed Layer Parameterizations



- Predicting vertical buoyancy flux

$$\Psi = \frac{\overline{\overline{w'b'}}^z}{\overline{|\nabla b|}^z}$$

Data-Driven

- Down-gradient flux
  (e.g. KPP, epbl):

$$\overline{\mathbf{u}'b'} = \kappa \nabla \overline{b}$$

Diffusivity

- Eddy Streamfunction
  (e.g. GM, FK08):

$$\overline{\mathbf{u}'b'} = \Psi_{MLE} \times \nabla \overline{b},$$

Eddy fluxes define streamfunction

$$\mathbf{u}^{MLE} = \nabla \times \Psi_{MLE}$$

Bolus velocity represents stirring

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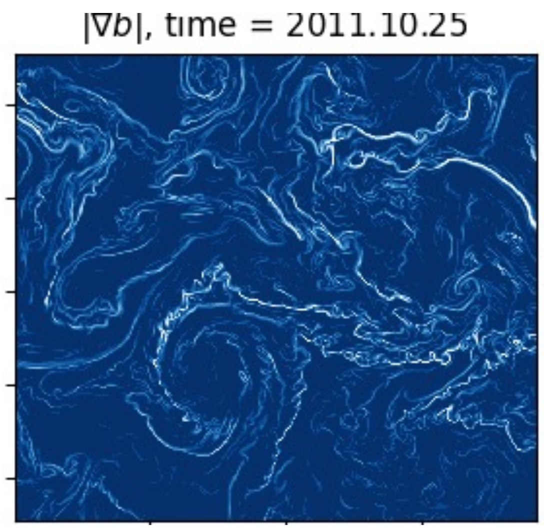
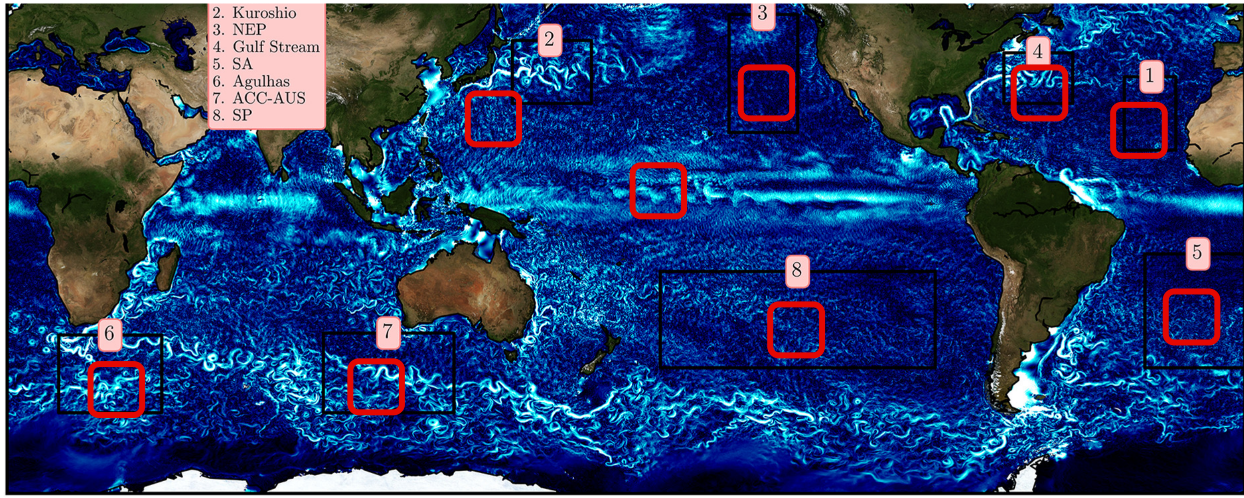
SCAN ME

Summary and future work

$$\Psi = \frac{\overline{w'b'}^z}{\overline{|\nabla b|}^z}$$



- Data-driven approach for parameterizing vertical submesoscale buoyancy fluxes given by the ultra-high resolution MITgcm-llc4230
- Predicted fluxes are smoother compared to target but resemble in large-scale statistics
- Exploring different NN architectures to learn finer-scale features
- Testing sensitivity to input variables
  - Do we need all?
  - Any others relevant? e.g. strain, divergence
- Developing different approaches for GCM implementation which correspond to relevant ocean parameterizations



Extra slides