Data-Driven Ocean Modeling

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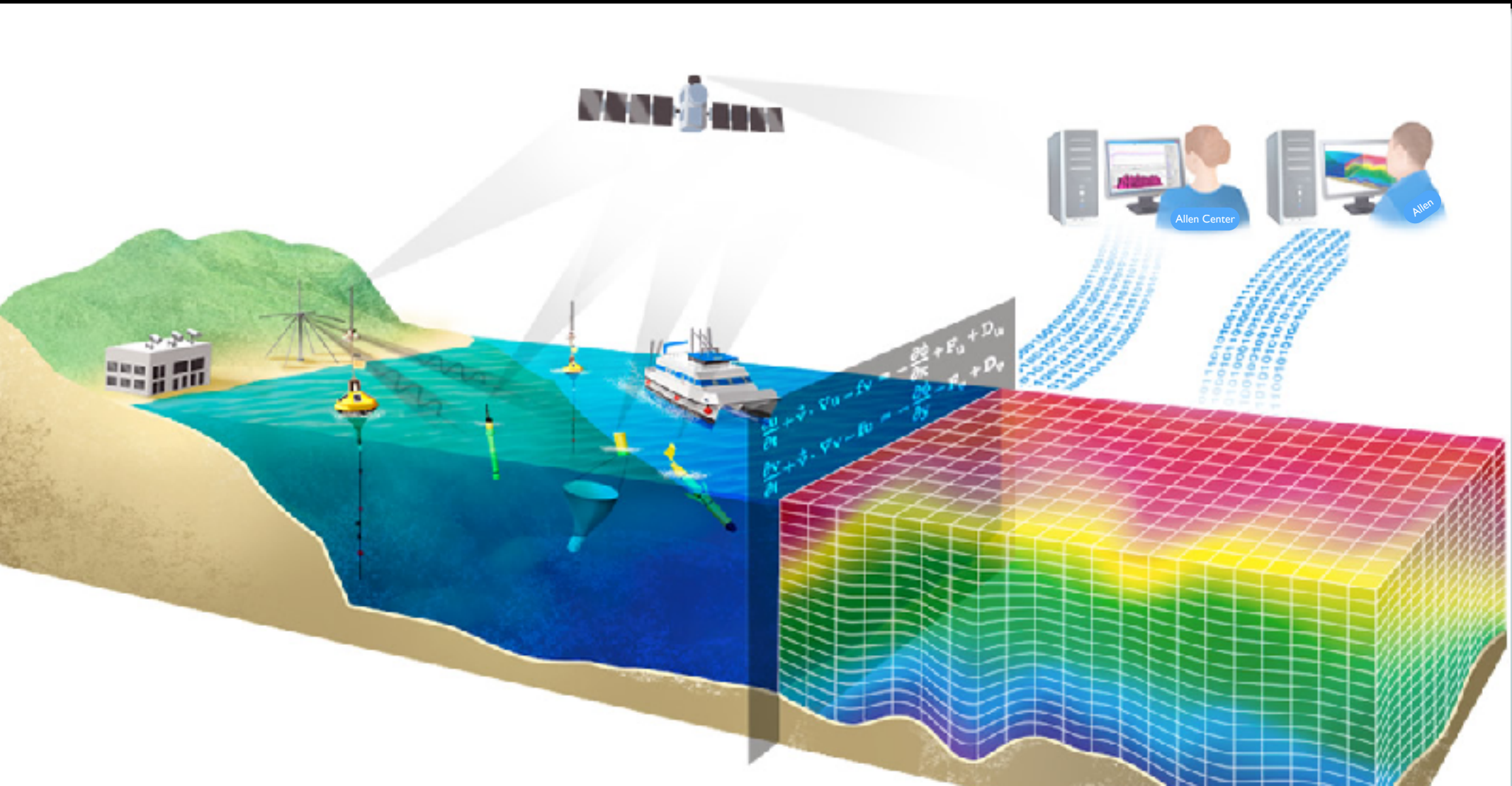
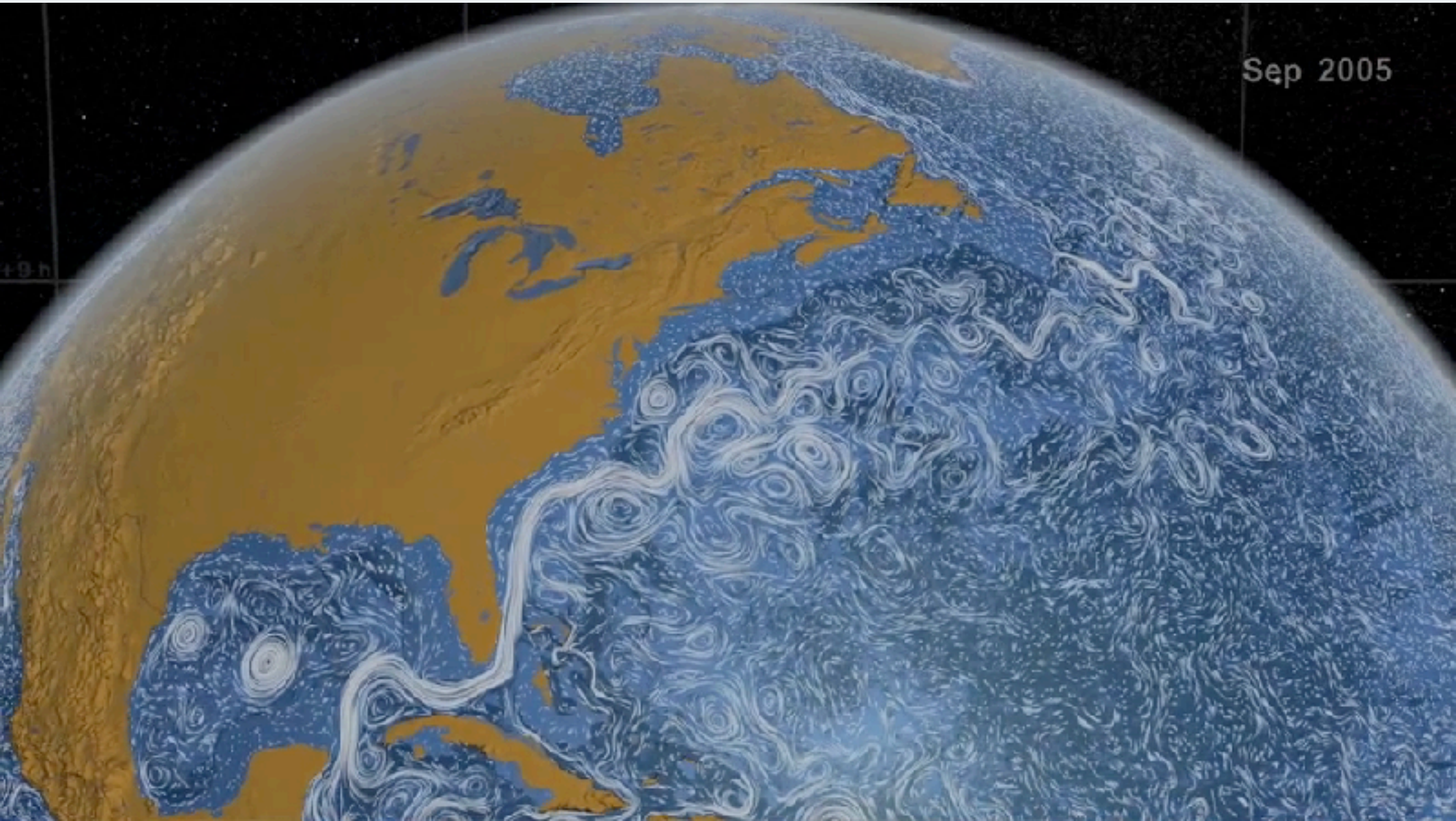


Ocean Modeling Challenge

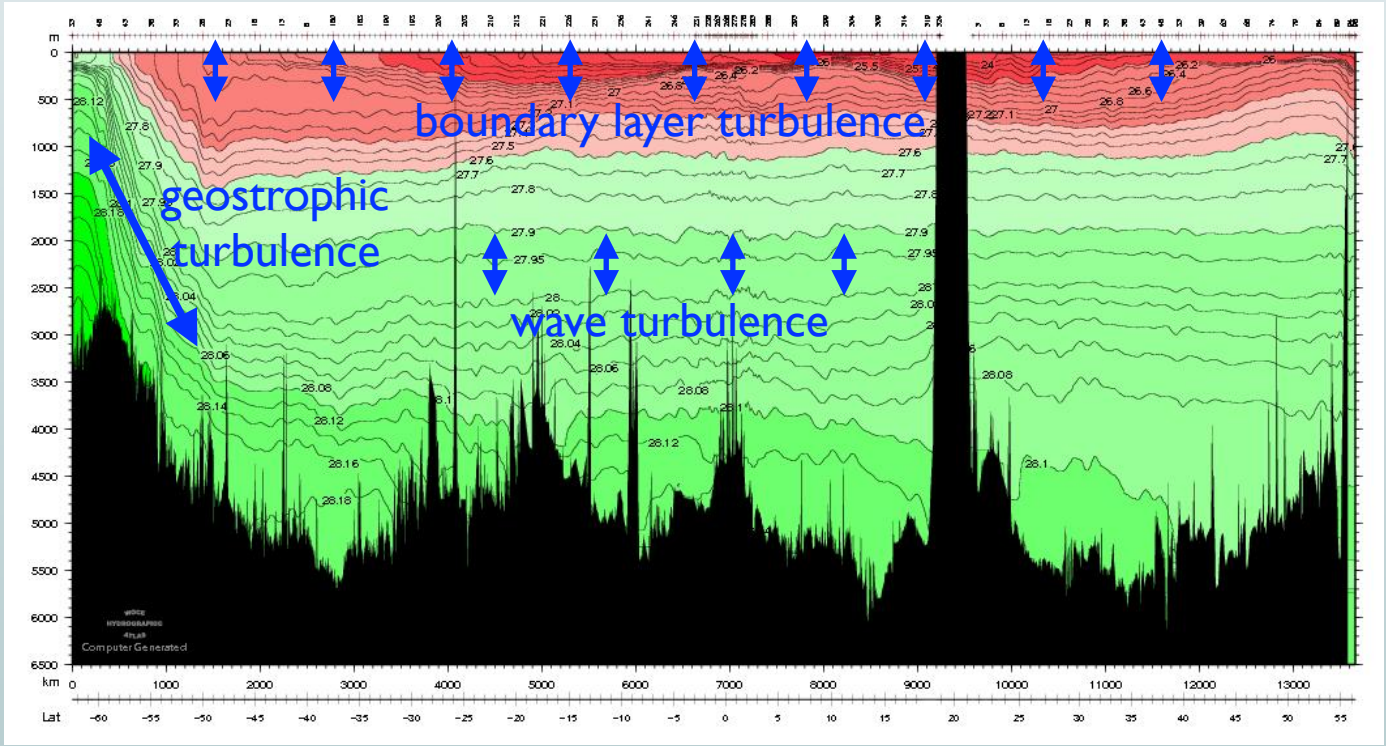
Ocean circulation is very turbulent: parametrization problem



Sub-Grid-Scale Physics

$$\frac{D\bar{\mathbf{u}}}{Dt} + \frac{1}{\rho_0}\nabla\bar{p} - \bar{b}\mathbf{z} - \nabla\cdot(\nu\nabla\bar{\mathbf{u}}) = \underbrace{-\nabla\cdot\overline{\mathbf{u}'\mathbf{u}'}}_{\text{Reynolds stresses}}$$

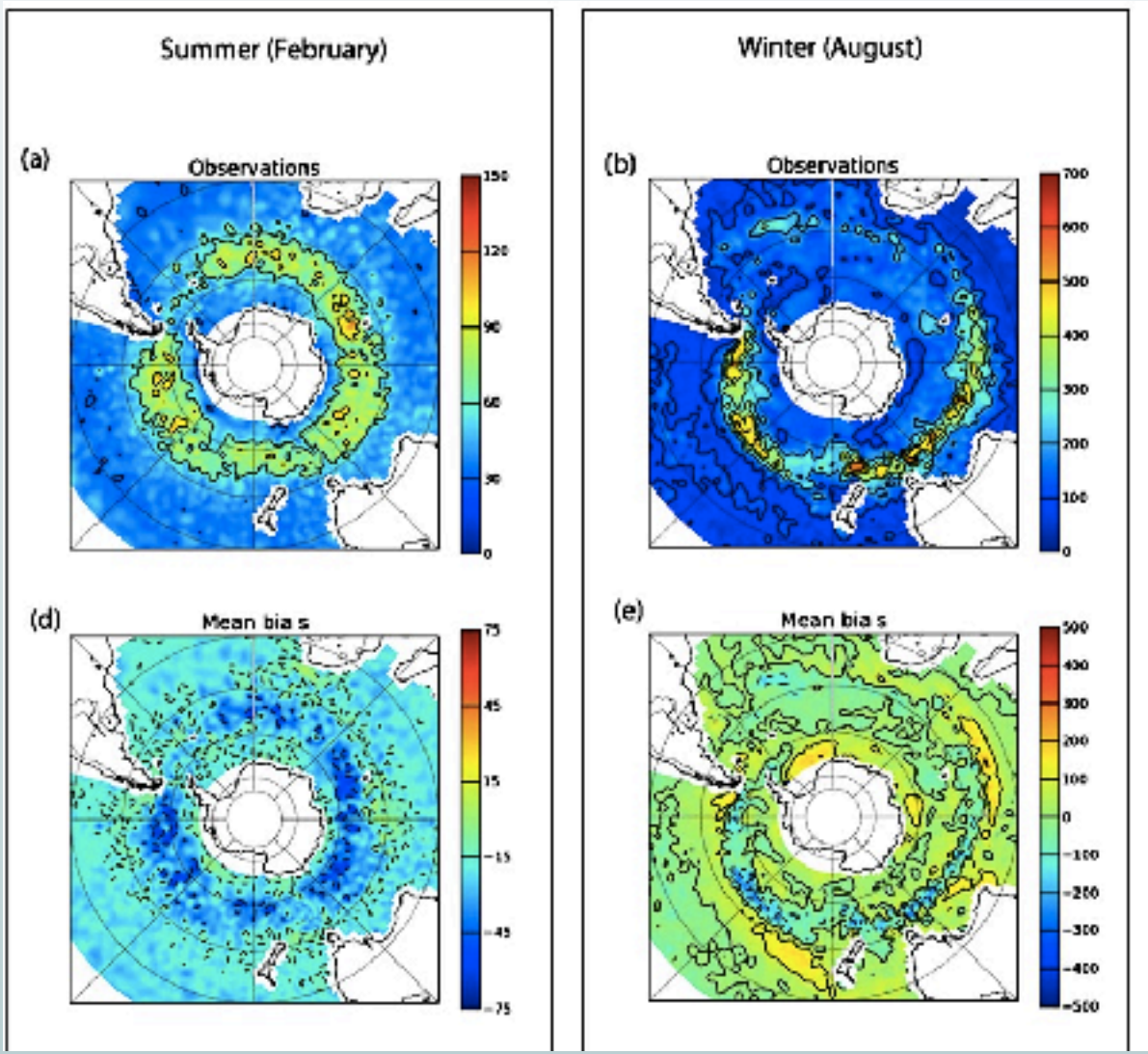
$$\frac{D\bar{b}}{Dt} - \nabla\cdot(\kappa\nabla\bar{b}) = \underbrace{-\nabla\cdot\overline{\mathbf{u}'b'}}_{\text{Reynolds fluxes}}$$



Neutral density (kg m^3) section in the Pacific Ocean (WOCE, P16)

Boundary Layer Biases

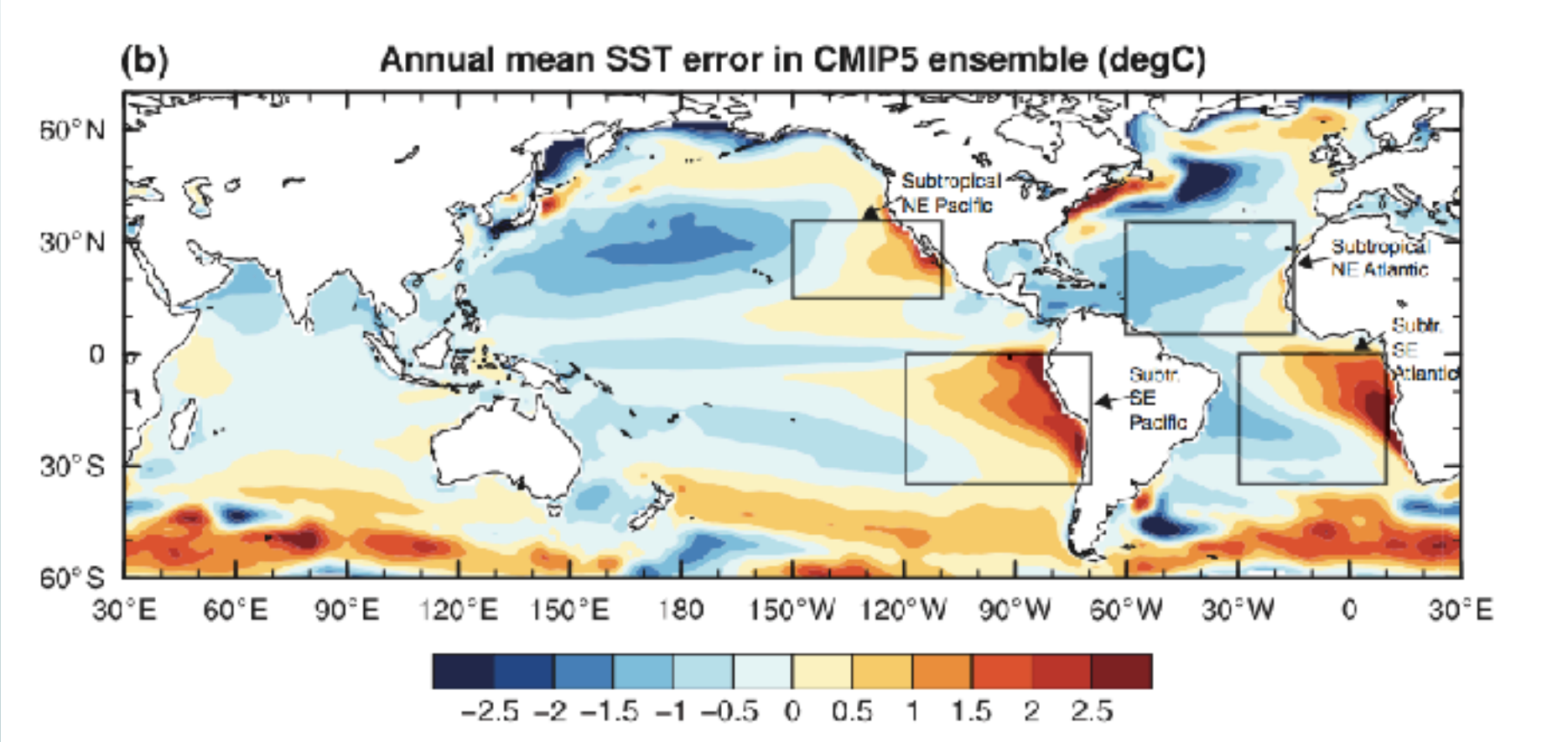
Assessment of Southern Ocean mixed−layer depths in CMIP5 models



Sallée et al. 2013

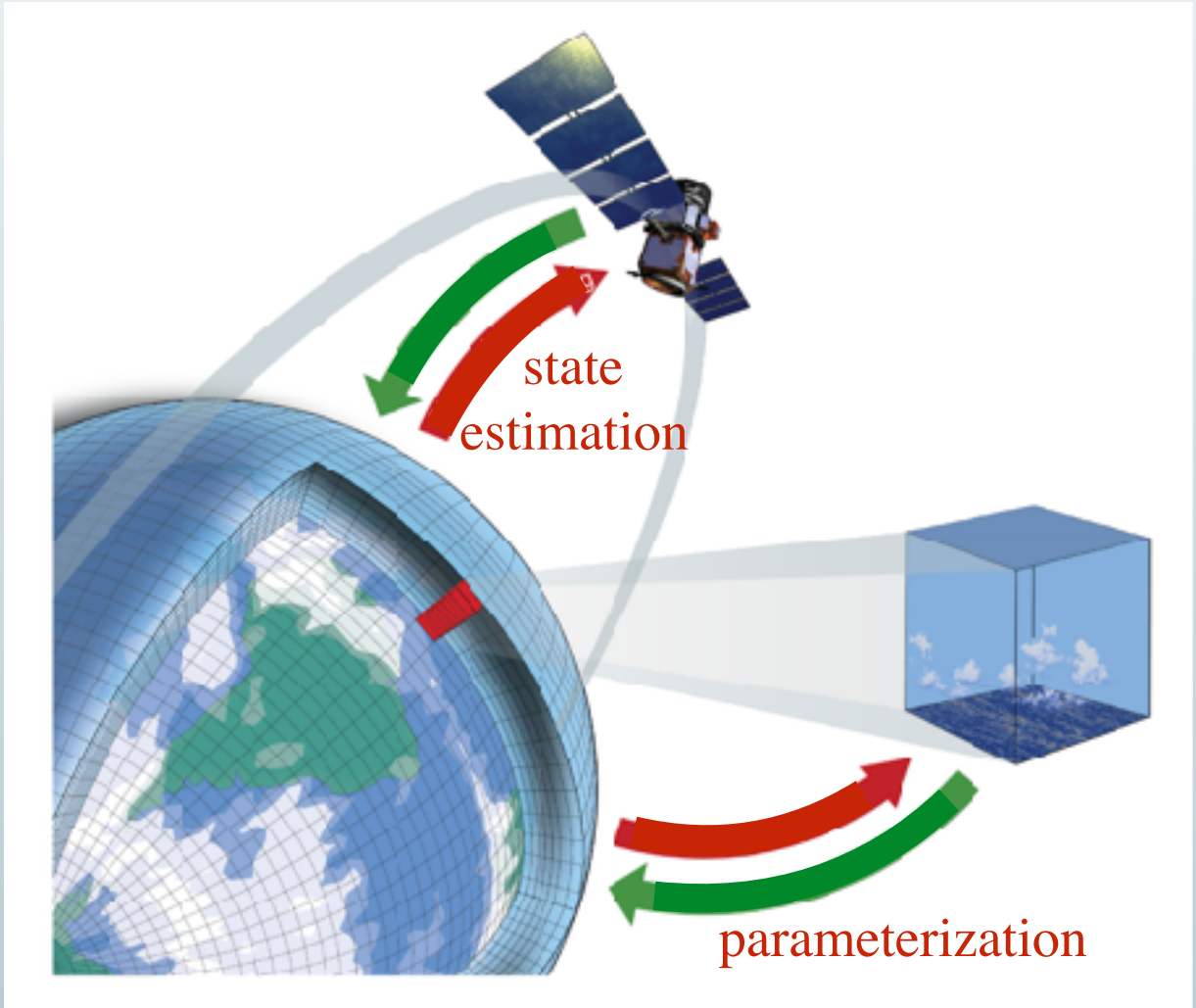
Boundary Layer Biases

Model bias is largest in regions where turbulence is strongest



Richter 2015

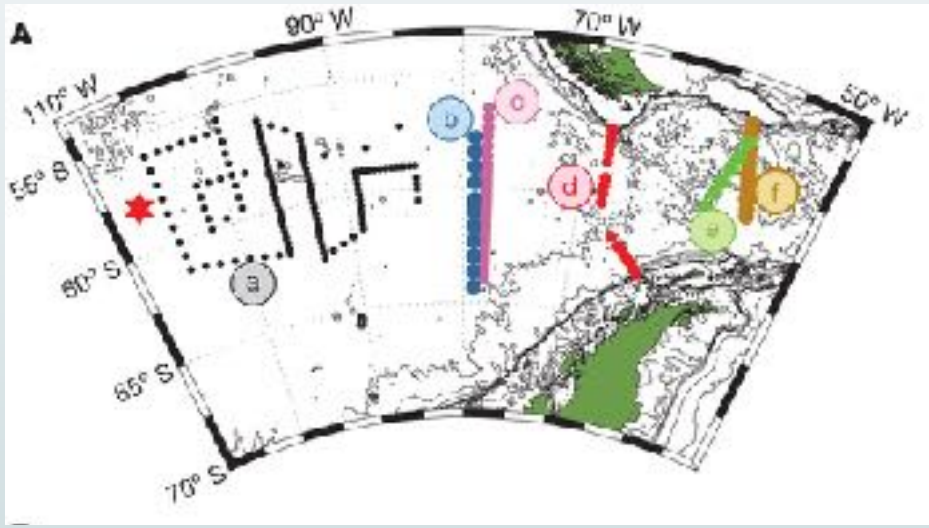
Present day approach to reducing model biases



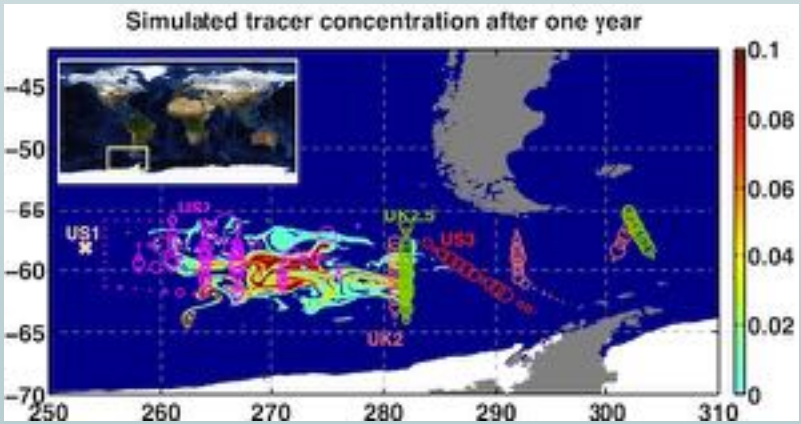
Process studies + LES = parameterizations

Geostrophic turbulence

Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean

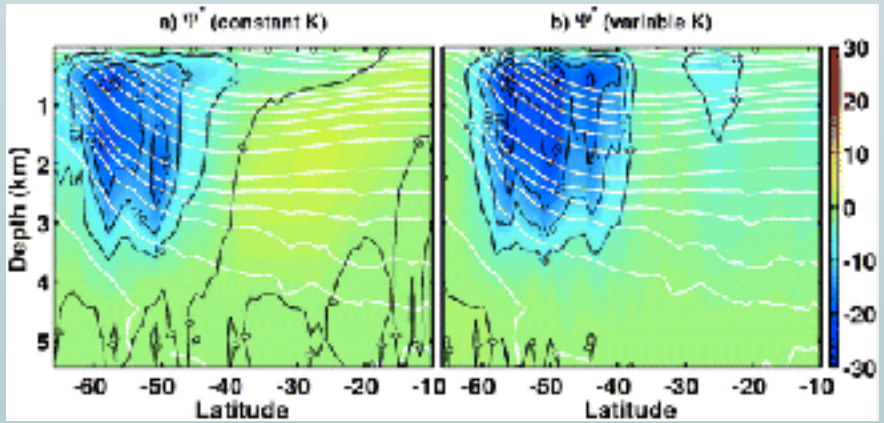


"LES" model



New SGS parameterization

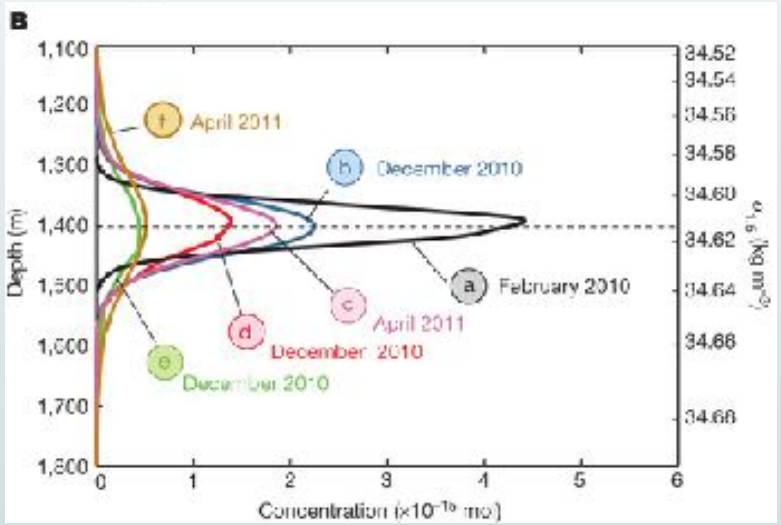
$$\mathbf{S} = \mathbf{S}(K_H, f, \text{slope})$$



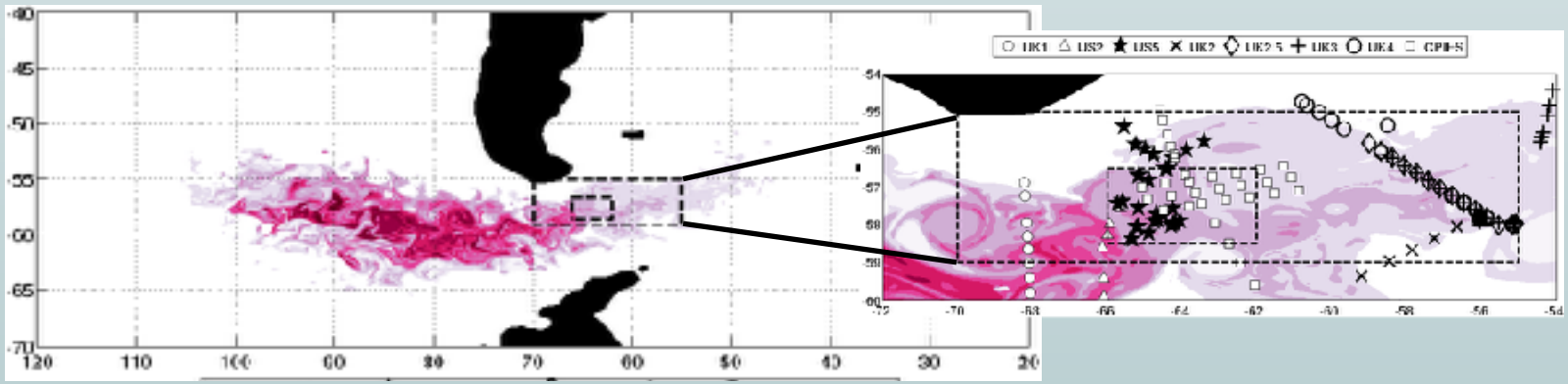
Tulloch, Ferrari et al. 2014; Bates, Marshall and Ferrari 2016

Wave turbulence

DIMES = Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean



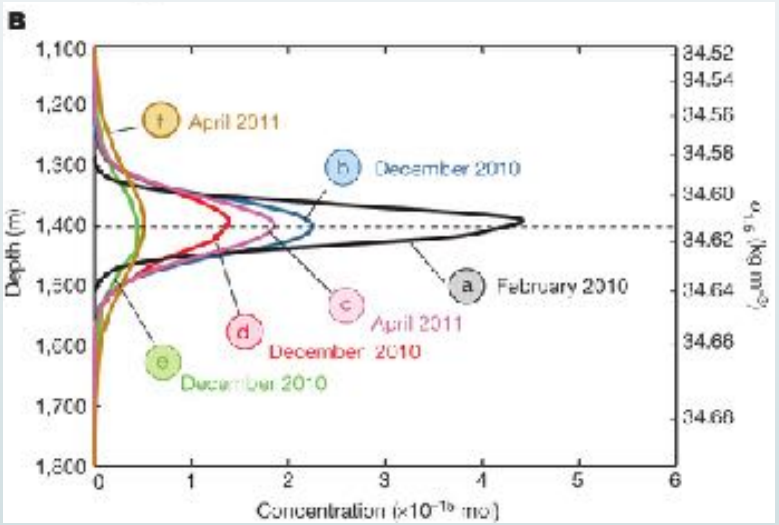
"LES" model



Mashayek, Ferrari et al., 2017

Wave turbulence

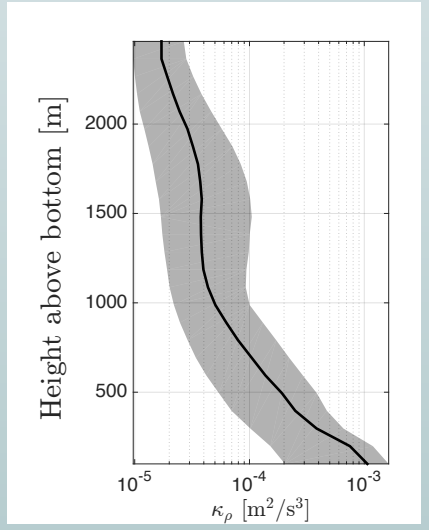
DIMES = Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean



New SGS parameterization

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

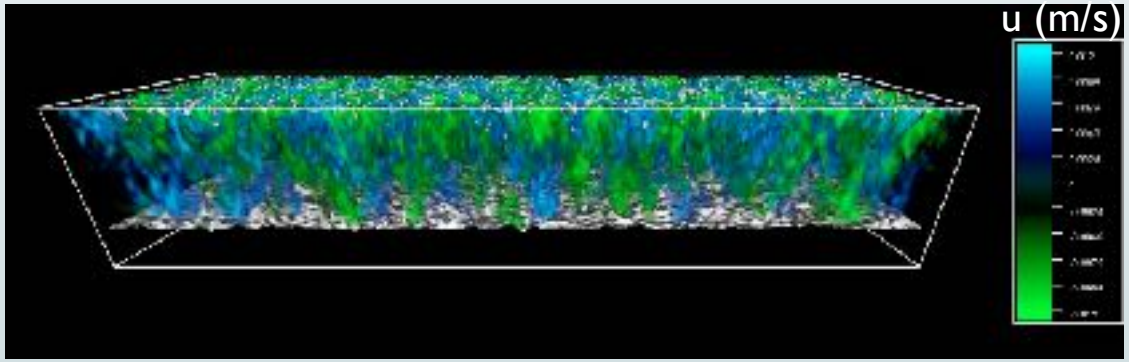
Mashayek, Ferrari et al., 2017



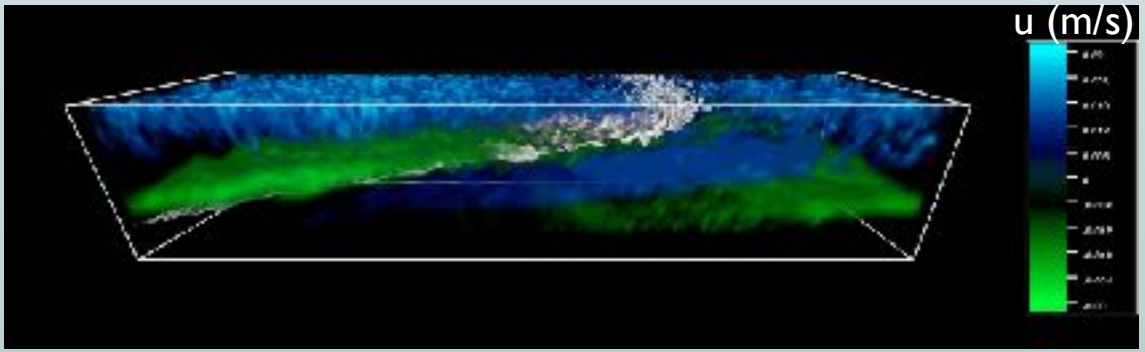
Boundary layer turbulence

Climate Process team on Eddy Mixed Layer Interactions

"LES" model with no front



"LES" model with lateral front



New SGS parameterization

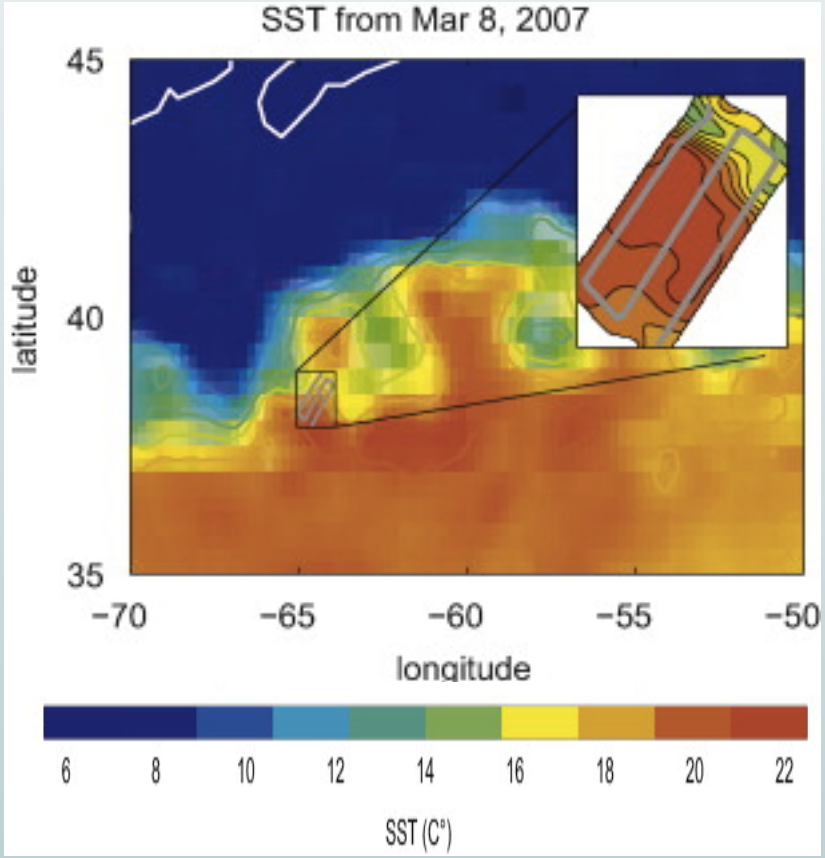
$$\mathbf{S} = \mu(z)\frac{h^2}{|f|}\hat{\mathbf{z}} \times \nabla \bar{b}$$

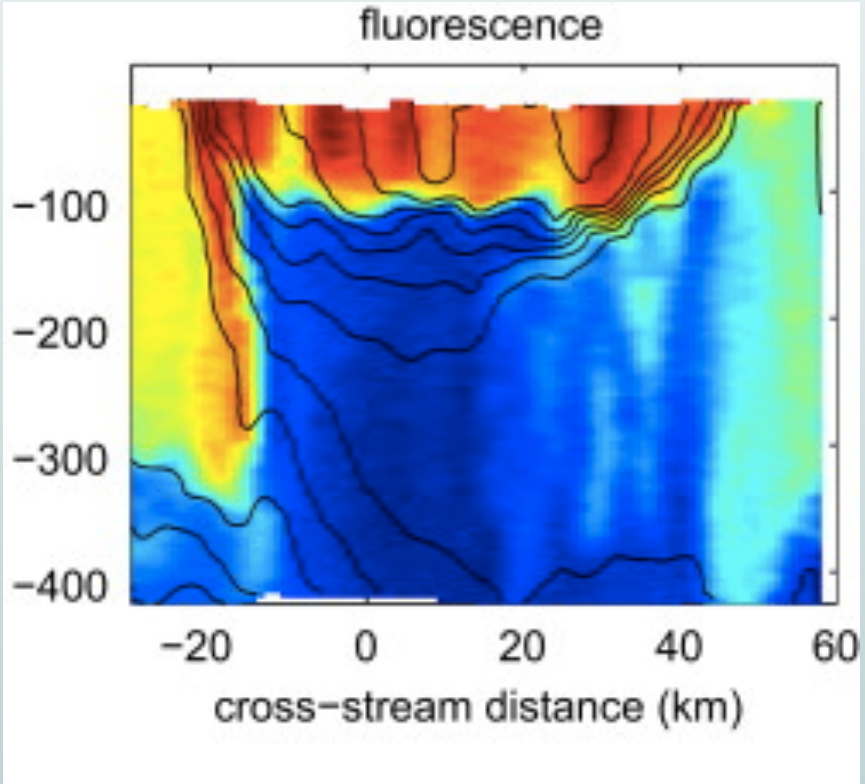
Fox-Kemper, Ferrari and Hallberg 2008, Taylor and Ferrari 2010

Boundary layer turbulence

CLIMODE Experiment

Observations





Tomas, Joyce, Taylor and Ferrari et al., 2013

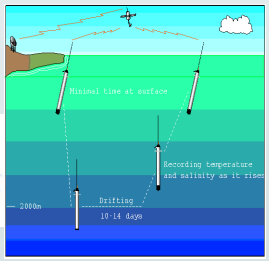
Observations + global model = state estimation

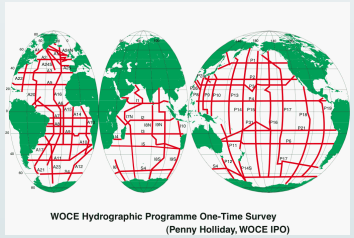
Ocean state estimation

Constrain global ocean circulation by assimilating in situ and remote data in global ocean solutions

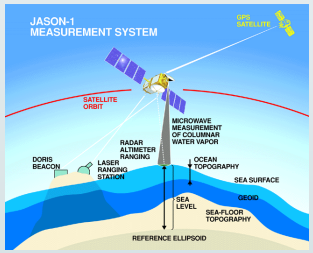
Ship profiles

Floats

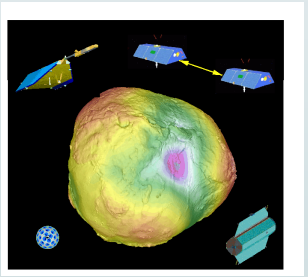




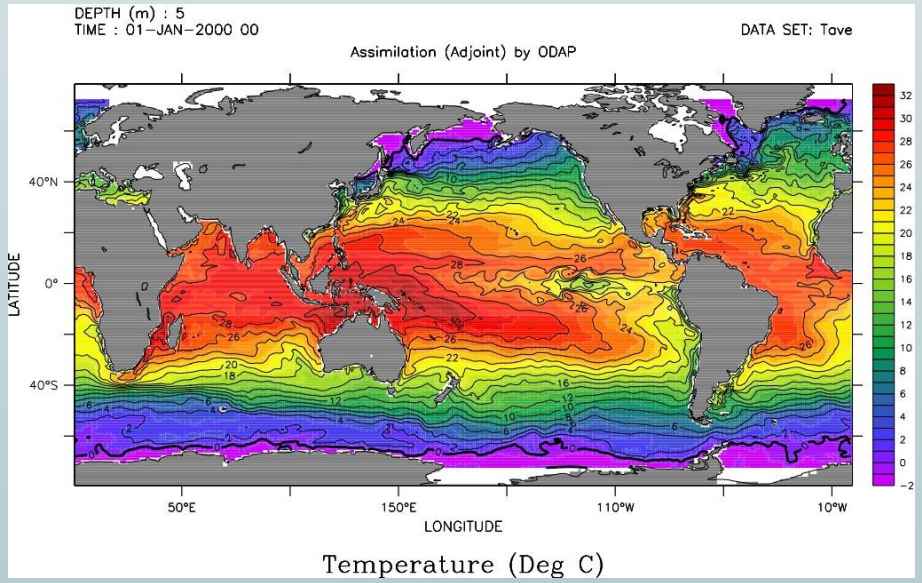
Altimeters



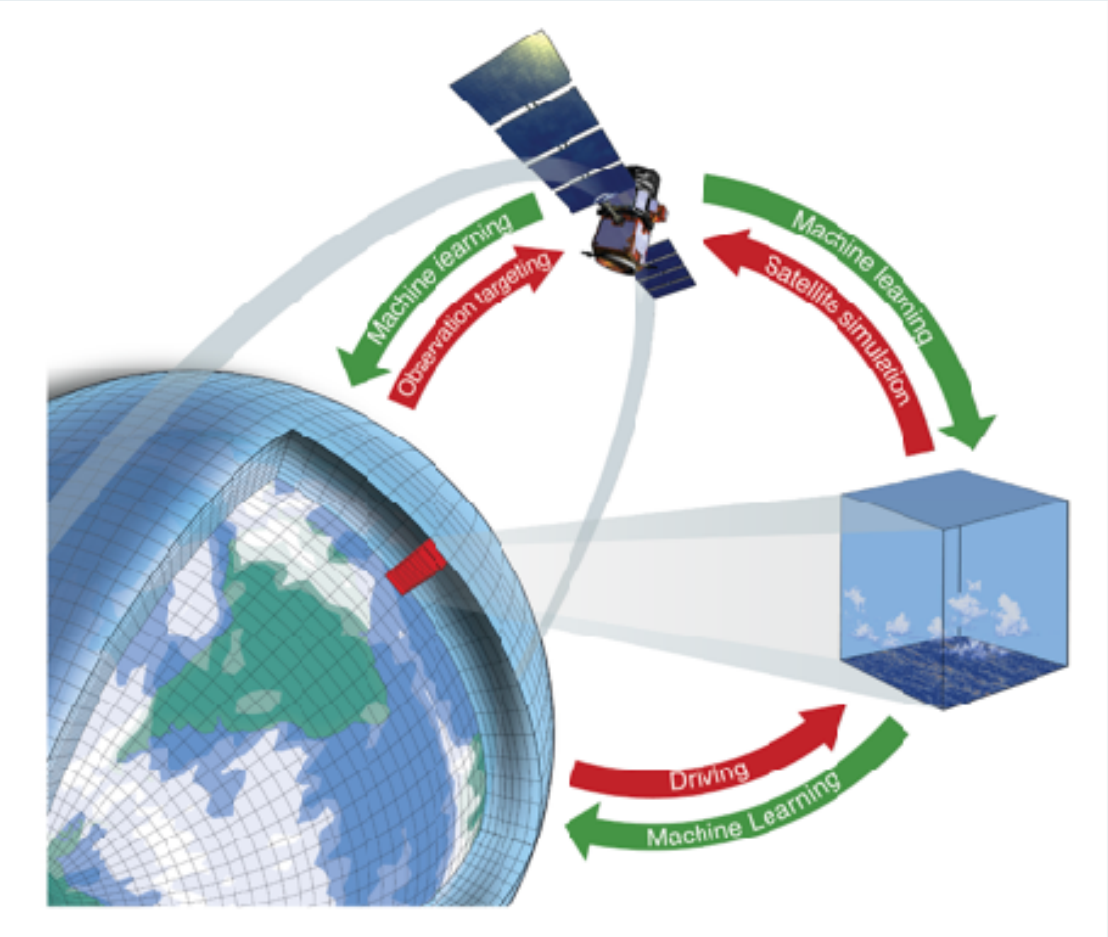
Gravity



MIT Ocean Model and Its



A new approach to reducing model biases



Schneider et al., 2017

Moving forward

1. Develop unified SGS process models of boundary layer turbulence in the atmosphere and ocean

2. Develop global atmosphere and ocean model with horizontal resolution of a few kilometers and with SGS models that learn from the fly from nested LES and global observations through scalable algorithms for DA/ML

3. Couple the atmosphere and ocean models

Improve the representation of SGS physics in climate models