The role of mesoscale eddies in sustaining oceanic production

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MOBY Meeting

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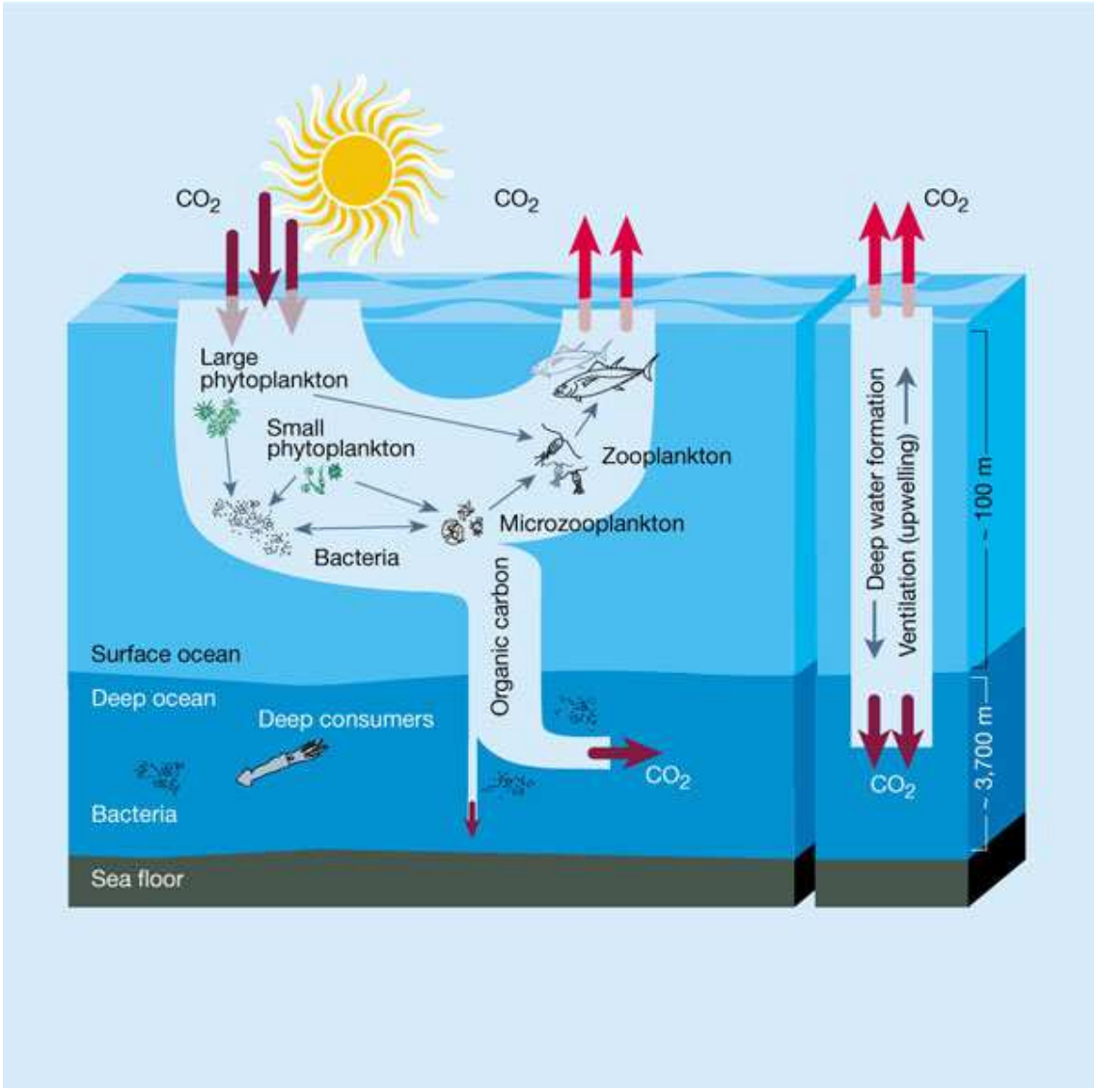
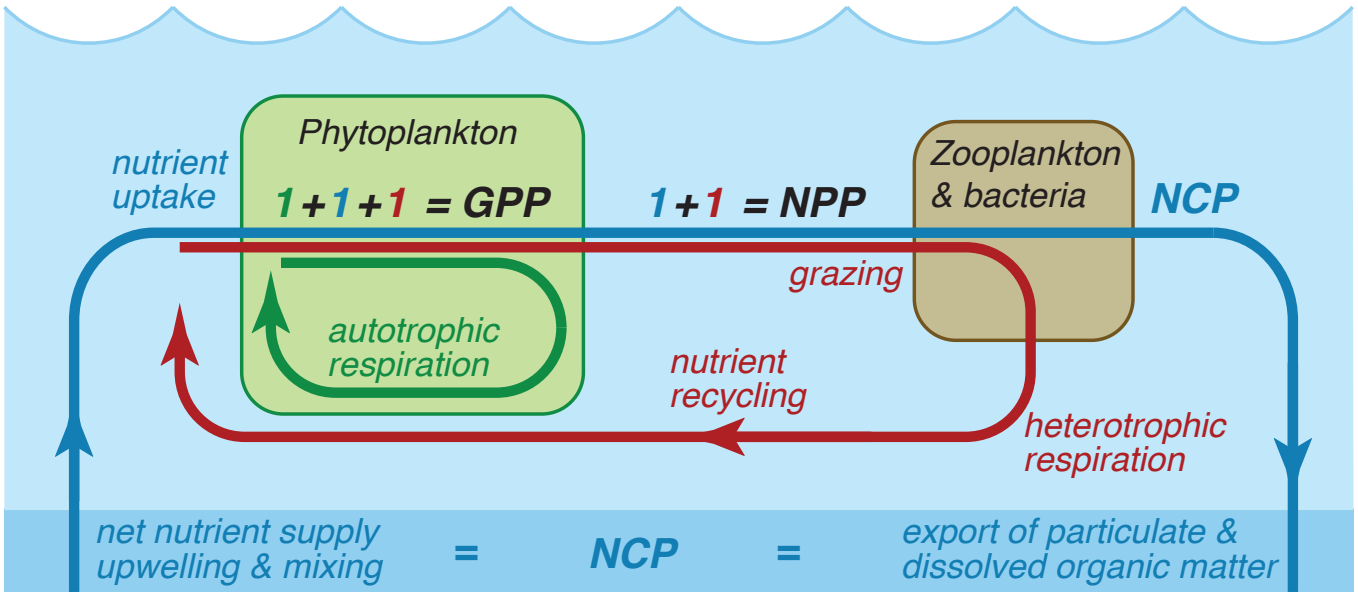
Primary productivity is a fundamental ecological and biogeochemical process



Chisholm 2000

Net community production



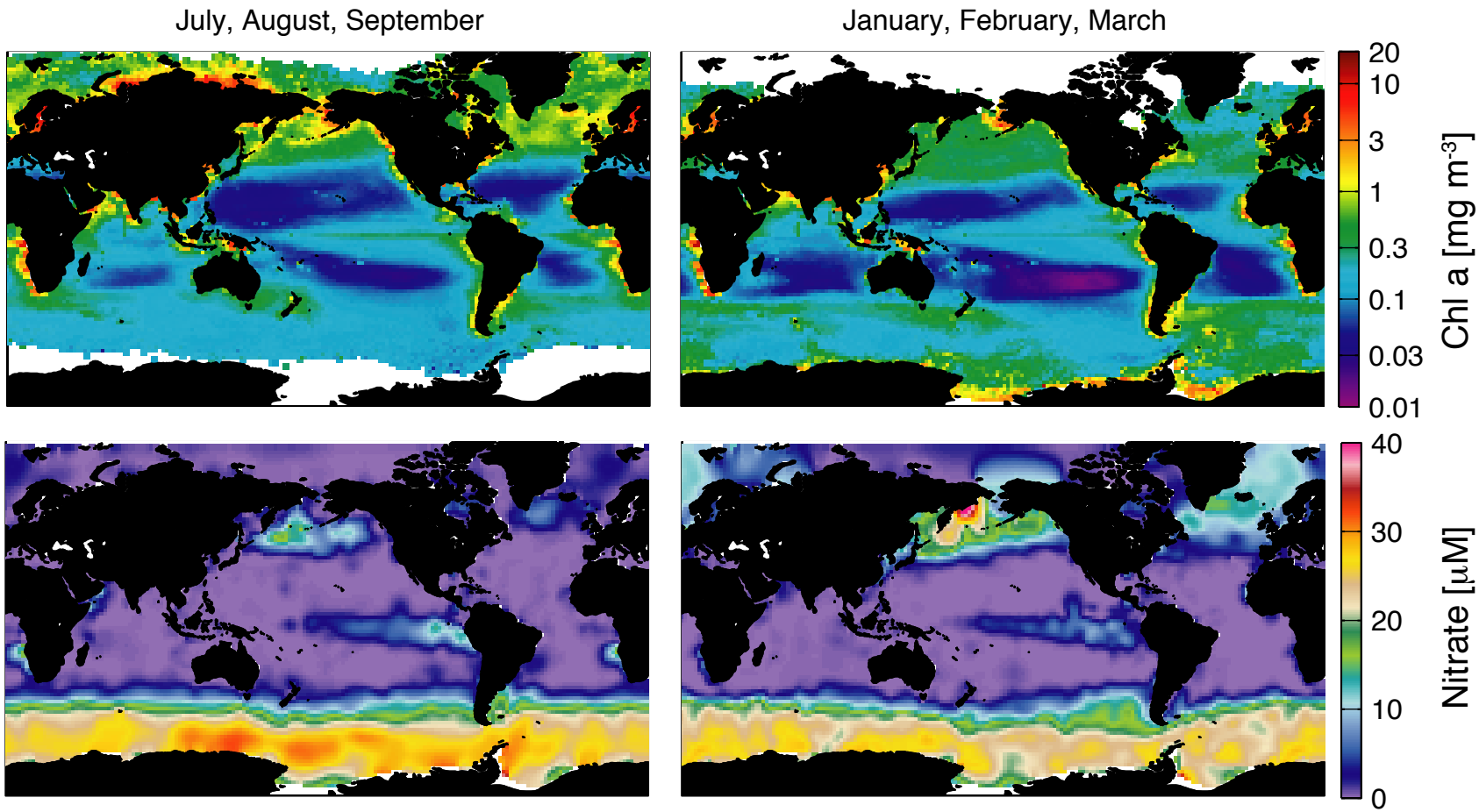
GPP: Gross primary productivity
NPP: Net primary productivity

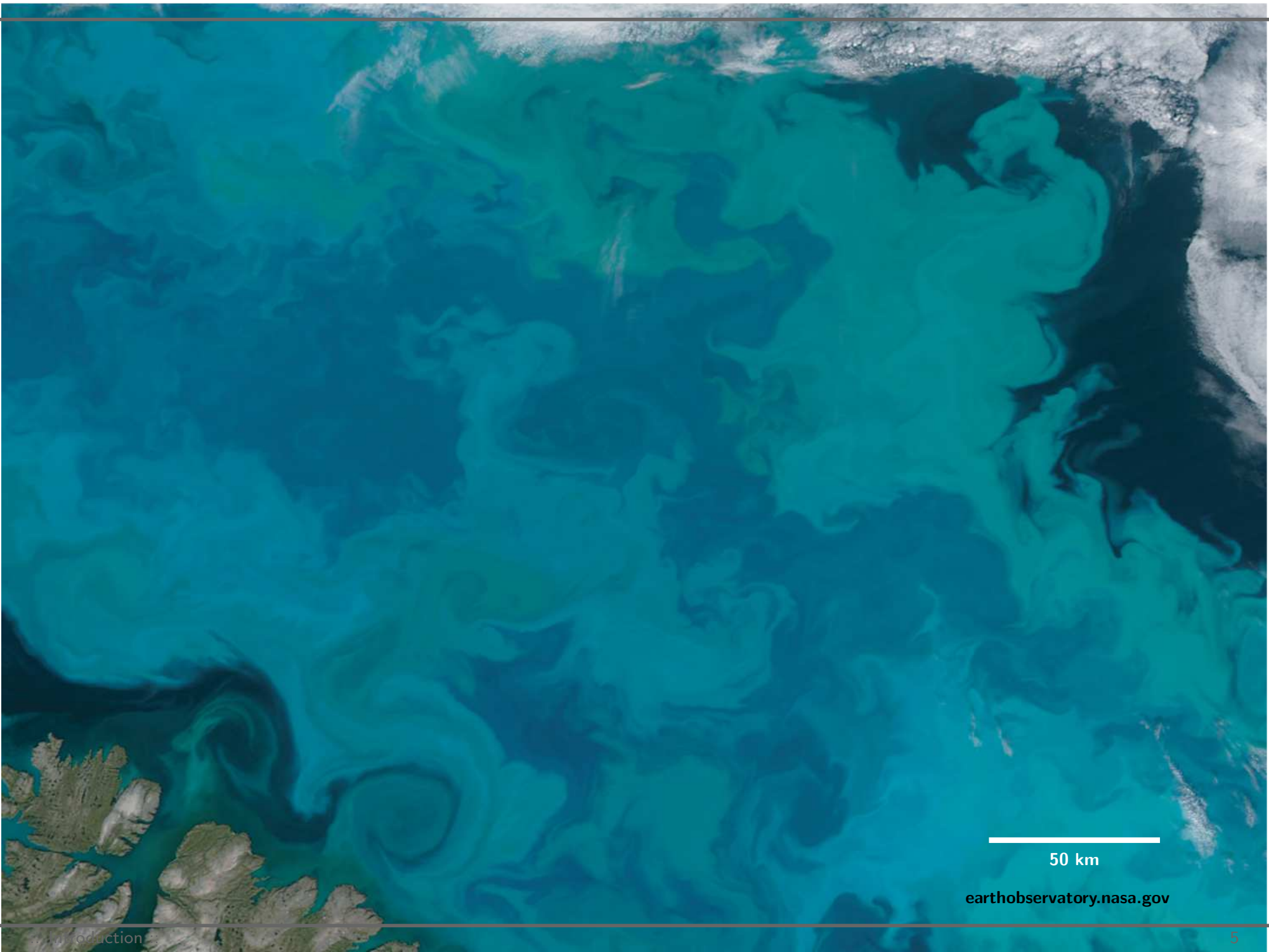
NCP: Net community production

after Sigman & Hain 2012

Physical-biological coupling: large-scale biogeography

Observationally-based seasonal surface chlorophyll and nitrate distributions




50 km
earthobservatory.nasa.gov

Research questions

Q1: What is the local impact of eddies on phytoplankton?

Q2: What is the rectified impact of mesoscale eddies on NCP?

Global eddy-resolving integration: Model configuration

Forcing

CORE 'Normal Year' (adjusted to climatology, i.e. repeating annual cycle)

Initialization

Physics (U, V, T, S): prior physics-only integration ($\sim$ 15 yrs)

Long-lived pools (DIC, Alk, nutrients): GLODAP/WOA climatologies, MLR gap-fill

Phytoplankton, Fe, etc.: interpolated from prior 1° solution

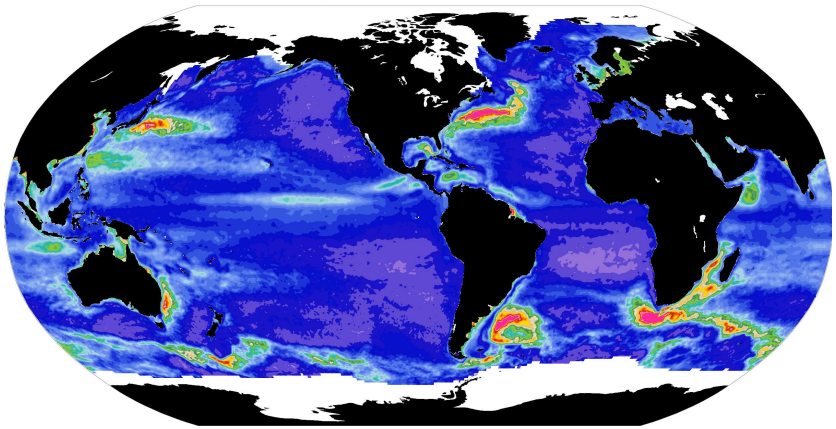
Configuration details

	Low resolution	**High resolution**
Grid	1° (60L), displaced pole	0.1°tripole (62L)
Tracer Horiz. Closure	GM, diagnostic κ	Biharmonic
Momentum Closure	Anisotropic harmonic viscosity	Biharmonic
Advection	Upwind-3	Centered (T&S), Upwind-3 (BGC)
Topography	Full-cell ETOPO2	Partial-cell ETOPO2
Coupling interval	Daily	6 hr

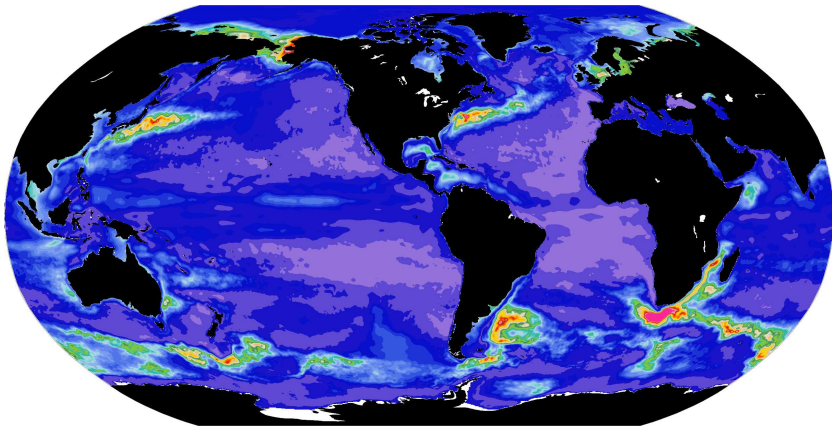
Physical solution: mesoscale variability

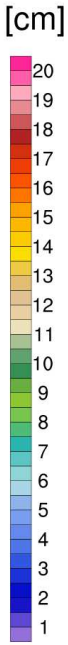
Standard deviation of sea level anomalies (14–120 day band-passed filtered)

AVISO observations



POP 0.1°



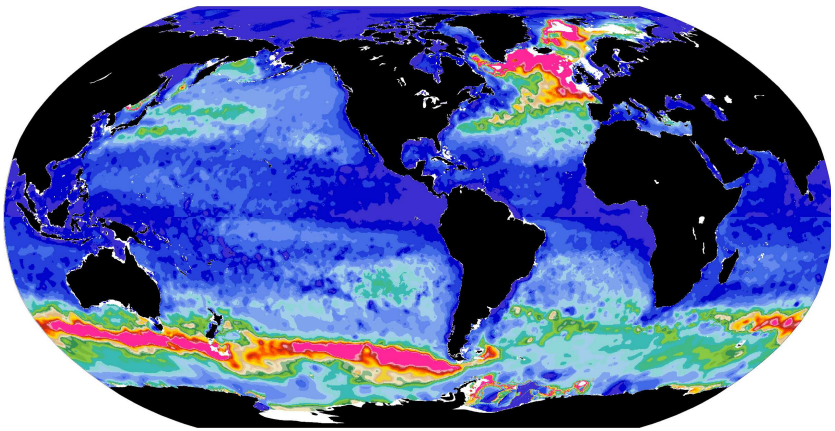


Physical solution: vertical mixing

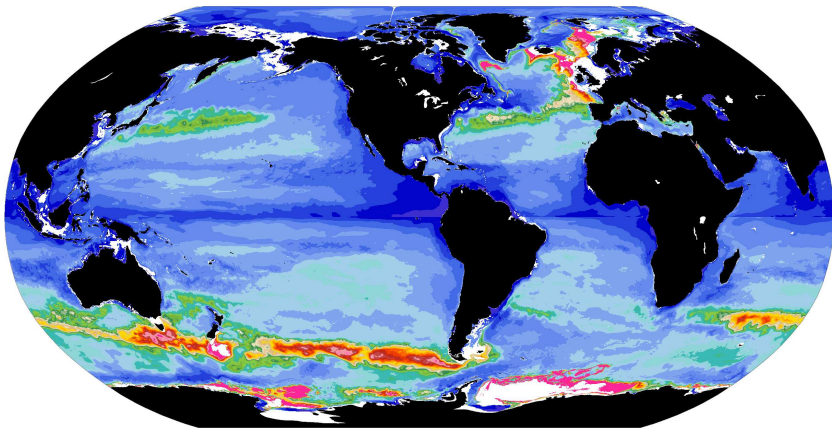
Winter mixed layer depth diagnosed from density structure ($\Delta\sigma_\theta = 0.125$)

(NH: JFM, SH: JAS)

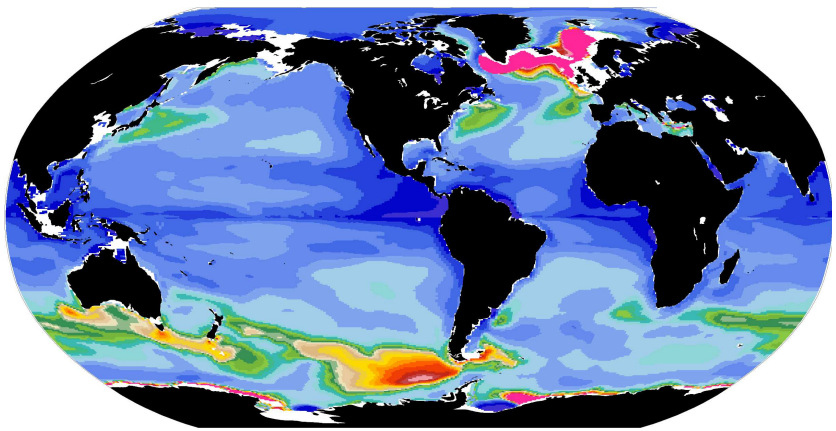
WOA observations (0.25°)

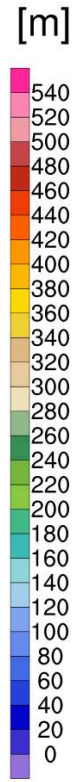


POP 0.1°

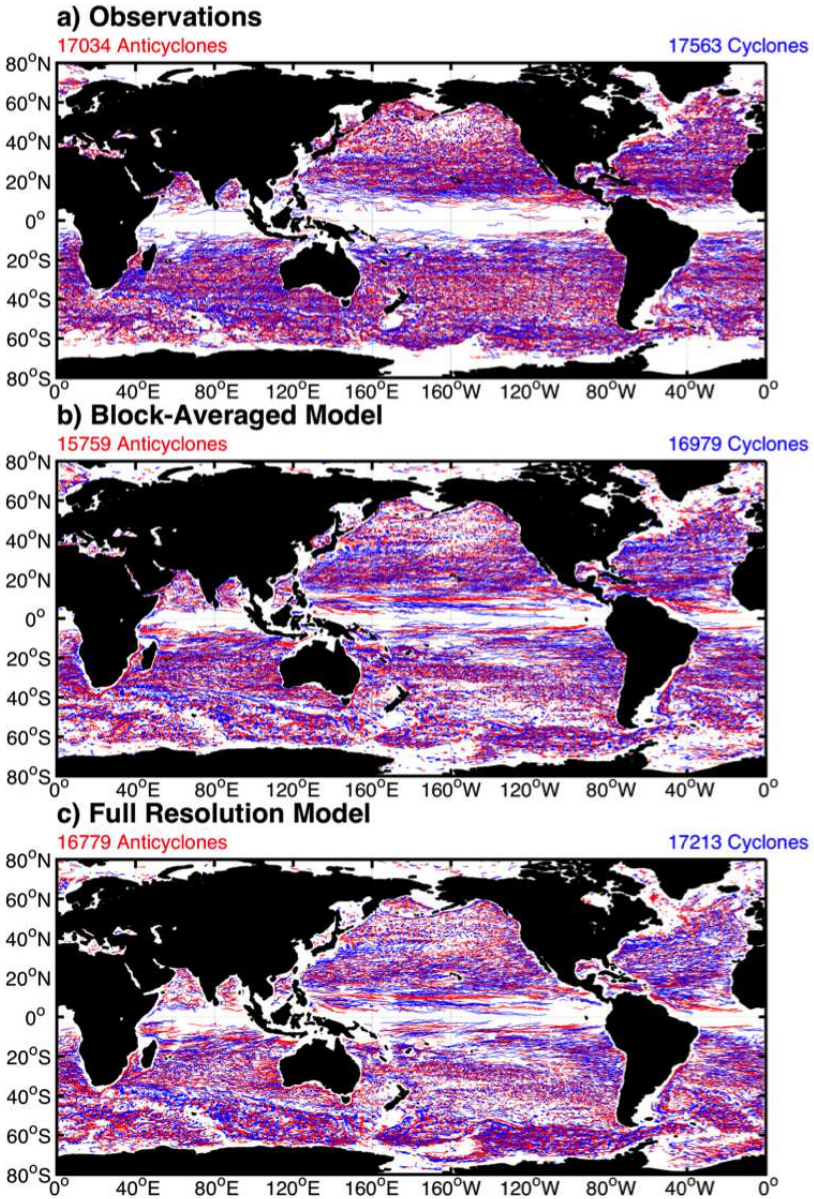


POP 1°





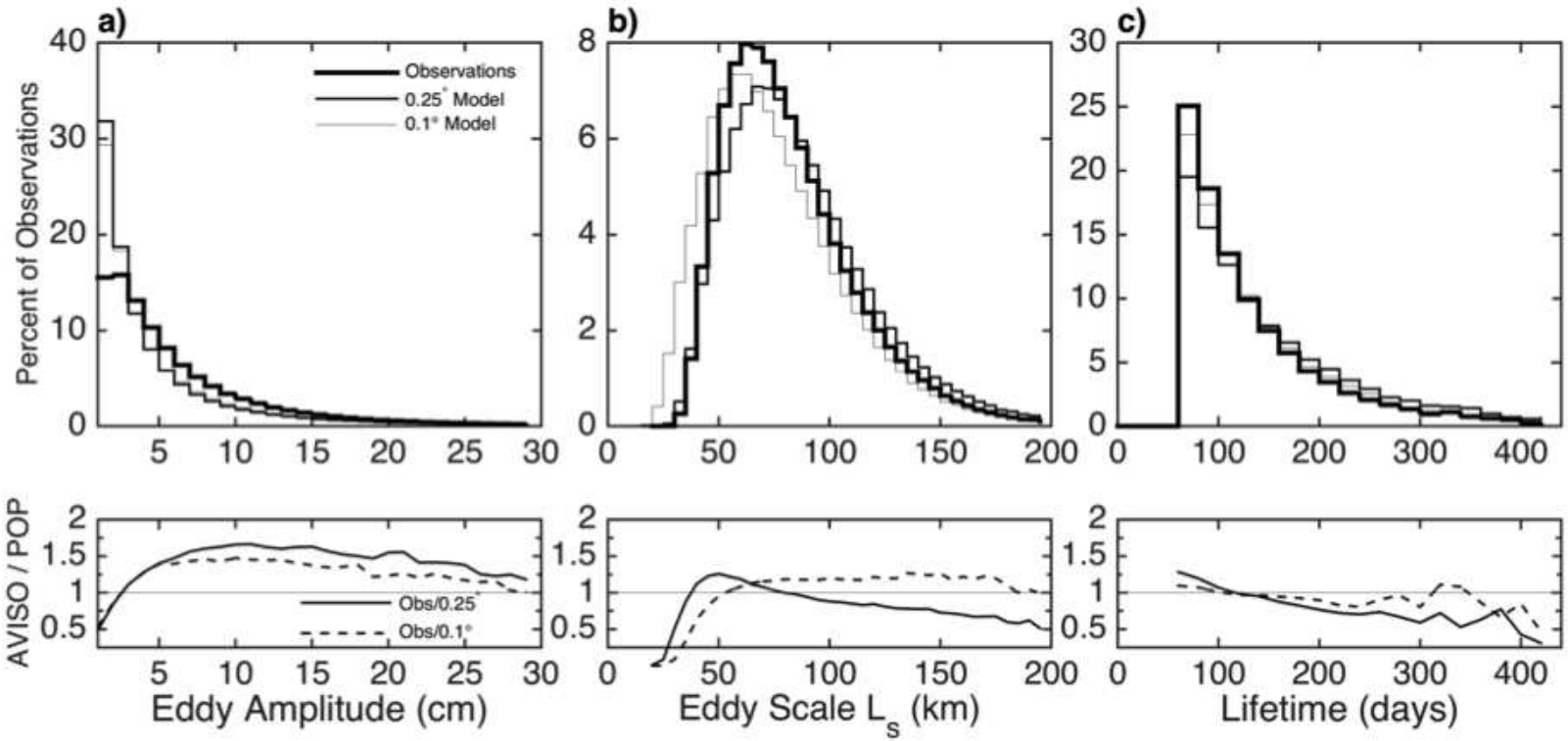
Trajectories of long-lived (lifetimes $\geq$ 60 days) eddies



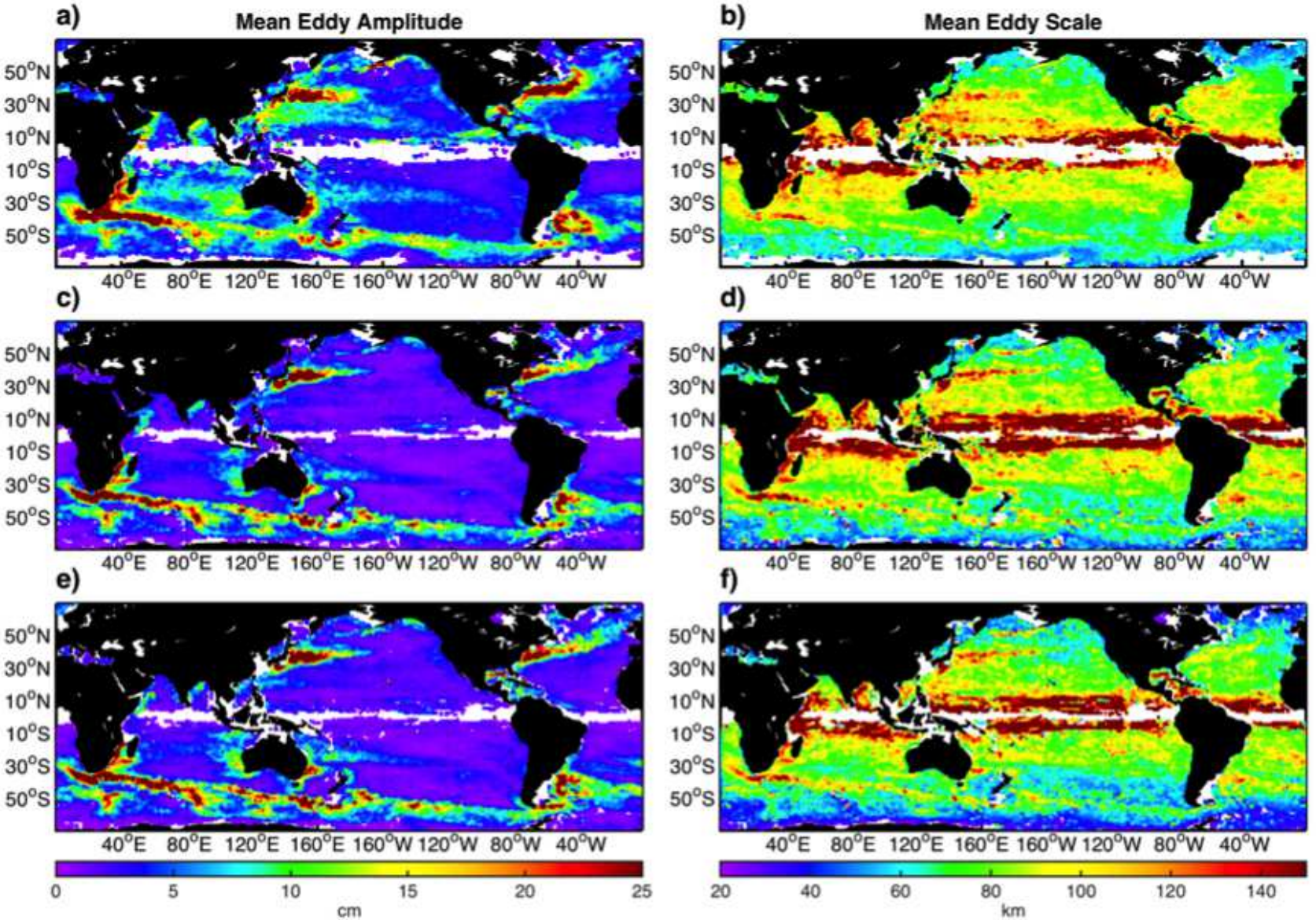
- Fewer mid-latitude open ocean eddies in simulation than in observations.
- Sampling bias in AVISO in equatorial regions? (Fast eddy propagations and dispersed satellite ground tracks.)
- Increased prevalence of cyclones (+3%) matches AVISO exactly (at native resolution).

Eddy demographics

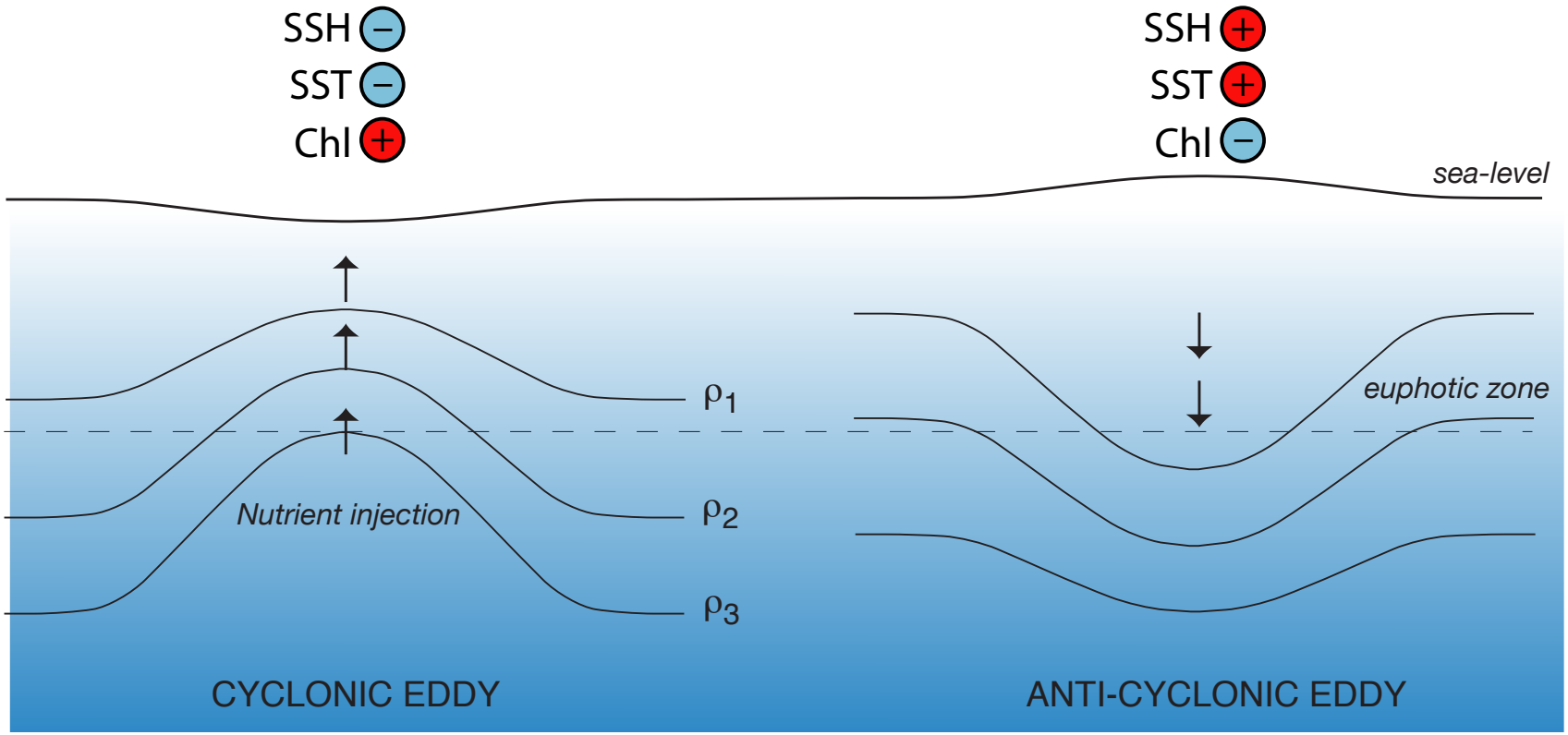
Amplitude Radius Lifetime



Ratios of observed to simulated eddy amplitude and scale



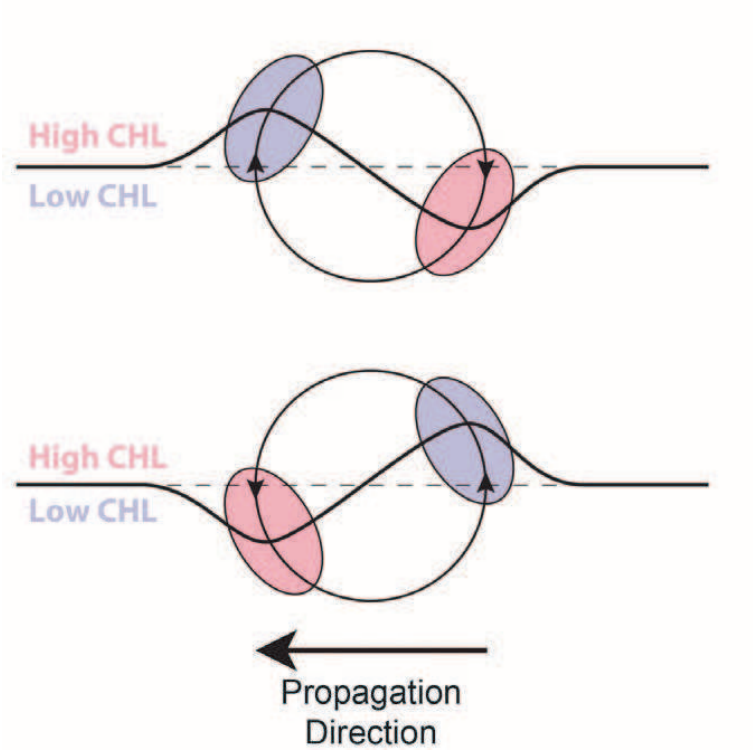
Eddy impacts on chlorophyll: eddy pumping (intensification)



after Sarmiento and Gruber 2006

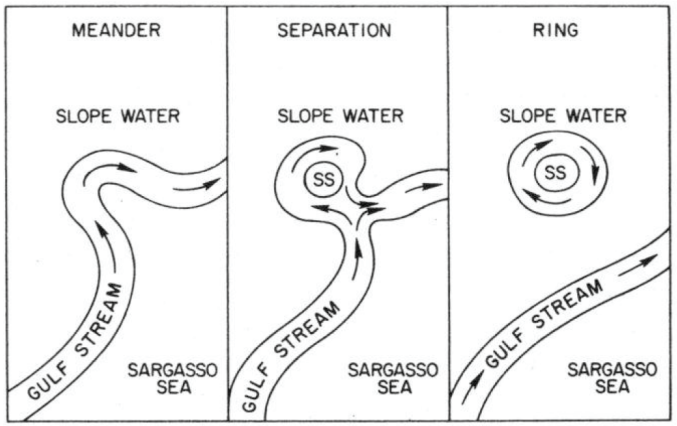
Eddy impacts on chlorophyll

Eddy stirring of tracer gradients



Chelton et al. 2011

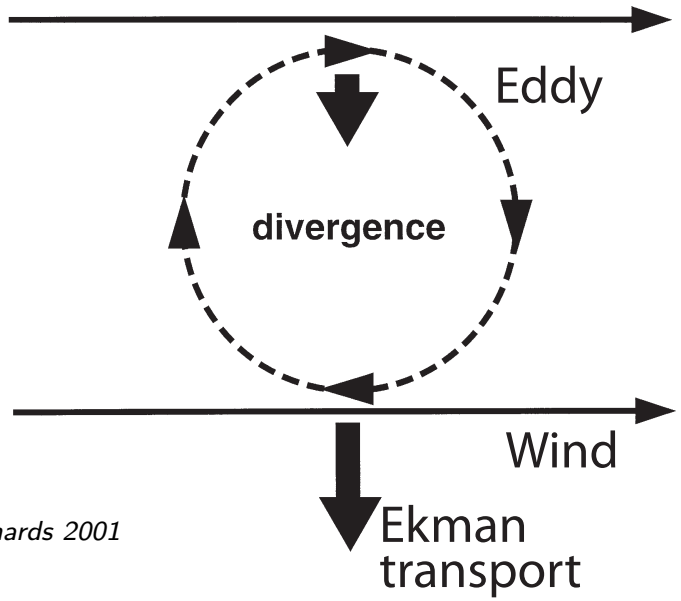
Eddy-trapping



Warm Core Ring Executive Commitee, 1982

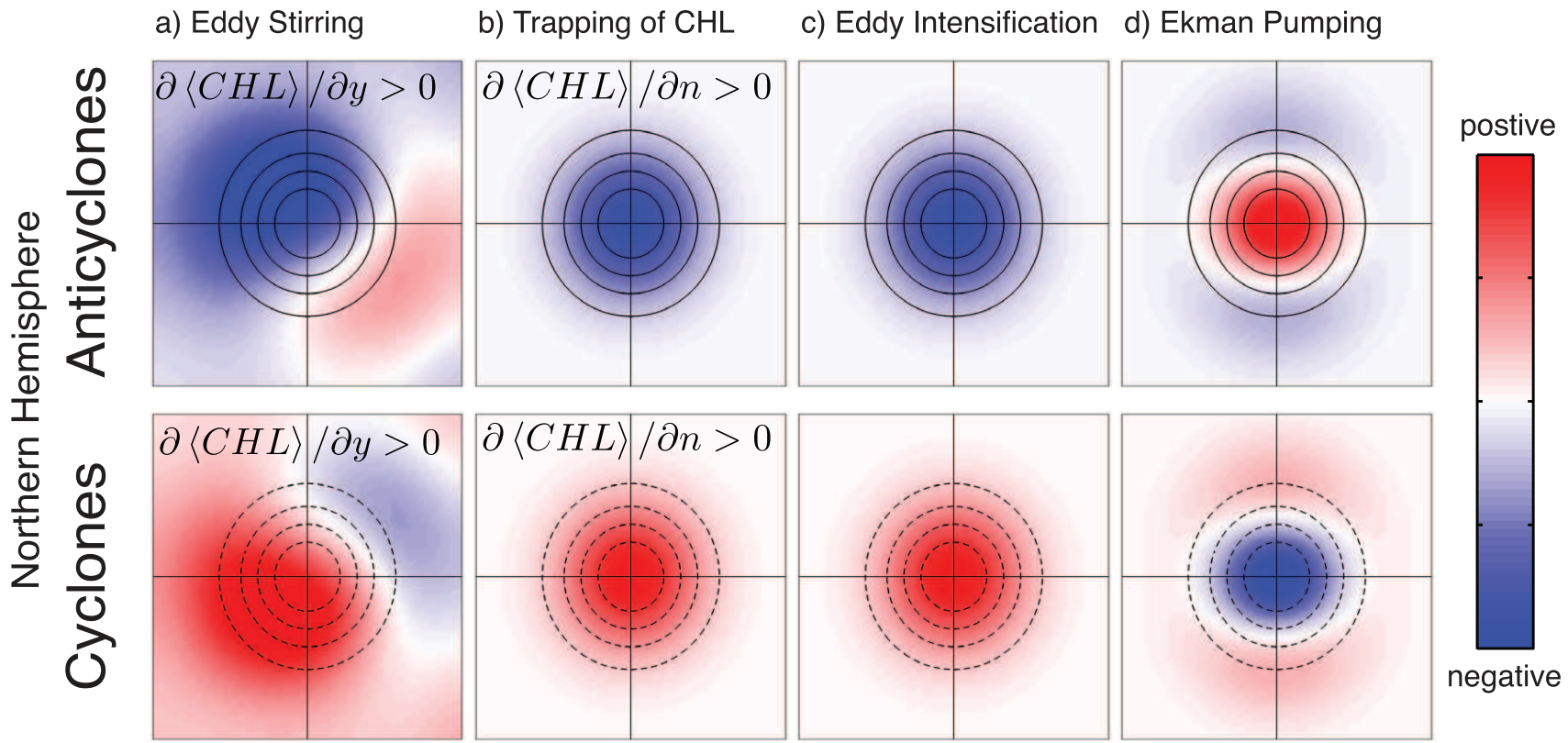
via P. Gaube

Eddy-induced Ekman pumping



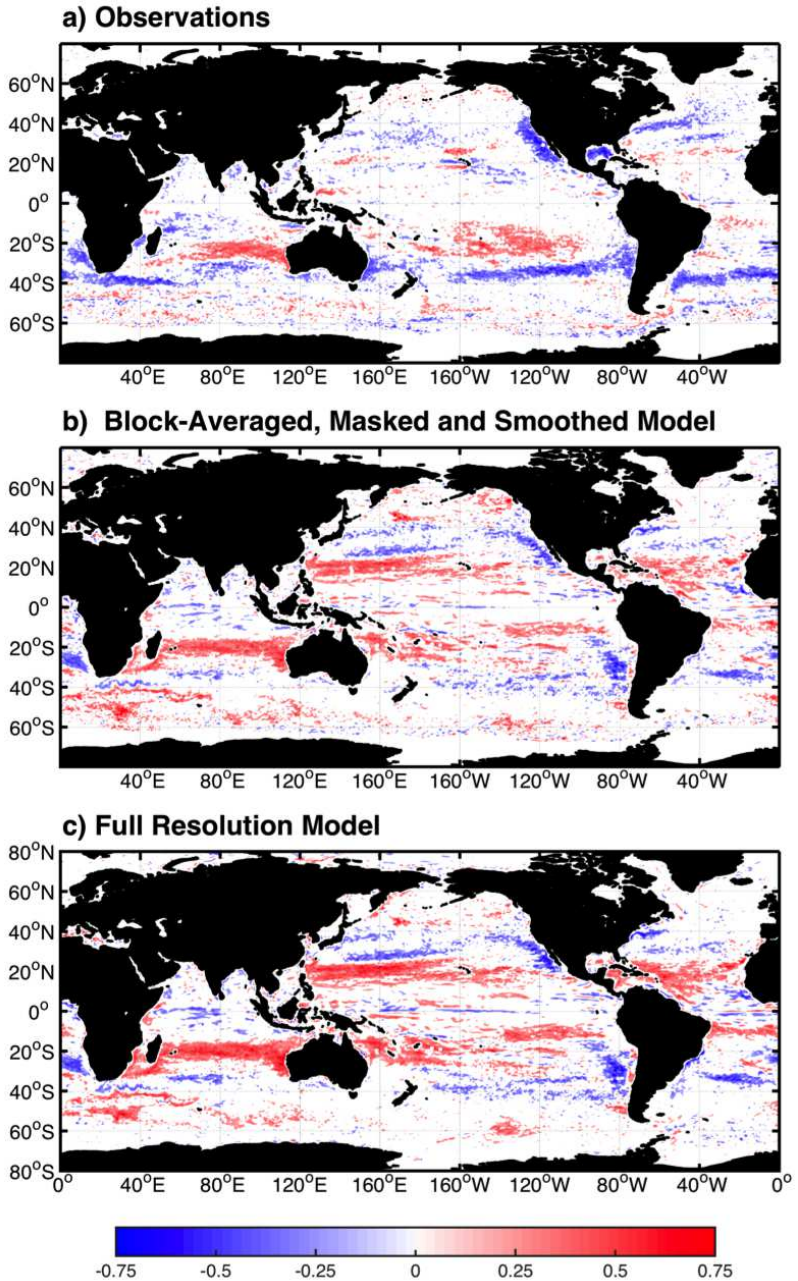
Martin and Richards 2001

Eddy impacts on chlorophyll



Gaube at al. 2014

Cross-correlation between high-pass filtered SLA and Chl



- Significant negative correlation in boundary current regions.
- Positive correlations appear to dominate open ocean regions.
- Model has about twice as much surface area with positive correlation than observations.

Tracer transport: resolved versus parameterized eddies

Tracer equations

Hi-res

$$\frac{\partial \varphi}{\partial t} + \nabla \cdot \overline{\mathbf{u}}\,\overline{\varphi} + \nabla \cdot \overline{\mathbf{u}'\,\varphi'} - \frac{\partial}{\partial z}\left(\kappa_v \frac{\partial \varphi}{\partial z}\right) = J_\varphi(\mathbf{x}) + \underbrace{\nabla_H^2\left(\kappa_H \nabla_H^2 \varphi\right)}_{\text{biharmonic lateral diffusion}}$$

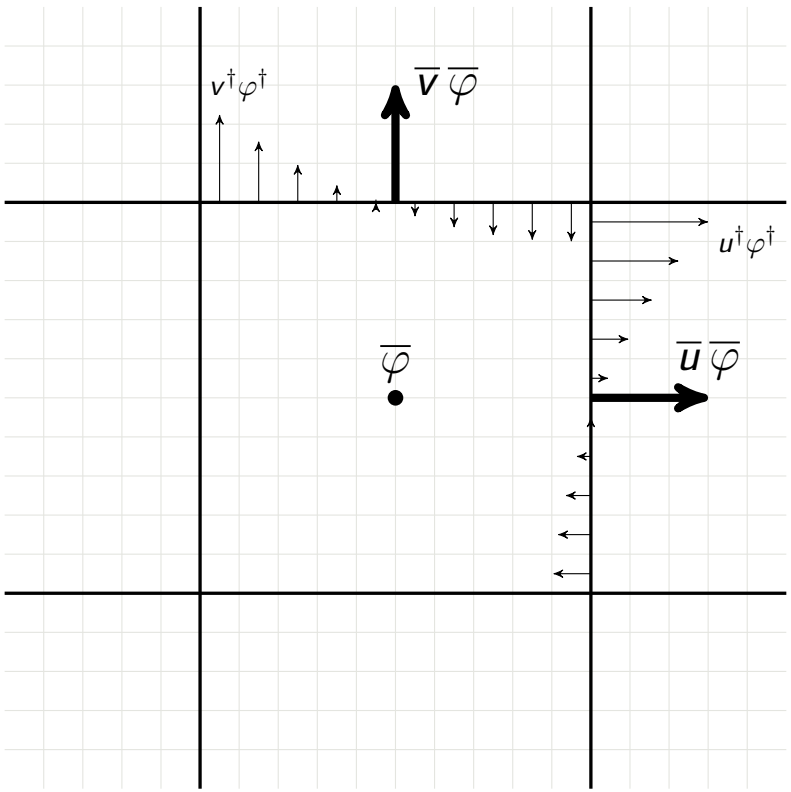
Tendency + Mean advection + Eddy advection − Vertical mixing = Source/sink

Lo-res

$$\frac{\partial \varphi}{\partial t} + \nabla \cdot \overline{u}\,\overline{\varphi} + \nabla \cdot \overline{\mathbf{u}'\,\varphi'} + \underbrace{\nabla \cdot \overline{\mathbf{u}_{GM}\,\varphi}}_{\text{eddy-induced advection}} - \underbrace{\nabla \cdot K_{iso} \nabla \varphi}_{\text{isopycnal mixing}} - \frac{\partial}{\partial z}\left(\kappa_v \frac{\partial \varphi}{\partial z}\right) = J_\varphi(\mathbf{x})$$

Eddy-mean decomposition

Coarsen grid by integer multiple



Mean filter: $\overline{(\cdot)} = \frac{1}{S}\int_S (\cdot)\, dS$

where S is a region of space and time (coarse grid, long-term mean).

Standing component: $(\cdot)^\dagger = (\cdot) - \overline{(\cdot)}$

Advection operator

$$A_\varphi = \nabla \cdot \overline{(\mathbf{u}\,\varphi)}$$

Mean advection

$$A_{\overline{\varphi}} = A_\varphi(\overline{\mathbf{u}}, \overline{\varphi})$$

Standing eddy component

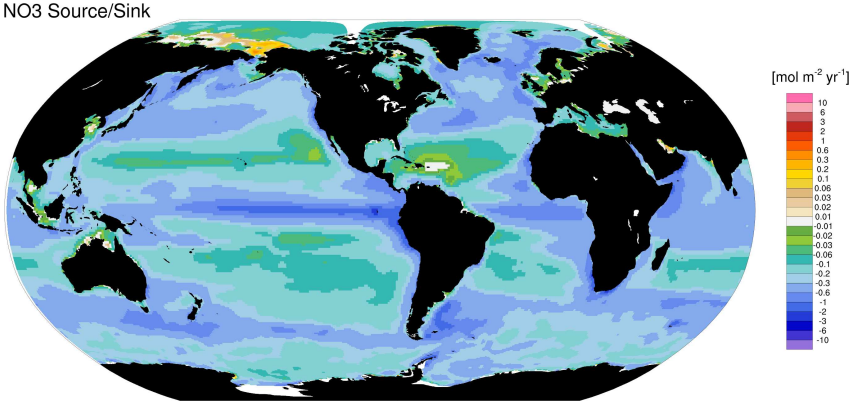
$$A_{\varphi^\dagger} = A_\varphi(\mathbf{u}^\dagger, \varphi^\dagger)$$

Transient eddy component

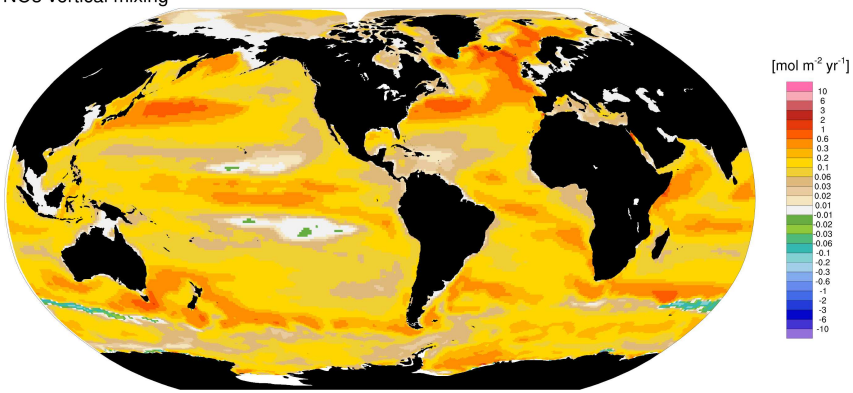
$$A'_\varphi = A_\varphi - A_{\overline{\varphi}} - A_{\varphi^\dagger}$$

Nitrate balance (0.1°)

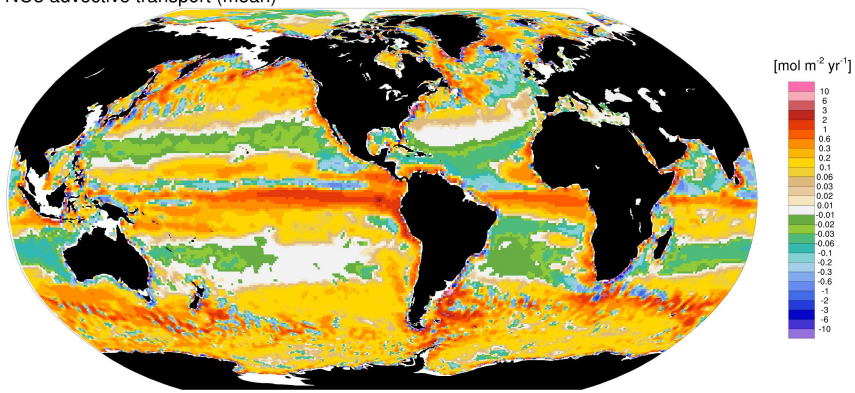
NO3 Source/Sink



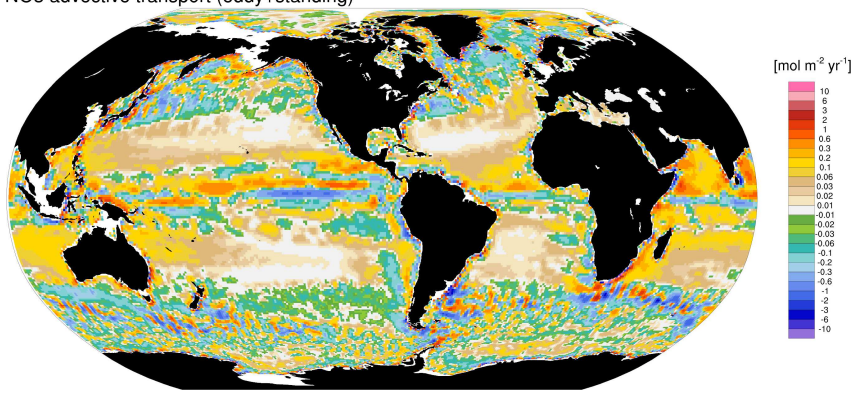
NO3 vertical mixing



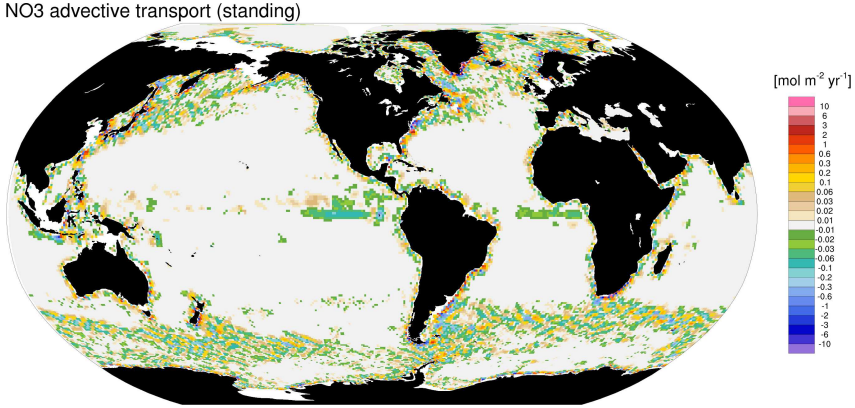
NO3 advective transport (mean)



NO3 advective transport (eddy+standing)



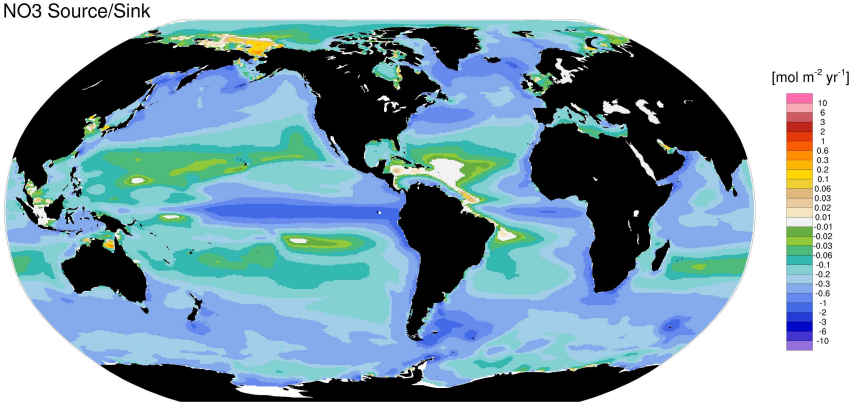
NO3 advective transport (standing)



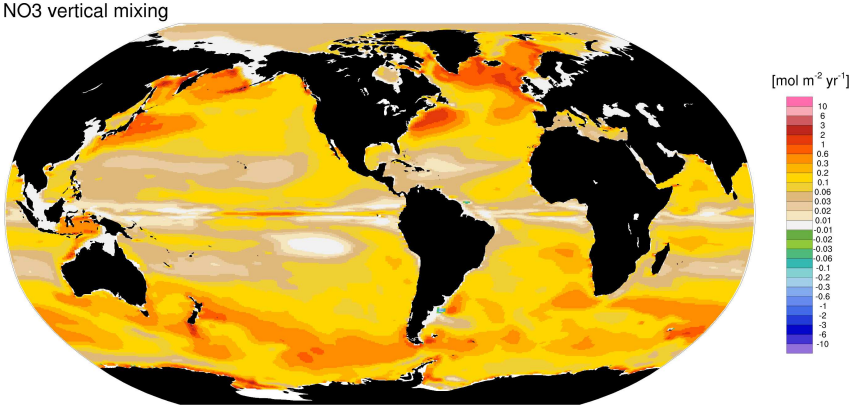
Surface ocean nitrate budget comparison: Net production and vertical mixing

Low resolution (1°)

NO3 Source/Sink

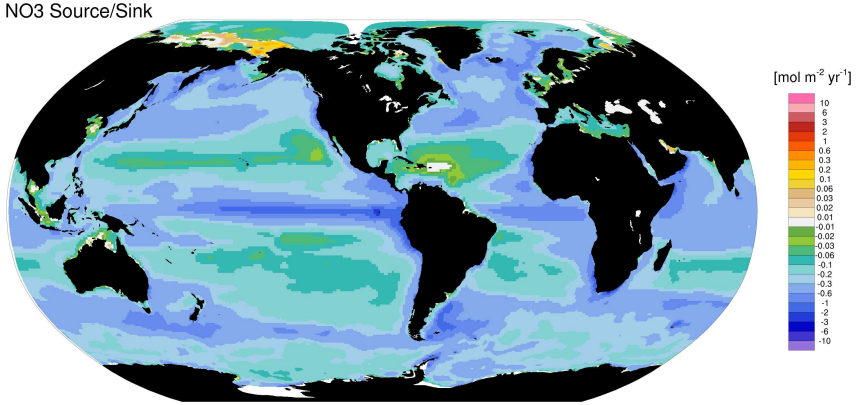


NO3 vertical mixing

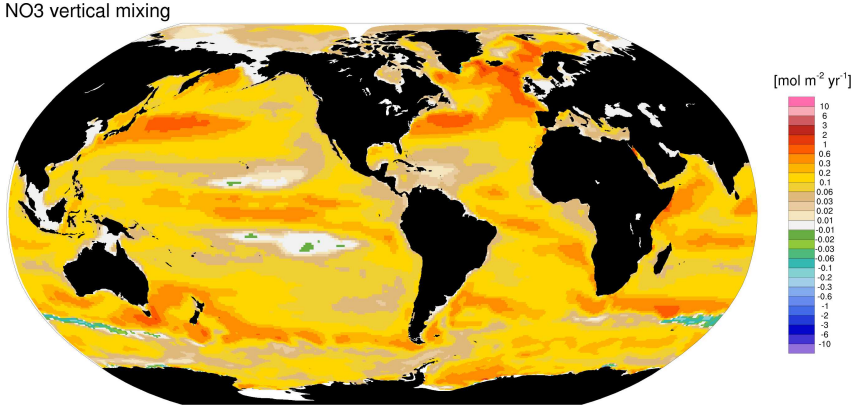


High resolution (0.1°)

NO3 Source/Sink

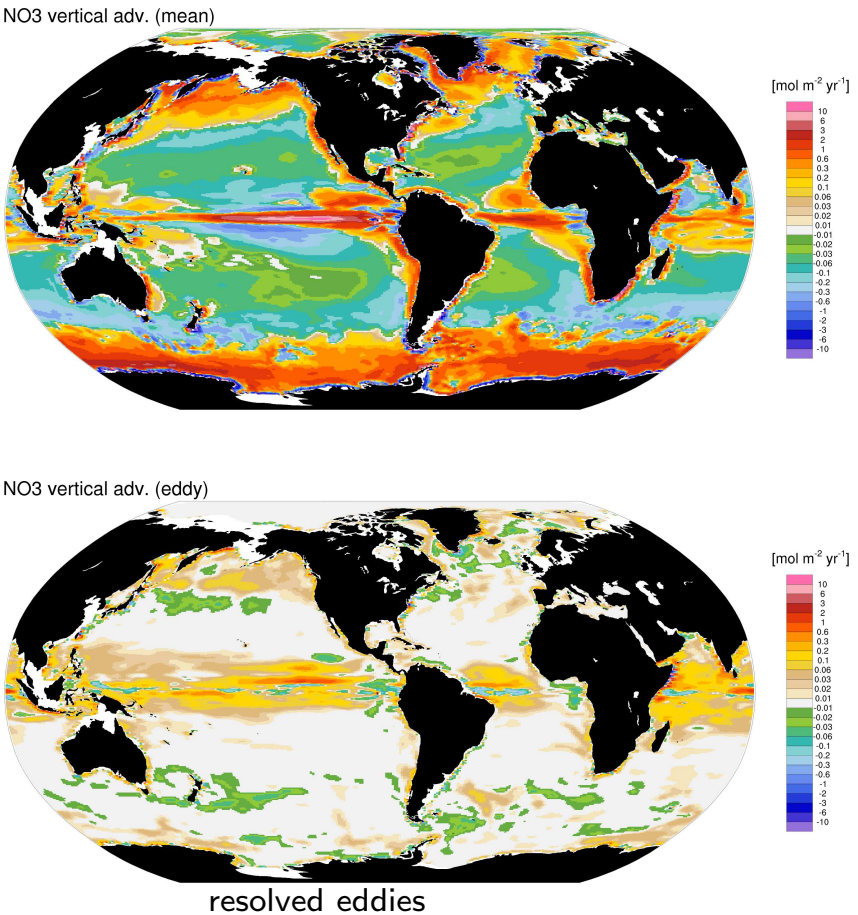


NO3 vertical mixing



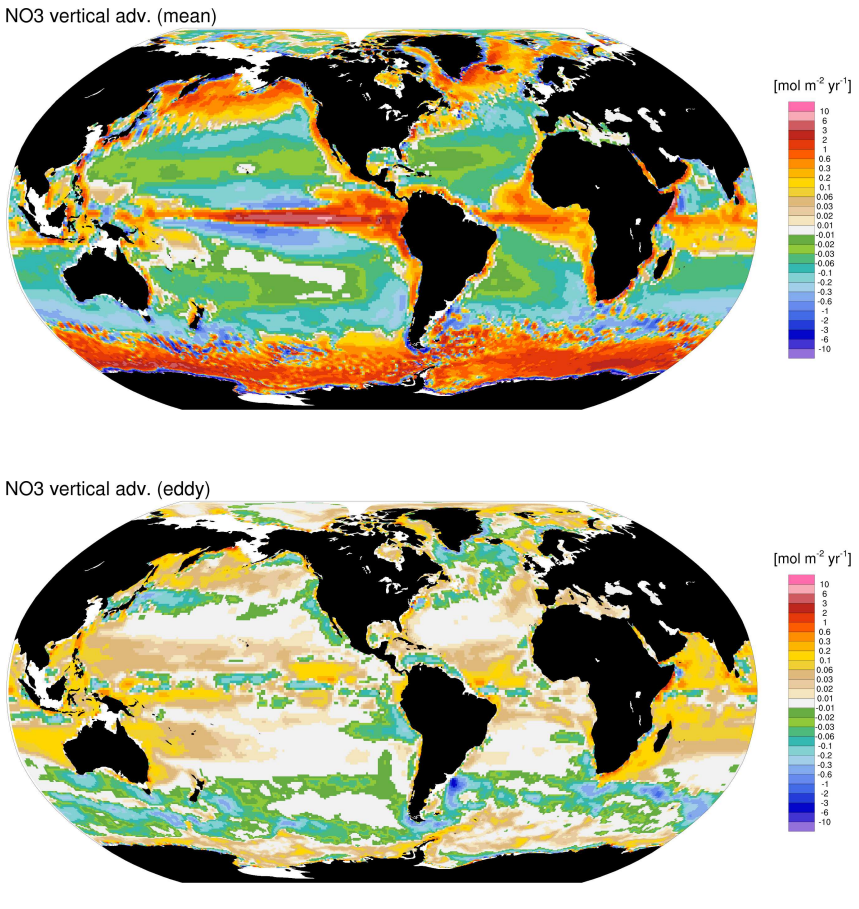
Surface ocean nitrate budget comparison: vertical advection

Low resolution (1°)



resolved eddies

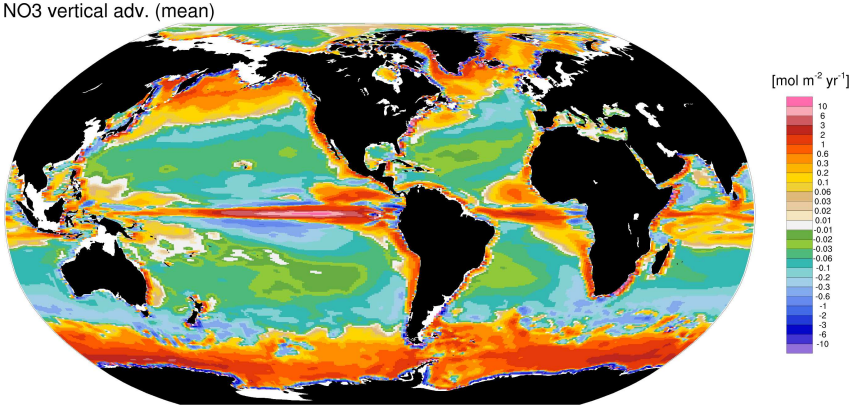
High resolution (0.1°)



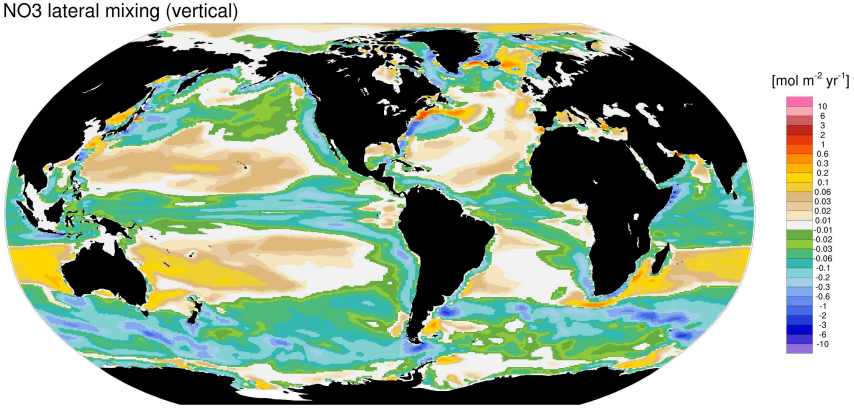
Surface ocean nitrate budget comparison: vertical advection

Low resolution (1°)

NO3 vertical adv. (mean)



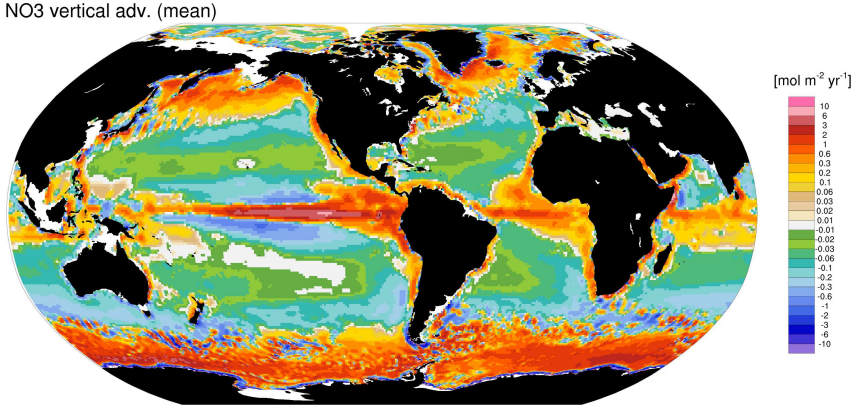
NO3 lateral mixing (vertical)



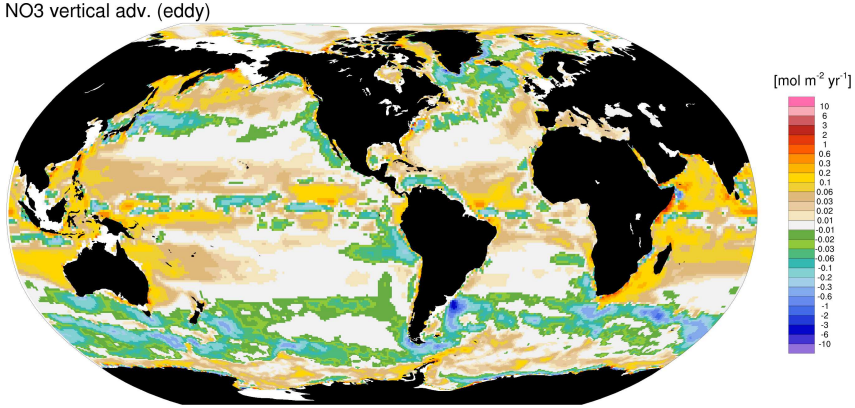
parameterized eddies

High resolution (0.1°)

NO3 vertical adv. (mean)



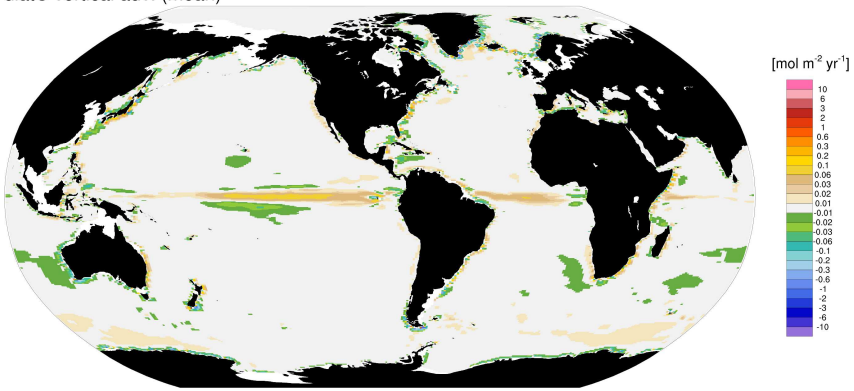
NO3 vertical adv. (eddy)



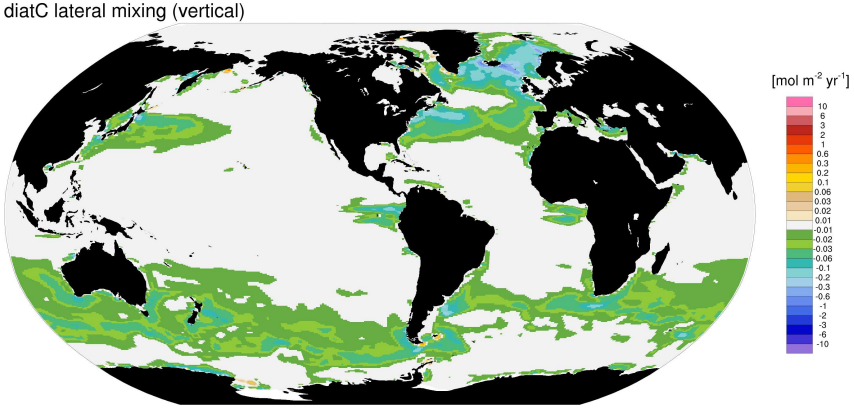
Vertical advection of living biomass: diatoms

Low resolution (1°)

diatC vertical adv. (mean)



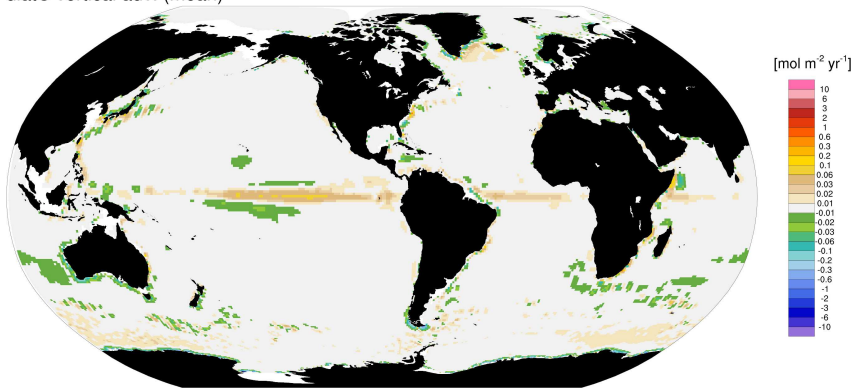
diatC lateral mixing (vertical)



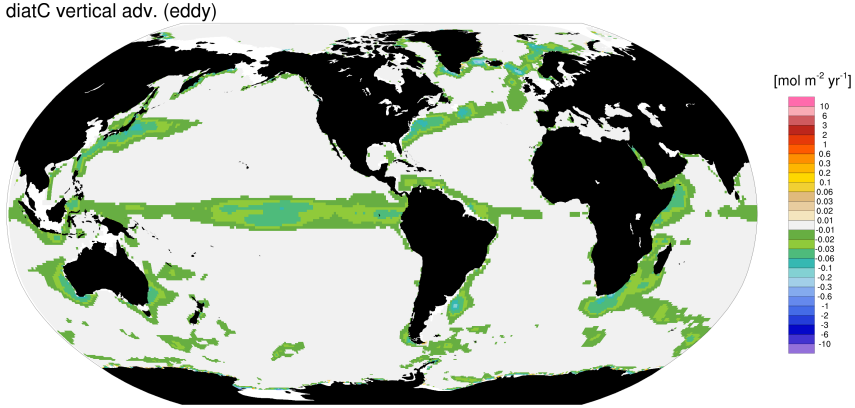
parameterized eddies

High resolution (0.1°)

diatC vertical adv. (mean)

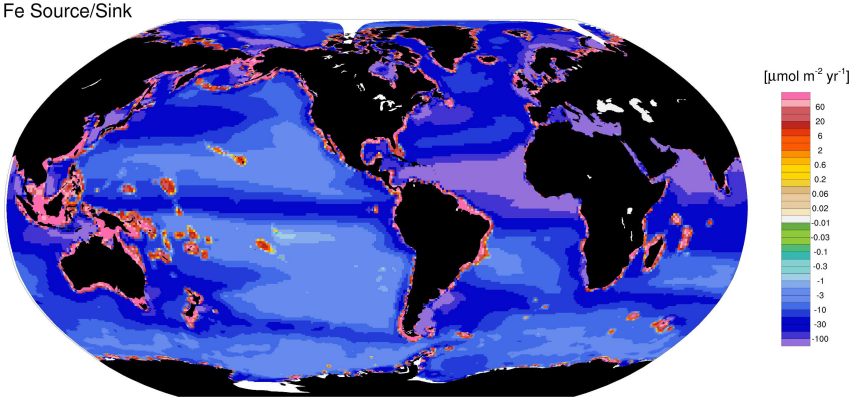


diatC vertical adv. (eddy)

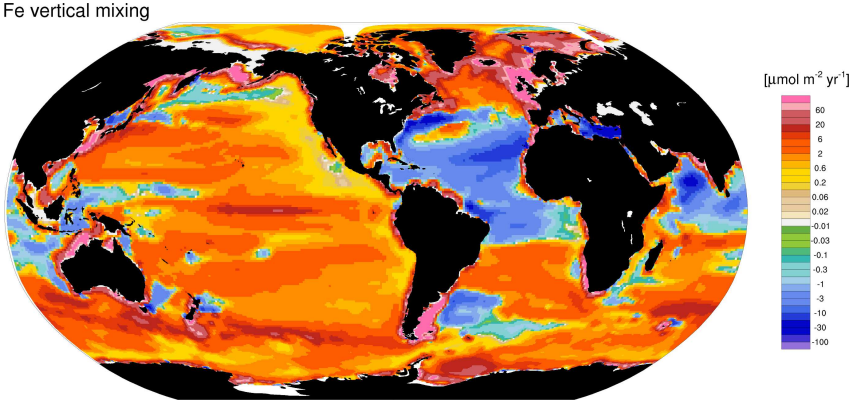


Dissolved iron balance (0.1°)

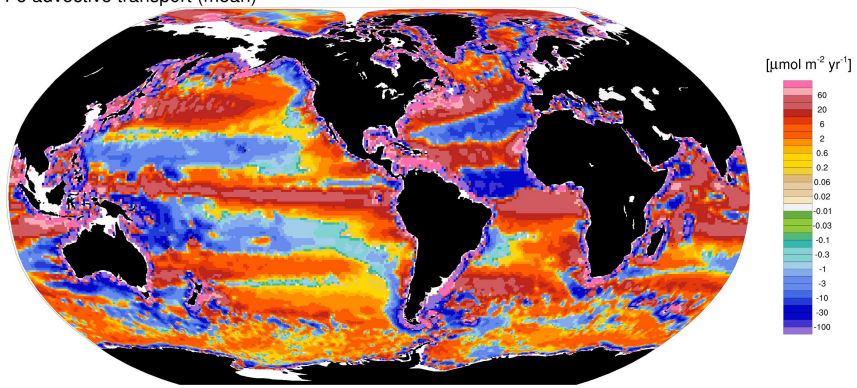
Fe Source/Sink



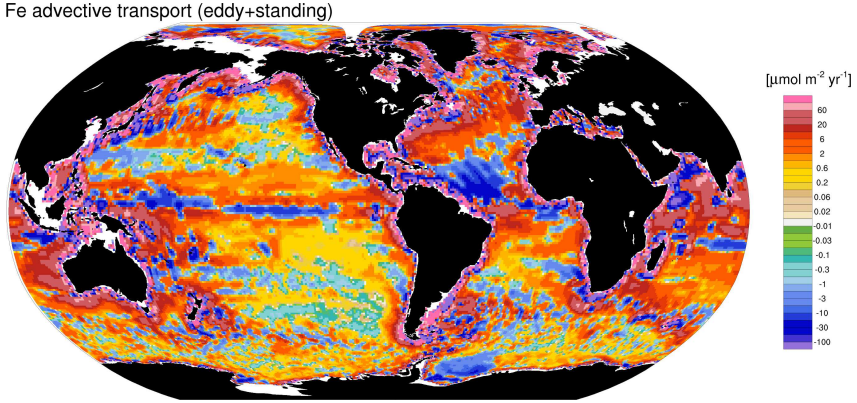
Fe vertical mixing



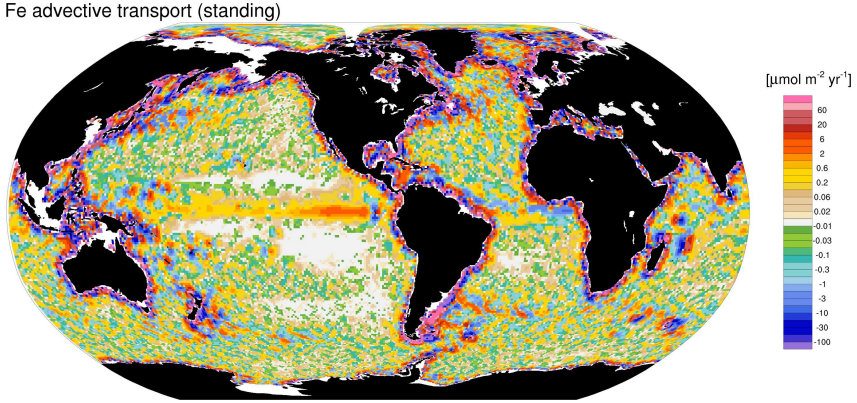
Fe advective transport (mean)



Fe advective transport (eddy+standing)



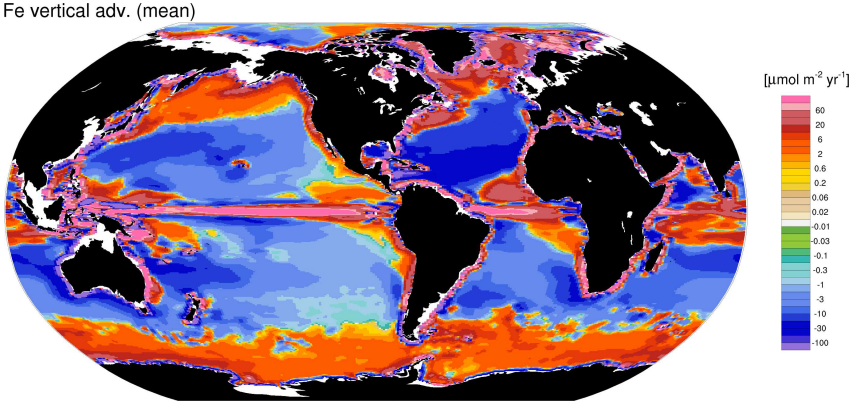
Fe advective transport (standing)



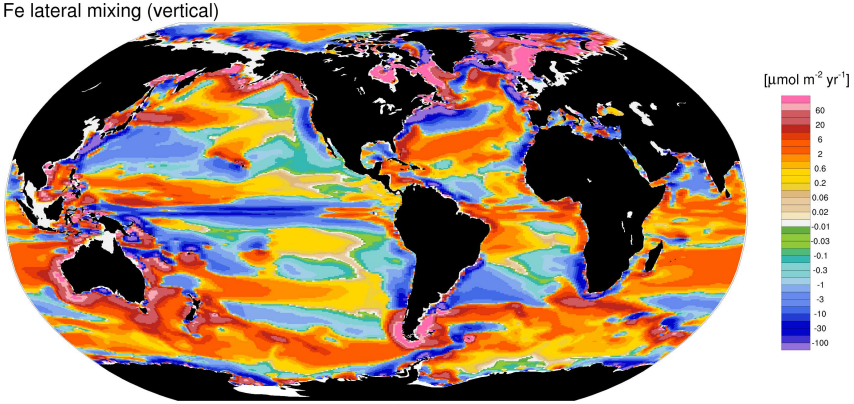
Surface ocean iron budget comparison: vertical advection

Low resolution (1°)

Fe vertical adv. (mean)



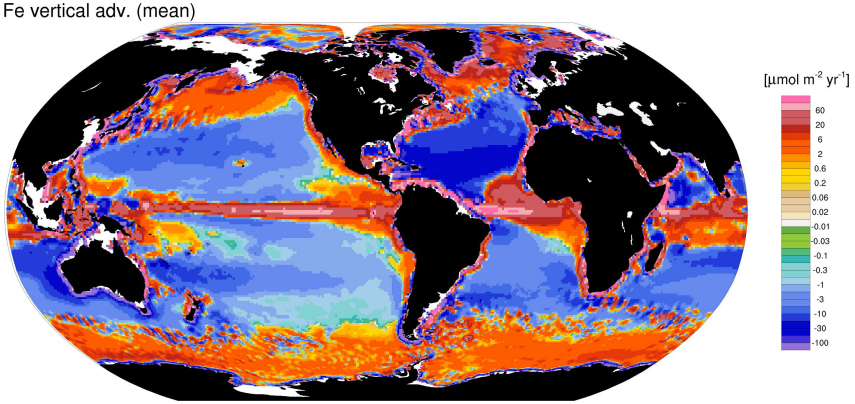
Fe lateral mixing (vertical)



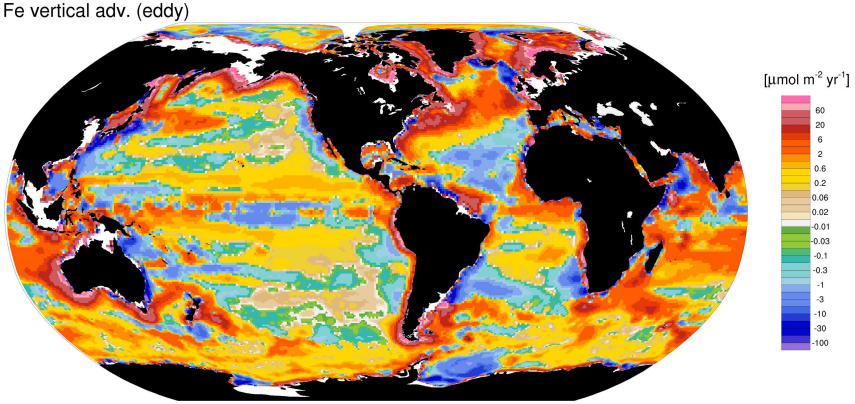
parameterized eddies

High resolution (0.1°)

Fe vertical adv. (mean)



Fe vertical adv. (eddy)



Discussion

Physical simulation: mesoscale variability, eddy demographics

Eddy impacts on surface chlorophyll

Surface nutrient budgets