The Impact of Eddy Advection and Diffusion on Passive Tracer Transport in a Global Ocean Model

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Abstract

Eddies have two distinct properties known as eddy advection (K_GM) and eddy diffusion (K_iso). These are parameterized by Gent-McWilliams [1990] (K_GM) and Redi [1982] (K_iso), respectively, in low to moderate resolution global ocean models. Both processes play an active part in the uptake of tracers such as CO_2 and CFCs. The advective role of eddies is associated with slumping of isopycnals, whereas the diffusive role is associated with the down-gradient diffusion [Lee et al., 2007]. In this work we investigate, for the first-time, which eddy process plays a dominant role in controlling tracer distribution in models. The model (pyOM2) used in this work is a coarse-resolution (2°x 2°) global ocean model [Eden et al., 2014]. We use a suite of nine different experiments, each with different K_GM and K_iso values. An idealised passive tracer is introduced at the surface of the ocean after the model is well equilibrated and it evolves for 100 years. We found on decadal time scales eddy diffusion and eddy advection both play equally important roles in controlling tracer distribution. However, on the time scale of hundred years or more eddy advection dominates over eddy diffusion. Small K_GM values set the isopycnal slopes to be steep, which allows the tracer to easily penetrate the deep ocean along isopycnals. On the contrary, large K_GM values flatten the isopycnals and therefore tracer only weakly penetrates the deep ocean. Near Antarctica, large values of K_iso exert strong control over the tracer distribution and brings tracer rich water to depth.

The Impact of Eddy Advection and Mixing on Passive Tracer Transport in a Global Ocean Model

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1. Motivation

- Two distinct properties of eddies are, advection and diffusion/mixing, these are parameterised in coarse resolution non-eddy-resolving ocean models as K_{GM} and K_{iso} , respectively.
- Active part in the atmosphere-ocean exchange of climatically important tracers.
- Eddy advection is associated with tilting of isopycnals and eddy mixing with the downgradient diffusion of tracers.
- In this work we investigate for the first time which of the two eddy processes dominate the tracer distribution on different time scales.

2. Model Description and Forcing

- Model used in this study is python Ocean Model (pyOM2.2), which is an energetically consistent model.
- We use a realistic configuration of the global ocean with resolution of 2°, (Eden *et al.* 2014) uses the same model with higher resolution of 1°.
- It has a stretched vertical grid with 45 vertical layers, the resolution is 10m close to the surface and increases to 250m towards the bottom of the ocean. The model domain is quasi global because Arctic Ocean is excluded poleward of 60°N but the Southern Ocean is fully included.
- It is forced with a monthly climatology of heat and momentum fluxes (Eden *et al.*, 2014). It uses a restoring boundary condition for the surface salinity with a restoring time scale of 90 days. There is no explicit sea ice in the model. When the surface temperature goes below the freezing point, the surface heat flux is negative (out of the ocean) and salinity restoring is set to zero.

3. Eddy Parameterisation & Experiments

We are interested to explore the effect of the choice of spatially uniform K_{GM} and K_{iso} on the tracer distribution. We start with tracer advection diffusion equation (Gent and Mcwilliams, 1990; Griffies, 1998),

$$\frac{\partial C}{\partial t} + \mathbf{u}.\nabla C - \mathbf{J}.\nabla C = Q$$

here C represents passive tracer and $\frac{\partial C}{\partial t}$ is the time derivative and Q represents tracer source and sinks. **u** represents the time-mean transport velocity. This eddy induced velocity is associated with eddy advection. Here, **J** represents a second-order tracer mixing tensor acting on the gradient of the tracer concentration ∇C (Griffies, 1998).

$$\mathbf{J} = k_{iso}\begin{bmatrix} 1 & 0 & S_x \\ 0 & 1 & S_y \\ S_x & S_y & {S_x}^2 + {S_y}^2 \end{bmatrix} + k_{GM}\begin{bmatrix} 0 & 0 & -S_x \\ 0 & 0 & -S_y \\ S_x & S_y & 0 \end{bmatrix}$$

$$\mathbf{J} = \begin{bmatrix} k_{iso} & 0 & (k_{iso} - k_{GM})S_x \\ 0 & k_{iso} & (k_{iso} - k_{GM})S_y \\ (k_{iso} + k_{GM})S_x & (k_{iso} + k_{GM})S_y & S^2(k_{iso}) \end{bmatrix}$$

Here, **S** is the magnitude of the isopycnal slope **S** = $\frac{-\nabla_z \rho}{\partial_z \rho}$, ρ is the locally referenced potential density, S_x and S_y are the isopycnal slopes in longitude and latitude respectively.

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Ex no.	K_{GM} $[m^2s^{-1}]$	K_{iso} $[m^2s^{-1}]$	MTD [°C]	MSD [g kg^{-1}] *10^{-2}
1	100	100	0.8184	0.489
2	500	100	0.7078	0.485
3	1000	100	0.6110	0.501
4	100	500	0.6742	0.365
5	500	500	0.5795	0.371
6	1000	500	0.4762	0.385
7	100	1000	0.6443	0.309
8	500	1000	0.5357	0.306
9	1000	1000	0.4257	0.307

Table1. Showing different values of K_{GM} & K_{iso} used in all nine experiments & corresponding mean temperature & salinity differences with respect to World Ocean Data. Experiment 5 is the reference experiment.

4. Results

- The model used in this study has an energetically consistent framework and estimates the mean kinetic energy (MKE) even at coarse resolution of 2°.

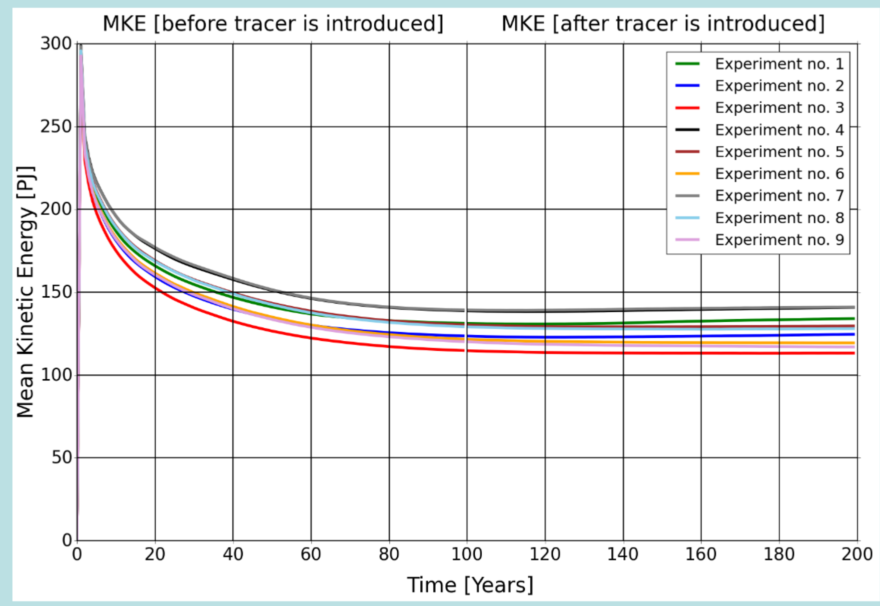

Figure 1. Mean Kinetic Energy for all nine experiments for 200 years. The first 100 years show how the model reached equilibration and 100 to 200 years show the period when the passive tracer was introduced.

- The time evolution of the tracer distribution of reference experiment is shown in figure 2.

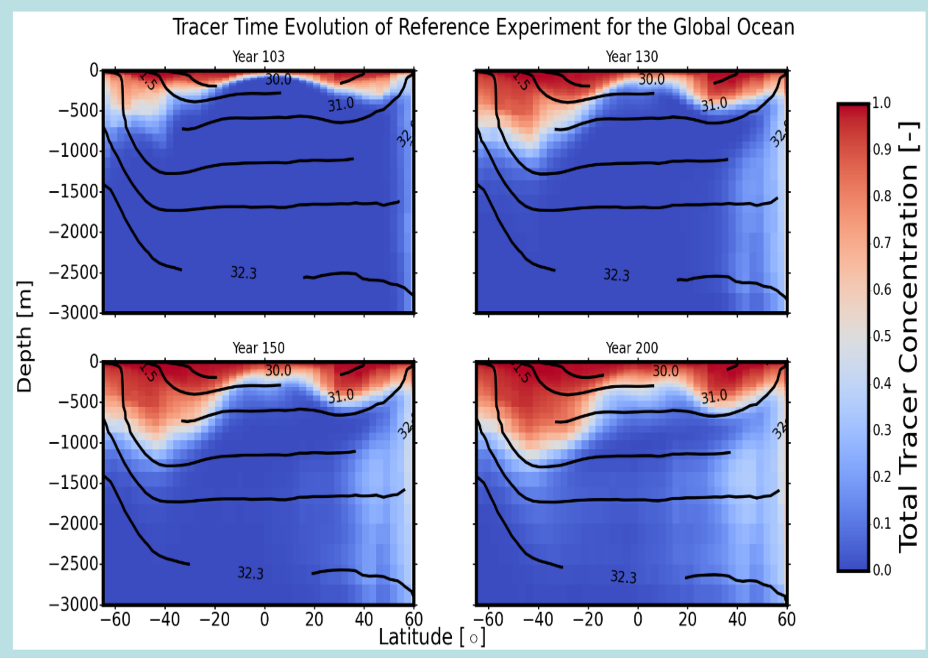

Figure 2. Snap shots of zonal mean of tracer distribution in the reference experiment at different times. The density shown is sigma1, potential density with respect to a reference pressure of 1000 dar, that is, this potential density – 1000 kg m^{-3}.

- $(\text{Tracer Difference}) = \frac{(\text{Experiments 1 to 9}) - (\text{Reference Experiment})}{(\text{Reference Experiment})}$x100%

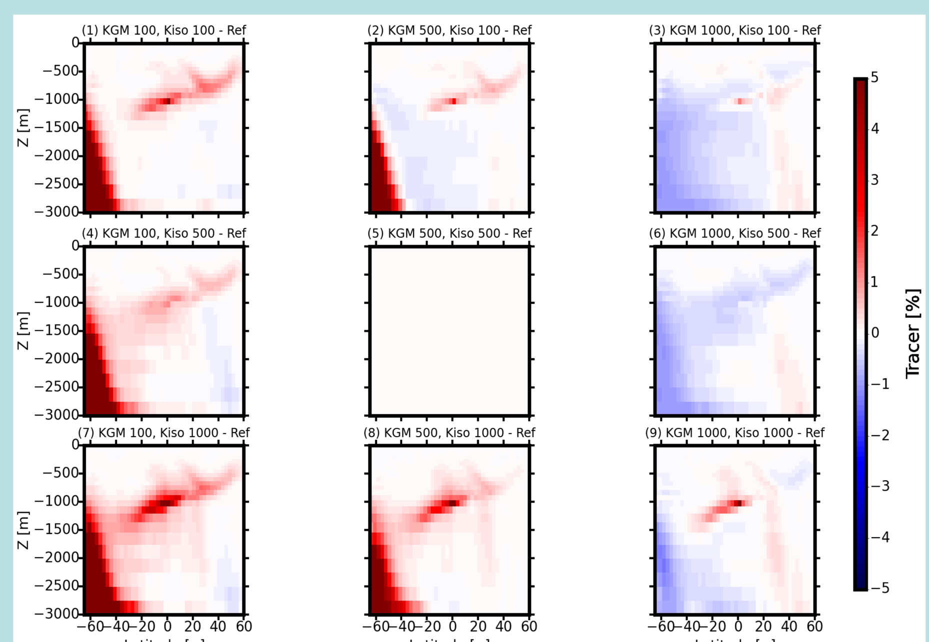

Figure 3. Tracer difference plots of all nine experiments. Each panel represents the tracer difference of the zonal and time mean w.r.t to reference experiment. The time used for this plot is from 190 to 200 years. The term 'Ref' is the reference experiment (experiment 5).

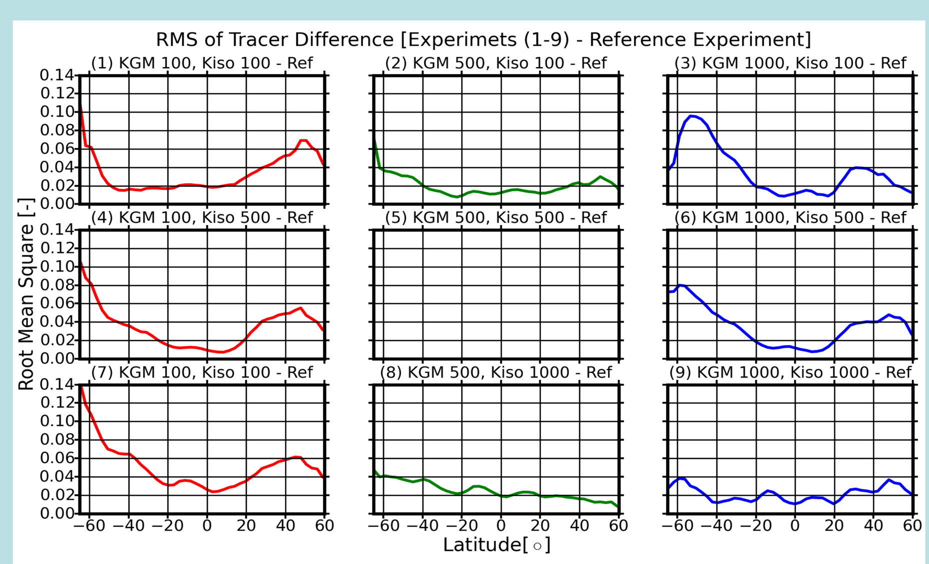

Figure 4. RMS of the tracer difference of all nine experiments. The time used for this plot is from 190 to 200 years, the red, green and blue lines represents K_{GM} 100, 500 and 1000 m^2s^{-1}. RMS is calculated over the 0-3000m depth range.

5. Summary and Conclusions

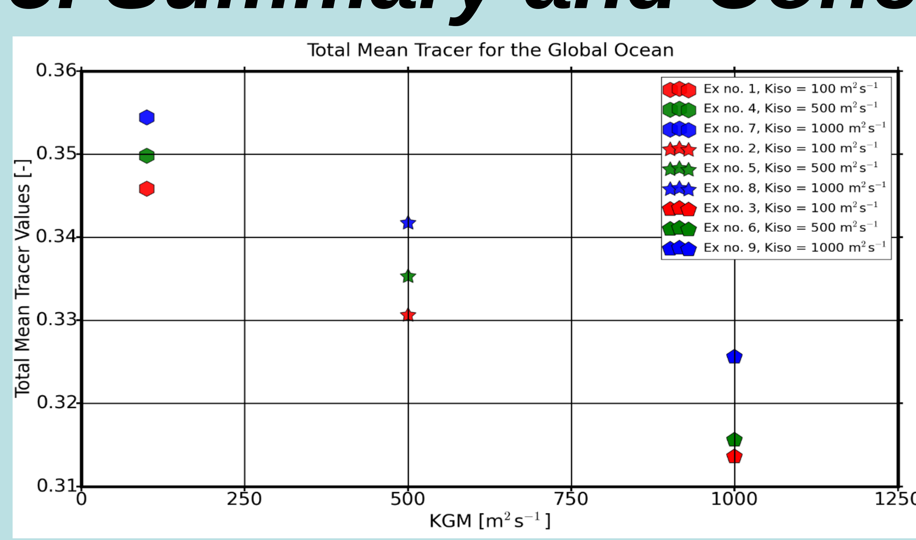

Figure 5. Tracer mean concentration for all nine experiments for the global ocean. Note the winds are fixed, and these values are for years 190 to 200 years

- The new results showed that on the long-time scales (a hundred years) K_{GM} had greater control over the global tracer distribution and K_{iso} tended to control the tracer distribution in the Southern Ocean.
- Fixed K_{GM} and K_{iso} parameterisations produced tracer differences from -5% to 5% with respect to the reference experiment on time scale of 100 years.
- Our results demonstrated that global tracer transport is highly sensitive to the choice of values for both K_{GM} and K_{iso}.