49th International Liege colloquium,
Liege,
22th -26th May 2017

ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
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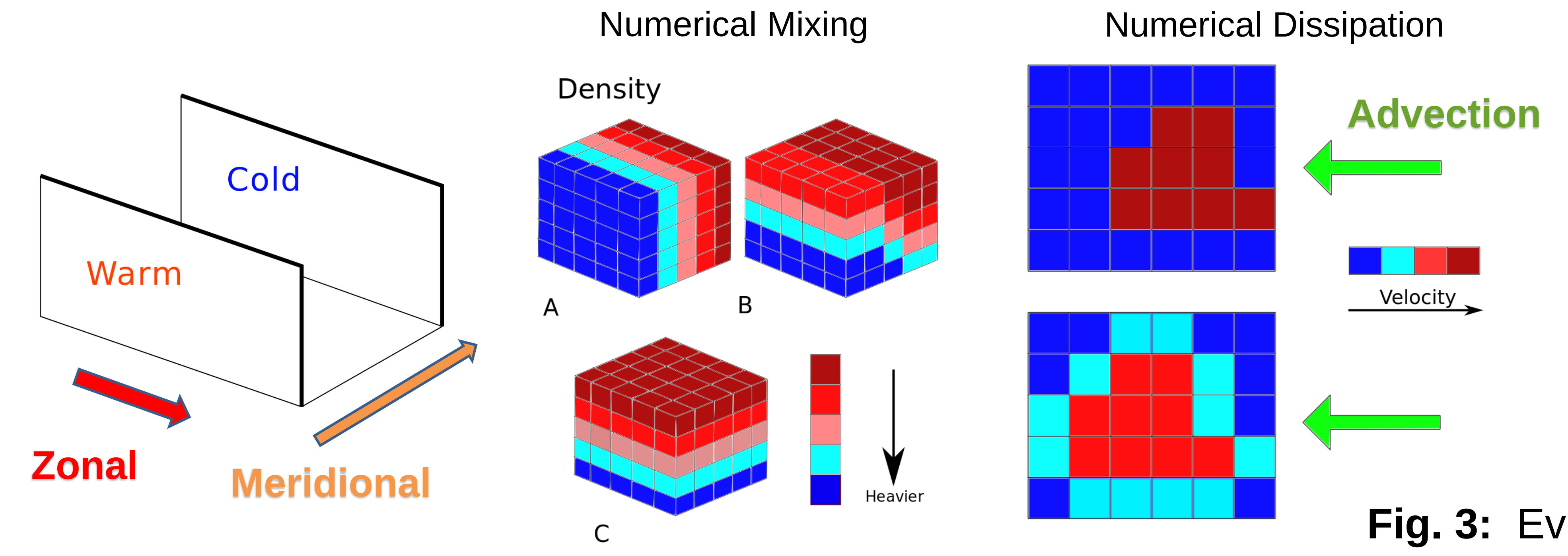
Impact of advection schemes on restratification

Abstract

A host of studies has recognized that truncation errors of the discretized advection terms lead to spurious mixing and dissipation (Fig. 1) and may interact nonlinearly with turbulent mixing and transport. To investigate the impacts of spurious mixing and dissipation, we implemented some of the most novel advection schemes into the coastal ocean model GETM. We quantified spurious dissipation [Klingbeil, 2014] and mixing of the advection schemes (Fig. 3) in idealized experiments of baroclinic instabilities (Fig. 2) ranging from mesoscales (small Rossby number) to sub-mesoscales (order-one Rossby number). The processes at submesosales are distinct from mesoscale by their contribution to restratification of the mixed layer. Such analyses (Fig. 4) help to choose between highly accurate but complex schemes and lower-order less complex schemes balancing accuracy and computational costs. The major outcome of the present study is that both, numerically induced dissipation (leading to a decrease of kinetic energy) and numerically induced mixing (leading to an increase of background potential energy), artificially delay the restratification process [Mohammadi-Aragh, 2015], an effect that needs to be taken into account if parameterizations for eddy-induced mixing and dissipation are compared with numerical model simulations.

Fig. 1: Advection schemes introduce numerical diffusion. How do we quantify it?



$$ND = \iint \frac{1}{2}\chi_d(u)\,\rho_0 \mathrm{d}V\,\mathrm{d}t$$

$$\frac{1}{2}\chi_d(u)_{i,j,k} = \frac{1}{V_{i,j,k}}\left(\chi_i + \chi_j + \chi_k\right) \qquad \chi_i = -\frac{(\mathrm{ADV}\{u_i\})^2 - \mathrm{ADV}\{u_i^2\}}{\Delta t}$$

ADV is the advection operator.

Baroclinic instability experiments

Low Rossby number	High Rossby number
Ro = 0.1	Ro = 0.8
Depth = 1600 m	Depth = 200 m
1280 km × 1280 km	160 km × 160 km

Vertical buoyancy gradient
$1.56 \times 10^{-6}\mathrm{s}^{-2}$

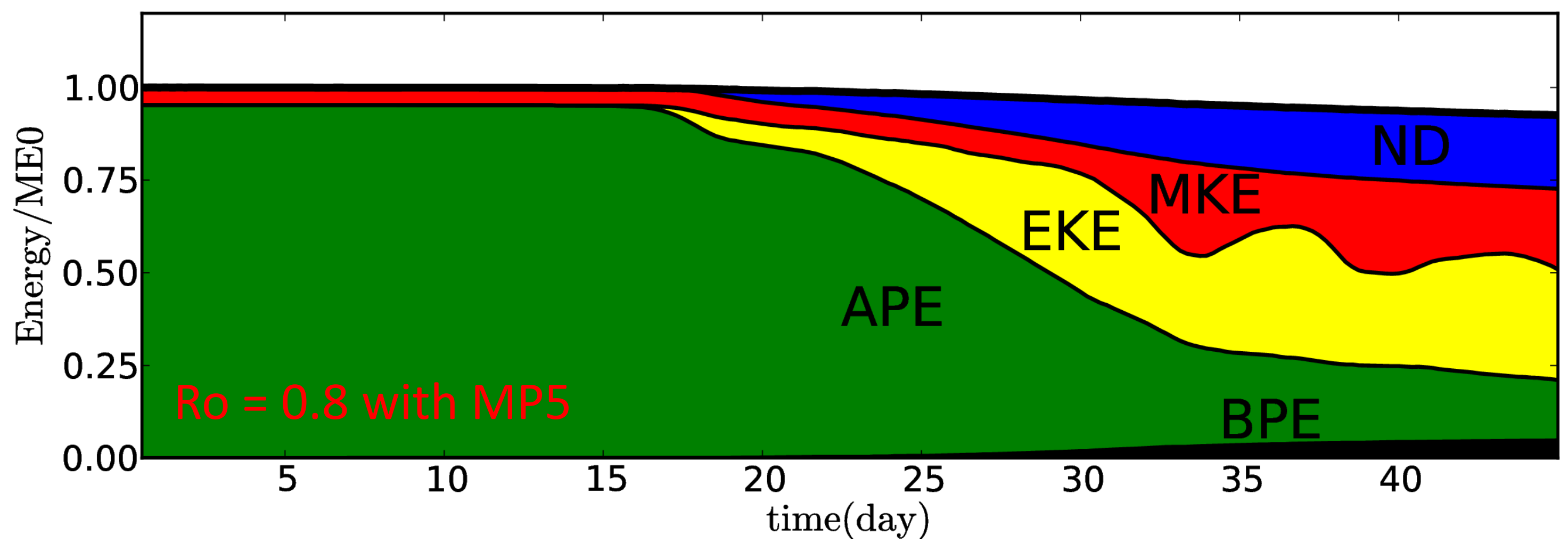
Horizontal buoyancy gradient

Low Rossby number	High Rossby number
$6.25 \times 10^{-9}\mathrm{s}^{-2}$	$5.0 \times 10^{-8}\mathrm{s}^{-2}$

Rossby radius of deformation (L0)

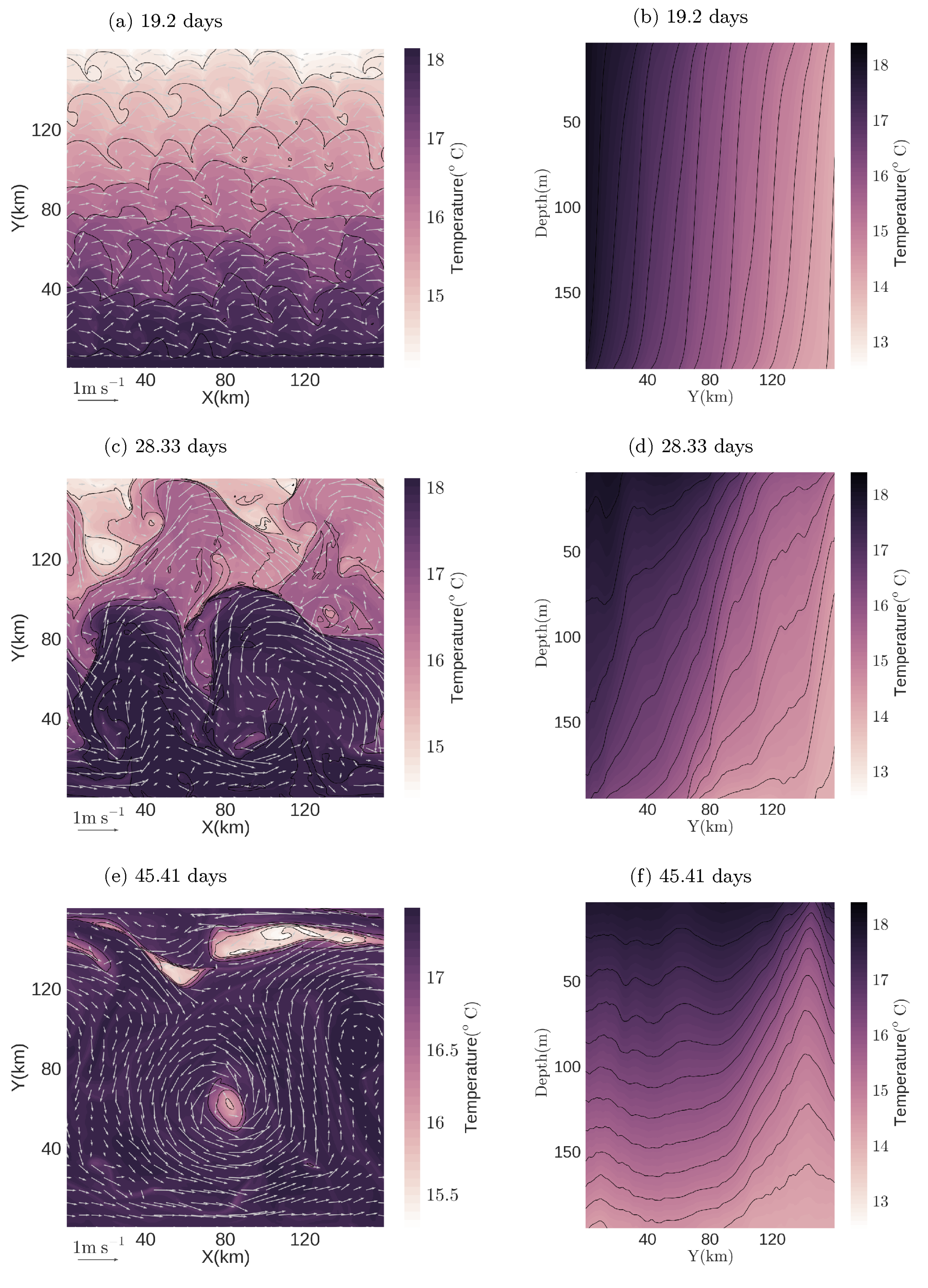
Low Rossby number	High Rossby number
5 km	40 km

Fig. 3: Evolution of energy distribution during restratification process.



BPE: Background Potential Energy MKE: Mean Kinetic Energy ND: Numerical Dissipation
APE: Available Potential Energy MEO: Initial Mechanical Energy EKE: Eddy Kinetic Energy

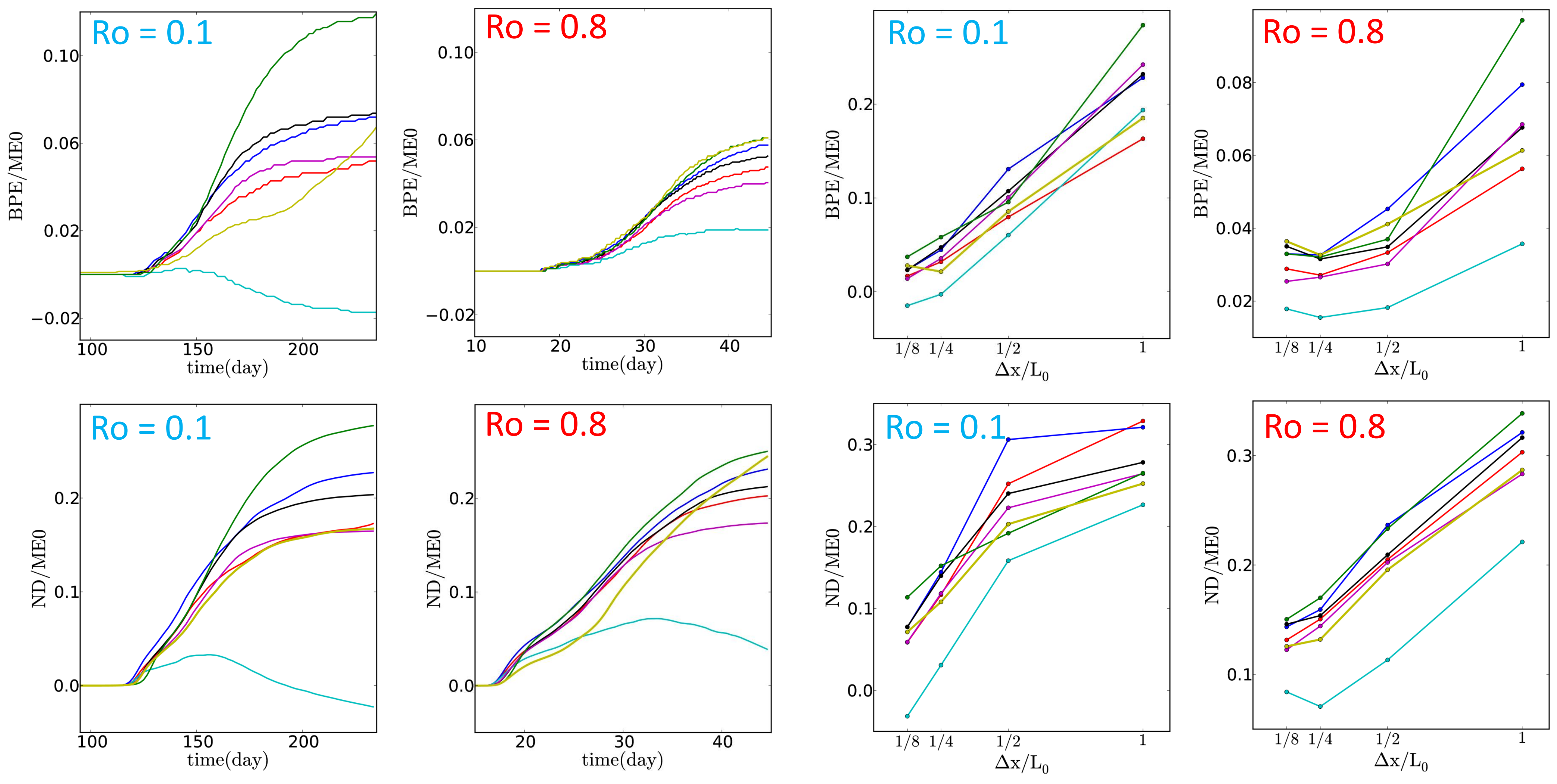
Fig. 2: Experiment: Baroclinically unstable front produces eddies which restratify the front. How large is numerical dissipation compared to mechanical energy?



Ro = 0.8 with MP5

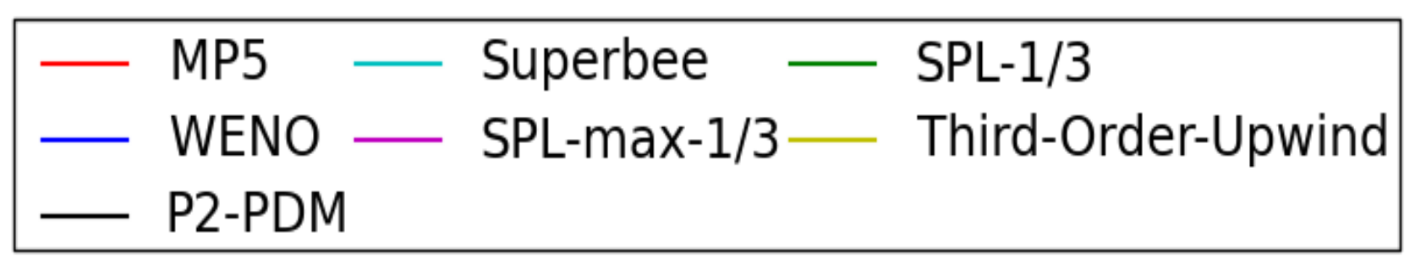
(a, c, e): Horizontal surface temperature, and (b,d,f): Zonally averaged temperature.

Fig. 4: Restratification with different advection schemes and resolutions.



Energy vs. time
Energy vs. resolution

Advection schemes



- SPL-1/3 and Superbee introduce the maximum positive and negative numerical diffusion, respectively.
- WENO performs better than most TVD schemes.
- MP5 performs best regarding the coservation of Energy.
- Increasing resolution reduces numerical diffusion.

Conclusions

1. Numerical dissipation is more responsible for the energy loss than numerical mixing.
2. Dissipative advection schemes slow down stratification process.
3. Different advection schemes affect restratification especially in low Ro regime.
4. Modern schemes like WENO or MP5 reduce artificial numerical mixing and thus improve the simulation of eddy restratification.
5. SPL-max-1/3 is the best energy conservative TVD scheme.

Refrences

Klingbeil, K., Mohammadi-Aragh, M., Gräwe, U. and Burchard, H., 2014. Quantification of spurious dissipation and mixing—Discrete Variance Decay in a Finite-Volume framework. Ocean Modelling, 81, 49-64.

Mohammadi-Aragh, M., Klingbeil, K., Brüggemann, N., Eden, C., and Burchard, H., 2015. The impact of advection schemes on restratifiction due to lateral shear and baroclinic instabilities. Ocean Modelling, 94, 112-127.

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