MODELLING EDDIES IN GLOBAL EDDY-PERMITTING SIMULATIONS:

IMPACTS OF AN OCEAN KINETIC ENERGY BACKSCATTER PARAMETRIZATION

Stephan Juricke,
Sergey Danilov, Nikolay Koldunov, Marcel Oliver, Dmitry Sidorenko

COMMODORE, Hamburg
31.01.2020
MOTIVATION

Sea surface height variability

Ocean kinetic energy backscatter
Stephan Juricke, 31.01.2020

http://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=30502
MOTIVATION

Sea surface height variability (AVISO relative to simulation)

Strong underestimation by $\frac{1}{4}^\circ$ simulation when compared to AVISO observational estimates

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No backscatter parametrization

Eddy permitting FESOM2
1/4° global ocean simulation

Classical harmonic viscosity
(modified harmonic Leith with biharmonic background)

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In eddy-permitting ocean models only some of the largest eddies are explicitly simulated.

Potential energy release by eddies through baroclinic instabilities is reduced.

Missing eddy effects are essential for accurate simulations of the mean flow and variability.

Viscosity closures dissipate not only enstrophy (i.e. vorticity variance; necessary for model stabilization) but also energy.

Kinetic energy backscatter allows to (stably) reinject excessively dissipated energy into momentum equation.
INTRODUCTION

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Momentum equation with $\vec{v} = (\vec{u}, w)$:

$$\vec{u}_t + \vec{u} \cdot \nabla \vec{u} + w \partial_z \vec{u} + f \vec{k} \times \vec{u} + \frac{1}{\rho_o} \nabla P = V(\vec{u}) + \partial_z (A_v \partial_z \vec{u})$$

$V(\vec{u})$ dissipation operator with flow-dependent coefficient (e.g. harmonic or biharmonic operator)
Momentum equation with $\vec{v} = (\vec{u}, w)$:

$$\vec{u}_t + \vec{u} \cdot \nabla \vec{u} + w \partial_z \vec{u} + f \vec{k} \times \vec{u} + \frac{1}{\rho_o} \nabla P = V(\vec{u}) + B(\vec{u}) + \partial_z (A_v \partial_z \vec{u})$$

- $V(\vec{u})$ dissipation operator with flow-dependent positive coefficient (e.g. harmonic or biharmonic operator)
- $B(\vec{u})$ backscatter operator with flow-dependent negative coefficient (e.g. harmonic or smoothed harmonic operator)
Momentum equation with $\vec{v} = (\vec{u}, w)$:

$$\vec{u}_t + \vec{u} \cdot \nabla \vec{u} + w \partial_z \vec{u} + f \vec{k} \times \vec{u} + \frac{1}{\rho_0} \nabla P = V(\vec{u}) + B(\vec{u}) + \partial_z (A_v \partial_z \vec{u})$$

$V(\vec{u})$ dissipation operator (small scales)
$B(\vec{u})$ backscatter operator (larger scales)

$V(\vec{u}) + B(\vec{u})$ dissipates energy and especially enstrophy (vorticity variance) at small scales, reinjects energy into larger scales to remain energetically consistent (as suggested by Jansen et al., 2015)
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\[ \bar{u}_t + \bar{u} \cdot \nabla \bar{u} + w \partial_z \bar{u} + f \bar{k} \times \bar{u} + \frac{1}{\rho_o} \nabla P = V(\bar{u}) + B(\bar{u}) + \partial_z (A_v \partial_z \bar{u}) \]

\[ \partial_t e = -c_{dis} \dot{E}_{dis} - \dot{E}_{back} + \text{Diffusion} \]

sub-grid kinetic energy \( e(x, y, z, t) \)

(Jansen et al., 2015; Klöwer et al., 2018)
Backscatter coefficient $\nu_b = -c_0 A \sqrt{\max(2e, 0)}$

with scaling $c_0$, grid spacing $A$

Remark: Smoothing in time and space as a tool to separate dissipation from forcing scales $\rightarrow$ stabilization
Idealized model configuration
RESULTS: EQUIDISTANT CHANNEL

Zonally reentrant channel simulation (FESOM2)

1/12° resolution

24 vertical layers, 1600m depth

Equidistant grid configuration

Boundary temperature relaxation

10 years simulation length

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RESULTS: EQUIDISTANT CHANNEL

Vertical structure (time mean layer averages)

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Global model configuration
RESULTS: GLOBAL SIMULATIONS

No backscatter parametrization

Backscatter parametrization

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RESULTS: GLOBAL SIMULATIONS

Sea surface height variability

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RESULTS: GLOBAL SIMULATIONS

Sea surface height variability

a) BACK1
b) AVISO
c) REF
d) AVISO to BACK1
e) AVISO to REF

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RESULTS: GLOBAL SIMULATIONS

Velocity snapshots

Mean velocity at 100m (Agulhas)

Mean velocity at 100m (Malvinas)

Mean velocity at 100m (Kuroshio)

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RESULTS: GLOBAL SIMULATIONS

Mean SSH

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Temperature bias

a) BACK1-CLIM
b) At 0m depth

Temperature bias

c) REF-CLIM
d) At 100m depth

Temperature bias

i) BACK1-REF

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Temperature bias

a) BACK1-CLIM

At 0m depth

b) At 100m depth

e) REF-CLIM

i) BACK1-REF

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Temperature bias

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Temperature bias

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### RMSE ratios BACK/REF

<table>
<thead>
<tr>
<th>Region</th>
<th>SSH mean bias ratio</th>
<th>SSH std bias ratio</th>
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</thead>
<tbody>
<tr>
<td>Global</td>
<td>0.894</td>
<td>0.925</td>
</tr>
<tr>
<td>Southern Ocean (30-60°S)</td>
<td>0.862</td>
<td>0.664</td>
</tr>
<tr>
<td>Agulhas (30-60°S, 0-60°E)</td>
<td>0.787</td>
<td>0.583</td>
</tr>
<tr>
<td>Malvinas (30-60°S, 60-0°W)</td>
<td>0.848</td>
<td>0.538</td>
</tr>
<tr>
<td>Kuroshio (20-50°N, 120-180°E)</td>
<td>1.075</td>
<td>1.007</td>
</tr>
<tr>
<td>Gulf Stream (30-60°N, 80-20°W)</td>
<td>0.992</td>
<td>0.949</td>
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<tr>
<td>30-60°S, 60-120°W</td>
<td>0.888</td>
<td>0.610</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>0.893</strong></td>
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### RESULTS: GLOBAL SIMULATIONS

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RESULTS: GLOBAL SIMULATIONS

Subgrid energy

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OUTLOOK

Improvement of parametrization of physical dissipation (reduction of timestep)

Use different resolutions and compare costs and quality of simulations

Different versions of backscattering, e.g. simplified, instantaneous backscattering; investigation of new combined operators

Extended diagnostics in the framework of effective resolution, dissipation vs. forcing scales, effects of operator choices

Idealized setups for intercomparison of different schemes, models (FESOM vs ICON), etc.

Extension to non eddy-resolving grids (inclusion of GM eddy parametrization)
CONCLUSIONS

Backscatter leads to strongly reduced energy dissipation and a more realistic total kinetic energy comparable to higher resolution simulations.

Additional costs for backscatter scheme around 50% (channel) to 150% (global) while costs for resolution increase are more than (channel) or around (global) an order of magnitude.

Improves variability as well as mean flow (with some exceptions) not only for velocity and SSH but also temperature and salinity.


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