The Stochastic GM+E closure: A framework for coupling stochastic backscatter with the Gent and McWilliams parameterization

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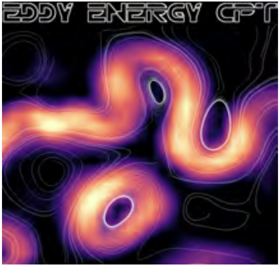
This research was funded by NSF grant number 1912332



Niraj Agarwal
Gustavo Marques
Phil Pegion
Houssam Yassin

Into the foreseeable future there remains a role for ocean general circulation models at non-eddying resolutions.

- Covering many climate change scenarios
- Large ensembles
- Simulations with many tracers, e.g. BGC
- Very long runs, e.g. for paleoclimate

Since they will be used, it’s worthwhile to try to make them better.

Ocean GCMs at non-eddying resolutions are deficient in variability.

They lack mesoscale eddies. This is unavoidable. But they also lack variability at large scales that is induced by the eddies.

Backscatter can be used to re-inject energy (hence variability) into the model.

Many backscatter schemes are designed for *eddying* ocean models, to strengthen partially-resolved eddies.

In these schemes the backscatter is often designed to counteract excess dissipation by viscosity.

This doesn’t seem appropriate for a non-eddying model.

Contents lists available at ScienceDirect

Ocean Modelling

journal homepage: www.elsevier.com/locate/ocemod

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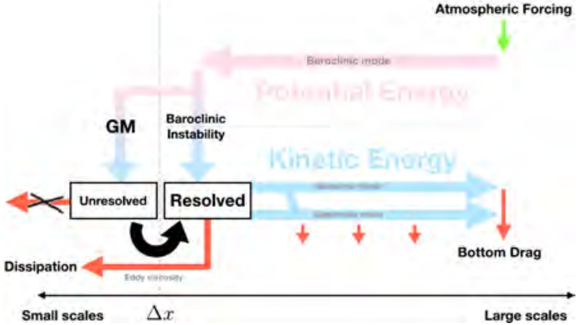


The GM+E scheme uses the Laplacian for viscosity *and* backscatter, but backscatter only acts on the barotropic part:

$$\partial_t \boldsymbol{u} = \ldots + \nu_{\text{damping}} \nabla^2 \left(\boldsymbol{u} - \langle \boldsymbol{u} \rangle \right) - \nu_{\text{back}} \nabla^2 \langle \boldsymbol{u} \rangle.$$

The original paper used MITgcm in a simple channel configuration.

Scott implemented in MOM6 and did some testing, but there was never a paper.

GM wants to damp eddies while negative-viscosity backscatter wants to amplify them.

Our experience in the CPT has been that it's hard to generate eddies using negative viscosity when GM is also present, so GM+E has a hard time working well.

At eddying resolution you can turn GM off (maybe selectively) so that negative-viscosity backscatter has a chance.

At coarse resolution we can't turn GM off. We need **stochastic** backscatter.

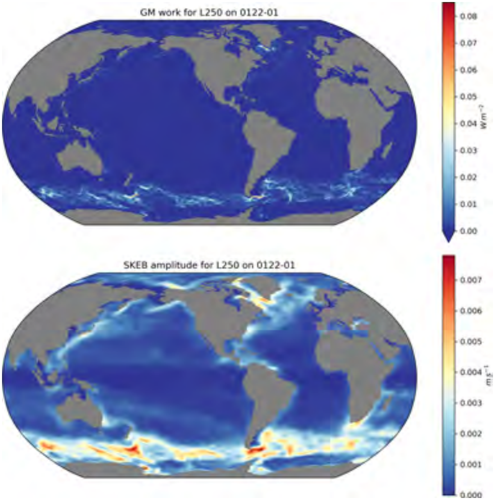
$$\partial_t \boldsymbol{u} = \ldots + \text{Stochastic Forcing.}$$

The backscatter rate in '**Stochastic GM+E**' is proportional to the GM work rate.

You can think of this as a forcing in the momentum equations, but we implement it by adding an increment to the horizontal velocity between time steps.

The velocity increments'

- Amplitude: KE Backscatter rate $\propto$ smoothed GM work rate
- Horizontal Scale/Structure:
- Vertical Structure:
- Time Scale/Structure:


GM work for L250 on 0122-01
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
W m⁻²
SKEB amplitude for L250 on 0122-01
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
m s⁻¹

The velocity increments'

- Amplitude: KE Backscatter rate $\propto$ smoothed GM work rate
- Horizontal Scale/Structure: Laterally incompressible, arbitrary spherical harmonic spectrum
- Vertical Structure:
- Time Scale/Structure:

The velocity increments'

- Amplitude: KE Backscatter rate $\propto$ smoothed GM work rate
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- Vertical Structure: Proportional to the first 'surface' mode
- Time Scale/Structure:

The velocity increments'

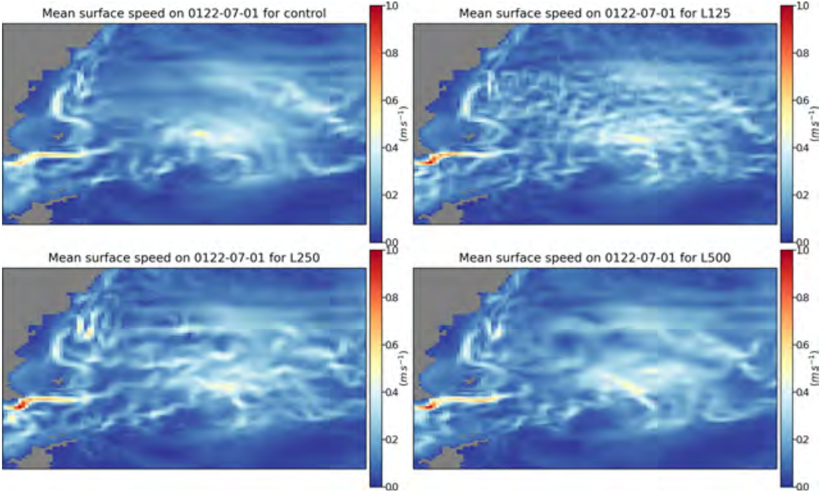
- Amplitude: KE Backscatter rate $\propto$ smoothed GM work rate
- Horizontal Scale/Structure: Laterally incompressible, arbitrary spherical harmonic spectrum
- Vertical Structure: Proportional to the first 'surface' mode
- Time Scale/Structure: AR1/Exponential with 6 hour decorrelation time - must be fast

We run a JRA-forced ocean-ice configuration of MOM6 at $2/3°$ resolution with 65 z^* levels.

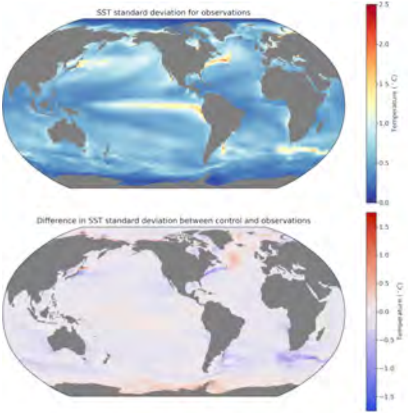
GM & Redi are used with the GEOMETRIC amplitude. Redi is depth-independent while GM has 'EBT' vertical structure.

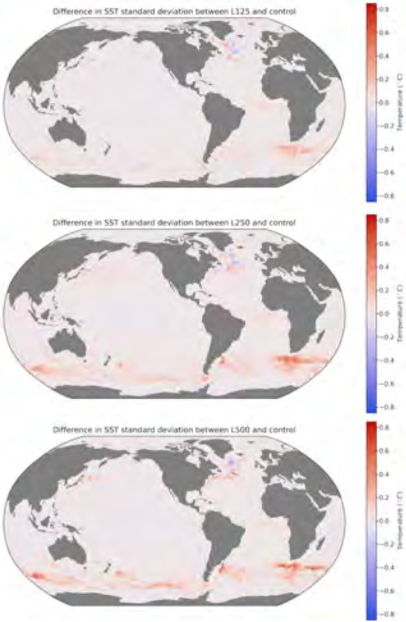
Spin up for 60 years, then 62 more years, diagnostics over the last 50 years.

We vary the length scale L of the stochastic forcing as well as the fraction c of the GM work that gets backscattered.



$c = 50\%$, $L = 125, 250, 500$ km.

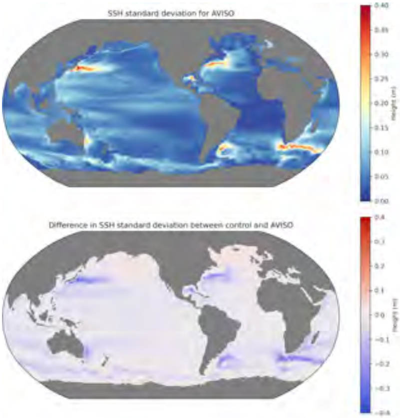


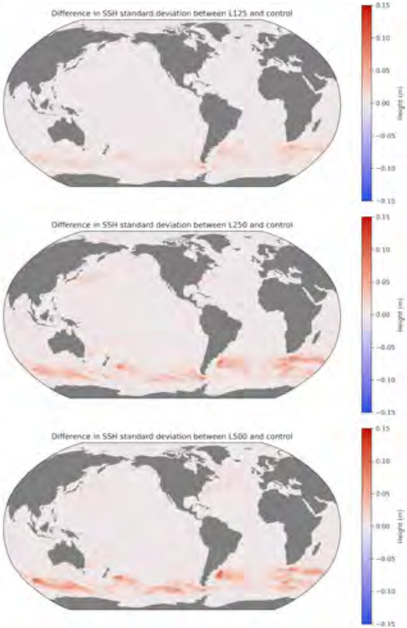


- Control lacks SST variability

- Stochastic increases variability

- Smaller length scale (125 km) is less efficient at generating SST variability

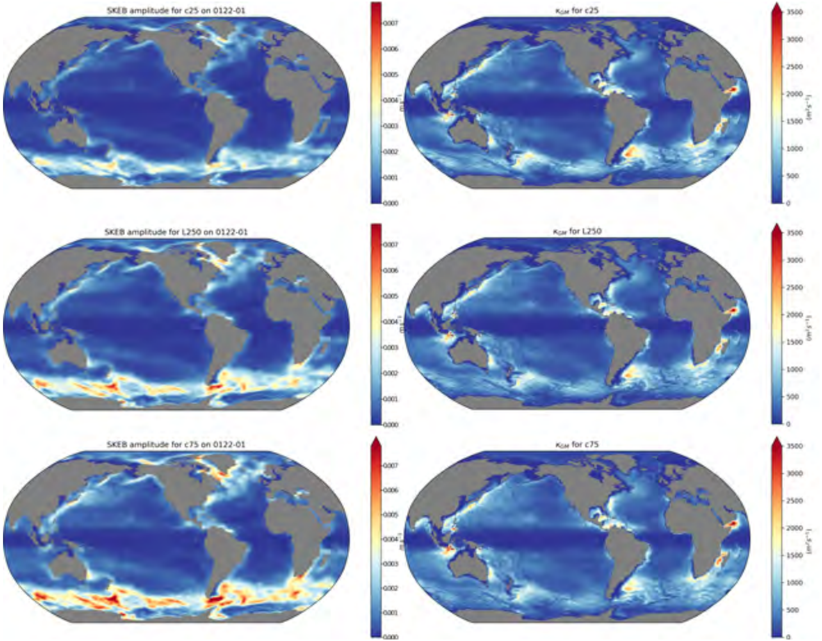




- Control lacks SSH variability

- Stochastic increases variability

- Smaller length scale (125 km) is less efficient at generating SSH variability


SKEB amplitude for c25 on 0122-01
0.000 0.001 0.002 0.003 0.004 0.005 0.006 0.007
κ_{GM} for c25
0 500 1000 1500 2000 2500 3000 3500
SKEB amplitude for L250 on 0122-01
0.000 0.001 0.002 0.003 0.004 0.005 0.006 0.007
κ_{GM} for L250
0 500 1000 1500 2000 2500 3000 3500
SKEB amplitude for c75 on 0122-01
0.000 0.001 0.002 0.003 0.004 0.005 0.006 0.007
κ_{GM} for c75
0 500 1000 1500 2000 2500 3000 3500

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ESSOAR DOI: 10.22541/essoar.172118408.85625257/v1