Oxygen simulations in GFDL eddy-resolving coupled climate model

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Climate Models are needed for projections

CMIP5 models predict warming and deoxygenation (Bopp et al., 2013)
but models suffer from biases…

- OMZ too strong, confined to the east
- OMZ reaching too deep in the water column
- Weak Arabian Sea and strong Bay of Bengal OMZ
- etc.

Bopp et al., 2013
Models predict $O_2$ either stable or increasing over open-ocean OMZs.

Bopp et al. 2013

Cocco et al. 2013
The ocean is turbulent

Kinetic energy is mostly at the scale of eddies (~100 km) - but current climate models do not resolve them.

Delworth et al., 2012
Fine-scale jets dominate the tropics

E.g. zonal currents in the Equatorial Pacific

Czeschel et al., 2012
Main Questions

- Do we have a biased view of ocean oxygen and its response to change?
- Is resolving the mesoscale necessary to represent the mean state and variability in OMZ?
- What is the role of eddies and jets in the OMZ oxygen balance?
Fully coupled eddy-resolving climate model

- 1/10° ocean resolution (3600x2700)
- 1/2° atmosphere resolution
- no parameterization of mesoscale eddy effects
- costly – 2 years/day on 20,000 processors

Developed for climate, added simple P, C and O₂ cycles

For comparison, ESM2M, a typical IPCC model:

- 1° ocean resolution (360x200)
- 2° atmosphere resolution
- parameterization of eddy effects
Running tracers is extremely costly (advection)

need to minimize the number of advected tracers

BLING – computationally efficient model based on:

\( \text{PO}_4, \text{DOP}, \text{O}_2, \text{Fe, DIC, Alk.} \)

Biogeochemistry Light Iron Nutrients Gases
Running tracers is extremely costly (advection)

need to minimize the number of advected tracers

miniBLING – more computationally efficient!

PO$_4$, DOP, O$_2$, Fe, DIC, Alk,
RUNS: (1) Control at 286 ppm pCO$_2$
(2) 1% per year pCO$_2$ increase to doubling
Model simulation - overview

- Rich mesoscale dynamics (eddies, jets, boundary currents)
- Realistic baseline simulation – winds, currents, T,S, climate
- Realistic internal variability (e.g. ENSO)
CM2.6 eddy kinetic energy

CM2.6 fully captures mesoscale dynamics

Delworth et al., 2012

Liege, 2014
Model $O_2$ (μmol kg$^{-3}$) at 250 m depth
OMZ – baseline simulation (O$_2$ at 250m)

Realistic upper OMZ:
- intensity
- westward propagation
- fine structure (jets)

Remaining biases:
- Indian Ocean
- South Pacific OMZ
- Gulf of Guinea
- low O$_2$ at depth

Liege, 2014
Main OMZ biases – Indian Ocean
Main OMZ biases – ETSP
Improvement from 1\textdegree{} models

- $O_2$ bias reduction
- more realistic ventilation of eastern OMZ by jets
- reduction of OMZ intensity and size
Projected $O_2$ changes

$\Delta O_2$ at 250 m (last 20 year)

high latitude losses, low latitude gains
largest $O_2$ increase in Indian and Atlantic
OMZ

Liege, 2014
Projected changes – CM2.6 vs ESM2M

- Large-scale pattern agreement
- Stronger signal at high resolution
- Regional differences noticeable
- Decadal variability?
Large variability (seasonal, interannual)

Timeseries of $O_2$ at 250 m over the ETNP
Summary

• Very preliminary work
• First global eddy-resolving atmosphere-ocean coupled simulation with O₂
• Realism of upper-ocean OMZ greatly improves, but biases remain
• Richness of the simulation is enormous – e.g. O₂ balances, variability and change, regional patterns etc.
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