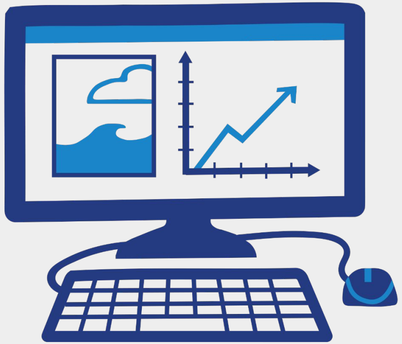


Overview of OM5 and MOM6 development

Presented by Brandon Reichl on behalf of OM5DT & MOM6 team

Q1: Concerning GFDL's core strength of building and improving models of the weather, oceans, and climate for societal benefits, how can GFDL leverage advances in science and computational capabilities to improve its key models? What are the strengths, gaps, and new frontiers?


Image Generated by ChatGPT

OM5 Mission

The next generation of GFDL's world-leading ocean and cryosphere models that will advance GFDL scientific interests and NOAA's mission

OM5 Goals

A. Simulate regional-to-global patterns and trends of sea level
B. Reduce polar ocean and cryosphere biases
C. Reduce tropical & mid-latitude ocean stratification biases
D. Improve representation of deep ocean circulation

MOM6
ocean model, 1/4°
hybrid-coordinate

SIS2
sea ice
simulator

***MOM6-IS**
Dynamic Ice
Sheet model

*Explicit
tides

Surface
waves

KID
Lagrangian
icebergs

**New Features beyond OM4*

MOM6 development activities are supporting OM5's goals

A. Simulate regional-to-global Sea Level

Non-Boussinesq implementation, explicit tides, self-attraction and loading, modern equation of state

B. Reduce Polar Biases

Ocean sea-ice coupling & numerical stability, improved sea-ice physics, double-diffusive mixing, internal gravity wave mixing, brine rejection

C. Reduce Tropical & Mid-latitude Ocean Biases

Boundary layer mixing improvements, shear mixing improvements, Implementing tidally-driven diffusivity, mesoscale eddies, mixed layer eddies

D. Improve Deep Ocean Circulation

Porous boundaries, vertical coordinate development, updated bathymetry and horizontal grids

Under the MOM6 open development paradigm, all of these capabilities are freely available.
OM4 is the basis of the UFS GFS v.17 ocean; OM5 will be available as a template for future versions of UFS

MOM6 algorithm and formulation improvements are available to OM5

- Non-Boussinesq version of MOM6 [goal A]
- Improved vertical coordinate algorithms [goal D]
- Improved various numerical aspects [goal A,D]
- "Porous" representation of bathymetry [goal D]
- Modern Equation of state [goals A,B,C,D]
- Surface wave-averaged equations [goals A,B,C]
- Explicit simulation of global tides [goal A]
- Add Great Lakes and waterfalls [goal A]
- Add support of evolving ice-sheet geometry [goal A,B]

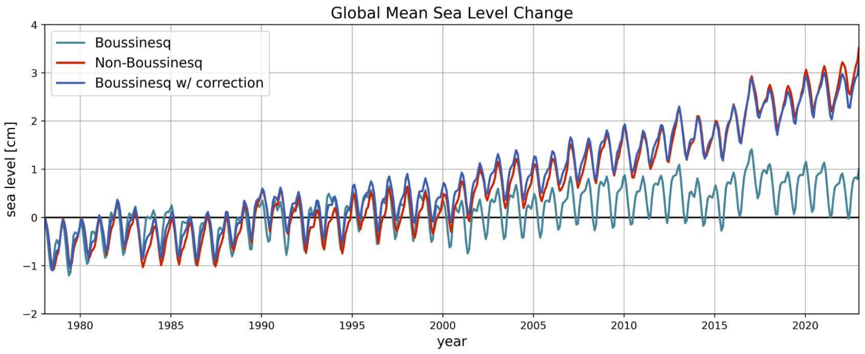


Fig 1: OM5 w/ non-Boussinesq version of MOM6 can explicitly simulate the thermal contraction (by cooling) and expansion (by warming) of sea level in the recent historical epoch.

Energetics Based Boundary Layer Parameterizations

- Upgrade surface mixing scheme (ePBL)[1,11,12]
  - *Improves mixed layer depths and diurnal cycle [goal A,B,C,D]*
- Include surface wave driven fluxes and mixing[2,3,4,5,6,8,10,16,17]
  - *Improves mixed layer depths and air-sea fluxes [goal A,B,C]*
- New submesoscale parameterization[10,15]
  - *Physically consistent frontal length scale in tropics [goal B,C,D]*
- Improve BBL mixing[12,14]
  - *Improves bottom water from coastal regions to deep overflows [goal D]*
- Machine learn ePBL enhancements[9,13]
  - *Further improves stratification and mixed layer depths [goal A,B,C,D]*
- New energetic mixed layer depth metrics and observations[7]
  - *Improves model bias diagnosis and process understanding*

Improve Diurnal "Deep Cycle" mixing

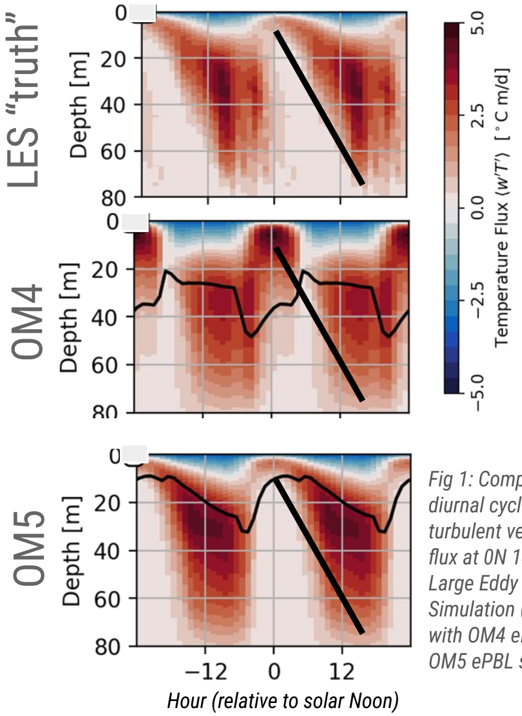


Fig 1: Comparing diurnal cycle of turbulent vertical heat flux at 0N 140W using Large Eddy Simulation ("truth") with OM4 ePBL vs OM5 ePBL setting

[1]Reichl and Hallberg (2018) [2]Li et al. (2019) [3]Reichl and Li (2019) [4]Reichl & Deike (2020) [5]Deike et al. (2022) [6]Kim et al. (2022) [7]Reichl et al. (2022) [8]Zhou et al. (2022) [9]Sane et al. (2023) [10]Zhou et al. (2023) [11]Reichl et al. (2024)[12]Griffies et al. (in review) [13]Sane et al. (in prep) [14]Hallberg et al. (in prep) [15]Uchida et al. (in prep) [16]Rustogi et al. (in review) [17]Deike et al. (in review)

Physically Consistent Interior Mixing Parameterizations

- More realistic (reduced) background viscosity[2]
  - *Improves mean shear and thermocline bias [goal C]*
- Improve tidal mixing physics[1]
  - *Major improvement to Arctic salinity bias [goal B]*
- Add double diffusive vertical mixing
  - Include mixing by salt fingers & diffusive convection [goal A,B,C]
- Improved interior shear driven mixing[3]
  - *Reduces numerical sensitivity of induced mixing [goal B,C,D]*
- Ray-tracing internal tide energy for mixing[5]
  - *Propagate energy and convert to turbulent mixing [goal B,C,D]*
- Implicit energetics-based full-column mixing[4]
  - *More robust & consistent mixing algorithms [goal A,B,C,D]*

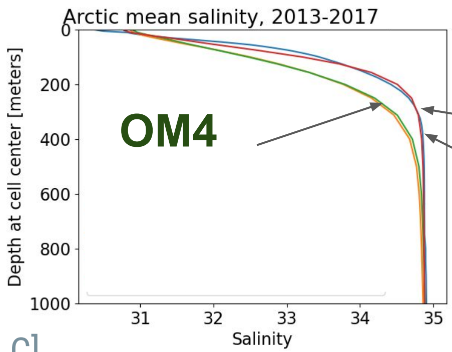
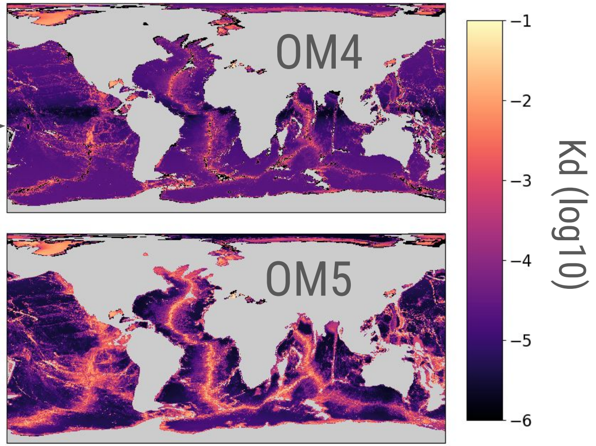


Fig 1: Arctic mean Salinity profiles in OM4 & OM5 vs world ocean atlas

Fig 2: Log10 of mean diffusivity at 1000m depth in OM4 vs OM5 w/ ray tracing scheme



[1]Harrison & Hallberg (2008) [2]Reichl et al. (2024) [3]Griffies et al. (in review) [4]Hallberg et al. (in prep) [5]Dussin et al. in prep

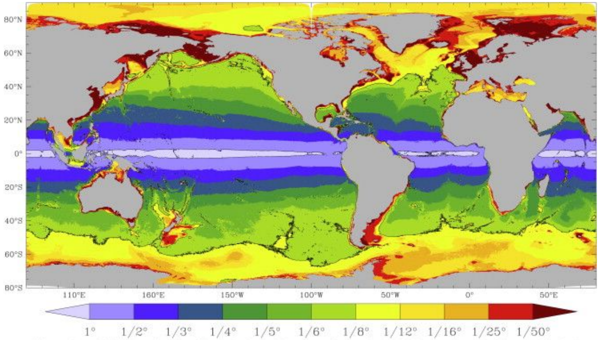
Mesoscale Eddy Mixing Parameterization Development

OM5's ¼° resolution is insufficient to resolve all mesoscale eddies

GFDL plays a critical role in eddy parameterization development

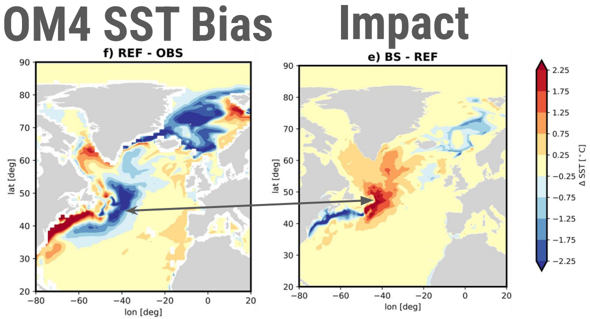
- Progress to understand and simulate processes, energetics, and scales of the ocean's mesoscale eddy field[1,4,5,7,8,9,10,18]
- Progress to develop energetically constrained eddy parameterizations with realistic vertical structures
    - *Improving resolved eddy characteristics[13] [goal C]*
    - *Improving sub-grid energy models[11,12,15] [goal B,C]*
    - *Improving algorithms and approaches[2,3,6,14,17,20,21] [goal A,B,C,D]*
- Progress in machine learning parameterizations[16,19]

[1]Naveira Garabato et al. (2019) [2]Shao et al. (2020) [3]Stanley et al. (2020) [4]Khatri et al. (2021) [5]Aluie et al. (2022) [6]Kenigson et al. (2022) [7]Marques et al. (2022) [8]Naveira Garabato et al. (2022) [9,10]Yassin & Griffies (2022a,2022b) [11]Storer et al. (2022) [12]Buzzicotti et al., 2023 [13]Chang et al. (2023) [14]Loose et al. (2023) [15]Storer et al. (2023) [16]C. Zhang et al. (2023) [17]Jansen et al. (2024) [18]Lobo et al. (2024) [19]Perezhogin et al. (2024) [20]W. Zhang & Wolfe (2024) [21]W. Zhang et al. (2024)



Hallberg (2013)

Fig 1: Simulation horizontal resolution requirement to resolve mesoscale eddy effects in global ocean model



Chang et al. (2023)

Fig 2: Impact of eddy backscatter parameterization on SST bias in OM5 prototype model

OM5 and future global ocean and cryosphere modeling at GFDL

- OM5 continues GFDL's role to advance the state of ocean and cryosphere modeling
- GFDL is addressing gaps in ocean and cryosphere modeling capabilities to enable better projections to address NOAA's mission objectives
  - Adding Great Lakes to global climate models for regional U.S. climate (See Q3 slides)
  - Ocean wave component for improved air-sea coupling (See Q3 slides)
  - Explicit Tides and self-attraction and loading for better regional circulation and changes
  - Ocean - Ice-sheet coupling for better sea-level rise projections
- OM5 prepares GFDL for a next generation of high resolution ocean and coupled modeling, subject to availability of computational resources (see also Q1 CM4X slides)