Ocean and Ice Sheet Modeling and Sea-level Rise

Presented by

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GFDL’s Ocean-Climate Models in Service to NOAA and the World

• MOM series of models is widely used & will continue to be so
  – MOM4.1 had many active users worldwide
  – MOM5 is the latest public release of MOM (October, 2012)
  – GOLD (GFDL’s isopycnal coordinate ocean) now incorporated into MOM6
  – *All GFDL ocean & climate model development is focused on MOM6*

• Aim for MOM6 is to capture the complete range of climatically important physical processes in the ocean, with robust diagnostics, and effective and efficient numerics (Talk by Adcroft)

• Key element of all GFDL coupled climate models

• Used for important operational products in NOAA and abroad
  – E.g., NCEP using MOM4.1 in seasonal predictions; CM2.1 is a part of CFS2.0; MOM5 is currently being ported for use in NCEP/CFS3.0
  – E.g., MOM4/MOM5 used for operational and research applications in Australia, Brazil, India, South Africa, …
The Ocean’s Role in Climate Change

Exploring the dynamics of Sea Level Rise

ESM2M & ESM2G – same atmosphere & ecosystems, different ocean models.

Historical & Scenario-projected Steric Sea Level Rise

Projecting sea-level rise is prominent in NOAA’s Next Generation Strategic Plan:
- Adaptation to Climate Change
- Resilient Coastal Communities

ESM2G & ESM2M 1980-2000

Horizontal-Mean Ocean Temperature

18% larger steric SLR in ESM2M
9% due to more & deeper heat uptake
7% due to warmer spun-up ocean

Ref: Hallberg et al., 2013, J. Climate
Coupled model ocean drift and equilibrium bias are sensitive to the magnitude of diapycnal diffusion (mixing) in the ocean.

**ESM2G Volume-mean Ocean Potential Temperatures**

Horizontal Mean Ocean Temperature and Bias with Various Added Ocean Diffusivities
Adding diapycnal diffusion increases steric sea level rise both by increasing heat uptake and by warming the ocean (warmer water expands more when heated). Both the initial conditions and mixing during the run contribute significantly.
Steric sea level studies

• Griffies and Greatbatch (2012):
  – Developed a theoretical framework for global mean steric sea level.
  – Emphasized role of ocean thermal expansion variations in determining how heating and mixing impact steric sea level.

• Griffies + 40 co-authors (2014):
  – Assessed sea level trends in 13 historically forced (CORE-II) global ocean-ice models.
  – Models generally capture recent linear trends in West Pacific and North Atlantic thermosteric sea level, both associated with natural variability in atmospheric forcing.

Observational Estimates of 1993-2007 Thermosteric Trends

Mean of 13 CORE-forced Ocean Models
CORE ensemble mean 700m thermosteric trend
Mesoscale eddies transmit energy to lee-waves at rough bottom topography, which break and cause mixing. Estimate of energy transferred from eddies to lee-waves.

Addition of lee-wave driven mixing parameterization leads to warmer deep ocean, cooler upper ocean.

Nikurashin, Vallis and Adcroft, 2013

Nikurashin and Ferrari, 2011

Melet, Hallberg, Nikurashin and Legg, 2014
Improved energetically consistent parameterizations are developed in collaboration with academic partners in the NOAA/NSF funded Internal Wave Driven Mixing Climate Process Team.

1500m Temperature difference due to improved vertical profile for internal tide driven mixing

Melet, Hallberg, Polzin and Legg, 2013
Parameterization of mixing by internal tides

Zonally-averaged temperature difference:
Same energy input, different wave-breaking locations
(Remote dissipation over slopes) - (Uniform diffusivity)

Internal wave shoaling leads to enhanced dissipation over tall ridges and continental slopes

Location of mixing matters to large-scale ocean and climate
Icesheet mass loss is the largest term and largest source of uncertainty in 21st century sea level rise projections.

GFDL is addressing this uncertainty by developing a fully coupled and dynamically evolving ice sheet modeling capability.

Sea Level Rise Scenarios from 2012 NOAA/CPO Report:
- Ocean warming + Maximal Ice-sheet Mass Loss = 2 m
- Ocean warming only = 0.5 m
- Lowest - 0.2 m
Coupled Ice-shelf-ocean Interaction


Ocean bottom temperature


Nichols et al (2005)
Dynamic Ice-shelf-ocean Interaction

Goldberg et al. JGR (2012)

Melt rates (m yr$^{-1}$)

10 yrs

30 yrs
Dynamic Ice-shelf-ocean Interaction

Melt rates (m yr$^{-1}$)

Rate of change of Volume Above Flotation

Goldberg et al *JGR* (2012)
Basal conditions under ice streams

Inverted basal shear stress (kPa)

Pine Island Glacier

Thwaites Glacier

Coupled Ice-shelf-ocean Interaction

MOM6 \( \frac{1}{8} \) deg Global Ocean Model

Ocean Mixed Layer Speed (m s\(^{-1}\))
Coupled Ice-shelf-ocean Interaction

MOM6 ⅛ deg Global Ocean Model

Modeled Melt Rates (m yr⁻¹)
Calving and Icebergs Climate Process Team

Antarctic mass loss

Melting 45% Calving 55%

Rignot et al. (2013)
Calving and Icebergs Climate Process Team

Ross Ice Shelf, Antarctica

- Ross Sea (cloudy)
- nascent iceberg
- iceberg detachment rift
- 25 km
- 50-100 years

Jakovshavn Isbrae, Greenland

- days-months
- 10 km

Larsen B Ice Shelf, Antarctica

- 60 km
- 12,000 years

Columbia Glacier, Alaska

- hours
- 2 km
Calving and Icebergs Climate Process Team

Icebergs tracks 1999-2010

The Antarctic Iceberg Tracking Database
Iceberg representation in GFDL climate models

## Team
- Princeton CICS (Lead)
- GFDL
- University of Alaska
- University of Michigan
- Kansas University
- Penn State

## Goals
- Calving parameterizations
- Iceberg-ocean interactions
- Compile available data on calving and icebergs

Calving and Icebergs Climate Process Team Supported by NOAA/MAPP via NOAA/CPO
• GFDL has unified its ocean model development efforts behind MOM6.

• Sea level rise exhibits significant sensitivity to the representation of the ocean and ocean mixing.

• GFDL is developing and adopting increasingly physically based representations of ocean mixing processes.
  – Success also requires limiting spurious numerical mixing

• Coupled ice-sheet / ocean interactions are central to societally important questions about Sea Level Rise.
  – GFDL is at the forefront in the development of the required fully coupled ice-sheet / ocean modeling capabilities.