Geophysical Fluid Dynamics Laboratory Review

June 30 - July 2, 2009

Ocean Modeling Introduction and Overview

Presented by

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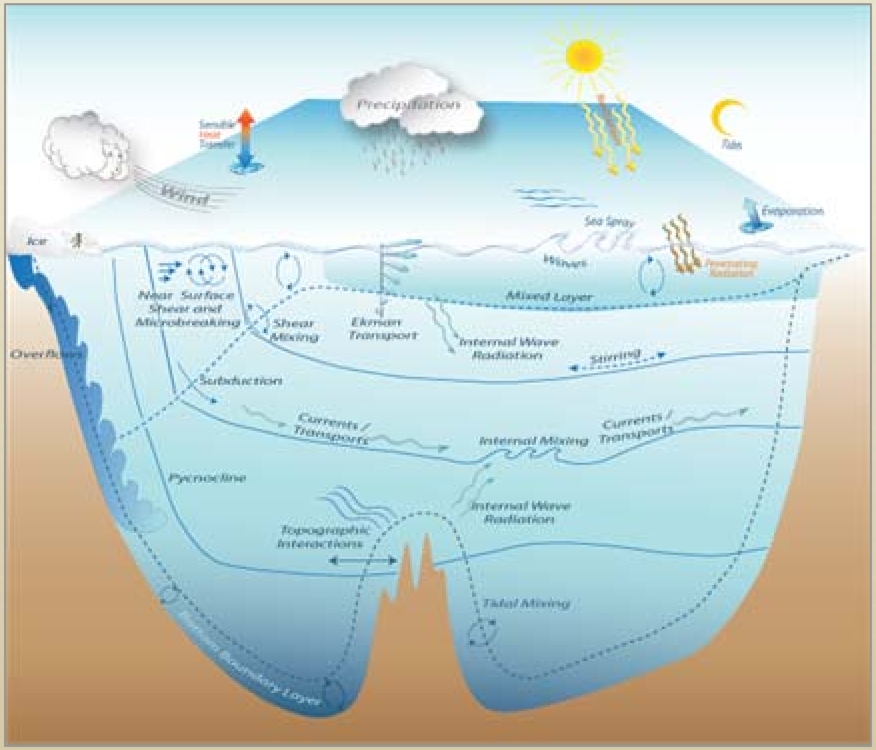
GFDL Ocean Models: Critical for NOAA's Mission

- Realistic climate simulations
- Detection of climate change
- Biogeochemical cycling and the fate of anthropogenic carbon
- Climate stability, variability and predictability
- Operational seasonal to decadal forecasts
- Marine ecosystem forecasts
- Impacts of climate change

GFDL Ocean Modeling Mission:

Improving the numerical and physical representations of ocean processes



Organizing Scientific Hypotheses

- **Ocean circulation and property distributions are determined by both large- and small- scale processes**
  - Global scales are sensitive to small scale processes
  - Getting the mixing right will improve the circulation
- **Explicitly resolving processes is necessary to develop physical parameterizations**
  - Process studies are key to ocean model development
- **The ocean circulation and state determine the long term behavior of the climate system**
  - Getting the physics of the ocean circulation right is essential for getting the longer term response to climate forcing right
  - Key aspects of climate change impact assessment will be more robust
- **Comparison between ocean model formulations is valuable for appraising uncertainty about the ocean's role in climate**

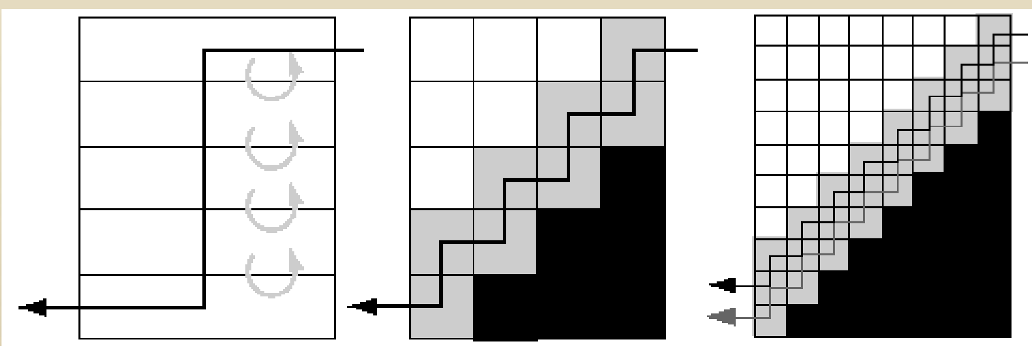
Major GFDL Oceanographic Activities

- **Coupled climate model ocean configuration development**
  - CM2M
  - CM2G
- **Ocean model capability & code development**
  - Modular Ocean Model (MOM)
  - Generalized Ocean Layered Dynamics (GOLD)
- **Process studies & parameterization development**
- **Studies of the ocean's role in climate & paleoclimate**

Why seek better ocean-climate models?

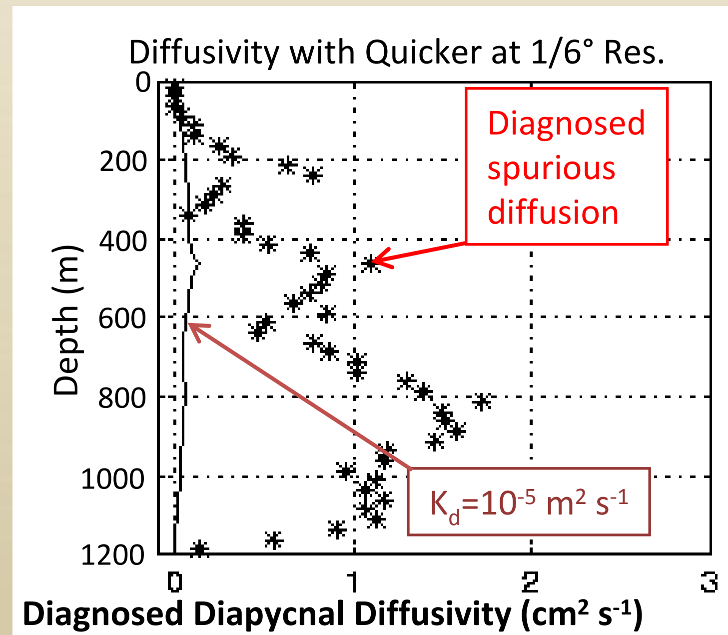
Two long-standing problems with Z-coordinate models are of great importance for the ocean's role in climate:

- Excessive entrainment in **overflows** *(Winton et al., 1998)*
- Unphysically large **spurious diapycnal mixing** from advective truncation errors, especially in eddy-resolving models *(Griffies et al., 2001)*



Excessive entrainment occurs unless

$(\Delta z < H_{BBL}/2 \approx 50m)$ and $(\Delta x < H_{BBL}/2slope \approx 5km)$



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Two approaches pursued at GFDL:

1. Improved numerics & new parameterizations in MOM
2. Make isopycnal coordinate models realistic enough to be useful for climate studies (GOLD)

GFDL's AR5 Coupled Climate Models

	CM2G	CM2M	CM2.1	CM3
Atmosphere	AM2.1 (L24)	AM2.1 (L24)	AM2.1 (L24)	AM3 (L48)
Land	LM3	LM3	LM2	LM3
Sea ice	SIS	SIS	SIS	SIS
Ocean	GOLD	MOM4p1 "M configuration"	MOM4	MOM4p1 "CM2.1-like"

ESM2G and ESM2M

Coupled Climate Model Ocean Component Development

CM2G – GOLD based
r- coord. ~1°, 63 levels

- Isopycnal coordinate eliminates spurious diapycnal mixing - even with eddies!
- Greatly improved representation of overflows & deep water formation processes (e.g. AMOC)
- Greatly improved exchanges with marginal seas

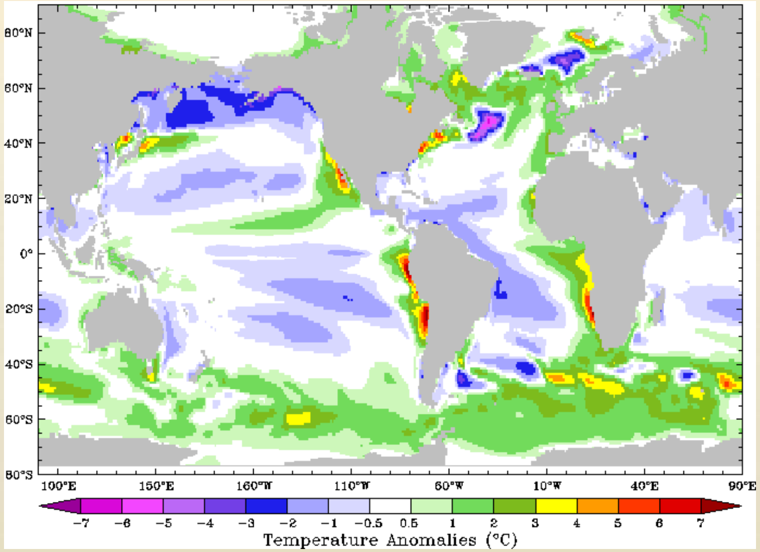
CM2M – MOM4.1 based
z*-coord. ~1°, 50 levels

- Improved numerics over CM2.1
  - Z* gives more uniform near-surface resolution
  - Less diffusive tracer advection
- Improvements in physical process parameterizations over CM2.1
  - Mesoscale & submesoscale eddy parameterizations
  - Tidal mixing parameterizations
  - Simpler form for horizontal viscosity

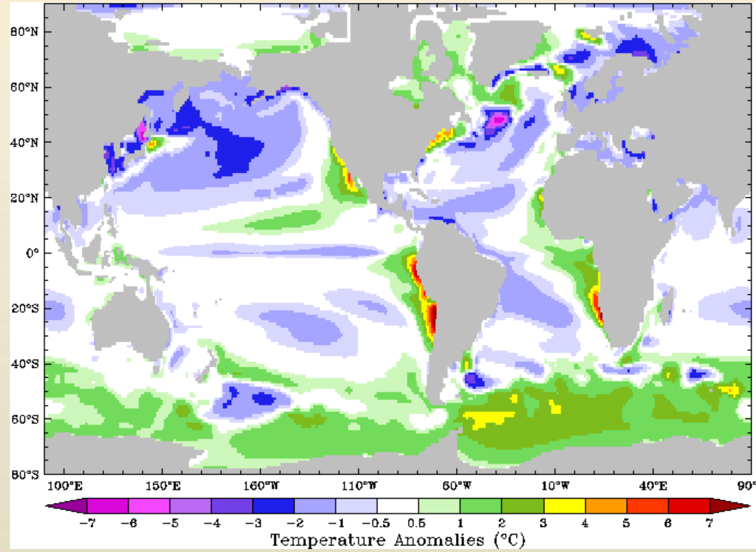
These models have very different inherent biases.
Comparison elucidates our uncertainty on the ocean's role in climate.

100-Year Mean SST Errors, 1990 Forcing

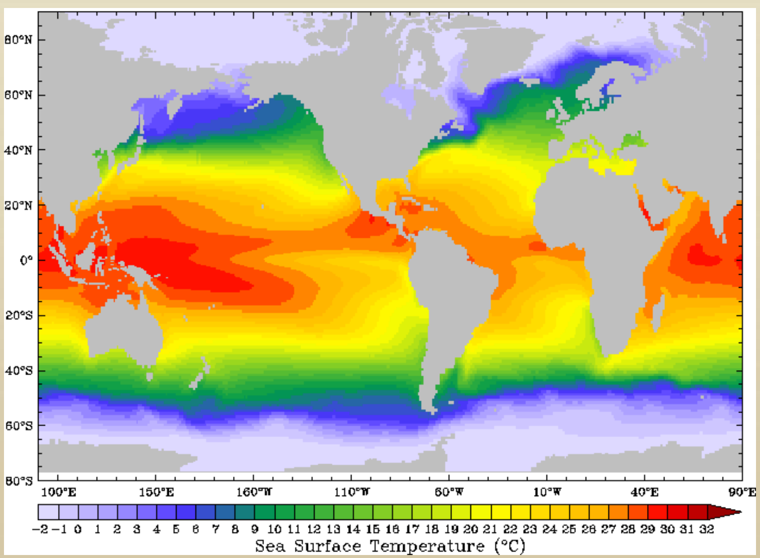
CM2G 1.18°C RMS



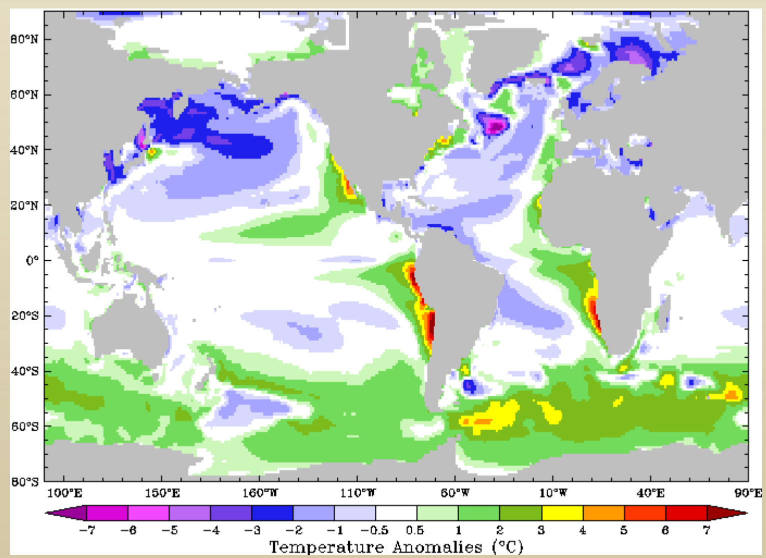
CM2.1 1.17°C RMS



Reynolds Climatology



CM2M 1.28°C RMS



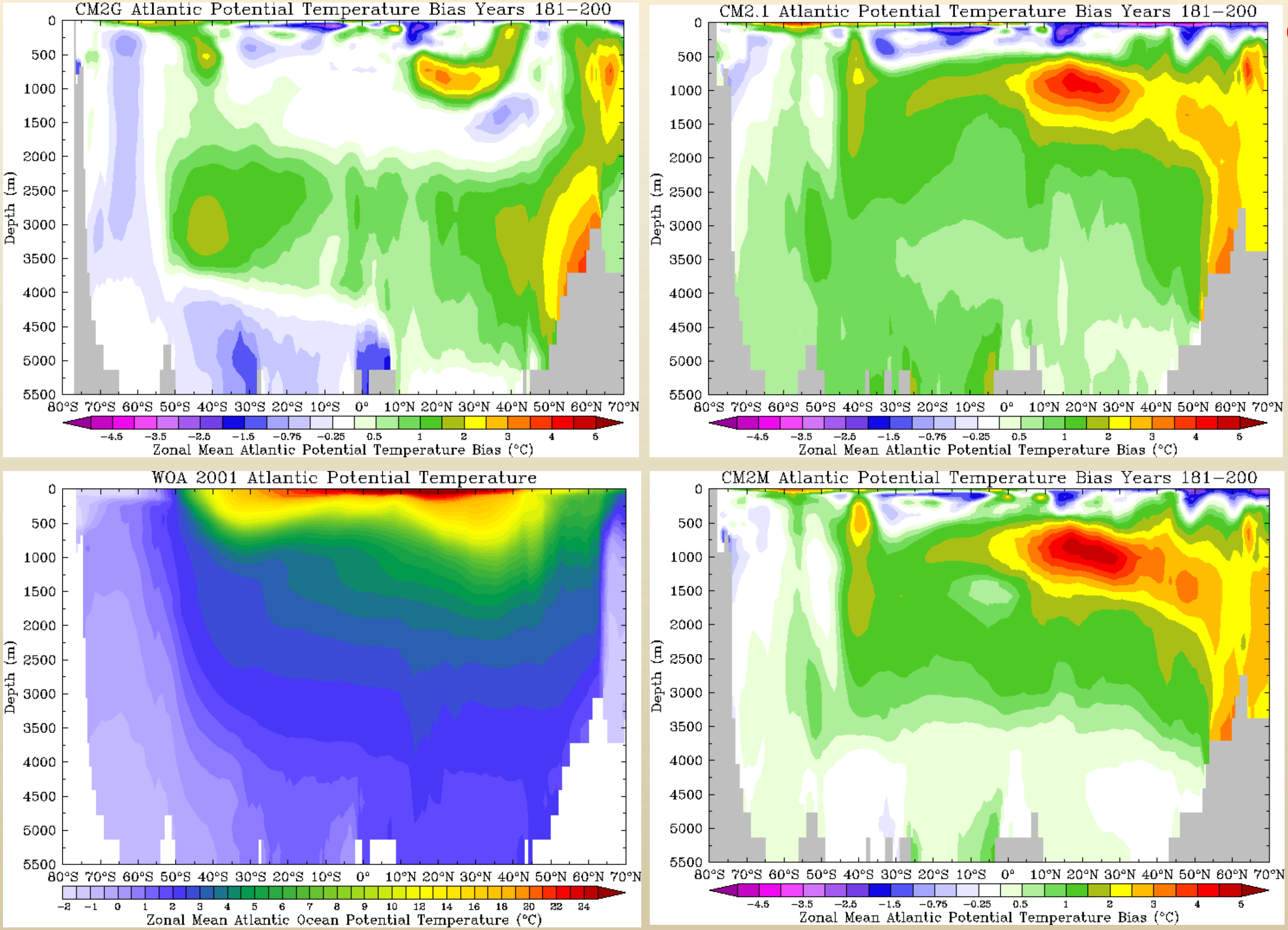
Atlantic Temperature Bias, Control after ~190 Years

CM2G

CM2.1

Climatology

CM2M

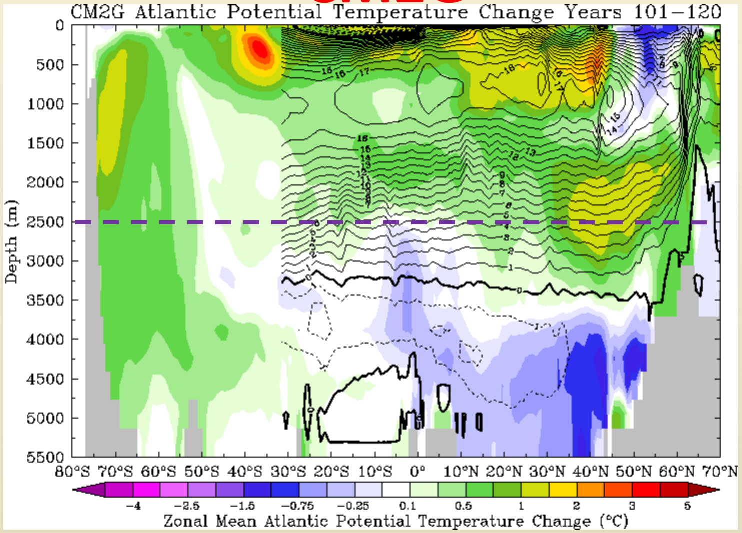


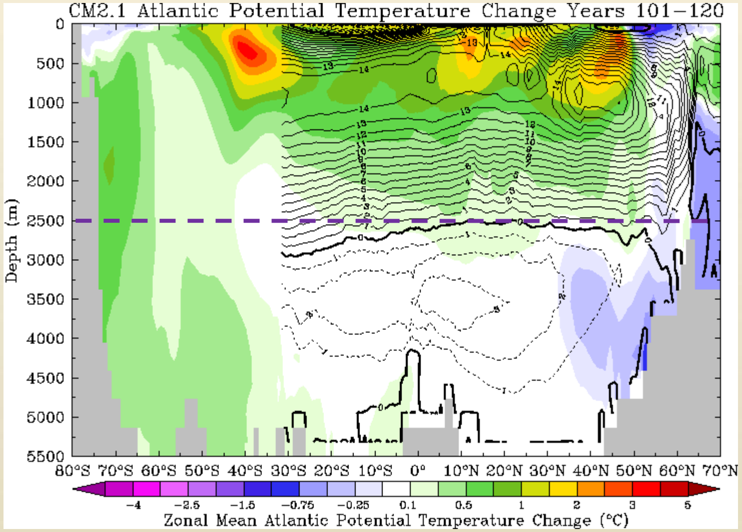
Changes after 110 Years in 1% per year CO2 Runs

CM2G

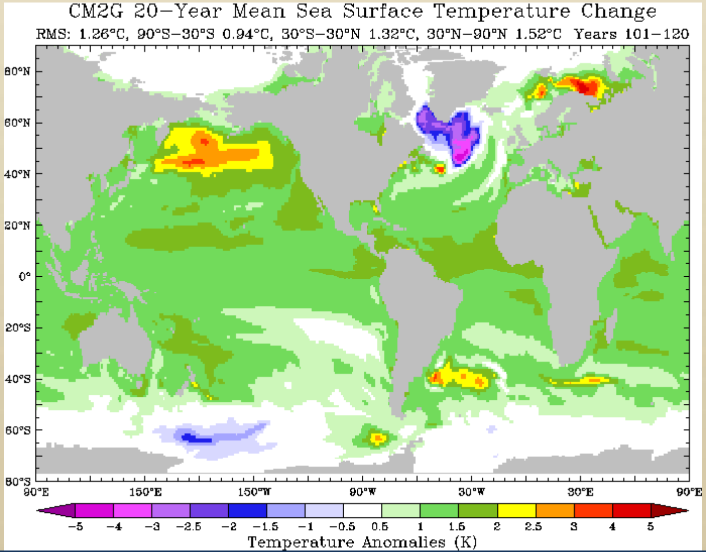
CM2.1

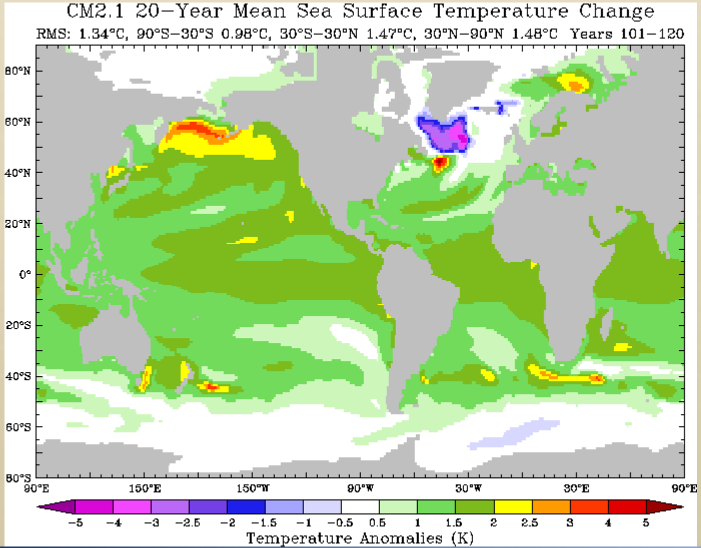
Atlantic Temperature Change & Overturning Streamfunction





SST Change





Scientific value of CM2M & CM2G

- CM2M improves key physical and numerical aspects of CM2.1, but with many similarities in the simulations
- CM2G exhibits clear improvements in interior watermass structure over CM2.1, and differs from CM2.1 in its interior-ocean climate response to forcing
- Comparisons between CM2G and CM2M offer insights into uncertainties about the ocean's role in the climate system

Major GFDL Oceanographic Activities

1. Coupled climate model ocean configuration development
   - R. Hallberg (just shown)
2. Ocean model capability & code development
   - The GFDL Modular Ocean Model (MOM) - S. Griffies
   - Ocean Modeling Innovations (and GOLD) - A. Adcroft
3. Ocean processes & parameterization
   - S. Legg
4. Climate & biogeochemistry in a turbulent, adiabatic ocean
   - A. Gnanadesikan

Other key contributors:

- W. Anderson, M. Harrison, B. Samuels, J. R. Toggweiler, G. Vallis, plus students and postdocs

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