MOM developments and applications

Presented by Stephen M. Griffies

Geophysical Fluid Dynamics Laboratory

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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Presentation outline

- Basic algorithms and dynamical core
- Physical parameterizations
- Online analysis features
- Notable applications
- Plans and the MOM/GOLD relationship

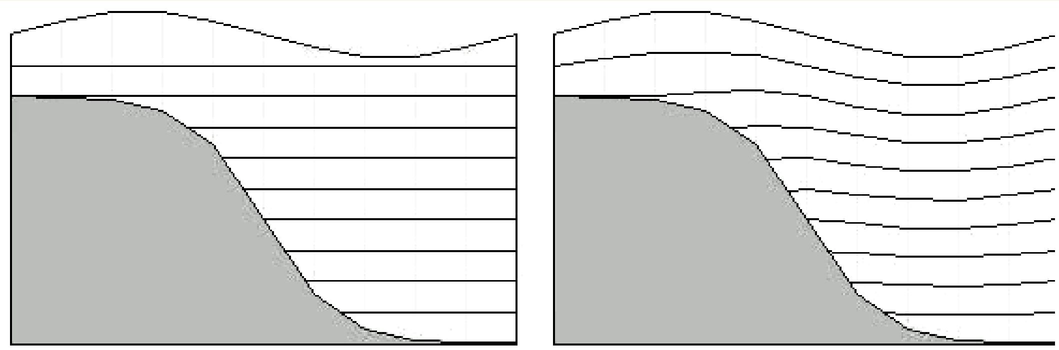
Basic algorithms and dynamical core

MOM4p1 is a hydrostatic generalized level coordinate ocean model code with mass conserving non-Boussinesq or volume conserving Boussinesq kinematics, coded in generalized horizontal coordinates on a B-grid, with a suite of physical parameterizations, diagnostic features, and test cases.

Basics of the dynamical core

- B-grid level model (1984)
- Tracer advection (non-centred schemes since 1998 and ongoing)
- Partial bottom cells (1998)
- Split-explicit free surface (2000) / split-explicit bottom pressure (2007)
- Real water fluxes (2000)
- Staggered baroclinic/tracer time stepping (2004)
- Tripolar grid (2004)
- Generalized levels coordinates (Bouss and non-Bouss options) (2007)
- TEOS-10 thermodynamics (2011 early stages)
- Lagrangian blob sub-model (2011 early stages)

Generalized Levels



Z with free surface   Z* with free surface

$$
\begin{aligned}
[\partial_t + (f + \mathcal{M})\,\hat{\mathbf{z}} \wedge]\,(\mathrm{d}z\,\rho\,\mathbf{u}) = {}& \rho\,\mathrm{d}z\,\mathcal{S}^{(\mathbf{u})} - \nabla_s \cdot [\,\mathrm{d}z\,\mathbf{u}\,(\rho\,\mathbf{u})] \\
& - \mathrm{d}z\,(\nabla_s p + \rho\,\nabla_s \Phi) + \mathrm{d}z\,\rho\,\mathbf{F} \\
& - [\,\rho\,(w^{(z)}\,\mathbf{u} - \kappa\,\mathbf{u}_{,z})\,]_{s=s_{k-1}} \\
& + [\,\rho\,(w^{(z)}\,\mathbf{u} - \kappa\,\mathbf{u}_{,z})\,]_{s=s_k}
\end{aligned}
$$

$$
\begin{aligned}
\partial_t(\mathrm{d}z\,\rho\,C) = {}& \mathrm{d}z\,\rho\,\mathcal{S}^{(C)} - \nabla_s \cdot [\mathrm{d}z\,\rho\,(\mathbf{u}\,C + \mathbf{F})] \\
& - [\rho\,(w^{(z)}\,C + F^{(s)})]_{s=s_{k-1}}
\end{aligned}
$$

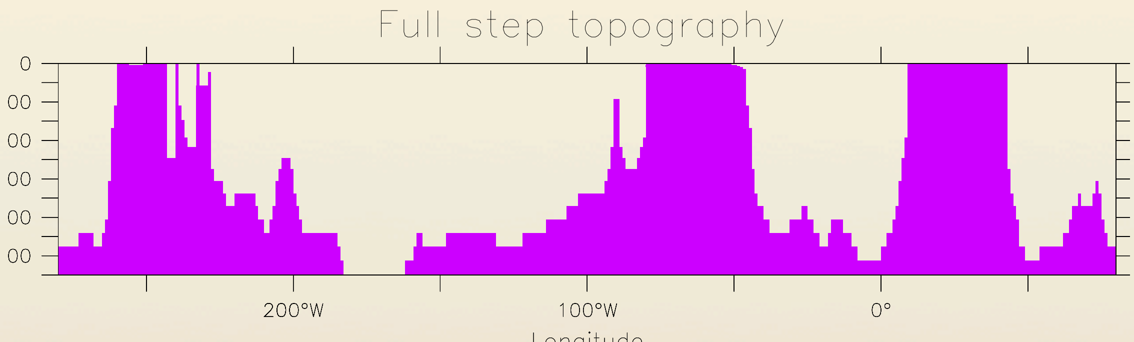
- Boussinesq and non-Boussinesq options (through depth/pressure analogs)
- Code development for z* matured by year 2007; pressure took longer
- All grid cell thicknesses are functions of (x,y,z,t)
  - cell thickness (or mass per area) time stepped via mass conservation; all cells can have mass source/sinks (critical for Lagrangian blob sub-model)
- Physical parameterizations and diagnostics are generalized for z,z*,p,p*
- Applied surface pressure (from atm and sea ice) depresses the ocean sea level
- Leap-frog with time filtering will not conserve scalars when grid cell thickness vary.
- Terrain following sigma implemented, but not fully tested
- Cannot handle vanishing cell thickness (unlike isopycnal codes)

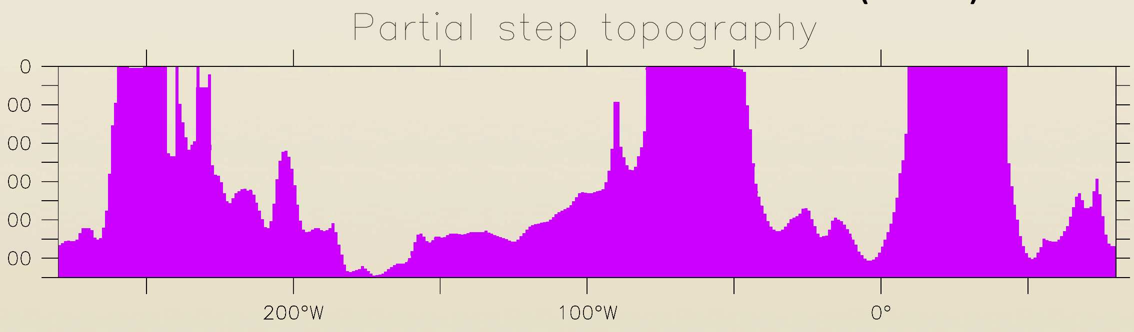
Time stepping basics

- Staggered two-level time step for baroclinic and tracer
  - 2 x (leap-frog time step) = 1 x (staggered time step)
    - 1 degree ocean in CM2.1 climate and ESM2M earth system models use 2hr time step (need to reduce to 1hr with leap-frog in CM2.0).
    - ¼ degree ocean in CM2.5 climate model uses 30min time step.
  - No Robert-Asselin time filtering
  - No special time steps to suppress computational modes.
  - Tracer content and mass/volume are conserved to numerical truncation; essential for generalized level models.
  - Similar method used in MITgcm.
- Split explicit free surface / bottom pressure for barotropic w/ predictor-corrector & time damping (as in GOLD)
  - Modest sea level filtering required to suppress B-grid null mode
- Real water fluxes (used in CM2.0, CM2.1, CM3, ESM2M, CM2.5…)

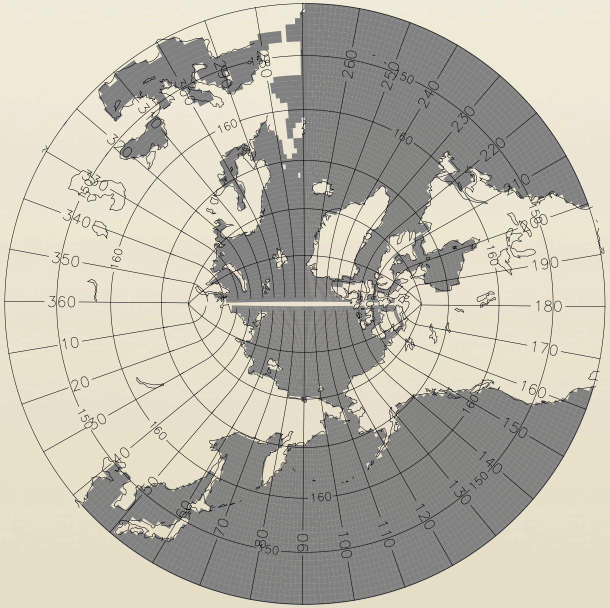
Partial bottom cells and tripolar grid

Pacanowski and Gnanadesikan (1998)





Murray (1996)



Both approaches standard in GFDL climate models since 2004

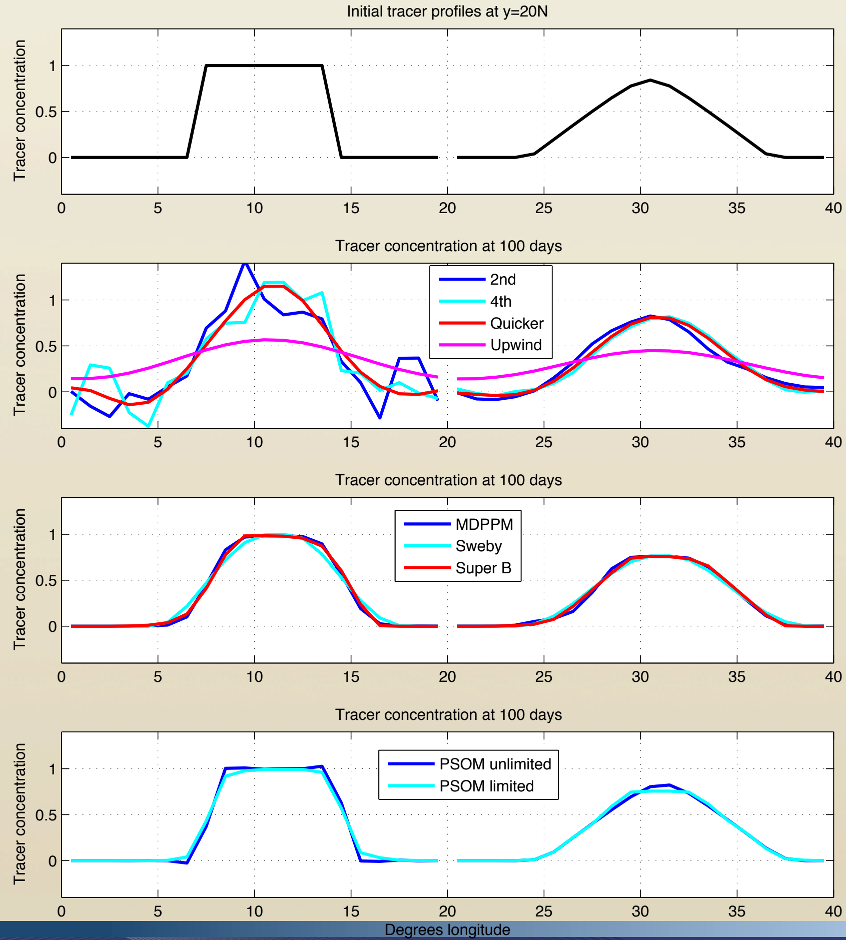
Tracer advection

Many schemes available. We favor high order monotonic upwind biased schemes, which are readily ported to MOM4p1 using 2-level time stepping scheme.

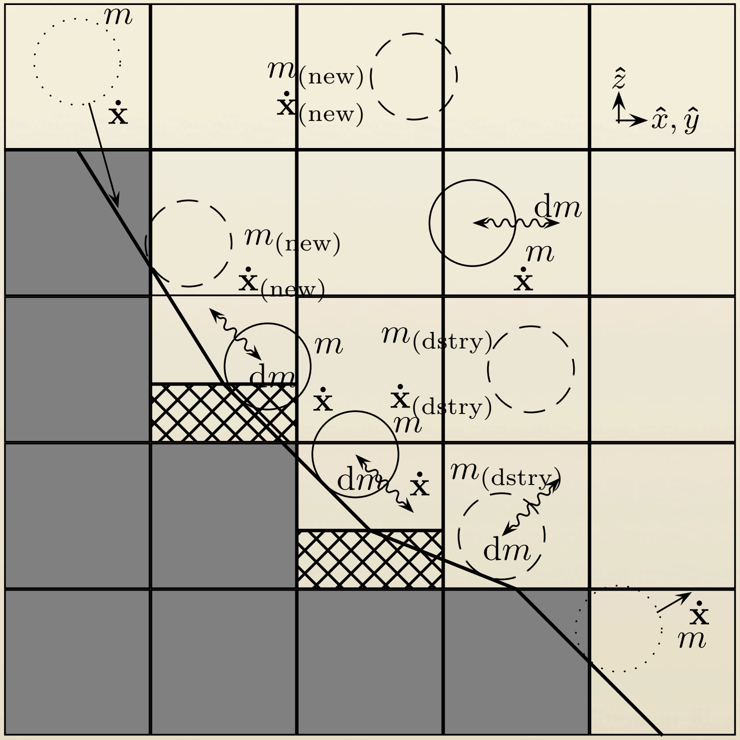
- 2nd, 4th, 6th centred for leap-frog only

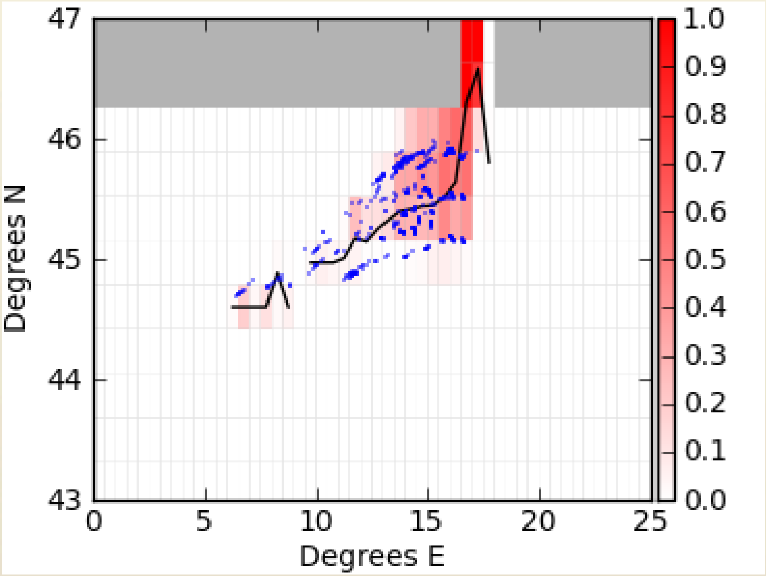
Two-level based schemes:

- 1st upwind (very diffusive)
- Quicker (from NCAR; can be leap-frogged)
- Sweby (from MIT and used in CM2.1)
- SuperB (from MIT)
- Piecewise parabolic (from MIT and GFDL favorite)
- Prather (in vogue, but beware need to flux limit)



Lagrangian blob sub-model





M. Bates (PhD thesis, UNSW Sydney)

- Dynamical two-way interacting Lagrangian sub-model
- Like a super-parameterization (blobs satisfy pseudo-non-hydrostatic equations)
- Early stages of testing in idealized and then global models

Physical parameterizations

- Neutral physics
- Gravity wave breaking induced mixing (via CPT)
- Mixed layer schemes
- Gravity current overflow schemes
- Lateral friction
- Patchy convection (via sea ice CPT)

Neutral physics

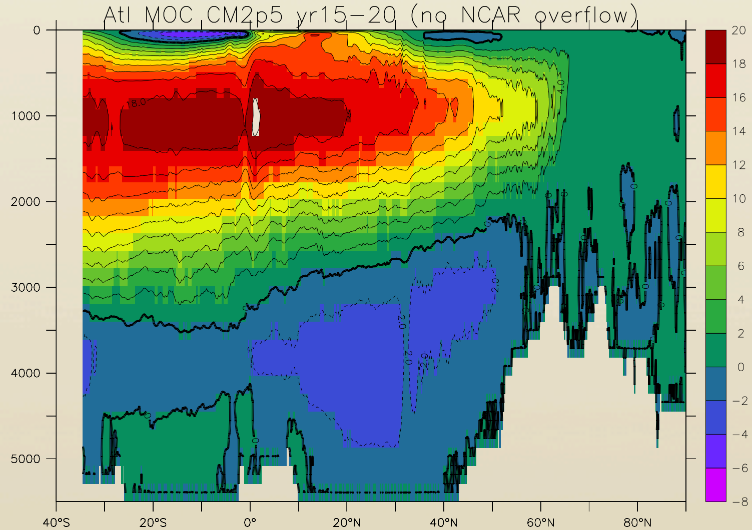
- Standard (used in CM2.1):
  - GM90/GM95 skew fluxes ala Griffies et al (1998) and Griffies (1998) with boundary matching as per Treguier et al (1997)
- GFDL favorite (used in ESM2M):
  - Ferrari et al (2010) boundary value problem (clean matching between stratification regimes)
- Eddy diffusivity calculations:
  - reasonably full suite of 2d and 3d diffusivities (including N^2 method from NCAR, and steady state Eden/Greatbatch)
- Researching anisotropic GM for eddying models

Mixed layer schemes

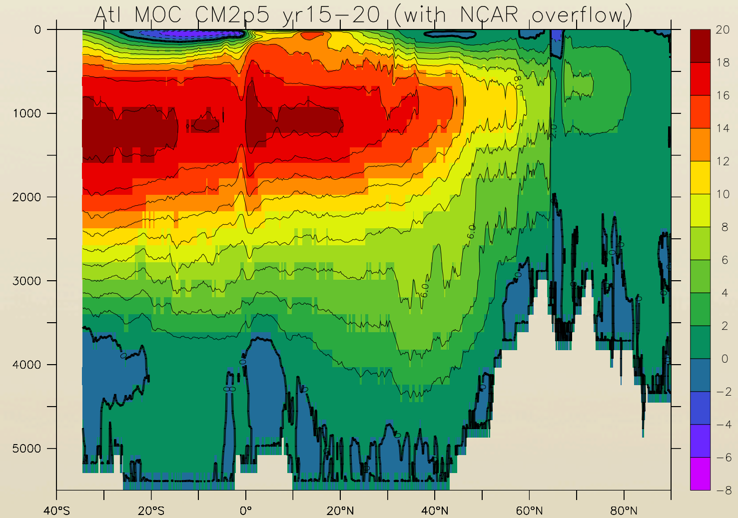
- KPP: standard scheme from NCAR
  - Wish to synchronize MOM version with POP.
  - Requires more than just a wrapper, since POP version of KPP assumes full cells and virtual salt fluxes.
- PP and Chen: for specialized studies
- GOTM: General Ocean Turbulence Model
  - Wrapper in MOM to use GOTM
  - Coastal applications (k-epsilon; Mellor-Yamada; Canuto; others)

Gravity current overflow schemes

- Beckmann & Doscher (1998)
- Campin and Goose (2000)
- Other ad hoc schemes
- Lagrangian blobs (ongoing research)
- NCAR scheme implemented through mass source/sinks



Without NCAR overflow param



With NCAR overflow param

Lateral friction

- Laplacian and biharmonic friction operators
  - Smagorinsky flow dependent
  - Anisotropic NCAR approach
  - Research into Leith-like scheme from Fox-Kemper and Menemenlis (2008)
- Work from Ilicak et al (2011) emphasizes lateral friction to suppress spurious mixing, as well as good tracer advection schemes.
  - Aim: strong eddying flows w/ trivial spurious mixing
  - Progress since Griffies et al. (2000), but more needed
  - Where is spurious mixing occurring? Near boundaries or open ocean?

Online diagnostics

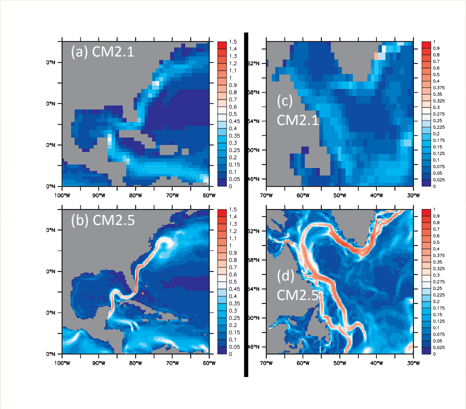
- Diagnostics registered at runtime via a table.
  - Can be spatially and temporally sub-sampled.
  - Time averages include all time steps.
- Diagnostics for all terms in all prognostic equations
- Water mass diagnostics (with density binning)
- Contributions to sea level evolution
- Standard remaining diagnostics (many 100s)

Sampling of Applications

- GFDL climate and earth system modeling
  - CM2.1, ESM2M, CM3, CM2.5, CM2.6
  - Coupled surface ocean wave modeling
- NCEP operational SI forecasting
- National multi-Model Ensemble for operational SI
  - NCEP, NASA, GFDL use MOM based climate models including data assimilation methods
- Australian collaborations
  - Global climate modeling
  - operational coastal forecasting (going global)

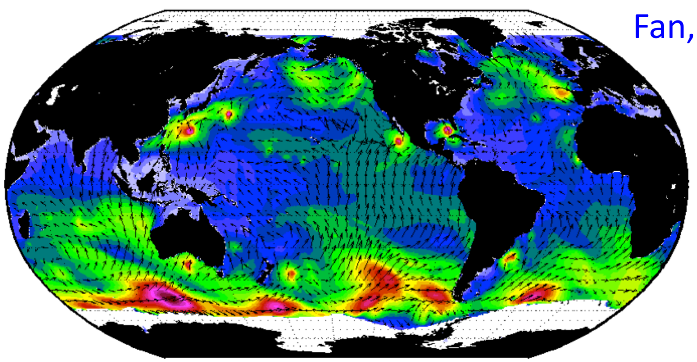
CM2.5/CM2.6

- Eddying climate simulations: new GFDL norm
  - CM2.5: nominally 0.25deg ocean (~1000yrs climate)
  - CM2.6: nominally 0.10deg ocean (~100yrs climate)
    - All use z* vertical coordinate
    - All have full diurnal cycle coupling
      - 2hr coupling for CM2.1, ESM2M, and CM3
      - 1hr coupling for CM2.5
      - 15min coupling for CM2.6



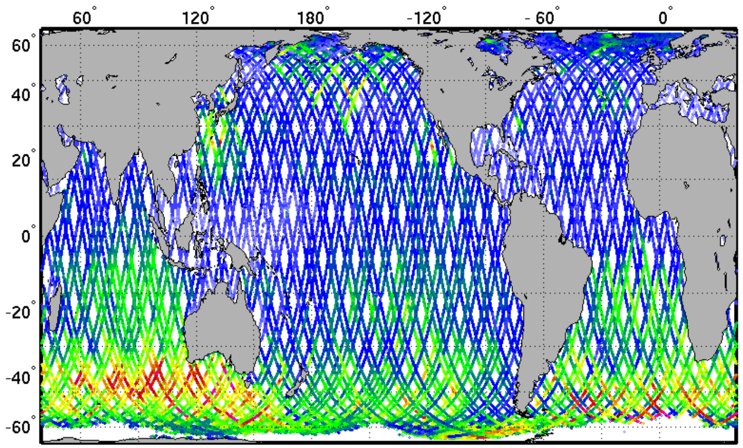
  - Each has biases, with ongoing research to address
      - Neutral physics in eddying regimes: anisotropic GM?
      - Overflows (NCAR scheme and Lagrangian blobs)
      - Friction & advection (want strong eddies w/ trivial spurious mixing)

Surface waves in global coupled models



Fan, Lin, Held, and Yu, 2011

Note four tropical cyclones and huge waves in Southern Ocean.



TOPEX

Atmospheric Model:
NOAA/GFDL High Resolution Atm Model (HIRAM). ½ degree

Wave Model:
NOAA/NCEP
WAVEWATCH III
½ degree
40 frequencies
24 directions

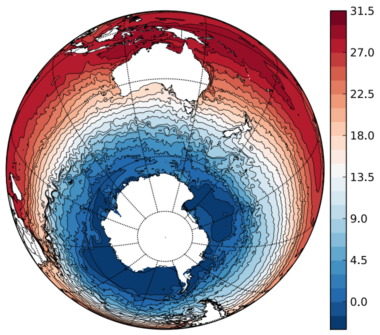
Research into coupled climate and ESMs

- Upper ocean wave mixing
- Changes in surface fluxes of momentum, heat, and gases.
- Application to sea level impacts

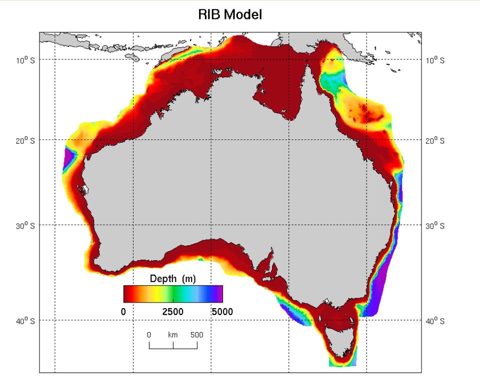
Significant wave height = average wave height of the 1/3 largest waves in the wave packet.
Mean wavelength = energy weighted averaged wavelength.
Wave direction = energy weighted averaged wave direction

Australian connection

- Centre of Excellence (AUS university consortium) global eddying ocean and coupled
- CSIRO and Bureau of Meteorology: ACCESS climate modeling (1 degree)



- CSIRO and Bureau of Met: BLUElink operational forecasting (1/10 degree with nesting to finer)
- Australians have provided input to
  - Parameterizations
  - Lagrangian sub-modelling
  - regional modelling
  - TEOS-10



Ribbon grid surrounding Aus

MOM4p1 status and plans

- MOM4p1 next public release Dec 2011 (few days)
- Ongoing research focus on items listed earlier, such as
  - Tracer advection (e.g., monotone 7th order from Adcroft)
  - SGS params (eddying neutral physics; CPT related work)
  - Upper ocean wave coupling and associated Langmuir mixing
  - Lagrangian sub-model for overflows
  - Analysis methods for water masses and sea level
  - Global mesoscale eddying applications ~100s-1000s yr climate

MOM effort is vigorous and ongoing at GFDL/Princeton and within international MOM community (~500 registered MOM4p1 users). There are no plans to slow development or applications.

Relationship between MOM and GOLD

Each code serves various applications and user bases at GFDL and abroad.

- MOM: generalized level
  - Global climate; regional/coastal; idealized process
  - Open source with 100s-1000s international users.
- GOLD: isopycnal layer (aspiring to generalized layer)
  - Global climate; ice shelves; idealized process
  - Not yet open source (select community of non-GFDL users)
- Developers sit in same corridor, exchanging ideas and nurturing a competitive environment that generally provokes the improvement of each code.
- Hypothesis: physical parameterizations are more important than vertical coordinates, so long as meet a certain level of numerical integrity.

Streamlining MOM and GOLD development

A vision for near-term MOM/GOLD development: share a selection of algorithms and params.

– Vertical mixing (e.g., CPT gravity wave induced mixing)
– Sea-ice CPT (patchy convection)
– Tracer advection schemes
– Equation of state
– Already share the same BGC model and coupler

- Aim to optimize GFDL resources without sacrificing distinct capabilities and applications of MOM and GOLD.
- It is too early to perform a wholesale code merger.