MOM6, SIS2 and OM4

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(Input from MOM6 team and OWG)

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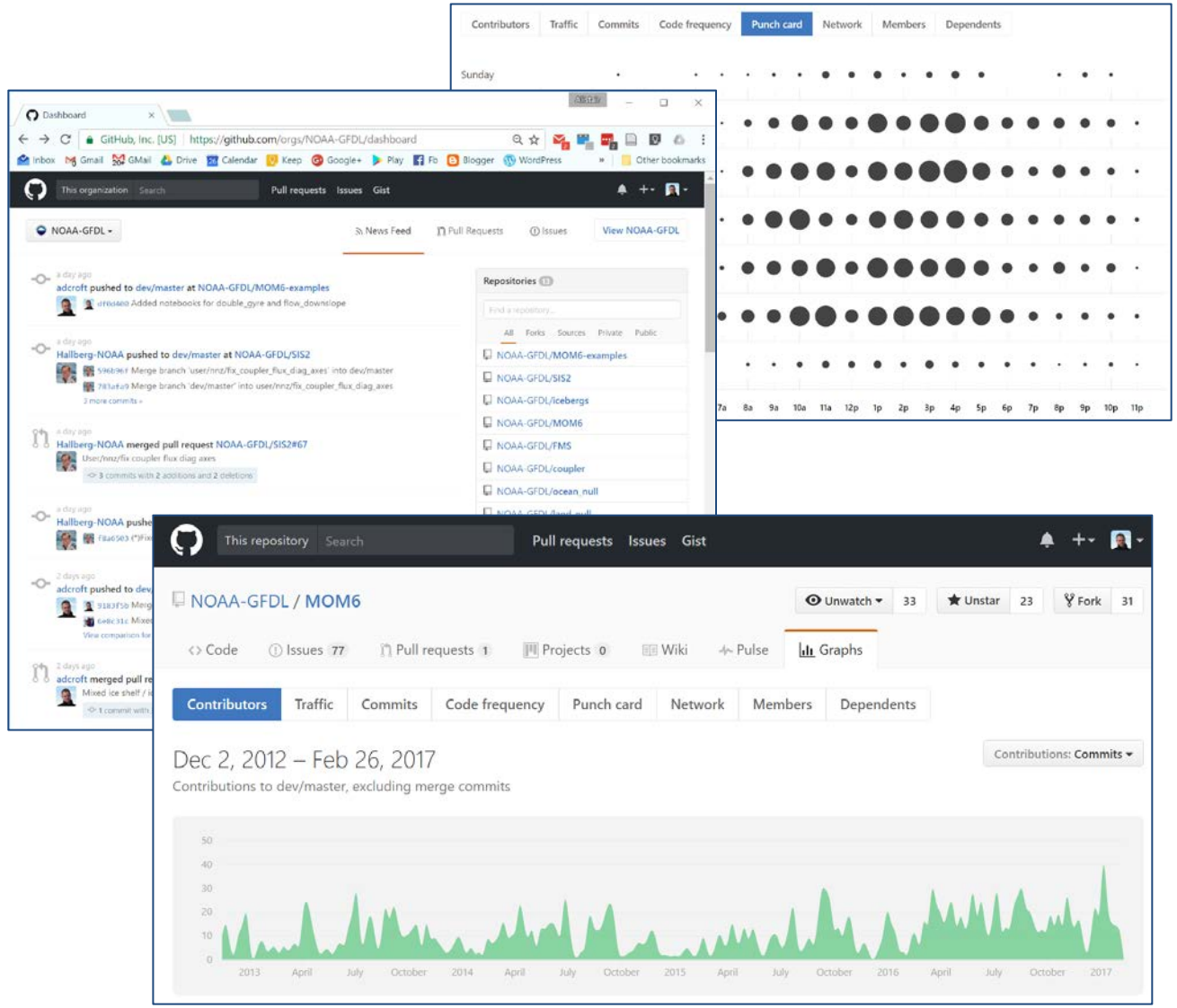
Modular Ocean Model, version 6 (MOM6)

- MOM6 unifies the efforts of MOM4/5 and GOLD
  - **Open development** philosophy
  - Community model
    - Adopted by NCEP, NCAR, Universities, …
- Arbitrary Lagrangian Eulerian method in the vertical
  - Used for general- & **hybrid coordinates**
  - Unconditionally stable/accurate
  - Wetting/drying
- Global ice-shelf/ocean coupling
  - Requires ALE for **wetting/drying**
- Energetically consistent closures
  - **Internal wave driven mixing** (CPT)
  - Community software (CVmix)
  - **Eddies in eddy-permitting models**
  - Second order mesoscale closure
- Boundary layer physics
  - **Mixed layers**
  - Overflows
- Numerics and formulation
  - Transport schemes, Solvers
  - Dynamically integrated sea-ice
  - Reduced cost of bio-tracers

Community model development with MOM6

- Open development
  - Not just open source + releases
  - All activity visible via GitHub
    - Anyone can contribute at anytime
- Good software practices
  - Version control, testing, …
- Everything is version controlled
  - Source code, input data, tools, tests, configurations, …
  - Helps *others* **replicate** our results

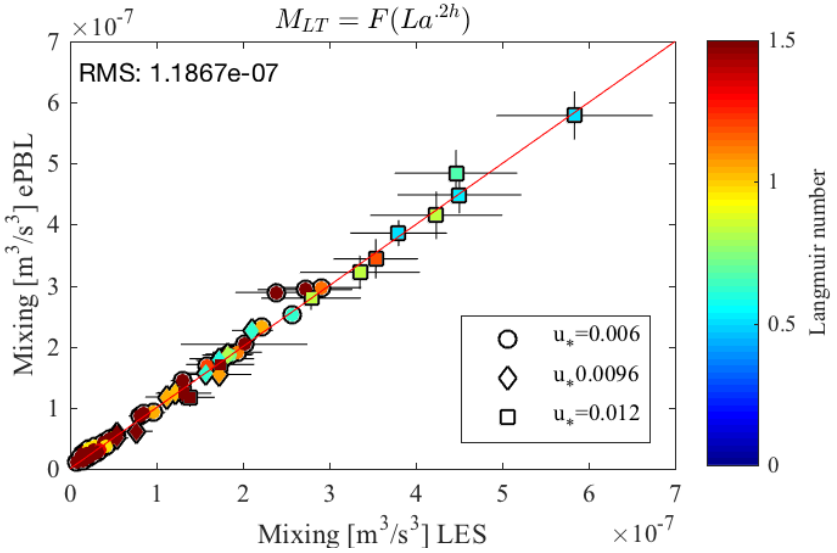


MOM6 capabilities: wetting and drying

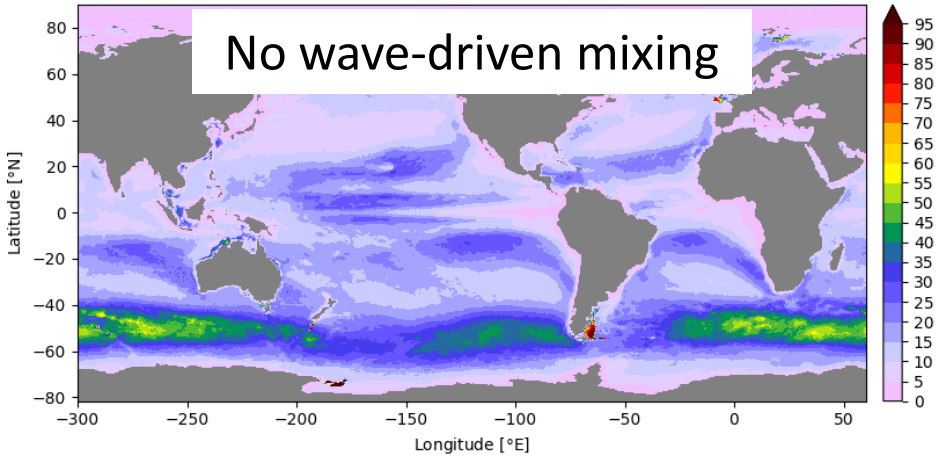
- ALE algorithm enables wetting and drying
- Ice shelf cavities simulated with evolving iceshelf model coupled to ocean
  - Moving upper boundary
  - Moving grounding line
- Note ocean squashed between shelf and bedrock
- Used in ⅛° coupled ocean-ice-shelf global simulations

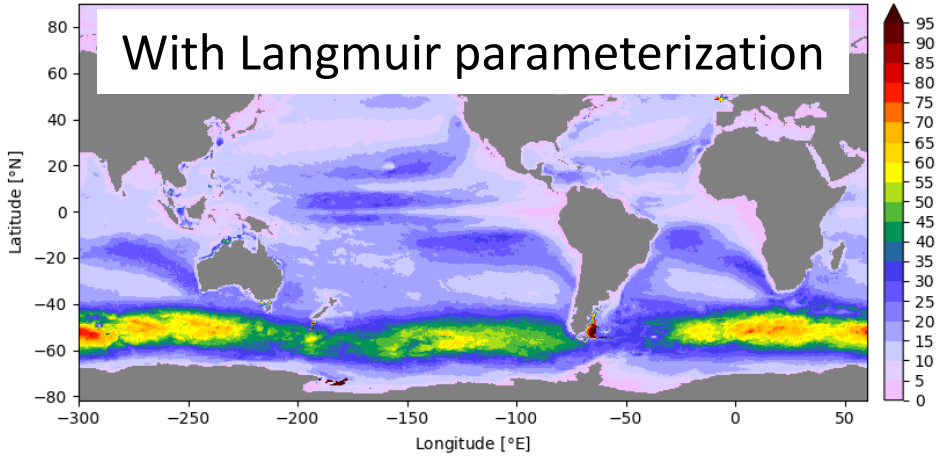
MOM6 feature: new boundary layer

- Energetically consistent planetary boundary layer scheme (ePBL)
- Developed to reproduce Large Eddy Simulations (LES)
  - No dimensional parameters
- Includes wind-, buoyancy- and wave-driven (Langmuir turbulence) mixing



Reichl and Hallberg, 2017

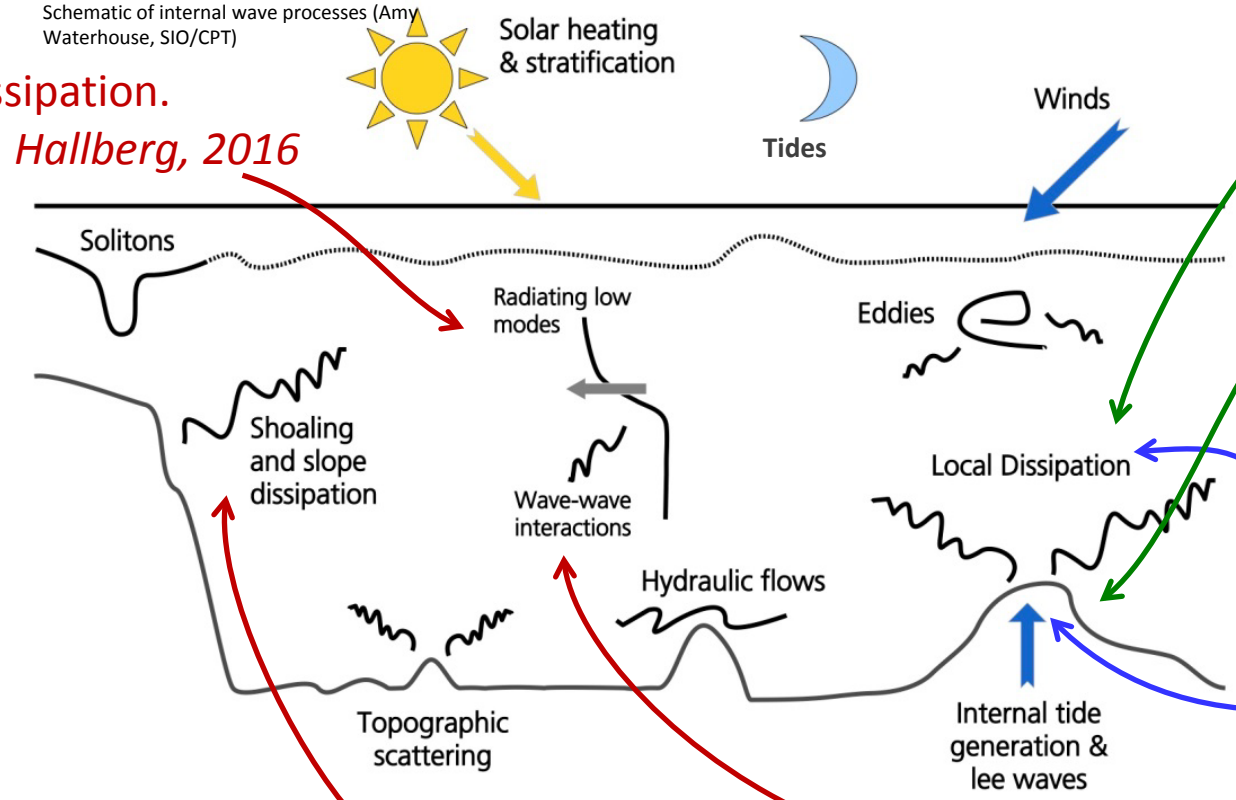




MOM6 comprehensive parameterizations:
Physically-based, energetically-consistent parameterizations of diapycnal

- NOAA/NSF Internal Wave-Driven Mixing **C**limate **P**rocess **T**eam; *MacKinnon et al., BAMS 2017*
- Parameterizations of sub-grid-scale mixing which allow mixing to vary spatially and **evolve in a changing climate**.

Schematic of internal wave processes (Amy Waterhouse, SIO/CPT)



Low-mode dissipation. *Melet, Legg & Hallberg, 2016*

Vertical profile of local dissipation. *Polzin, 2009; Melet et al, 2013a*

Parameterization of lee-waves. *Nikurashin and Ferrari, 2011; Melet et al, 2013b; Melet et al., 2015*

Local dissipation at tall steep topography. *Klymak, Legg and Pinkel, 2010; Klymak et al, 2012*

Contribution to generation from abyssal hills. *Melet et al, 2013c*

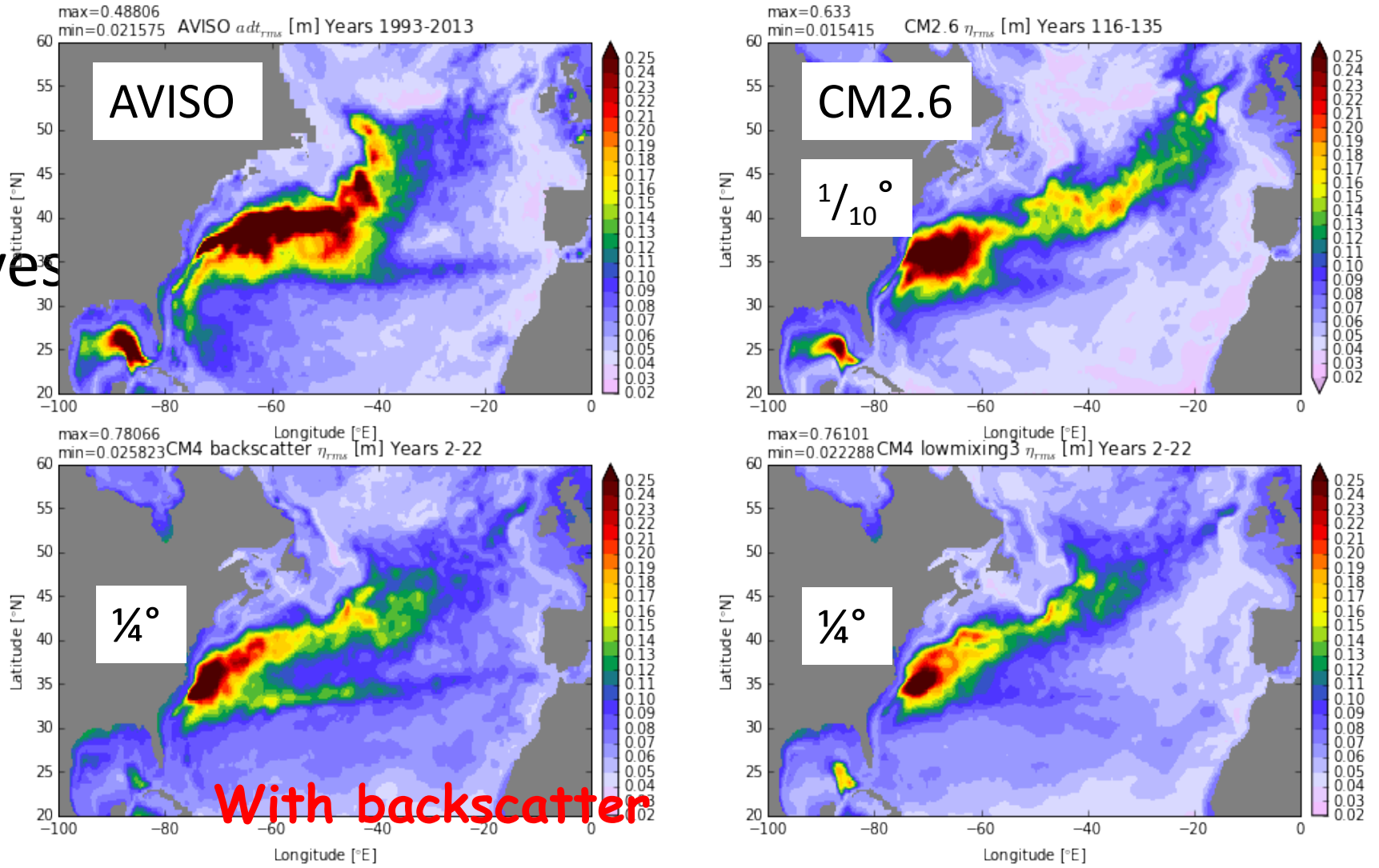
Low-mode shoaling and reflection. *Legg, 2014*

Latitudinal dependence of wave-wave interactions. *Nikurashin and Legg, 2011*

MOM6 feature: energizing the "resolved" eddies

- Backscatter of energy from unresolved scales
- Backscatter improves some features
  - Sometimes competitive with $^1/_{10}$° model
  - Azores front is strengthened

… work in progress



Jansen et al., 2015

Ocean component of CM4: OM4 design

Objectives:

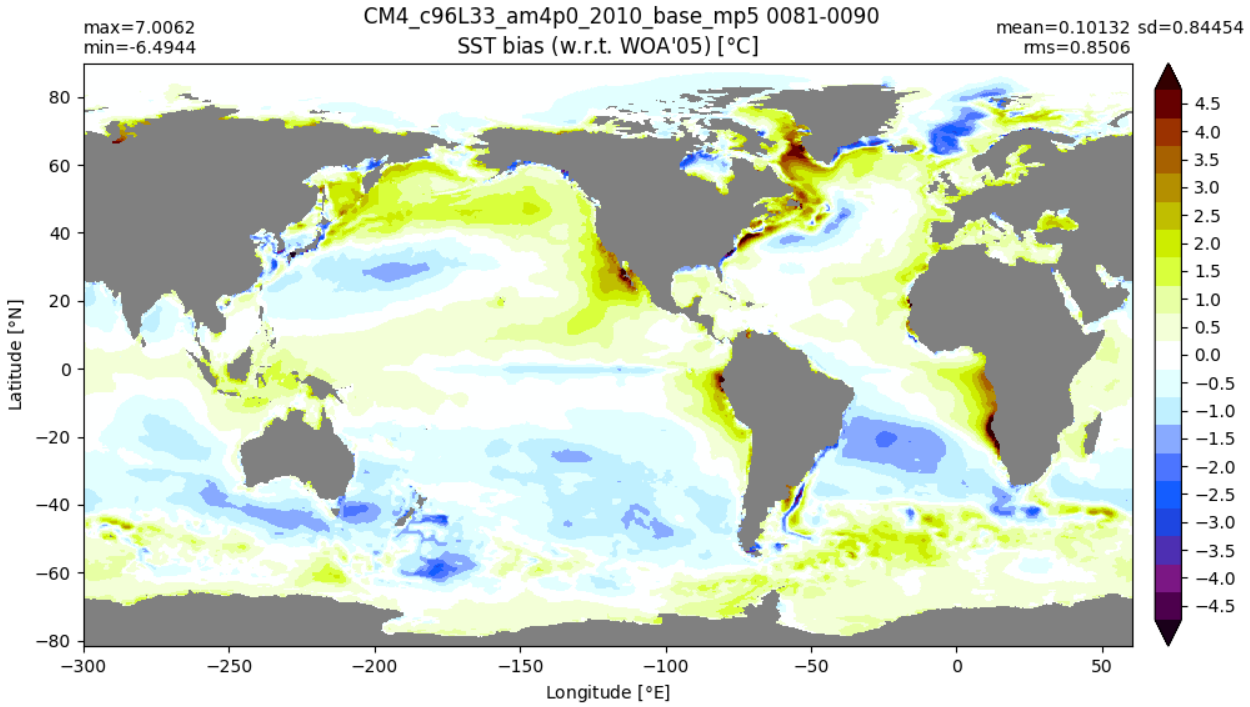
- Build a ¼° ocean model with fidelity of CM2.6 (0.1°)
- Can we build models that are "configured" the same way at all resolutions?
  - scale aware parameterizations

Starting point:

- Coded from scratch
- Parameterizations needed re-writing to work in general coordinates

- What finer resolution might get us
  - Resolve boundary currents - ½-⅓°?
  - Meanders (standing eddies) - ¼°?
  - Resolve upwelling zones - ⅛°?
  - Overflows – $^{1}/_{x}$° + vertical coord.?
  - Mesoscale eddies - $^{1}/_{20}$°?
- OM4 notionally ¼° horizontal resolution
  - Also ½° for ESMs and other MIPs
  - 1° built in parallel effort
  - ⅛° already developed for global coupled ocean-ice-shelf

OM4-¼° resolution

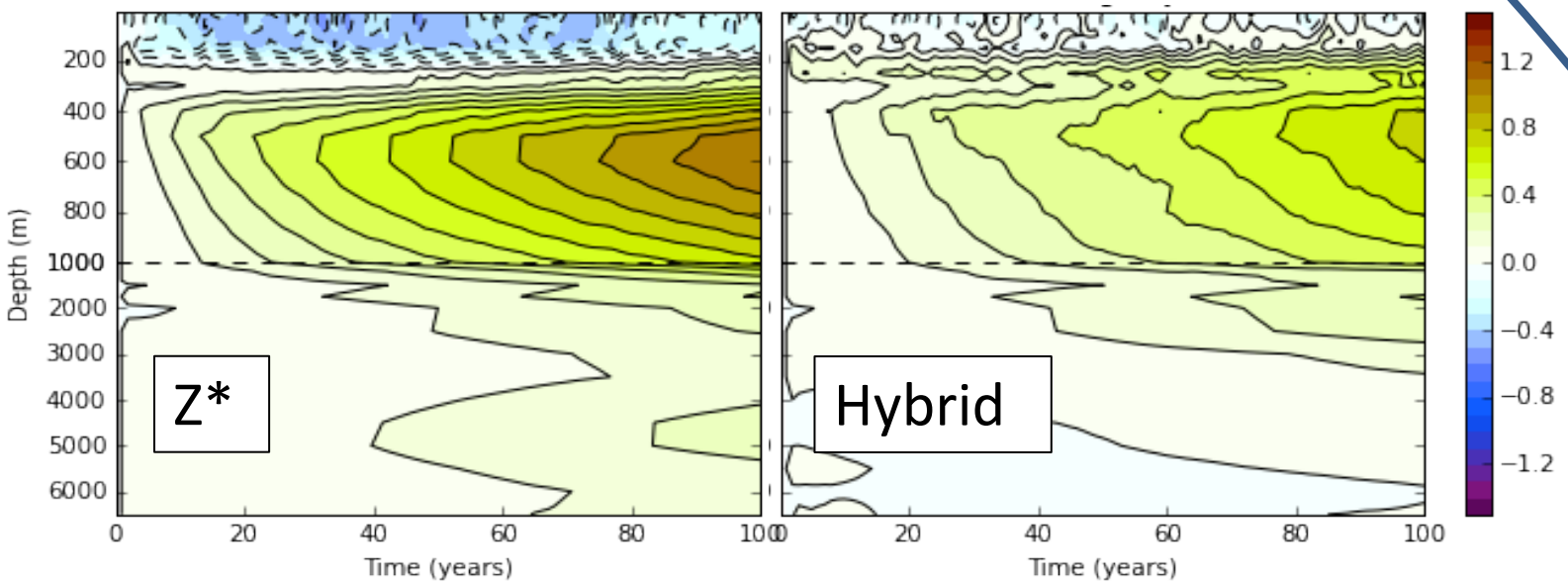


- OM4 development focused on shorter time-scales
  - Good surface climate in CM4
  - RMS SST error ~ 0.85°C
    (for 2010 forcing runs)
- Improvements still in the pipe
  - Vertical coordinates
    - Overflows and AABW formation(?)
  - Deep mixing parameterizations
  - Eddy parameterizations in ¼°

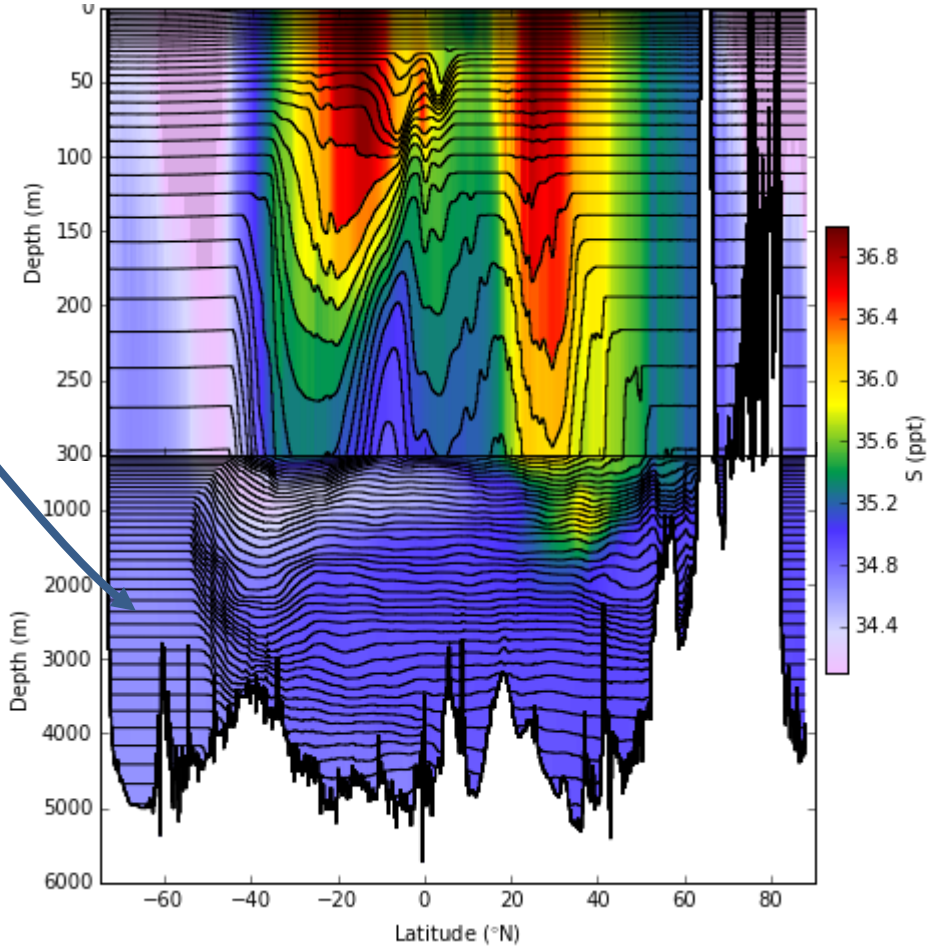
Role of vertical coordinate (¼° ocean in CM4)

- **Changing vertical coordinate alone**
  - Replaced z* with hybrid z^*/ρ_2 (aka HYCOM)
  - Simple prototype reduced heat uptake by 0.27 Wm^{-2}
  - Use of z* at high-latitudes is far from ideal

Horizontally averaged temperature (°C)



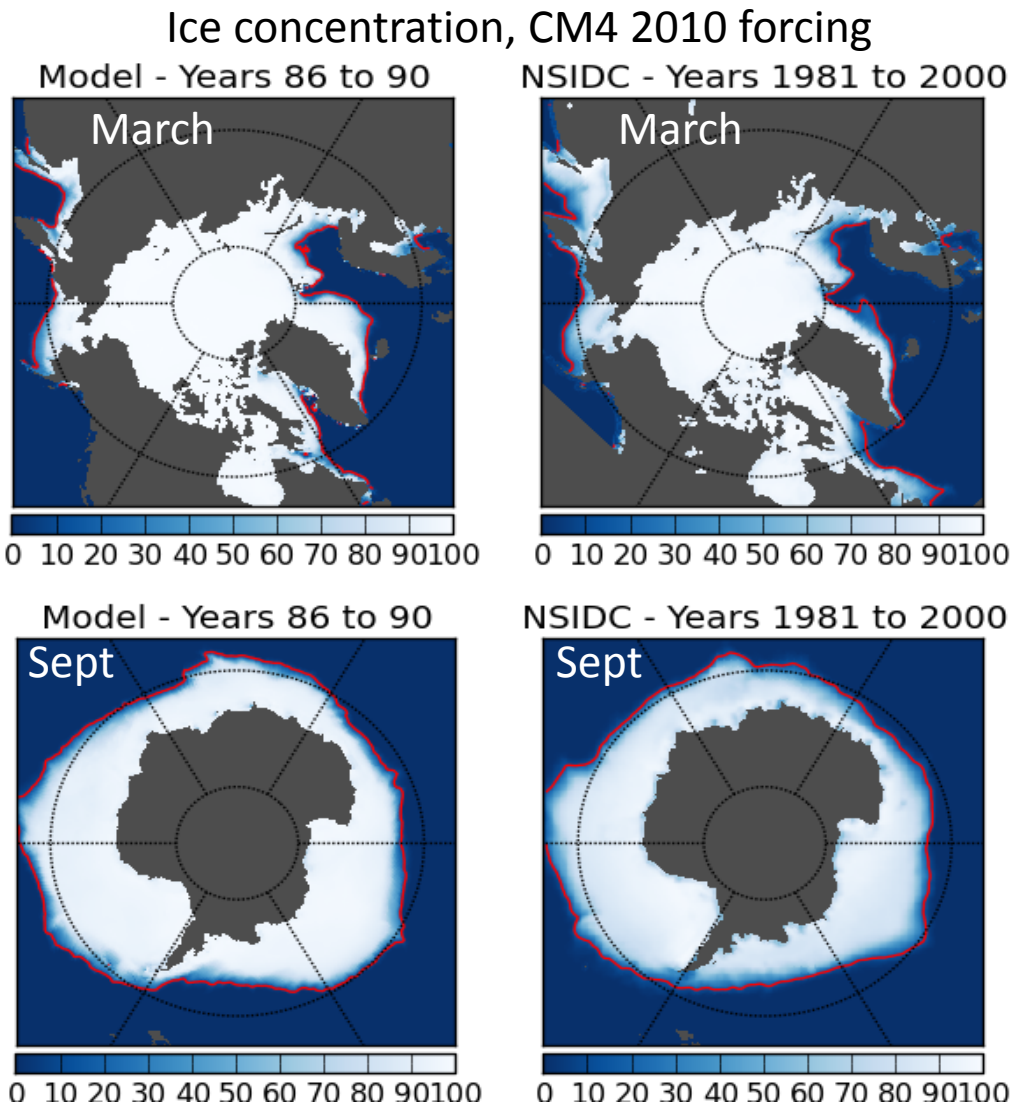
Salinity (shaded), Vertical grid (lines)



Chassignet et al., 2003; Megann et al., 2010; Ilicak et al., 2012

Sea-Ice Simulator, version 2 (SIS2)

- Improved conservation
- Improved stability
- C-grid for compatibility with ocean
  - Permits single point channels
- Improved thermodynamics and radiative transfer (following CICE)
- Can carry tracers
  - Evolving sea-ice salinity, ice age, …
  - Bio-geochemistry (future ESMs)



Summary

- MOM6/SIS2 continues GFDL tradition of providing a community ocean/ice circulation models
  - Open development is engaging community in the development process
  - Enables productive collaborations, e.g. NCEP, NCAR, Universities, …
- New features represented in MOM6
  - ALE algorithm permits hybrid (and other) coordinates
  - New parameterizations based on energetics and physical principles
- Comprehensive feature set
  - Always being extended
    - e.g. Regional modeling capability in collaboration with Rutgers