Small scale mixing – a brief summary

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with a little input from Markus Jochum (NCAR)

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Forward

Bias towards z-level models in this talk

There are many mixing parameterizations:

- Within an individual model there are mixed layer models, convective mixing, Richardson number mixing, shear-driven mixing, abyssal mixing, background mixing and implicit numerical mixing
- Wide variation between models and model types

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4 key problems in PO: Wunsch (1990)

1. Mixing, including scale dependence, boundary enhancements, etc.
2. Air-sea transfer, heat flux, gas exchange, etc.
3. Where and how the ocean tides are dissipated.
4. Understanding the interactions in the ocean's internal wave field.

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Some background

- Sandström (1908): heating and cooling on same geopotential = no overturning circulation
- Jeffreys (1925): turbulent mixing moves heat downward
- Munk (1966): downward diffusion is balanced by abyssal upwelling on the basin scale
- Gregg (1977): Mixing in the thermocline is small
- Davis (1994): You will never observe it…
- Munk and Wunsch (1998): Where does the energy that drives ocean mixing come from? Tides and wind.

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In the beginning: Byran & Lewis (1979)

Where it all began:

$$K_V = 0.8 + \frac{1.05}{\pi}\tan^{-1}\left(\frac{z - 2500\mathrm{m}}{222.2\mathrm{m}}\right)\mathrm{cm}^2/\mathrm{s}$$

The parameters were chosen such that:

- Deep ocean: 1.3 cm^2/s (Munk 1966)
- Upper ocean: 0.3 cm^2/s (Gregg 1977)
- Transition at 2500 m

Bryan & Lewis continued

The basic parameterization works well:

- Reproduces our idea of the MOC
- Poleward heat transport reasonable
- Changed for CCSM such that upper ocean diffusivity of 0.1 cm^2/s, abyssal of 1.0 cm^2/s, and transition at 1000 m
- Other variations, low upper ocean, higher deep, but all very ad hoc.

So why change?

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Gargett (1984)

The vertical mixing varies with an inverse power of the stratification:

$$K_V = \sigma N^{-n}$$

Modest impact on circulation: warmer abyssal temperature, stronger MOC, stronger abyssal stratification

- Cummins et al. (1990) & Hirst and Cai (1994)

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Bryan (1987)

Vertical mixing controls many aspects of the circulation:

- K_v = 0.1 – 5 cm^2/s
- Spatially constant (vertically and horizontally)
- MOC was enhanced with stronger mixing
- PHT increased with stronger mixing
- But since the diffusivity was increased in the thermocline, this may not be relevant

Marotzke (1997), Samelson (1998)

Mixing can all occur at the boundaries and still have a sensible circulation

- No explicit mixing in the interior
- Mixing only at lateral boundaries
- Scott and Marotzke (2002) found that boundary mixing is more efficient a driving a strong MOC than interior mixing

Towards physical parameterizations

The surface fluxes in OGCMs have a strong control on the MOC and this leads to discussions of the MOC “shutting down”

Is this physical? Are the mixing parameterizations to blame?

Upwelling of abyssal water must be driven by the mechanical mixing since it requires an increase in potential energy

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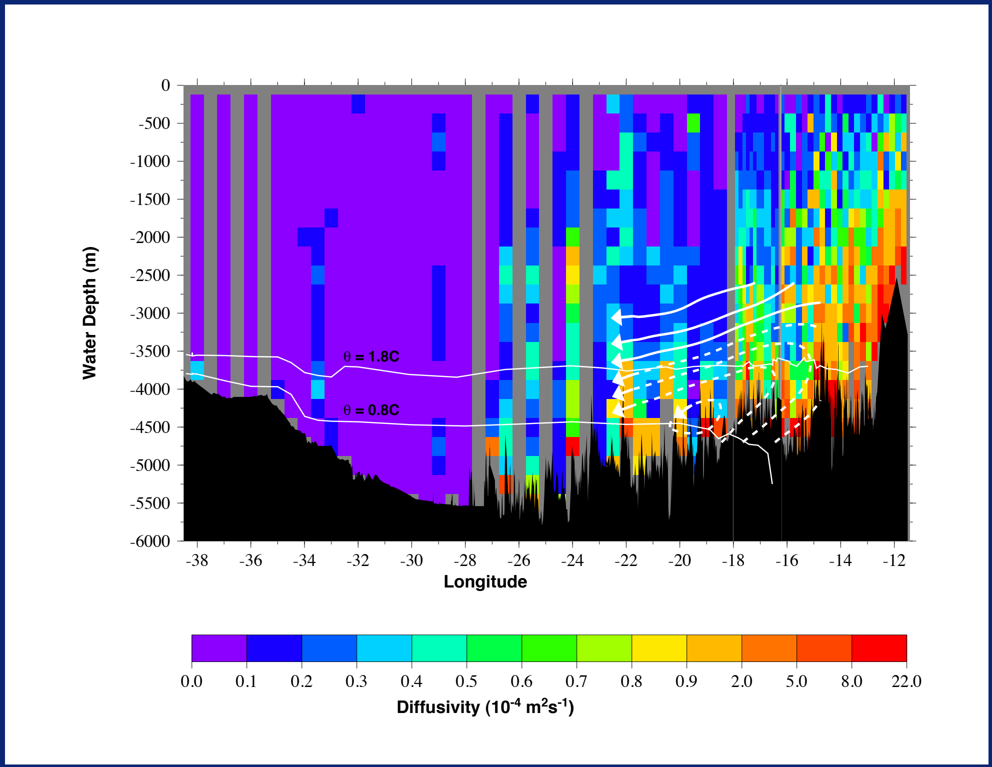
Brazil Basin

The diffusivity observations that launched a thousand parameterizations:



Polzin et al. (1997)

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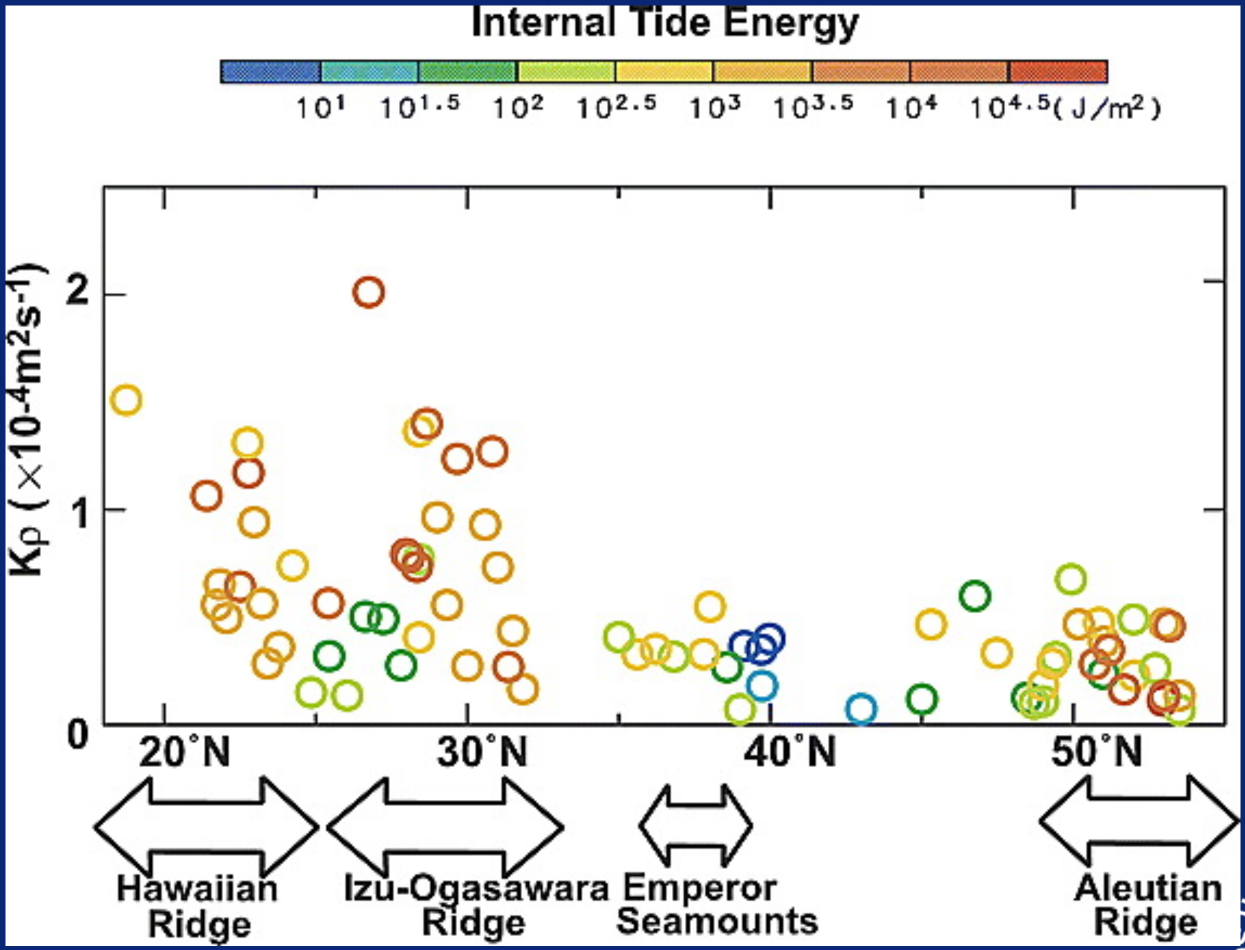
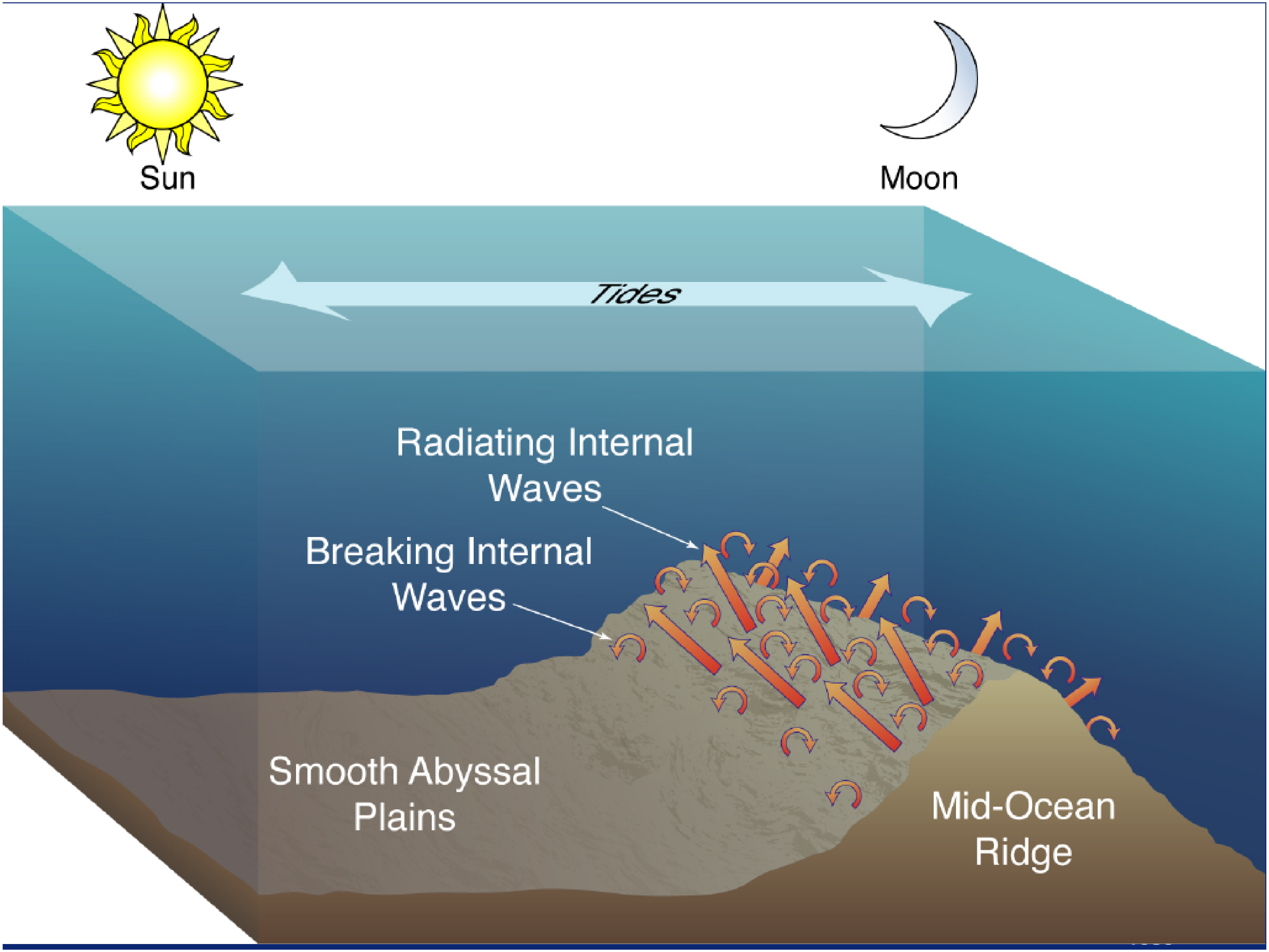
Some diffusivity observations



- Hibiya and Nagasawa (2004)


Sun
Moon
Tides
Radiating Internal Waves
Breaking Internal Waves
Smooth Abyssal Plains
Mid-Ocean Ridge

Mixing & rough topography

One source of mechanical energy in the abyssal ocean is the conversion of barotropic tidal velocity into internal waves by flow over rough topography in the presence of stratification:

$$E_f \sim \frac{1}{2}\rho\kappa h^2 N u^2$$

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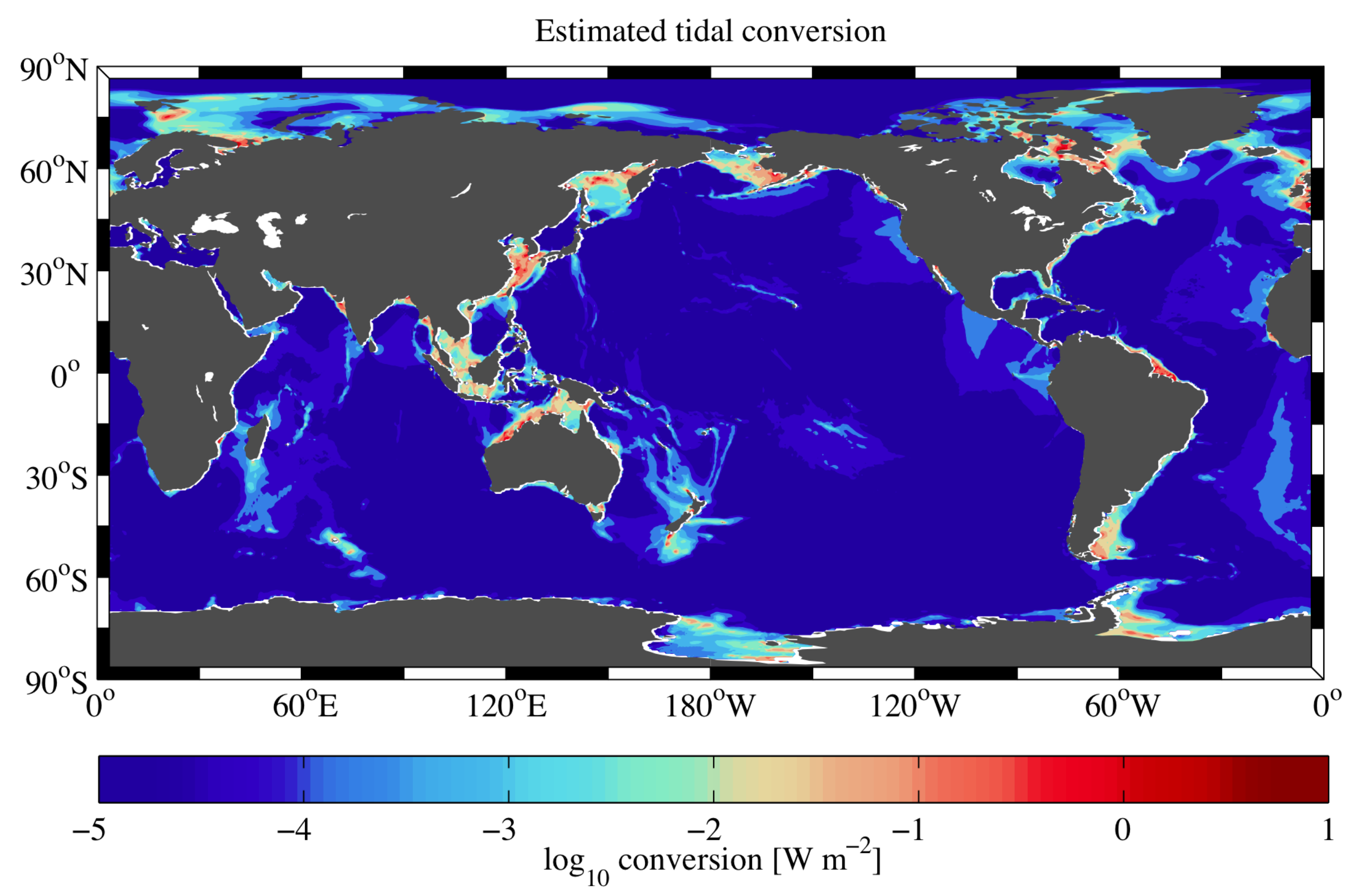
Jayne, St. Laurent, Simmons, et al.



Estimated conversion of barotropic tidal kinetic energy into internal wave energy in a tide model.

- Jayne and St. Laurent (2001), Arbic et al. (2004)

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More on mixing & rough topography

Parameterization of diffusivity from energy flux (St. Laurent et al. (2002):

$$K_v = K_0 + \frac{\Gamma \varepsilon}{N^2} = 0.1 + \frac{\Gamma q E_f\left(x,y\right) F(z)}{\rho N^2}$$

- Problem: K_0, q, Γ, F(z) are all ad hoc (likely wrong), are largely unknown, and probably vary spatially and in time
- Viscosity is proportional to diffusivity assuming a Prandtl # (which is unknown)

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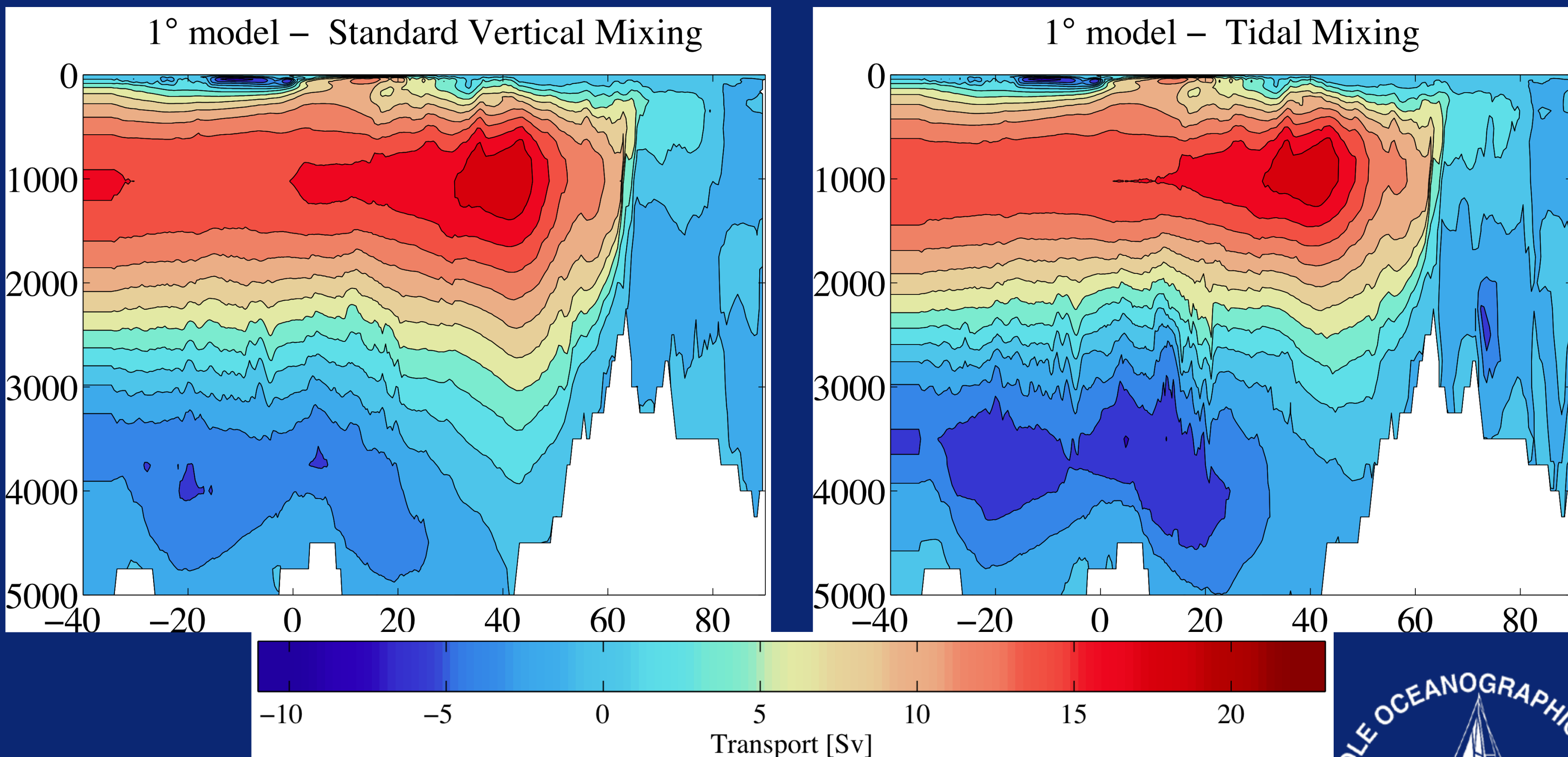
Atlantic Meridional Overturning



- Jayne (2009) amongst many others

Other model considerations

How small (or large) is the implicit vertical mixing in models? Can they even achieve the small values (order 10^{-5} m^2/s)?

Spurious diapycnal mixing due to horizontal advection through tilted isopycnals by the advection scheme, worse at higher resolution (Griffies et al. 2000)

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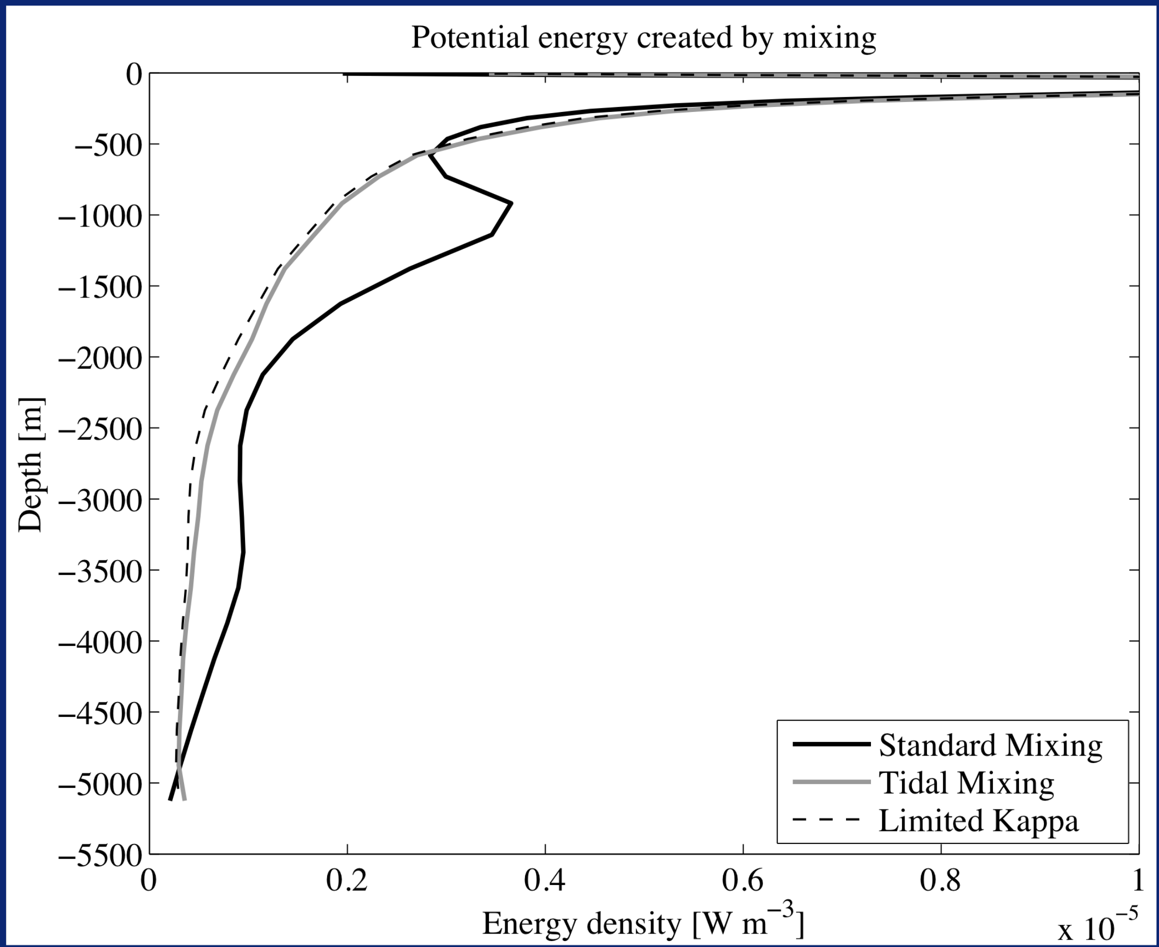
Energetics

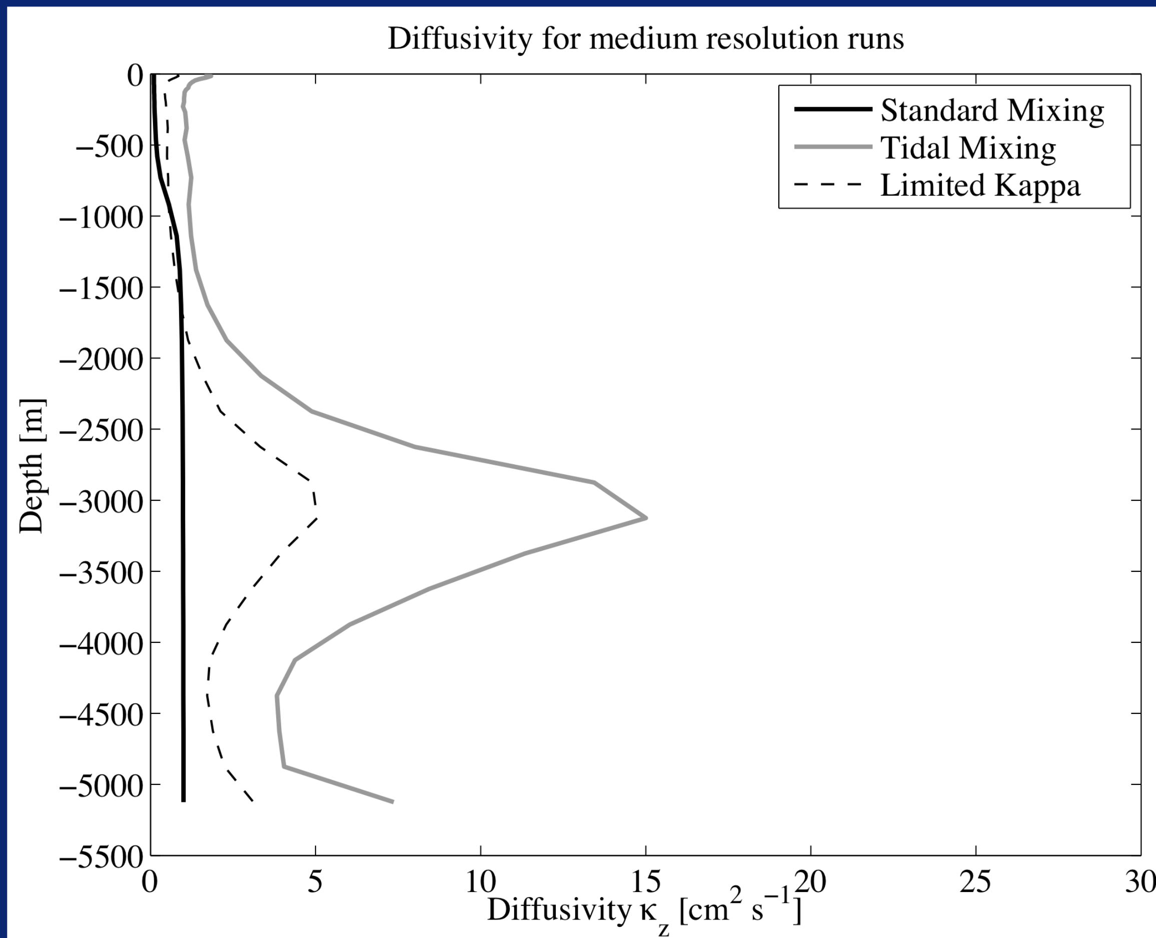
Mixing of buoyancy implies an energy input (the conversion of mechanical energy into potential energy)

Models generally give very little consideration to the implied energetics of the parameterizations

Increase of potential energy by mixing



Trouble


Diffusivity for medium resolution runs
Standard Mixing
Tidal Mixing
Limited Kappa
Depth [m]
0
−500
−1000
−1500
−2000
−2500
−3000
−3500
−4000
−4500
−5000
−5500
0
5
10
15
20
25
30
Diffusivity κz [cm2 s−1]

Is all of this a red herring?

Models (MOC & PHT) seem somewhat insensitive to the details of the mixing…

By necessity, all parameterizations are tuned to simulate a realistic circulation.

So… What do we learn from models?

“Wisdom” from Markus Jochum

- There is no need to worry about diffusivity in the context of MOC or energetics
- Two areas do stand out as important:
  - Tropics: winds and SST feedback
  - North Atlantic: spiceness-convection feedback
  - Southern Ocean: Eddies, waves & topography
- Time-variable mixing in Indonesian archipelago region (spring-neap and 18.6-year nodal cycle)

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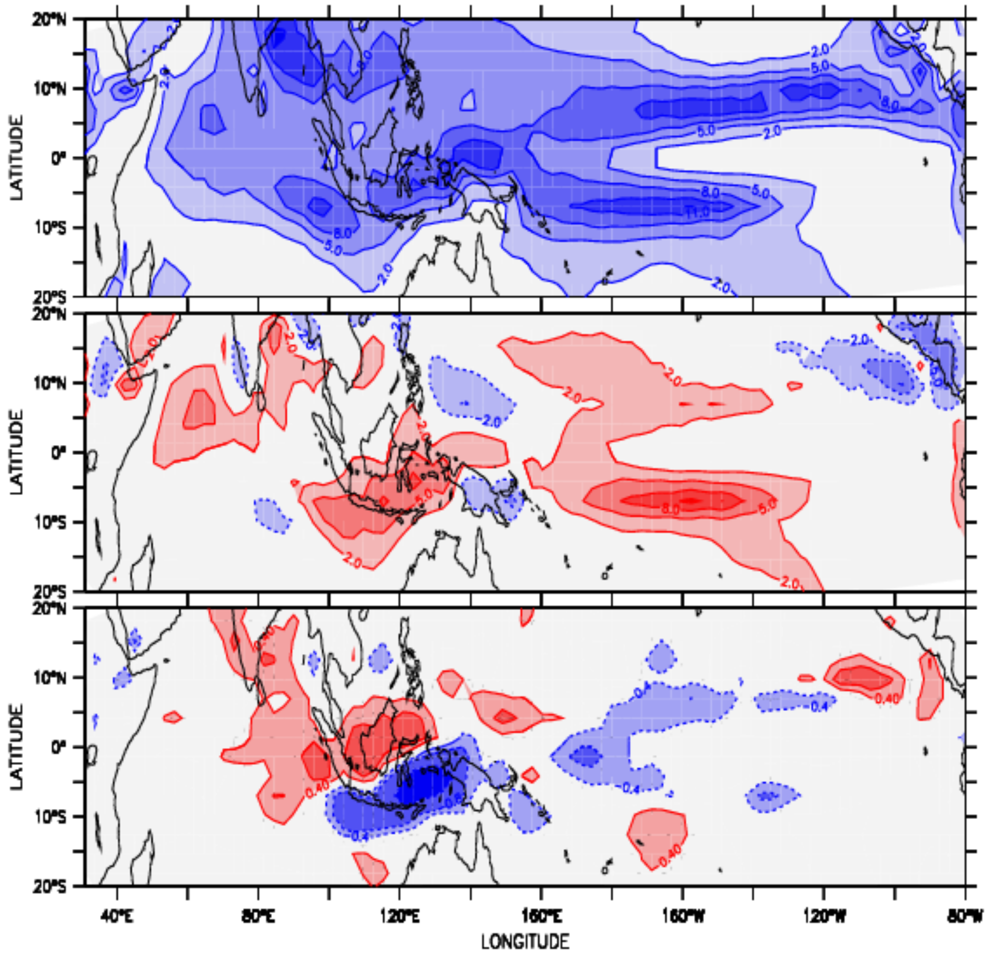
Enhanced Banda Sea mixing

Indo-Pacific JJA Precipitation in CCSM 3.5 control

Control – Observation (GPCP)

Enhanced Banda Sea mixing run – Control

Jochum and Potemra (2008)



Is this better than that?

How do we demonstrate that any particular mixing parameterization is better than another scheme?

- Many knobs to tune with compensating effects on tracers and transports
- Unknown forcing, unknown equilibrium

In the absence of a compelling deficiency, the best physics based on dynamics and energetics should be used.

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Metrics – pretty sorry lot

- Temperature and salinity
- MOC strength
- Poleward heat transport
- ACC strength and structure
- Equatorial currents strength and structure
- Passive tracers, real (*e.g.* CFCs and oxygen) and imaginary (ideal age)

Where do we go from here?

Ultimately we need to understand the full mixing budget in ocean; abyssal mixing by tides is only about $1/6^{th}$ of the budget.

Will need a full model of internal waves, sources, sinks, radiation, advection, and interaction.

Upper ocean mixing – wind-driven, near-inertial shear driven is probably much more important

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More work to be done

- Interactions in the wave continuum
- Parametric subharmonic instability (PSI)
- Wave generation by the general circulation over rough topography – Antarctic Circumpolar Current, etc.
- Interaction of (sub)mesoscale eddies and internal waves
- Loss of balance
- Baroclinic instability
- Inertial gravity waves
- Strong mixing under tropical cyclones
- Near-inertial wave energy

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Postscript

There is a vast amount of work to be done on understanding the impact of buoyancy mixing on the dynamics of the ocean circulation:

- Complete parameterization of the physics
- Energy budget considerations
- Topography, forcing, mixing

Adding tides to OGCMs

This is a bad idea… at least for diapycnal mixing

- Won't get internal wave generation right
- Won't model the tides well at all
- Self-attraction and loading is very costly

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