CPT: Representing internal-wave driven mixing in global ocean models

http://www-pord.ucsd.edu/~jen/cpt/

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Goal: Development of ocean mixing parameterizations for use in representing internal wave driven mixing in climate simulations.

1) Near-field parameterizations accounting for mixing processes at internal wave generation sites

2) A new parameterization for the mixing resulting from the breakdown of near inertial energy transported in the wave field

3) Parameterization for the breakdown of internal wave energy in the ocean interior far away from sources.

Overview

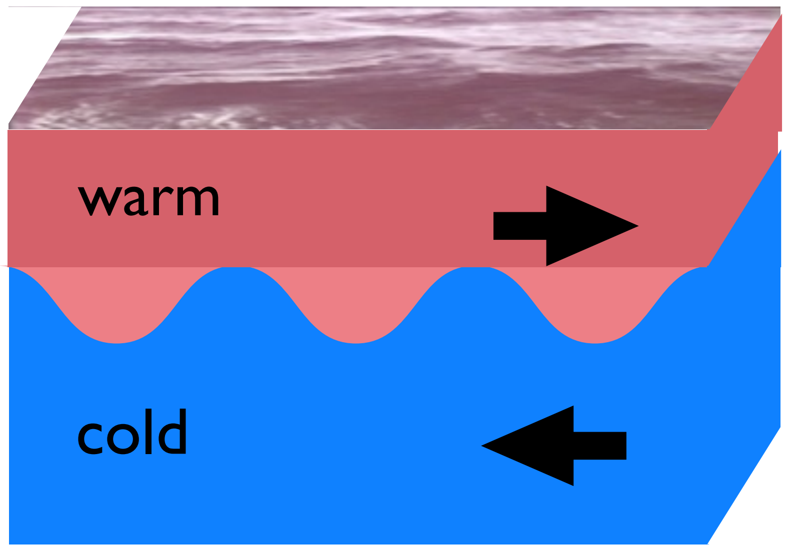
1. Most diapycnal (vertical) mixing in the ocean interior is due to breaking internal gravity waves

2. Mixing is patchy in space and time, reflecting the complex geography of internal wave generation, propagation, and dissipation.

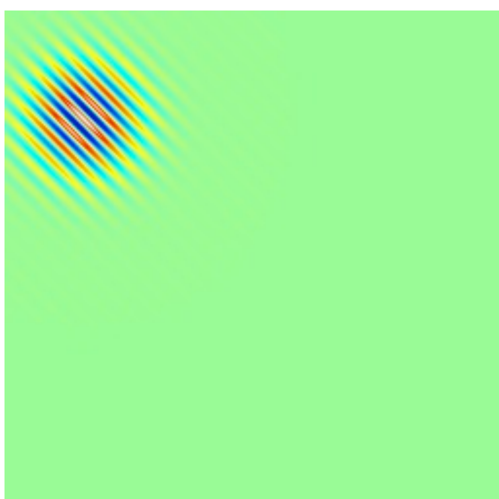
3. Patchy mixing matters for ocean circulation and fluxes. It's important to "get it right".

4. Our plan: use what we collectively know about internal wave physics to develop dynamic parameterizations of diapycnal mixing that can evolve in a changing climate.

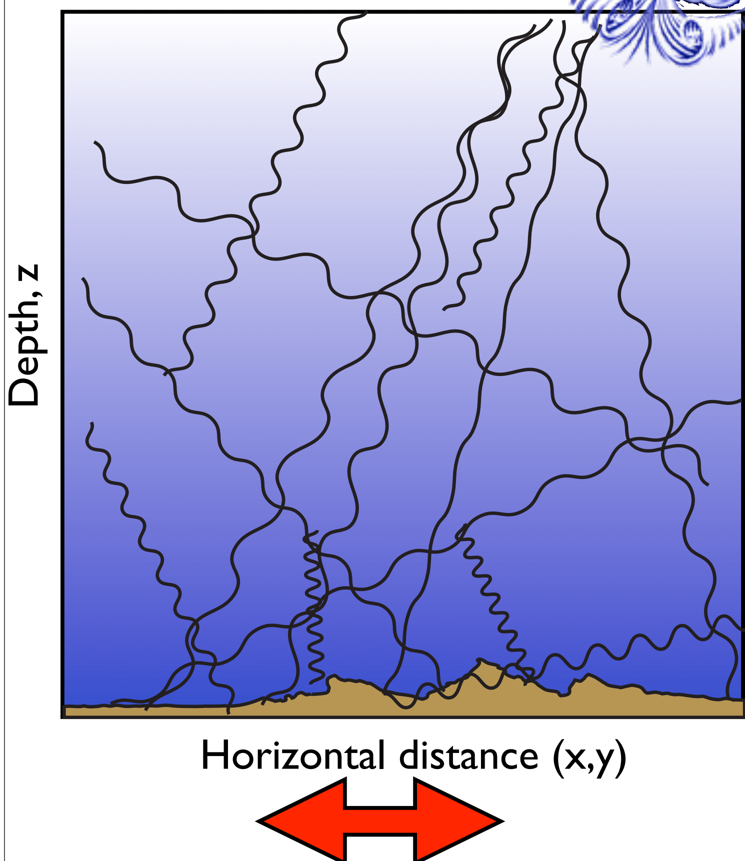
Internal gravity wave primer



- Low-mode ~interfacial waves
- High-mode ~ plane waves
- Rapid: $f \leq \omega \leq N$
- Breaking waves are at small (1-10 m) scales



The zoo of internal waves in the ocean



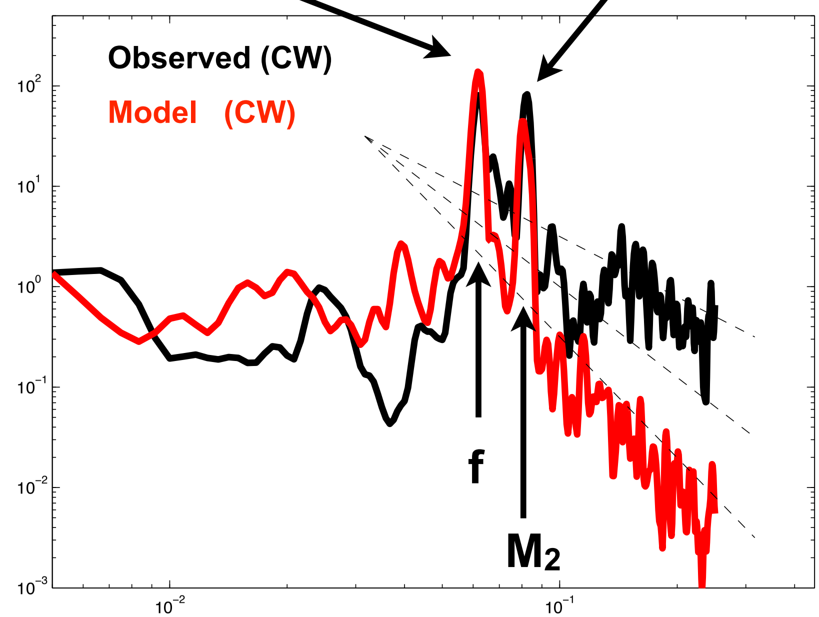
Internal Tides: generated by oscillatory tidal flow over topography. Waves have tidal period (M_2=12.4 hour)

Two frequencies dominate energetically

Near-inertial waves: often wind generated, have a frequency close to the local inertial frequency (latitude dependent)

Near-inertial waves

Internal Tides



Parameterizing mixing

Cant' explicitly resolve internal waves in climate models.
3 steps to parameterize their role:

1) Wave generation
2) **Wave propagation**
3) Wave dissipation

Near-Inertial Waves

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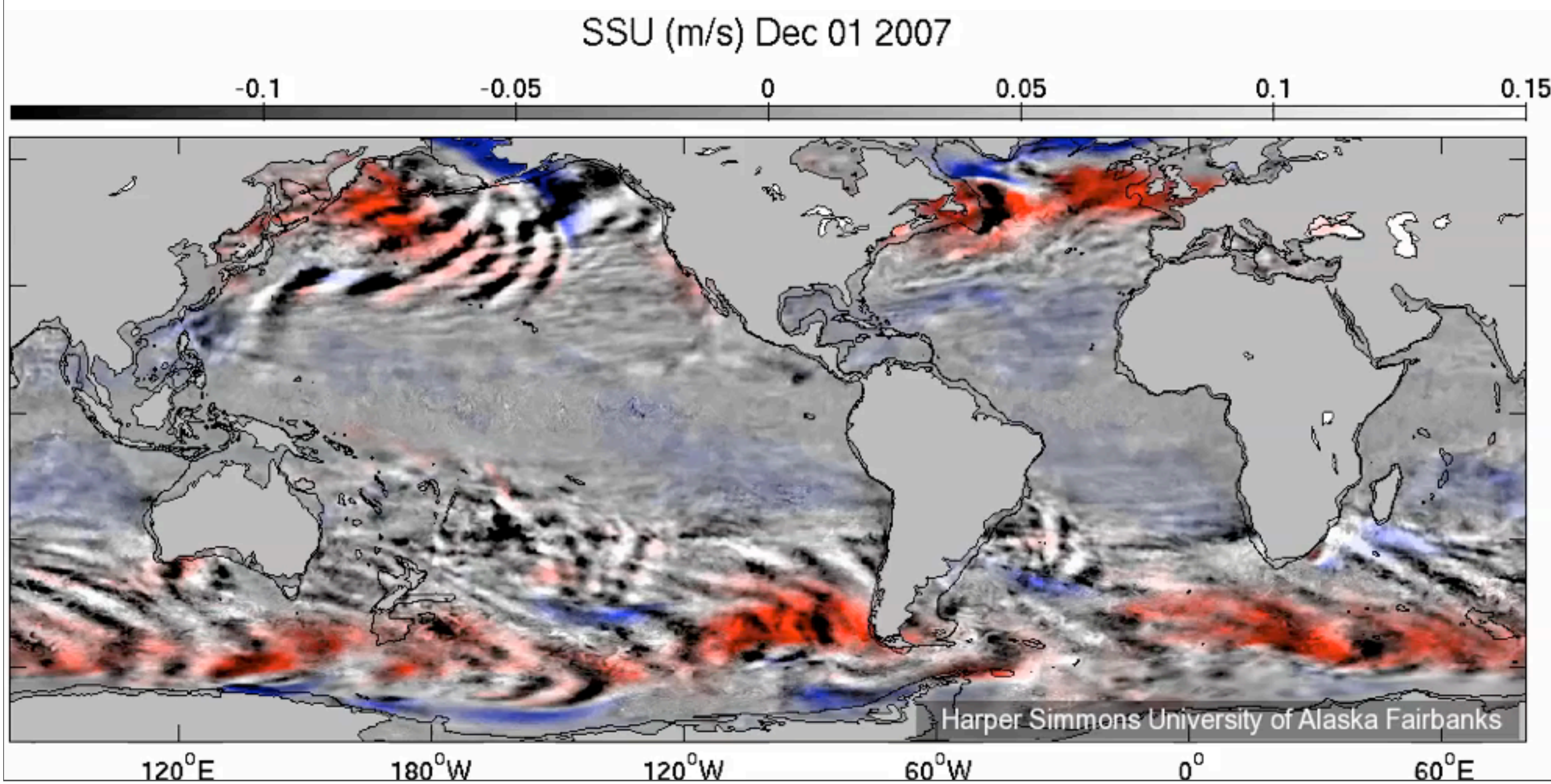
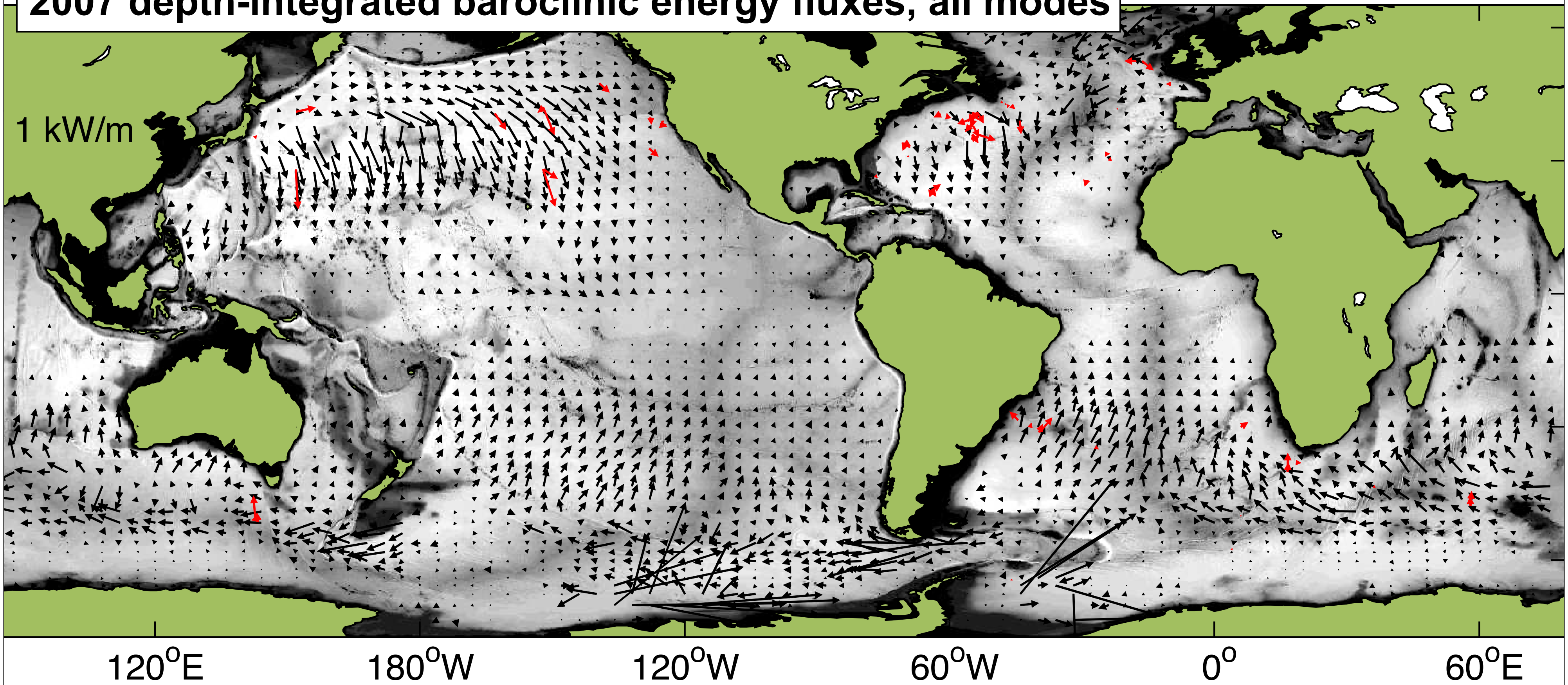
Near-Inertial Waves



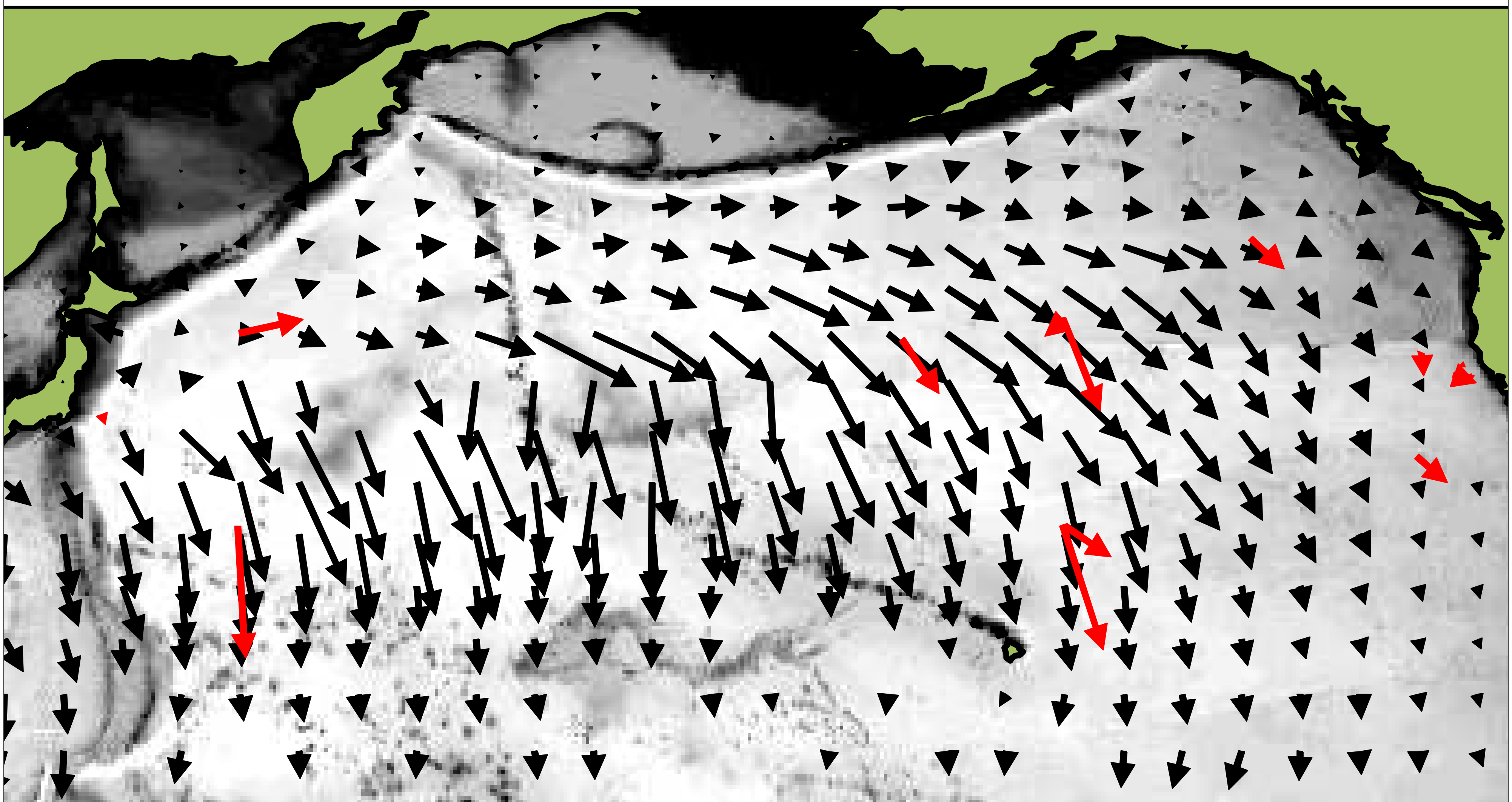
2007 depth-integrated baroclinic energy fluxes, all modes



GOLD SIMULATION

Alford NIW fluxes (80 moorings)

details



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Internal Tides

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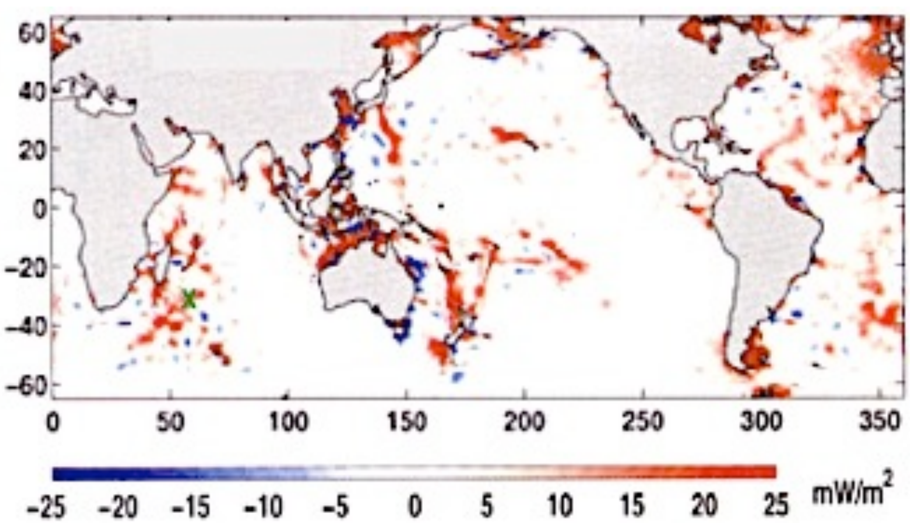
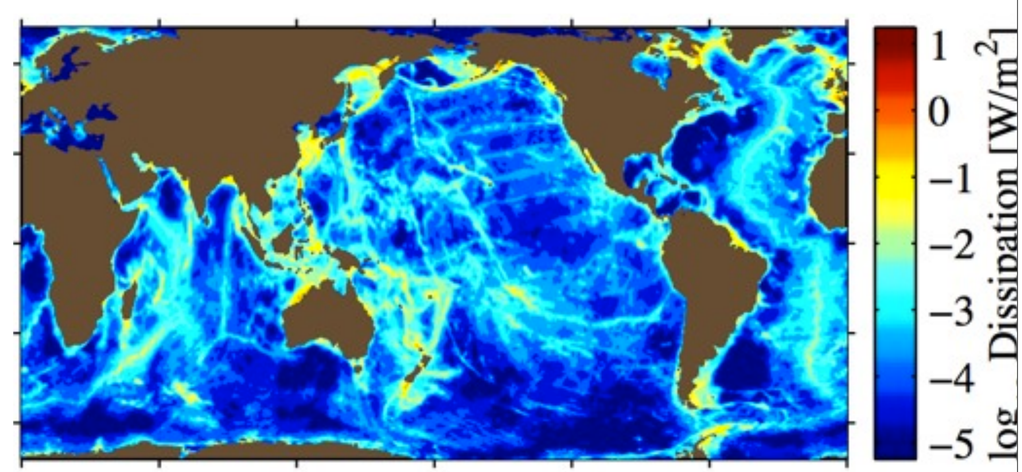
Maps of Internal-Tide Generation

Data inversion from TPXO Tidal assimilation



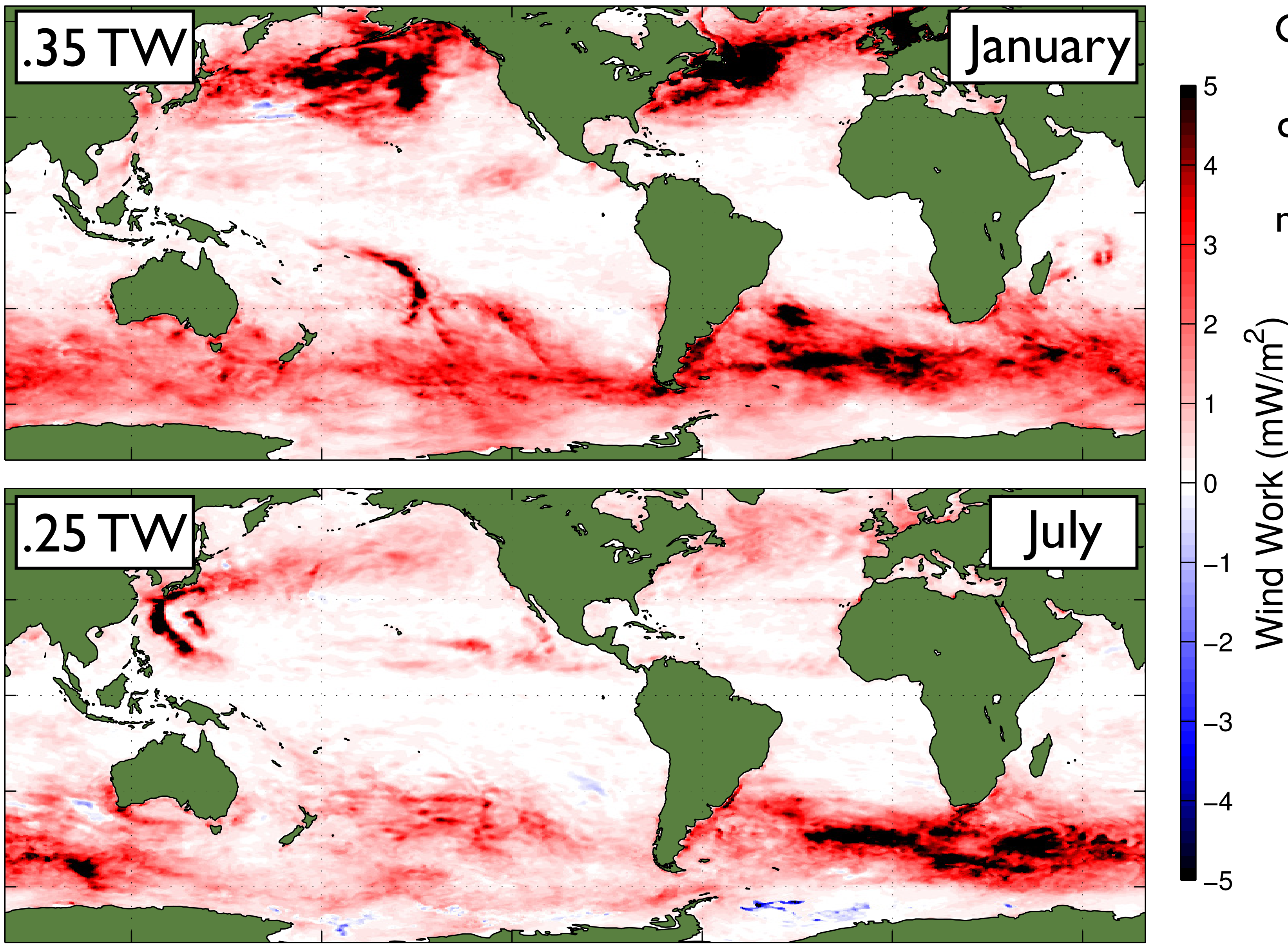
Egbert and Ray 2001

Direct estimate from tidal/oceanographic parameters



Jayne and St. Laurent (2001)

Maps of Near-Inertial Wave Generation



Generation by rotating component of wind stress, mirrors storm tracks

N.B., strong dependence on the wind forcing employed!

Parameterizing mixing

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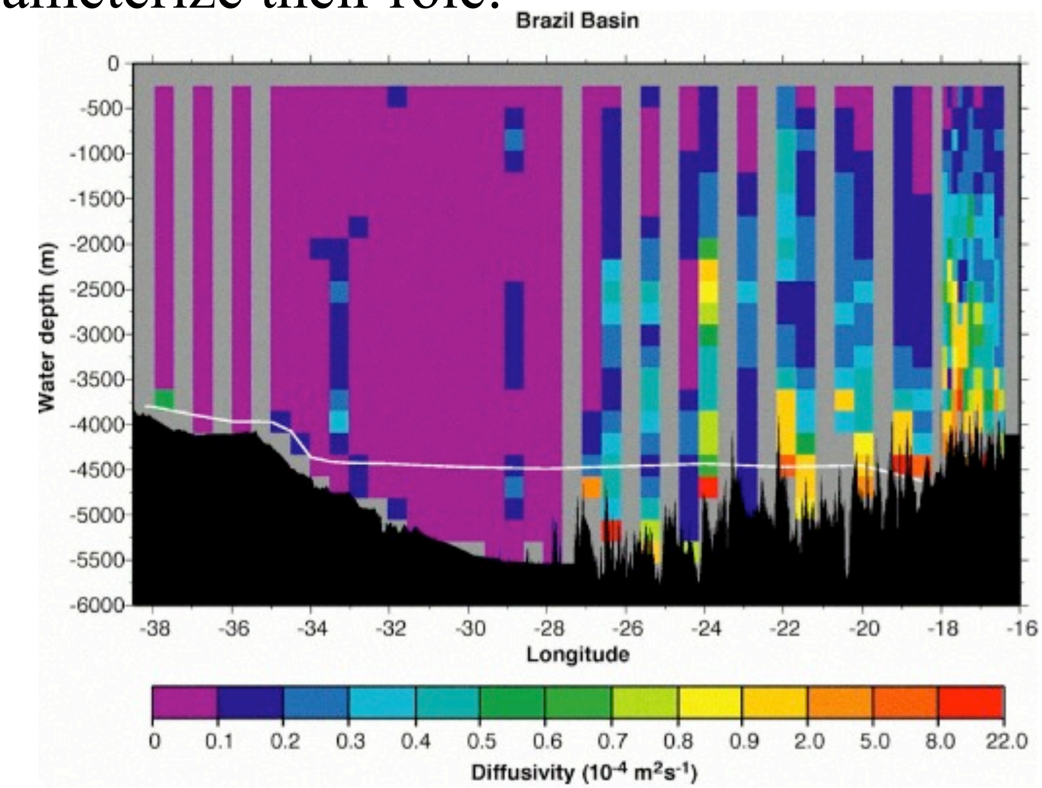


Polzin et al. 97

Internal tides propagating up from the rough (eastern) bathymetry steadily break, producing elevated mixing up into the main thermocline

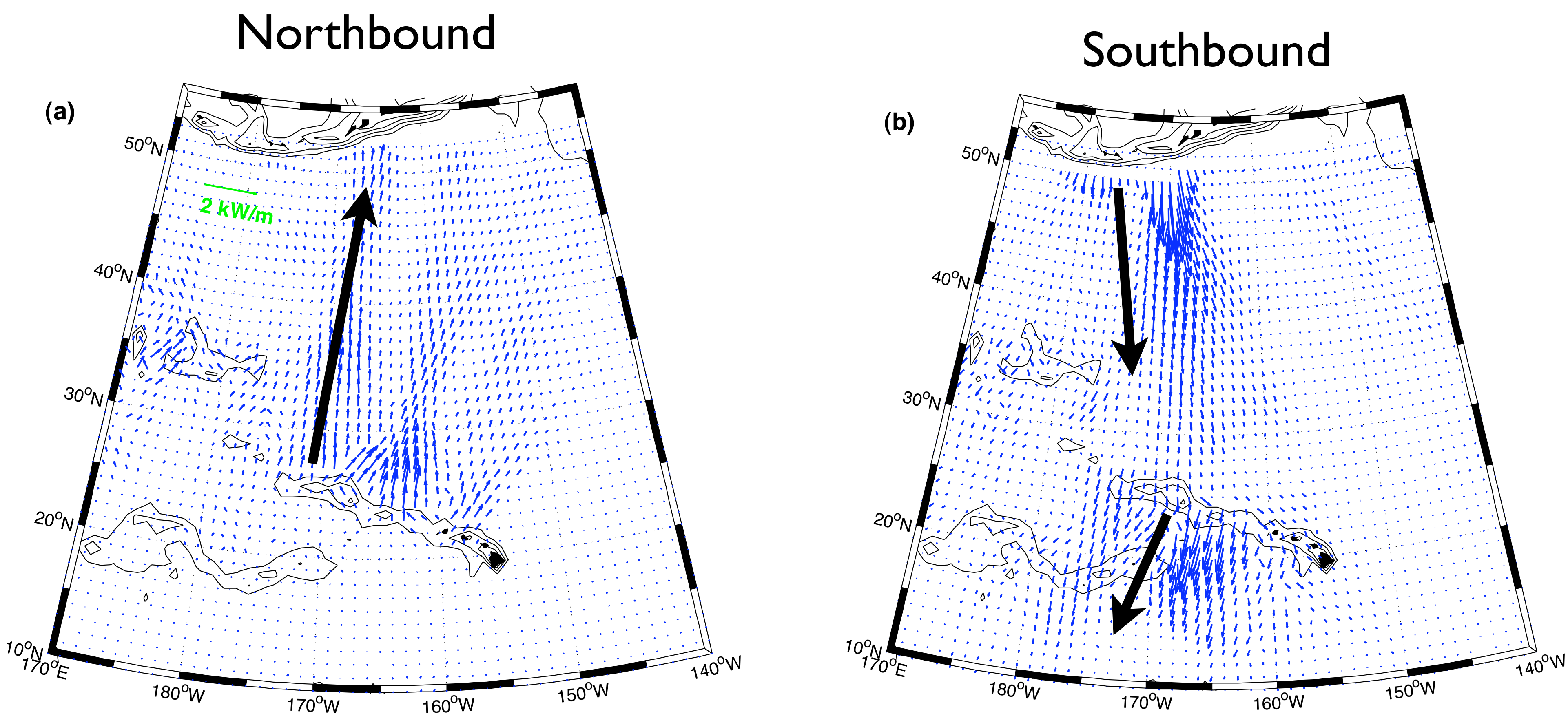
Global pattern of mixing that mirrors wave generation

"Farfield" wave breaking / mixing

Most (70-90%) internal tide energy escapes to propagate thousands of km away.

Where do these waves break? [St. Laurent and Nash 04]

Altimetric tidal fluxes

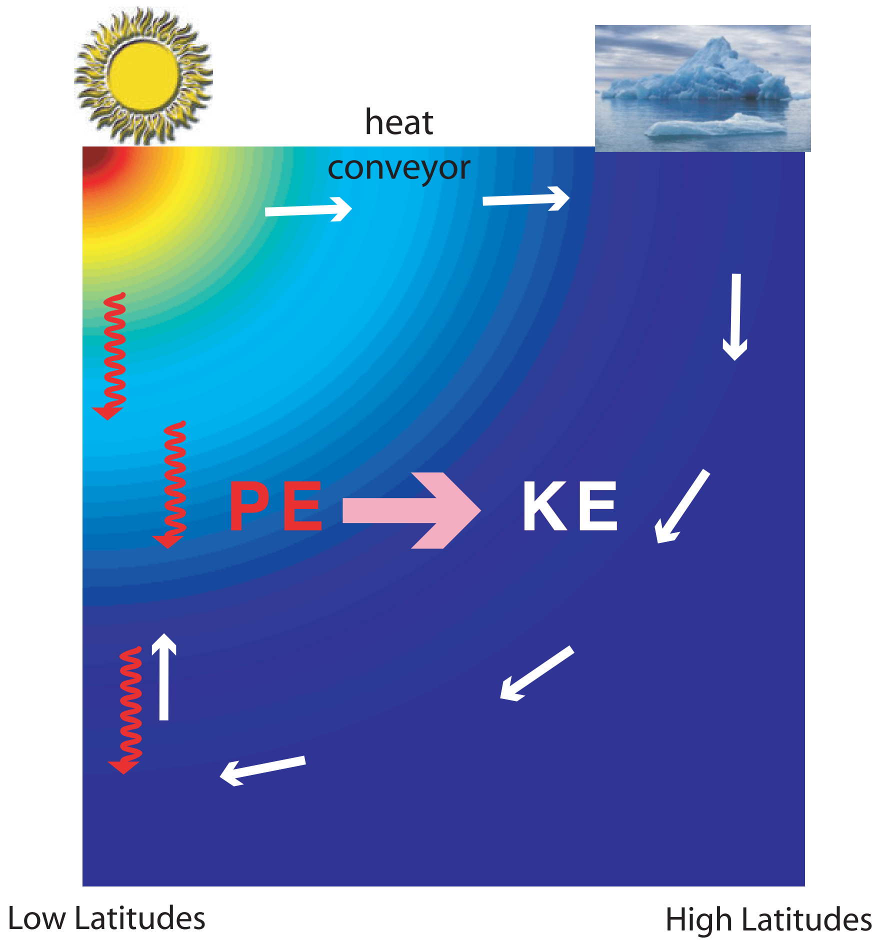


Zhongxiang Zhao, UW

Desirable Properties of Parameterizations

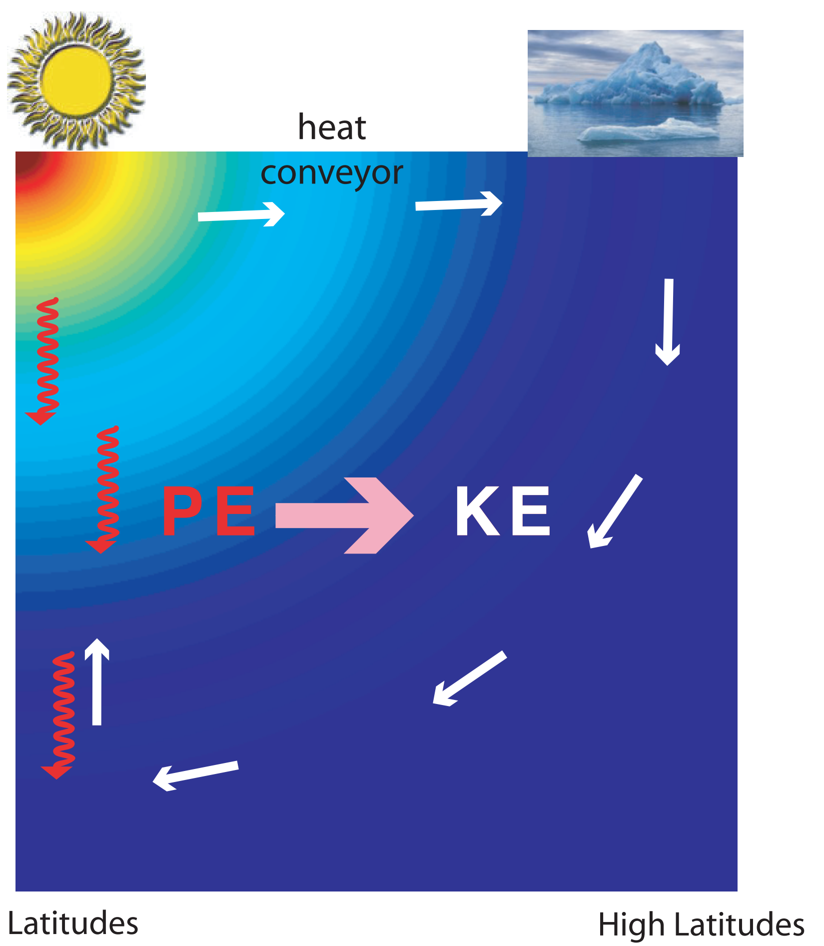
- Energy-based prescriptions are more likely to avoid physical inconsistencies.
- Should use model's own properties (e.g., stratification) for calculating the energy conversion to allow for negative feedbacks on mixing.
  - Static maps can get scary when the control the ocean structure.
- Energy fluxes (and hence buoyancy fluxes) should respond to the changing model state.
- Vertically elliptic or iterative equations are O.K.; Horizontally elliptic equations, iterations, or large numbers of wavenumber bins will be a challenge.
- Minimize <u>dimensional</u> "parameters" wherever possible.
- Should work across a range of model resolutions.
  (1° - 1/8° climate models now.)

Turbulent mixing helps make the ocean go round



Some more complex implementation in more complex models →

Turbulent mixing helps make the ocean go round



But (patchy) mixing changes the story

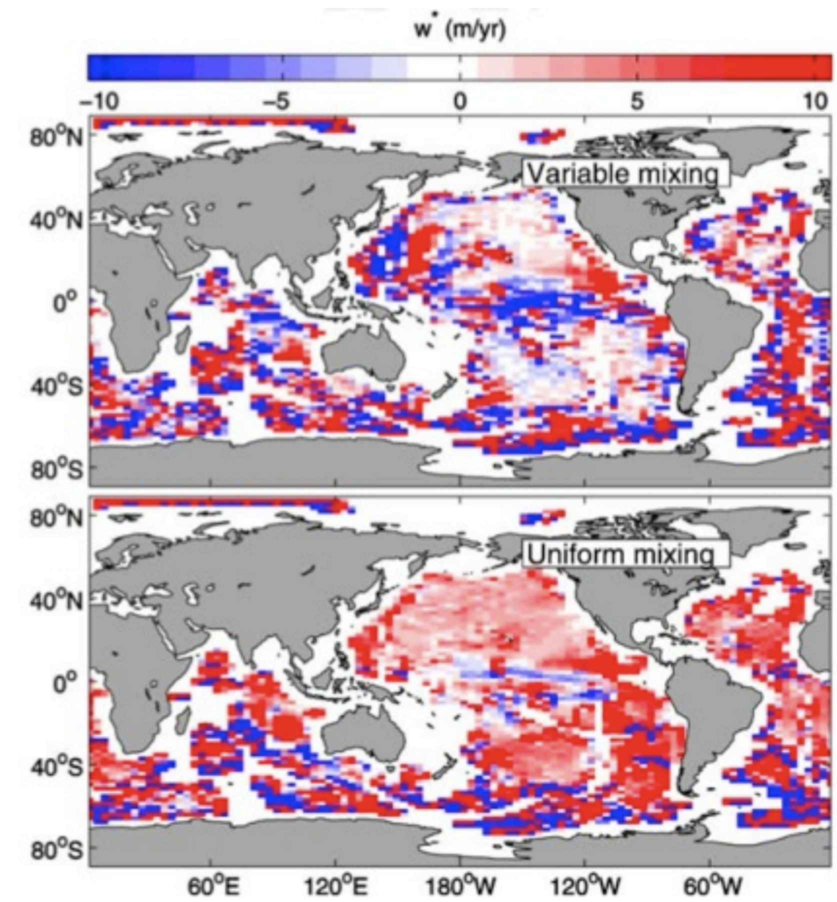
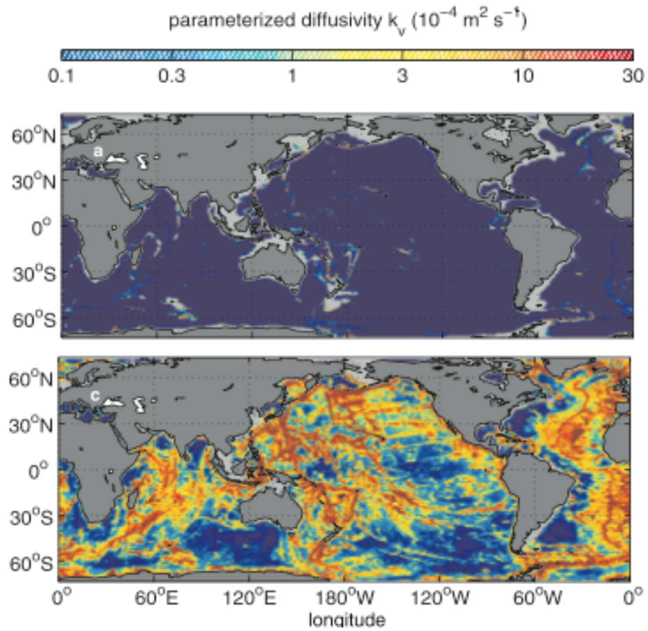


Fig. 5. Diapycnal mass flux (w^*) through the 3300 m depth level.

Some more complex implementation in more complex models →

"Nearfield" tidal mixing

St. Laurent et al 02



1000 meters

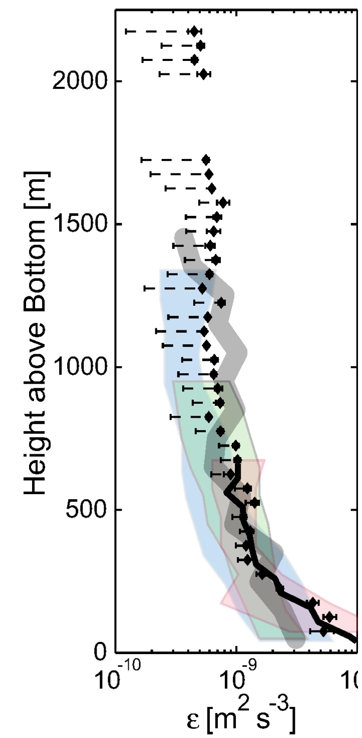
ocean bottom

dissipation rate (related to diffusivity)

map of internal tide generation (U_{bt}, N)

vertical structure (exponential decay)

$$\epsilon = \frac{\mathbf{qE(x,y)F(z)}}{\rho}$$



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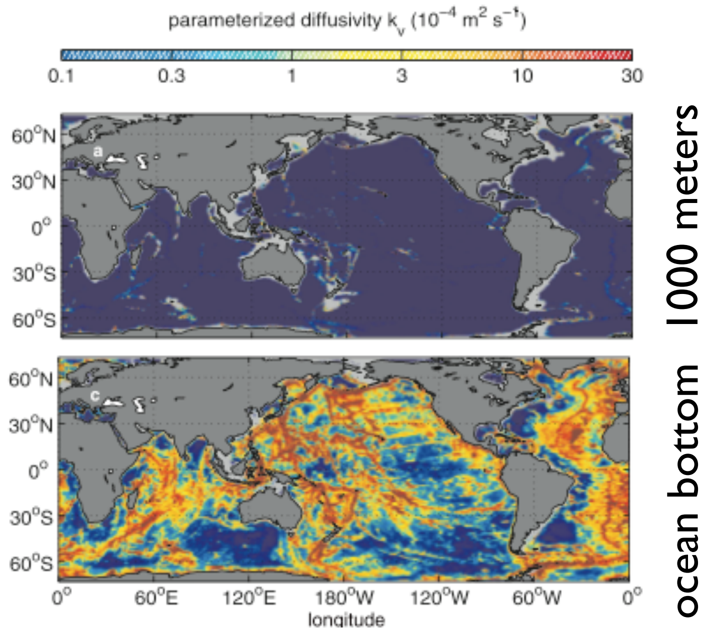

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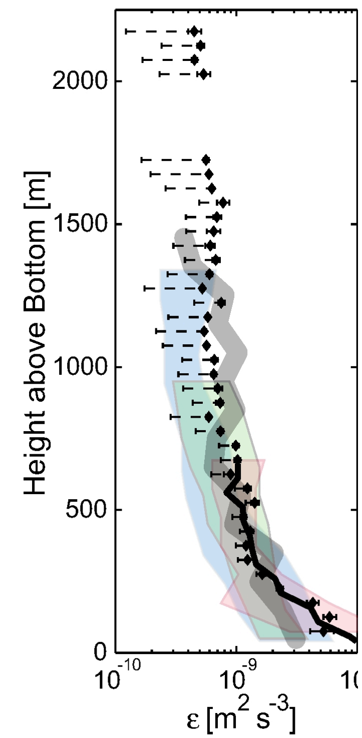

PLANNED WORK

Develop a vertical decay scale based on nonlinear dynamics of wave interaction and breaking

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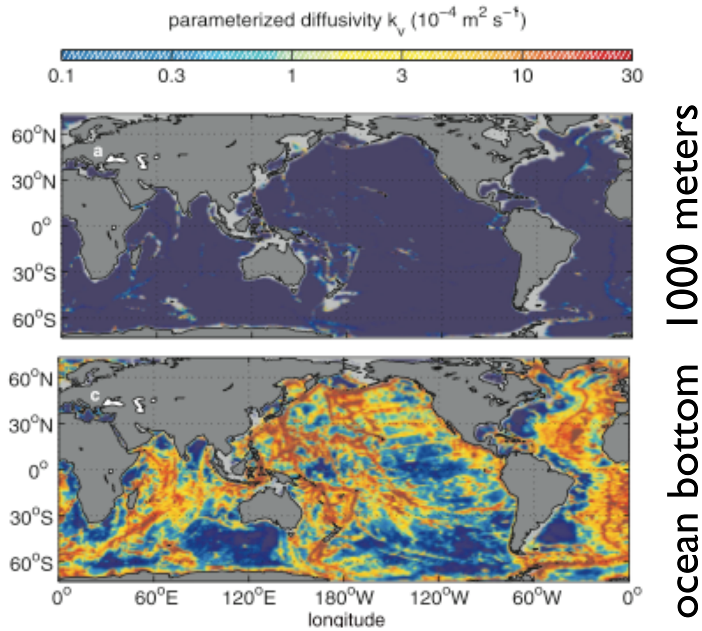

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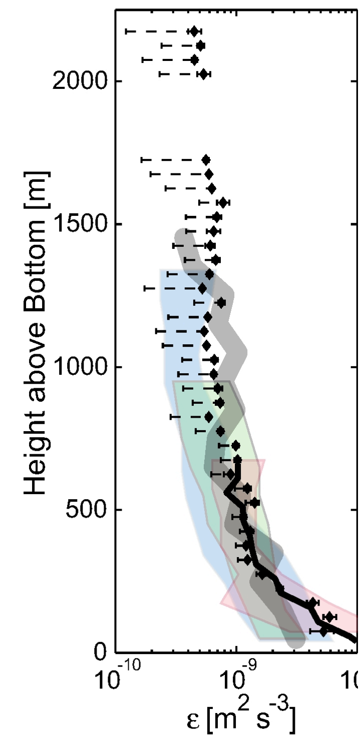

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Develop a vertical decay scale based on nonlinear dynamics of wave interaction and breaking

PLANNED WORK

Develop a similar representation for elevated mixing in the upper ocean under storm tracks

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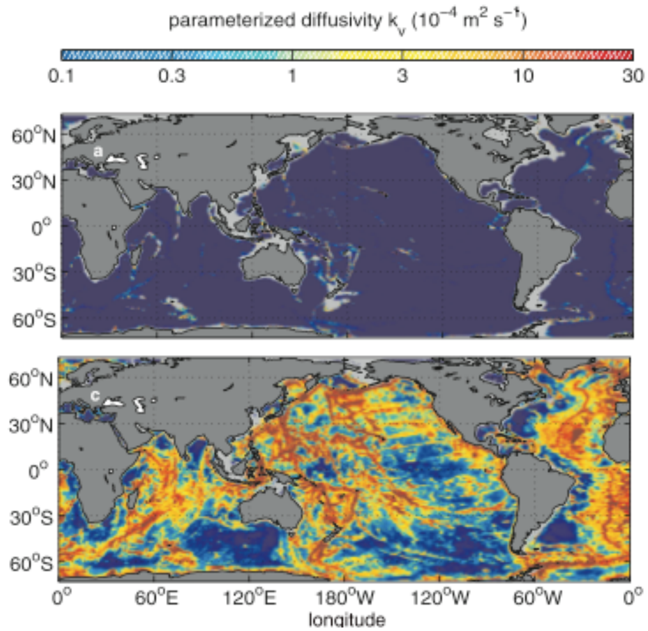

1000 meters

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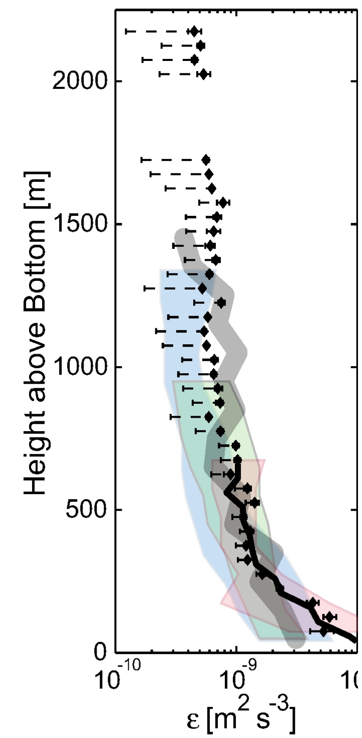
% of energy that dissipates locally



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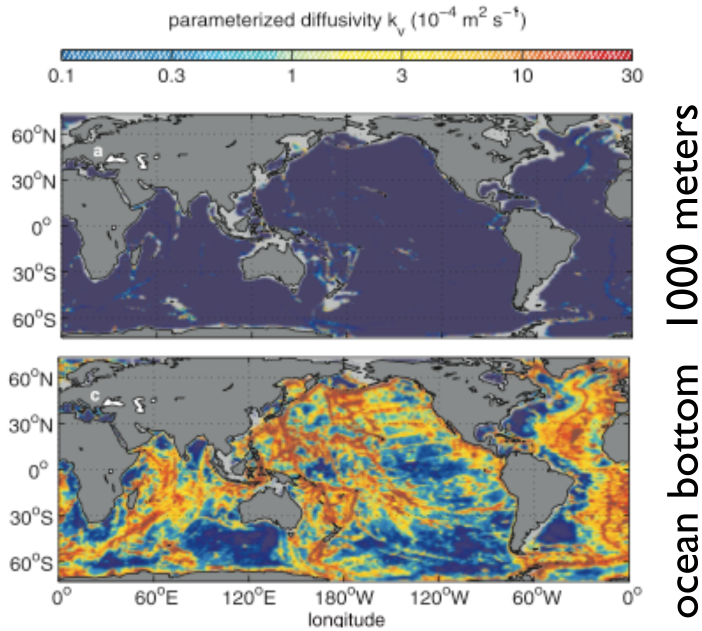

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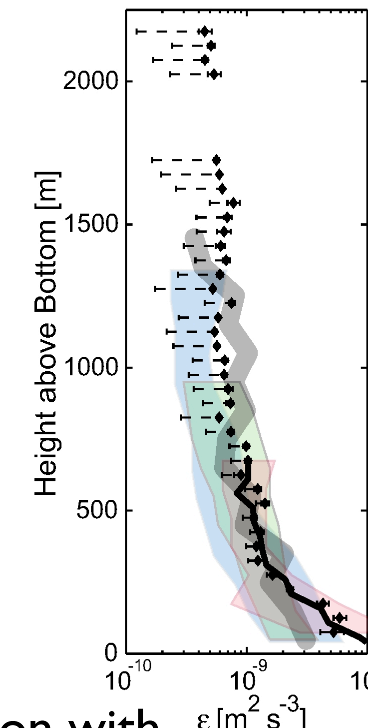


PLANNED WORK

Develop a vertical decay scale based on nonlinear dynamics of wave interaction and breaking

PLANNED WORK

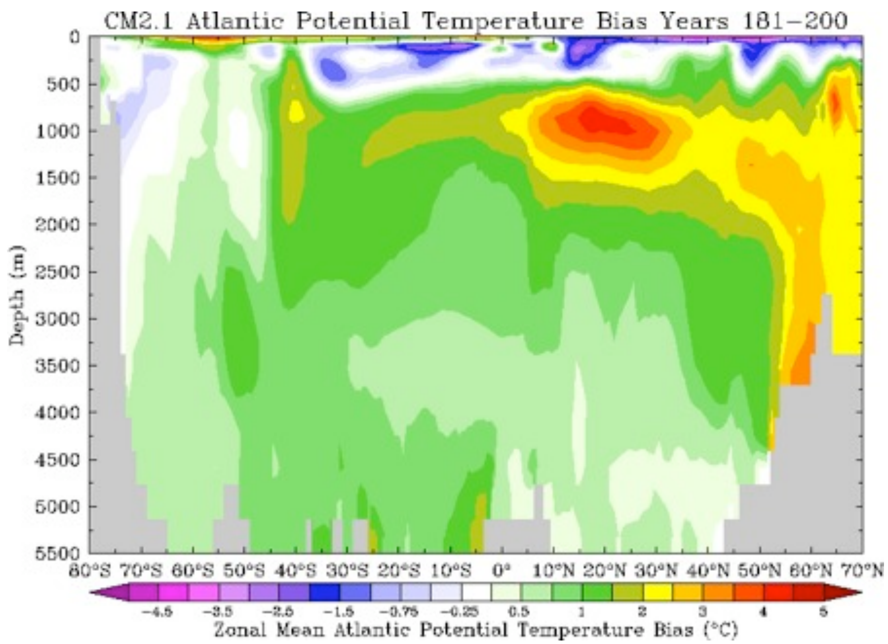
Develop a similar representation for elevated mixing in the upper ocean under storm tracks

PLANNED WORK

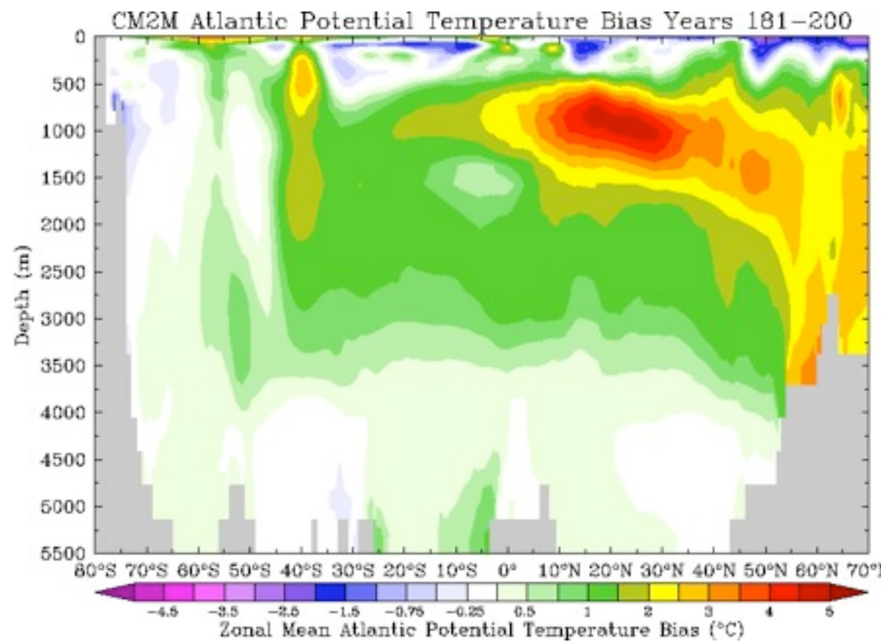
Propagating waves steadily lose energy due to interaction with other internal waves and mesoscale eddies. Apply existing wave-wave interaction theory to develop a map of dissipation for low-mode internal waves

Patchiness of Deep Ocean Mixing matters

Zonal mean Atlantic temperature bias



CM2.1 (in AR4)



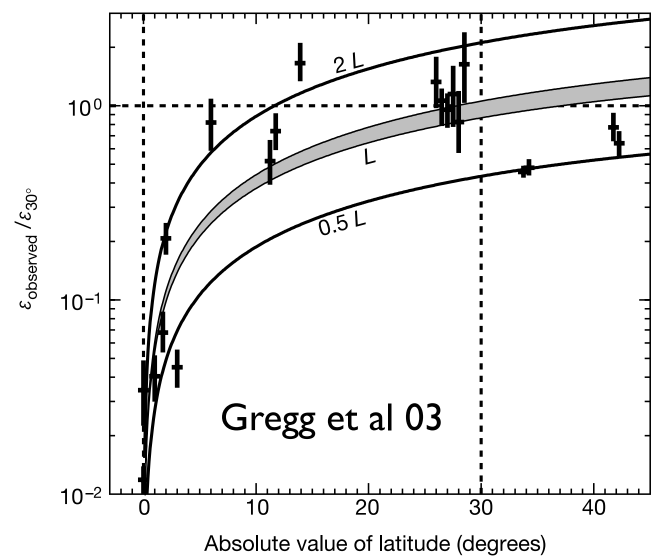
CM2M (in AR5)
Elevated mixing over rough topography

Hallberg

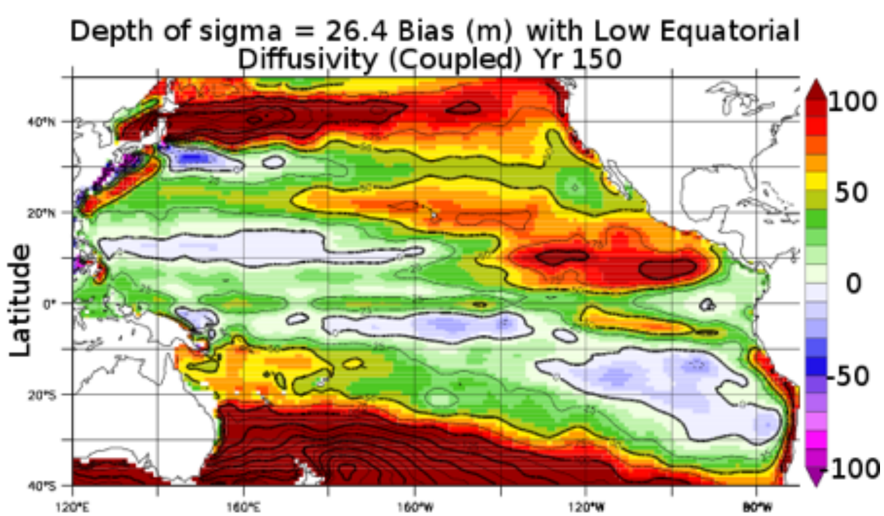
Patchiness of Upper Ocean Mixing matters

Successful application of wave-wave interaction theory: breaking of ambient internal wave field scales with latitude because of changing internal wave frequency band (f<ω<N).

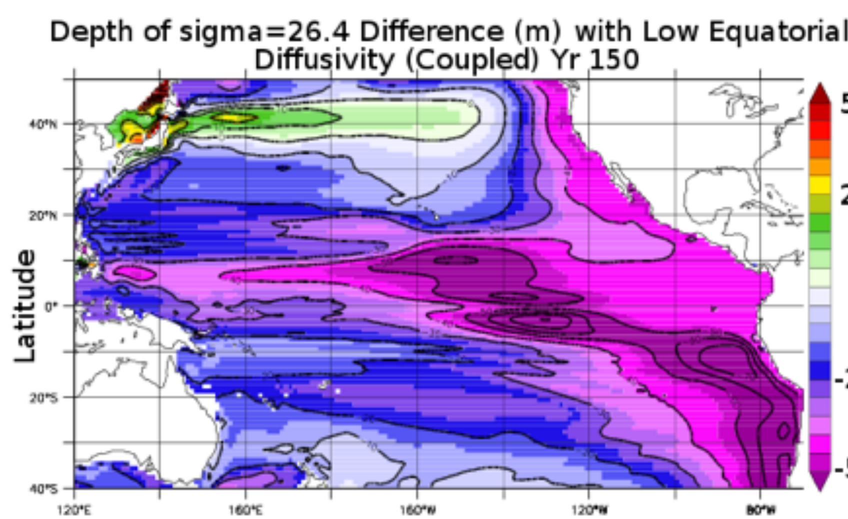
Observational evidence



GFDL modeled implications



Harrison and Hallberg 08 Longitude Avg = 50.1 m



C.I. = 10m Longitude Avg = -28.0 m

Present Progress

Continued process-oriented GCM analysis & data comparisons:
Simmons/Alford, this talk.

GCM investigation of energetically constrained, spatially variable mixing:
Jochum-NCAR - Implementation of NIW parameterization --
Upside down version of St. Laurent et al (2002)

Hallberg, Legg & Griffies (GFDL) - tidal and other contributions to
spatial variable & topographically controlled
mixing --this talk

Planned Work

Dynamics of wave breaking

- observations
- process modeling
- theory

Postdoc

Postdoc

implement test parameterizations

do resultant wave patterns agree with observations?

Global wave modeling

Postdoc

- high-resolution
- tide and wind-forced
- w/ or w/o mesoscale

extract essential mixing patterns for lower-resolution models (functions of N, wind stress, etc)

Global climate modeling

- high-resolution
- tide and wind-forced
- w/ or w/o mesoscsale

Postdoc

do resultant mixing patterns agree with observations?

Four CPT postdocs hired this year:

Oliver Sun (WHOI): Analysis of wave-mean flow interactions (Polzin et al.) applied to Equatorial wave guide.

Angelique Melet (GFDL): Effects of spatially and temporally varying ocean mixing, parameterizing the effects of internal wave processes on the mean watermass structure, circulation and variability of realistic coupled and ocean-only climate models.

Amy Waterhouse (SIO): Consolidating available data to develop a comprehensive global map of internal wave energy levels and mixing.

Joseph Ansong (UMich): Process studies of directly resolved internal wave dynamics in eddy resolving GCMs