Diapycnal Mixing in the Equatorial Cold Tongue and its Parameterization

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Mixing Observatories at GEOMAR

Ship-based microstructure systems

Autonomous microstructure platforms (MicroRider / Glider)
Ship-board microstructure measurements (2005-2011)

- Repetitive microstructure sections within the cold tongue region from 11 cruises during different seasons
- Individual stations with at least 3 profiles (>2000 profiles)
- Shipboard ADCP measurements
Time series of turbulent kinetic energy

May-July 2011, 0°N, 10°W

- Mixed layer depth

November 2009, 0°N, 23°W

- microstructure probe (Rockland Scientific) attached to a Glider
- measures autonomously for up to 4 weeks
- profiles the water column to 1000m in about 45 minutes
• elevated vertical shear of horizontal velocity at the base of the mixed layer extends from 3°S to 1.5°N

• elevated turbulence levels below mixed layer are found between 3°S and 1°N

• little mixing in stratified layer below MLD south of 4°N
Seasonal cycle of mixed layer heat budget at 0°N, 10°W

Individual terms of mixed layer heat balance

Sum of terms and heat storage

(Hummels et al., 2013)
Vertical shear of horizontal current and turbulent kinetic energy dissipation rates

Shear variance \( S^2 = (\frac{du}{dz})^2 + (\frac{dv}{dz})^2 \)

- Elevated dissipation rates coincide with elevated shear variance.
- Bursts of elevated turbulence in the thermocline occur sporadically and last up to a few hours.
Horizontal currents observed during the MircoRider/Glider mission

- Strong tidal currents in record with amplitude of ~8 cm s$^{-1}$
- Core of the EUC located at 40m-60m depth
Vertical shear of horizontal current and turbulent kinetic energy dissipation rates

Shear variance $S^2 = (\frac{du}{dz})^2 + (\frac{dv}{dz})^2$

- Elevated shear variance above the EUC core
- Elevated dissipation rates coincide with elevated shear variance
- Bursts of elevated turbulence in the thermocline occur sporadically and last up to a few hours
Vertical shear of horizontal current and turbulent kinetic energy dissipation rates:

- Elevated shear variance above the EUC core coincides with elevated dissipation rates.
- Bursts of elevated turbulence in the thermocline occur sporadically and last up to a few hours.

Can shear and stratification be used to parameterize equatorial turbulence?
Average TKE dissipation rates in $N^2$ and $S^2$ bins

Observations (1.5°N – 2°S)

Upper Thermocline (high shear region) from base of the mixed layer to 20m below

Thermocline (lower shear region) from 40m below the mixed layer to 150m
Ri-dependent mixing parameterizations

\[ \nu = \frac{50 \times 10^{-4} \text{m}^2 \text{s}^{-1}}{(1 + 5 \text{Ri})^2} + 10^{-4} \text{m}^2 \text{s}^{-1} \]

\[ K_\rho = \frac{\nu}{(1 + 5 \text{Ri})} + 10^{-5} \text{m}^2 \text{s}^{-1} \]

\[ K_\rho = \frac{5 \times 10^{-4} \text{m}^2 \text{s}^{-1}}{(1 + 5 \text{Ri})^{2.5}} + 10^{-6} \text{m}^2 \text{s}^{-1} \]

KPP
Large et al., (1994)
Large and Gent (1999)

\[ K_\rho = 50 \times 10^{-4} \text{m}^2 \text{s}^{-1} \left[ 1 - \left( \frac{\text{Ri}}{0.7} \right)^2 \right]^3 \]
Evaluation of Ri-dependent Parameterizations

Zaron & Moum (2009)

\[ K_{h_1}^{alt} = \left| V \right|^2 / S \cdot a \left( \frac{Ri_1}{Ri - Ri_1} \right)^\alpha + be^{-\beta \cdot Ri} + c \]

\[ K_{h_2}^{rev} = \left| V \right|^2 / S \cdot \Delta \phi_h e^{-\gamma (Ri - Ri_2)} + \phi_h^w \]

Uses additional parameter:

\[ \left| V \right|^2 - \text{large-scale kinetic energy} \]

\[ S - \text{shear} \]
Average TKE dissipation rates in $N^2$ and $S^2$ bins

Upper Thermocline (MLD to MLD+20m)
Average TKE dissipation rates in $N^2$ and $S^2$ bins

Thermocline (MLD+40m to 150m)
Evaluation of Ri-dependent Parameterizations

- Pac & Phi 81
- Peters et al high 88
- Peters et al low 88
- KPP Large et al 95
- Zaron & Moum 09
- Zaron & Moum rev 09

Microstructure data from 2°S-1.5°N
Evaluation of Ri-dependent Parameterizations

<table>
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<th>Model</th>
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Microstructure data from 2°S-1.5°N

Equatorial Pacific microstructure data
(Zaron & Moum ‘09)
Evaluation of Ri-dependent Parameterizations

- Pac & Phi 81
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Microstructure data from 2°S-1.5°N

![Graph showing the relationship between \( K_p \) and \( \tan^{-1}(Ri) \) for different models and microstructure data.](image-url)
Evaluation of Ri-dependent Parameterizations

Thank you
existing Ri-dependent mixing parameterizations do not well reproduce
Roadmap

- Mixing Observatories at GEOMAR
- Parameterization of shear driven mixing in the tropical ocean
- Parameterization of internal wave driven mixing
- Conclusions