Estimates of bottom flows and bottom boundary layer dissipation of the oceanic general circulation from global high resolution models

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Central questions

• How well do the bottom flows in high-resolution ocean general circulation models compare to those in current meter observations?
• What is the globally integrated, time-averaged bottom boundary layer (BBL) dissipation of the general circulation estimated from high-resolution models? Is it a significant fraction of the ∼1 TW wind-power input into geostrophic flows (e.g. Wunsch 1998, Scott and Xu 2008)?

Motivation

• The realism of high-resolution oceanic general circulation models has been frequently tested by comparisons to surface and near-surface observations (e.g., McClean et al. 2002, Maltrud and McClean 2005), but less often by subsurface observations (see Penduff et al. 2006 for one example of the latter). Here we compare high-resolution models to current meter observations of bottom flows.
• Emphasis on bottom flows is motivated by possibility that bottom drag is an important control on the dynamics and energy budget of mesoscale eddies, as seen in both idealized geostrophic turbulence models (e.g., Arbic and Flierl 2004, Thompson and Young 2006, 2007, Arbic et al. 2007, Arbic and Scott 2008), idealized primitive equation models (Riviere et al. 2004, Cessi et al. 2006), and basin-scale energy budget studies (Weatherly 1984).
• Community interest in sources and sinks of mixing continues (Munk and Wunsch 1998, St. Laurent and Simmons 2006). Sinks of general circulation energy still poorly understood.
• Sen et al. (2008) estimated 0.2-0.8 TW in BBL dissipation of low-frequency flows. Relationships between satellite-derived surface currents and deep currents were combined with the satellite maps to infer bottom flows on a global scale. Models offer direct estimates of bottom flows.

Models used

• POP: we analyze year 2003 of the simulation of Maltrud and McClean (2005). Snapshots saved every 10 days. 2400 × 3600 gridpoints in each of 40 full-cell z-levels.
• Global NLOM: we analyze year 2006 of data-assimilative NLOM (DANLOM–Shriver et al. 2007 and references therein), and year 2002 of non-assimilative NLOM (NANLOM). DANLOM/NANLOM snapshots saved every day/3 days. 4384 × 8192 gridpoints in each of 6 Lagrangian layers.

Current meter data

• We use moored current meter data obtained from the Deep Water Archive and Buoy Group Archive of Oregon State University's Buoy Group.
• Require current meters to lie at least 10 m above the bottom, and within 10% of the seafloor depth above the seafloor, with a record length exceeding 180 days.
• Tides and other high-frequency motions removed with a 72-hour lowpass filter.

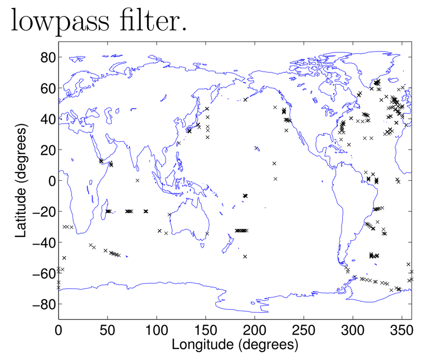

Figure 1 Locations of 382 moored near-bottom current meters used to compare to DANLOM, NANLOM, and POP.

Dissipation formula

• Time-averaged BBL dissipation at a model gridpoint (or mooring location) is computed as

$$\overline{D}(\theta,\phi)=\rho c_d\overline{|\mathbf{u}_b|^3}, \qquad (1)$$

(Taylor 1919), where θ and ϕ are respectively the longitude and latitude of the gridpoint, ρ=1035 kg m^{-3} is the average density of seawater, $|\mathbf{u}_b|$ is the magnitude of the bottom velocity vector, and overbars denote time-averaging.
• Bottom velocity is velocity in bottom (sixth) layer for DANLOM and NANLOM, and is the velocity in the lowest active level for POP.
• c_d=0.003/0.002/0.001225 for DANLOM/NANLOM/POP.

Comparison of models with current meter data

• We measure the model values of $\overline{|\mathbf{u}_b|^3}$ at mooring sites in two ways, by interpolation to the mooring coordinates ("Interpolated"), and by searching for the model values in 1° by 1° boxes around the mooring sites that match the mooring values most closely ("Best").

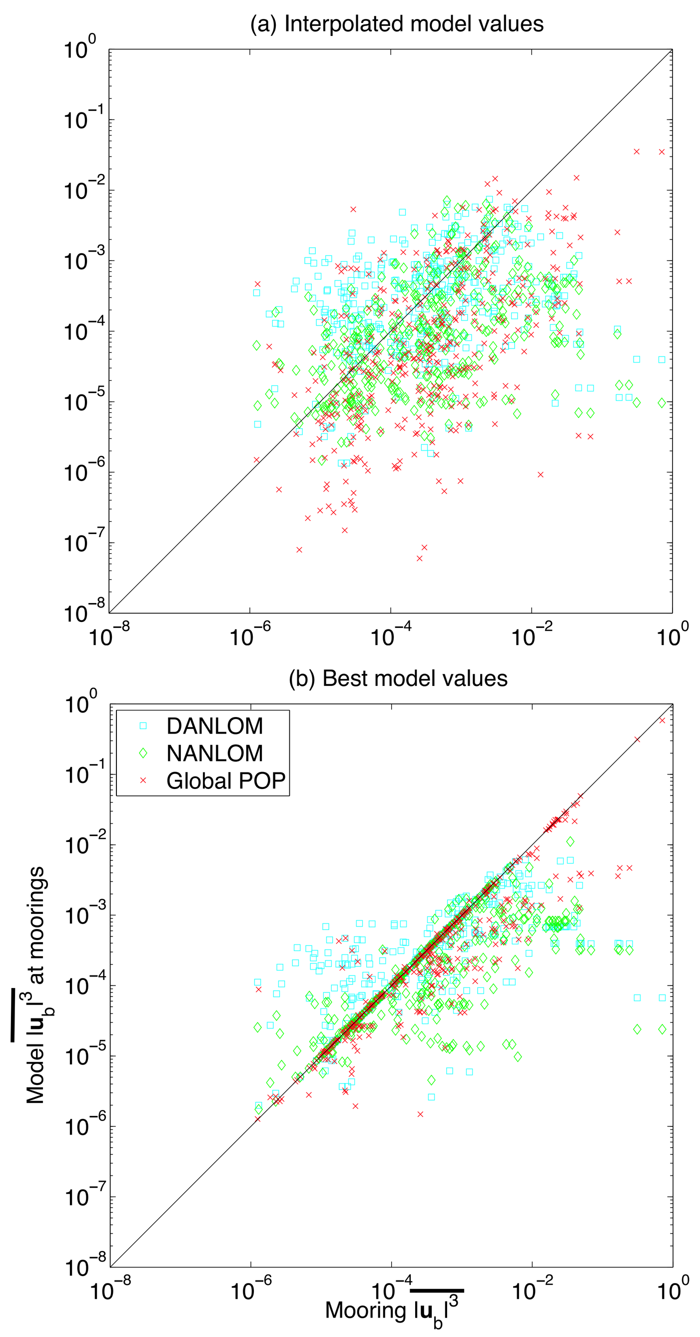

Figure 2 Values of $\overline{|\mathbf{u}_b|^3}$ computed from DANLOM, NANLOM, and global POP at 382 mooring locations, plotted versus the values computed from the moorings themselves. (a) Model values interpolated to the mooring coordinates. (b) Model values, taken from 1° by 1° boxes centered on the moorings, which compare most closely to the mooring values. Units of $\overline{|\mathbf{u}_b|^3}$ are m^3s^{-3}.
• The interpolated values do not match the model values well on a point-by-point basis, but there is no obvious bias, suggesting that averages over many mooring locations may show better agreement. To better quantify this we compute

$$\gamma=\frac{\sum_{i=1}^{M}\overline{|\mathbf{u}_{bmodel}|^3_{,i}}}{\sum_{i=1}^{M}\overline{|\mathbf{u}_{bmooring,i}|^3}}. \qquad (2)$$

Model	Measure	γ (Shallow)	γ (Intermediate)	γ (Abyssal)
DANLOM	Interpolated	0.0041	0.031	0.73
DANLOM	Best	0.0037	0.060	0.62
NANLOM	Interpolated	0.0043	0.028	0.37
NANLOM	Best	0.0023	0.060	0.40
POP	Interpolated	0.045	0.15	0.40
POP	Best	0.52	0.83	0.46
POP	Best Random	0.048	0.10	0.15

Table 1 Values of γ computed across all 382 near-bottom current meters in the global database. The number of moorings M equals 14, 94, and 274 for shallow, intermediate, and abyssal seafloor depths, respectively, where "shallow" denotes depths less than 1000 m, "intermediate" denotes depths between 1000 and 3000 m, and "abyssal" denotes depths exceeding 3000 m.

• γ is of order one for all models in the abyss, and for POP in shallow and intermediate waters as well (at least when best values are used). JGR paper on this work includes more detail–1) comparison is done in North Atlantic as well as over entire globe, and North Atlantic POP simulation of Smith et al. (2000) is brought in for this comparison, 2) comparison as function of seafloor depth is included.

• "Best Random" values in POP computed in like manner as "Best" values, but from model locations sampled randomly (as opposed to in the vicinity of the mooring location). They are much lower than the "Best" values, which is suggestive of some degree of model skill.

Globally integrated dissipation rates

• We compute globally integrated dissipation rates from

$$[\overline{D}]=\int\overline{D}(\theta,\phi)\,dA=\int\rho c_d\overline{|\mathbf{u}_b|^3}\,dA, \qquad (3)$$

where the [] operator represents an areal integral.

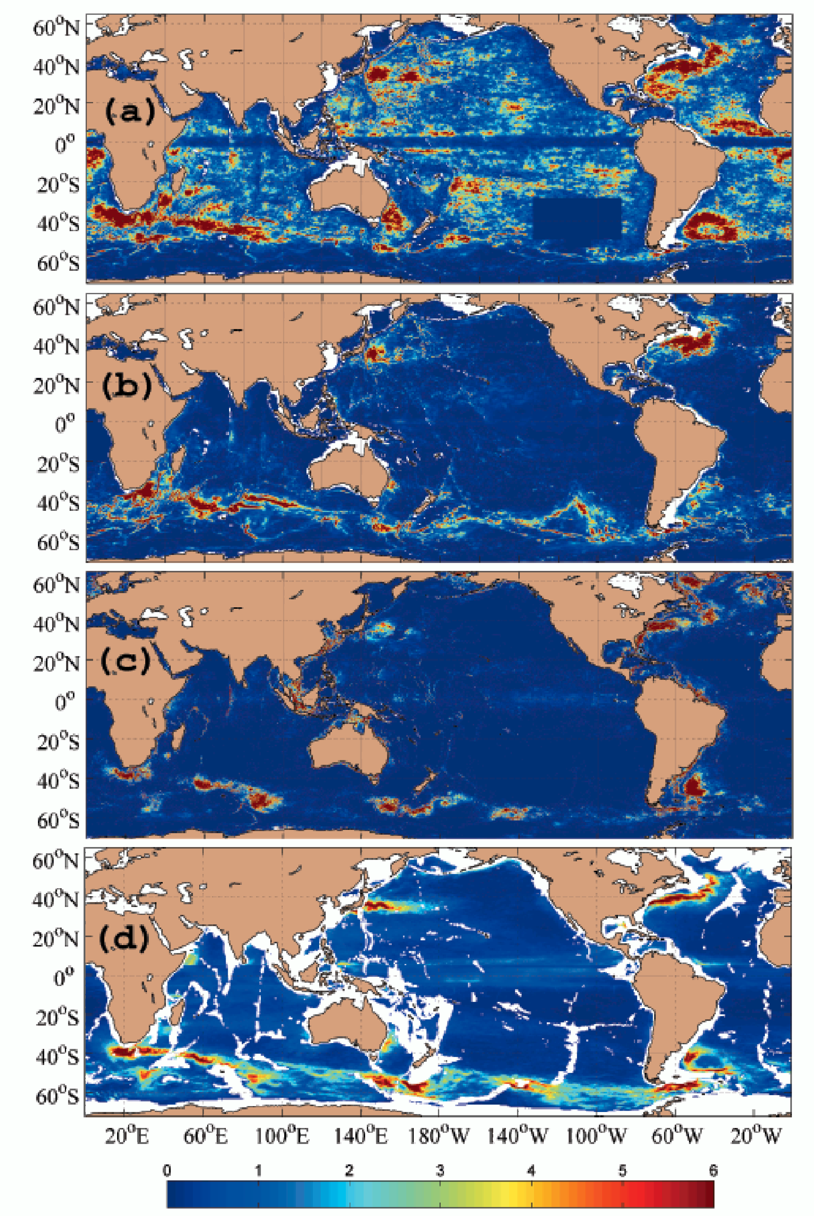

Figure 3 Maps of dissipation rate (mW m^{-2}) in (a) DANLOM, (b) NANLOM, (c) POP, (d) the $[\overline{D}_3]$ observationally-based estimate of Sen et al. (2008). A common value of c_d=0.0025 is used to make all four subplots. Note that the last estimate only covers seafloor depths exceeding 3000 m.

Model	c_d	$[\overline{D}]$
DANLOM	Native	0.65
NANLOM	Native	0.16
POP	Native	0.14
DANLOM	Common	0.54
NANLOM	Common	0.20
POP	Common	0.29

Table 2 Values of dissipation rate $[\overline{D}]$ (TW). Computations are done with both native values of c_d (0.003/0.002/0.001225 for DANLOM/NANLOM/POP), and a common value of c_d=0.0025.

Summary and discussion

• Bottom flows in NLOM and POP generally do not compare well to those in current meters on a point-by-point basis, but do compare well when averaged over many current meter sites, suggesting that the models may provide reasonable order-of-magnitude estimates of globally integrated dissipation.
• Globally integrated dissipation estimates range from 0.14-0.65 TW, comparable to the 0.2-0.8 TW estimated in waters deeper than 3000 m from observations alone in Sen et al. (2008), and a significant fraction of the 1 TW wind power input.
• Range and uncertainty large enough that other dissipation mechanisms–for instance internal wave breaking over rough topography (Nikurashin 2008) or energy transfer to submesoscale eddies and fronts (Müller et al. 2005, Polzin 2008) cannot be ruled out.

Related poster

• See Rob Scott's poster. Rob is undertaking a more comprehensive comparison, involving more models, more current meters, and comparison throughout the entire water column, not just the bottom.

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