Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean

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**Funding:** NSF (US) and NERC (UK)

**Web:** http://dimes.ucsd.edu
DIMES Status as of November 2015

• Funded proposals submitted to NSF (US) and NERC (UK): 2006, funding starting July 2007
• Field work: 2009-2014
• Analysis proposals: 2012-2015
• Now: final analysis stage. See JPO special collection & DIMES web site publication list.
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• For many of us, this means that we’re now asking how to apply the ideas that have emerged from DIMES to the entire Southern Ocean (and beyond.)
Observationalists
Ledwell
Duda
Speer
Girton
Owens
Rainville
St. Laurent
Toole
Naveira Garabato
Watson
Messias
Meijers
Meredith
Sallée
Meijers

Modelers
Ferrari
Marshall
Griesel
LaCasce
Mazloff
Shuckburgh
Stevens
Smeed

Blue: UK
Red: US
Motivation: Meridional Overturning in the Southern Ocean

- Meridional overturning depends on along-isopycnal adiabatic mixing, which is difficult to characterize.
- Diapycnal mixing could be high over rough topography and could short-circuit the adiabatic pathways.
Hypotheses:
- Diapycnal mixing smaller over smooth topography and to increase over rough topography in Drake Passage.
- Isopycnal mixing varies with depth and position, influenced by critical layer.
Implementation: Observational campaign

Components:
- Tracer release (yellow star): tracked annually for diapycnal and horizontal spread.
- Microstructure surveys: during annual research cruises
- Acoustically-tracked floats: approximately 180 at 2 levels
- UK mooring (blue star)
- Modeling (global and process, US and UK)
DIMES floats

Real floats deployed through DIMES

Floats deployed in numerical model

LaCasce et al., 2013
DIMES Eddy Diffusivity

Results from the Southeast Pacific
- Blue: DIMES eddy diffusivity from tracer
- Ensemble: multiple realizations of tracer in model
- Solid black line: tracer diffusivity as function of depth

Slide: Raf Ferrari

Tulloch et al., 2014
Isopycnal Mixing

- DIMES floats and model simulations provide consistent effective eddy diffusivity ($800 \pm 200$ m$^2$ s$^{-1}$) upstream of Drake Passage.
- Open questions:
  - How do we characterize eddy mixing in Drake Passage?
  - What is vertical structure of eddy stirring?
  - How much of stirring by eddies can a parameterization explain?

LaCasce et al, JPO, 2014
Diapycnal mixing from EM-APEX

Shear spectra

Vertical diffusivity

Southeast Pacific
Drake Passage and Scotia Sea
Tracer estimate after 1 year

Courtesy of James Girton, UW APL
Diapycnal mixing

Order of magnitude difference in mixing from abyssal plain to Phoenix Ridge in Drake Passage, with enhanced mixing near bottom.

Open questions:

- What sets diapycnal mixing? Do topography, current speed, other processes matter?
- What happens in upper ocean? How does wind drive mixing?

Implementation: Analysis and modeling

US efforts:
- Parallel Ocean Program (POP): float releases used to plan experiment, to evaluate uncertainties (Griesel et al, 2010), and to assess hypotheses (Chen et al, 2015)
- Geoid + altimetry idealized model (Klocker et al, 2012): concluded a million Lagrangian particles would be appropriate
- Regional modeling with MITgcm (Tulloch et al, 2014): used to interpret isopycnal mixing upstream of Drake Passage
Implementation: Expected Contributions to Sustained Observations

• DIMES was a process study with no plans to build sustained observations, but.....
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• EM-APEX platform development and data product development have led to more work in Antarctic margins

• Growing international interest in process studies and sustained observations (UK, Australia, Japan, France, India)
Implementation: What helped integrate modeling and observations?

Isopycnal:

• Observations are sparse, so modeling is enormously beneficial for planning, interpretation, assimilation
• Integrated interpretation takes time.
• Annual meetings, some telecons, and collaborative work help bring ideas to fruition.

Diapycnal:

• Not ready yet: models need many vertical levels, tidal forcing, and internal wave generation
Difficulties (scientific, administrative, or otherwise)

• On the whole, DIMES has been successful
• Challenges mostly beyond our control and inherent in sea-going work in a remote area (severe weather, med-evacs + death of ship captain, ship repairs, too little tracer shipped from supplier, floats with ballasting problems, lost HRP)
• On shore: UK/US collaboration exposed visa problems
• DIMES successes are a testament to resilience.
Coordination between agencies

11 cruises alternating between US and UK ships
Data sharing: CCHDO at Scripps

CCHDO=CLIVAR Carbon Hydrographic Data Office
US1 data page on DIMES web site: see http://dimes.ucsd.edu
Challenges to data management

- Data requirements relatively new; PIs unsure of requirements and (in some cases) still working on reporting data.
- UK and US data have different specific data management requirements (BODC vs CCHDO/NODC)
- DIMES involves a number of unconventional data types:
  - Microstructure
  - Floats
  - CTD and XCTD co-located with microstructure
  - EM-APEX
  - Voluminous model output
Data management successes

• Microstructure: decision to allow turbulent mixing CPT to take the lead on defining requirements. Push for CF compliant netCDF.

• Implemented password protected data management to allow data sharing amongst DIMES researchers prior to official release.

• CCHDO has implemented data management system that is seamless with other hydrographic data management.
Science emerging from DIMES

• Should DIMES results lead directly to a CPT?
  Not obvious: DIMES is an international project with strong modeling component. Would want to coordinate with other process studies.

• Should DIMES results guide future process studies?
  Undoubtedly---”DIMES was simultaneously too big (for resolving detailed mixing processes) and too small (for capturing integrated Southern Ocean mixing).”

Themes:
• Diapycnal: Topographically-generated turbulence (e.g. topographic lee waves and their impact on mixing)
• Isopycnal: Topographic stress, topographic barriers, and non-local mixing; Spatially varying lateral mixing