Mixed-Layer Depth and Air-Sea Exchange in the Southern Ocean: Examples from Drake Passage

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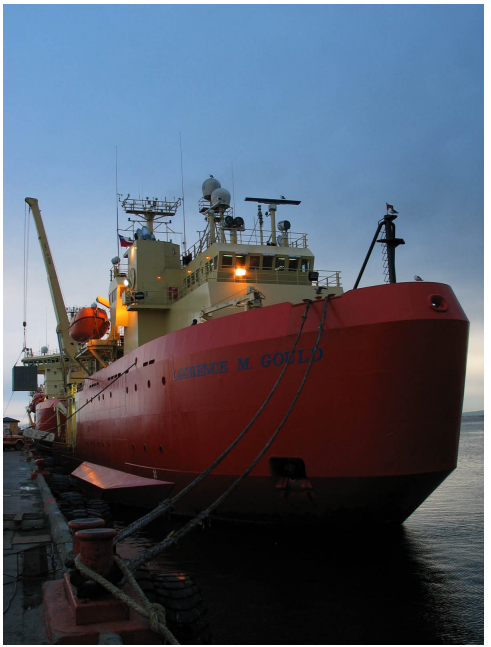
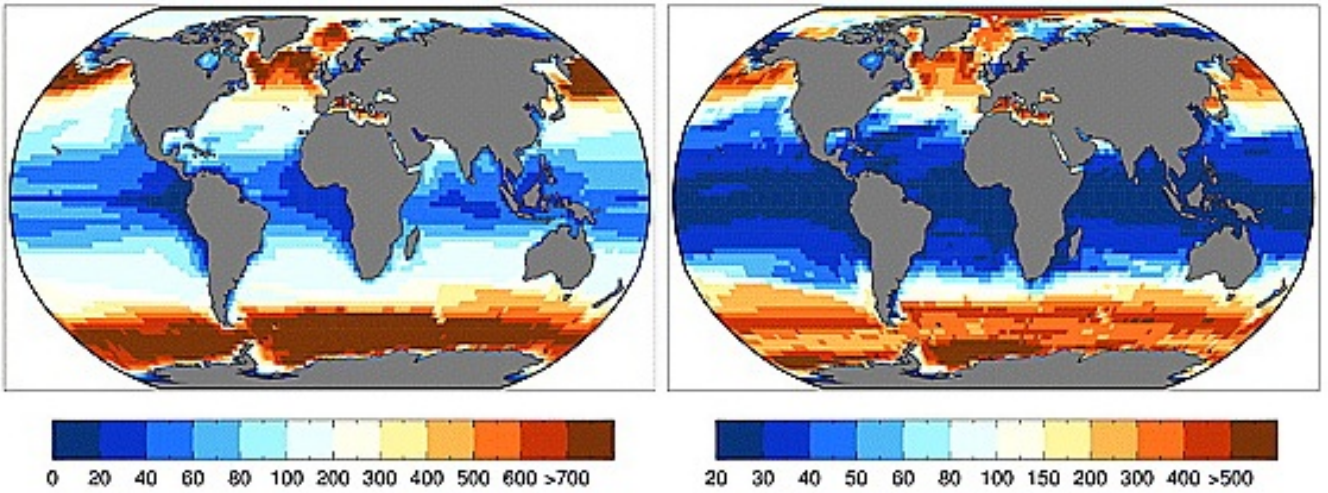


Photo: http://www.sethwhite.org/lm gould.htm

Motivation: Why look at the mixed layer?

- Ensemble of 19 IPCC AR4 models
- Compare deep winter mixed-layer depth (MLD) for 1950-1999

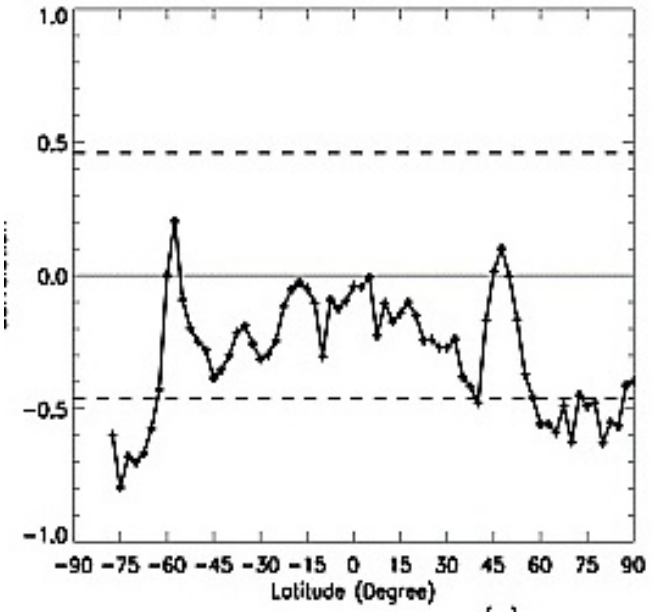


Ensemble mean MLD

Standard deviation of MLD

Boé et al., GRL, 2009

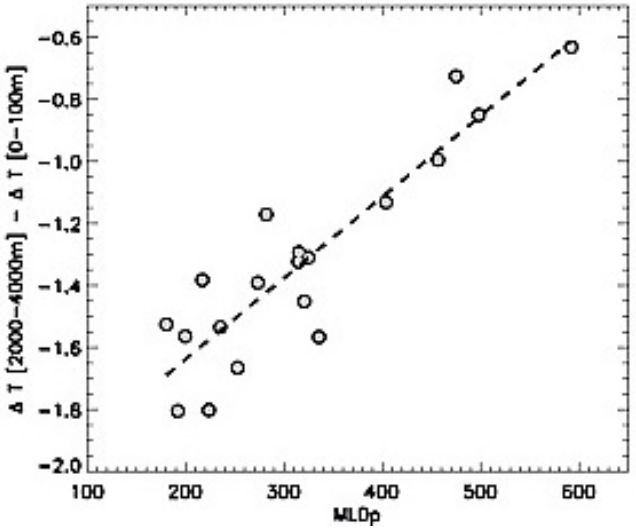
Model mixed-layer impact on future climate



- Compare global surface temperature rise from 2070-2099 versus 1950-1999.
- At high latitudes, deep mixed layers correlate with low anthropogenic warming.

Boé et al., GRL, 2009

Deep mixed layers mean warmer deep ocean



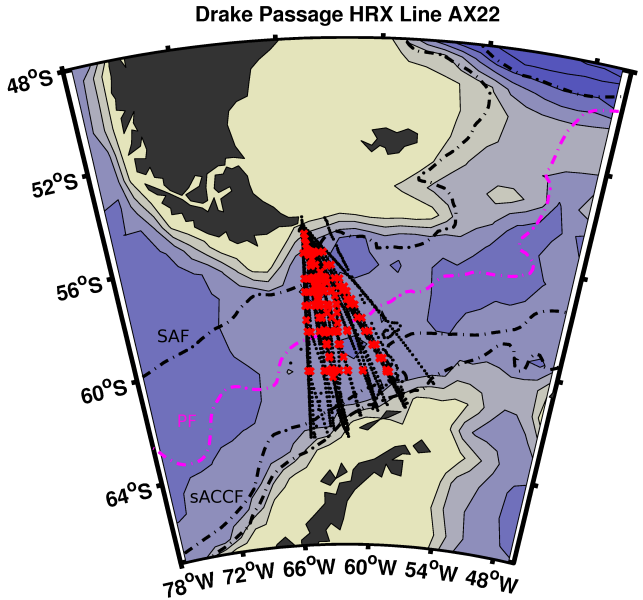
Boé et al., GRL, 2009

- Temperature difference of deep ocean (2000-4000 m) versus top 100 m.
- Less difference when mixed layer deeper.
- Bottom line: Climate projections will ultimately depend on getting the mixed layer right.

Observations from the L. M. Gould

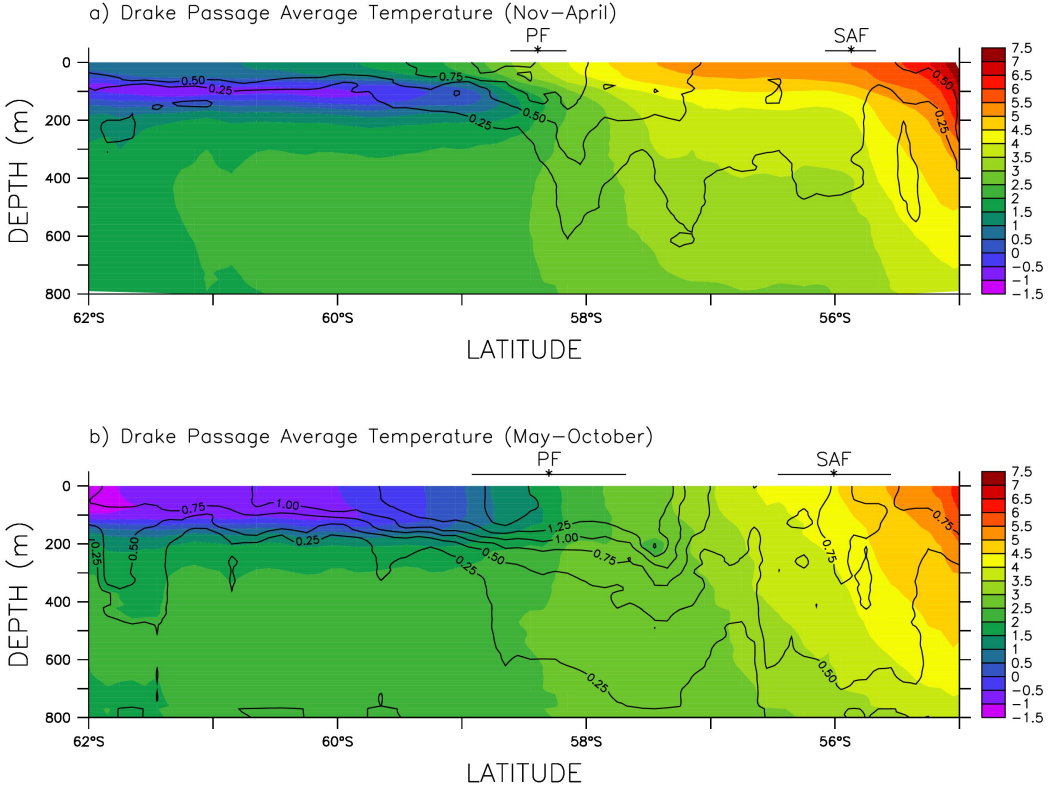
- L. M. Gould crosses Drake Passage about 20 times per year to resupply Palmer Station
- Since 1996: eXpendable BathyThermographs (XBTs) launched from stern of L. M. Gould
- Ship also collects upper ocean currents (ADCP), meteorological data (discussed by ChuanLi Jiang), and pCO_2

Drake Passage XBT Repeat Line



- High-resolution XBT lines 6-8 times per year.
- 92 XBT cruises (Sept 96-Oct 09) used for this study.
- 3 predominant crossings.

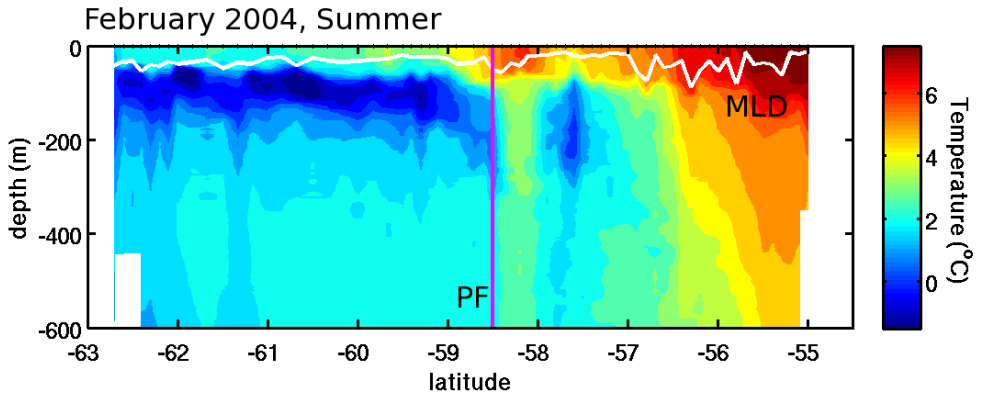
Seasonal mean sections from XBTs

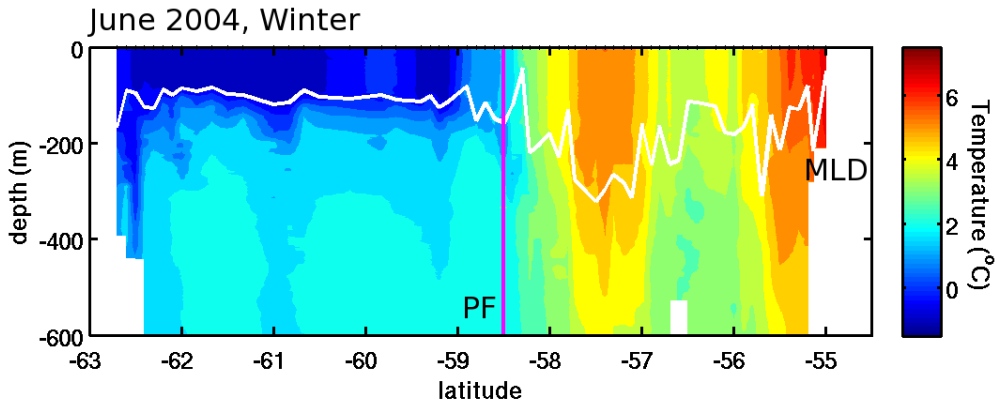


- Seasonal differences in upper ocean temperature
- Water mass properties change at Polar Front.

Graphic: Sprintall

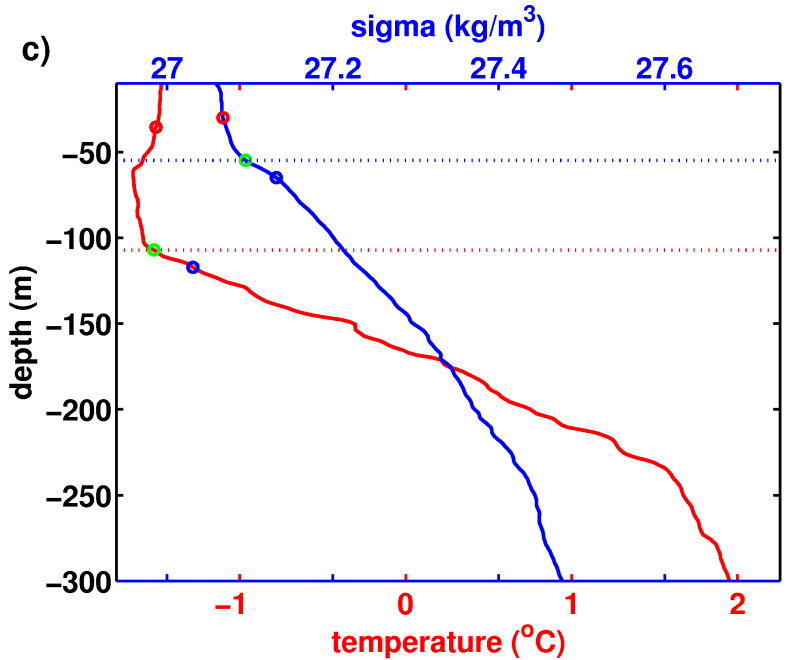
February and June, 2004





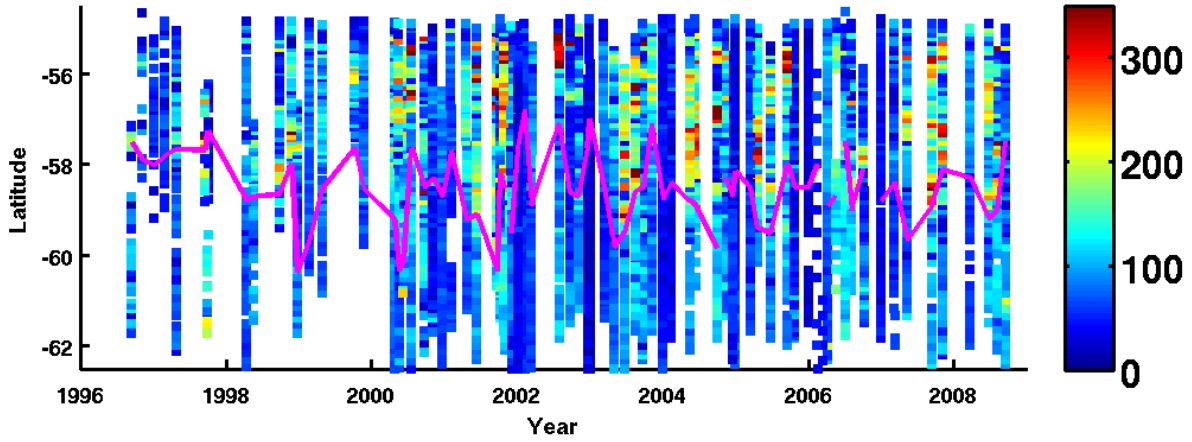
- Winter: warm-core eddies coincide with deep mixed layers.
- Summer: cold core eddy has shallow mixed layer.

Defining the mixed-layer



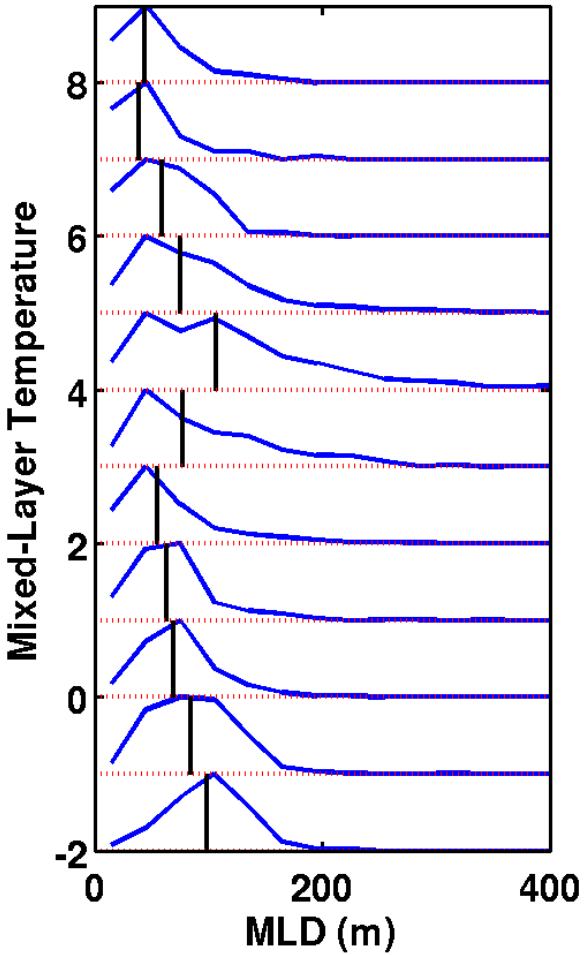
- MLD can be defined multiple ways: Inflection, gradient, threshold, using either temperature or density.
- In low-stratification water, MLD not always easy to define.

MLD in time and space



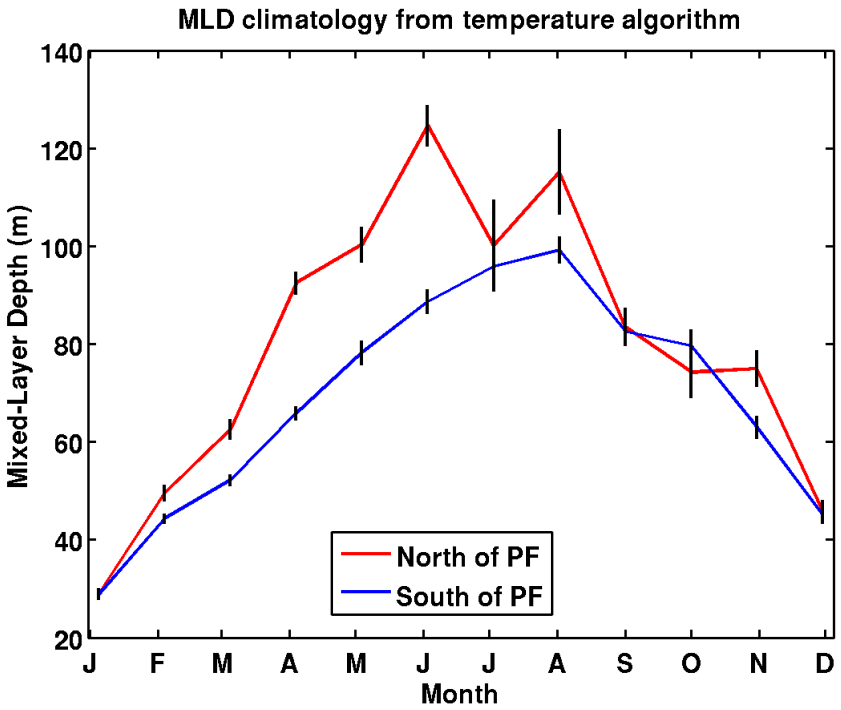
- Deep mixed layers just north of PF (purple line) when they occur.
- South of PF, mixed layer uniform in depth for any given cruise.

PDFs of the mixed-layer depth



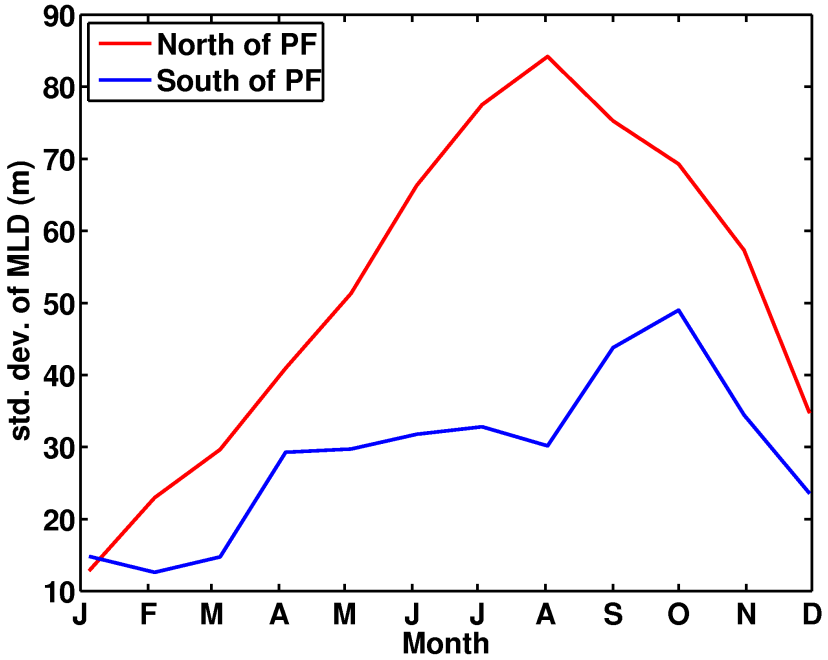
- Deep mixed layers occur in 3-6°C temperature band—north of the PF.

Seasonal cycle in mixed-layer depth



- Strong seasonal cycle in mixed-layer depth.
- MLD South of Polar Front is consistently shallower than north of Polar Front.

Variability larger north of Polar Front

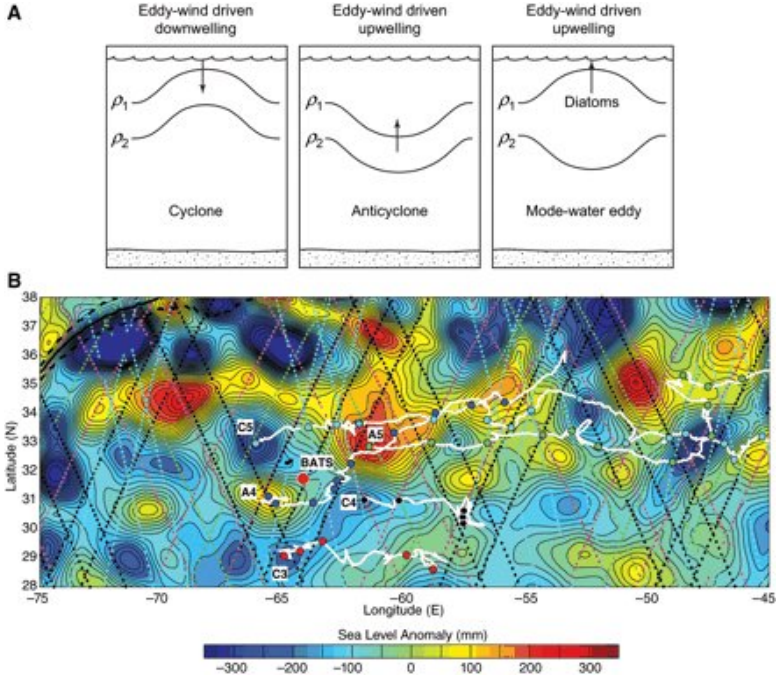


- Variability peaks in late winter, when mixed layer is deepest.
- Seasonal cycle in variability stronger north of Polar Front.

What mechanisms account for mixed-layer variability?

- Large-scale homogeneous seasonal cycle (e.g. south of Polar Front): controlled by large-scale heat fluxes and wind variability acting on water with uniform stratification.
- Eddy scale variations (e.g. north of Polar Front):
  - — Eddy preconditions stratification, so deep mixed layers form easily.
  - — Eddy SST influences local heat/momentum fluxes, altering typical mixed-layer.

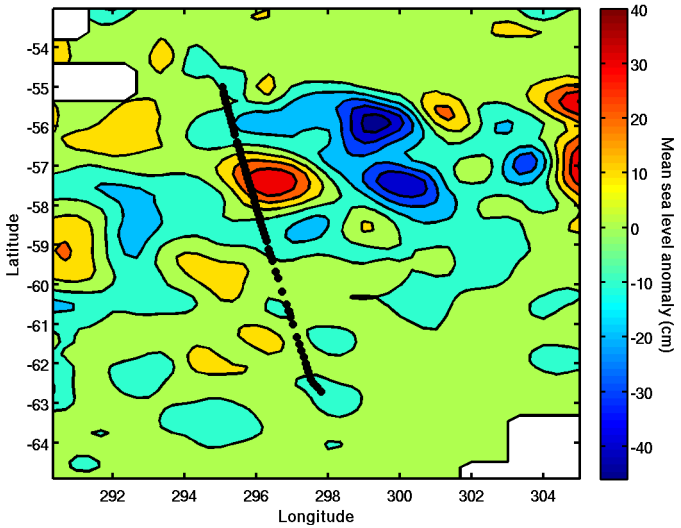
Example: Gulf Stream eddies, wind interactions, and upwelling



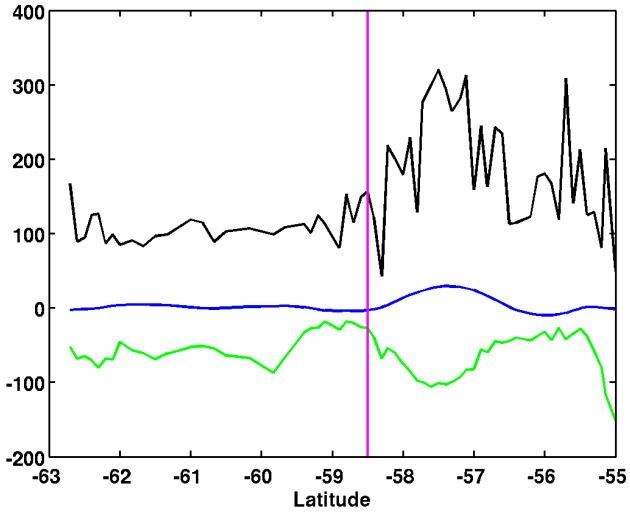
McGillicuddy et al, Science, 2007

- In mode water regions, both mode water eddies (anticyclones) and cyclones can have upwelling.
- Ocean response is different, possibly because local wind interacts with eddy surface velocities.
- Existence of varying eddy responses implies consistent patterns may not easily emerge in Drake Pasasge observations.....

Eddies and the mixed-layer: June 2004



- Altimetry indicates presence of an eddy along ship track.



MLD (m)
SSHA (cm)
Turbulent heat flux (W/m^2)

Summary

- Over 14 years of XBT/XCTD repeat lines show upper ocean variability in Drake Passage.
- Low stratification makes mixed layer an ill-defined concept.
- Mixed layers vary seasonally, with deep mixed layers in winter.
- Spatial variability is greatest north of Polar Front and regions of deep mixed layers have spatial scales consistent with eddy length-scales.
- Work in progress suggests that deep mixed layers within eddies linked to heat fluxes.