Eddy Heat Fluxes across the Antarctic Circumpolar Current in Northern Drake Passage

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Overview
For ocean mesoscale eddy heat fluxes, the dynamically important component is the divergent field, because it modifies its environment, whereas the non-divergent component just recirculates. Helmholtz showed that vector fields are uniquely separable into non-divergent and divergent parts. Divergent eddy heat fluxes are driven by nearly depth-independent geostrophic eddy currents that can cross the temperature front. Observed 4-yr mean divergent eddy heat fluxes (DEHF) in the Drake Passage are stable estimates. The strongest DEHFs occur immediately downstream of Shackleton Fracture Zone (SFZ, topographic ridge) between the Subantarctic Front (SAF) and Polar Front (PF), where meanders and deep eddies jointly develop rapidly via baroclinic instability, and rings pinch off, and SSH variability is highest.

1. Local dynamics array

* mesoscale-resolution 24 current and pressure recording inverted echo sounders (CPIES)
* 3-D maps of temperature and geostrophic current vector, \( \mathbf{U} \)
* 4-years, 11/07-11/11
* In maximum SSH variance region between SAF and PF.

2. Method to identify divergent eddy heat fluxes

\[ \mathbf{U} = \mathbf{U}_d + \mathbf{U}_n \]

Absolute geostrophic currents \( \mathbf{U} \) are the vector sum of a vertically-aligned baroclinic current, \( \mathbf{U}_d \), and a nearly depth-independent reference current that barotropic current, \( \mathbf{U}_n \) measured at 4000m depth.

3. Four-year mapped DEHF/EFH fields

All five panels: 4-yr mean eddy heat flux fields at 400m; DEHF vectors enlarged (bottom right). (All four 1-yr mean fields are remarkably similar.)

Top: \( \mathbf{u}'T' \) tends to be high where EKE is high; sum of ‘bc’ and ‘bc’ parts, shown in next row.

Bottom left: \( \mathbf{u}'T' \) is the larger component roughly parallel to \( T' > 0 \); also resembles mean 4000 m flow (not shown).

4. Vertical structure

DEHFs at six sites chosen to represent strong and weak down- and up-gradient fluxes.

* strongest sites have same sign top-to-bottom
* peaked in 200-400m at \( 4 \times 10^{-3} \text{C/m/s} \) (15KW/m²)
* 50% of flux below 700m
* contrast total EFH at 400m is \( \sim 750 \text{KW/m²} \)
* 5x larger

5. Time series & case study

Meridional DEHF time series at site 2 typifies all six sites. The mean accumulates from many episodic short-lived events. The short integral time scale ~4 days accounts for why 1-yr means are similar.

Poleward DEHFs arise from ~8 southward crests of the warmer SAF steepening jointly with a deep anticyclone, as illustrated in the case-study map sequence. Additional ~3 poleward peaks arise when northward troughs of the colder PF develop.

Case-study daily snapshots at 6-7 interval in December 2007, during poleward peak DEHF. Geopotential \( \phi = \text{const.} \) (solid contours; proxy SSH for SAF and PF (gray contours)); deep reference current (gray vectors) and \( R_{4000} \) (colorbar). Green arrows: DEHF at same six sites.

This case exemplifies rapid growth of a SAF meander crest (A) that jointly steepens with deep anticyclone. (B) is a canonical example of BC instability with upper crest and trough led \( \sim (T') \) by high deep and low pressure centers; note strong poleward DEHFs. (C) intensifies further, becoming more vertically aligned. (D) shows a separated ring, characterized by mature vertically-aligned current structure and thereafter little heat flux.

6. Context / Summary

The mean poleward DEHF peaks are associated with several events per year of strong meander growth; the strongest events result in ring formation. The growth is generated by joint interaction with deep eddies, with phase-offset such that their currents cross the baroclinic front and release APE consistent with BC instability. This process drives the eddy variability and drives the poleward DEHF.

Peak mean downgradient DEHF at 400m is \( (3.6 \pm 1.2) \times 10^{-3} \text{C/m/s} \) \( \approx 15 \text{KW/m²} \)

-contrast \( \mathbf{u}'T' \) at 400m are ~5 times larger, poleward but mainly non-divergent

-contrast \( \mathbf{u}'T' \) have similarly large magnitude, but in recirculating directions

Vertically integrated poleward DEHF is \( 6-19 \text{MW/m across the front (sites 1, 2).} \)

Compare Phillips & Rintoul (2000) south of Australia vertical average EFH in shear coordinates 11.3Kw/m/m. (vertical integral) \( \sim 40 \text{MW/m} \).

Compare Bryden (1979) Drake P average EFH \( \sim 0.16 \text{Kw/m²} \) at 2700m.

Compare Lenn, et al. (2011) Drake P XBT +SADCP transects, poleward EFHs in top 300m up to \( 290 \pm 80 \text{KW/m²} \) (incl Ekman) calculated relative mean stream coordinates. None separate DEHFs from EFHs.

References and Acknowledgments

See also Bishop, S.P. AGU Fall Meeting Session OS21A, poster #1657.


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