Divergent Eddy Heat Fluxes in the Kuroshio Extension at 143°-149°E

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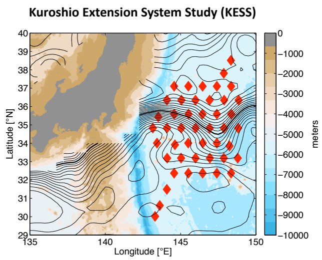
Overview

The Kuroshio Extension differs from the Gulf Stream in that it has a shallower thermocline and it flows over a much deeper subthermocline layer. As a result, meander growth through self development that has been observed in the Gulf Stream is not as effective in the Kuroshio extension. Instead, meander growth and decay processes are driven by external mesoscale perturbations. The largest down- and up-gradient eddy heat fluxes are driven by remotely-generated deep eddies and ring interactions with the Kuroshio Extension.

I. Introduction

Kuroshio Extension System Study (KESS)



Current and Pressure Equipped Inverted Echo Sounders (CPIES)

KESS

- Mesoscale-resolving array of 46 current and pressure equipped inverted echo sounders (CPIES).
- Located east of Japan in region of highest EKE.
- Provides 3-D maps of geostrophic velocity and temperature for 16 months (Donohue et al. 2010)[1].
- This poster presents eddy heat flux estimates from the KESS observations.

Motivation

- Eddy-mean flow interactions:

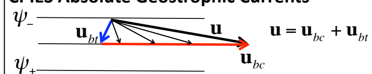
1. Eddies release mean potential energy of baroclinic jet.
2. Eddies act as an eddy force on the mean flow.

II. Eddy Heat Flux

- The eddy heat flux is the depth-averaged density, ρ_0, times the specific heat at constant pressure, C_p, times the temporal correlation between the geostrophic currents, **u**, and the temperature field, T:

$$\rho_0 C_p \overline{\mathbf{u}'T'}$$

CPIES Absolute Geostrophic Currents



- Absolute geostrophic currents are the vector sum between a vertically aligned current in thermal-wind balance called the baroclinic current, $\mathbf{u}_{bc}$, and a weakly depth-dependent reference current called the barotropic current, $\mathbf{u}_{bt}$, measured at 5300 m.

CPIES Mapped Eddy Heat Flux

$$\rho_0 C_p \overline{\mathbf{u}'T'} = \rho_0 C_p \overline{\mathbf{u}'_{bc}T'} + \rho_0 C_p \overline{\mathbf{u}'_{bt}T'}$$

III. Eddy Heat Fluxes: Rotational vs. Divergent

Rotational Fluxes

- The baroclinic component is completely rotational (nondivergent) (Marshall and Shutts 1981)[2]:

$$\overline{\mathbf{u}'_{bc}T'} \propto \hat{\mathbf{k}} \times \nabla \overline{T'^2}$$

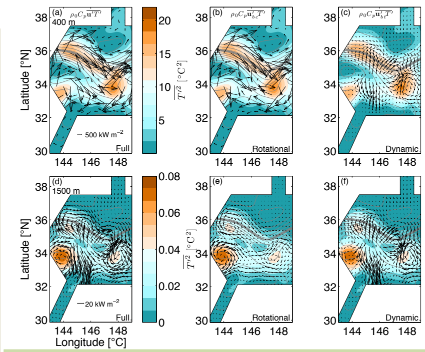
- **Divergent fluxes** are driven by the weakly depth-dependent reference currents.

Upper Ocean at 400 m (a-c)

- Total fluxes (a) are ~2000 kW m^{-2} and comparable to the Gulf Stream (Cronin and Watts 1996)[3].
- Rotational fluxes (b) dominate the total fluxes (a), follow temperature variance contours, and mask the divergent fluxes (c) which are < 25% as large.
- The divergent component (c) crosses the front.

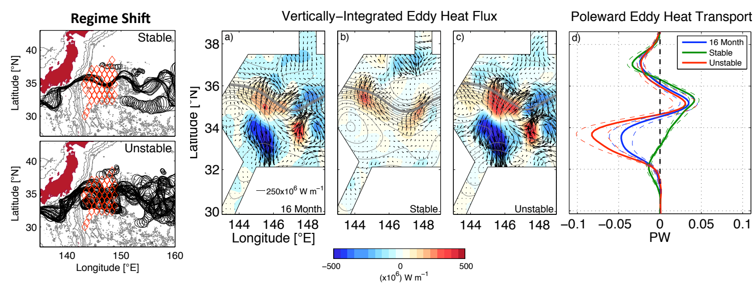
Subthermocline Ocean at 1500 m (d-f)

- Total fluxes (d) have equal contribution from rotational (e) and divergent (f) fluxes.
- Rotational fluxes (e) diminish with depth.



Weakly depth-dependent reference currents drive divergent fluxes

IV. Spatial Structure of Divergent Eddy Heat Fluxes



The Kuroshio Extension exhibits decadal variability within 1000 km of Japan coast (Qiu and Chen 2005)[4].

Vertically-Integrated Eddy Heat Flux

$$\mathbf{Q}_{dyn} = \rho_0 C_p \int \overline{\mathbf{u}'_{bt}T'}dz$$

a) 16 month: asymmetry along mean path
- Down-gradient upstream of trough
- Up-gradient downstream of trough

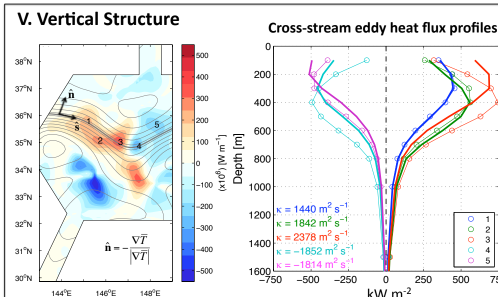
b) "Stable" regime: 1st 6 months – mostly down-gradient.

c) "Unstable" regime: 10 months – similar to 16 month mean with asymmetry along mean path.

Poleward Eddy Heat Transport

d) Peaks near 35°N at ~0.04 PW

V. Vertical Structure



○ Observations
— Parameterization

Vertical Structure

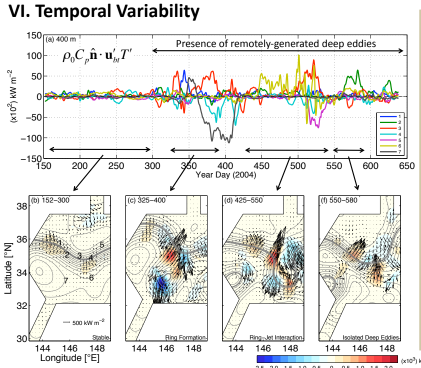
- Vertically-coherent cross-stream fluxes peak 200-500 m, mid-thermocline.
- Peak fluxes are in excess of ±500 kW m^{-2}.

Parameterization

$$\hat{\mathbf{n}} \cdot \overline{\mathbf{u}'_{bt}T'} = -\kappa \frac{\partial \overline{T}}{\partial n}$$

- Down-gradient parameterization good upstream of trough.
- κ ranges 1000-3000 m^2 s^{-1}
- Parameterization doesn't account for up-gradient fluxes downstream of trough.

VI. Temporal Variability



Time Series at 400 m

a) Episodic time series

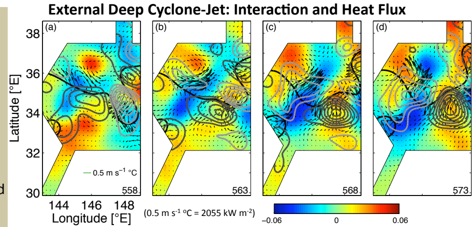
b) Days 152-300 – 1st 6 months "Stable" regime:
- Dominated by 10-15 day low-amplitude eastward propagating baroclinic waves.
- Heat fluxes are weak and down-gradient.

c) Days 325-400 – Cold-Core Ring Formation:
- Strong down-gradient fluxes directly upstream of where the ring formed.
- Up-gradient fluxes within where the ring formed and downstream.

d) Days 425-550 – Cold-Core Ring/Jet Interaction:
- Similar spatial structure to cold-core ring formation

e) Days 550-580 – Remotely-generated abyssal eddy/jet interaction in absence of rings:
- Strong down-gradient fluxes 35°N 145°E.
- Weak up-gradient fluxes downstream.

External Deep Cyclone-Jet: Interaction and Heat Flux



a) Deep cyclone begins crossing jet.

b) Poleward heat flux associated with joint-development between deep cyclone and upper geopotential height anomaly.

c) Strong poleward heat flux.
- Joint development between upper and deep continues.
- Axis of jet steepens into a trough.

d) Joint development reaches a maximum as deep cyclone passes almost completely south of jet.

Figure Legend

- **Jet axis:** Thick black contour
- 30-60 day band-pass filtered upper geopotential height anomaly (CI = 1 cm):
- Dark gray: positive
- Light gray: negative
- 30-60 day band-pass filtered bottom pressure anomaly: color contour.
- Eddy heat flux vectors at 400 m.

VII. Summary

1) Divergent eddy heat fluxes in the Kuroshio Extension are driven by weakly depth-dependent currents.
2) 16 month mean divergent fluxes change alongstream from down-gradient to up-gradient at the mean trough.
3) Fluxes are vertically coherent with extrema exceeding 500 kW m^{-2} between 200-500 m.
4) The mean spatial structure arose from episodic mesoscale phenomena: cold-core ring formation, ring-jet interaction, and remotely-generated deep eddy-jet interactions.

VIII. References and Acknowledgements

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4. Qiu, B., and S. Chen, 2005. Variability of the Kuroshio Extension jet, recirculation gyre and mesoscale eddies on decadal timescales. *J. Phys. Oceanogr.*, 35, 2090-2103.

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