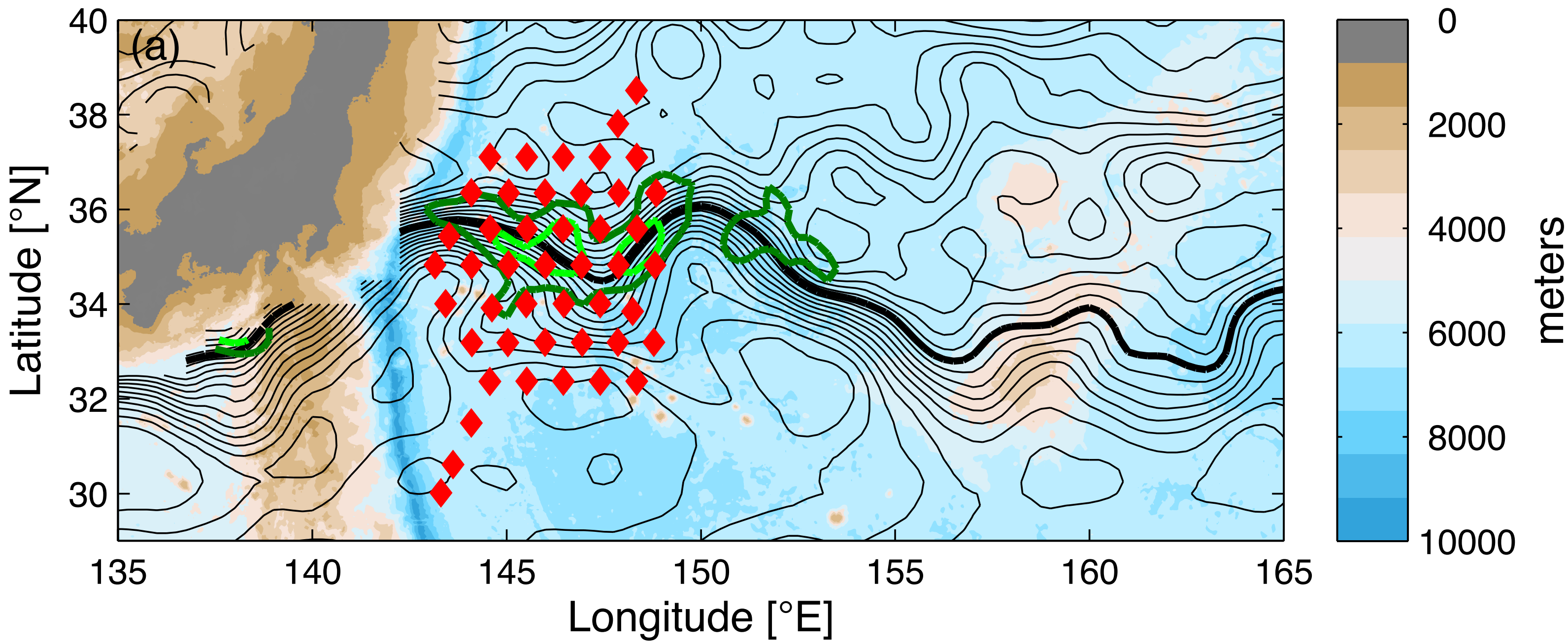
Oceanic Heat Transport By Eddies in the Kuroshio Current East of Japan



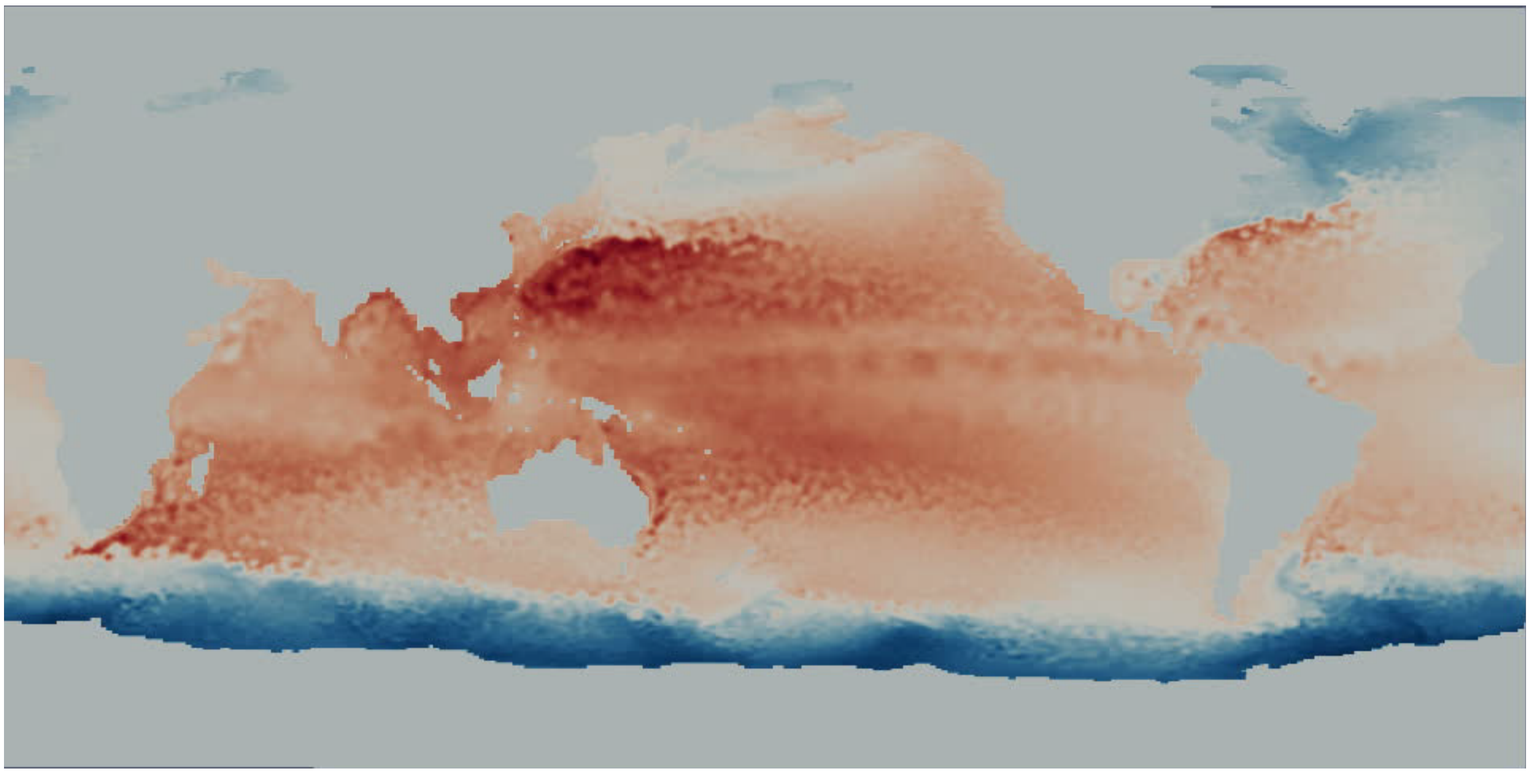
Stuart P. Bishop

Advanced Study Program (NCAR)

Boulder Fluids Seminar
University of Colorado Boulder
September 3, 2013

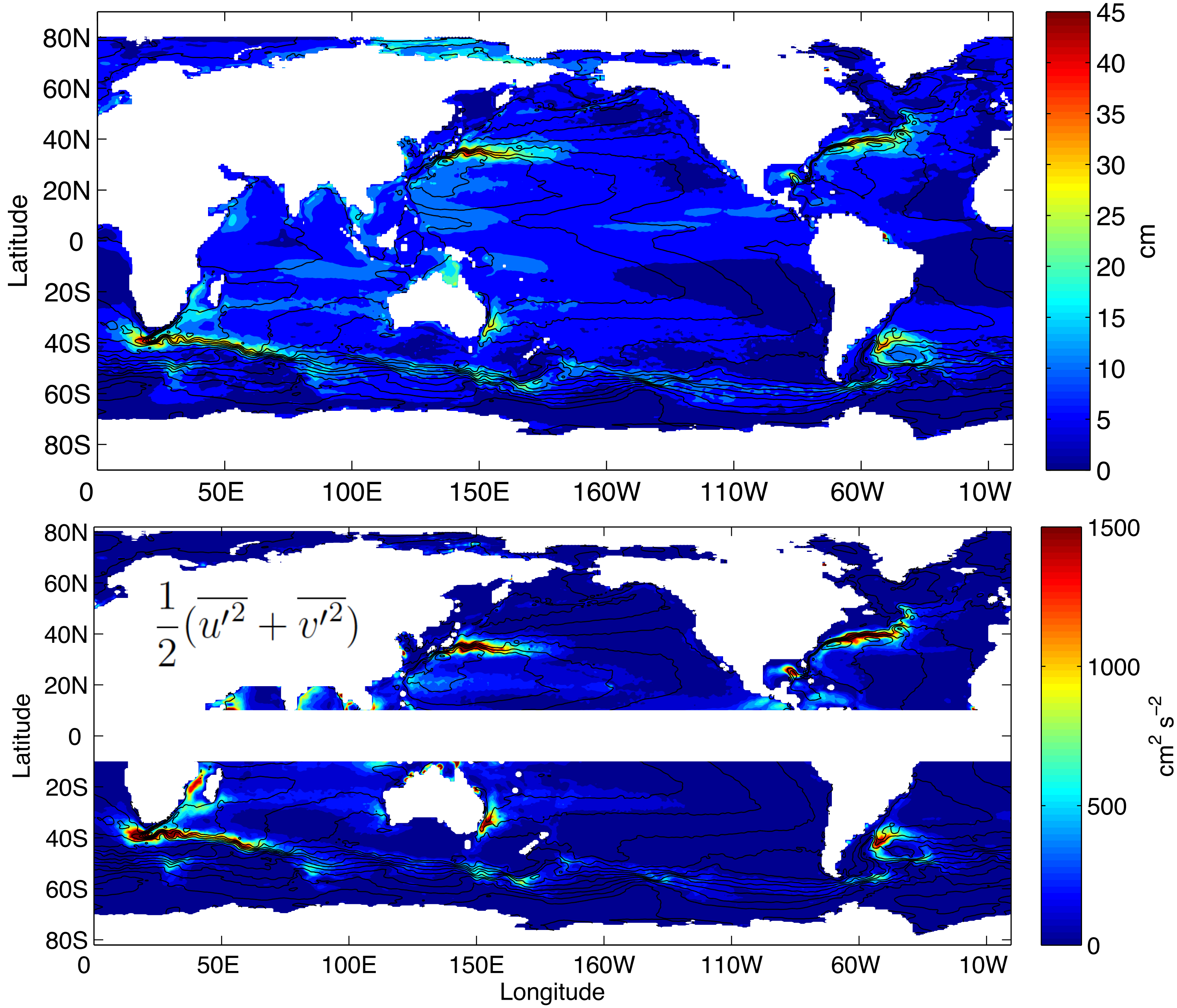
NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Sea Surface Height (SSH) From Satellite Altimetry



http://www.aviso.oceanobs.com/en/

SSH Variance and EKE

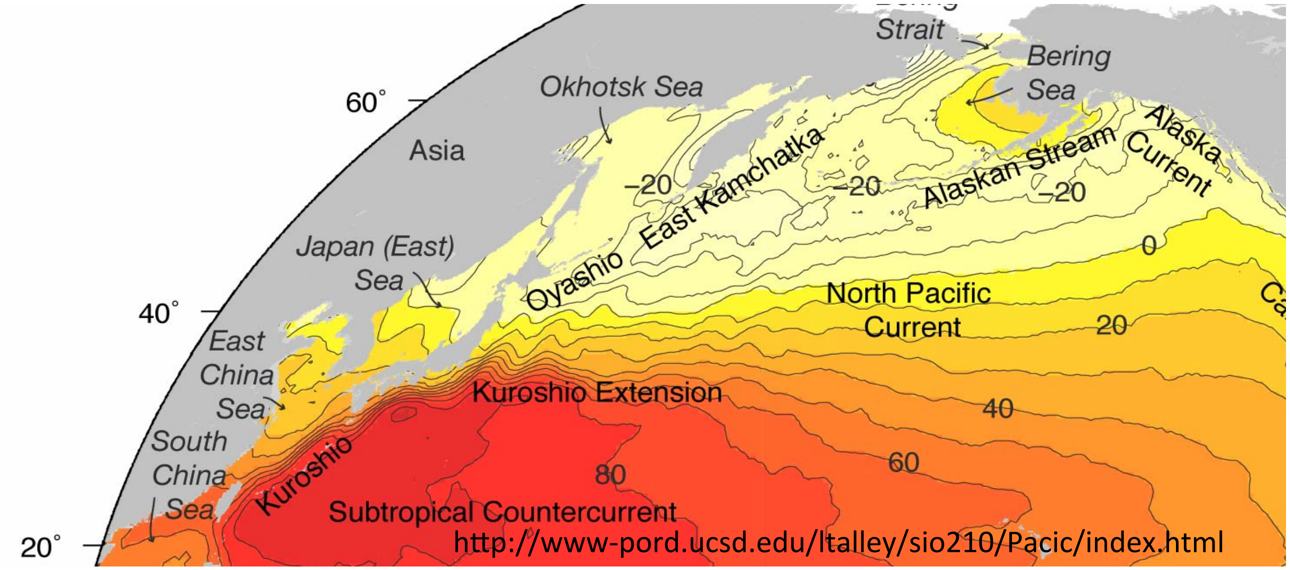


Geostrophy

$$u = -\frac{g'}{f}\frac{\partial \eta}{\partial y}$$

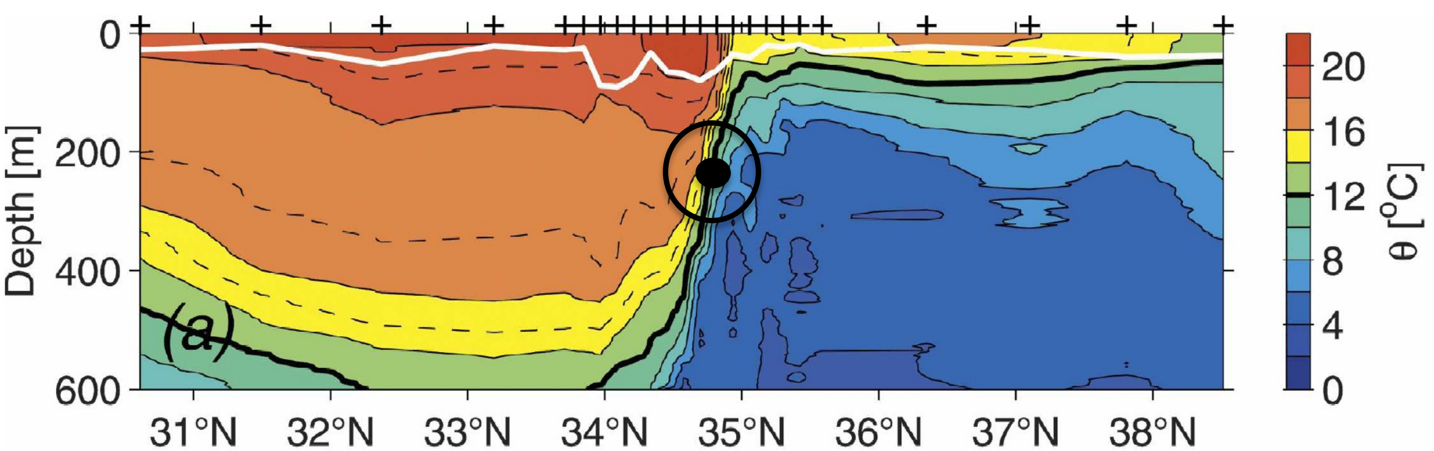
$$v = \frac{g'}{f}\frac{\partial \eta}{\partial x}$$

North Pacific Circulation

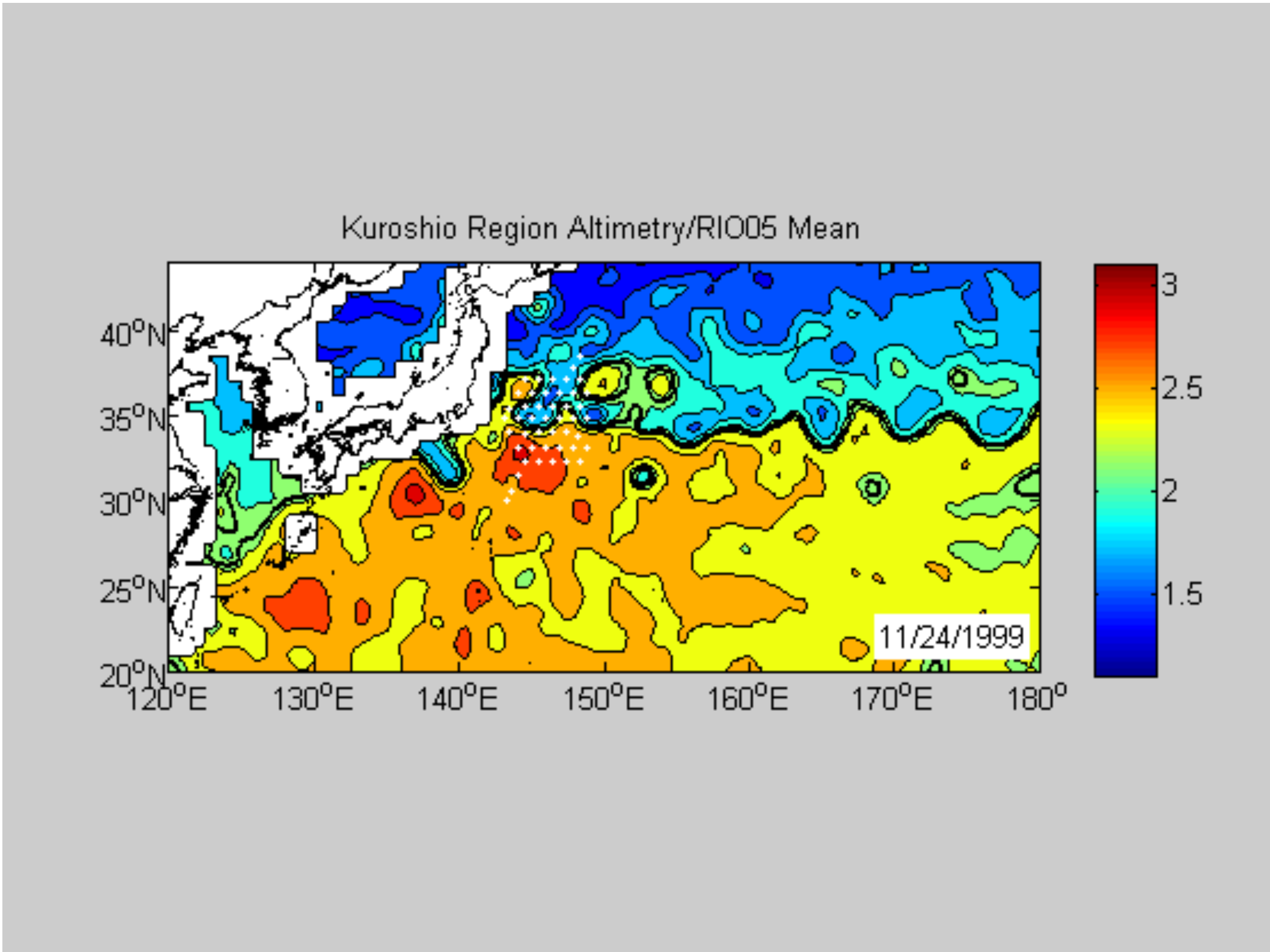


- Meandering jet
- Frontal boundary
- Available Potential Energy (APE)
- > 1 m s^{-1}
- Width ~100km
- High EKE

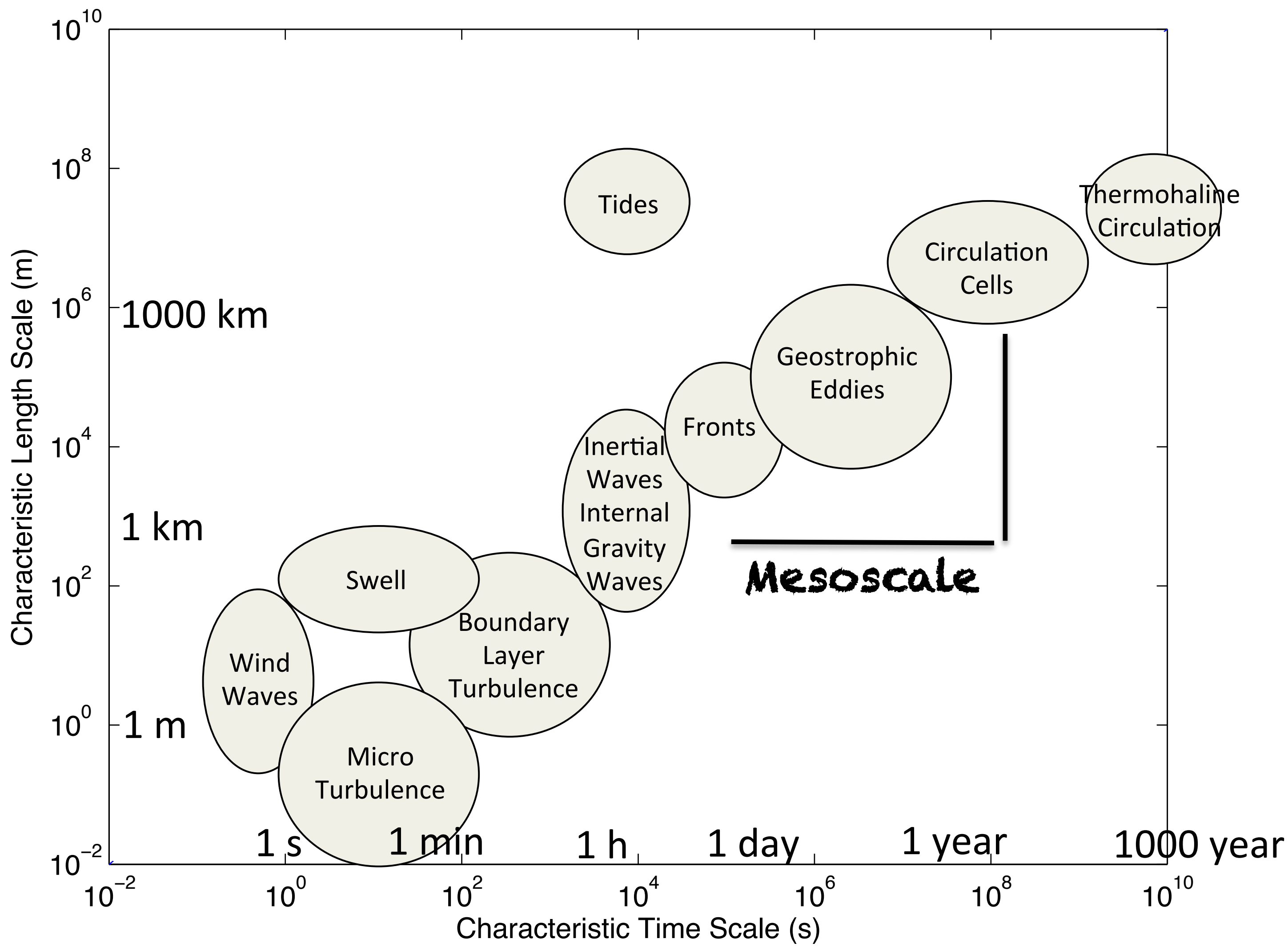
Temperature Cross-Section



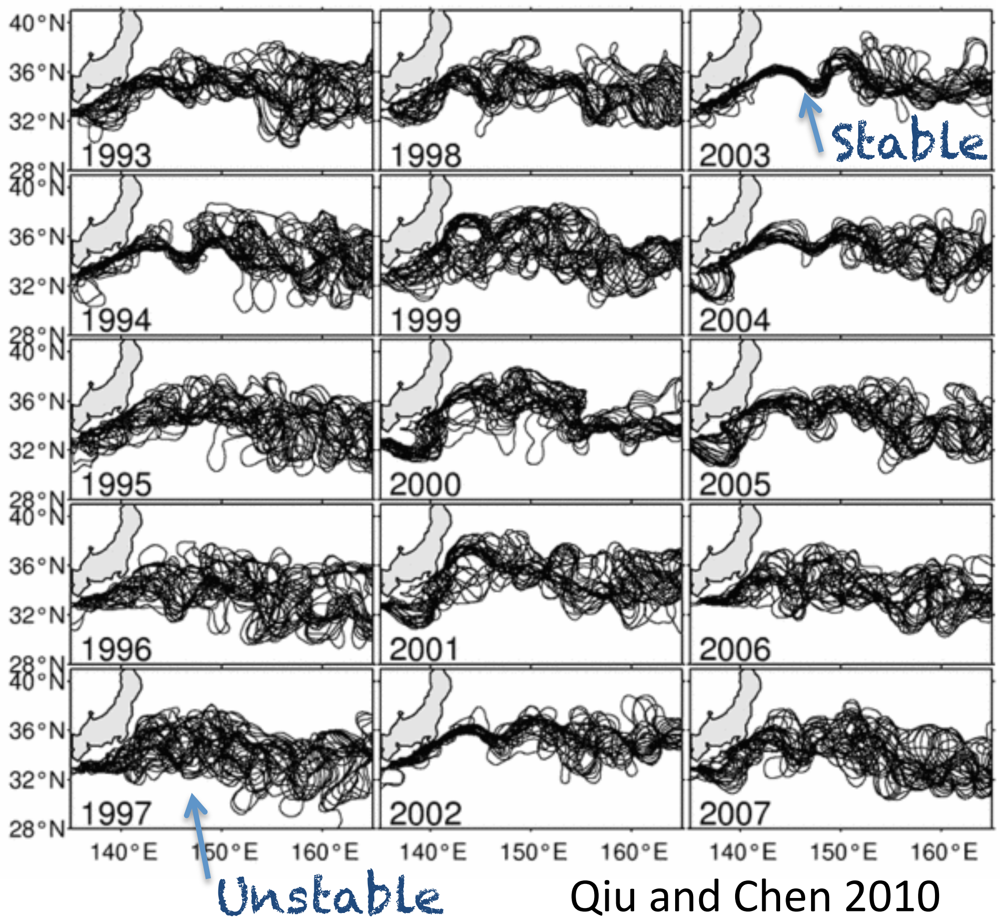
Kuroshio Extension SSH



Ocean Spectrum



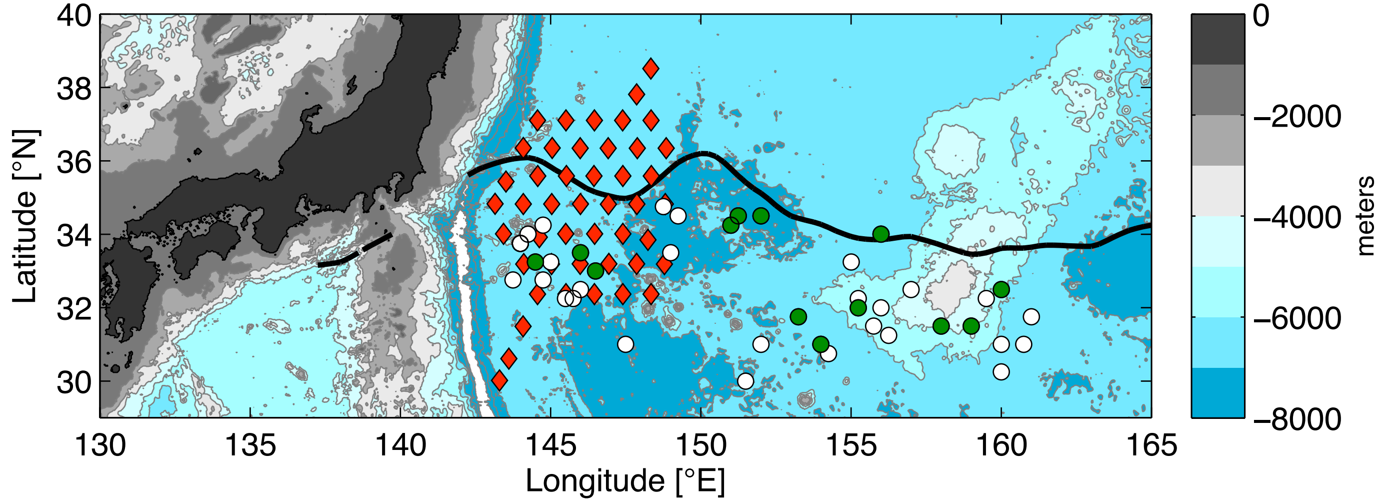
Decadal Varability

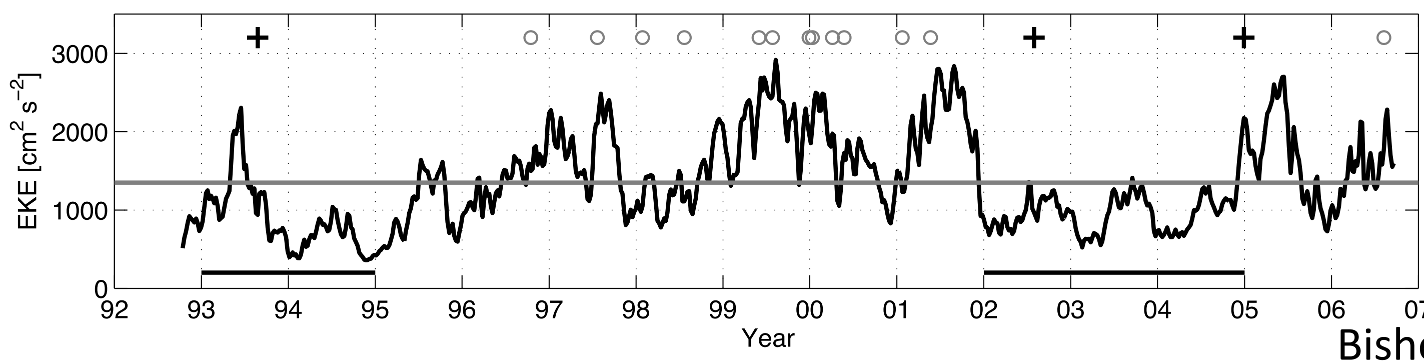


Qiu and Chen 2010

- Path variability from satellite altimetry (bi-weekly)
- Vascillation: stable (unstable)
  - Stronger (weaker)
    - Transport
    - STMW formation
- Mechanism: Tied to PDO Qiu and Chen 2005

Suppression of CCRs During Stable Regimes





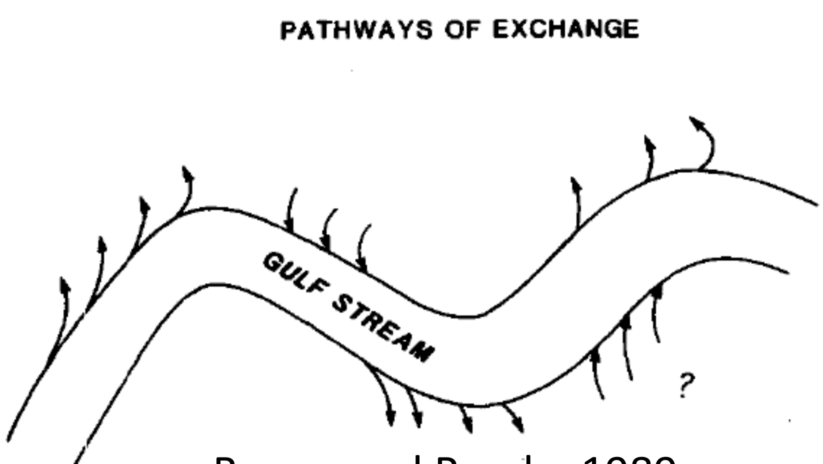
Bishop 2013, JPO

- 16 CCRs formed within KESS region from late 1993-2007
- 3 formed during stable Regimes
  - 2 formed during elevated levels of EKE at transition
  - 1 formed mid 2002
  - No CCRs formed from mid 2002-December 2004

Importance of Mesoscale Eddies

Cross-Frontal Exchange

- Eddy fluxes:
  - Heat
  - Momentum
  - PV
- Nutrient exchange
- Water mass exchange



Bower and Rossby 1989

Eddy-Mean Flow Interactions

- Two-way energy conversion between eddies and mean flow
- Vary the stability properties of the jet
- Force the mean flow:
  - Slow down
  - Turn – add curvature
  - Diffluence/confluence

Mesoscale Dynamics

QG dynamics $R_0 = \frac{U}{fL}$ << 1 $\qquad \frac{\text{Advection}}{\text{Coriolis}}$

Equations of Motion O(R₀)

1) $$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} + \beta y \mathbf{k} \times \mathbf{u} + f_0 \mathbf{k} \times \mathbf{u}_a = 0$$ Momentum

2) $$\frac{\partial b}{\partial t} + \mathbf{u} \cdot \nabla b + w N^2 = 0 \qquad b = \alpha g T$$ Buoyancy

3) $$\nabla \cdot \mathbf{u}_a = -\frac{\partial w}{\partial z}$$ Continuity

Time Mean Equations

Equations of Motion $O(R_o)$

1) $\overline{\mathbf{u}} \cdot \nabla \overline{\mathbf{u}} + \beta y \mathbf{k} \times \overline{\mathbf{u}} + f_0 \mathbf{k} \times \overline{\mathbf{u}}_a = -\nabla \cdot \overline{\mathbf{u}'\mathbf{u}'}$ Momentum

2) $\overline{\mathbf{u}} \cdot \nabla \overline{b} + \overline{w} N^2 = -\nabla \cdot \overline{\mathbf{u}'b'}$ Buoyancy

3) $\nabla \cdot \overline{\mathbf{u}}_a = -\dfrac{\partial \overline{w}}{\partial z}$ Continuity

Eddy Fluxes

Eddy Buoyancy (Heat) Flux

$$\overline{\mathbf{u}'b'}^{div} = \alpha g \overline{\mathbf{u}'T'}^{div}$$

Importance of Mesoscale Eddy Heat Flux

1. Energy Conversion
2. Meridional Heat Transport

1. Energy Conversion

$$BC = -\overline{\mathbf{u}'b'}^{div} \cdot \nabla \left(\frac{\bar{b}}{N^2} \right)$$

- +ve APE → EPE Conversion
- -ve EPE → APE
- Baroclinic instability: conversion of APE to EPE

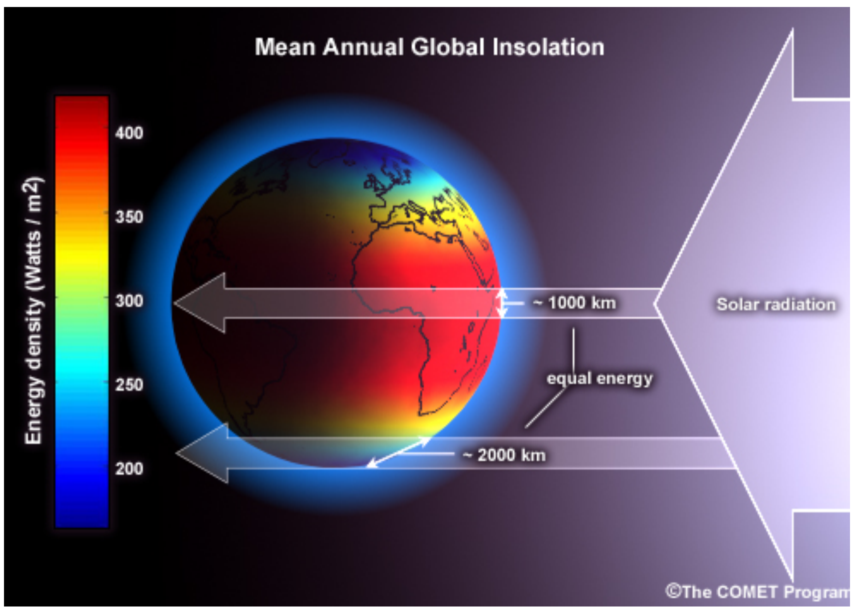
2. Meridional Eddy Heat Transport

$$Q = \rho_0 C_p \int_0^L \int_{-H}^0 \overline{v'T'}^{div} dz dx$$

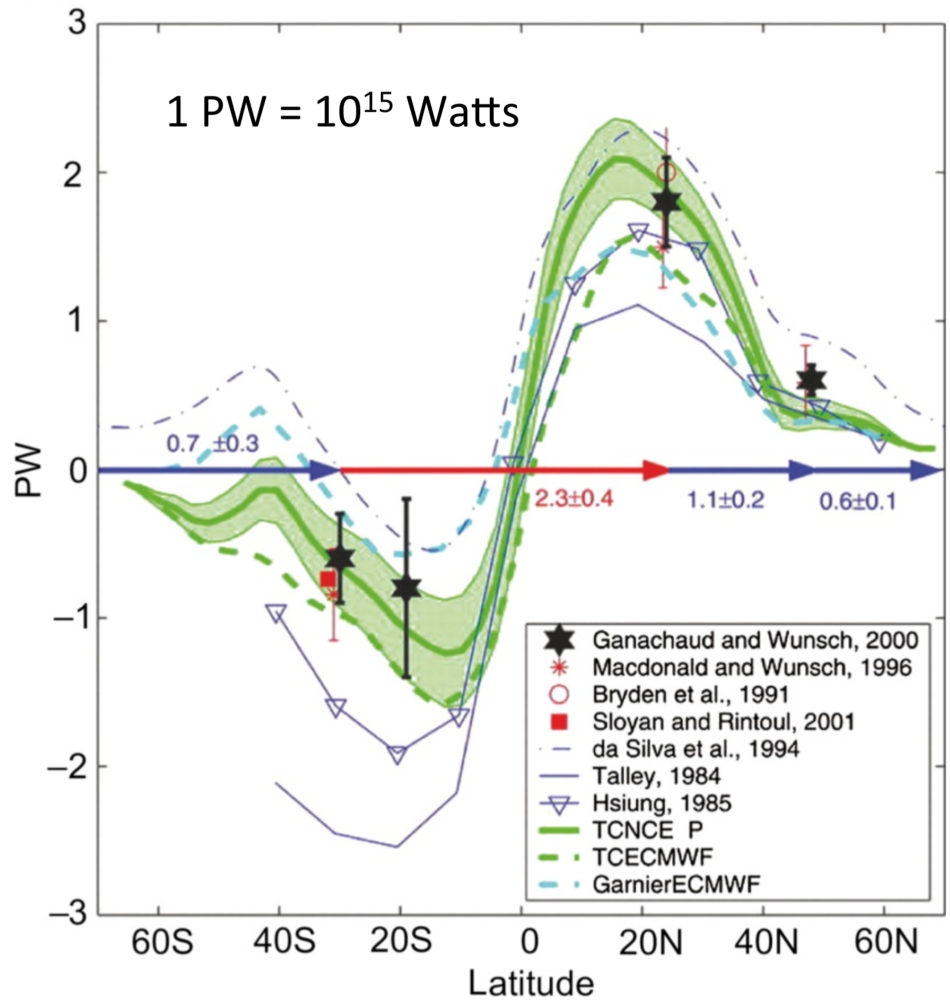
Meridional Heat Transport

2. Eddy Heat Transport

$$Q = \rho_0 C_p \int_0^L \int_{-H}^0 \overline{v'T'}^{div} dz dx$$



http://www.meted.ucar.edu



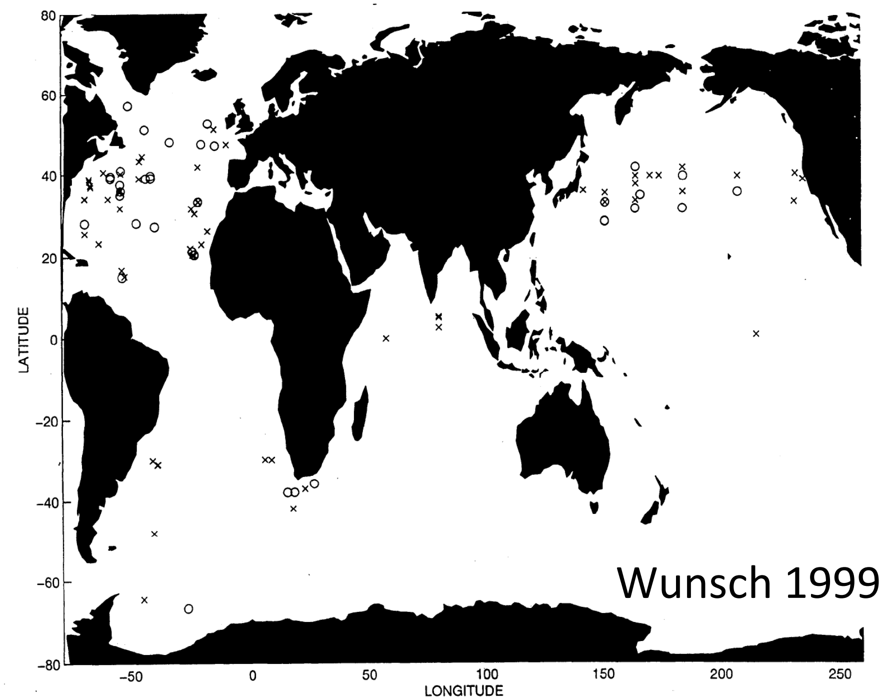
Validation of Parameterizations

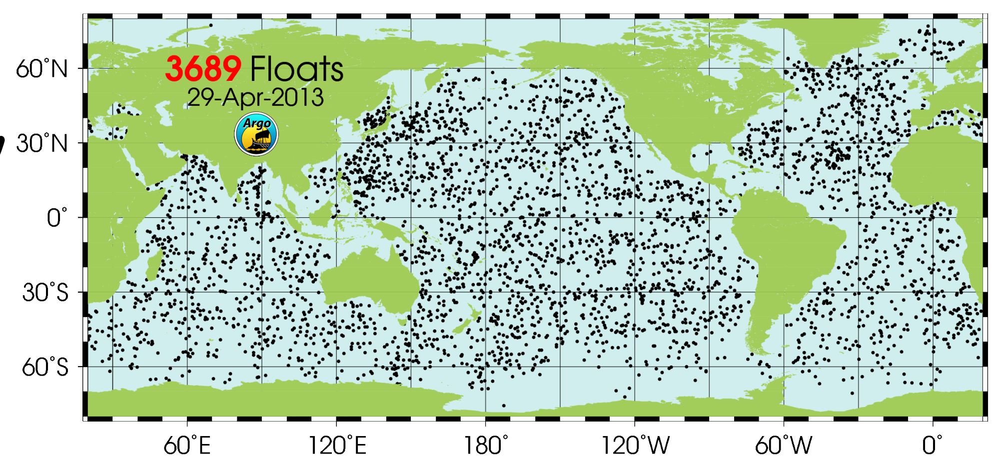
- General lack of ocean observations
- Need long time series for eddy statistics to converge

(Flierl and McWilliams, 1977)

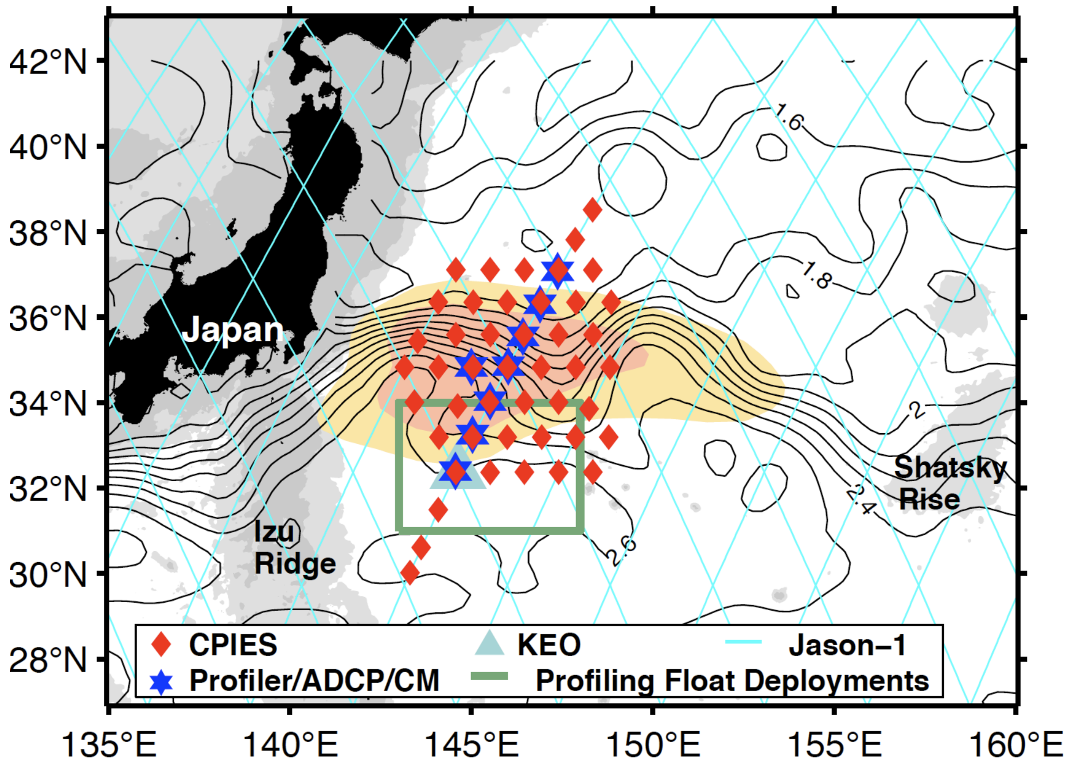
- Argo floats offer potential: tend to underestimate eddy statistics

(Chinn and Gille 2007)



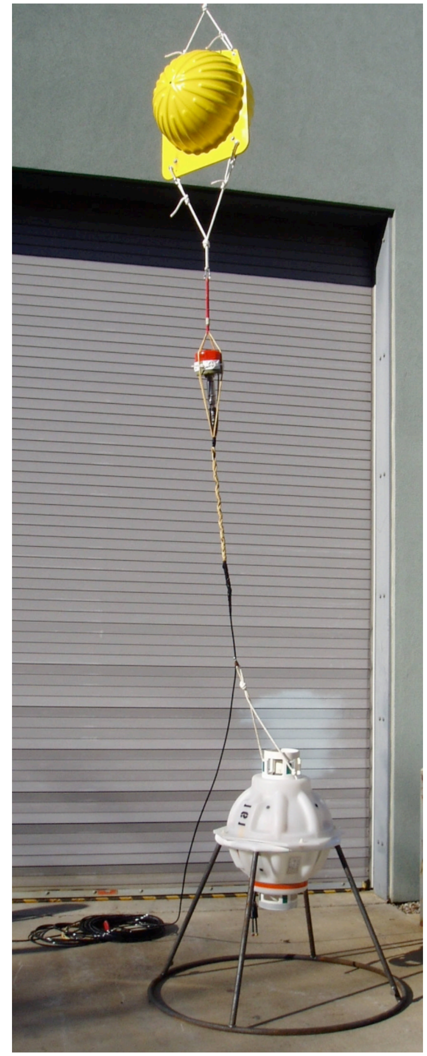


Kuroshio Extension System Study (KESS)

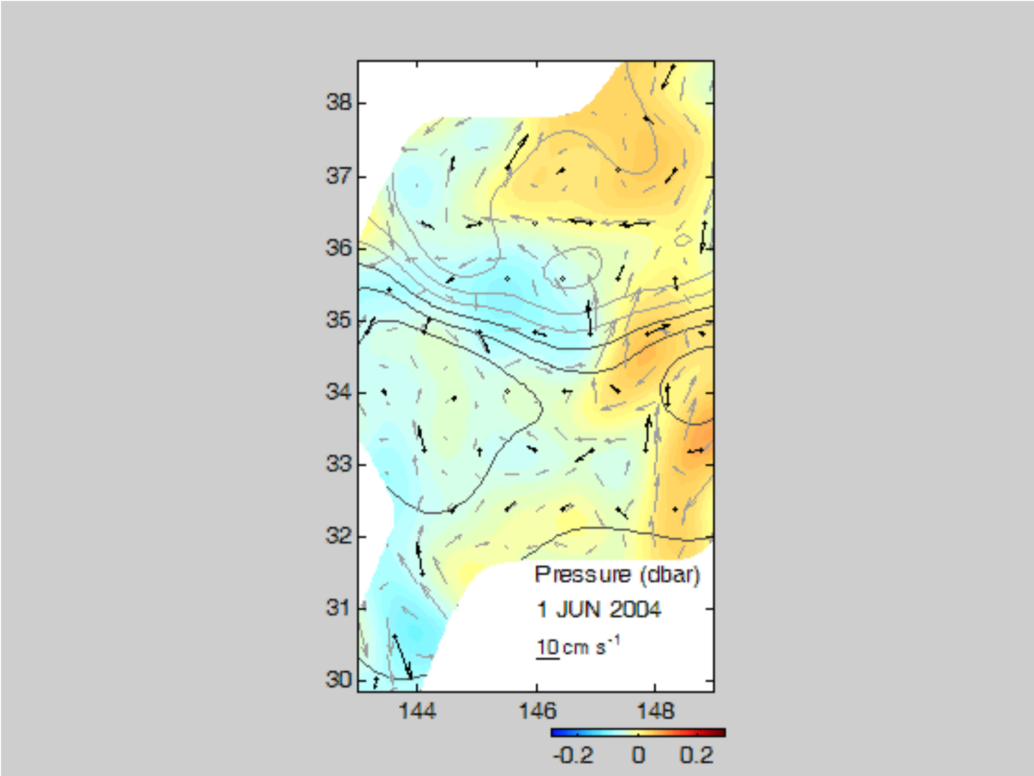


- 600 km x 600 km grid – 46 CPIES
- 2004-2006
- Mesoscale resolving
- Daily 3-D maps for 16 months:
  - Geostrophic currents
  - Temperature field

CPIES



KESS Movie



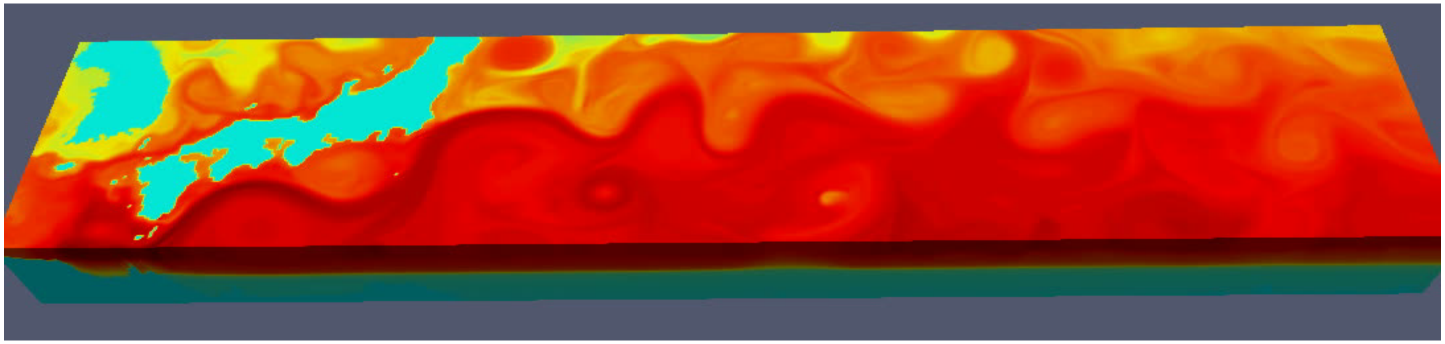
Video courtesy of Karen Tracey (URI)

0.1° POP Model

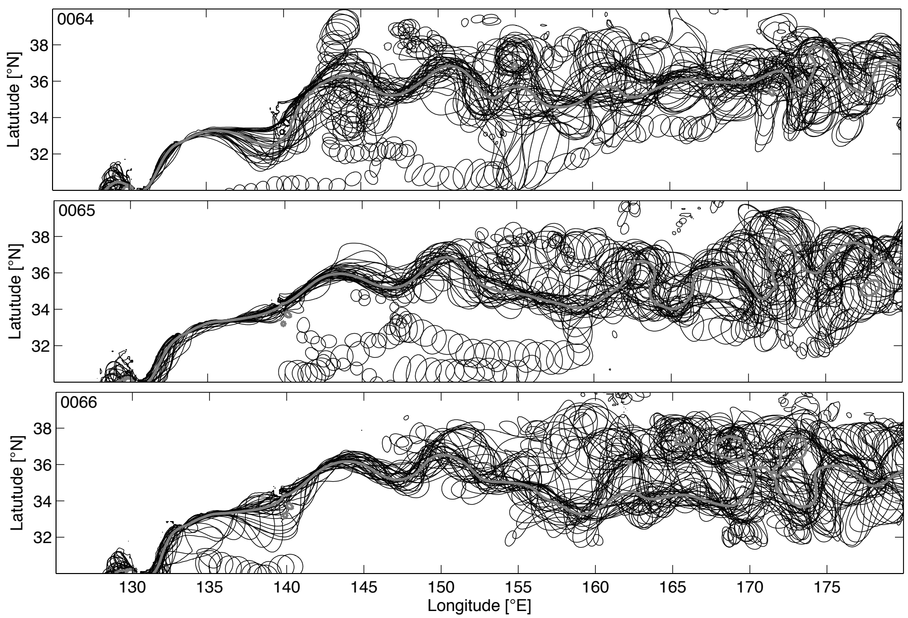
- Parallel Ocean Program (POP)
- Developed at Los Alamos National Lab
- 1/10° horizontal resolution
- 42 vertical levels
- Climatologically forced
- 120 years monthly-averaged U,V,T
- 3 Years (64-67) 5-day averaged U,V,T

Los Alamos
NATIONAL LABORATORY
EST. 1943

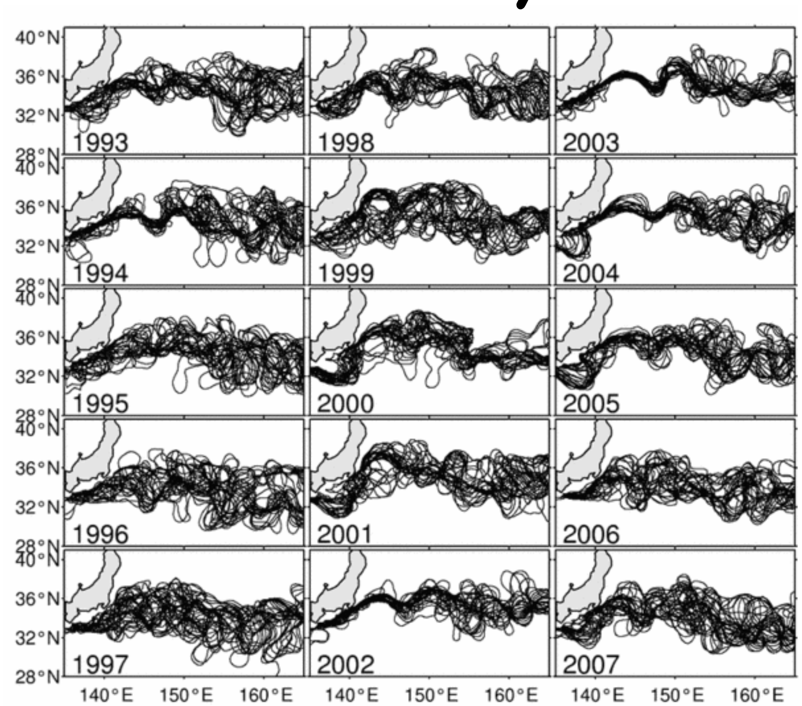
Kuroshio Variability in POP



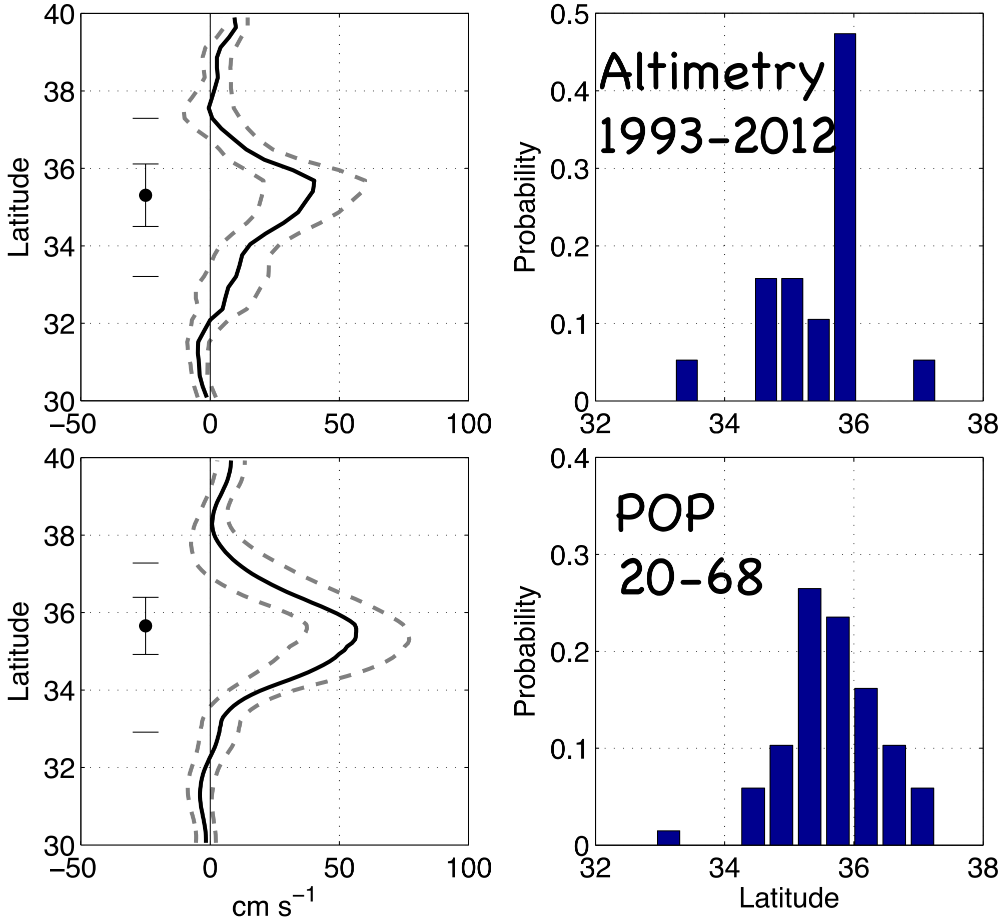
0.1° POP



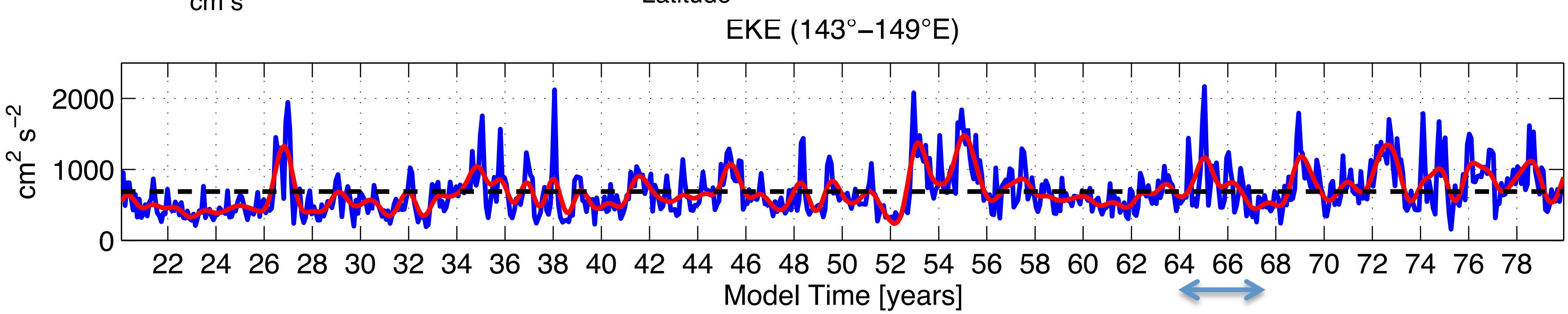
Altimetry



Mean Flow Variability

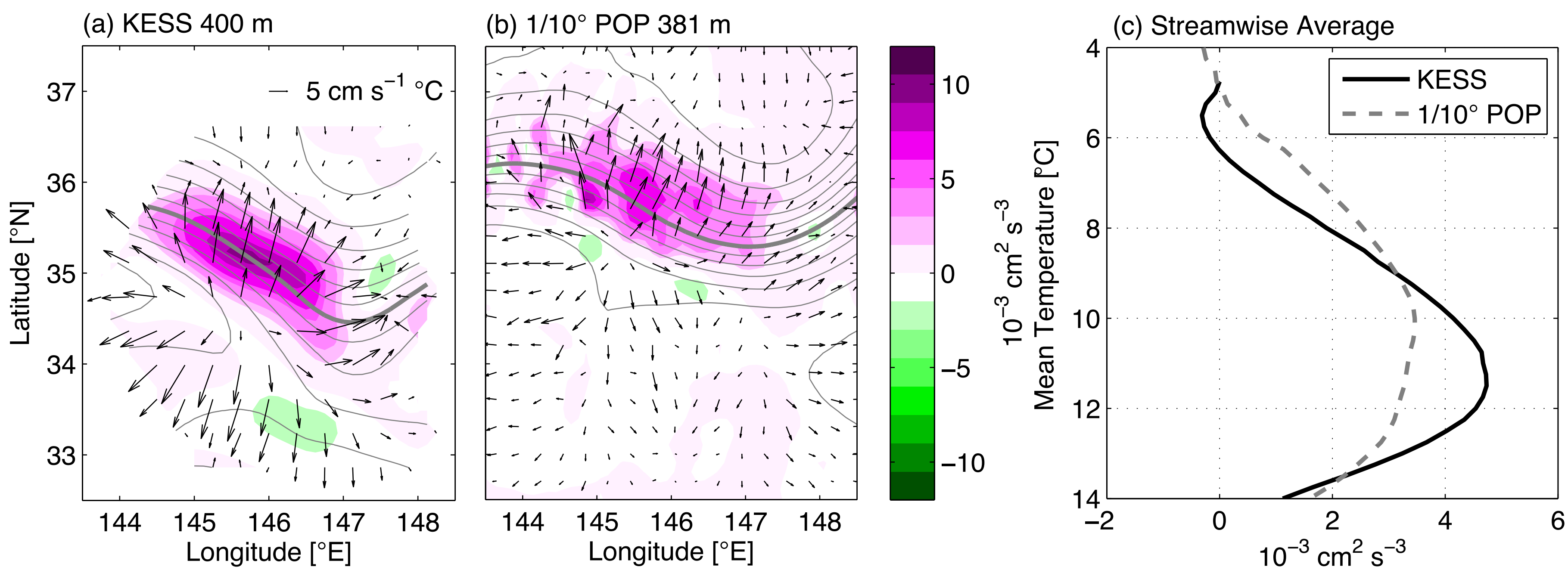


- Mean flow, u (yearly ave. 143-149E)
- Mean jet migrates north and south
- POP more likely to be north of 35N
- Obs rarely north of 36N
- Intrinsic decadal variability in the model (still an open question)



KESS/POP Energy Conversion

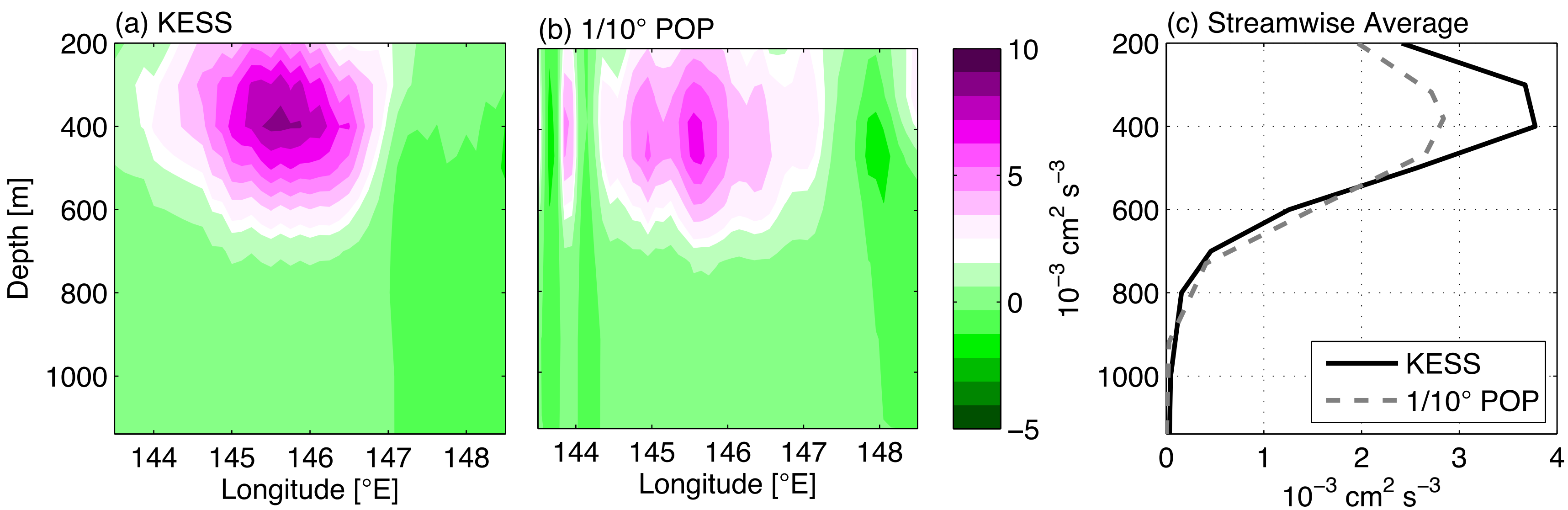
$$BC = -\overline{\mathbf{u}'b'}^{div} \cdot \nabla \left(\frac{\overline{b}}{N^2} \right)$$



- Comparison
  - Eddy heat fluxes are downgradient
  - POP underestimates BC: 27% smaller along 11°C
  - POP stayed in a stable configuration
  - Kuroshio Ext. takes a more northerly path in POP

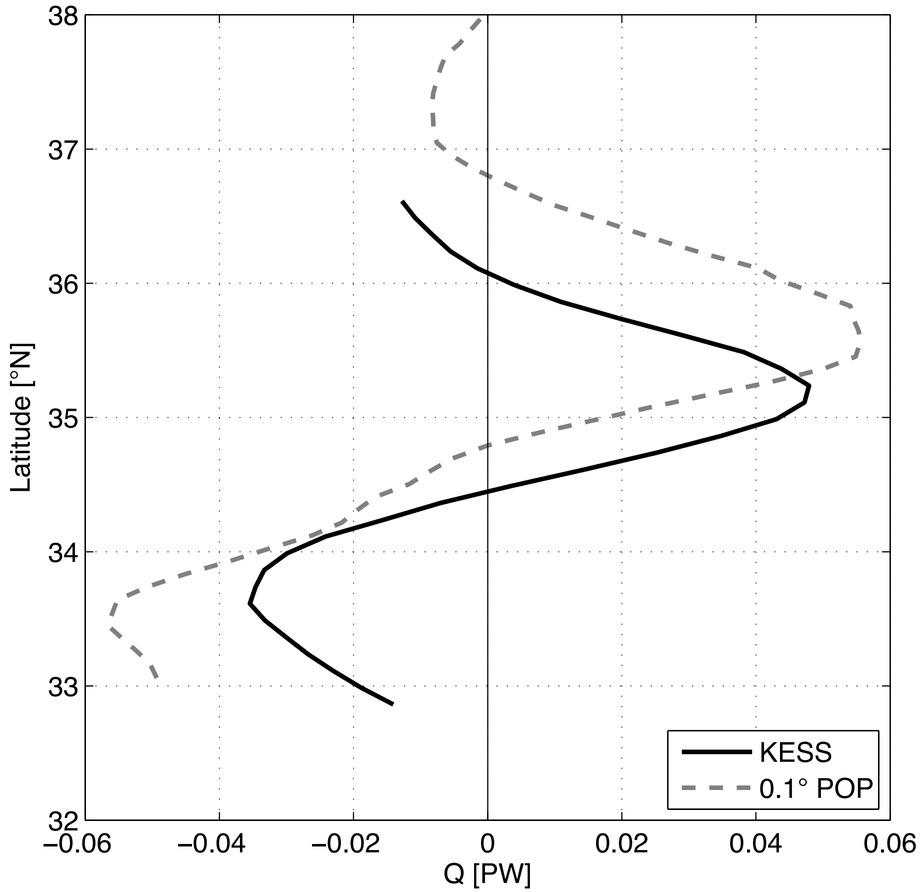
KESS/POP Energy Conversion

BC: Vertical Structure



- BC vertical structure:
  - Similar vertical structure along 11°C isotherm at 400 m (381 m) (similar for other temperature isotherms)
  - POP underestimates BC

Meridional Eddy Heat Transport



$$Q = \rho_0 C_p \int_0^L \int_{-H}^0 \overline{v'T'}^{div} dz$$

- Peak heat transport:
  - KESS: 0.048 PW at 35.2N
  - POP: 0.055 PW at 35.5N
  - POP ≈14% larger
  - Latitudinal offset

Conclusions

- POP compared to KESS:
  - Comparable mean-to-eddy PE conversion rates
    - POP underestimates conversion (≈30%)
  - Eddy heat transport
    - POP overestimate (≈14%)
- Overall 0.1^0 POP does a reasonable job estimating DEHFs in the Kuroshio Extension region

Acknowledgements

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- Frank Bryan (NCAR)
- Randy Watts, Kathy Donohue, and Karen Tracey (URI)

References

Bishop, S.P., D.R. Watts, K.A. Donohue. 2013. Divergent eddy heat fluxes in the Kuroshio Extension at 144-148E. Part 1: Mean Structure. *J. Phys. Oceanogr.* 43: 1553-1550.

Bishop, S.P. 2013. Divergent eddy heat fluxes in the Kuroshio Extension at 144-148E. Part 2: Spatiotemporal variability. *J. Phys. Oceanogr.* in press

Bishop, S.P. and F.O. Bryan. 2013. Mesoscale eddy heat fluxes from observations and a high-resolution ocean model simulation of the Kuroshio Extension. *J. Phys. Oceanogr.* minor revisions

http://www.po.gso.uri.edu/~sbishop