Eddy-Mean Flow Interactions in Western Boundary Current Jets

An observationally driven theoretical study

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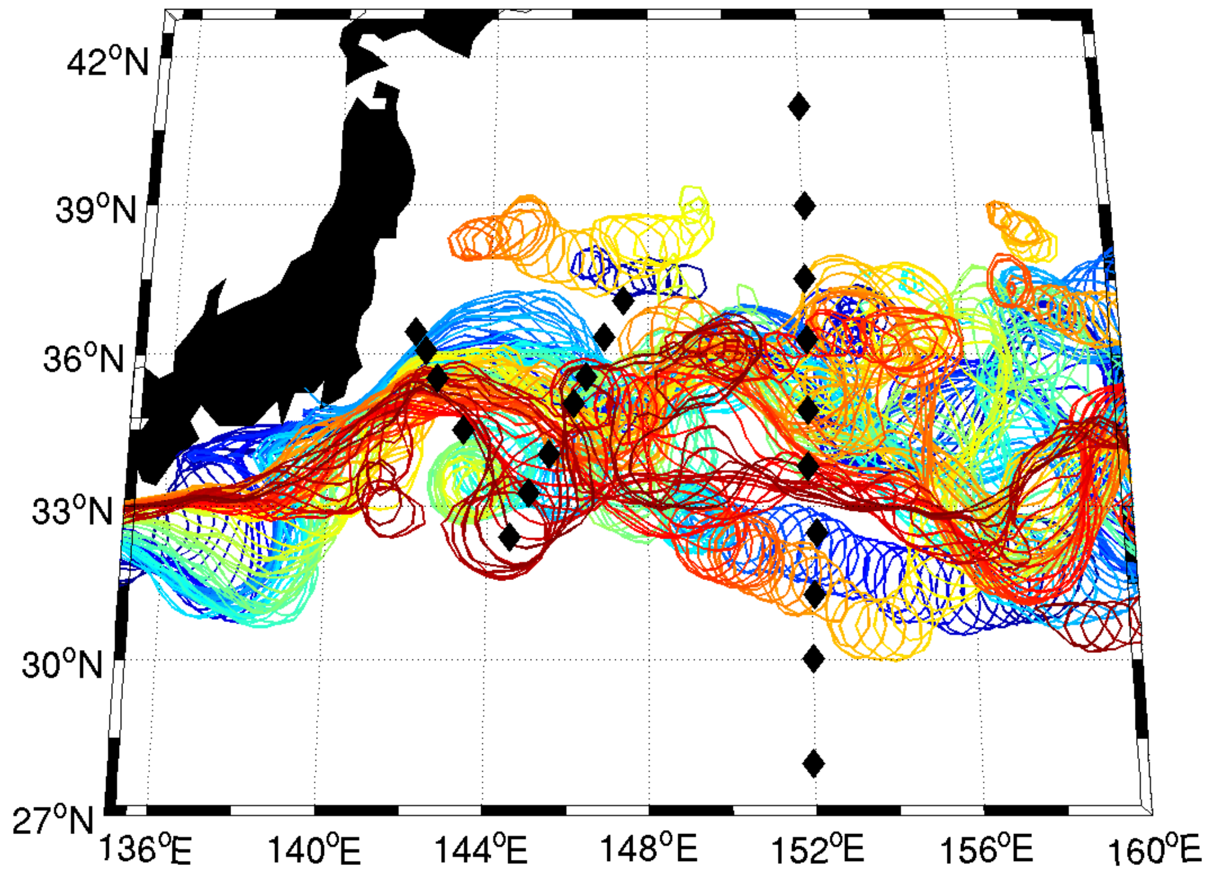
March 3, 2008

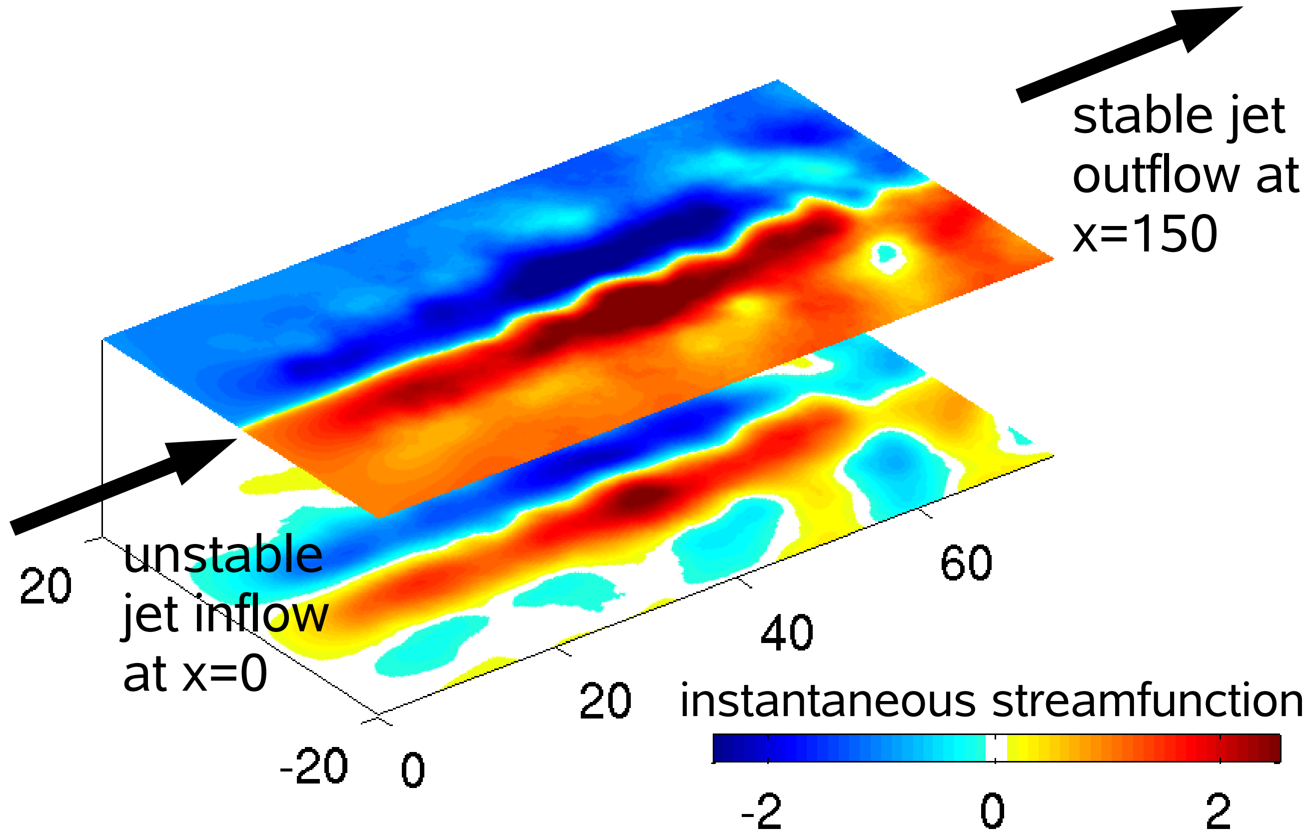


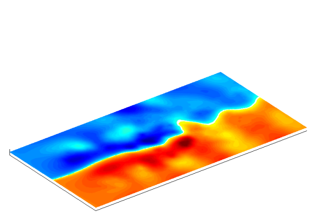
weekly snapshots of the 2.1 m SSH contour (proxy for the Kuroshio Extension jet axis) during the KESS observational period: May 2004 – June 2006

The Model

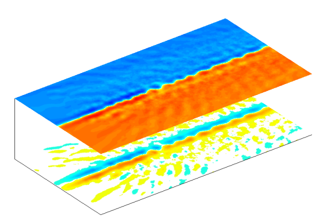
a baroclinic, unstable, boundary-forced jet in an open domain

- QG
- fully non-linear
- 1 or 2-layer
- unstable jet inflow
- insensitive to outflow condition
- sponge layers on all boundaries to model “open ocean”
- posed in terms of time-mean and deviation from time-mean state

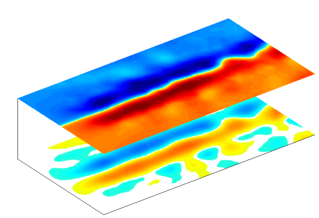




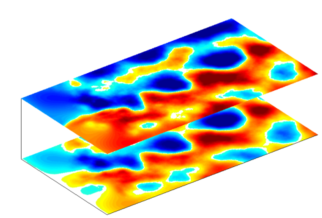
barotropic instability only



baroclinic instability only



mixed instability barotropic dominant



mixed instability baroclinic dominant

The Model

simplifications we employ and the physics we retain are appropriate to the Kuroshio Extension system

- weakly depth-dependent below the thermocline

- subject to mixed instability

- strongly nonlinear

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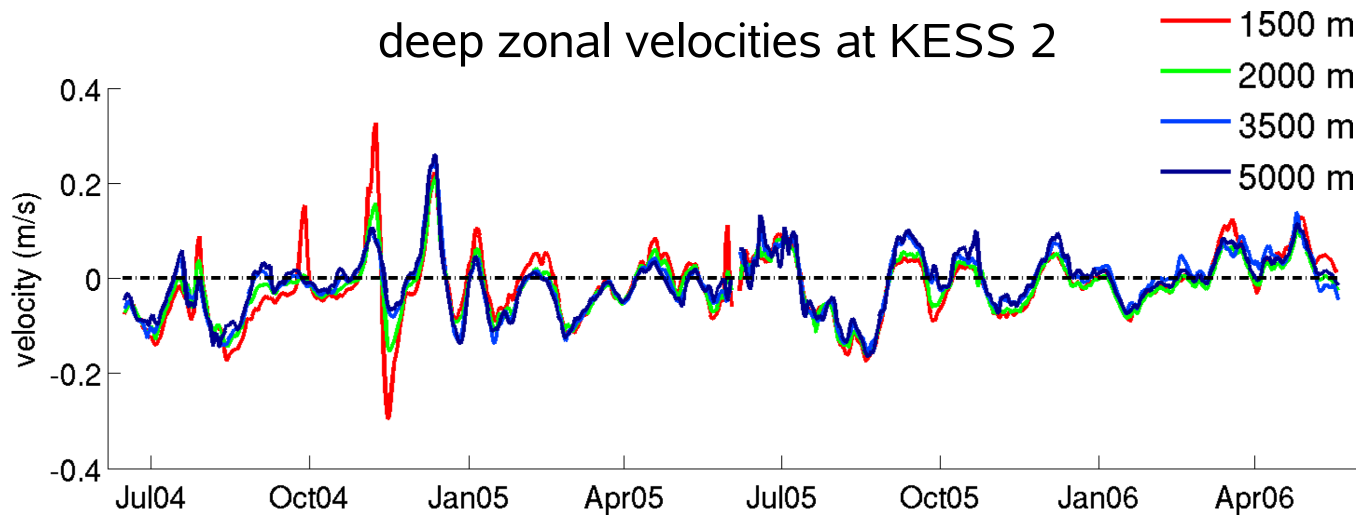
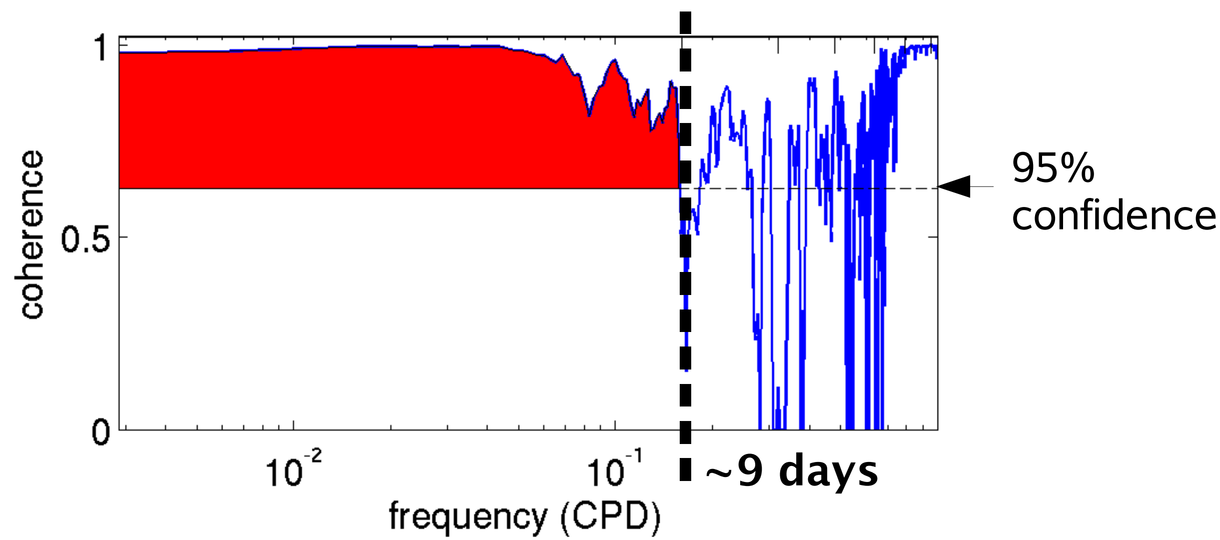
deep zonal velocities at KESS 2



vertical coherence between records at 1500 m and 5000 m



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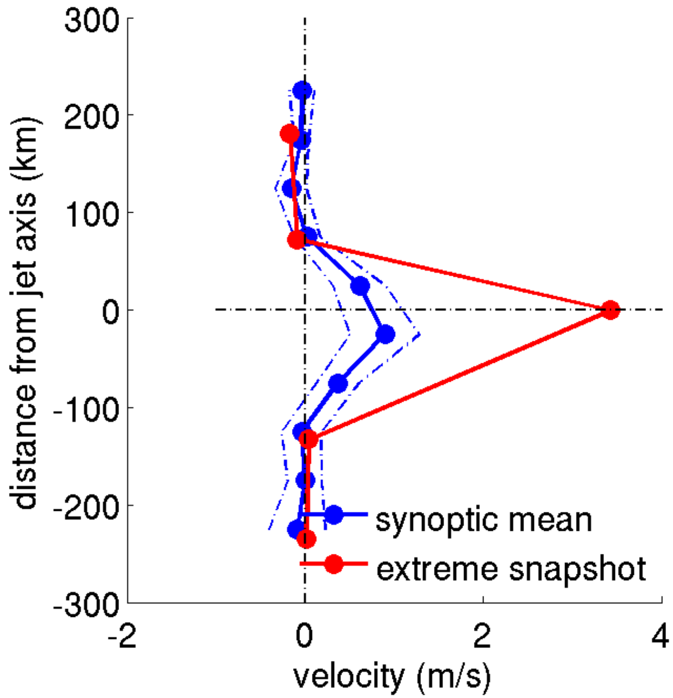
horizontal shear at 250 m

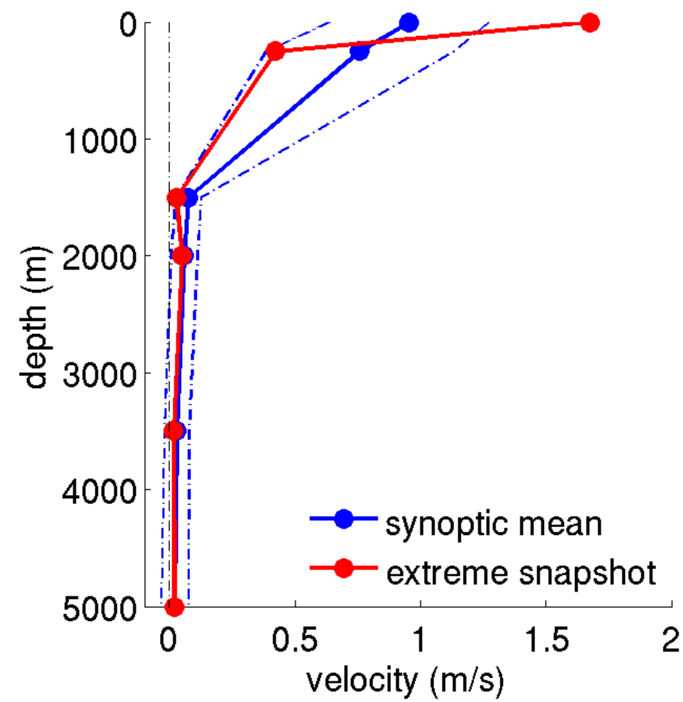


$$\frac{\partial^2 U}{\partial y^2}\Big|_{mean} \sim 2 \times 10^{-5}\frac{1}{ms}$$

$$\frac{\partial^2 U}{\partial y^2}\Big|_{extreme} \sim 7 \times 10^{-5}\frac{1}{ms}$$

(vs. $\beta \sim 2 \times 10^{-11}\frac{1}{ms}$)

vertical shear



$$\Delta U\Big|_{mean} \sim 0.8\frac{m}{s}$$

$$\Delta U\Big|_{extreme} \sim 1.0\frac{m}{s}$$

(vs. $\Delta U\Big|_{critical} \sim 0.1\frac{m}{s}$)

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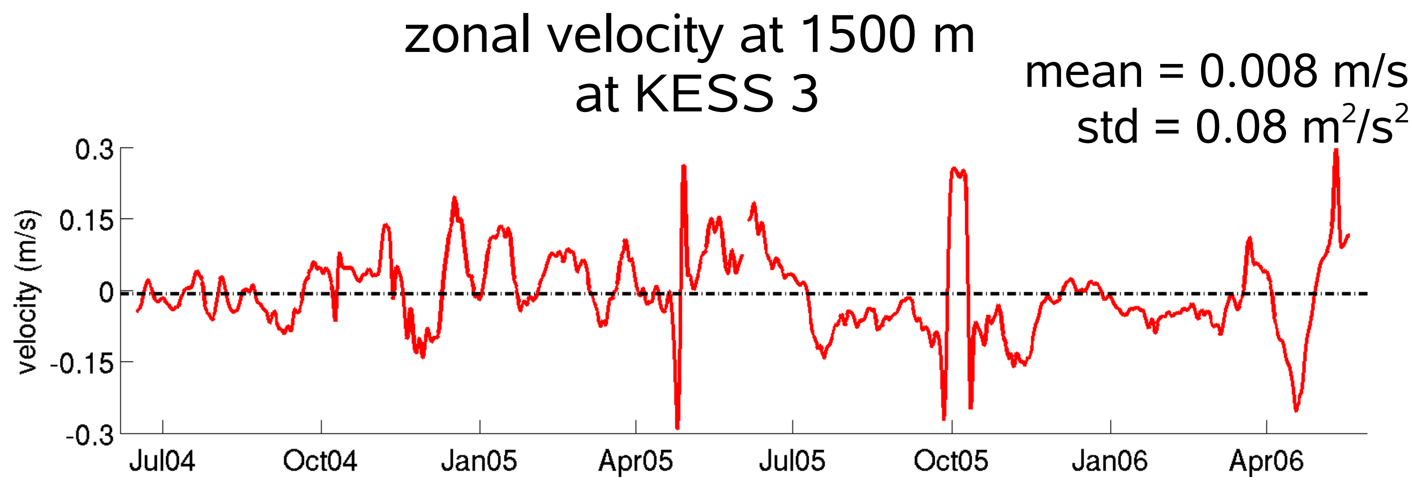
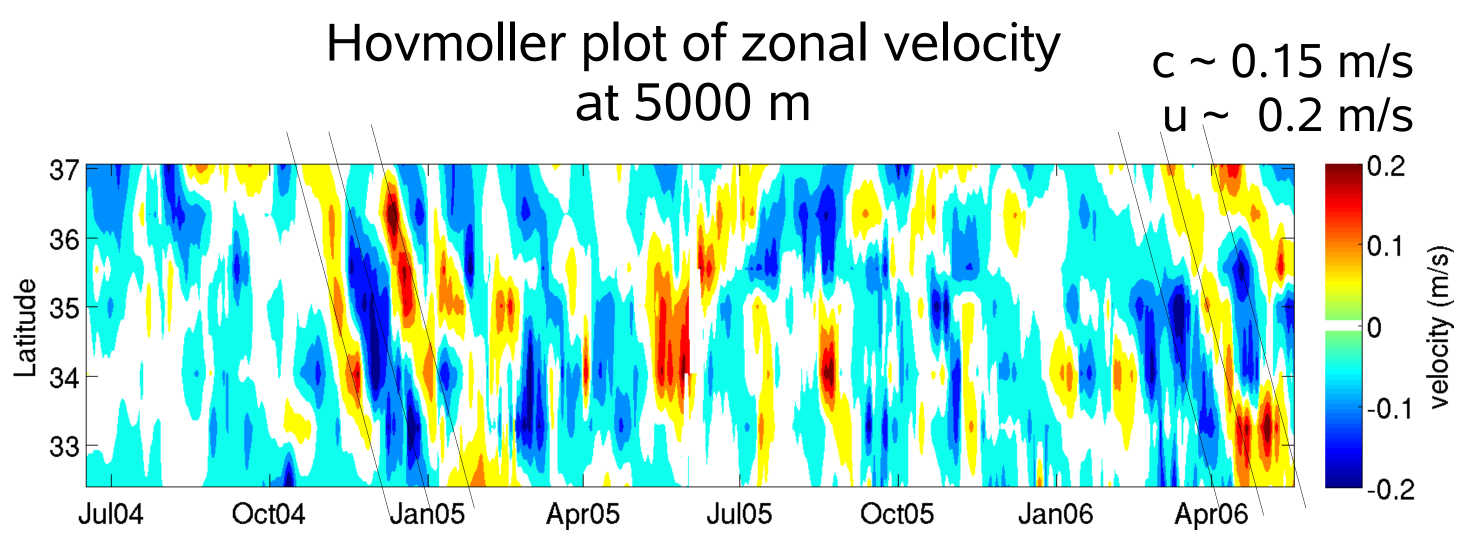


- subject to mixed instability

- **strongly nonlinear**

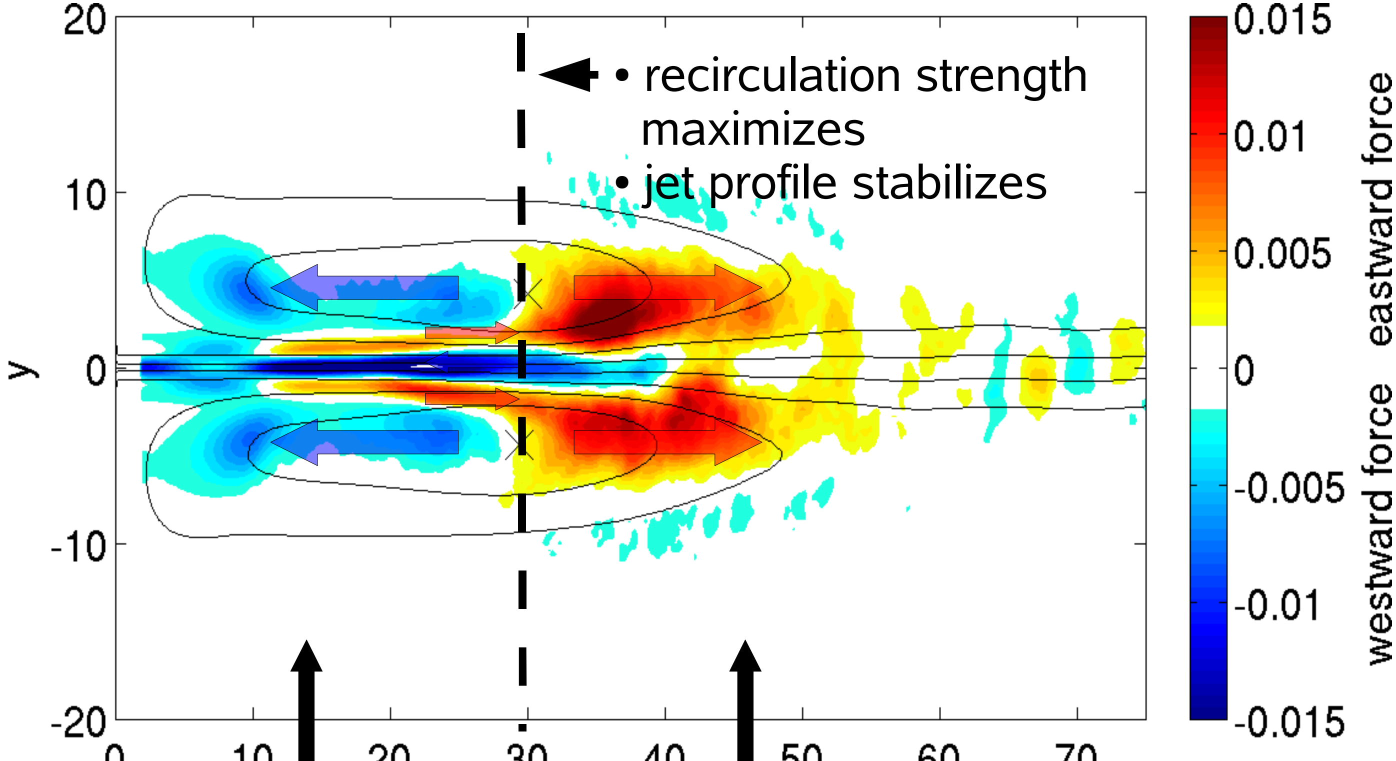


Model Results:

eddies play a critical role in the downstream evolution of the jet through:

1. **stabilizing** the jet
2. **driving** the time-mean recirculations

The Effective "Eddy Force"



"unstable jet" regime
(eddies stabilize jet and accelerate westward flows)

"wave radiator" regime
(eddies decelerate westward flows and close recirculation gyres)

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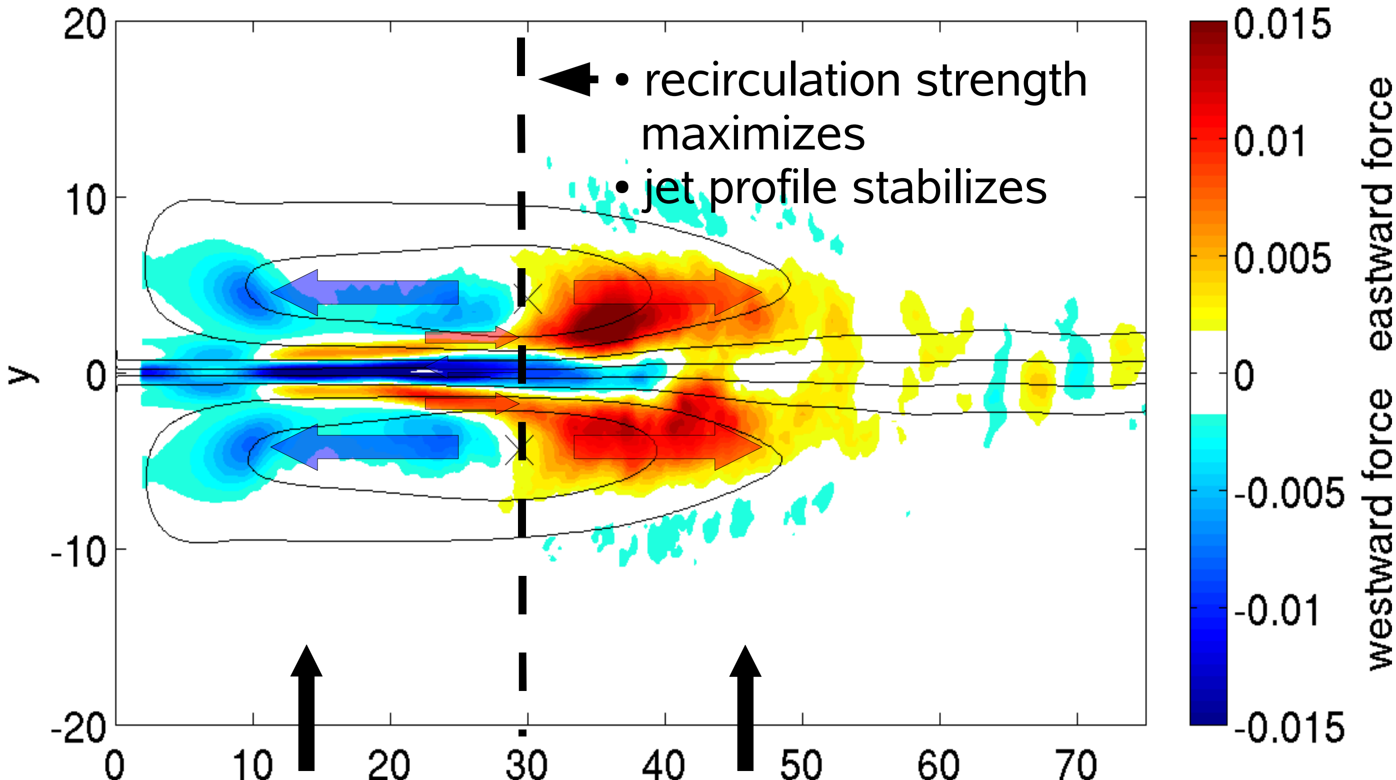

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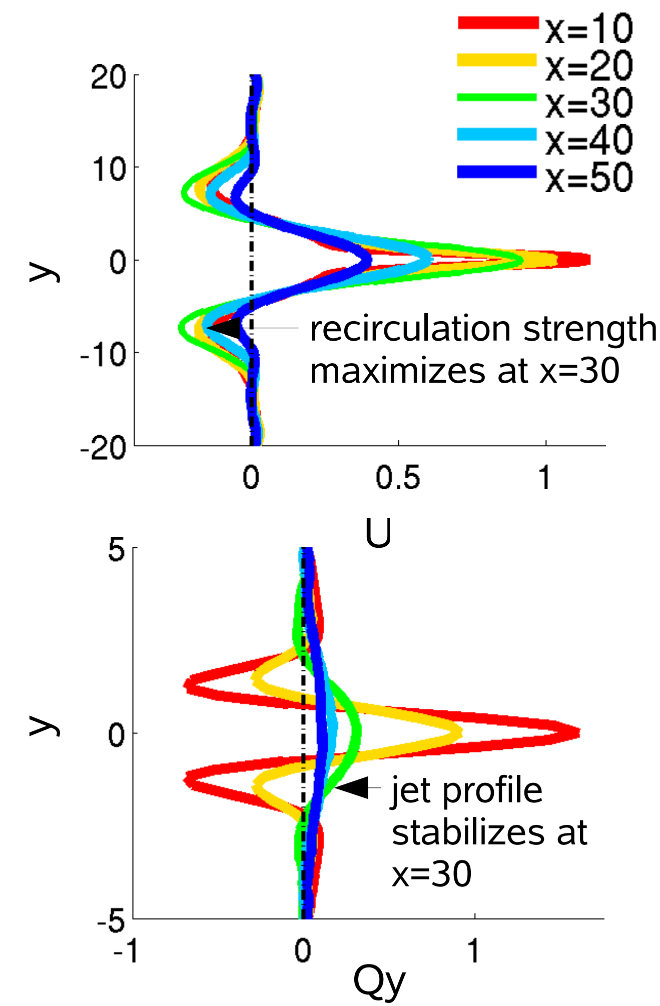
downstream evolution of U (top) and Qy (bottom)



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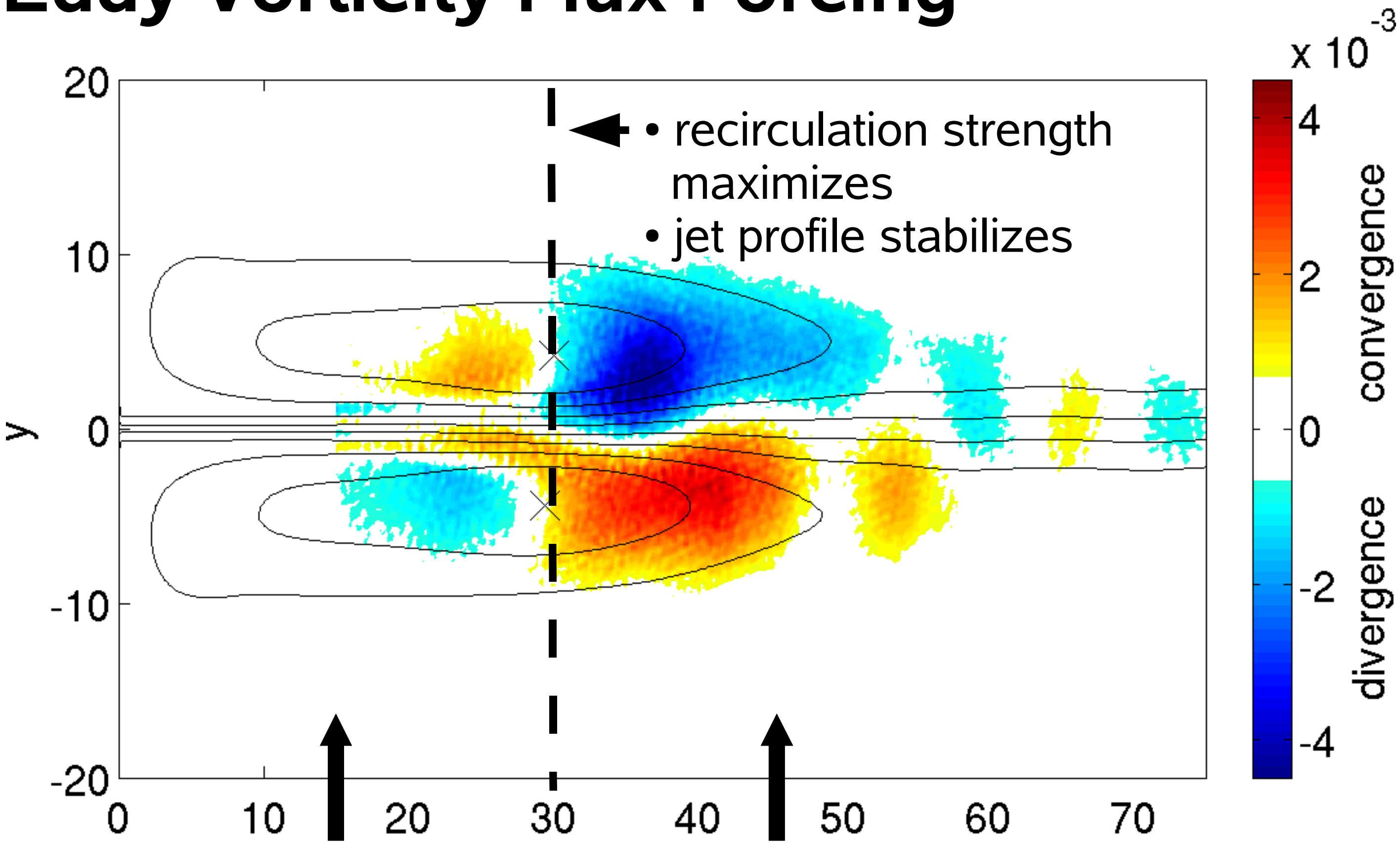
Eddy Vorticity Flux Forcing



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(eddies drive recirculations via vorticity flux divergence pattern)

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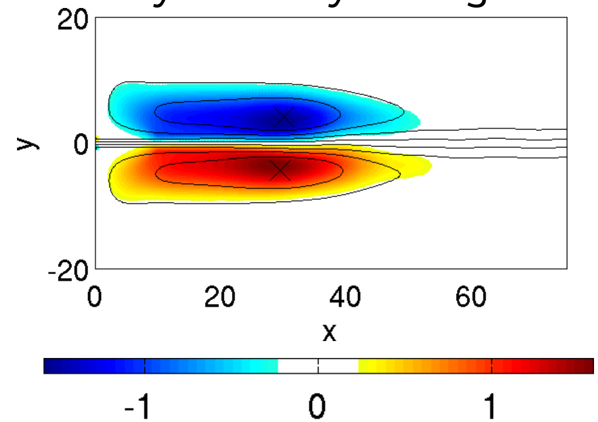
time-mean circulation forced by the eddy forcing



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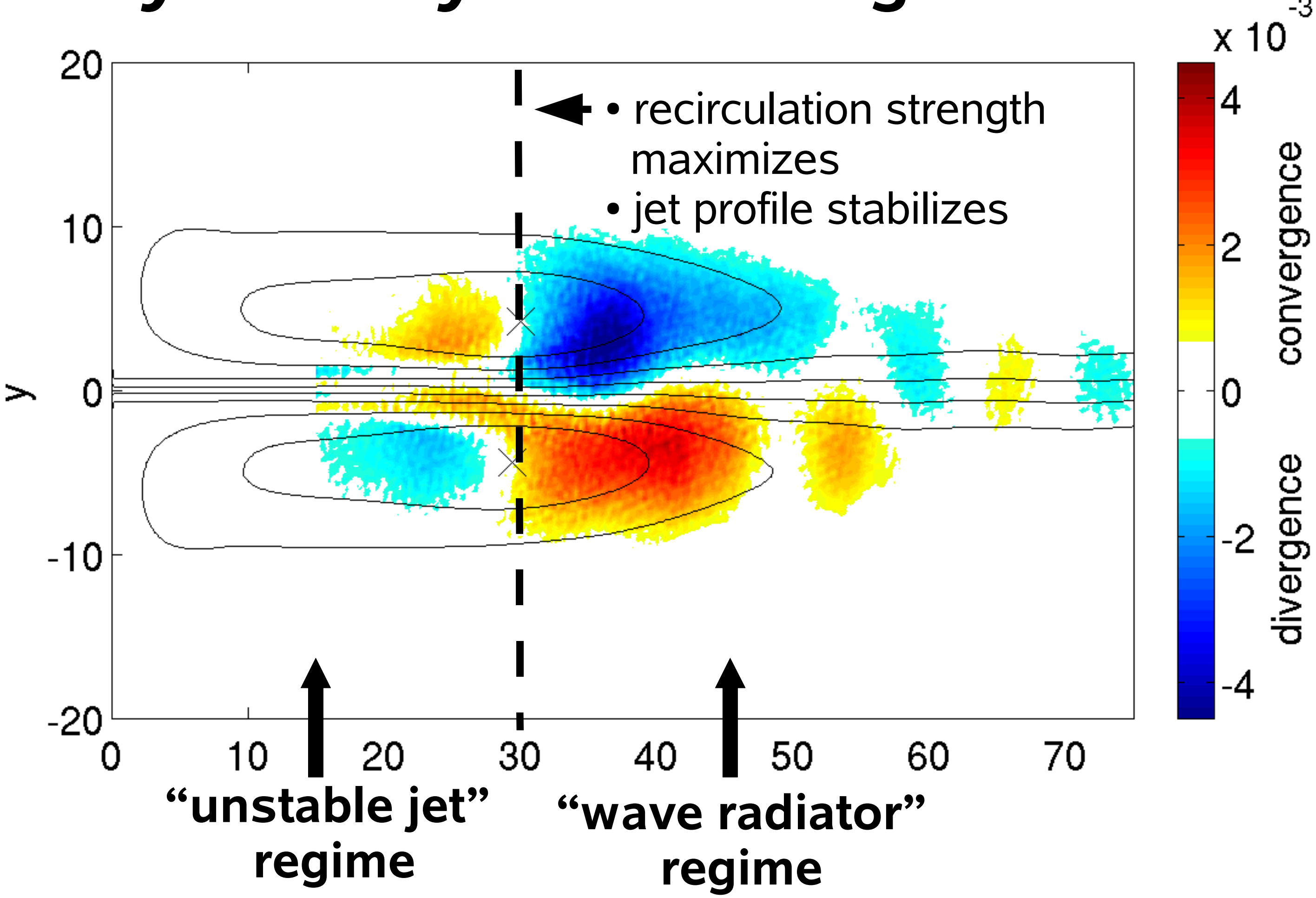

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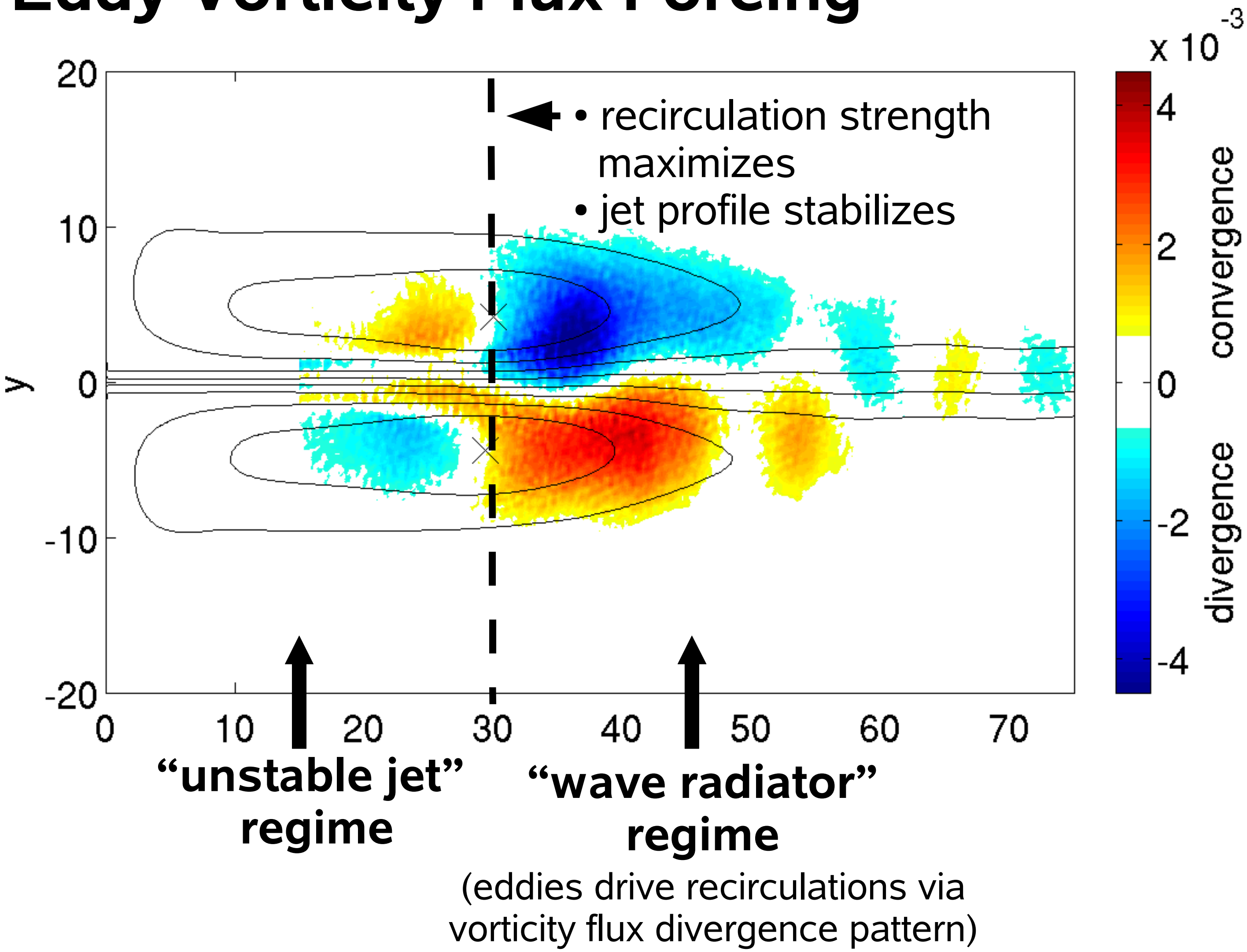

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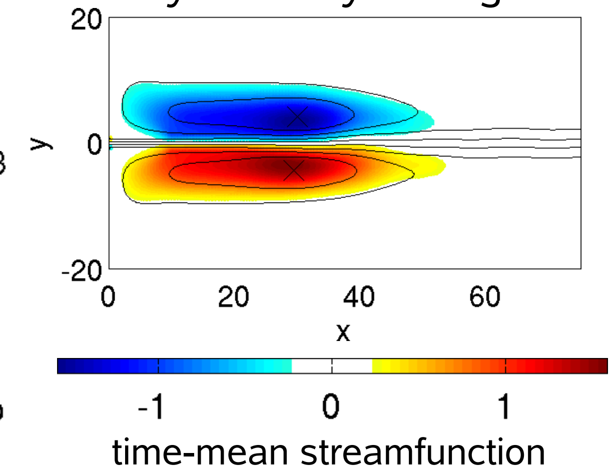
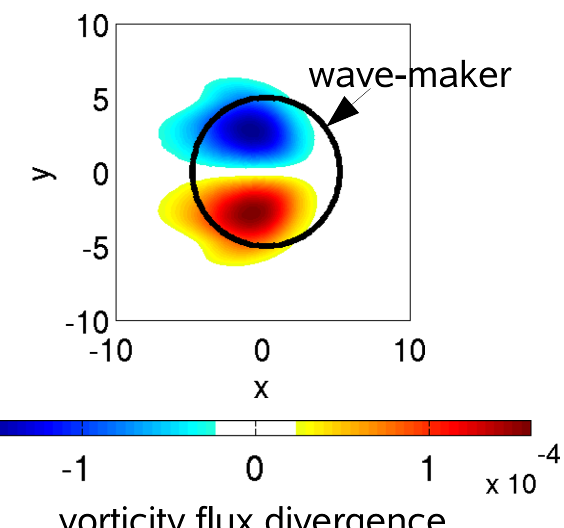


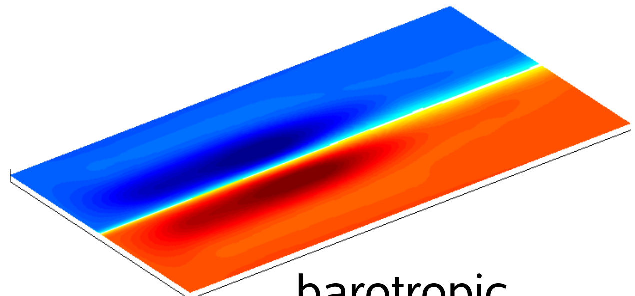
eddy vorticity flux forcing from a localized wave source



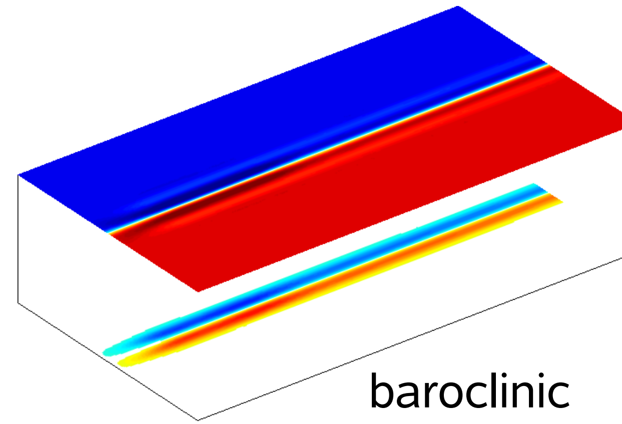
Model Results:

the mechanism is unchanged by the addition of baroclinicity and/or baroclinic instability

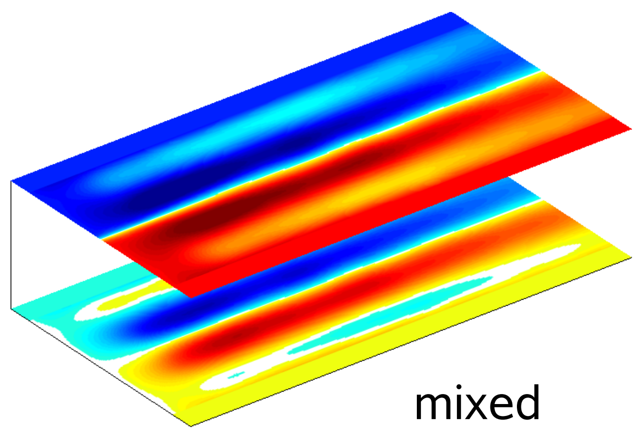
- regardless of unstable configuration - eddies drive recirculations
- baroclinic instability postpones (in x) the barotropic mechanism: it creates (or adds to) the barotropically unstable jet
- new thickness fluxes reduce recirculation strength in the upper layer but drive lower layer recirculations



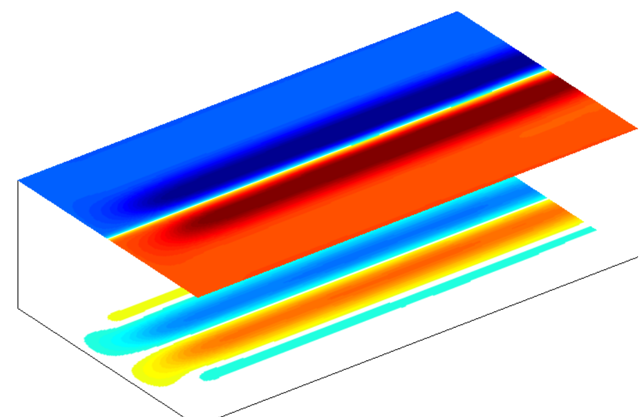
barotropic instability only



baroclinic instability only



mixed instability (barotropic dominant)



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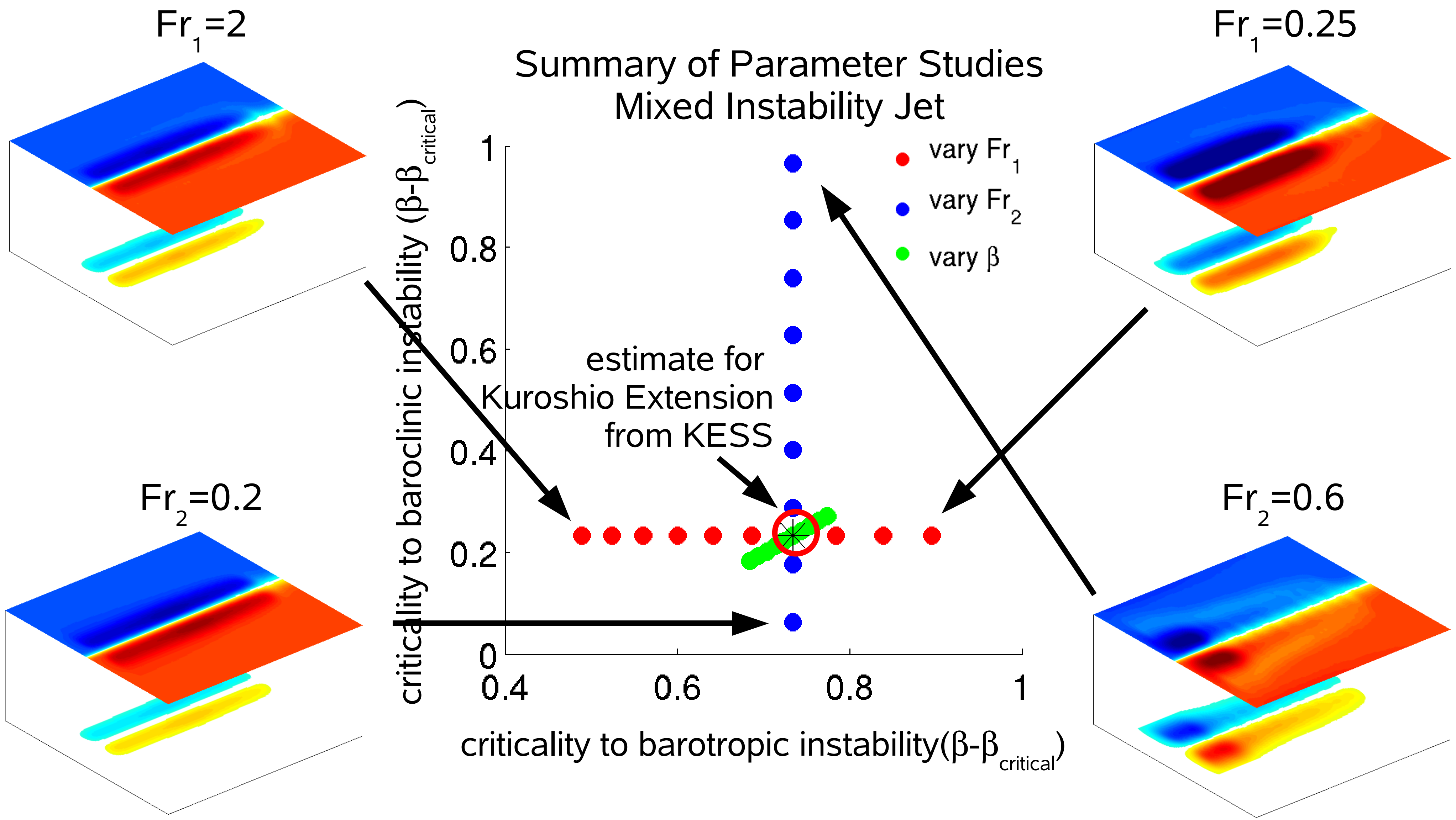
Model Results:

eddy-driven time-mean circulation can be predicted empirically given the stability properties of the upstream jet



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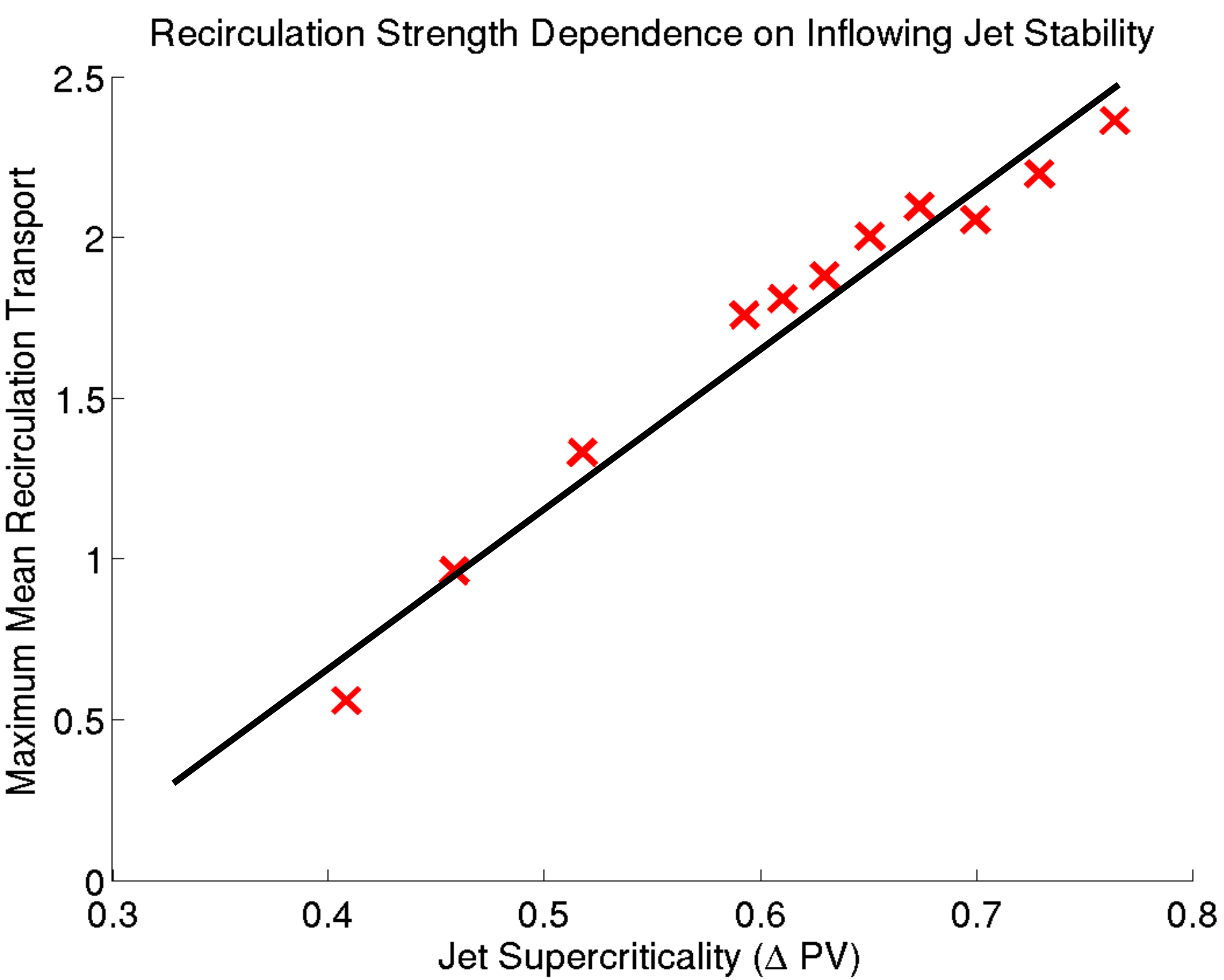
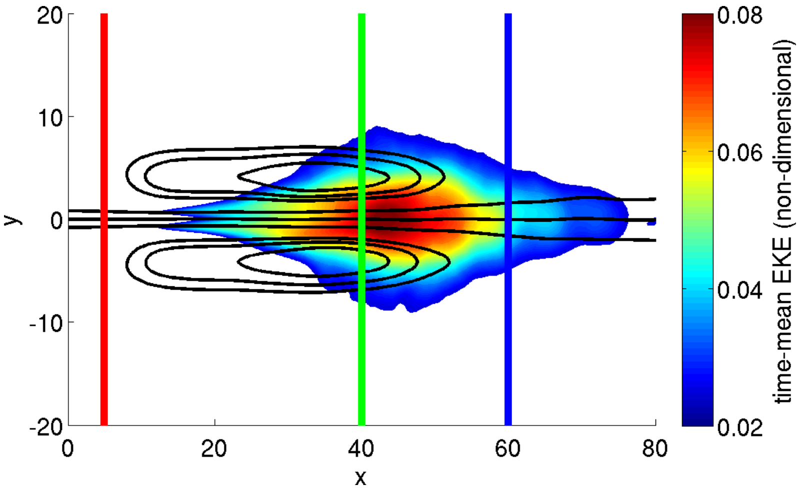
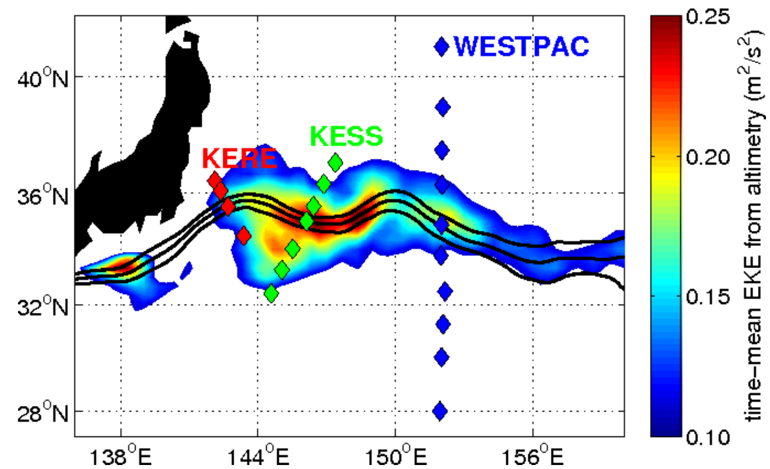


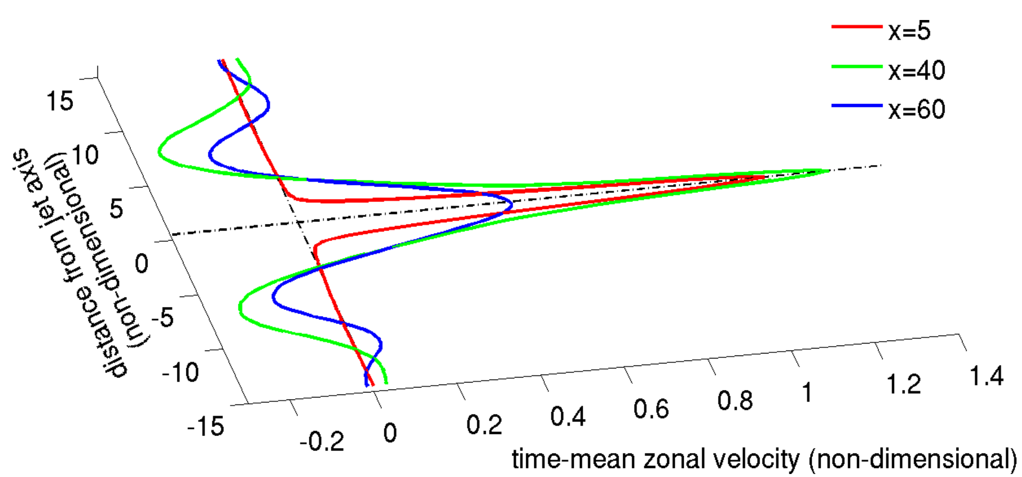
Model – Observation Comparison:

consistencies in downstream development of **mean** and eddy properties suggest model has relevance to oceanic system

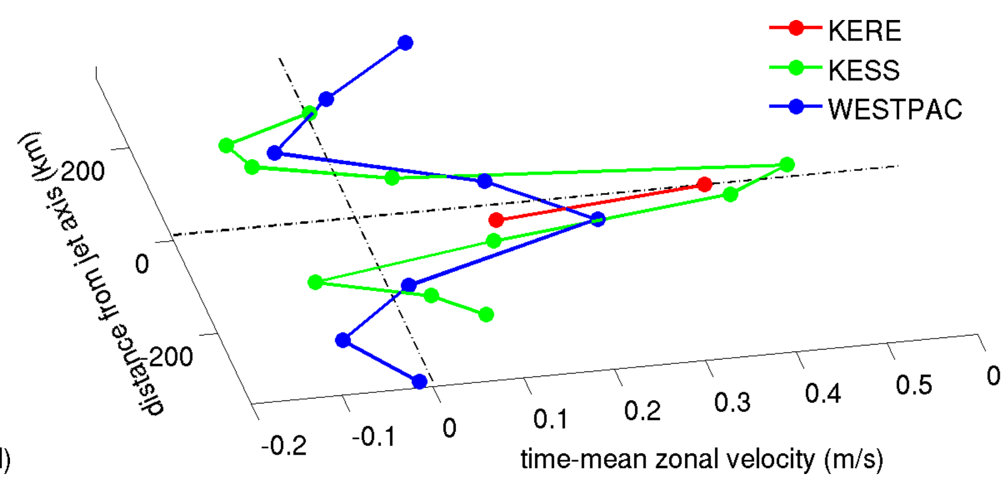




time-mean jet structure in upper layer
model run with Kuroshio-like parameters



time-mean jet structure at 500 m
observed



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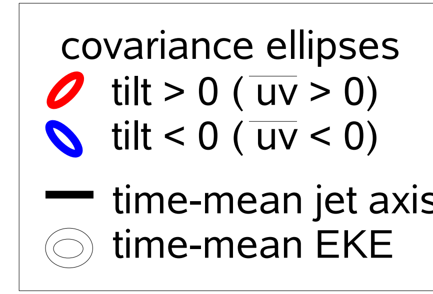
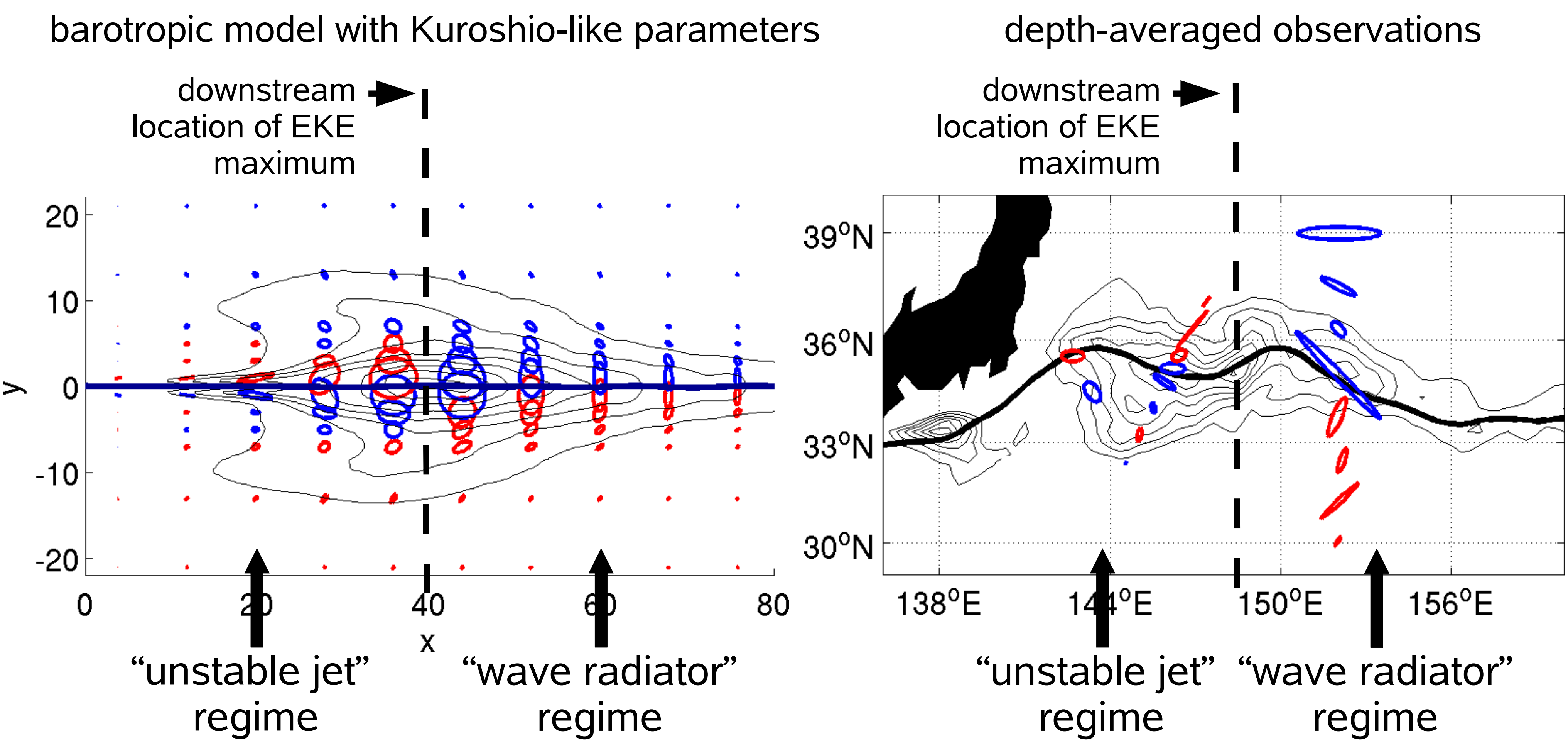


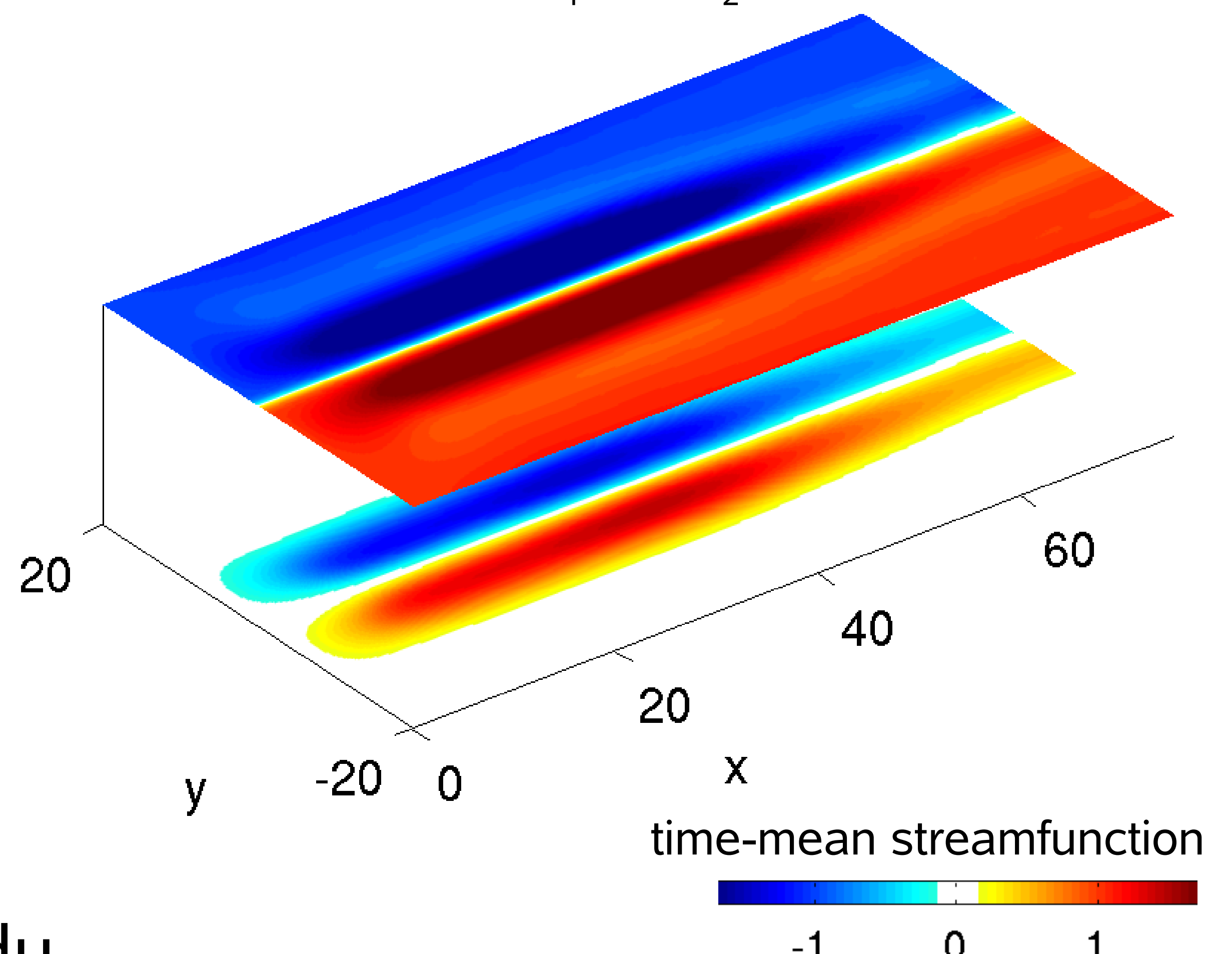


In summary...

model teaches us the importance of eddy-mean flow interactions in the Kuroshio system

- eddies stabilize the jet
- eddies drive the time-mean recirculations
- zonal variation is important
- jet criticality determines mean recirculation properties
- model-observation consistencies suggest model has relevance to real oceanic system
- model in Kuroshio-like regime suggests Kuroshio is dominated by barotropic instability and eddies can drive recirculations of strength and extent consistent with observations

Time-mean circulation for a model run with Kuroshio Extension-like parameters (β=0.03, Fr_1=1, Fr_2=0.25)



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