

REEVALUATING THE ROLES OF EDDIES IN THE  
BAROTROPIC MULTIPLE-GYRE OCEAN MODEL

**Baylor Fox-Kemper**

*Atmospheric and Oceanic Sciences Program*

*Princeton University, Princeton, New Jersey*

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## **0.1 Background for Multi-Gyre Ocean Model**

- **Inertial Domination/Vorticity Removal** (Welander (1964), Veronis (1966))
- **Multi-Gyre Internal Cancellation of Vorticity** (Harrison and Holland (1981), Marshall (1984))
- **Limited Intergyre Mass Flux/Dissipative Meandering** (Lozier and Riser (1989), Lozier and Riser (1990))

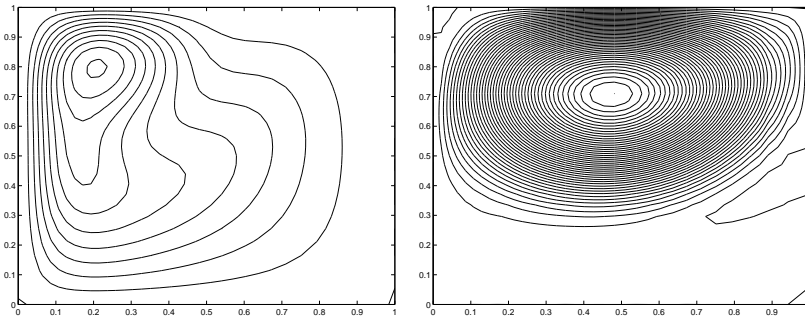
## **0.2 Outline**

- **Boundary Conditions affect Intergyre Vorticity Flux**
- **Sinuuous Modes affect Efficiency of Vorticity Flux**

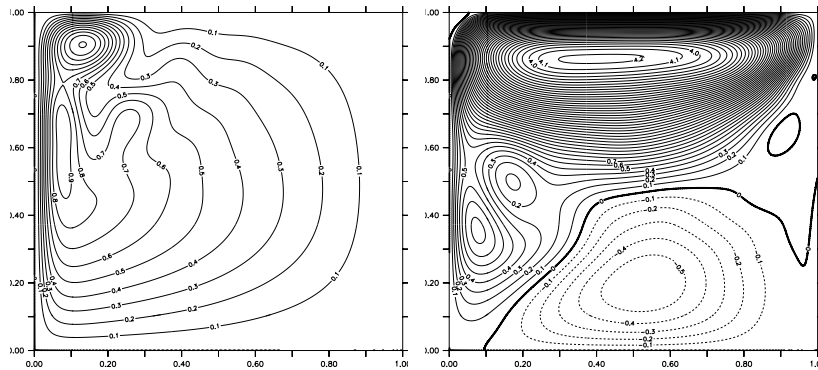
# 1 Inertial Domination (a.k.a Runaway)

( $\psi$ , No-slip E&W) [Movie](#)

Steady, Re=1    Steady, Re= 4.3



Eddying, Re=1    Eddying, Re=5



## 1.1 Single Gyre

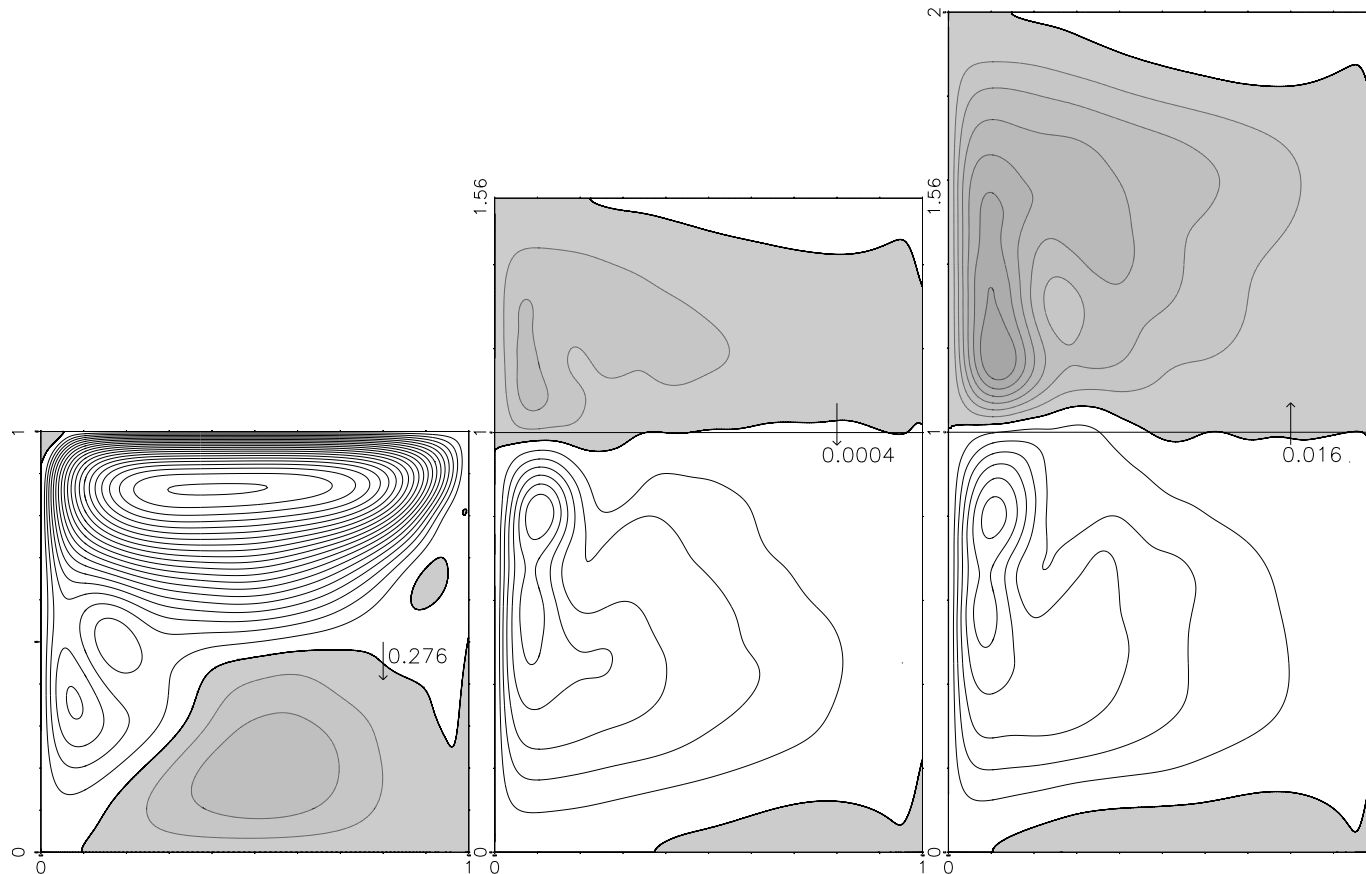
- Mean flow fluxes vorticity to IWBC
- Eddies flux from IWBC to FSL
- Friction removes vorticity
- If bdy. visc. too small, inertia takes over basin
- Only eddies & fric. flux across mean streamlines

## 2 What about Multi-Gyres? Internal Cancellation?

Will eddies dispose of vorticity by an inter-gyre eddy flux or by a flux to the frictional sublayer?

Does internal cancellation control the circulation strength at high  $Re$ ?

## 2.1 Very Little Inter-gyre Flux with No-slip

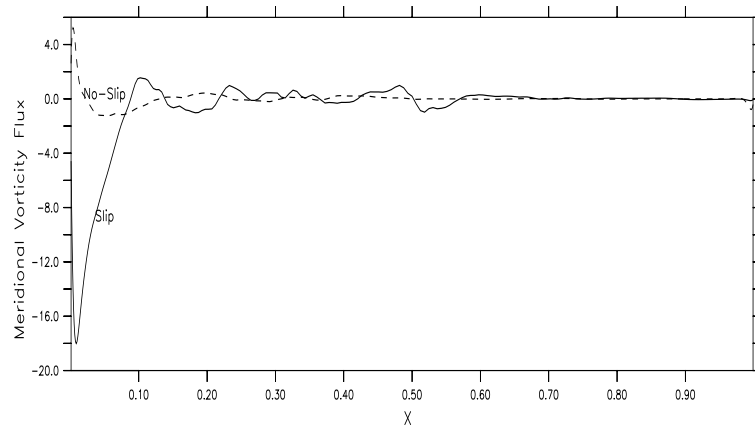


$\text{Re}(\text{bdy})=5$ ,  $\text{Re}(\text{int})=5$ , and no-slip boundary conditions.

Arrows=Eddy Vort. Flux, Subtrop. input=0.637. [Movie](#)

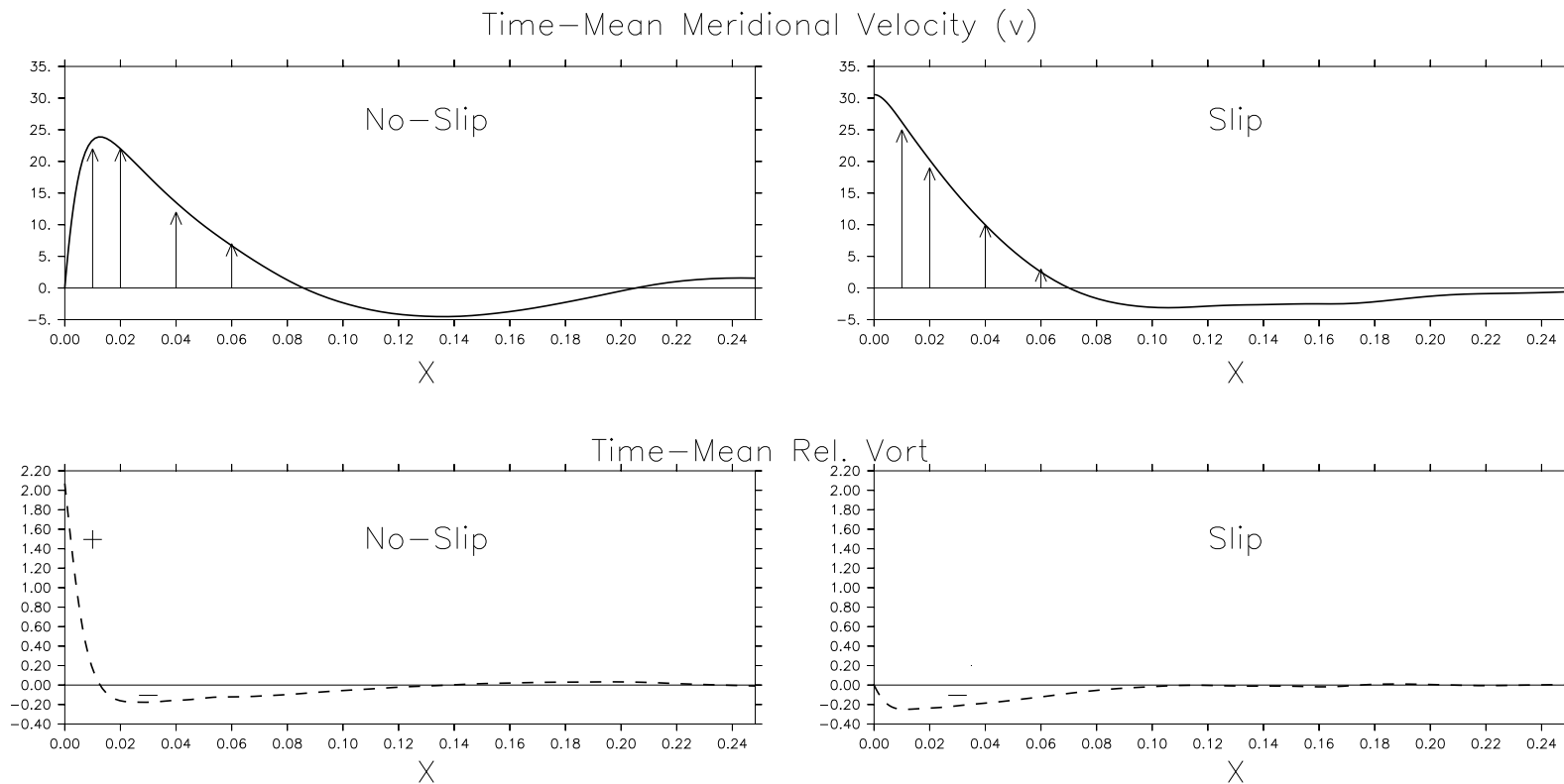
## 2.2 Conflict with Slippery BC results

Eddy flux across  $y=1$



- Different from Harrison and Holland (1981), Marshall (1984), Lozier and Riser (1990) who use slippery bcs.
- Most inter-gyre eddy flux in slippery models is dissipative meandering, not by parcel exchange Lozier and Riser (1989), Berloff et al. (2002).

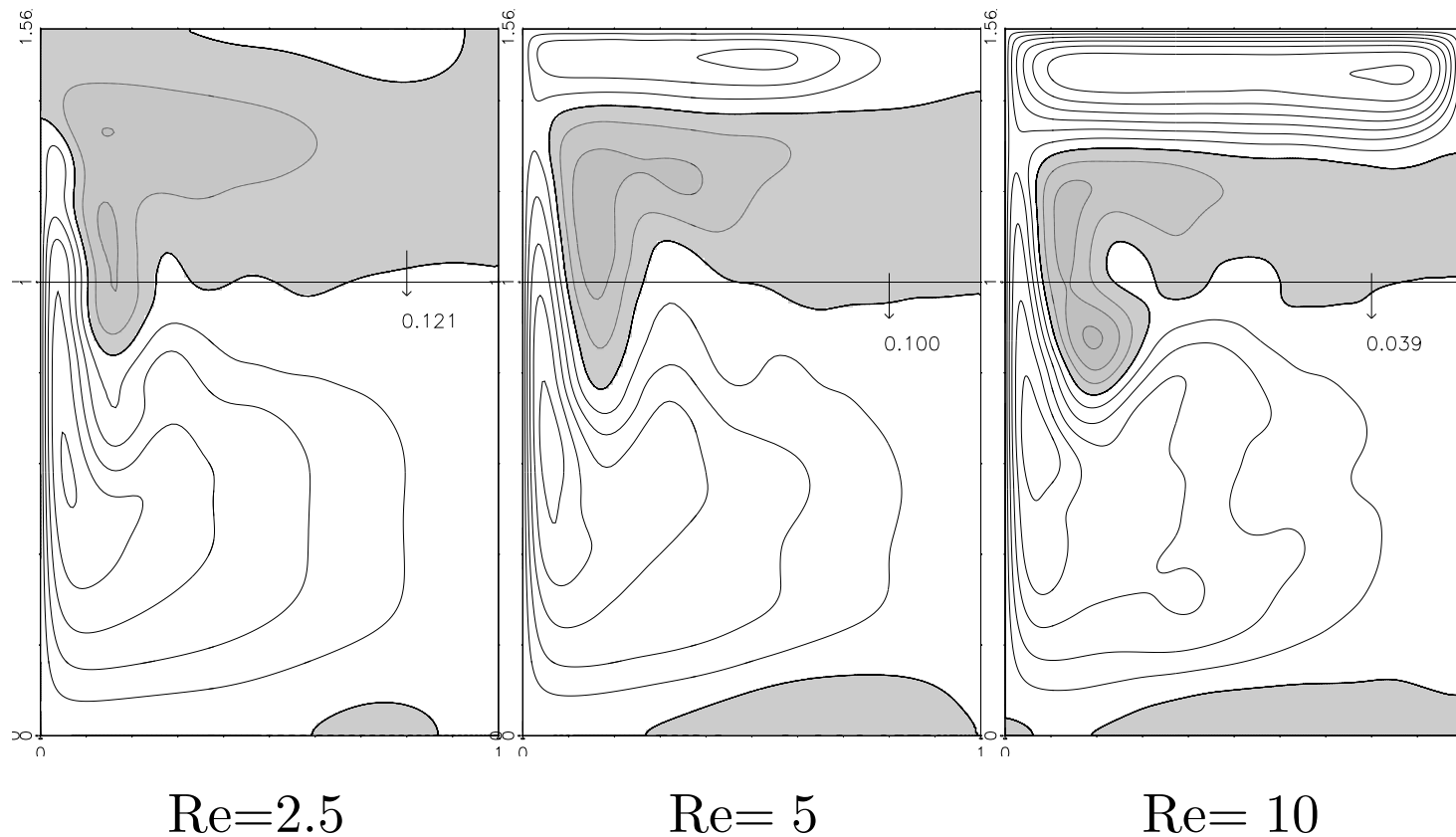
## 2.3 Intergyre Flux due to Rel. Vort. in BL



No dissipative meandering with no-slip because 1) separation point doesn't meander easily and 2) rel. vorticity in BL is different. [Movie](#)

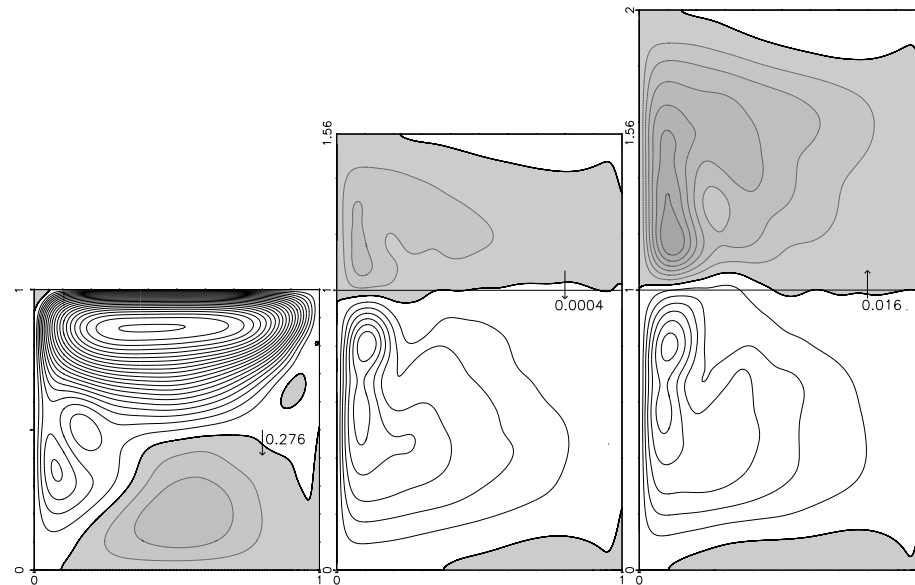
## 2.4 So why not Slip BCs & Eddy Fluxes?

**Slip Two-Gyre:** w/o *antisymmetric* wind, intergyre *eddy flux* not preferred, instead it's *mean flux*. Cessi (1991): stronger WBC no-slip/slip under/overshoots.



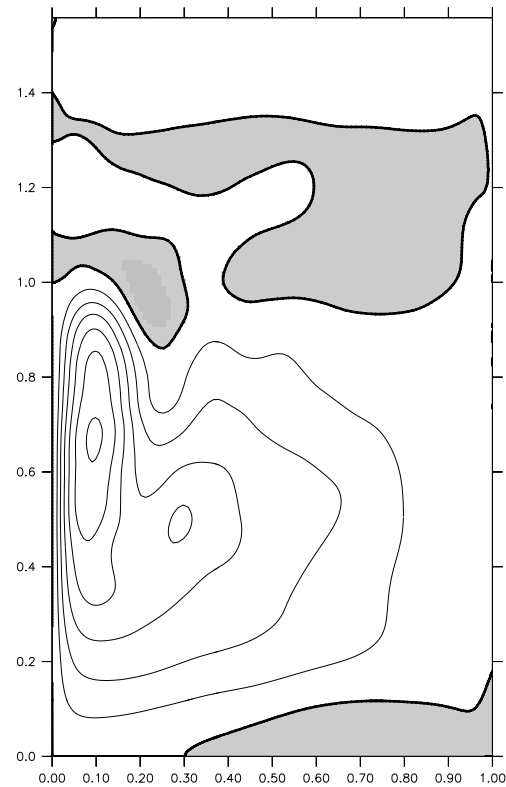
### 3 Why is No-Slip Multi-gyre Circ. Controlled?

*Negligible inter-gyre eddy flux of vorticity, yet circ. is reduced with addition of a second gyre.*



$\text{Re}(\text{bdy})=5$ ,  $\text{Re}(\text{int})=5$ , and no-slip boundary conditions.

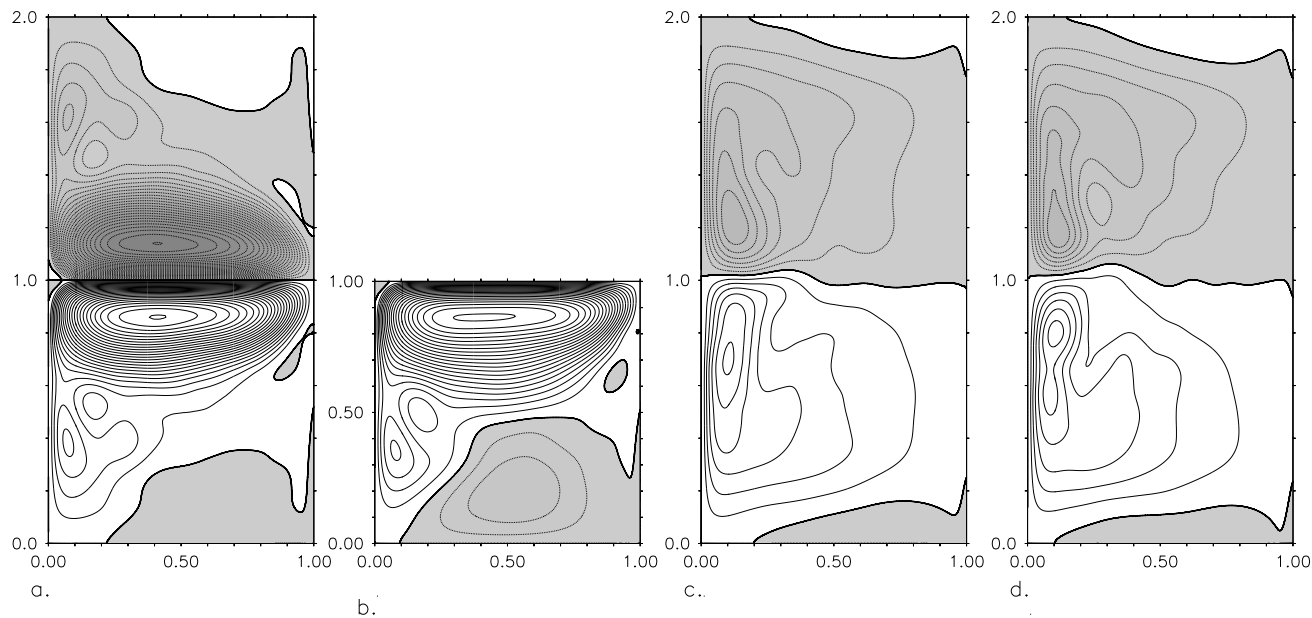
Circulation reduced even *without subpolar wind forcing!*



$\text{Re}(\text{bdy})=5$ ,  $\text{Re}(\text{int})=5$ , and no-slip boundary conditions.

## 4 Sinuous Modes

Removing northern boundary changes eddies that flux vorticity to the frictional sublayer. Rapidly-growing *sinuous modes* are then present: [Movie](#)



Rest initial

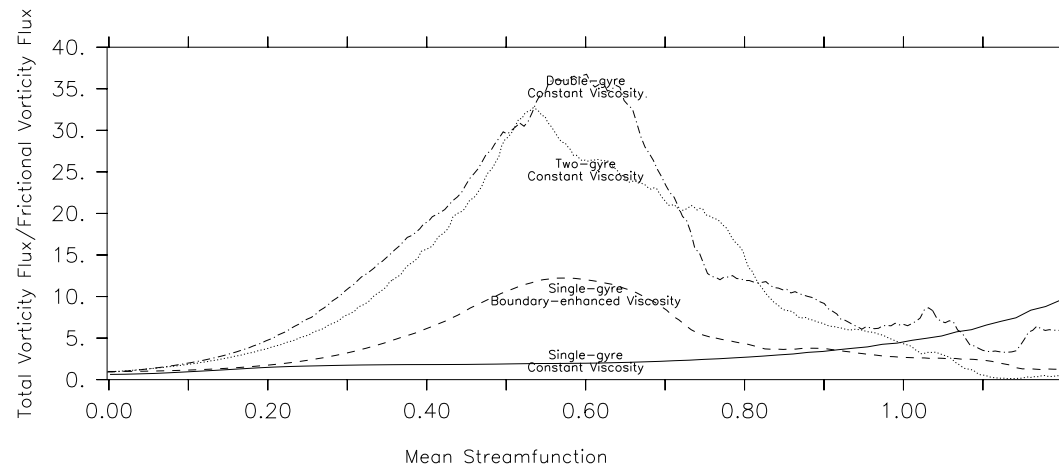
Single-gyre

Rest initial after

Asym. initial

## 4.1 Sinuous Efficiency (Total Flux/Fric. Flux)

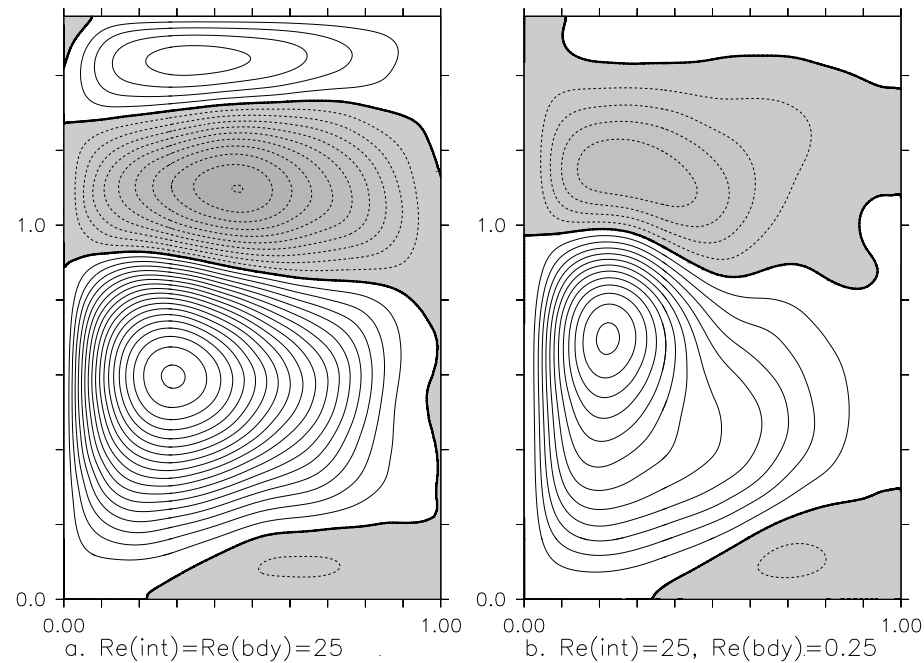
Sinuuous modes known to mix strongly on either side of the jet: *e.g.*, Balmforth and Piccolo (2001), Rogerson et al. (1999).



Sinuuous modes are *extremely efficient* at tearing vorticity from the recirculation gyre. The recirculation gyre and circ. strength limited by sinuous modes. No inter-gyre eddy flux required.

## 4.2 Eventual Inertial Domination

At a sufficiently high Reynolds number inertial domination returns even with sinous modes,



Thus, vorticity removal at high  $Re$  must still be considered.

## 5 Conclusions

- Only slip double gyre shows significant intergyre eddy fluxes at high Reynolds number, due to dissipative meandering
- No-slip models have *negligible inter-gyre eddy flux* and slip (asymmetric) two-gyre calculations have primarily mean inter-gyre flux
- Sinuous modes increase the efficiency of vort. flux to the FSL and reduce circ. w/o requiring inter-gyre eddy flux
- At really high Re, even sinuous modes can't control the circ., as they cannot ultimately remove vorticity. Then, boundary-enhanced visc. can recover a Sverdrup interior as in single-gyre.

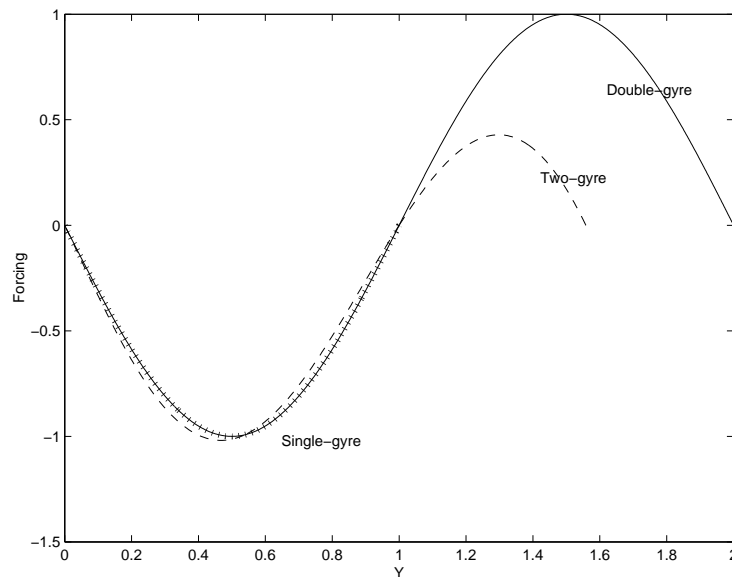
## 6 Implications?

- Eddy vort. flux is very important at high Re when mean streamlines are closed. True also in real ocean.
- The removal of vorticity at the boundary can be very important in determining the interior solution. *Nonlocal control*.
- If eddies are more efficient—as sinuous modes are—circulation strength can be reduced, but vorticity removal always important
- Inter-gyre eddy vort. flux seems to be restricted to symmetric slip double-gyre, probably not a major player in real ocean.

## 7 Issues?

- Baroclinicity? Thickness fluxes, outcropping, buoyancy budget.
- Precisely how does boundary remove vorticity? Perhaps Hughes & De Cuevas ('02).
- What are the instabilities in the real ocean, and how efficient are they?

## 7.1 We Compare 3 Models: Vorticity Input



**Single-gyre** is in square basin.

**Two-gyre** is in asymmetric basin.  $0 \leq y \leq 1.56$

**Double-gyre** is in symmetric basin.  $0 \leq y \leq 2$

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