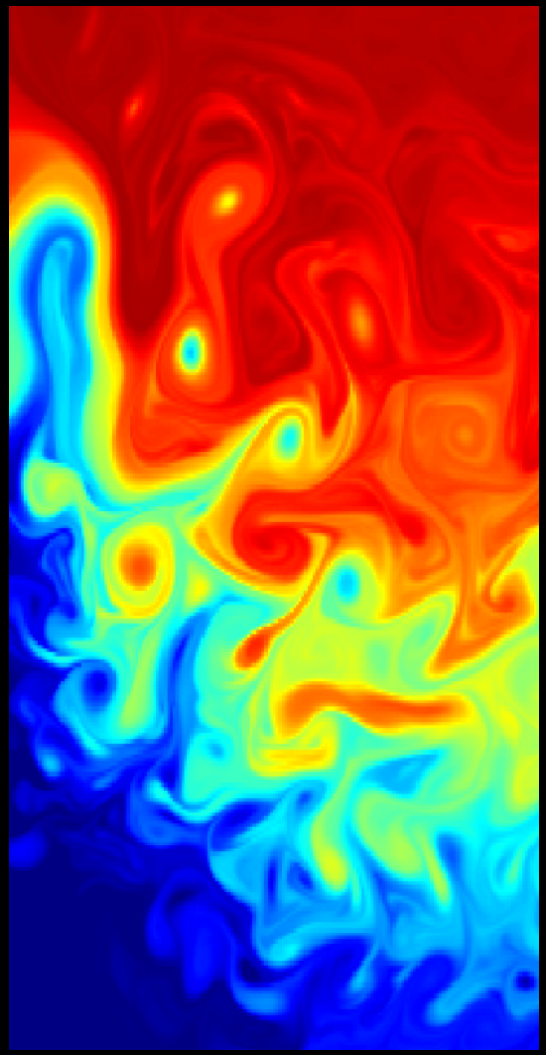
The role of closed gyres in the zonal transport of the ACC

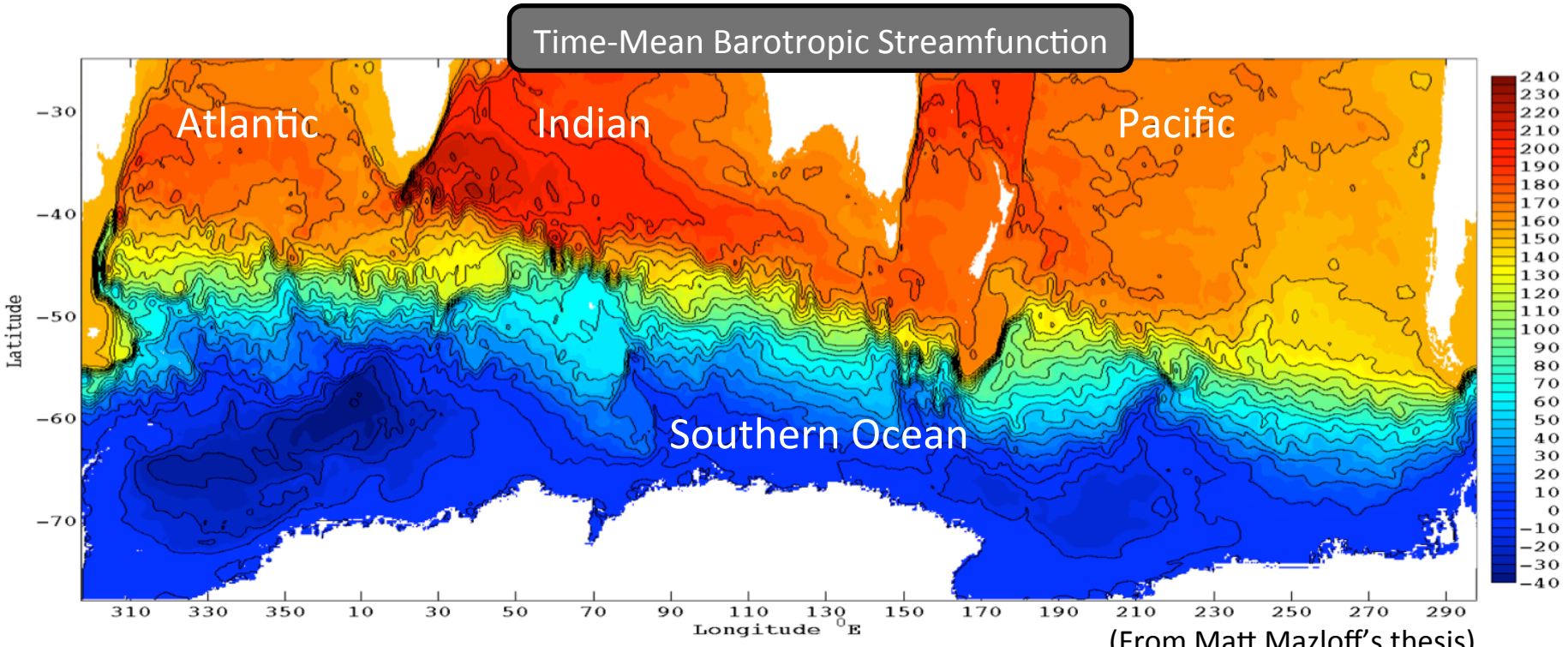
L.-P. Nadeau and R. Ferrari



Introduction

Antarctic Circumpolar Current

- Most voluminous ocean current (transport= 130 Sv)
- Global importance: mixes together Atlantic, Indian and Pacific Oceans waters
- **Still lack a robust quantitative theory for what sets the magnitude of the circumpolar transport**



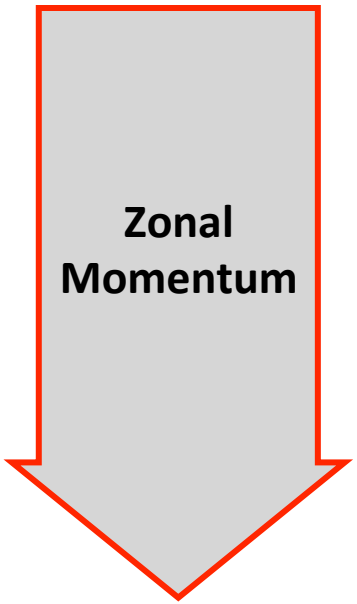
(From Matt Mazloff's thesis)

Introduction

Consensus:

Transport = Balance of 3 terms in Zonal Momentum Budget

- **Surface** ⟶ ***Input*** by the wind
- **Interior** ⟶ ***Downward transport*** by geostrophic eddies
- **Bottom** ⟶ ***Sink*** by topographic form drag



Introduction

Focus of most recent studies

- **Surface** ⟶
- **Interior** ⟶

Input by the wind

↑

Explains Transport

↓

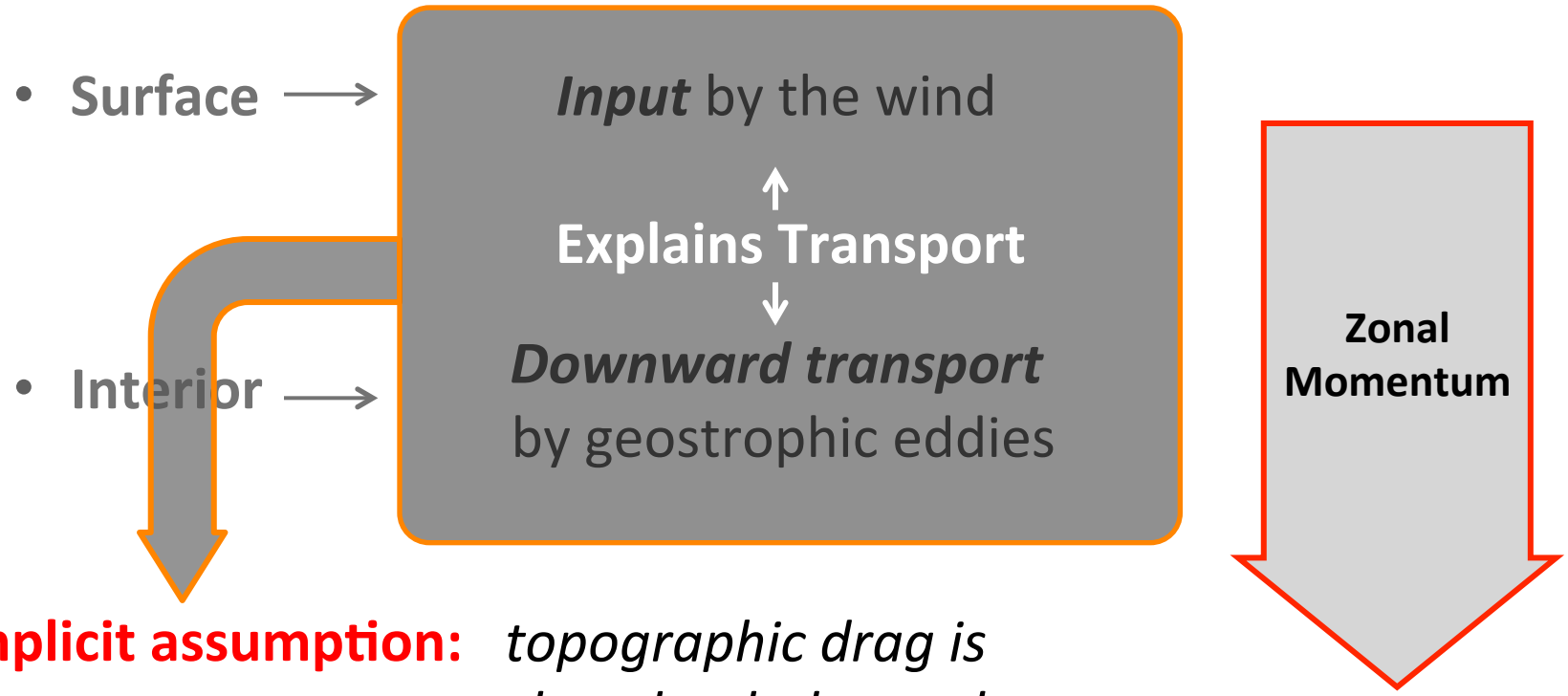
Downward transport
by geostrophic eddies

Zonal Momentum

- **Bottom** ⟶ ***Sink*** by topographic form drag

Introduction

Focus of most recent studies



Implicit assumption: *topographic drag is slaved to balance the downward eddy transport of momentum*

Questions:

- Does the topograghic form drag exert an active control on the (baroclinic) transport?
  - ***yes***
- Is the effect of the topography on the ACC better thought of as a local or a global constraint?
  - ***global***

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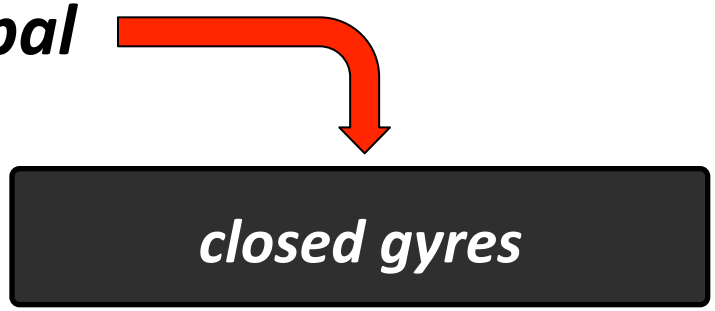
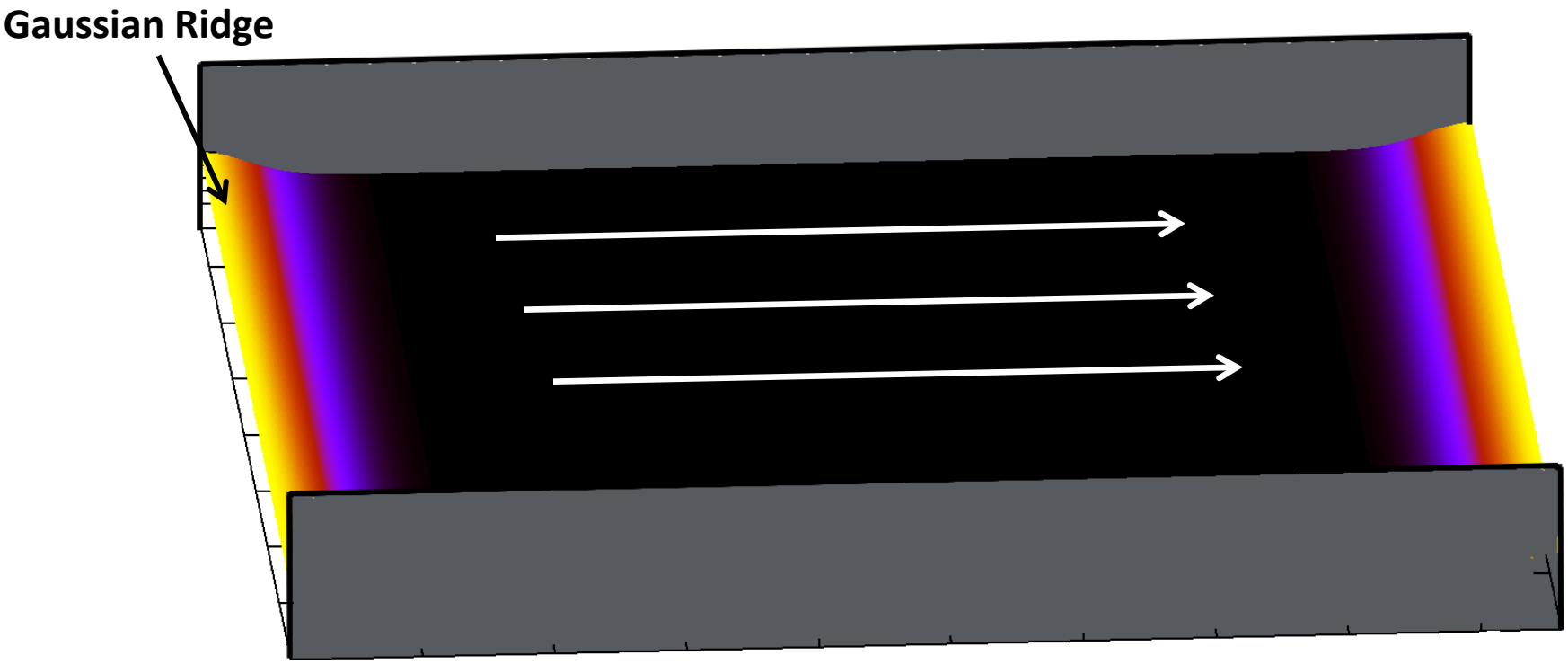


Experimental Setup

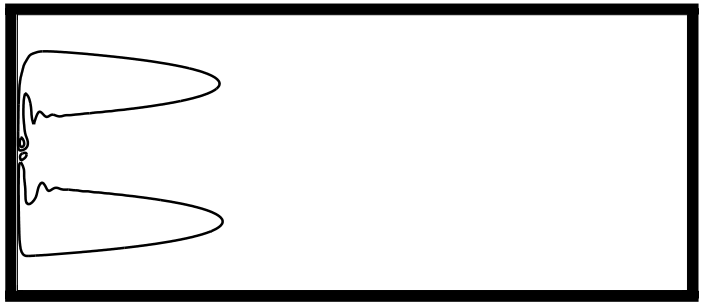
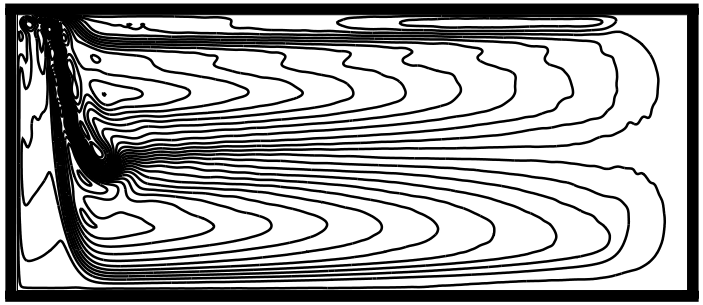
1. **Closed box with topography**
2. **Channel with topography**
3. **Flat bottom Channel**

- **QG** and **Primitive Eq.** numerical simulations
- Wind forcing but **no buoyancy forcing**



Closed Gyres

Barotropic Streamfunction

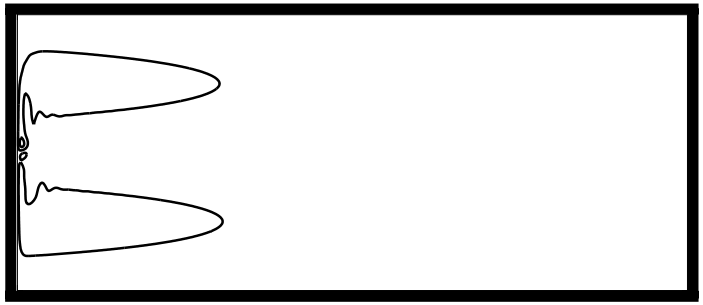
	Weak Forcing	Strong Forcing
Box + Ridge		
Channel + Ridge		
Channel Flat		

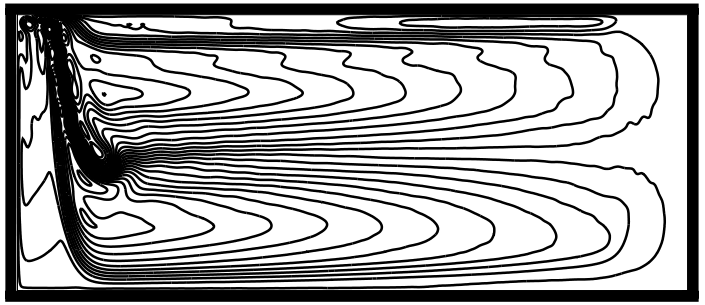
Closed Gyres

Weak Forcing

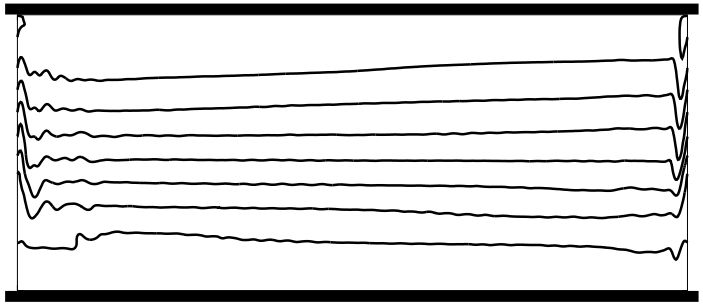
Strong Forcing

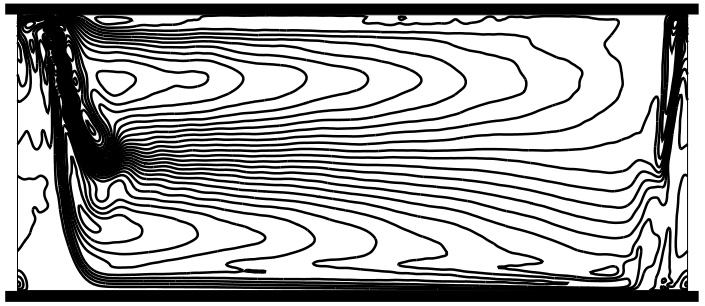
Box
+ Ridge





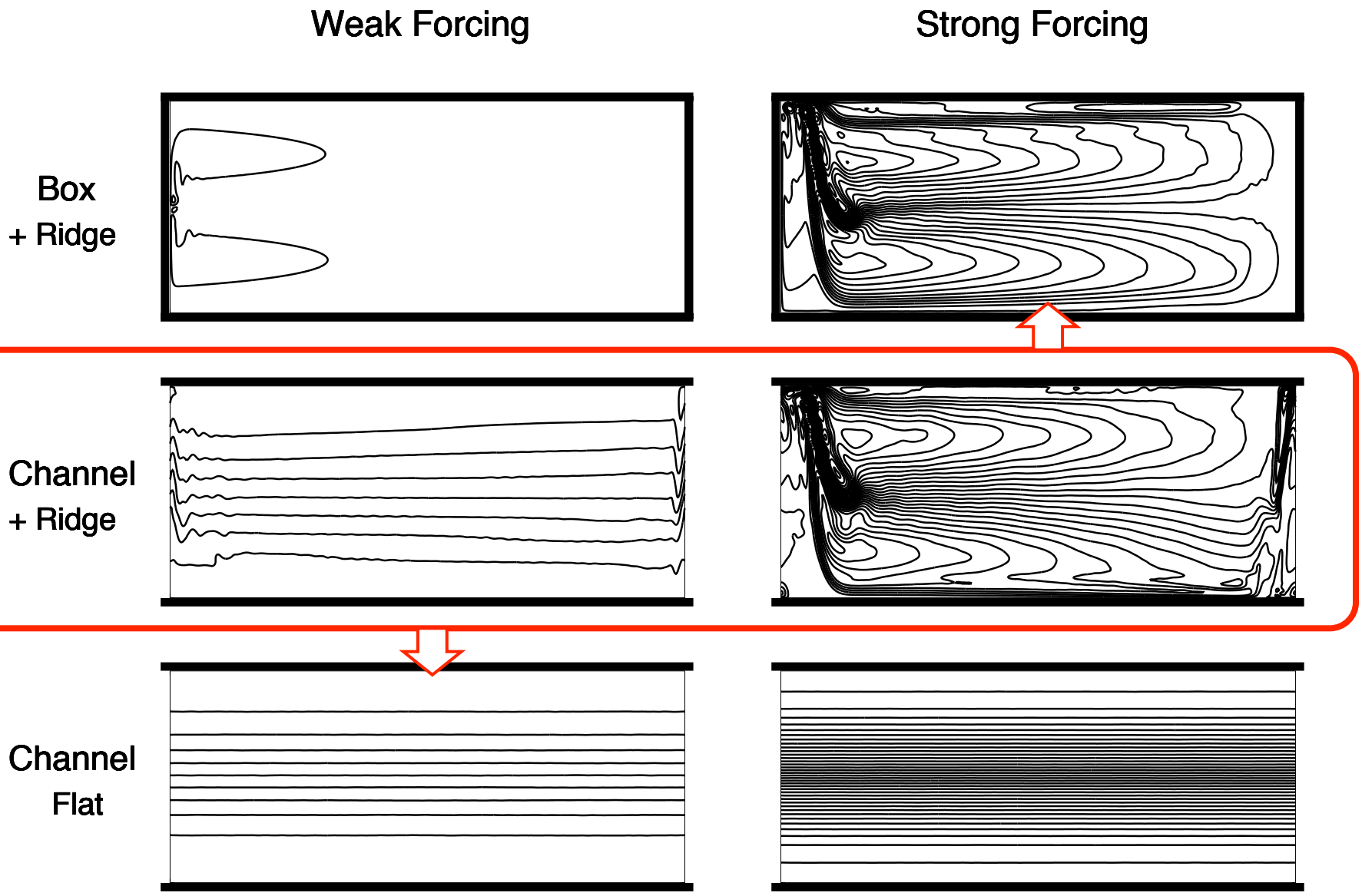
Channel
+ Ridge





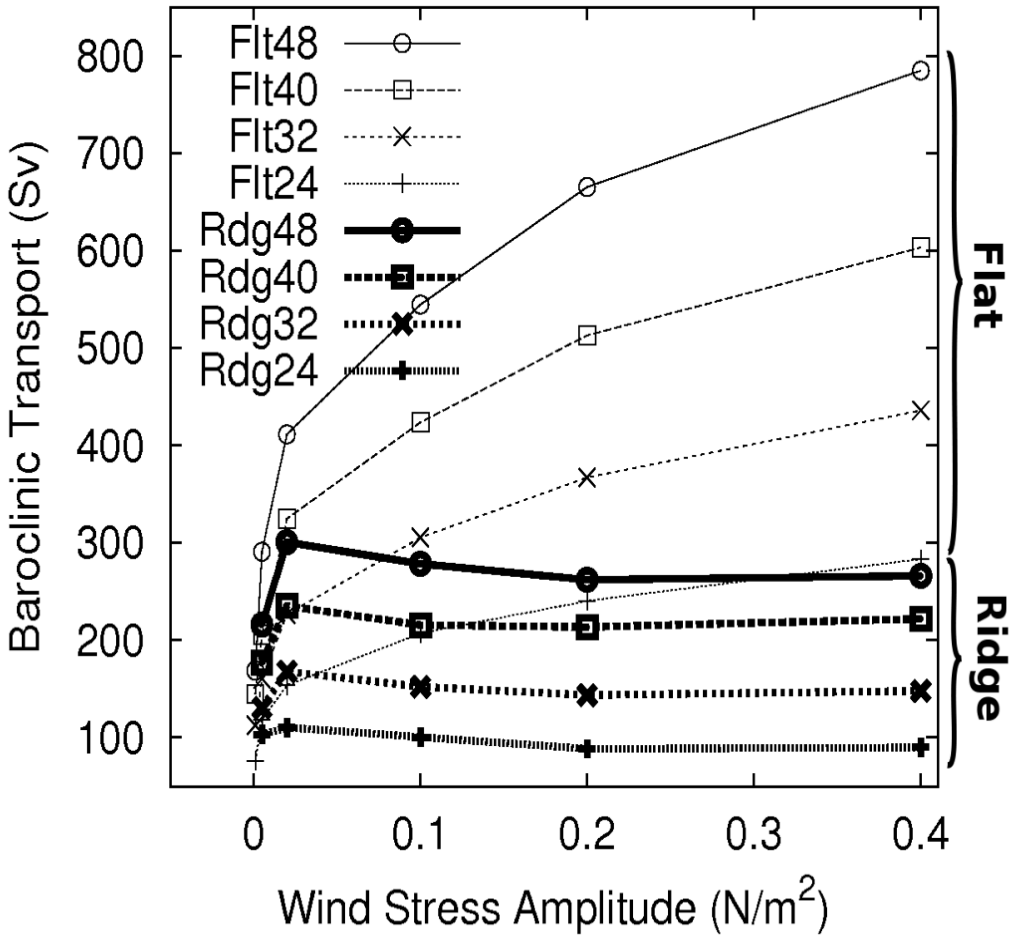
Channel
Flat

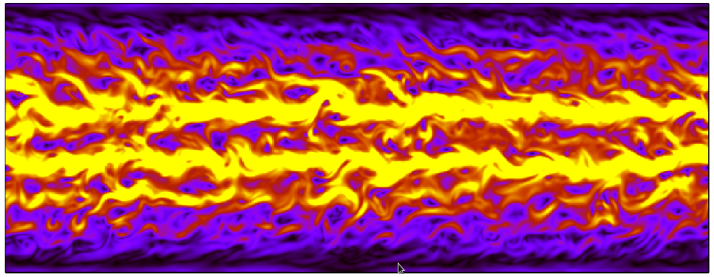
Closed Gyres



Comparison Flat and Ridge

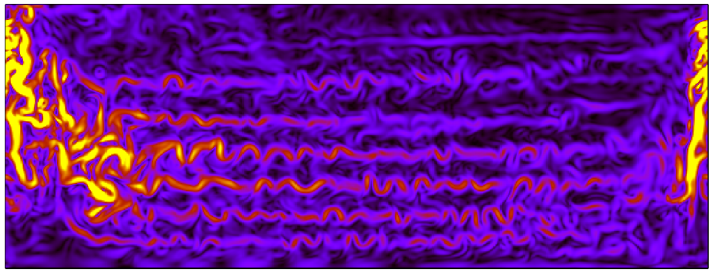
Baroclinic Transport



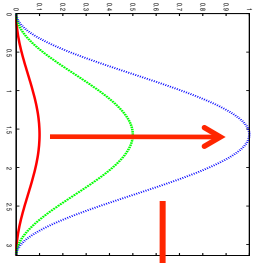


Flat Bottom: $T \sim \tau^{0.2}$

Gaussian Ridge: Saturated Transport

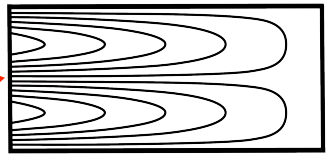


Closed Gyres



Gaussian Ridge: Saturated Transport

$$\psi_{SV}(x,y) = -\frac{1}{\rho_0 H \beta}\int_x^{L_x} \mathrm{curl}_z \boldsymbol{\tau}\ \mathrm{d}x$$



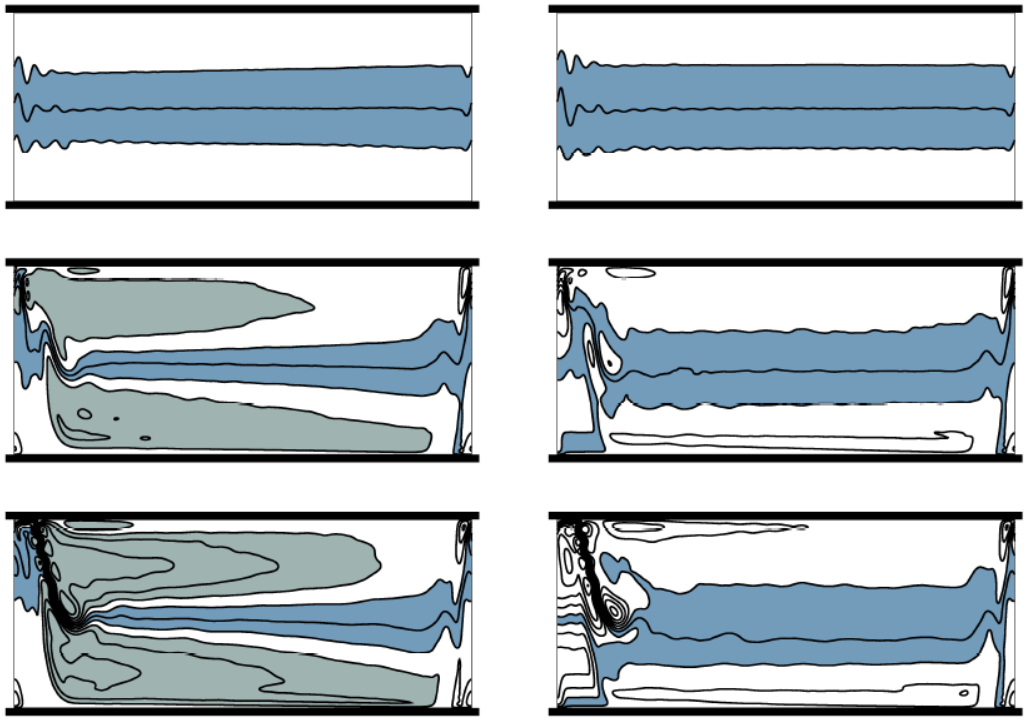
Ψ_{BT} $\Psi_{diff} = \Psi_{BT} - \Psi_{Sv}$

Wind Forcing

τ_0=0.02

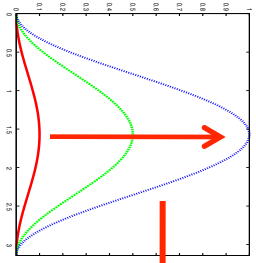
τ_0=0.2

τ_0=0.4



Primitive Equations τ_0=0.4

Closed Gyres



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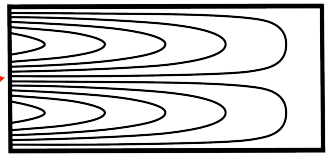

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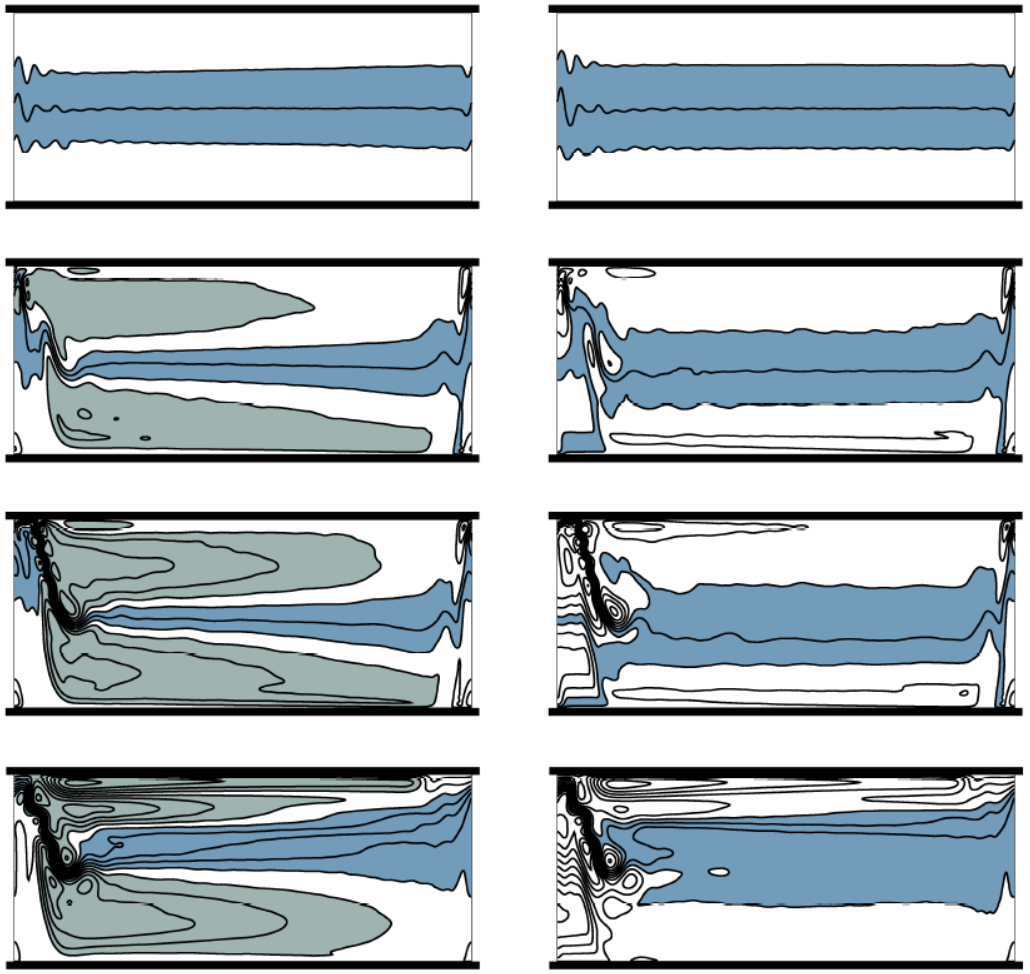
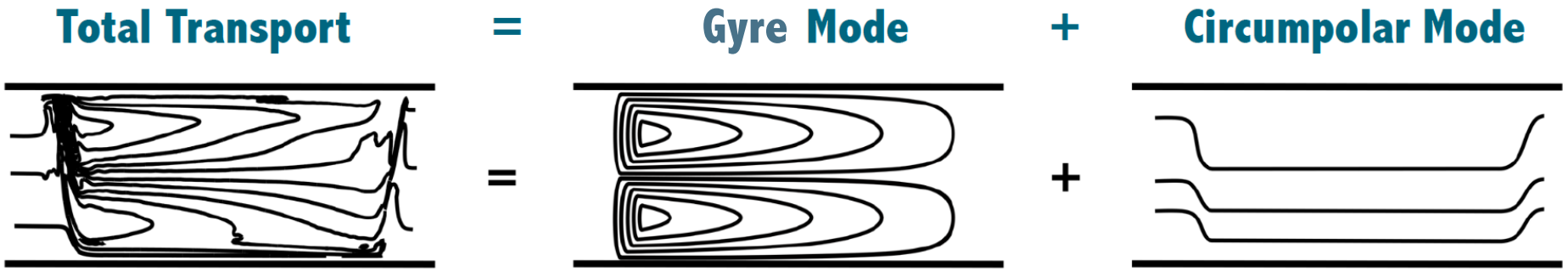


Decomposition Hypothesis

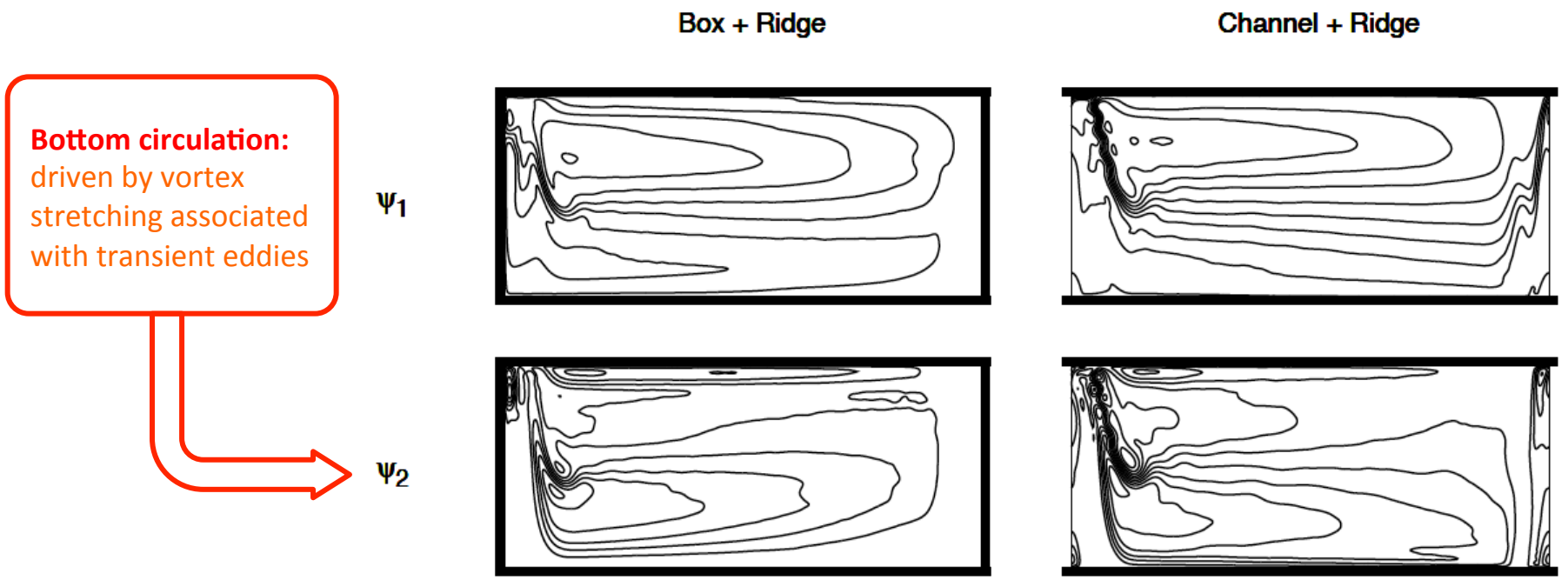
Hypothesis



Total barotropic streamfunction can be decomposed in a **"gyre mode"** (Sverdrup gyres), contributing no barotropic transport, and a **"circumpolar mode"**, contributing all barotropic transport.

Role of eddies

Vertical Structure of the Sverdrup Flow



Bottom circulation: driven by vortex stretching associated with transient eddies

Physical Mechanism:

Eddy driven bottom circulation sustains **topographic form drag** that balances wind stress and causes transport saturation

Eddy Momentum Transfer

Dominant zonal momentum balance at statistical equilibrium

Reynolds Interfacial Wind

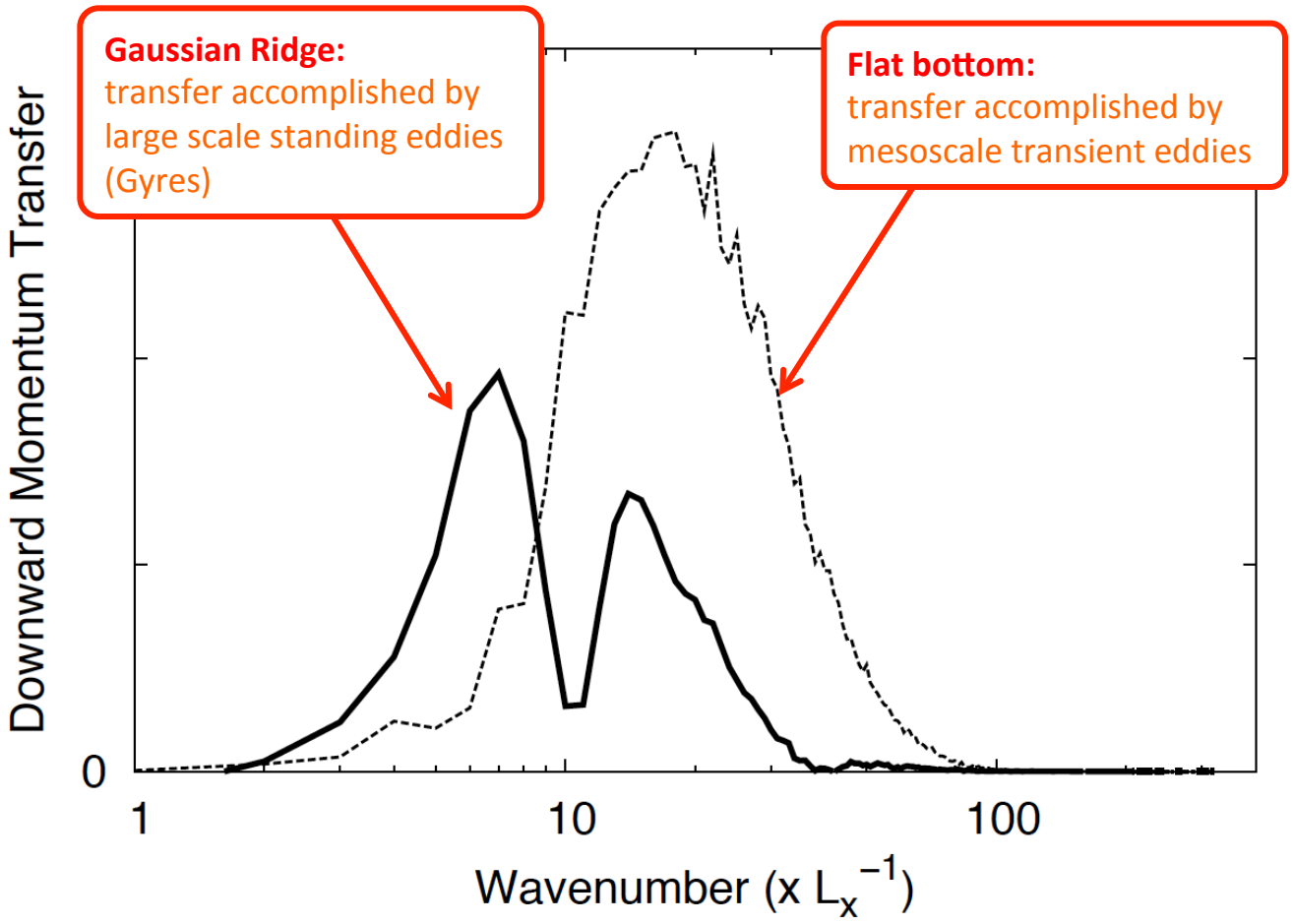
Upper: $$\langle \psi_{1x}\psi_{1yy}\rangle - \frac{f_0^2}{g'H_1}\langle \psi_2\psi_{1x}\rangle = \frac{1}{\rho_0 H_1}\langle \tau\rangle = 0$$

Lower: $$\langle \psi_{2x}\psi_{2yy}\rangle - \frac{f_0^2}{g'H_2}\langle \psi_1\psi_{2x}\rangle + \frac{f_0}{H_2}\langle \psi_{2x}h_b\rangle = 0$$

Topographic

Eddy Momentum Transfer

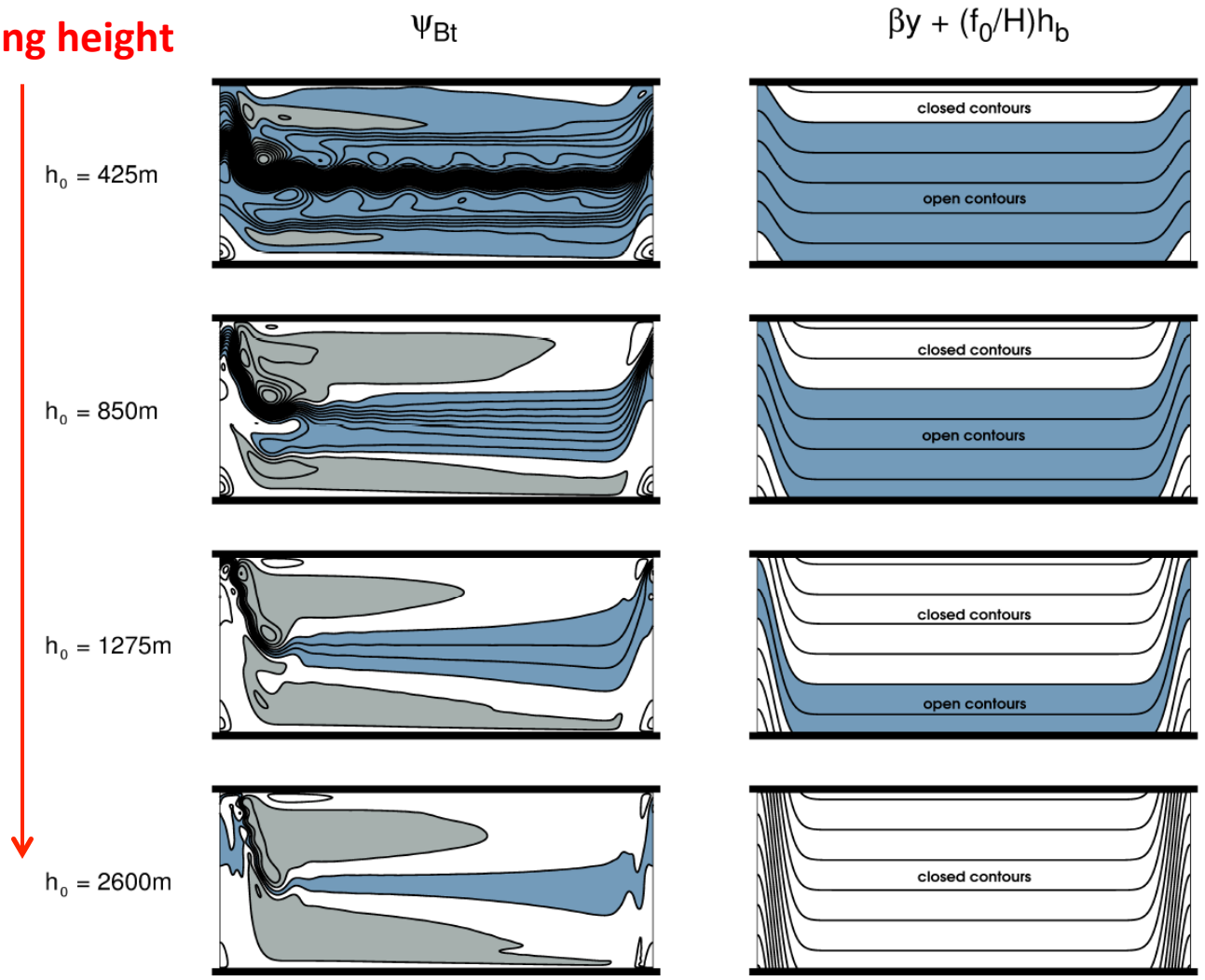
Spectral decomposition according to zonal wavenumber of the interfacial form stress term



Effect of the ridge height

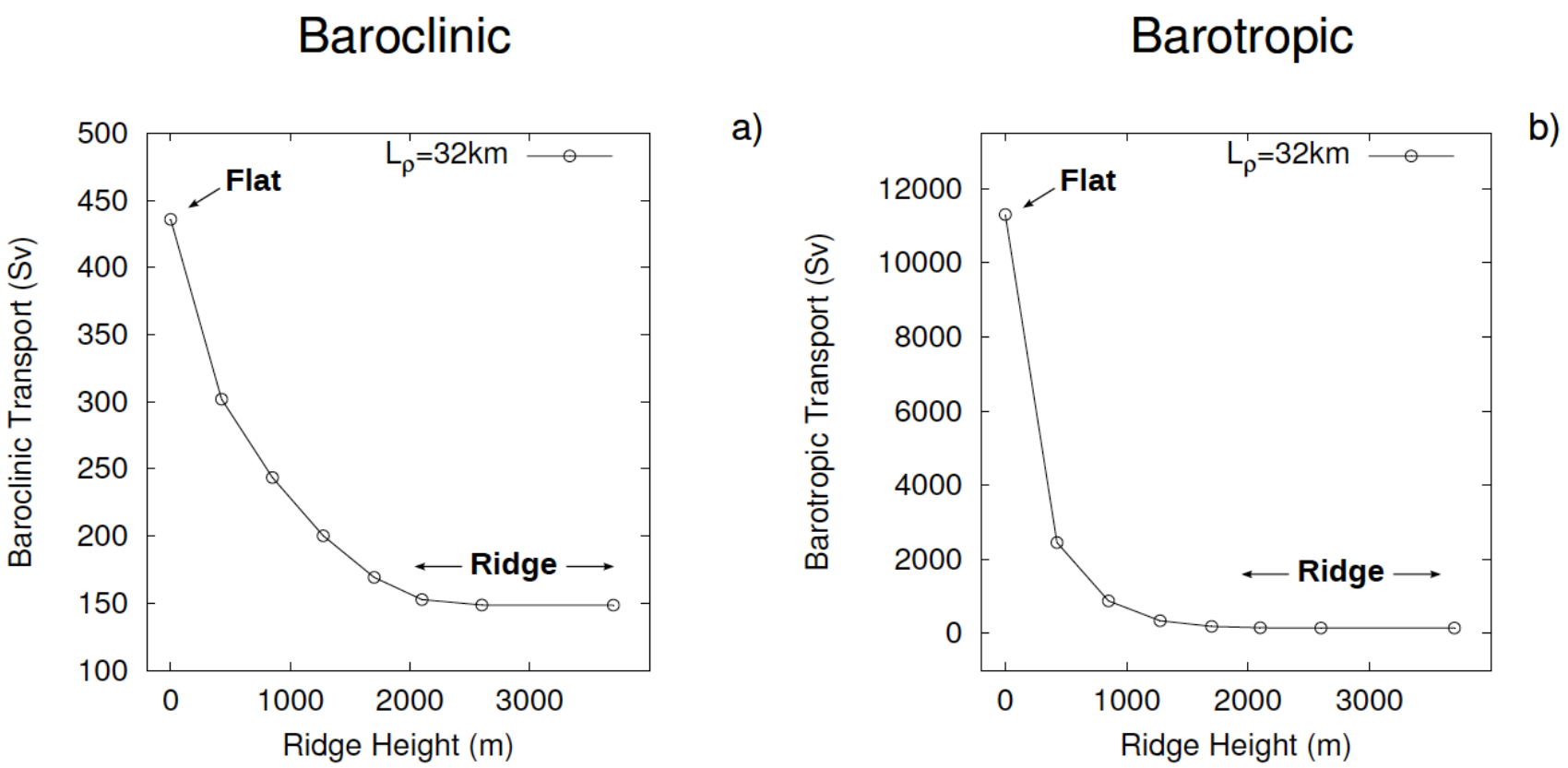
Why do we observe gyres in an open channel?

If topogrophy is sufficiently steep to bring geostrophic contours close together, a frictional boundary layer develops that acts as an "effective wall".



Effect of the ridge height

Effect of the Ridge height on the transport

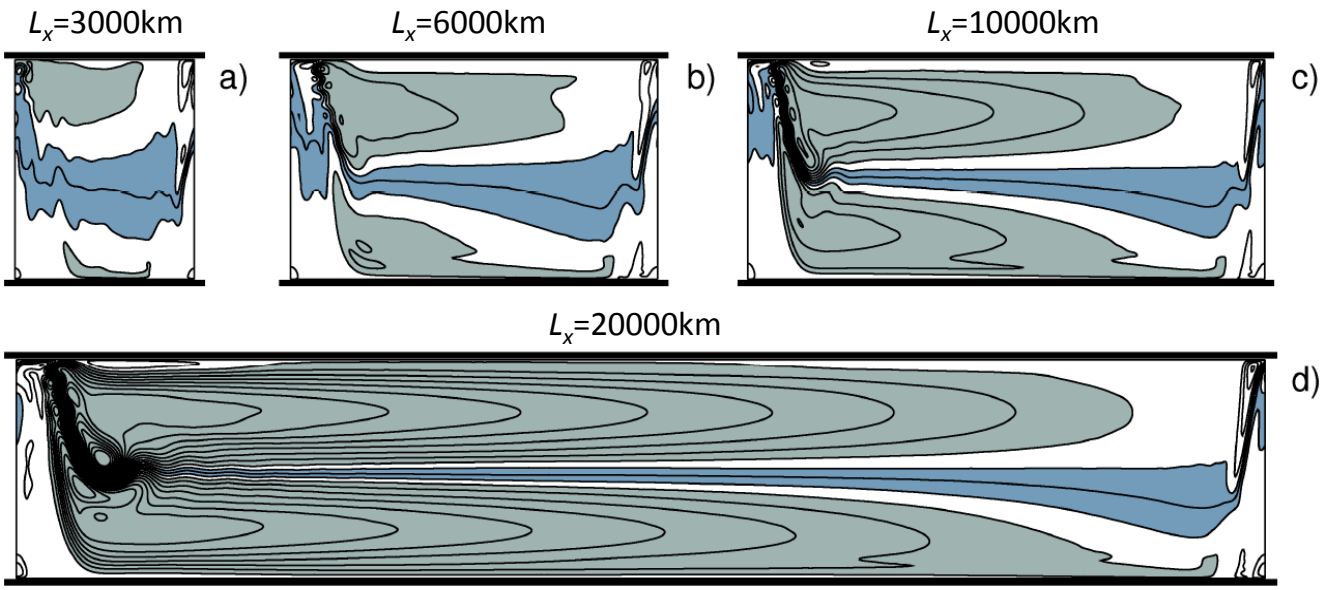


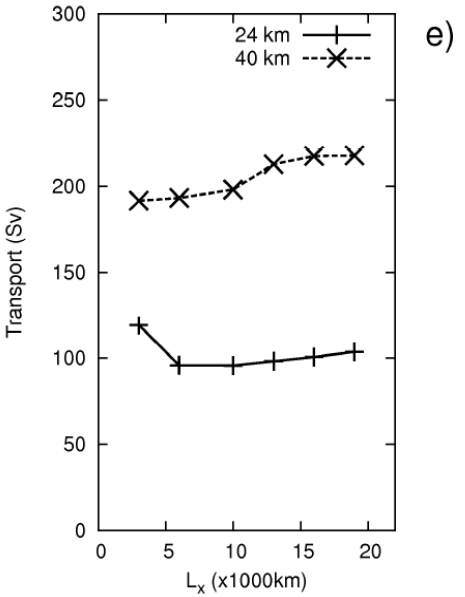
Effect of the Channel Length

Varying Channel Length: modes can be decoupled

Gyre mode increases increases with L_x

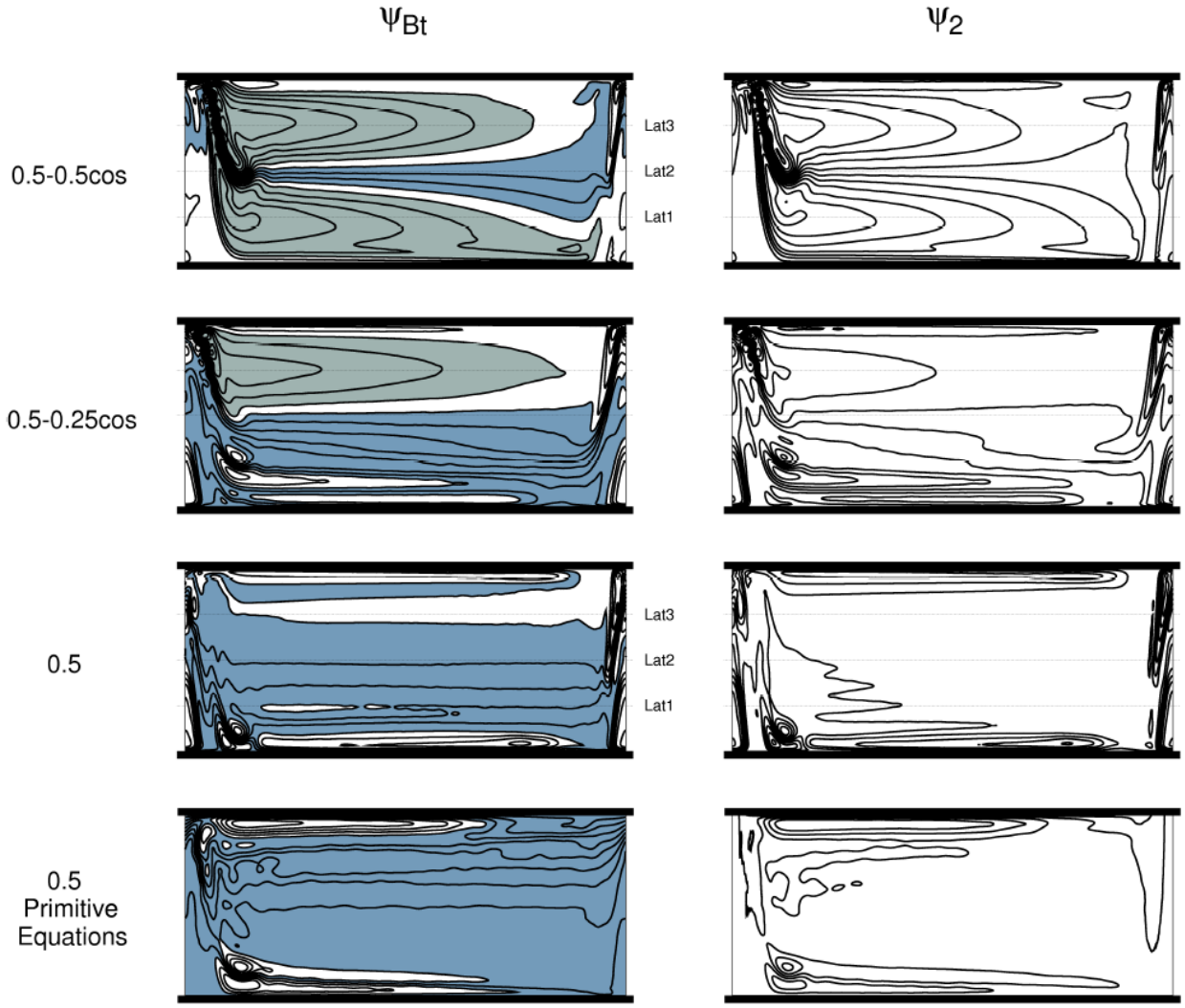
Circumpolar mode independent of L_x

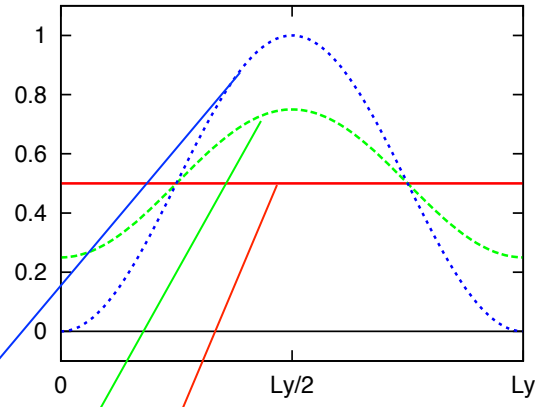




Effect of the wind stress curl

Varying wind stress curl
for a fixed averaged wind stress





Less bottom circulation

Less Topographic form drag

Effect of the wind stress curl

Varying wind stress curl
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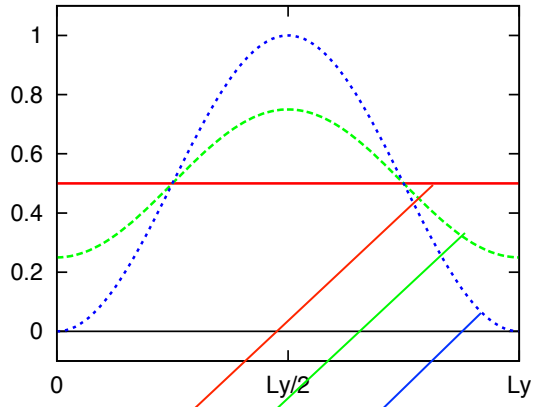
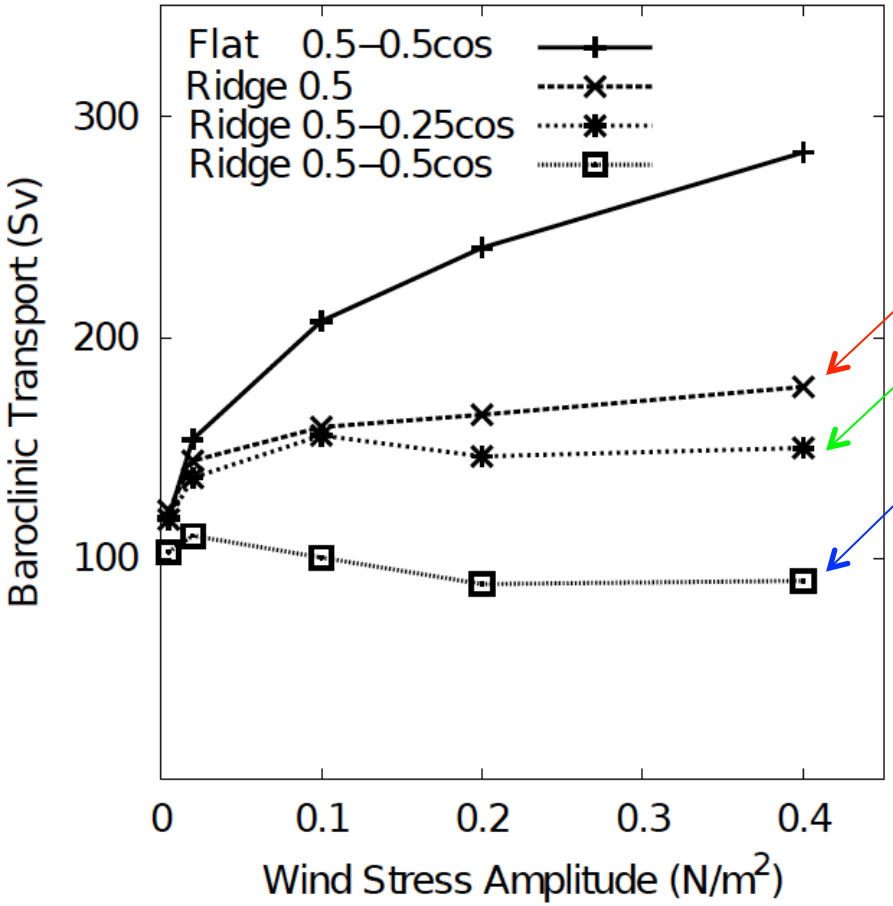
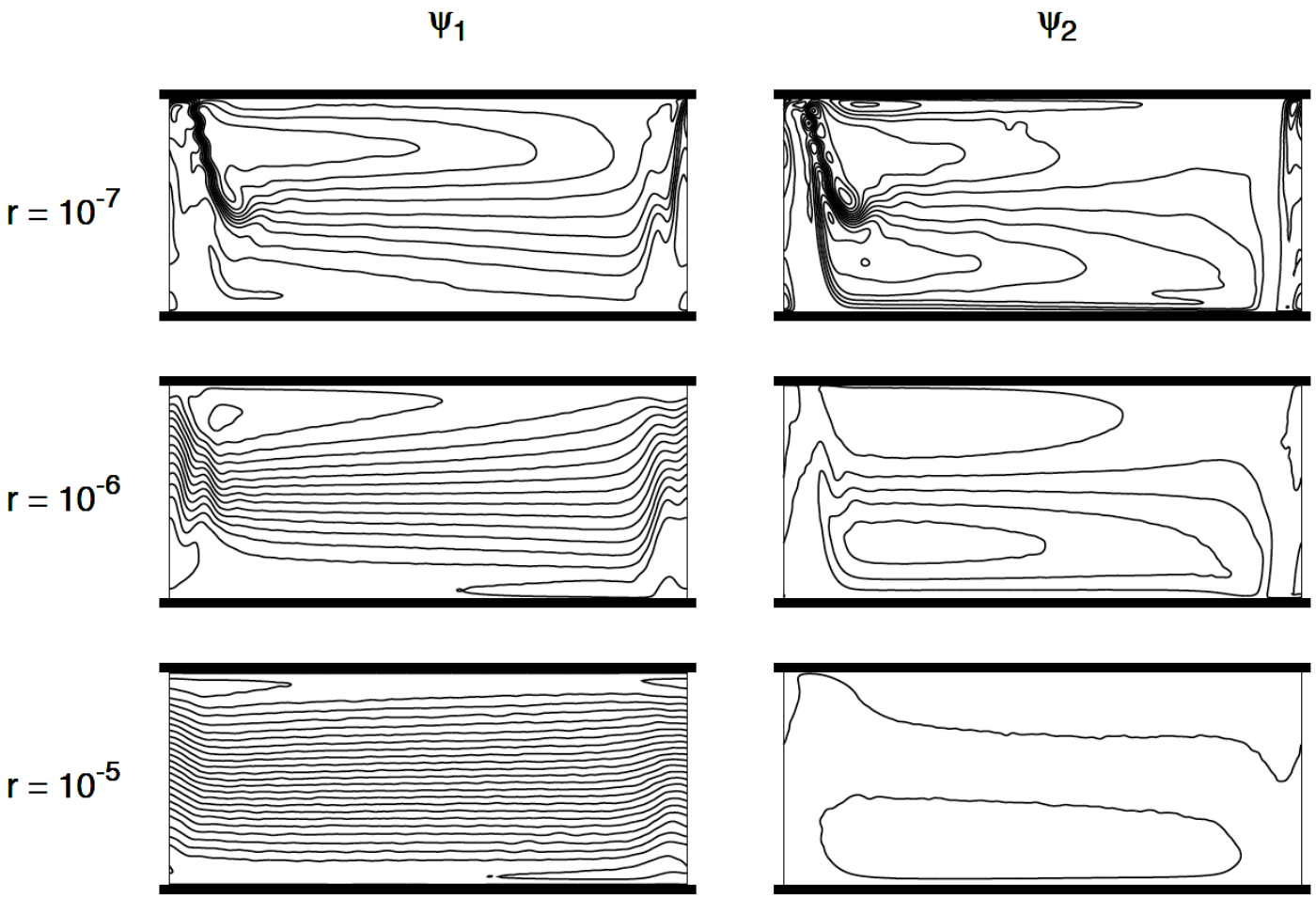




Effect of the Bottom Friction

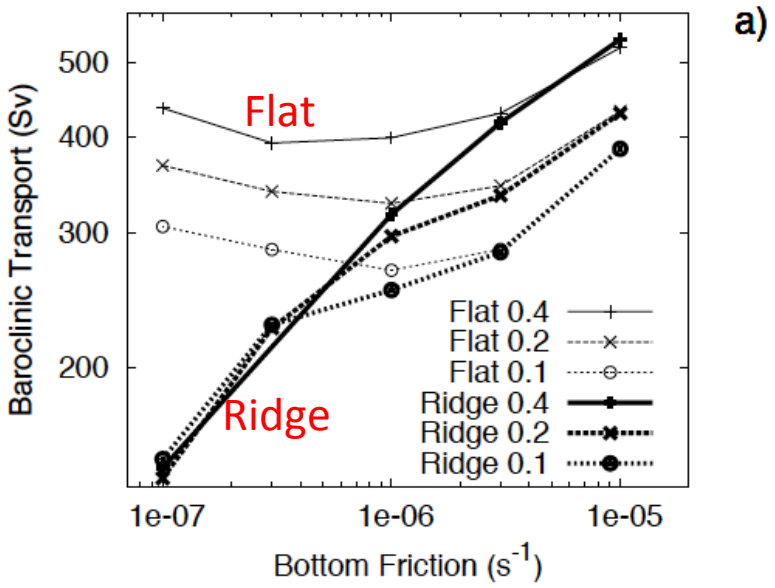
Bottom Friction



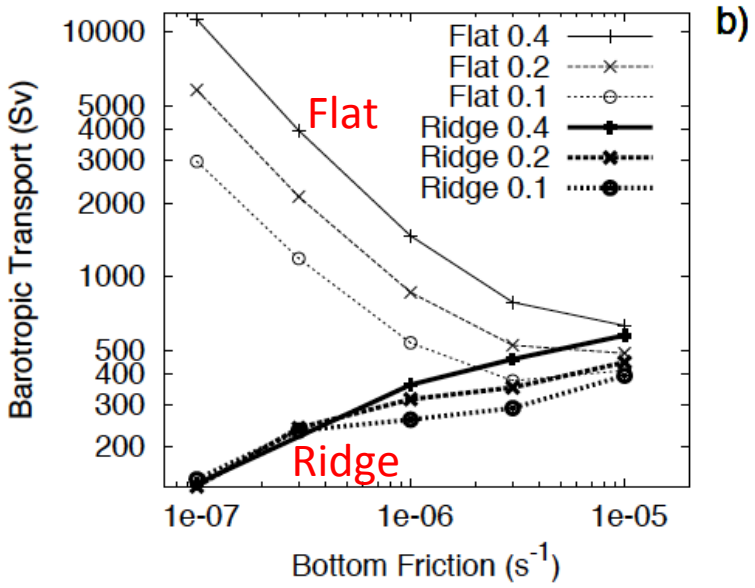
Effect of the Bottom Friction

Bottom Friction

Baroclinic



Barotropic

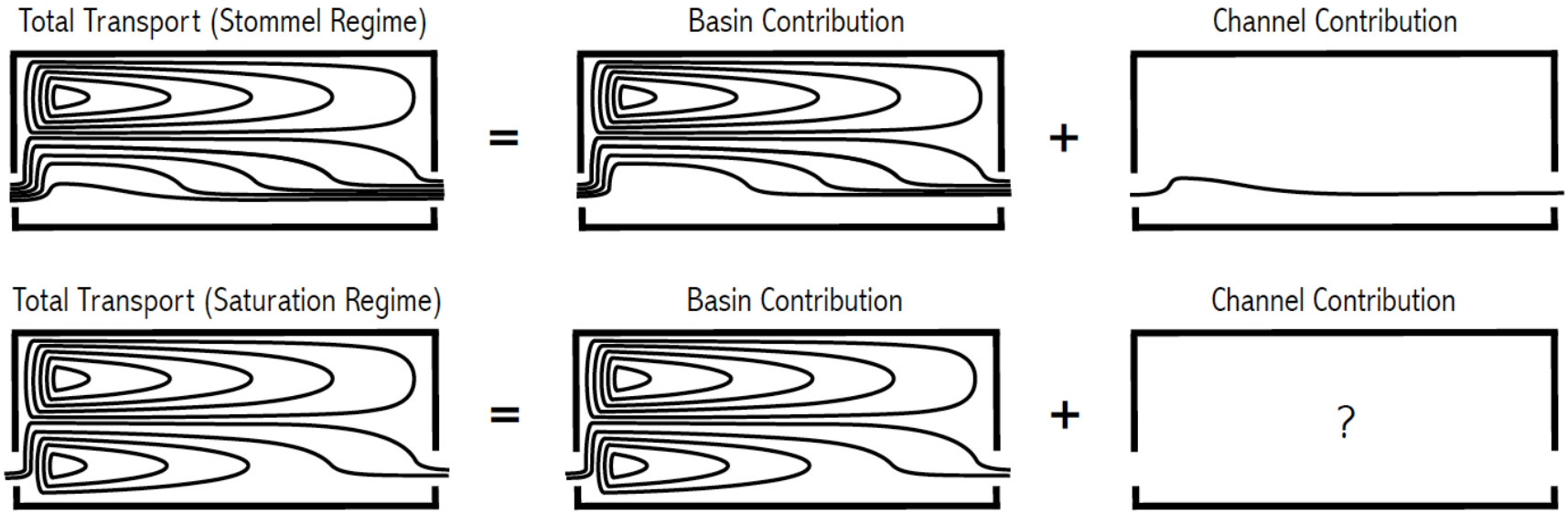


Summary

- Closed **recirculating gyres** develop in the lee of major topographic ridges.
- Circulation can be decomposed in a **gyre mode** and a **circumpolar mode**.
- Each **mode can be decoupled** (can favor one mode without affecting the other).
- However, specific effect of the form drag generated by the gyre mode onto the circumpolar mode is still not clearly defined.

Summary

Initial hypothesis



Revised hypothesis