Some Outstanding Issues in the Jet Formation Mechanisms

Da Zhu

Department of Geophysical Sciences,

University of Chicago

Advisor: Noboru Nakamura

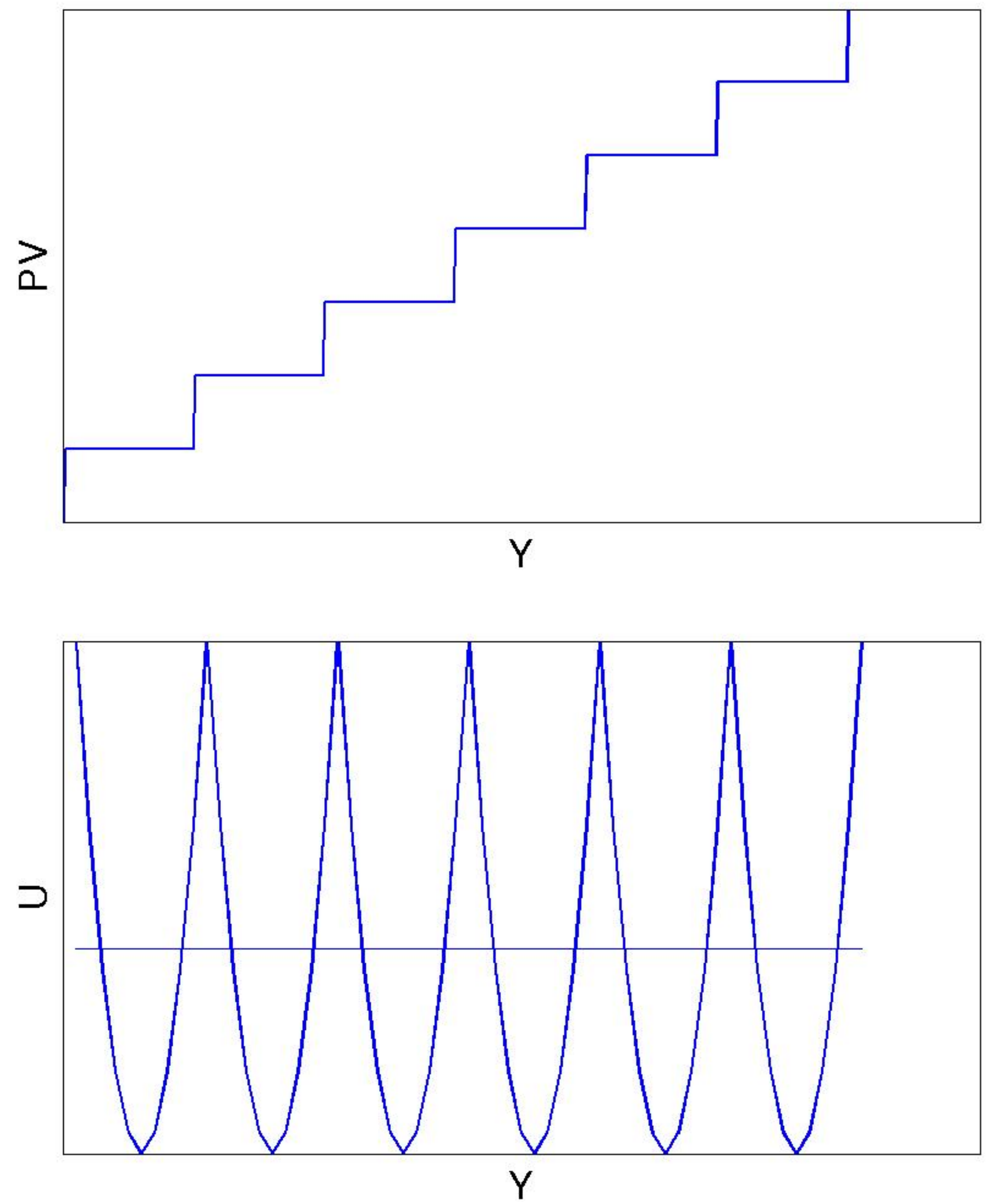
Brief Survey of Jovian Atmosphere

- Gas giant planet
- Convective interior with high temperature ($\sim 10000K$)
- Six alternating jets in each hemisphere

Two perspectives concerning the jet formation in Jupiter's weather layer:

- geostrophic turbulence on $\beta-$plane (Rhines, JFM, 1975;Williams, JAS, 1978,1979; Maltrud, M. and G.K. Vallis. Physics of Fluids A, 1993)

- Potential Vorticity (PV) staircase model
  - turbulence-PV mixing feedback (Baldwin et al, Science, 2007)
  - formation of westly jets and PV mixing (Dritschel and McIntyre, JAS, 2008)



schematical illustration of $u(y)$ for infinite number of PV steps

Different emphasis of these two perspectives

- Geophysical Turbulence——small-scale turbulence and large-scale wave-like motion (upscale energy cascade)

- PV staircase model—— understanding the PV structure (and use invertibility to back out flow)

Our goal for this problem

- understand and predict the PV structure

Two experiments

- beta-plane turbulence
- stationary Rossby wave breaking

Geostrophic Turbulence Experiment

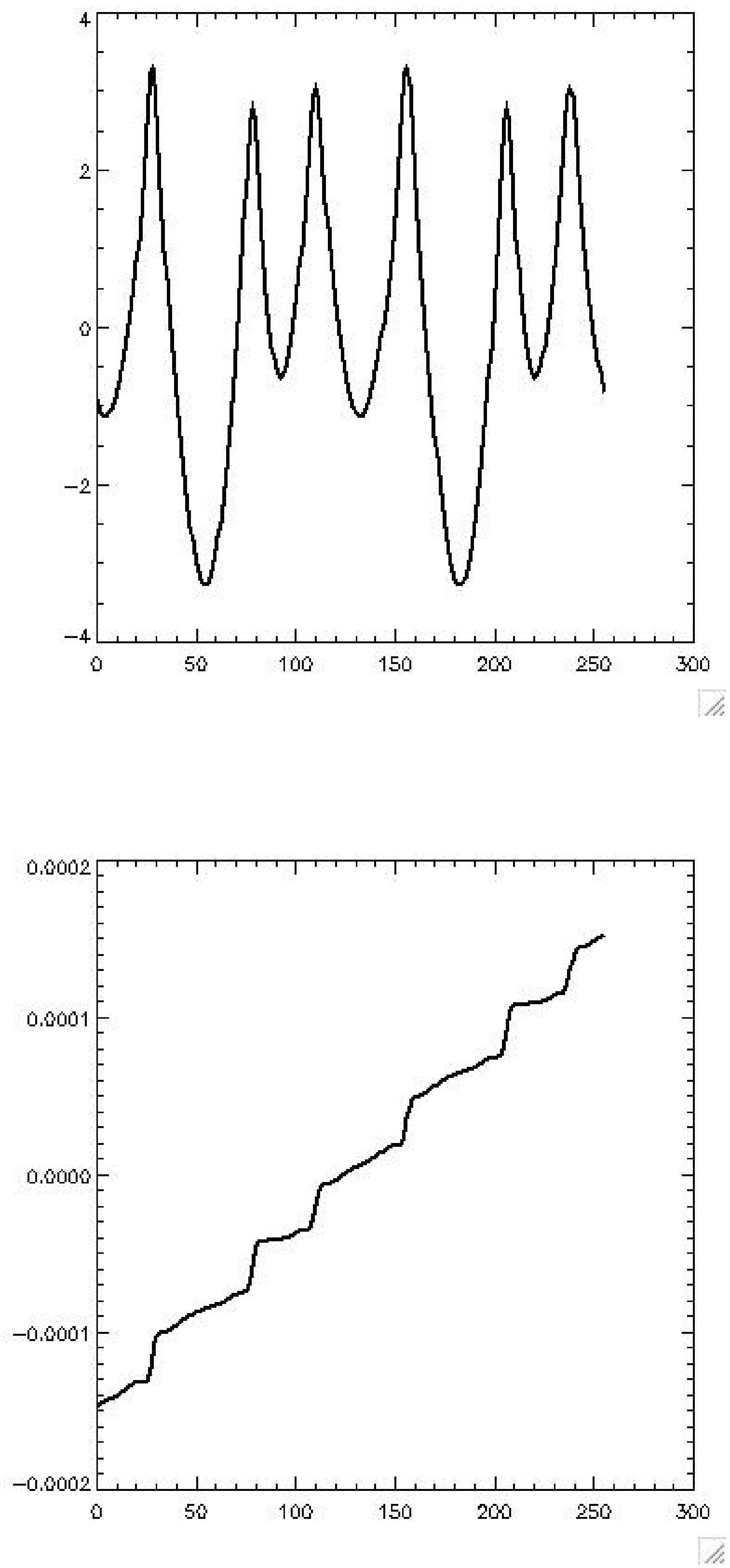
Barotropic Vorticity Equation on $\beta-$plane with isotropic small scale random forcing(F) and linear damping ($\bar{\gamma}$) in the zonal direction

$$\frac{\partial \nabla^2 \psi}{\partial t} + J(\psi, \nabla^2 \psi) + \beta \frac{\partial \psi}{\partial x} = -\nu \nabla^6 \psi + \bar{\gamma} U_y + F$$

- Spatial resolution: 256×256 (T228)

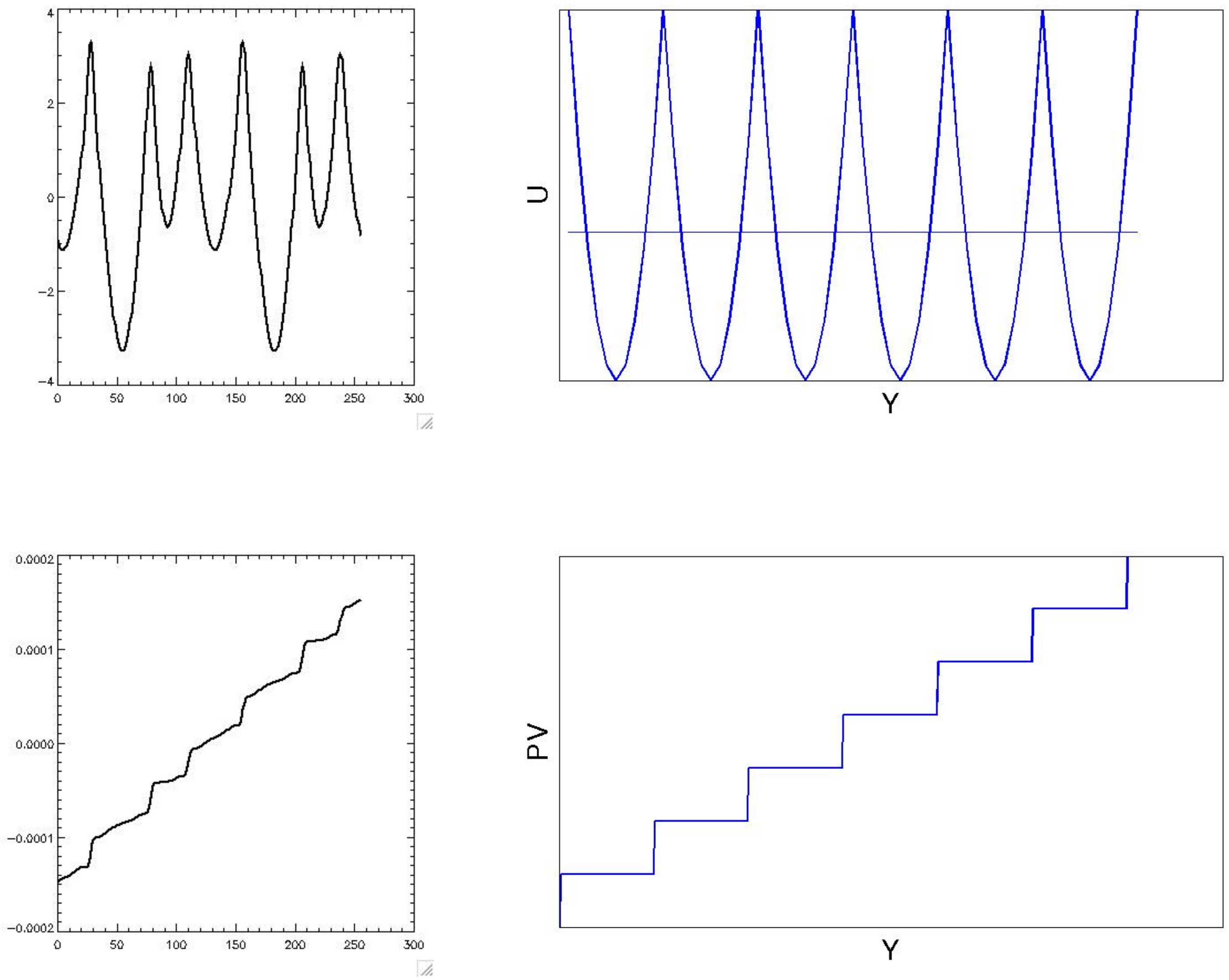
- Periodic in zonal and meridional direction

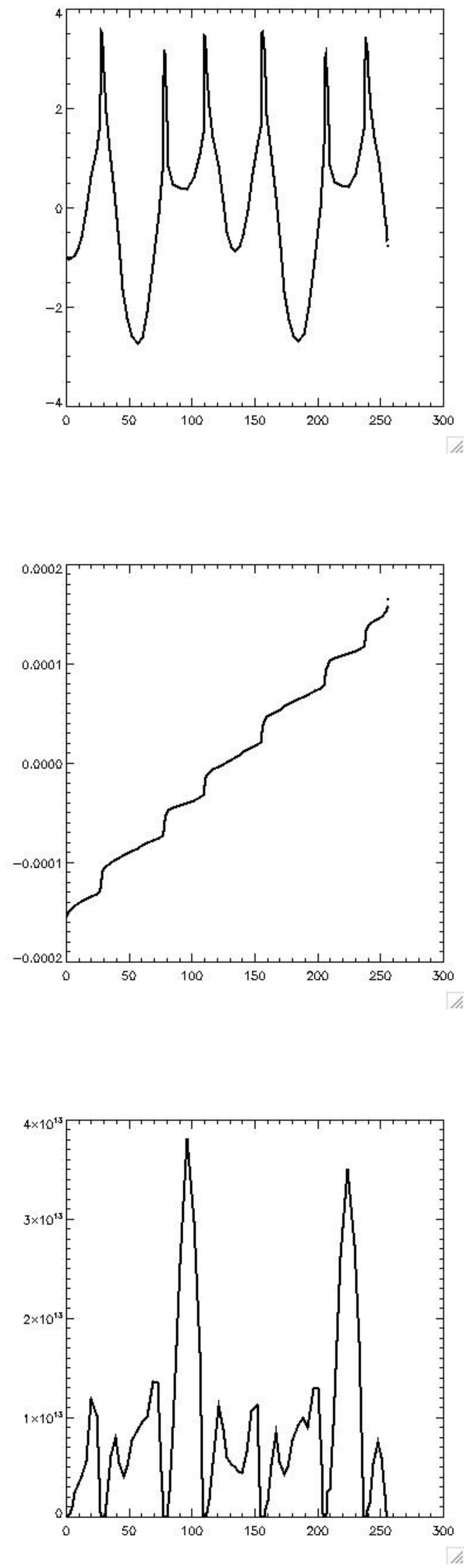
- effect of anisotropic damping is very modest compared to isotropic result (Zhu and Nakamura, AMS poster, 2007; Danilov and Gurarie, Physical Review E, 2002)



time mean zonal mean(TMZM) U and PV vs. latitude

comparison to PV staircase model





TMZM U, PV, effective diffusivity(κ_{eff}) vs. equivalent latitude

Q1: Why is PV not homogenized between the steps in the geostrophic turbulence? Is it due to relaxation ($\bar{\gamma}$)?

Q2: Is the jet spacing considered to be Rhines scale?

Q3: Is the mixing done by the large scale or small scale eddies?

Rossby Wave Breaking Experiment

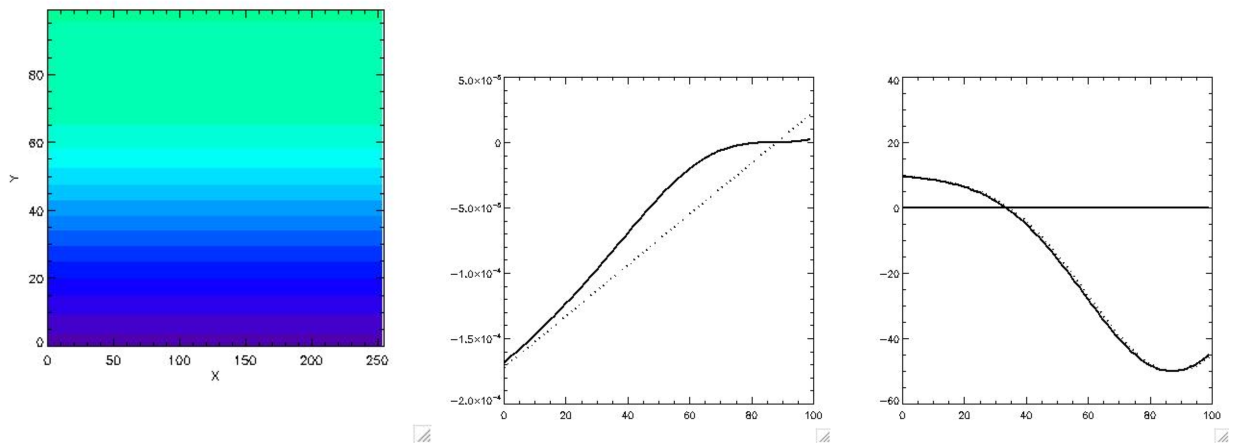
Forced-disspative QG β plane model

$$\frac{\partial \nabla^2 \psi}{\partial t} + J(\psi, \nabla^2 \psi) + \beta \frac{\partial \psi}{\partial x} = -\nu \nabla^6 \psi - T(x, y_0, \delta)$$

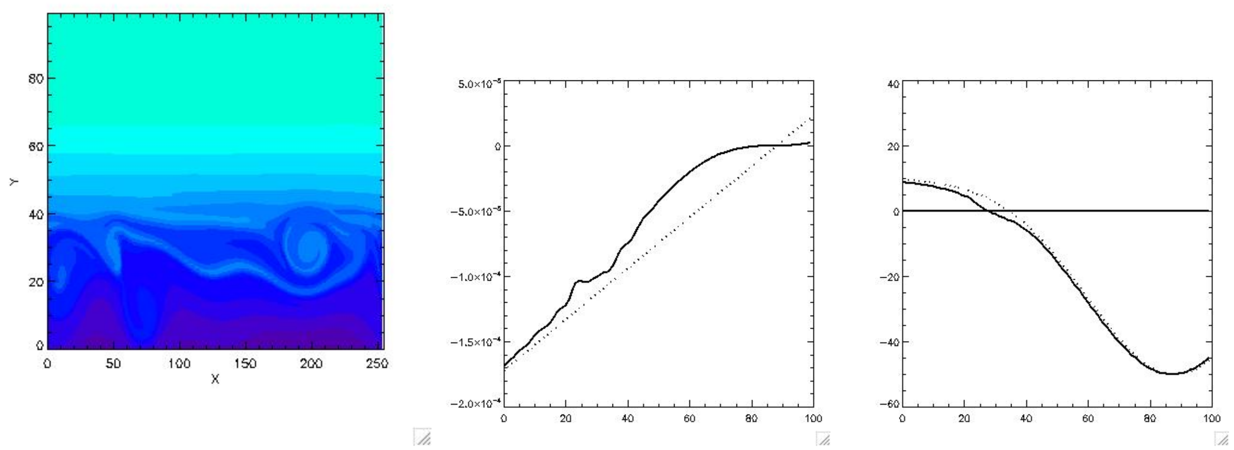
where $T(x, y_0, \delta) = \sin(\hat{k}x)G(y_0, \delta)$ mimics the mountain sinusoidal in x direction and bell-shaped(centered at y_0) in y direction. The wind profile is westly over the mountain.

PV is expected to be irreversibly rearranged and mixed at the critical latitude $U = 0$.

PV contours / zonal mean PV / zonal mean U



t=0



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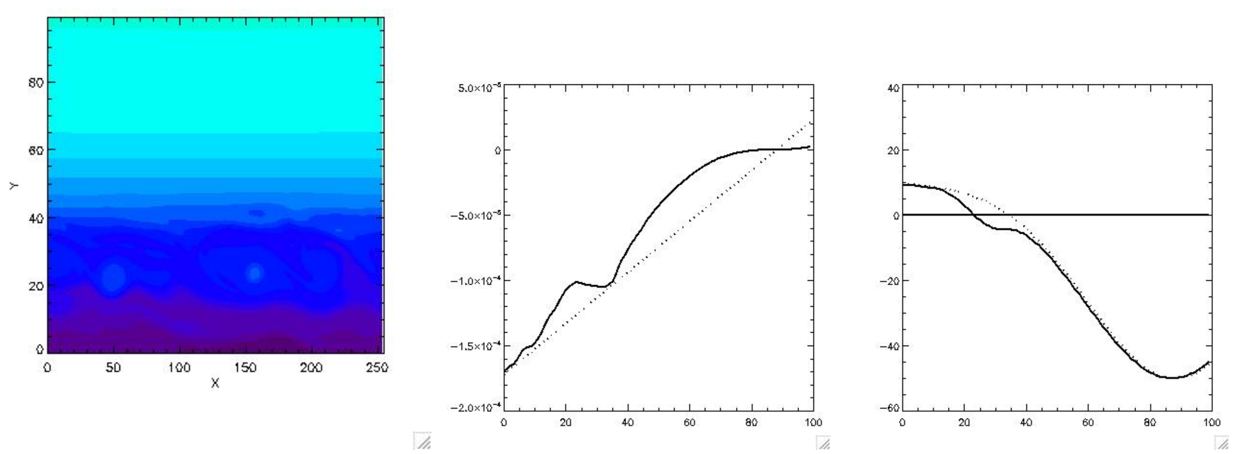
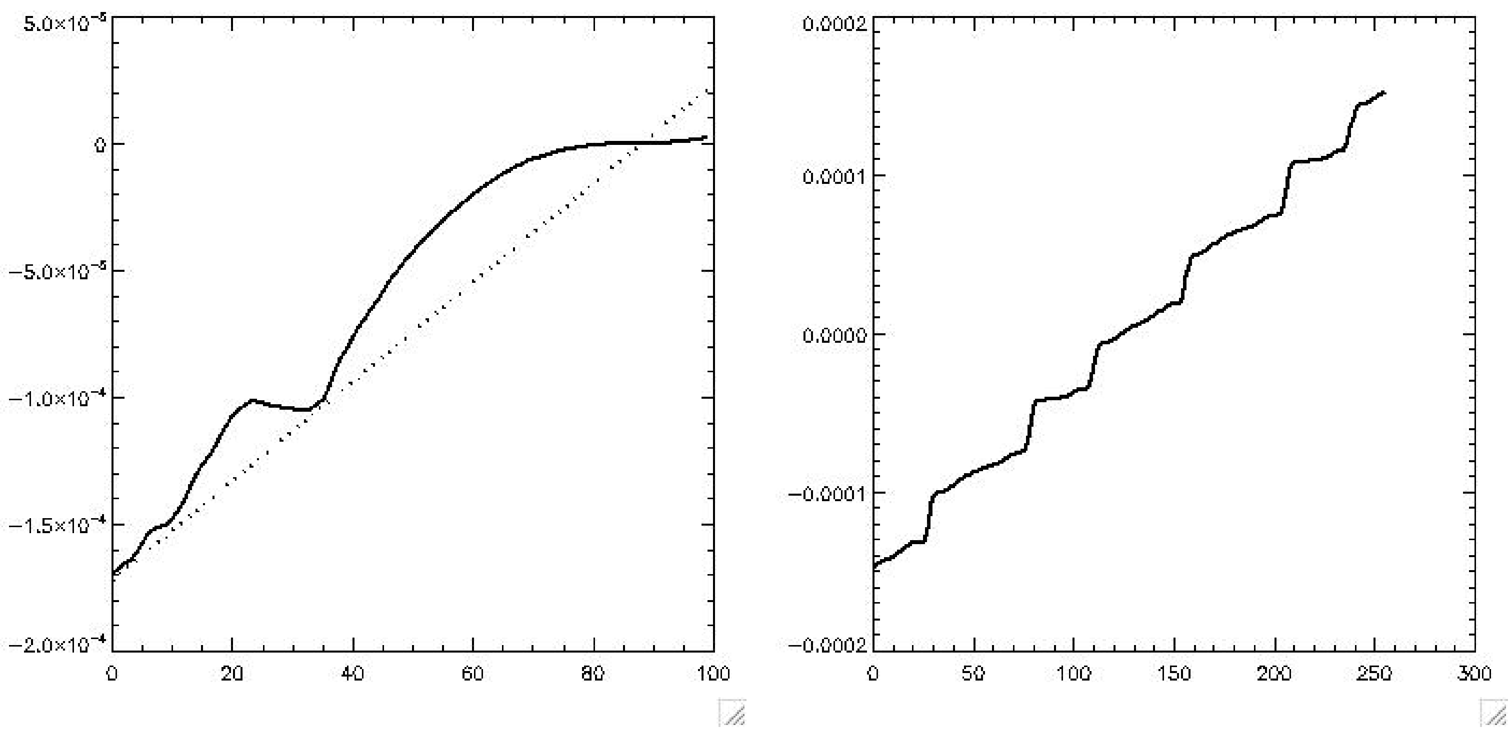


t=78000

comparison to beta-plane results



1-D Diffusion-Reaction Model

Idea: Relaxation($\bar{\gamma}$)+Effective Diffusivity(κ_{eff})$\Rightarrow$ PV slope ?

Governing Equation:

$$0 \approx \frac{\partial q}{\partial t} = \frac{\partial}{\partial y}(K_{eff}(y)\frac{\partial q}{\partial y}) - \gamma(q - \beta y)$$

with boundary Condition:

$$\frac{dq}{dy}(0) = \frac{dq}{dy}(L)$$
$$\frac{d^2q}{dy^2}(0) = \frac{d^2q}{dy^2}(L)$$

(1) Blue dot-dashed—-constant $max(K_{eff})$,γ_1

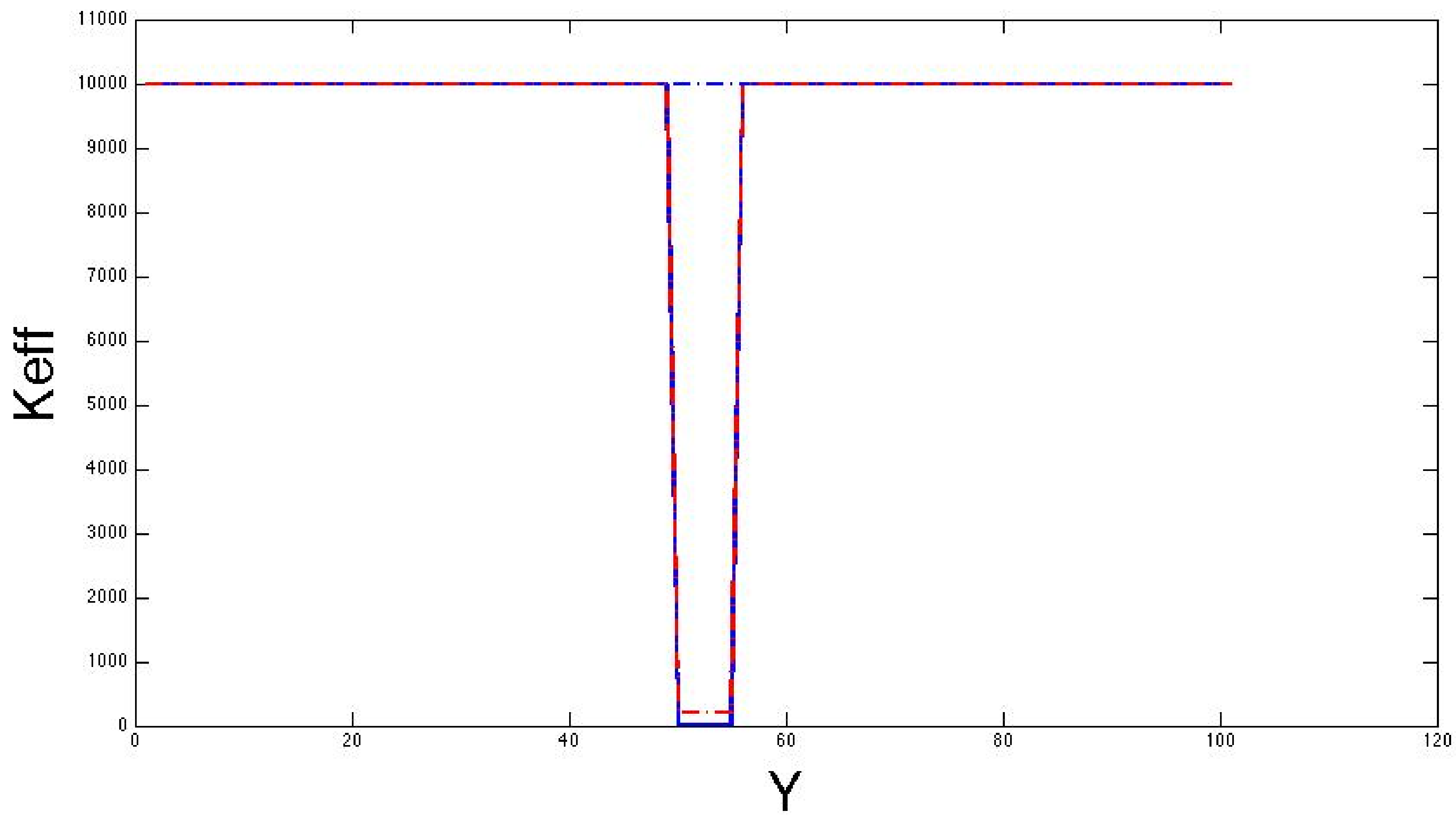
(2) Blue SOLID line——$min(K_{eff1})$,γ_1

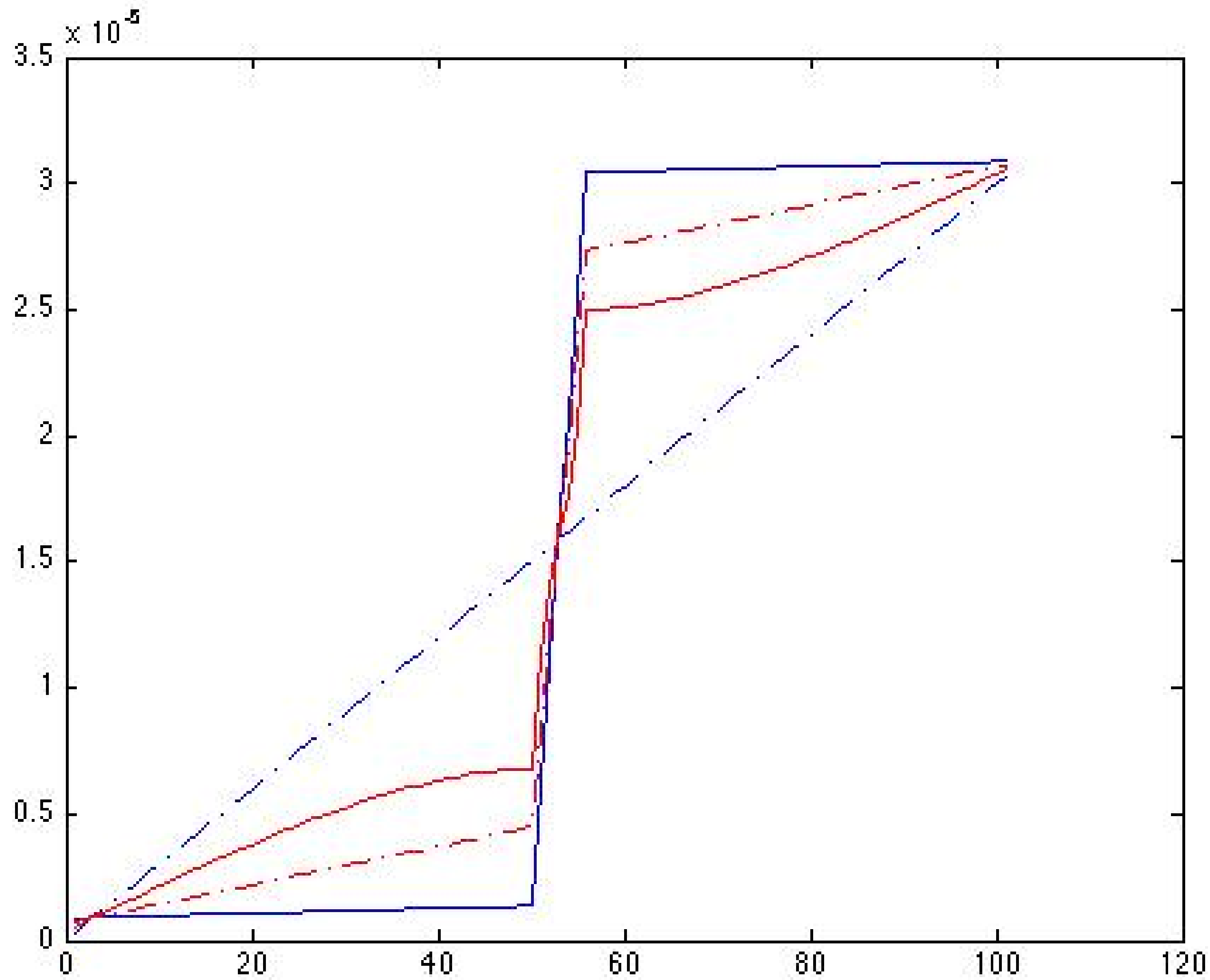
(3) Red dot-dashed line——$min(K_{eff2})$,γ_1

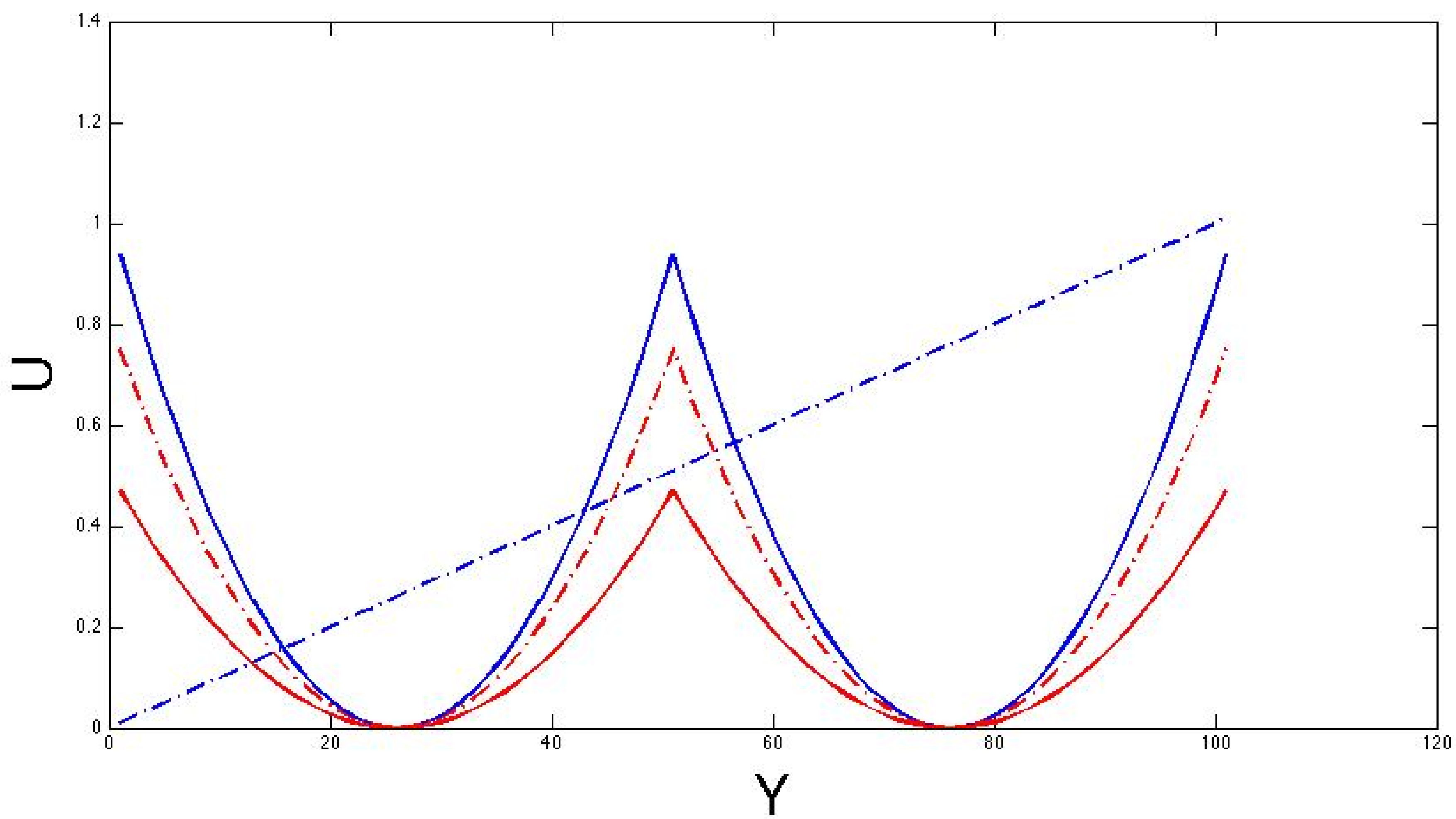
$(min(K_{eff2}) > min(K_{eff1}))$

(4) Red SOLID line——$min(K_{eff1})$,γ_2

$(\gamma_2 > \gamma_1)$




x 10^-5
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
120



1.4
1.2
1
0.8
0.6
0.4
0.2
0
U
0
20
40
60
80
100
120
Y

Summary

- the PV gradient in the surf zone is determined by the combination of the relaxation γ and $min(K_{eff})$, NOT K_{eff} in the surf zone. This finding is consistent with Nakamura's most recent result. (Nakamura, JAS, to appear, 2008)

- getting the "leakiness" of the barriers($min(K_{eff})$)correctly is important to predict PV profile (and hence the flow) correctly.

- Wave-mean flow interaction and barotropic instability might have an important impact in homogenizing the PV within some particular regions.