Mixing in a Dynamic Quadrupole Model

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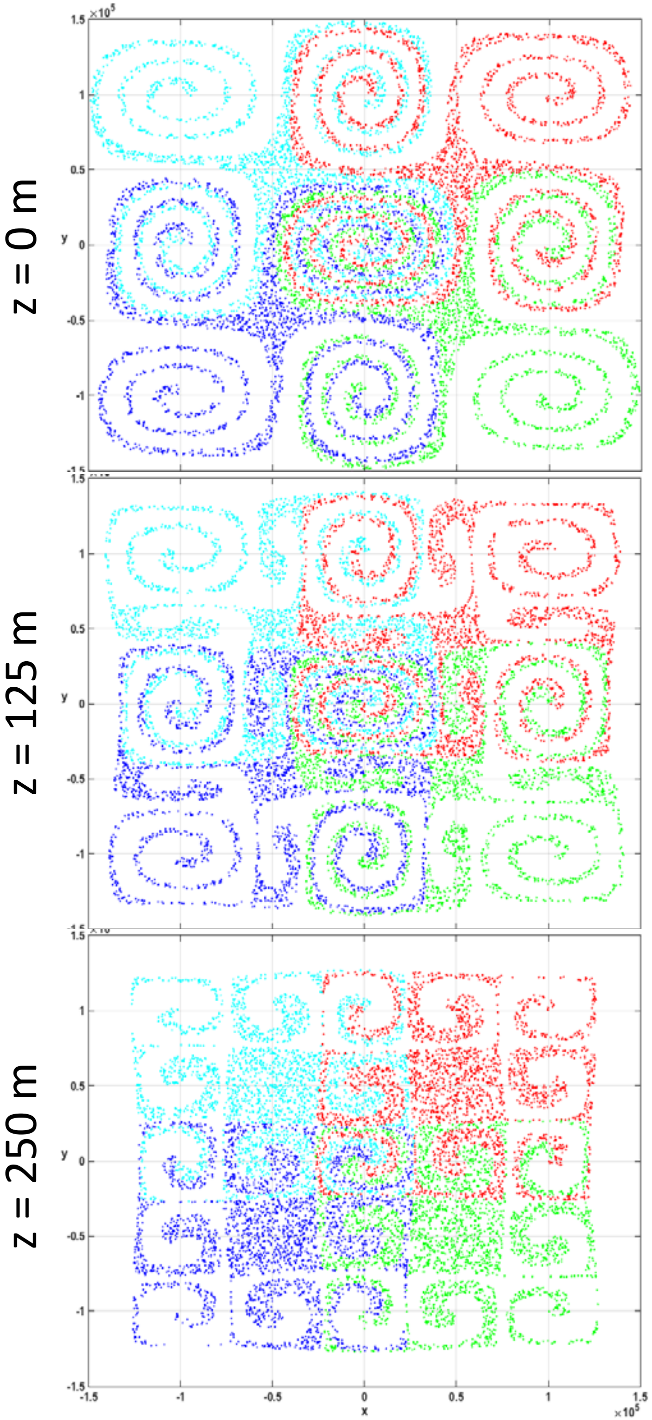
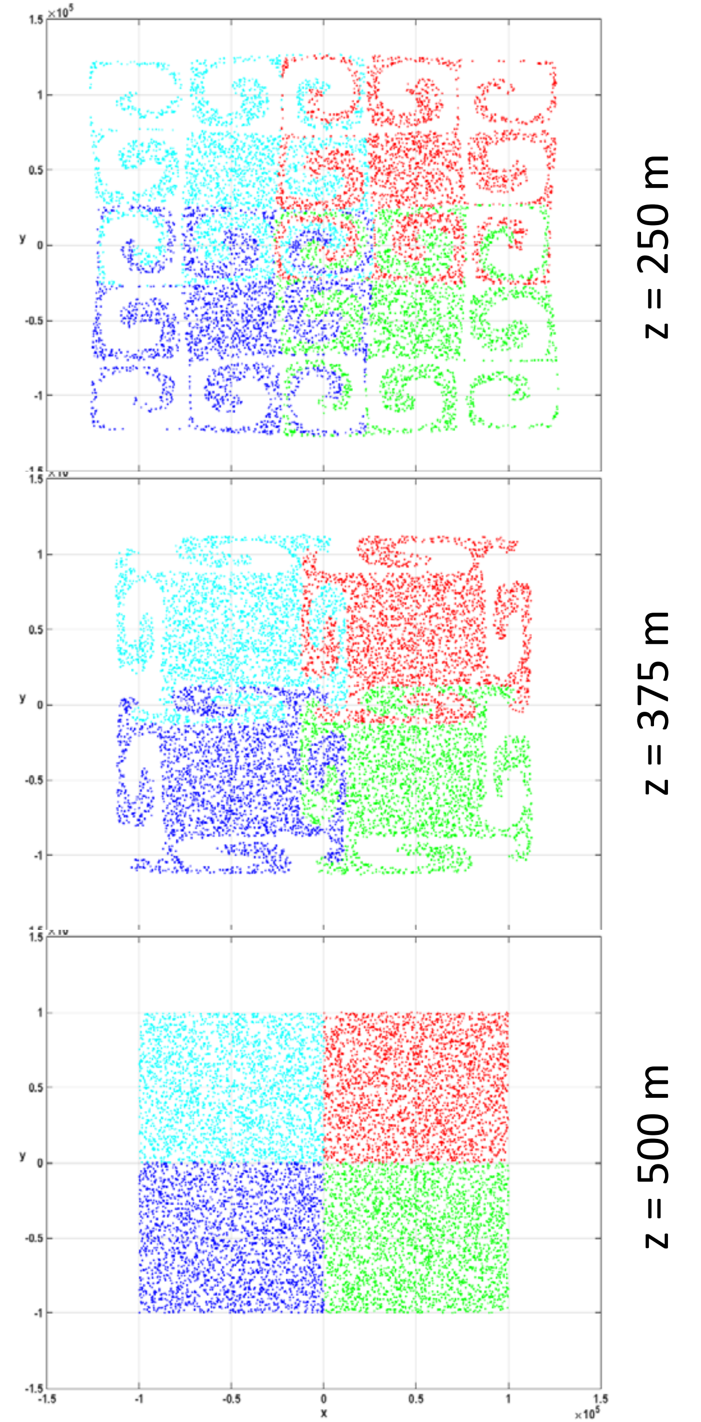
Outline

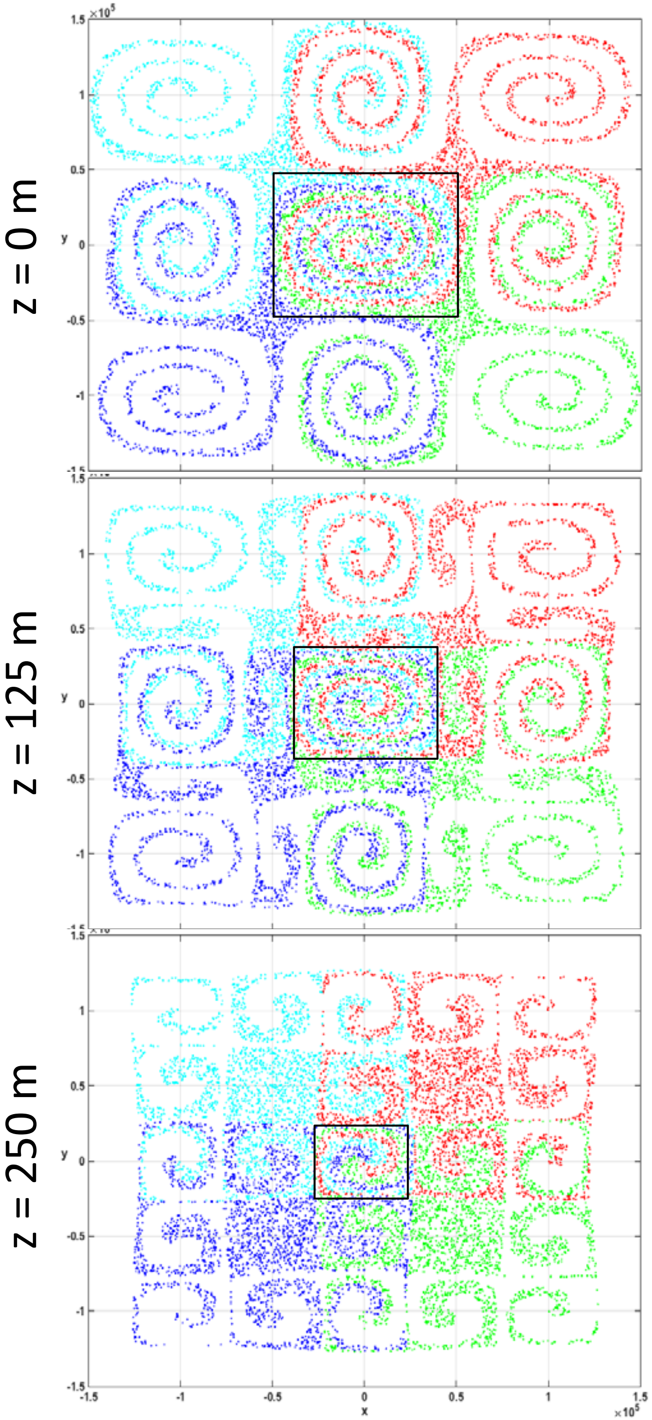
- Vertical structure of transport boundaries for perturbation QP
- Mixing for composite (steady + perturbation) QP

Vertical Structure of Transport Boundaries

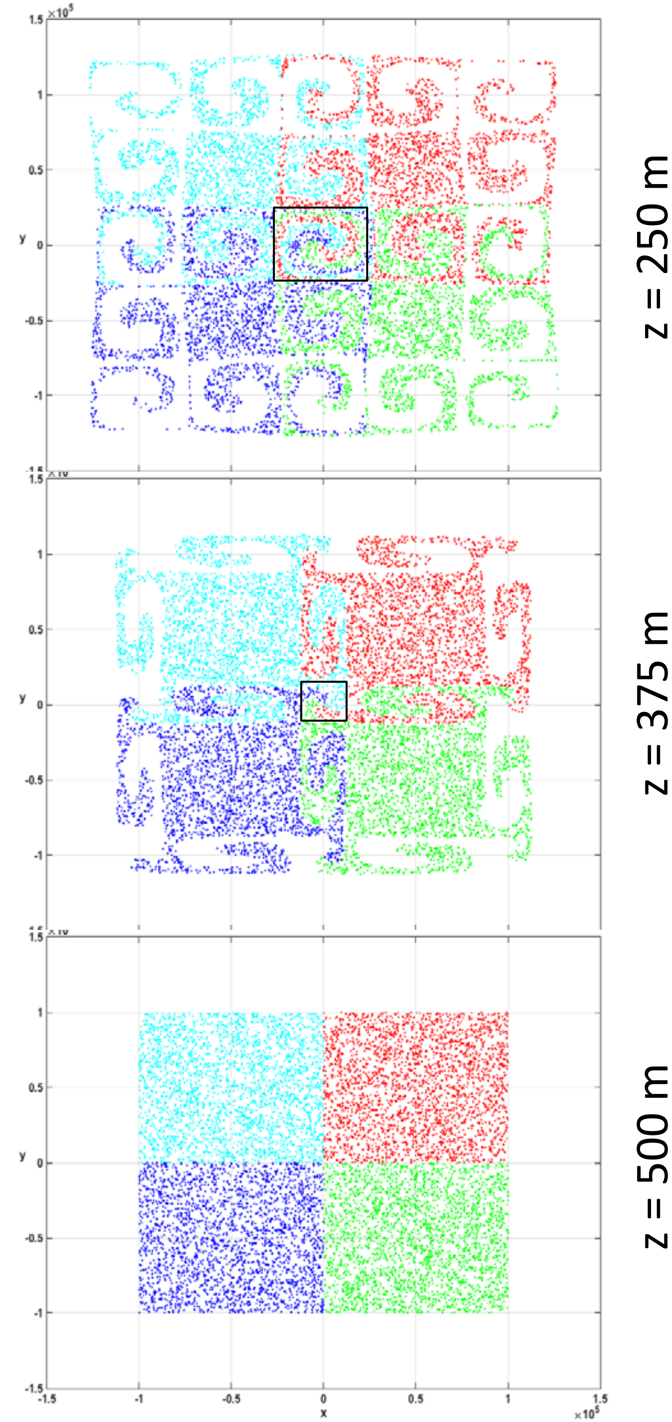




Vertical Structure of Transport Boundaries



Vertex Centered Cells
- length decreases linearly with depth
- clockwise rotation

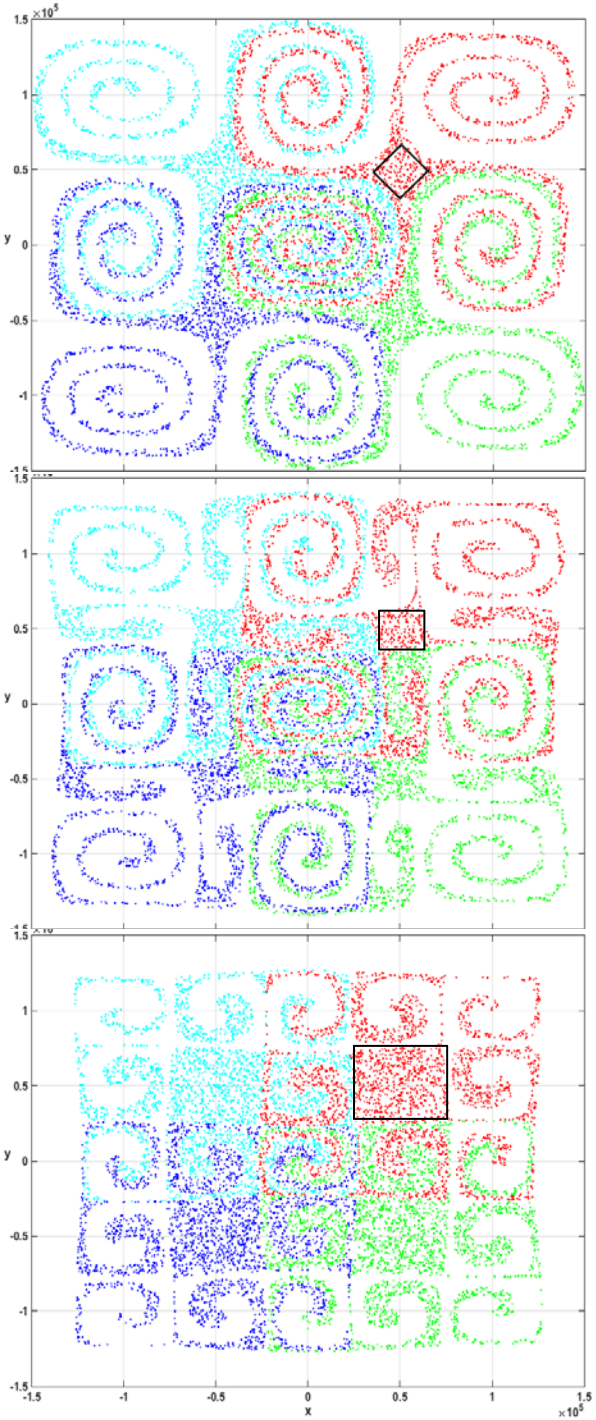


Vertical Structure of Transport Boundaries

z = 0 m

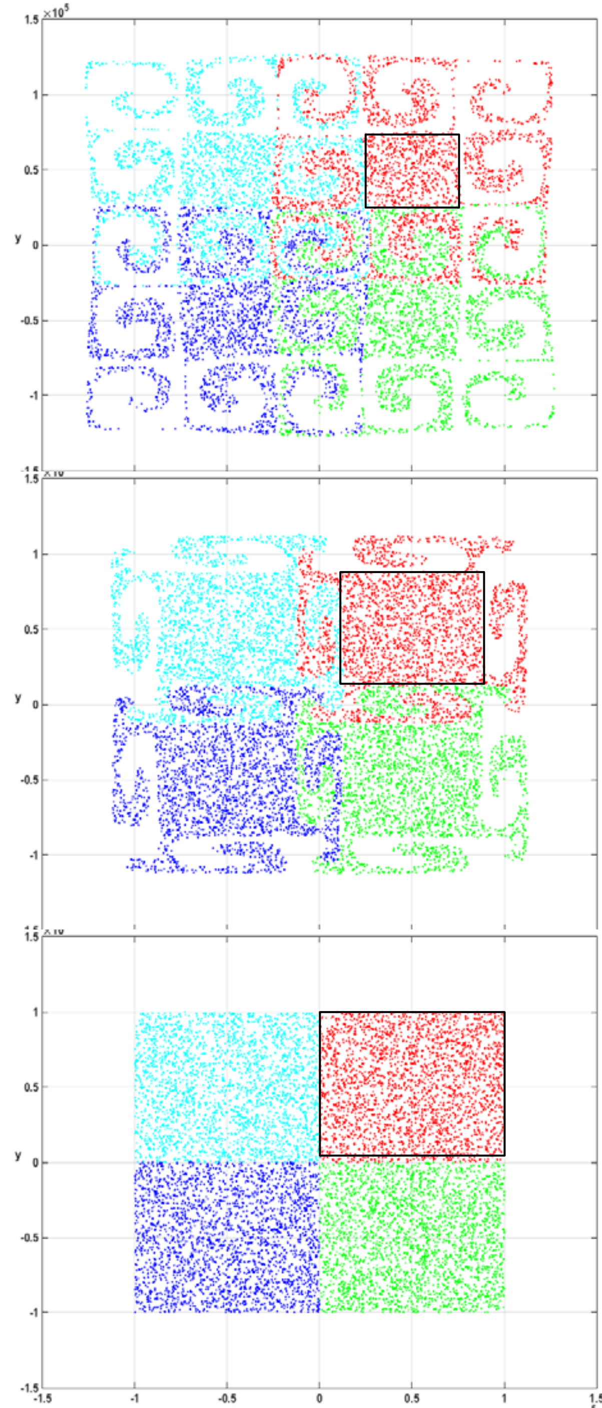
z = 125 m

z = 250 m



Vertex Centered Cells
- length decreases linearly with depth
- clockwise rotation

Eddy Centered Cells
- length increases linearly with depth
- clockwise rotation

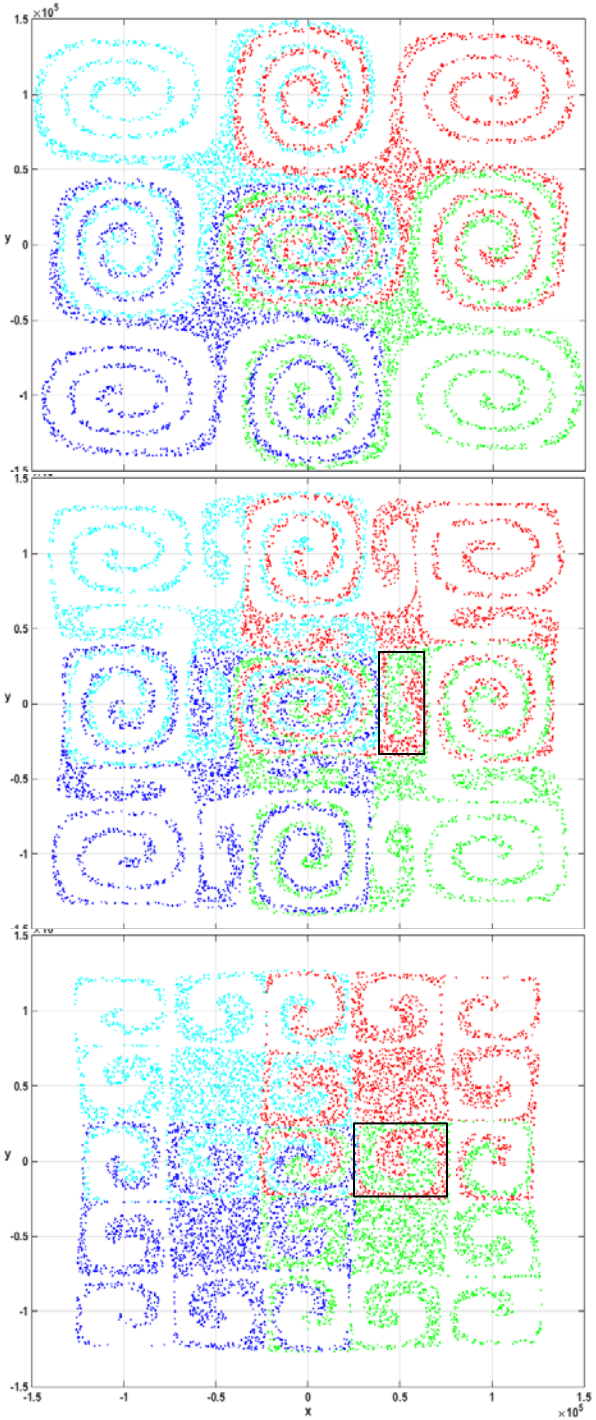


z = 250 m

z = 375 m

z = 500 m

Vertical Structure of Transport Boundaries



z = 0 m

z = 125 m

z = 250 m

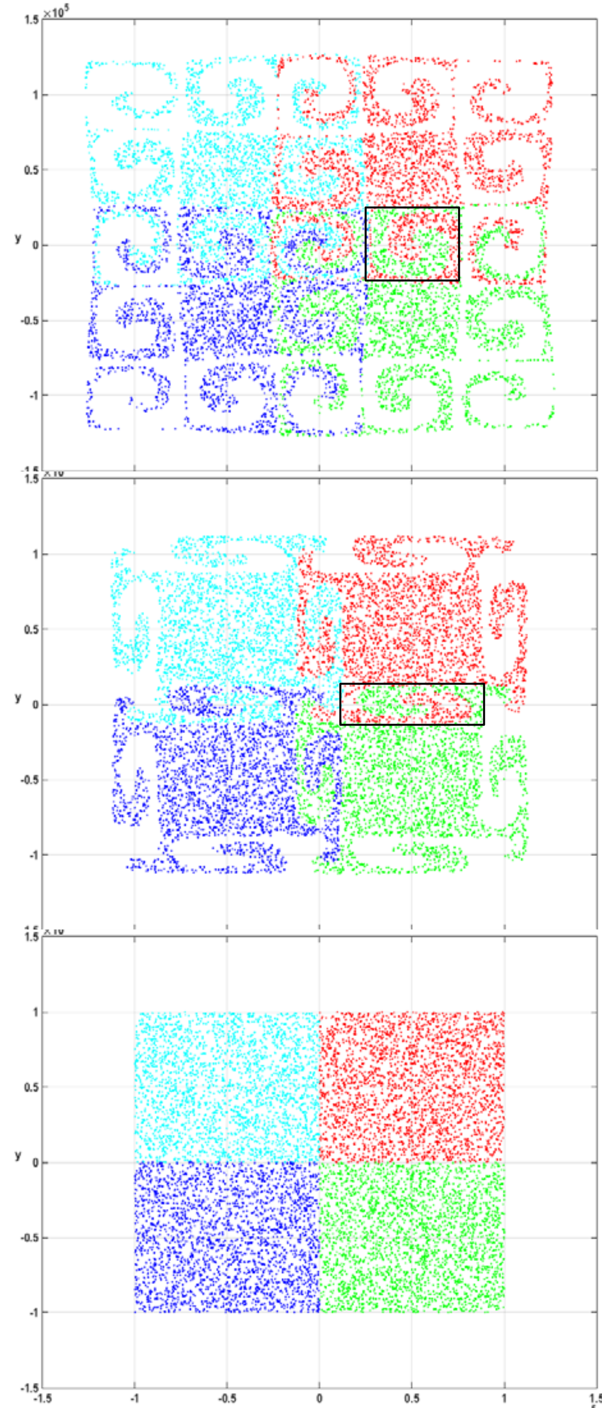
Vertex Centered Cells

- length decreases linearly with depth
- clockwise rotation

Eddy Centered Cells

- length increases linearly with depth
- clockwise rotation

Remaining Cells rotate counter clockwise

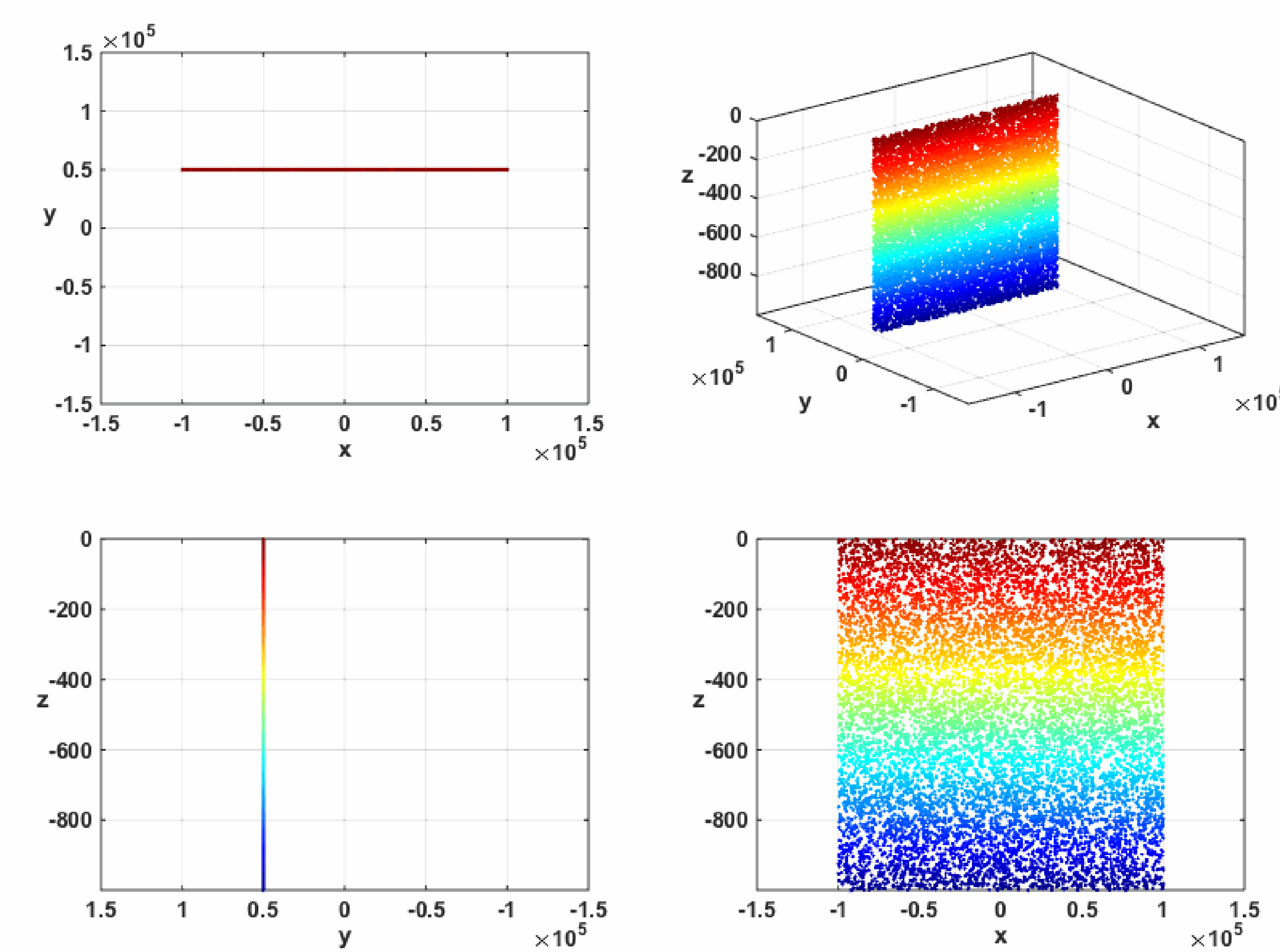


z = 250 m

z = 375 m

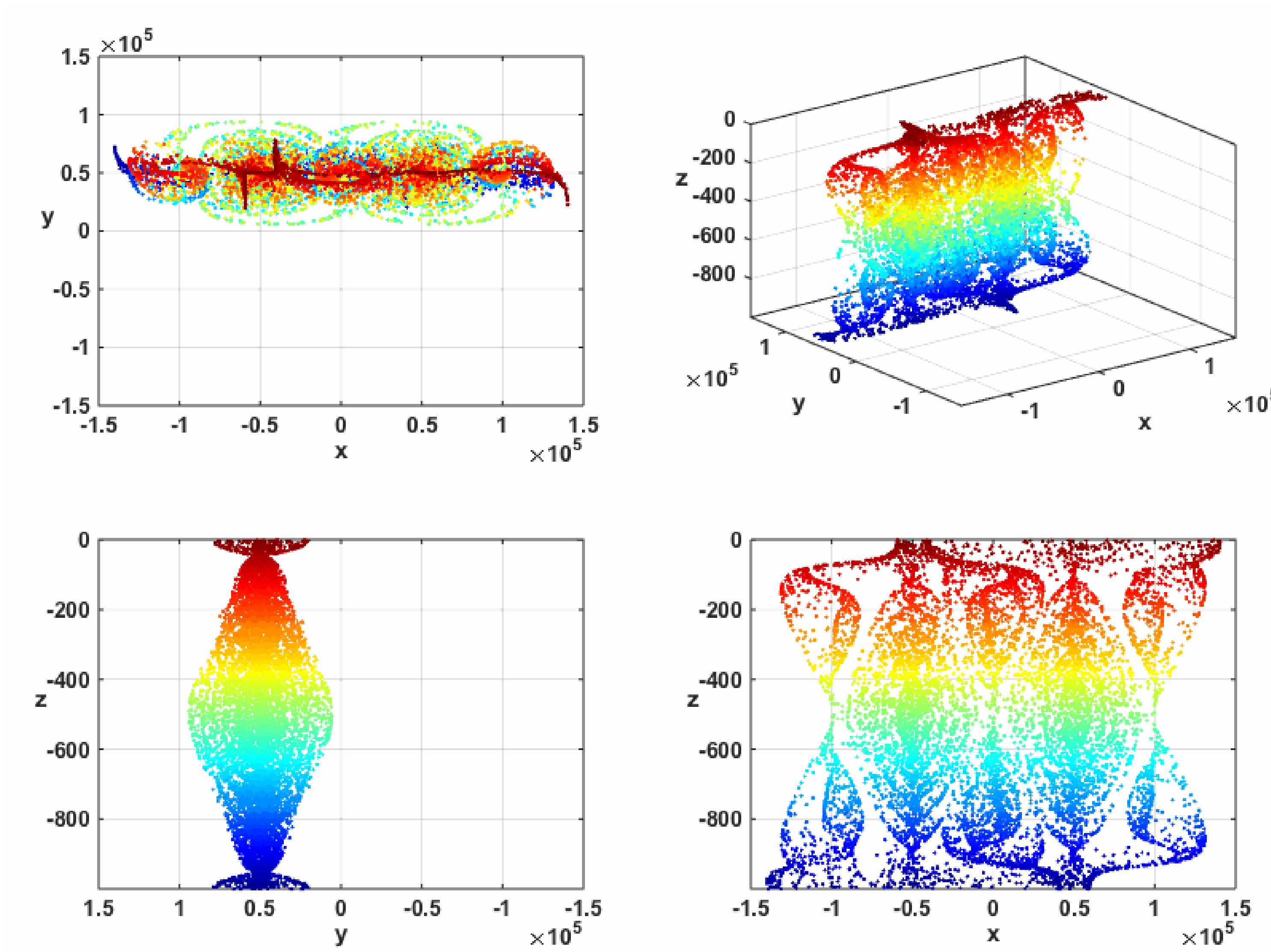
z = 500 m

3D Dynamics



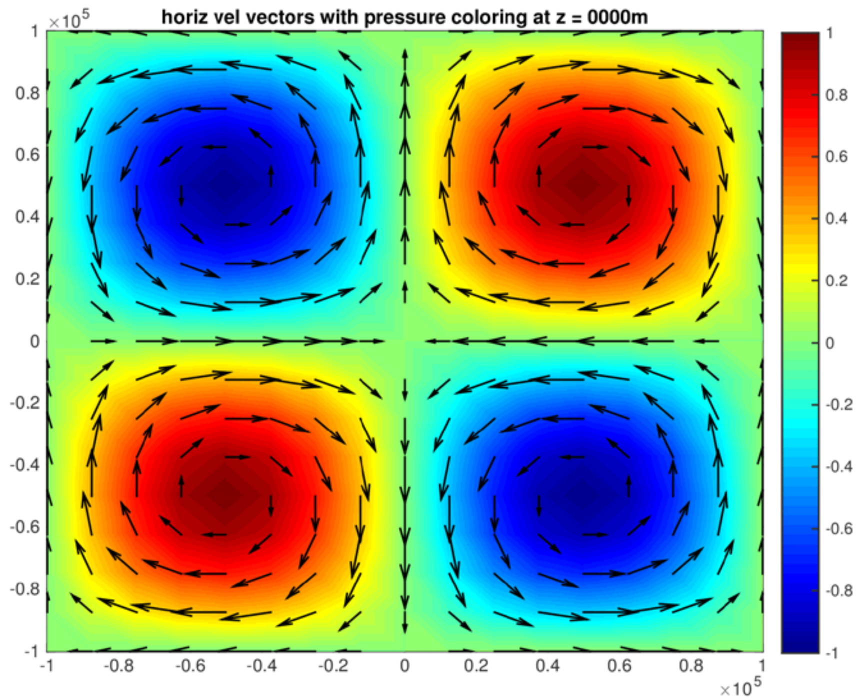
1.5
1
0.5
0
-0.5
-1
-1.5
y
-1.5
-1
-0.5
0
0.5
1
1.5
x
×10^5
0
-200
-400
-600
-800
z
y
x
×10^5
-200
-400
-600
-800
1.5
1
0.5
0
-0.5
-1
-1.5

3D Dynamics



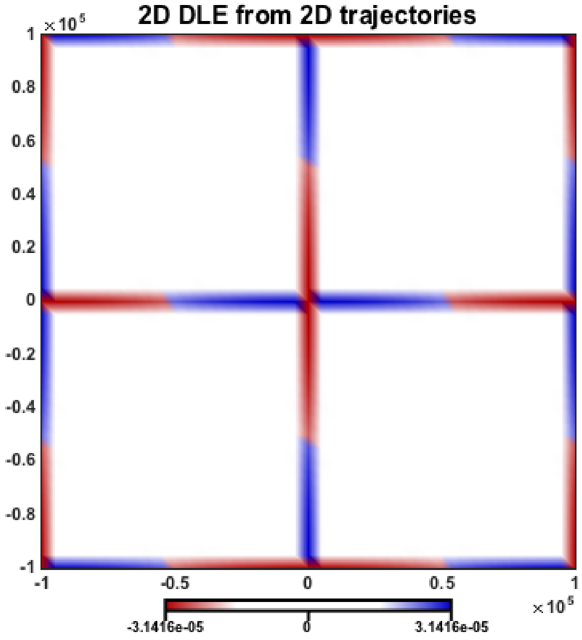
Steady Flow

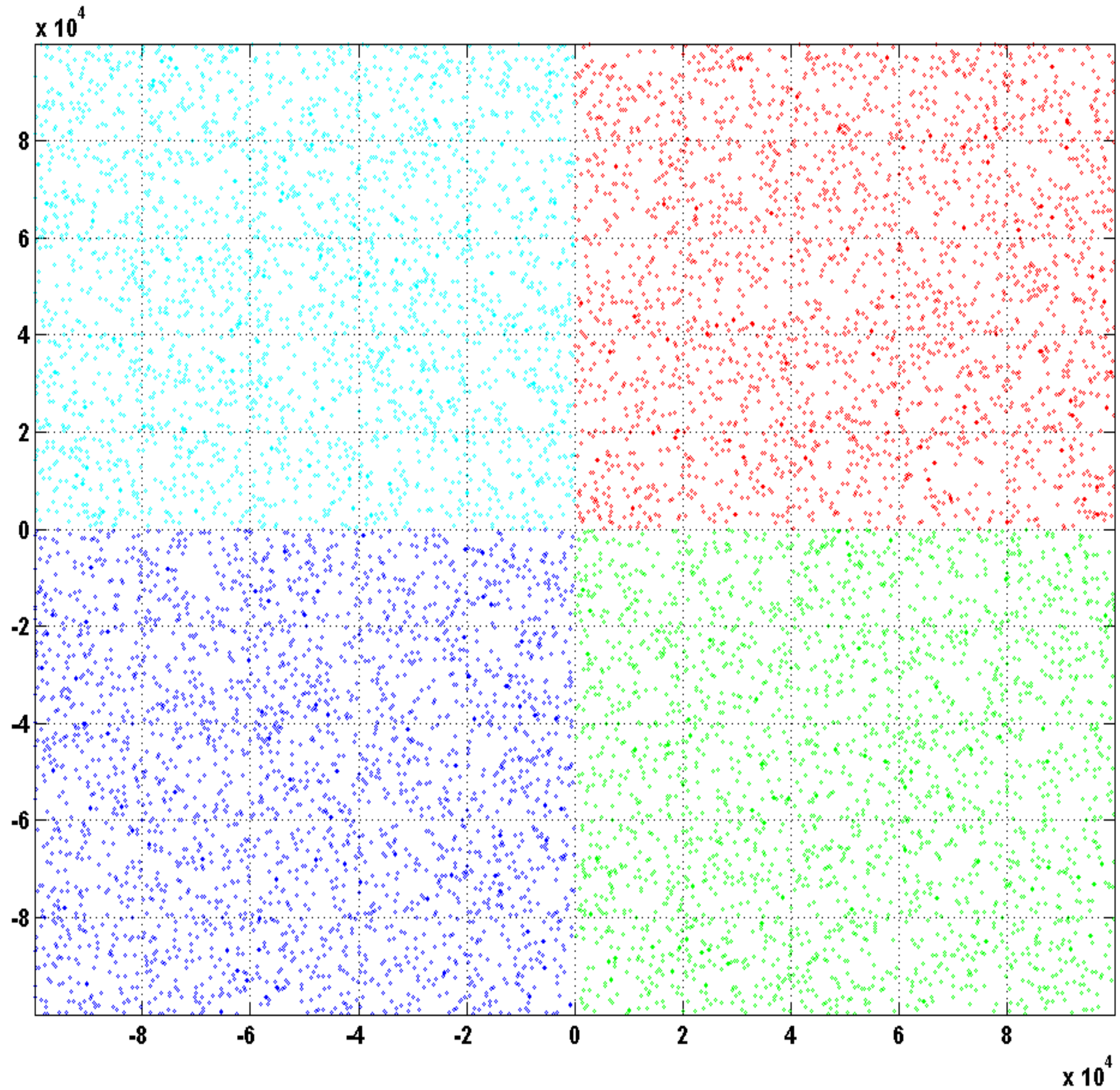
- Geostrophic velocity scale U = 1 m/s
- L = 100 km



Steady Flow

U = 1 m/s   L = 100 km

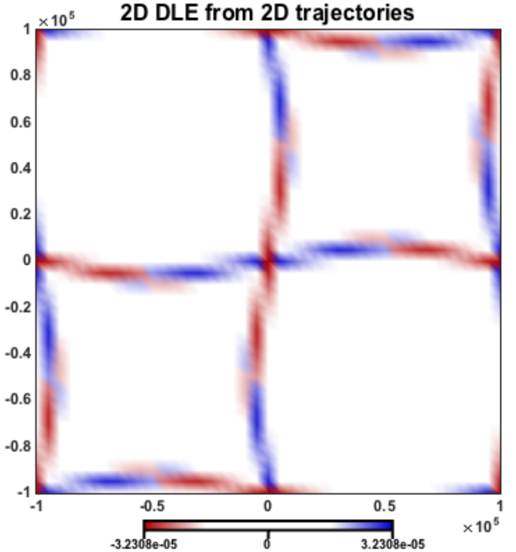


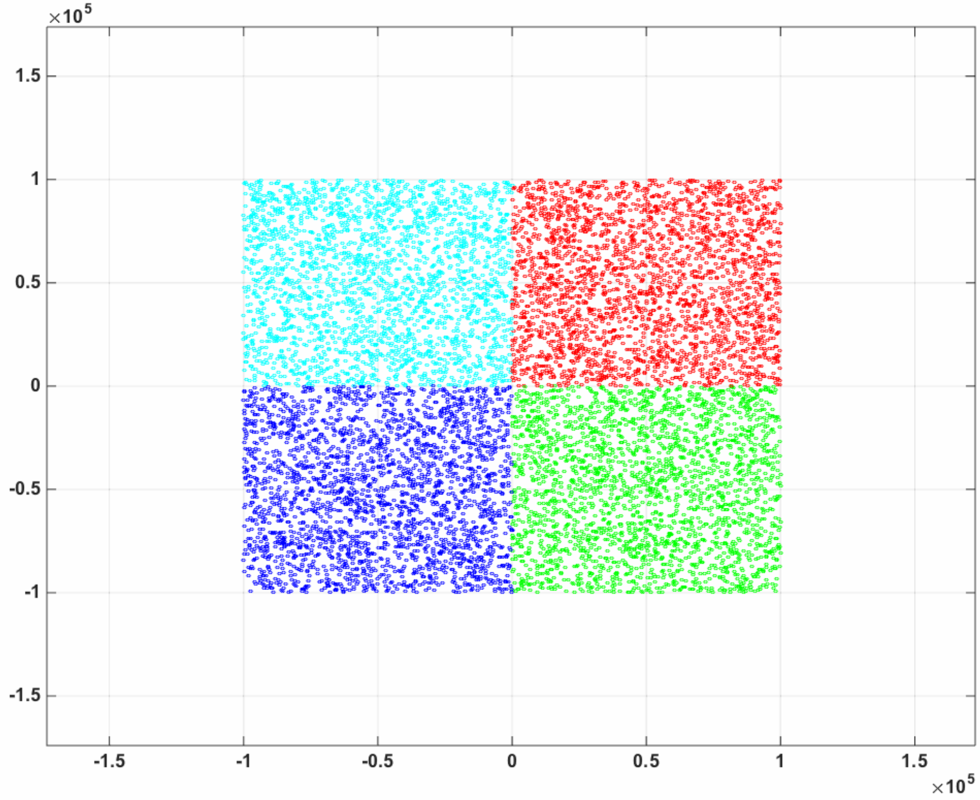


Composite Flow

U = 1 m/s **L = 100 km**

U_j = 0.5 m/s **L_j = 100 km**

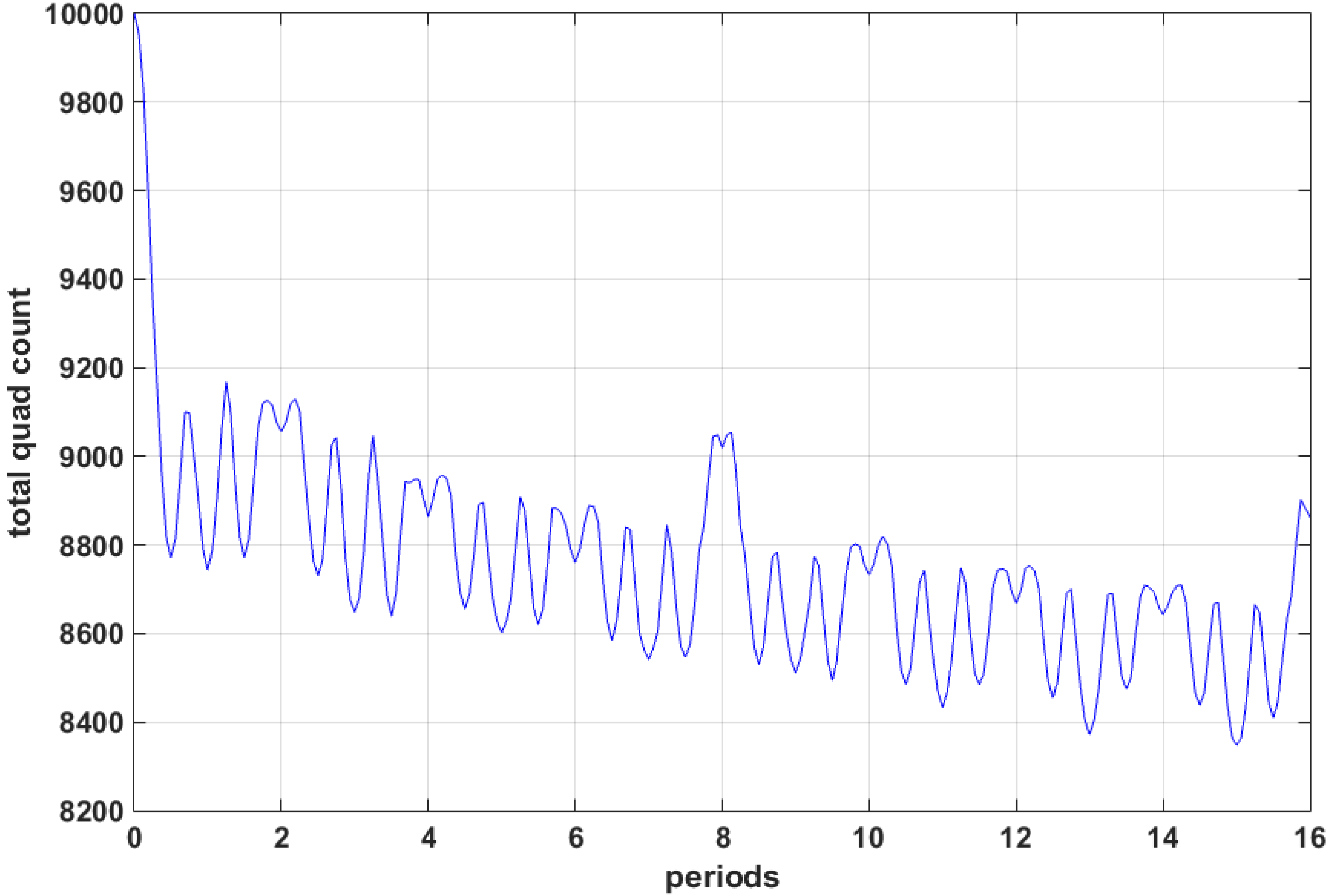




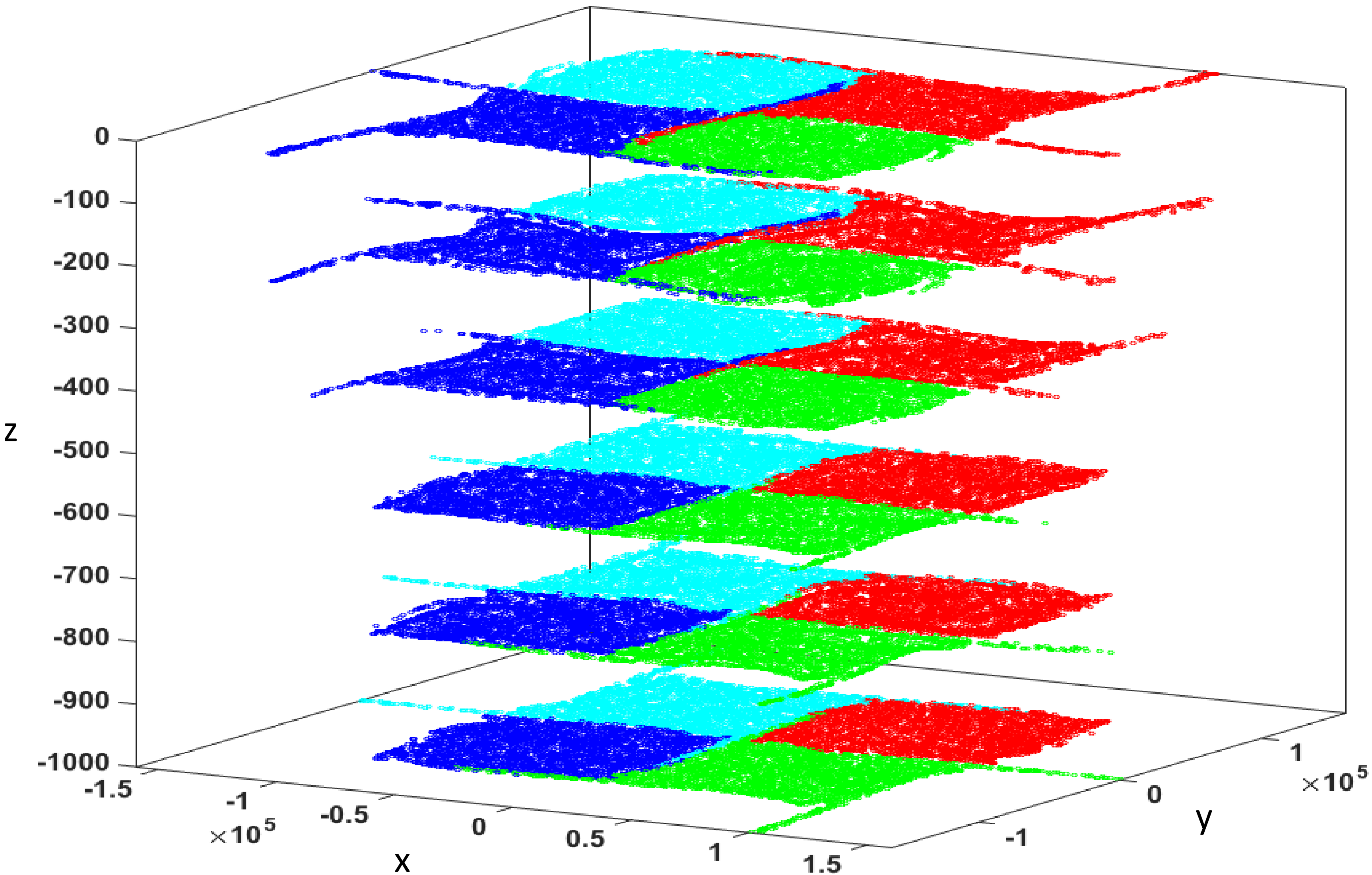
Quadrant Count

- **Initialize steady flow quadrants with 10000 particles**
- **Count number of particles remaining in quadrants as function of time**

Quadrant Count

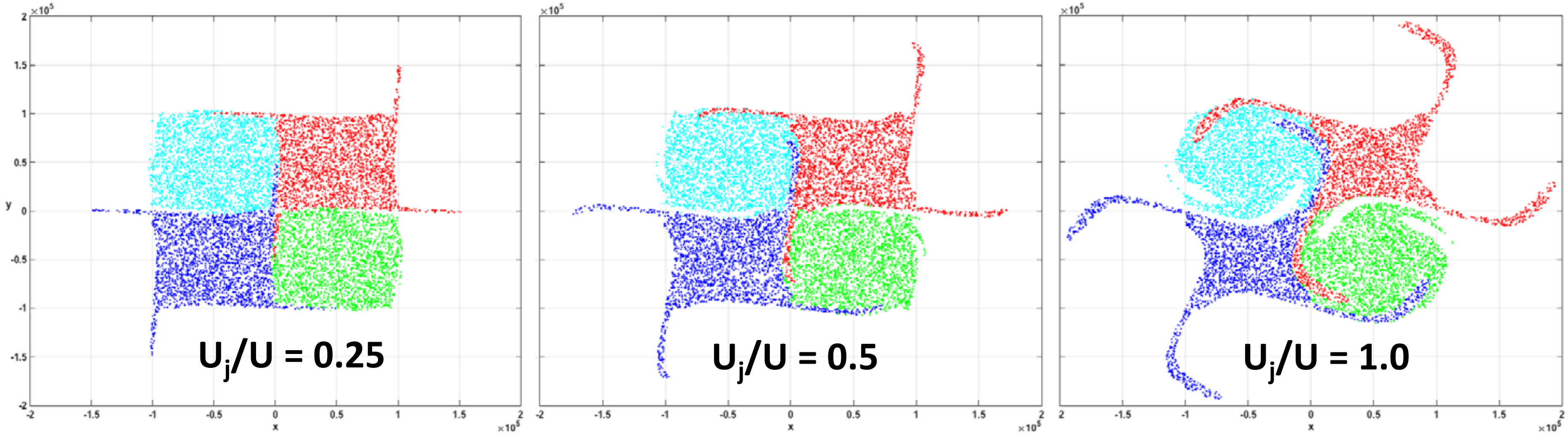


Vertical Structure of Mixing

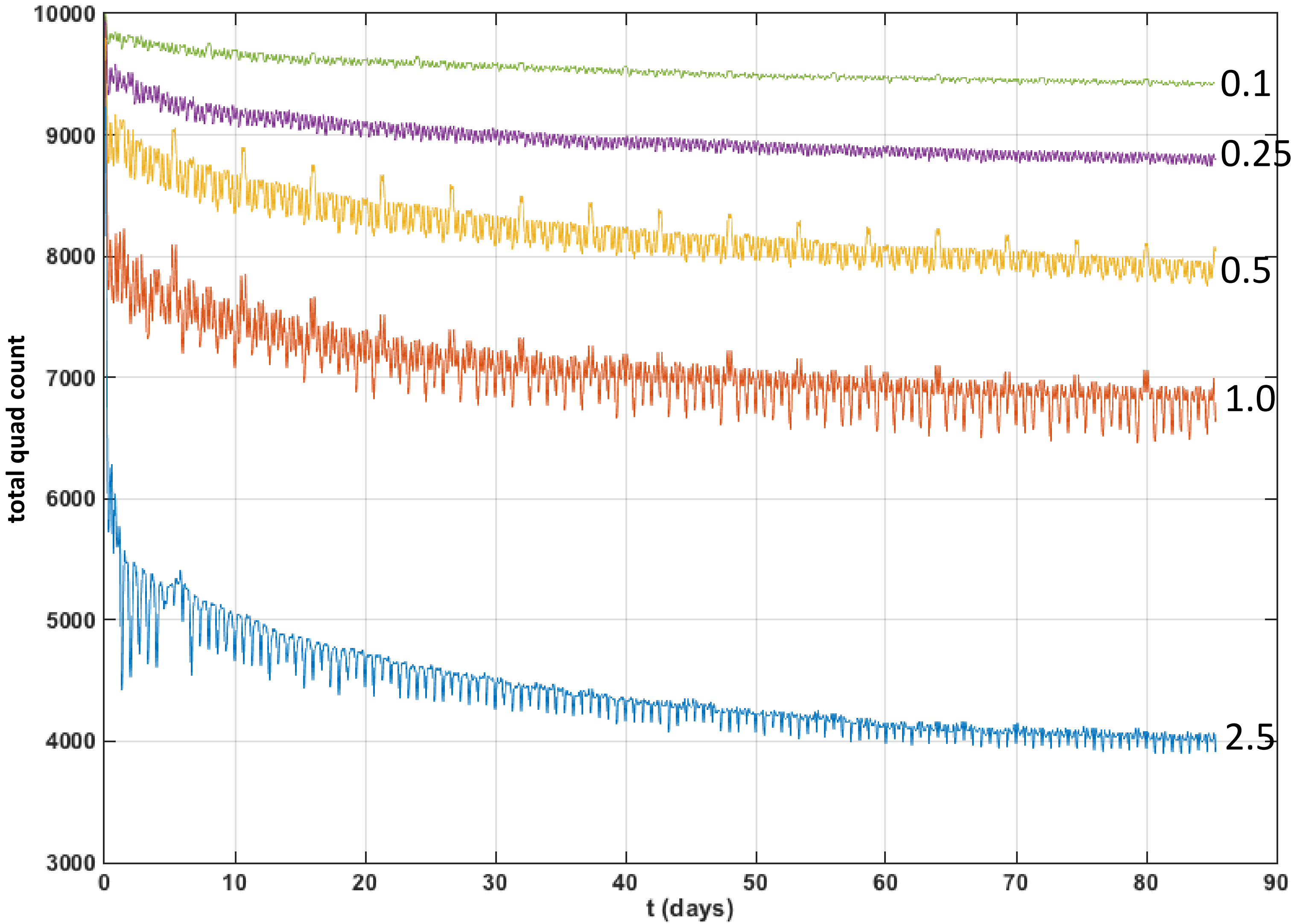


Perturbation Parameter

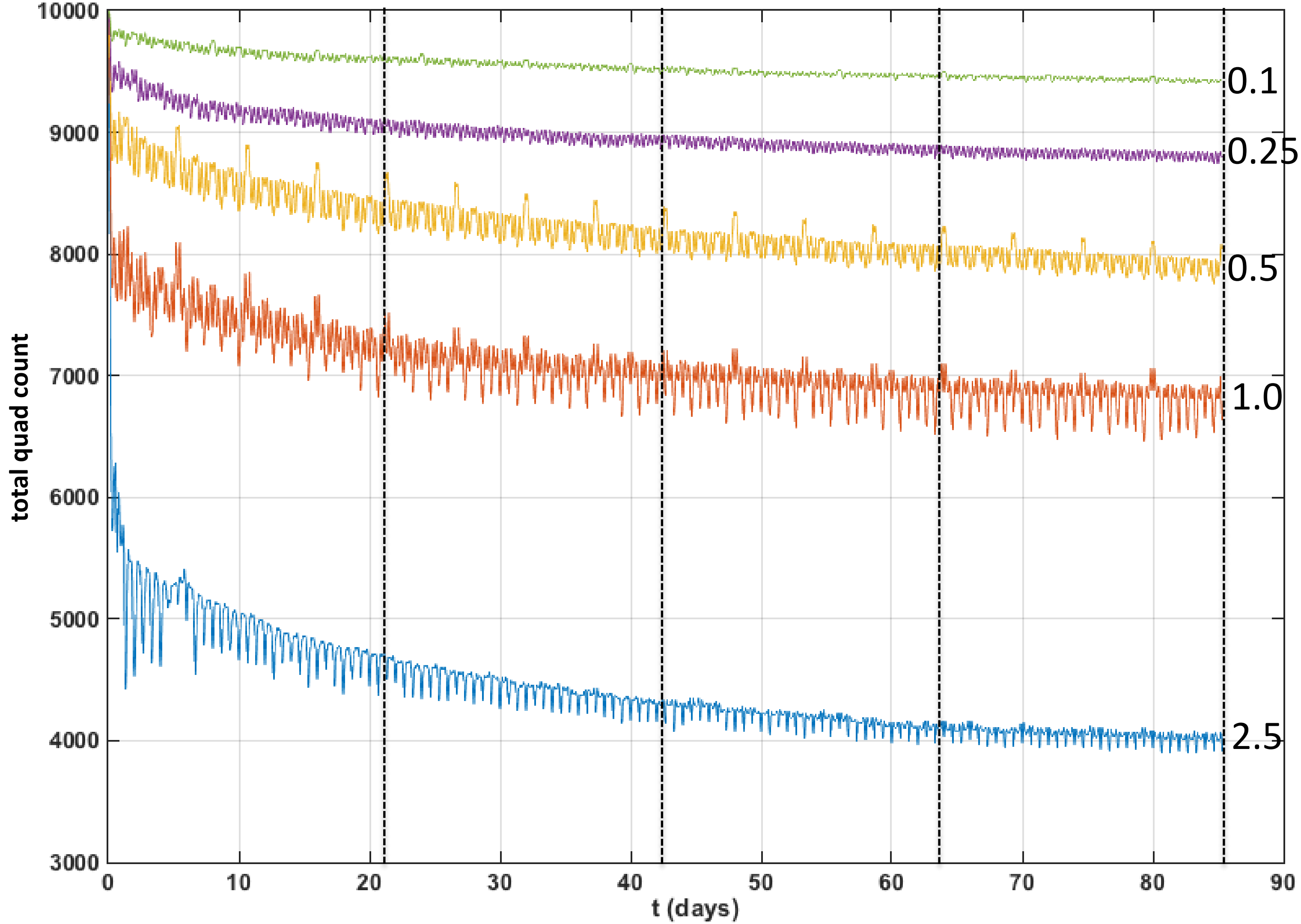
- Velocity scale U_j/U = 0.1, 0.25, 0.5, 1.0, 2.5



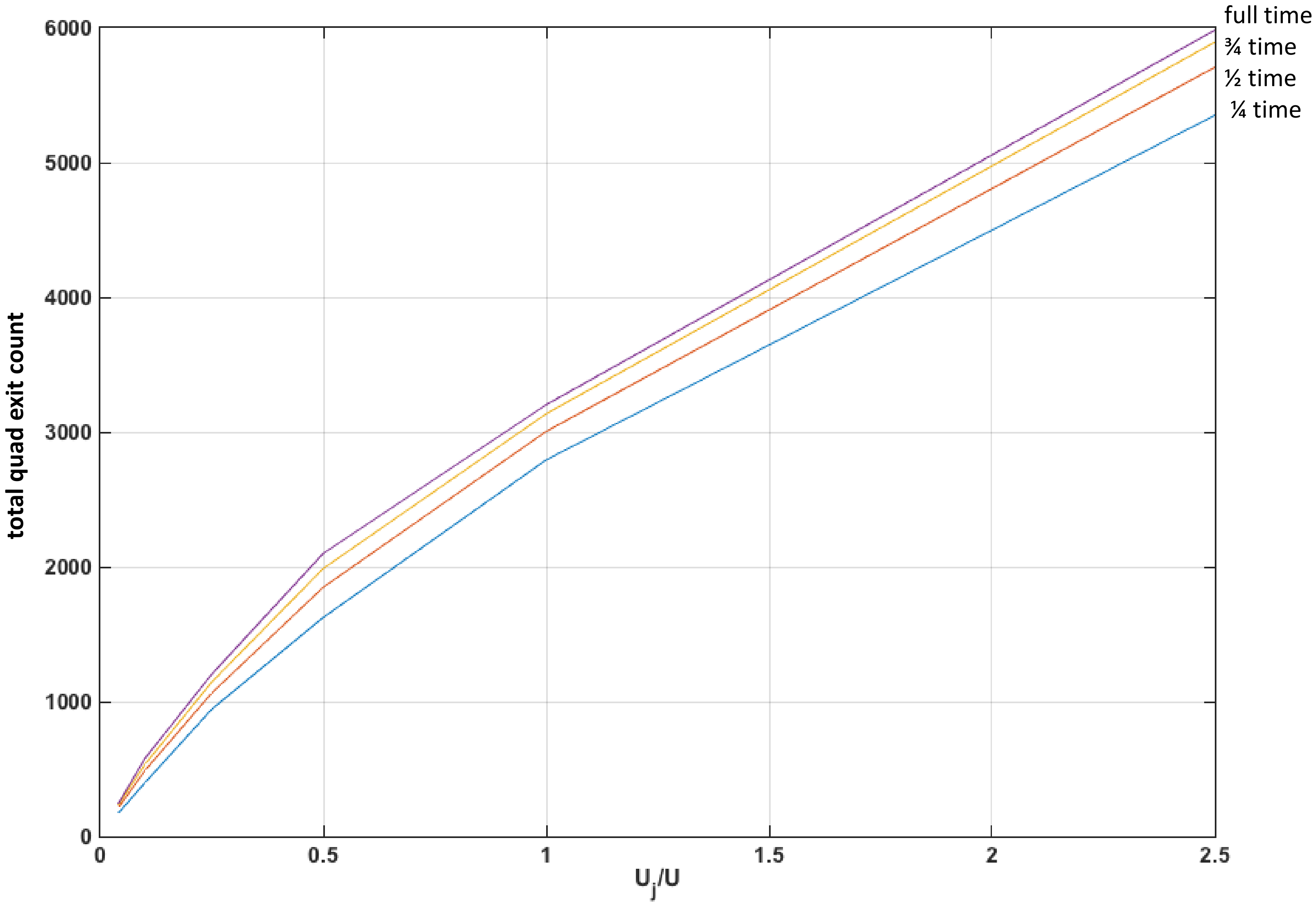
Quad Count (U_j/U)



Quad Count (U_j/U)

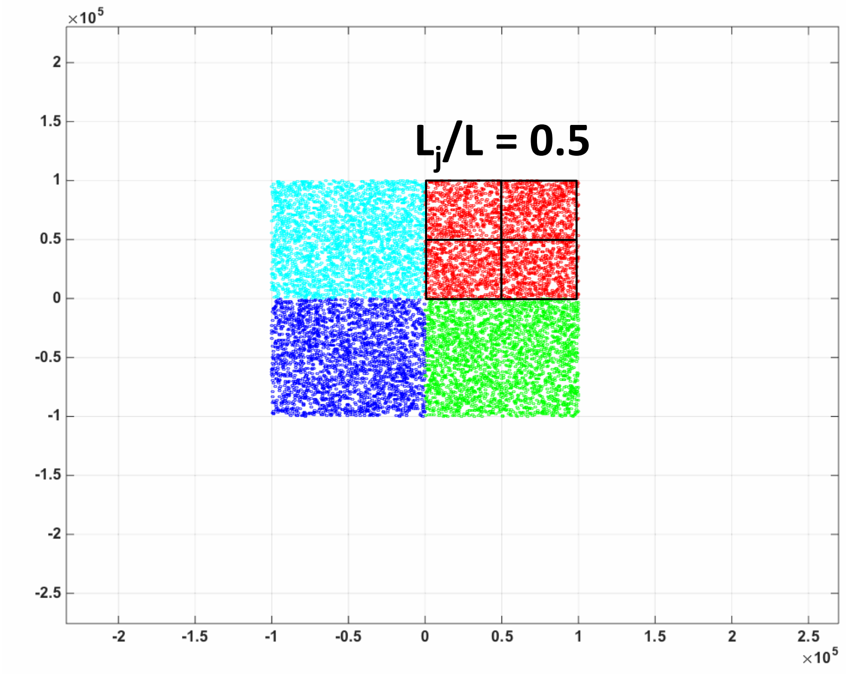


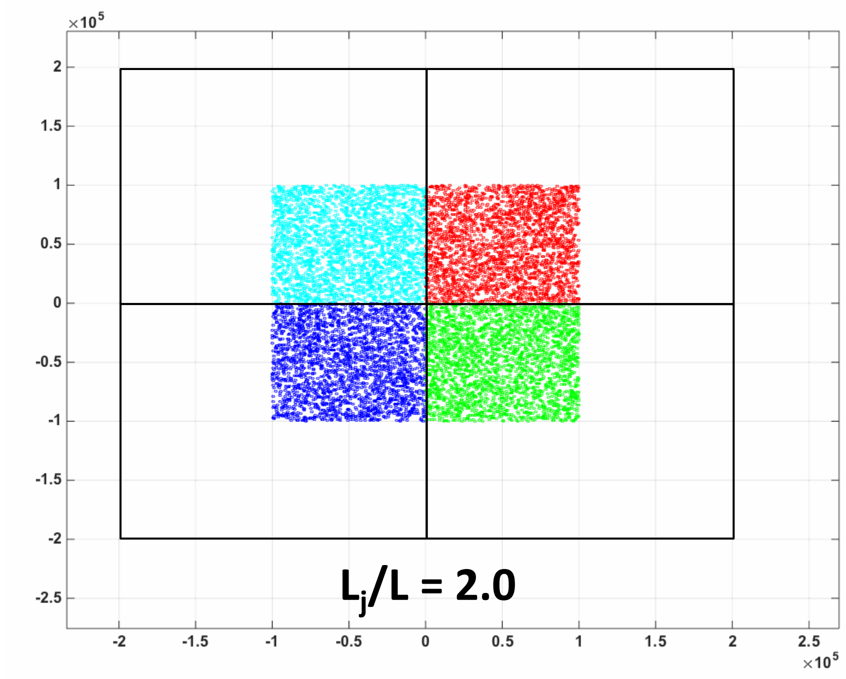
Quad Exit (U_j/U)

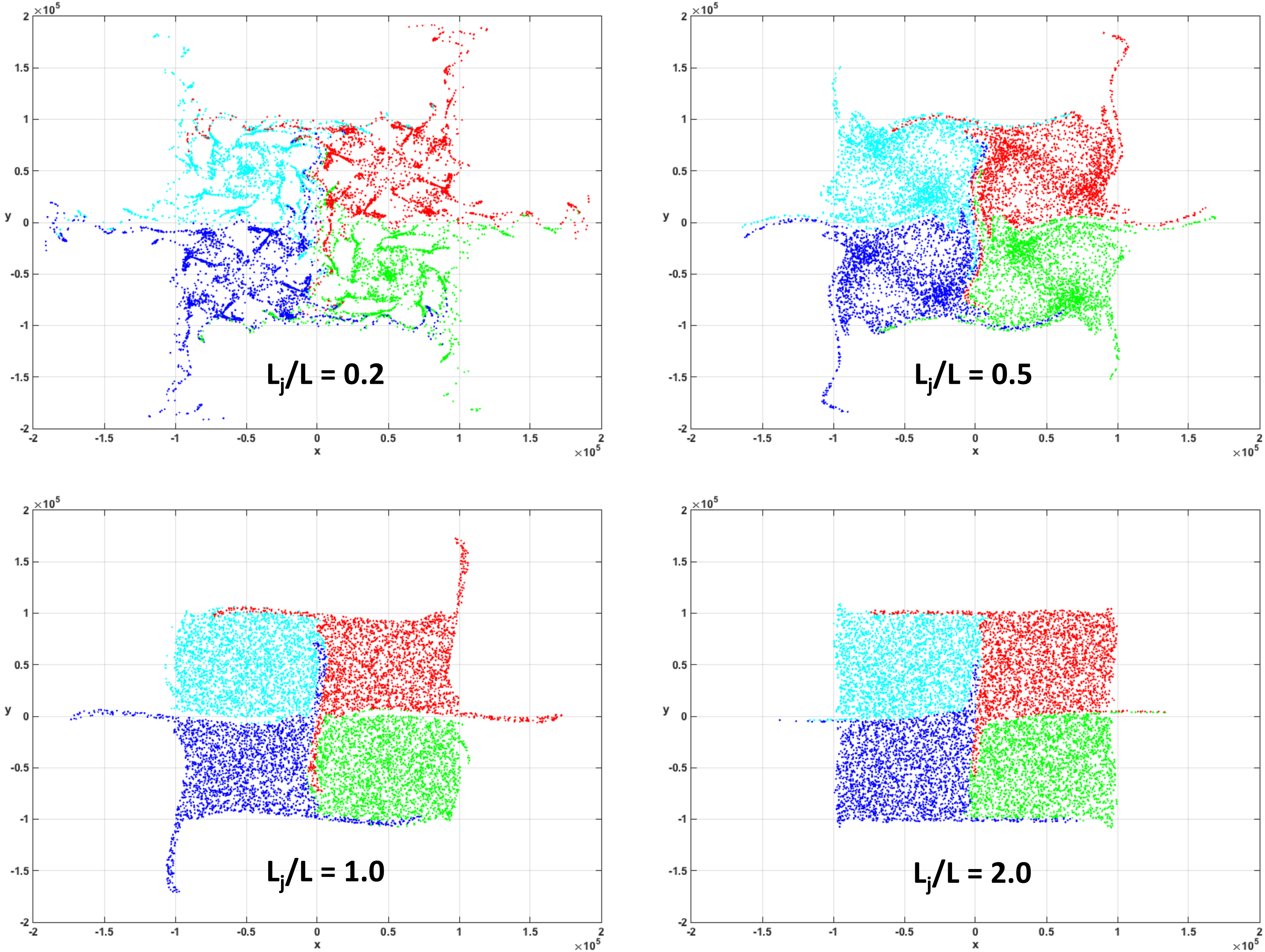


Perturbation Parameter

- Length scale L_j/L = 0.2, 0.5, 1.0, 2.0, 5.0

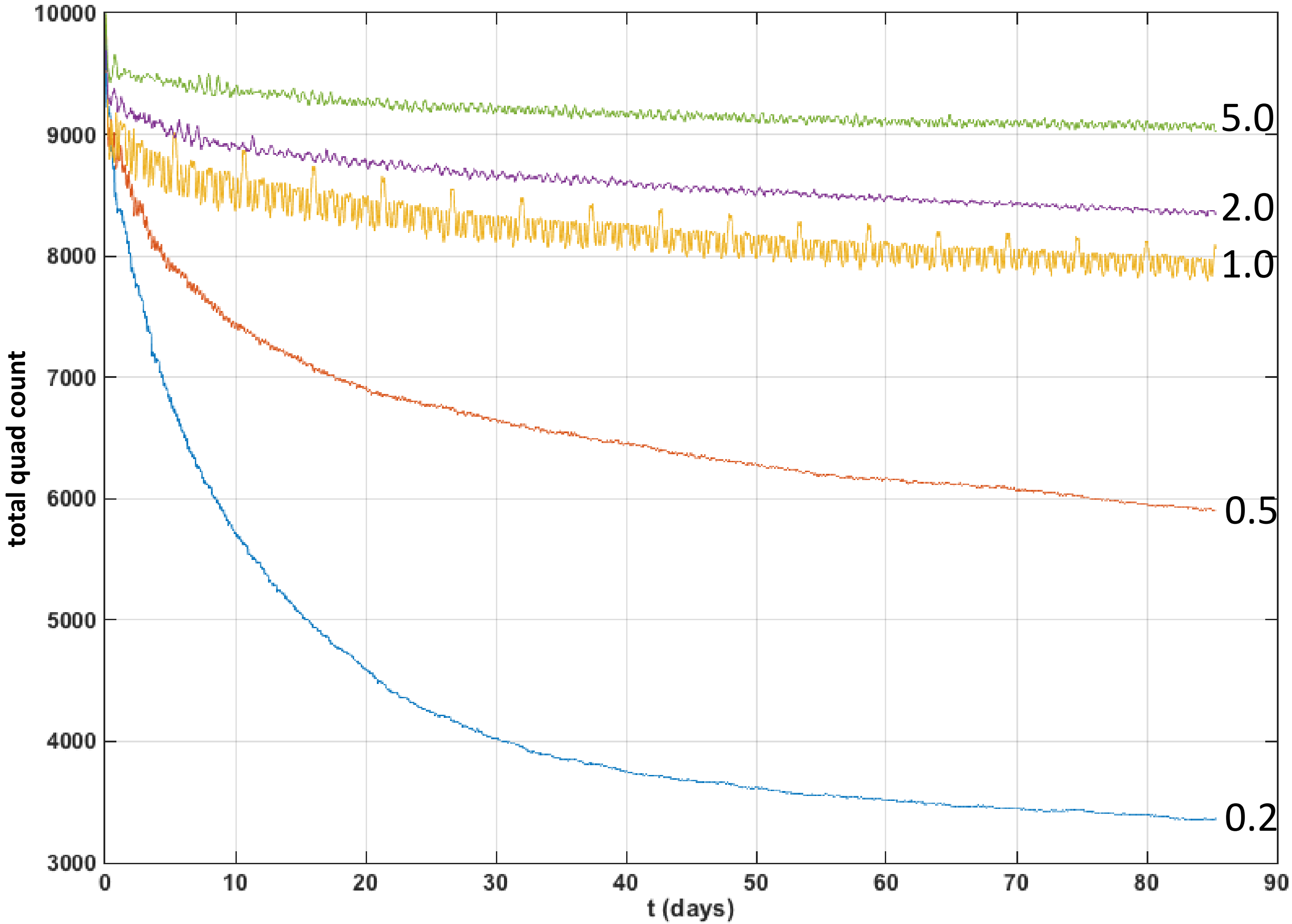




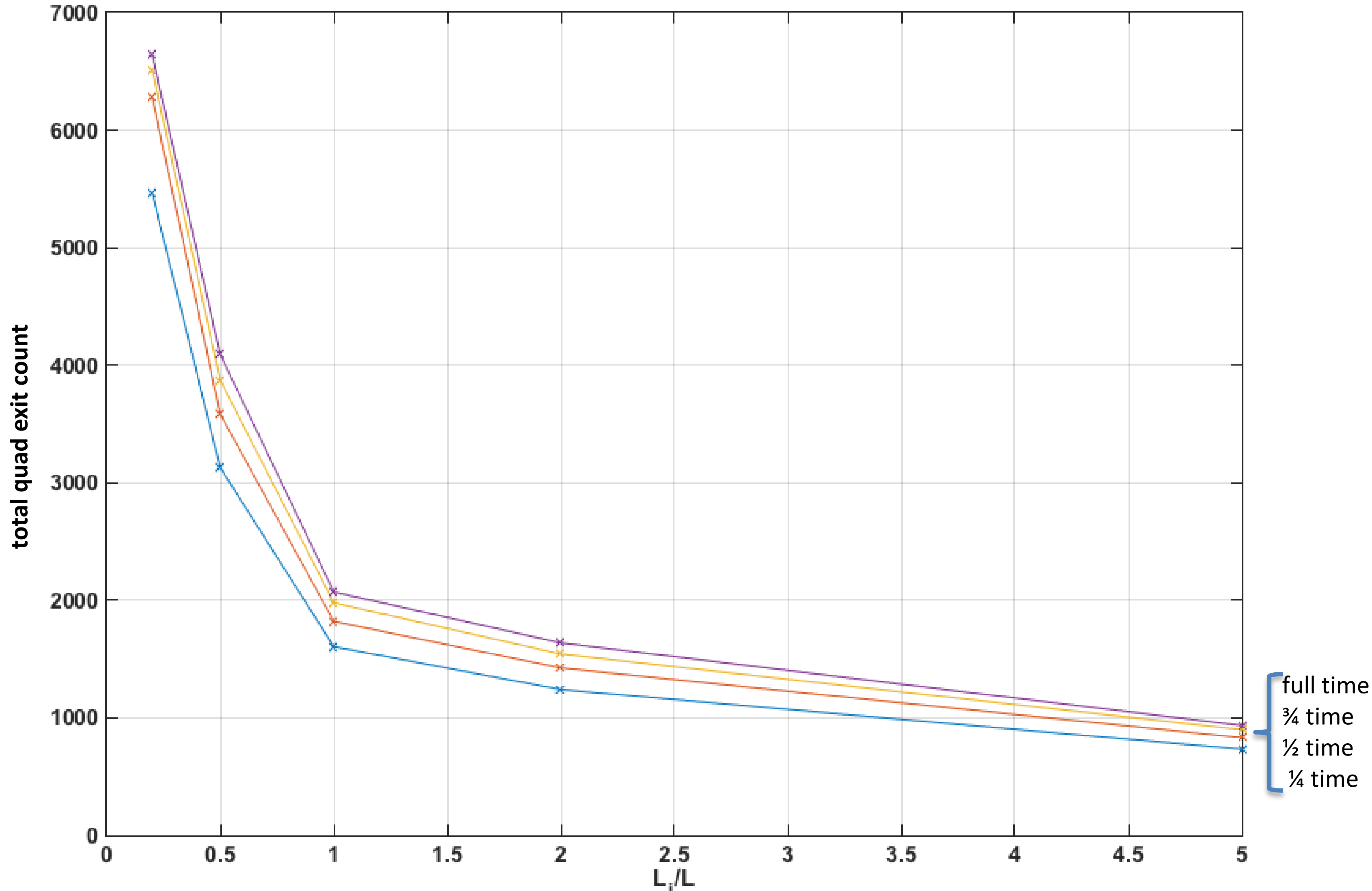


$L_j/L = 0.2$
$L_j/L = 0.5$
$L_j/L = 1.0$
$L_j/L = 2.0$
x
y
×10^5

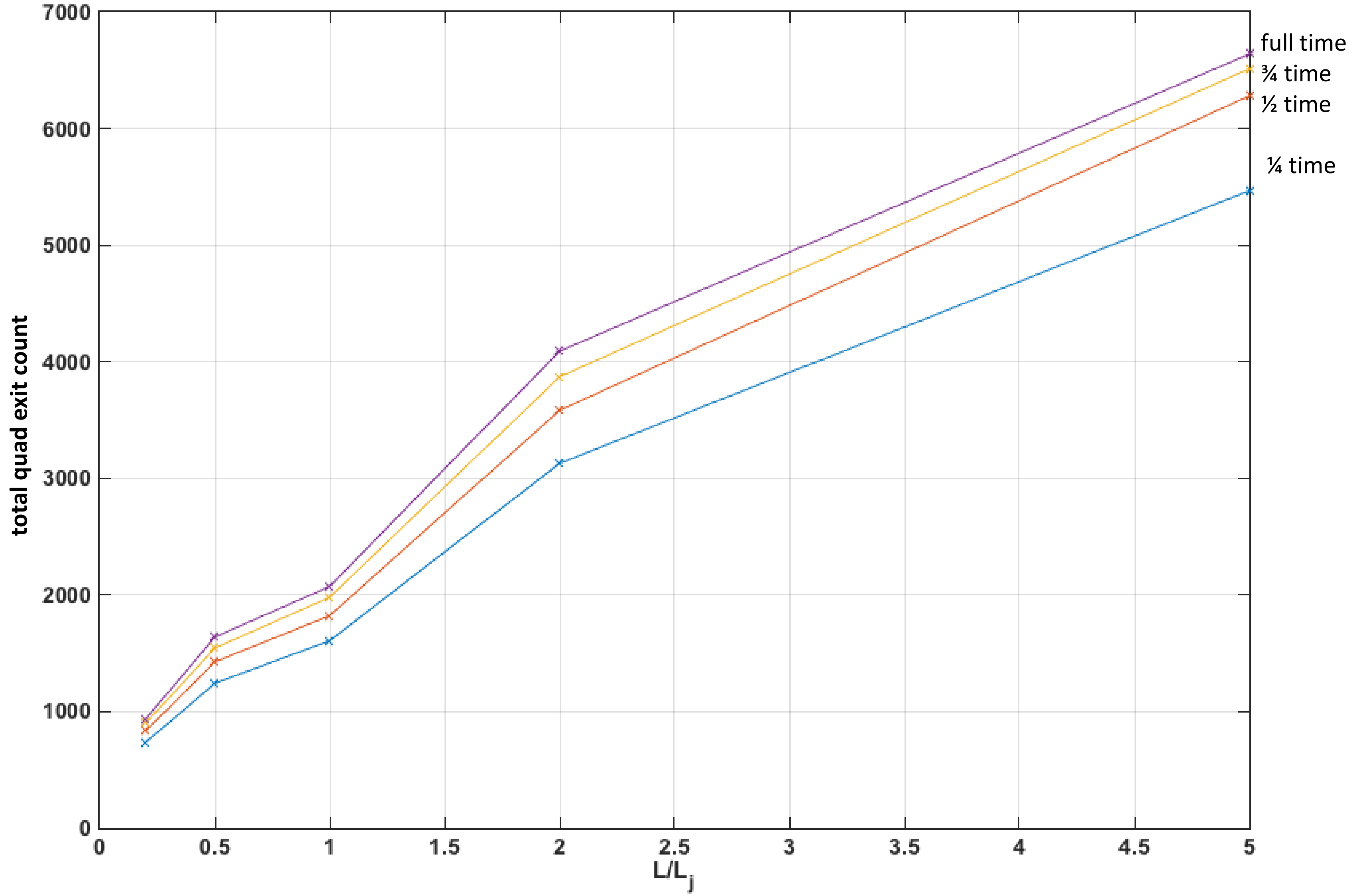
Quad Count (L_j/L)



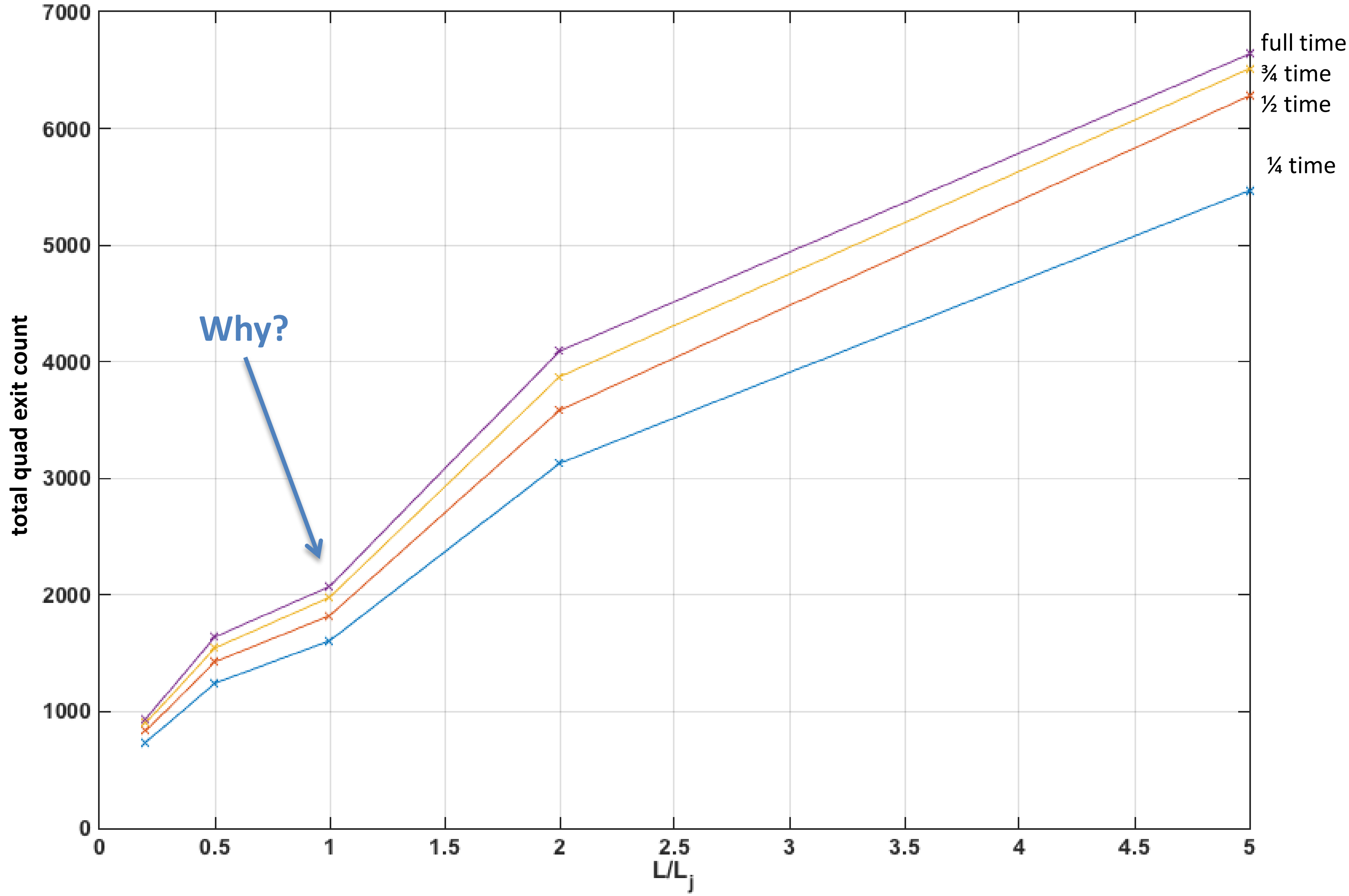
Quad Exit (L_j/L)



Quad Exit (L_j/L)



Quad Exit (L_j/L)

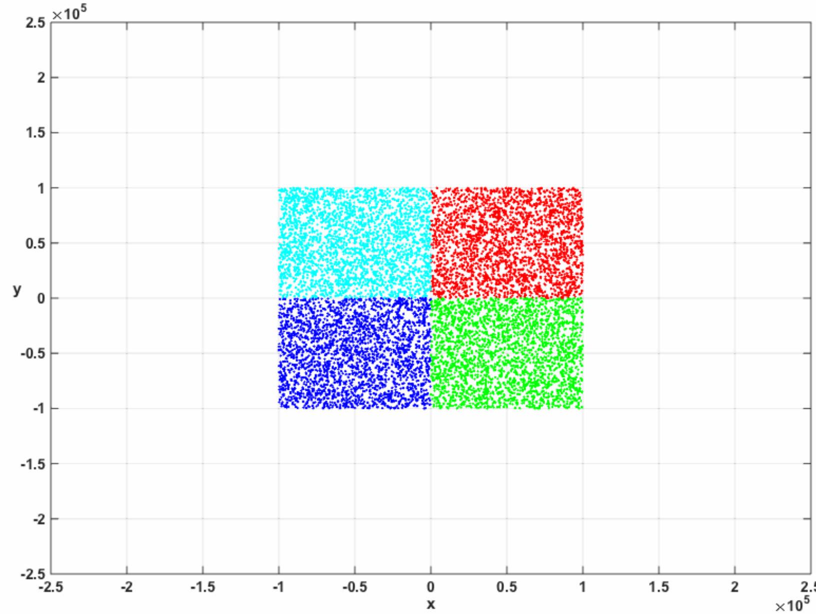


“Recycling”

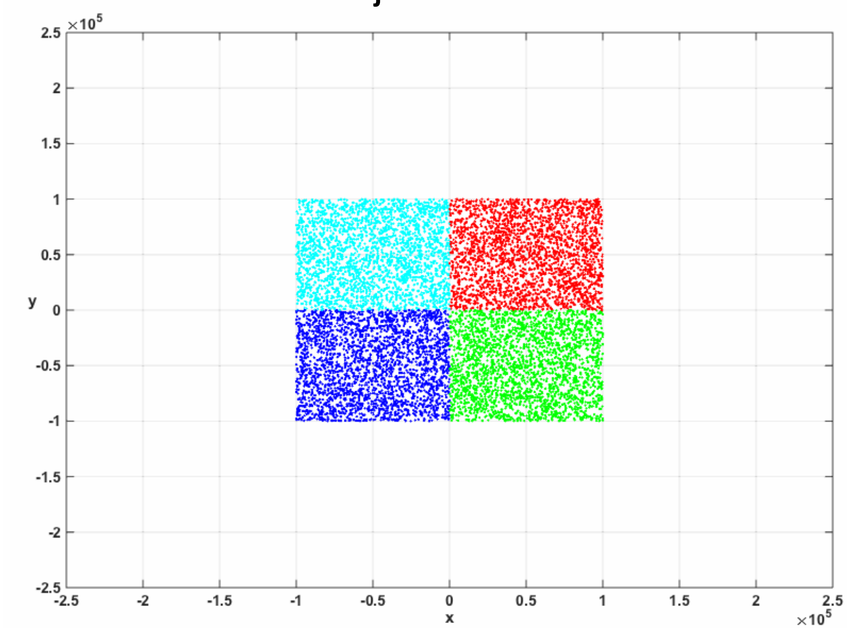
“Recycling”

- **Periodic return of exited particles to their original box**
- **Strongest for $L_j/L = 1$**
- **Weaker for other L_j/L**

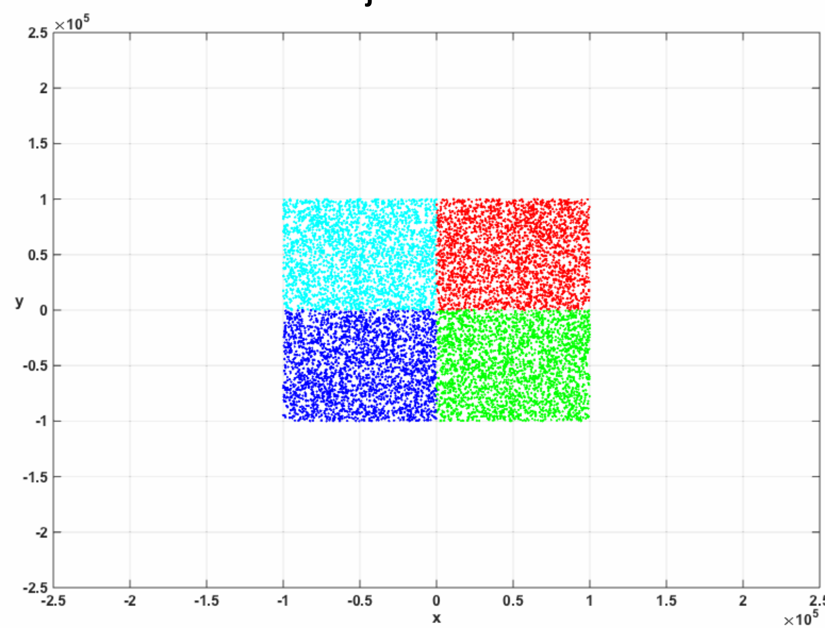
$L_j/L = 1.0$



$L_j/L = 0.5$



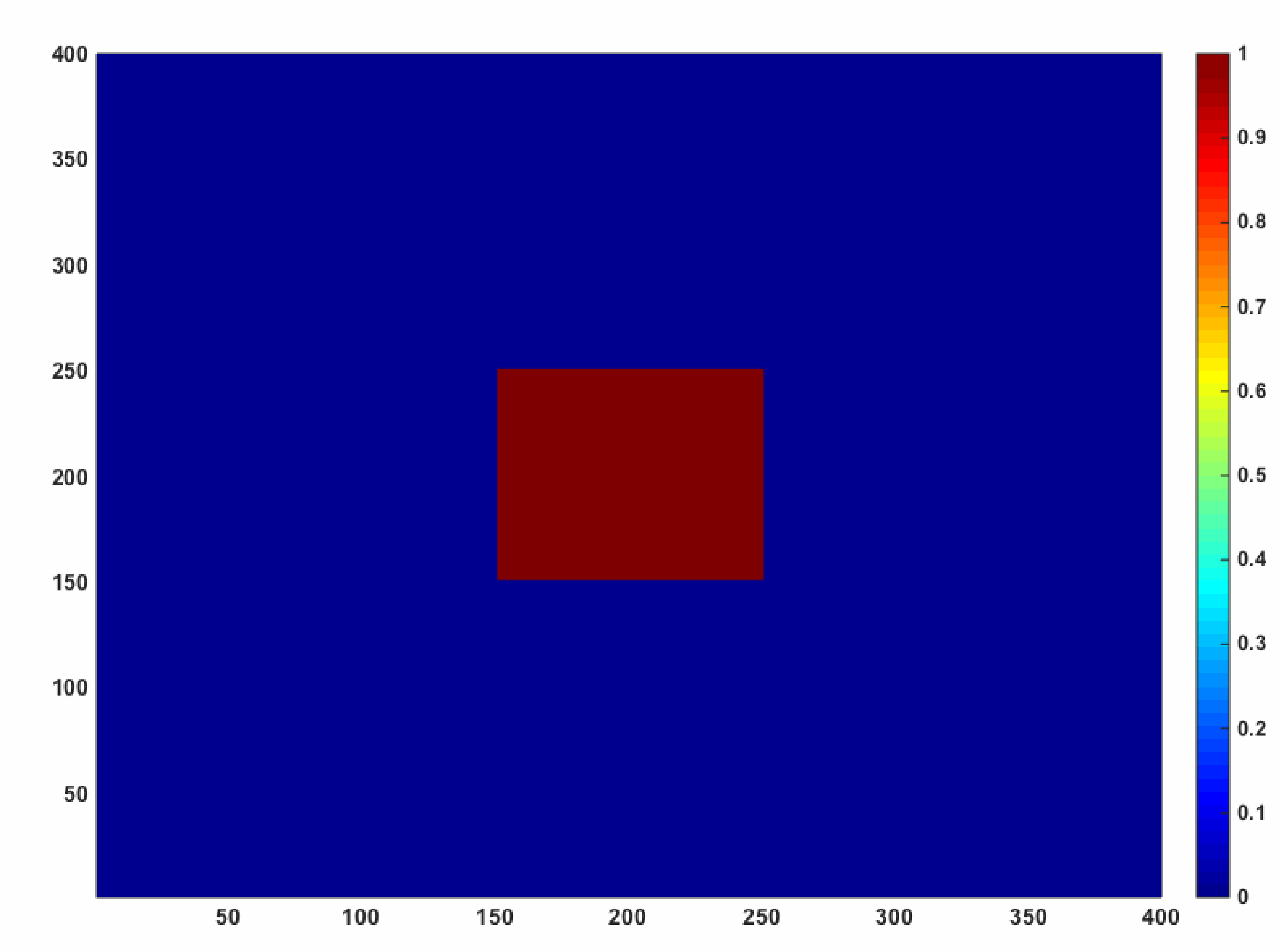
$L_j/L = 2.0$



Conclusions

- 3D perturbation QP produces cell transport boundaries which vary linearly with depth
- Vertical mixing is inhibited by stratification
- Although steady QP and perturbation QP individually do not mix, their composite flow exhibits mixing
- Mixing (quad exit count) in composite QP flow
  - directly (not quite linearly) related to U_j/U
  - inversely related to L_j/L

Concentration Evolution



Particles vs Concentration